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Translation

Manual on Communications and Radio-Engineering Flight Services

By

Yu. I. Dukhon, N. N. Il'inskiy, G. I. Laushev

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MANUAL ON COMMUNICATIONS AND RADIO-ENGINEERING FLIGHT SERVICES

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CONTENTS PAGE

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Part III. Fundamentals of Servicing and Maintenance of Air Traffic Control Communications and Radio-Radar Support Services Equipment

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Part I. GENERAL PROVISIONS ON AIR TRAFFIC CONTROL COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES

Chapter I. BASIC DEFINITIONS AND REQUIREMENTS ON COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES

1.1. Basic Definitions in Communications and Radio-Radar Support Services

Communications and radio-radar support services are the principal means of control of air units, subunits and individual aircrews.

Any disruption of communications and operation of RTO [radiotekhnicheskoye obespecheniye -- radiotechnical support, rendered in this translation as radio-radar support services] leads to loss of control, which can lead to worsening of quality and in many cases to failure to accomplish the assigned mission.

Air traffic control communications and radio-radar support services are assigned the following tasks:

rapid transmission and reception of high-priority signals and commands pertaining to bringing units, subunits, and individual aircrews into the required state of readiness;

reception at command posts of information required by a commander for decision-making for forthcoming actions;

securement of communication of commander orders, commands and instructions to subordinates and receipt from subordinates of reports on execution of the assigned task, plus various information;

securement of exchange of information between coordinating air forces in performance of a common mission;

securement of control of aircraft at all stages of a mission, from takeoff to landing;

securement of control of rear services, which provide air units with everything required for the conduct of combat operations.

A communications and RTO system is established in aviation units (subunits) for accomplishment of these tasks, a system which constitutes an aggregate of communications and RTO centers and facilities, interconnected by communications links in a specified order in conformity with the commander's decision pertaining to organization of control.

Communications equipment and radio-radar support services equipment form the basis of a communications and RTO system.

Communications equipment includes devices performing specific functions in communications transmission or reception. With the aid of this equipment communications channels are established, which include the physical environment and communications line or link, along which signals travel from the point of transmission to the point of reception.

Figure 1.1 shows the principal elements of a communications channel, their linkage and message passage. The communications equipment of ground control facilities and aircraft form a transmitting or receiving channel and take part in transmission of messages from the point of transmission to the point of reception.

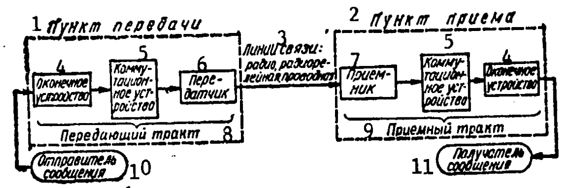


Figure 1.1. Diagram of Communications Channel

Key:
1. Transmission point
2. Receiving point
3. Communications links: radio, radio relay, wire
4. Terminal device
5. Switching device
6. Transmitter
7. Receiver
8. Transmitting circuit
9. Receiving circuit
10. Message sender
11. Message receiver

Functioning of signals in a communications channel can occur only if channel capacity V_k is equal to or greater than signal volume V_c.

Signal volume is characterized by three parameters: duration, energy (amount by which signal level exceeds noise level), and bandwidth.

Signal duration T_c is the time of signal existence.

Signal energy Q_c is expressed by the ratio of average signal power P_c to average noise level $P_п$ and is determined with the formula

$$Q_c = \lg \frac{P_c}{P_п}. \qquad (1.1)$$

Signal bandwidth F_c comprises the continuous band of frequencies occupied by the signal.

Signal volume is determined with the formula

$$V_c = T_c Q_c F_c. \qquad (1.2)$$

Channel capacity V_k is determined by the product of the following channel parameters:

$$V_к = T_к Q_к F_к, \qquad (1.3)$$

where T_k is the time during which the channel is made available for communication; Q_k -- ratio of signal output and noise levels, determined by the allowable channel load; F_k -- band of frequencies which the channel is capable of passing.

A communications channel will pass a signal if

$$V_k \geq V_c.$$

Table 1.1 lists the parameters of various communications channels.

Table 1.1. Parameters of Various Communications Channels

1 Каналы связи	2 Скорость передачи		5 Необходимое превышение уровня сигнала над уровнем помех, дБ	6 Требуемая полоса частот, Гц
	3 слов в минуту	4 бод		
7 Слуховые телеграфные каналы радиосвязи	20—50	15—20	4—5	100—120
8 Буквопечатающие каналы проводной связи	100—150	50—75	7—8	120
9 Буквопечатающие каналы радиосвязи	100—150	50—75	7—8	250—500
10 Фототелеграфные каналы	60	1200—3000	10—11	2400—3100
11 Телефонные каналы	120	—	17—18	3100
12 Телекодовые каналы	—	50—75	17—18	250—500
	—	600—1200	17—18	3 100
	—	до 12 000	17—18	12 000
	—	до 48 000	17—18	48 000
13 Телевизионные каналы	—	10^7	13—14	$6,5 \cdot 10^6$

Key:
1. Communications channels
2. Rate of transmission
3. Words per minute
4. Bauds
5. Requisite amount by which signal level exceeds noise level, db
6. Required frequency band, Hz

(Key to Table 1.1 , cont'd)

7. Radio communications telegraphy sound channels
8. Wire communications printer channels
9. Radio communications printer channels
10. Facsimile channels
11. Telephone channels
12. Telecode channels
13. Television channels

до -- up to

Radio, radio relay and wire facilities are employed to establish communication lines or links.

Radio communications facilities are the most important in aviation for establishing ground communications and the sole means of communicating with aircraft. Two-way radio communications are maintained with aircrews to the extreme range of the aircraft in question. Radio provides more reliable immediate communications under conditions where it is not possible to employ other means because of the time factor. Radio communications make it possible to convey information simultaneously to a practically unlimited number of aircrews.

Radio-relay facilities are extensively employed for establishing aviation control facility communication links.

Wire communications facilities are employed to establish communication between ground control facilities, air bases, as well as communications between aircraft and communications centers, RTO and control facilities.

Radio-radar support services occupy an important position within the aircraft control system. They are employed for the acquisition and forming of information required by control facility personnel for controlling aircraft and by aircrews for determining their location at all stages of a flight.

Radio-radar support facilities include ground radar facilities, radio navigation and lighting systems.

Ground radar facilities are primary sources of information on the air situation and principal means of spotting aircraft in the air.

Radio navigation and lighting systems are employed in forming and communicating information required by aircrews to determine their location in the air.

Table 1.2 lists radio-radar support service facilities, the tasks they perform and their deployment.

Table 1.2. RTO Facilities, Tasks Performed and Deployment

RTO Facilities	Tasks Performed	Location or Deployment
	Ground Radar Facilities	
Detection, guidance, and identification radars	Detection of aircraft in the air, determination of their present coordinates and characteristics	In a specified area, with the objective of establishing a radar field of the required configuration, upper and lower detection limit altitudes, as well as with consideration of eliminating mutual interference and a minimal industrial interference level
Distance-measuring and altitude-determining radar	Determination that aircraft belong to friendly forces, as well as individual identification of friendly aircraft	
Portable equipment set up at control facilities	Provision of control facilities with radar information	At air traffic control facility locations, for obtaining primary air situation data
Radar information transmission devices	Aircraft guidance to air and ground targets	
Information collection, processing and display devices	Guidance of aircraft to specified airspace or ground targets	
Radar information documenting devices		
	Radio Navigation and Lighting Systems	
Surveillance, controller, and precision approach radar	Terminal area air traffic control, and glidepath monitoring	At airfields, standard layout
Radar transponder-beacons	Marking objects, designating areas, and target designation	At specified locations
Radionavigation systems	Determination of aircraft's bearing to or from station or aircraft's position coordinates	In a specified location area, for the purpose of establishing a radionavigation field of specified configuration
DME retransmitters	Aircrew determination of distance to control facility (airfield)	At airfield, control facility
Localizer beacon and glideslope transmitters	Determination of an aircraft's position relative to landing approach course and glide path	At airfield, standard layout

Table 1.2 (cont'd)

RTO Facilities	Tasks Performed	Location or Deployment
Lighting systems	Runway marking, establishment of artificial reference points utilized in takeoff, landing and airfield ground traffic in instrument weather and at night, as well as marking hazardous obstacles	At airfield, standard layout, at artificial reference points and on hazardous obstacles
Pyrotechnic devices	Aircraft guidance to specified areas, signalling, marking control facilities and establishment of artificial reference points	At specified points, at control facilities and artificial reference points
Ground control radar	Control of aircraft on the airfield in instrument weather and at night	At or by military airfield control towers
Nondirectional radio beacons, radio direction finders	Aircraft guidance to designated areas, to airfields, marking of specific objects, designation of areas, and target designation	In a specified area, for the purpose of establishing a radio navigation field, at airfields, for the purpose of establishing a landing approach route

1.2. Demands on Communications and Radio-Radar Support Services

Quality of communications and RTO is nothing other than the aggregate of properties and requirements which make it possible objectively to estimate the degree of satisfaction of control requirements, the expediency and efficiency of utilization of communications channels, lines and links, and radio-radar support facilities.

These demands include promptness of organization, reliability, speed and concealment or security.

Table 1.3 lists the physical substance and quantitative indices of requirements on communications and RTO.

Table 1.3. Requirements on Communications and RTO, Quantitative Criteria of Their Evaluation, and Conditions of Fulfillment

Requirement	Physical Substance	Quantitative Evaluation Criteria	Conditions of Fulfillment of Requirements
Promptness of Organization of communications and RTO	Readiness of communications and RTO to perform air traffic control at the designated time	Determined by coefficient of promptness $K_{ов} = \frac{T_з}{T_Ф}$, (1.4) where $T_з$ -- time specified for organization of communications and RTO; $T_Ф$ -- time expended on organization of communications and RTO	1. Training and deployment of communications and RTO facilities personnel 2. Skilled actions of initiative by communications and RTO unit (subunit) personnel 3. Good working order of communications and RTO equipment 4. High-quality performance of preventive maintenance 5. Prompt issuing of instructions to deploy communications and RTO equipment 6. Advance equipping of airfields and air traffic control communications and RTO facilities
Reliability of communications and RTO	Capability of communications and RTO to ensure continuous, uninterrupted air control under all situation conditions	Evaluated by several particular criteria: by communication channel coefficient of good working order (KID): $КИД = \frac{\sum_{i=1}^{n} T_{нi}}{\sum_{i=1}^{n} T_{нi} + \sum_{i=1}^{n} T_{пi}}$, (1.5) where $T_{нi}$ -- duration of i interval of communications channel (equipment) failure-free operation, hours;	1. Combined employment of equipment at communications and RTO facilities 2. Establishment of reserve manpower, communications and RTO equipment and the ability to maneuver and deploy them 3. Proper servicing and maintenance of communications and RTO equipment and the performance of

Table 1.3, cont'd

Requirement	Physical Substance	Quantitative Evaluation Criteria	Conditions of Fulfillment of Requirements
		$T_{\pi i}$ -- duration of i interruption in communication channel operation, hours; n -- number of intervals of failure-free operation during communication activity; by the coefficient of communications down time: $K_{п} = \frac{\sum_{i=1}^{n} T_{пi}}{\sum_{i=1}^{n} T_{нi} + \sum_{i=1}^{n} T_{пi}}.$ (1.6)	technical measures ensuring their operation in any and all situation conditions 4. Protection of communications and RTO facilities from hostile fire and electronic countermeasures 5. Securement of electromagnetic compatibility of communications and RTO equipment 6. Security and defense of station, communication links and RTO facilities 7. High degree of specialized training of communications and RTO facilities personnel
Authenticity of communications and RTO	Degree of accuracy of reproduction of information at the receiving point	The general criterion of evaluation of communications authenticity is the probability of correct, undistorted reception of information. Coefficient of authenticity $K_{д}$ and coefficient of information distortion $K_{и}$ are usually taken as partial criteria: $K_{д} = \frac{M_0}{M}$ (1.7); $K_{и} = \frac{M_{и}}{M}$, (1.8) where M_0 -- number of correctly received characters; $M_{и}$ -- number of characters received with distortion; M -- total number of transmitted characters. The total value of the coefficient of communications authenticity and coefficient of distortion is equal to 1.	1. Training personnel to operate communications and RTO equipment 2. Increasing responsibility of duty personnel for authenticity of received information 3. Employment of communications equipment with the smallest coefficient of distortion on important links 4. Employment of special equipment enabling one to find and correct errors

Table 1.3, cont'd

Requirement	Physical Substance	Quantitative Evaluation Criteria	Conditions of Fulfillment of Requirements
		Applied to RTO, authenticity is characterized by objectivity of formed information adopted for aircraft control.	
Speed of communications and RTO	Capability of communications and RTO equipment to provide information within the time frame required for air traffic control	One determines the passage time of one telephone, telegraph or facsimile message from the moment it enters the communications system from one control entity to receipt by another. This time, T_π, is formed of time of message passage along the communications and RTO system channel T_C and auxiliary operations time $T_{B.O}$: $$T_п = T_с + T_{в.о}. \quad (1.9)$$ For telephone communications message (conversation) passage time within the communications and RTO system is formed of waiting time, connection time, and conversation time. For telegraph (wirephoto) communications, telegram (radiotelegram) passage time in a communications and RTO system is formed of makeup time at the transmission point, telegraph station delivery time, waiting time for transmission, exchange time, delivery time to receiving point, preparation time at receiving point, and destination delivery time	1. Employment of communications and RTO equipment with a high throughput capacity 2. Selection of modes of organization of communications and RTO which ensure information transmission within the specified time frame 3. High degree of qualifications on the part of communications and RTO equipment operators and aircrews 4. Employment of automated information collection, processing, display and documenting equipment both at ground control facilities and on board aircraft [14] 5. Placement of communications and RTO terminal equipment directly at the work stations of military control facility personnel and on board aircraft for utilization by the aircrew in flight 6. Ability of control facility and headquarters personnel personally to operate communications and RTO equipment 7. Correct determination of volumes of information for various headquarters services, observance of these volumes during transmission by communications equipment, as well as

Table 1.3, cont'd

Requirement	Physical Substance	Quantitative Evaluation Criteria	Conditions of Fulfillment of Requirements
		As applied to radio-radar support services, speed is characterized by the time required to convey information to the control facility or to the aircraft whose position in airspace is being determined. Information passage time in a communications and RTO system can be average and standard (allowable). Message average passage time in a communications and RTO system for one direction is determined from the expression $T_{CG} = \frac{\sum_{i=1}^{\gamma} T_{CCi}}{\gamma}$, (1.10) where T_{CCi} -- passage time of i message; γ -- number of messages. Standard (allowable) information passage time is determined by the operational-tactical requirements on aircraft control and is established on the basis of its maximum allowable value	employment of standard documents and brief signals for aircraft control 8. Reduction of message passage time at communications and RTO facilities 9. Strict monitoring of delivery of information to the destination within the specified time frame
Security of communications and RTO	This property of communication and RTO facilities makes it impossible or extremely difficult for the enemy to determine the content of transmitted information	Determined by that portion of information which has not been determined by the enemy in the course of a specified period of time and which cannot be utilized by him for response actions. It is quantitatively determined by the formula $Q_{T<T_{pasv}} = \frac{I_{CC} - I_{pasv}}{I_{CC}}$, (1.11)	1. Observance of specified rules and procedure of communication and transmission by communication links (channels). 2. RTO facilities operation mode in conformity with the situation. 3. Employment of special equipment and documents

Table 1.3, cont'd

Requirement	Physical Substance	Quantitative Evaluation Criteria	Conditions of Fulfillment of Requirements
	and the location of control facilities and airfields	where I_{CC} -- quantity of information passing through the communications and RTO system (in characters); $I_{разв}$ -- quantity of information intercepted and determined; $T_{разв}$ -- time of conduct of reconnaissance	4. Restriction of the number of persons authorized to communicate by communications channels 5. Increased vigilance by communications and RTO personnel

1.3. Types of Communications

Communications of the following kinds are organized with the aid of radio, radio relay, and wire equipment and corresponding station equipment: telephone, telegraph, telecode, signal-code, and television. Table 1.4 lists the area of application of these types of communication.

Table 1.4. Types of Communication and Areas of Application

Type of Communication	Area of Application
Telephone and telegraph	Employed for direct communication between officials of different command echelons, for transmission and receiving of various information between ground control facilities and between control facilities and aircrews
Telecode	Employed in automated control systems for exchange of information between automated air traffic control facilities, as well as for transmission of commands to actuating mechanisms or aircraft guidance indicator instruments [6]
Signal-code	Employed for transmission of brief commands and reports, aircraft callup signals, for mutual identification between aircraft and ground troops, naval forces and National Air Defense forces
Television	Employed for transmitting and receiving reports, diagrams, maps, as well as for transmitting (receiving) moving and stationary images

Chapter 2. MODES OF COMMUNICATION

2.1. Modes of Radio Communications

Radio is one of the most important means of communication in aviation. It is the only efficient means of communication for controlling aircraft in the air.

The advantages and drawbacks of radio communications are listed in Table 2.1.

Table 2.1. Advantages and Drawbacks of Radio Communications

Advantages	Drawbacks
Capability to establish communication with control facilities the location of which is not known.	Possibility of eavesdropping on (interception of) transmissions and jamming radio communications.
Conduct of communications across enemy-occupied territory	Determination of the location of a radio transmitter with the aid of radio direction finders
High mobility	Dependence on atmospheric and local radio interference
Capability to conduct communication with mobile objects	Dependence on state of the ionosphere
Simultaneous transmission of information to a large number of stations	Possibility of mutual radio interference and difficulty of electromagnetic compatibility of radio equipment operations at communications and RTO facilities
Comparatively economical	Effect of nuclear explosions on operation of radio facilities

The principal modes of radio communications are communication by radio link and communication by radio net. Employment of these modes depends on the concrete situation conditions, the place of radio communications in the communications and RTO system, the degree of its importance for ensuring uninterrupted aircraft control, volume of flows of information circulating on communication channels, as well as availability of radio communications manpower and equipment.

Table 2.2 contains a description of modes of radio communications.

Table 2.2. Description of Modes of Radio Communications

Mode	Substance of Mode	Advantages of Mode	Drawbacks of Mode
Radio communi-cations by radio link	Effected between two control facilities (headquarters) or between individual aircrews	Simplicity of execution, high communications channel throughput capacity. Capability of obtaining duplex channels for telecode communica-tions. Comparatively high degree of communica-tions security. High reliability	Considerable expen-diture of radio com-munications manpower and equipment. Difficulty of con-duct of collective transmissions. Considerable flow of radio data
Radio communi-cations by radio net	Effected between three and more con-trol facilities (headquarters) or between individual aircrews	Less expenditure of radio communications personnel and equipment as well as volume of radio data in com-parison with radio link. Collective transmission capability	Less transmission security, through-put capacity and reliability in com-parison with radio link

Communication by radio link can be effected directly between two radio sets or via an intermediate (relay) transceiver at one or several frequencies. Table 2.3 contains different variants of communication by radio link and operating procedures.

Table 2.3. Radio Link Communication Variants

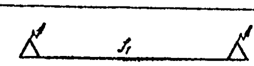
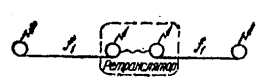
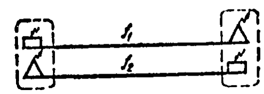
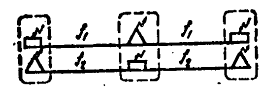
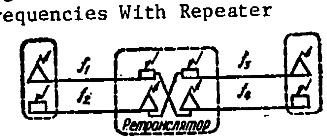
Radio Link Variant	Operating Procedure	Graphic Representation
Radio link on one frequency without relay	Terminal sets transmit by turn, that is, only simplex communication is possible	 Main set Other set Figure 2.1. Radio Link on Single Frequency
Radio link on one frequency with relay	Employed in those cases where it is im-possible to establish direct communication between two trans-ceivers, and is ef-fected via an inter-mediate transceiver (relay)	 Relay Main set Other set Figure 2.2. Radio Link on Single Frequency With Repeater

Table 2.3, cont'd

Radio Link Variant	Operating Procedure	Graphic Representation
Radio link on two frequencies without repeater	Terminal sets can simultaneously transmit and receive information, that is, operate in duplex mode	 Main set Other set Figure 2.3. Radio Link on Two Frequencies Without Repeater
Radio link on two frequencies with relaying	Terminal sets transmit on one frequency and receive on another. Sequential transmission (simplex relaying) is performed at an intermediate point	 Main set Relay Other set Figure 2.4. Radio Link on Two Frequencies With Repeater
Radio link on four frequencies with duplex relaying	Terminal sets receive and transmit on different frequencies. Duplex relaying is performed	 Main set Relay Other set Figure 2.5. Radio Link on Four Frequencies With Duplex Relaying
Radio link on two frequencies employing automatic relaying	Terminal sets each transmit and receive on their own frequency. Simplex relaying is provided	 Main set Automatic Relaying Other set Figure 2.6. Radio Link on Two Frequencies With Automatic Relaying

Communication by radio net, in comparison with communication by radio link, requires less radio equipment and provides collective transmission capability. These positive properties of the radio net promote its extensive employment in organizing radio communications for air traffic control.

Operation of transceivers in a radio net, depending on importance and function, can be organized on a common frequency, on different receiving and transmitting frequencies, on transmitter frequencies and on listening watch frequencies.

Table 2.4 contains radio net communication variants.

Table 2.4. Radio Net Communication Variants

Radio Net Variant	Operating Procedure	Graphic Representation
Radio net on a common frequency	All radio sets tuned to one frequency. Radio communications are effected by any two sets, while the remaining sets in the radio net operate on receive. Extensively employed in air traffic control	 Main set Other sets Figure 2.7. Radio Net on Common Frequency
Radio net on receiving and transmitting frequencies	Transmitters are tuned to one frequency -- transmission frequency, and receivers to another frequency -- receiving frequency	 Main set Other sets Figure 2.8. Radio Net on Transmitting and Receiving Frequencies
Radio net on transmitter frequencies	Each transceiver in the radio net transmits on an assigned frequency and receives information on the operating frequencies of the other transmitters in the net. Radio net members should have an additional receiver for each other member of the net	 Main set Other sets Figure 2.9. Radio Net on Transmitter Frequencies
Radio net on listening watch frequencies	Each member is assigned its own listening watch frequency. Required callup is performed by tuning transmitters to the listening watch frequency of the element to be called. Reply to callup and exchange between radios is performed at the listening watch frequency of that radio which makes the initial call. Only brief communication is conducted on listening watch frequencies	 Main set Other sets Figure 2.10. Radio Net on Listening Watch Frequencies

2.2. Modes of Radio Relay and Line Communications

Radio relay communications can be set up by link, net and main artery, depending on situation, manpower and equipment availability (Table 2.5).

Table 2.5. Description of Modes of Radio-Relay Communications

Mode	Substance of Mode	Advantages of Mode	Drawbacks of Mode
Radio-relay communications by link	Communications are effected between two elements by a radio-relay link constructed directly between them	Simplicity of execution. High reliability. High throughput capacity. Comparatively good security of transmissions	Considerable expenditure of radio-relay communications personnel and equipment at higher-echelon control facility. Difficulty of designating frequencies at communications center and RTO of higher-echelon control facility
Radio-relay communications by net	Communications between higher-echelon control facility and subordinate entities are effected in sequence with the aid of a single radio-relay station; stations of subordinate control facilities operate on listening watch mode and transmit by turns at the request of the radio-relay station of the higher-echelon control facility	Small radio-relay communications personnel and equipment expenditure and small radio data flow at higher-echelon control facility. Capability to organize radio-relay communications with limited means at a higher-echelon control facility	Complexity in organizing radio-relay communications, insufficient flexibility and reliability. Poor resistance to jamming
Radio-relay communications by main artery	Communications between higher-echelon control facility, subordinate and coordinating entities are effected by radio-relay link constructed in the direction of displacement of the higher-echelon facility or one of the control entities of subordinate units	Small radio-relay communications personnel and equipment requirements at higher-echelon control facility. Capability to establish collective communications with several subordinate control entities. High degree of communications flexibility. Long communication links	Complexity of organization of radio-relay communications and inadequate communications reliability. Poor throughput capacity. Necessity of constructing links for branching communication channels to control entities. Difficulty of allocating channels on radio-relay communications main artery

When establishing radio-relay communications by any of the above-listed modes, it is essential thoroughly to take topography into account, by plotting topography profiles between stations. The relay link profile constitutes a vertical topographic section with all elevated points, including forest and various man-made structures (Figure 2.11)

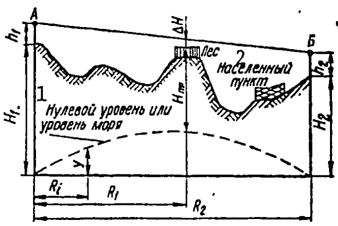


Figure 2.11. Radio-Relay Communications Link Profile

Key:
1. Zero level or sea level
2. Inhabited locality

A radio-relay link route is selected on a map of a scale of 1:50,000 or 1:100,000. A map with a scale of 1:25,000 can be used for route selection on stretches with complex topography. After the route has been selected, relay hop profiles are plotted. All elevation high points are laid out not by radii as in actuality but on the Y axis, and distances not by an arc of a circle but on the X axis. An arbitrary zero level, or sea level, from which all elevations are figured, is in the form of a parabola and is calculated with the formula

$$Y = \frac{R_0^2}{2R_э} K (1 - K), \qquad (2.1)$$

where Y is the present heights of the datum line, in meters; R_0 -- length of radio-relay hop, km; $R_э$ -- equivalent earth's radius, km; K -- relative coordinate of the specified point.

The relative coordinate of the specified point is a dimensionless quantity and is determined from expression

$$K = \frac{R_i}{R_0}, \qquad (2.2)$$

where R_i is distance to present point, km.

Points on the datum line can be determined from the graph in Figure 2.12.

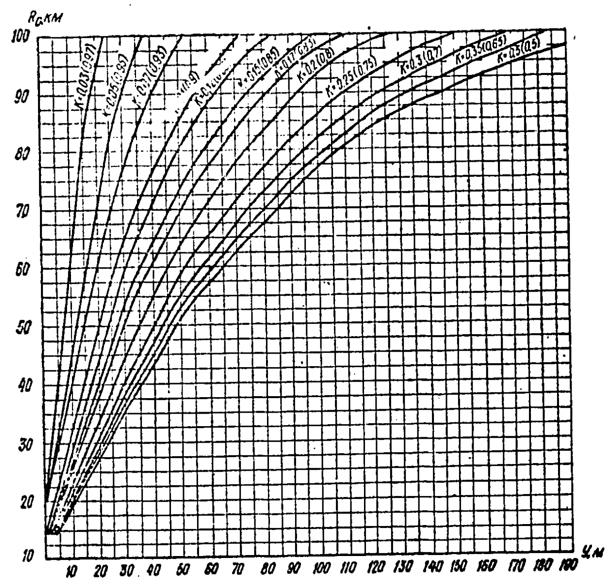


Figure 2.12. Graph for Computing Datum Level

In practice relay hop profiles are plotted for a geometric earth's radius. It is advisable to observe the following sequence:

1) connect by a straight line on the map the points of the proposed location of the terminal stations of the relay hop;

2) place a line representing the datum level -- the points on this line are to be determined with formula (2.1) or from the curves in Figure 2.12;

3) take from the map and place, counting from the datum level, profile point elevation marks at different distances from the terminal relay stations and connect them with a solid line;

4) place local features on the profile;

5) taking into account relay station antenna height, join them with straight line AB; the distance between line AB and the hop route profile is called clearance (Figure 2.11).

Clearance ΔH is determined graphically at the highest point on the profile. Relay hops are divided into three types, depending on amount of clearance: open, semi-open, and closed.

We define as an open hop one for which the relation $\Delta H \geq H_0$ applies, where H_0 is that clearance at which the field at the receiving point is equal to a free-space field, and is determined with the formula

$$H_0 = \sqrt{\frac{1}{3} R_0 \lambda K (1 - K)}. \qquad (2.3)$$

Quantity H_0 can be determined with the nomogram in Figure 2.13.

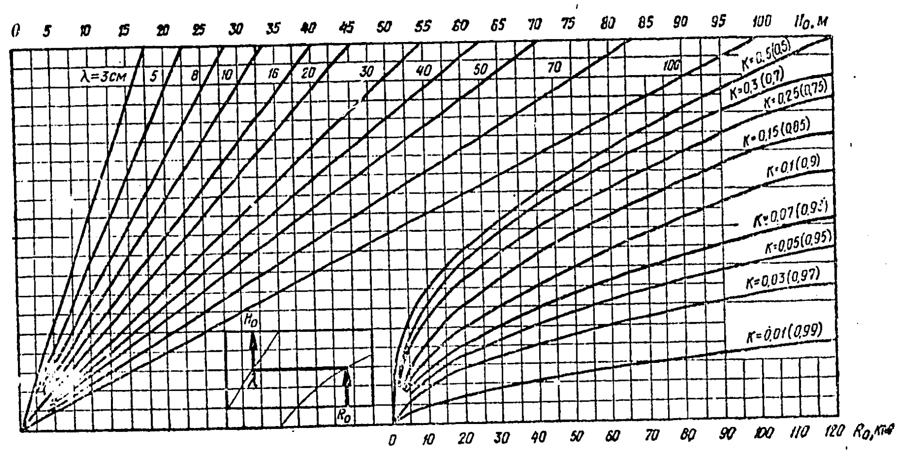


Figure 2.13. Nomogram for Determining H_0

On a semi-open relay hop the clearance is less than that with which the field at the receiving point is equal to a free-space field, that is, $H_0 > \Delta H > 0$.

For closed relay hops clearance is always less than zero. Communications are effected in a normal manner on relay hops employing meter-band relay stations and calculated to be open and semi-open.

For centimeter-band relay links, actual clearance is compared with allowable clearance indicated in station specifications.

When constructing radio-relay links in the meter-band with hops not exceeding 50 km, there is no need to plot a route profile for each hop. It suffices to evaluate the existence of line-of-sight and value of line-of-sight blockage by local features ΔH, then calculate with the formula

$$\Delta H = \frac{(H_1 + H_2) + (h_1 + h_2)}{2} - (H_{\text{пр}} + Y), \qquad (2.4)$$

where H_1, H_2 are the geographic elevations (taken from a map) of the relay station antenna locations for that hop, m; h_1, h_2 -- elevations of relay station antenna supports, m; $H_{\text{пр}}$ -- elevation of the highest obstacle along the relay path, m; Y -- elevation of arbitrary datum level (sea level) at the point of the highest obstacle on the relay hop, m.

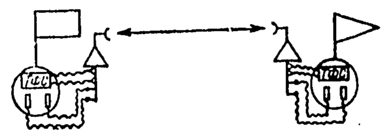


Figure 2.14. Radio-Relay Communications by Route

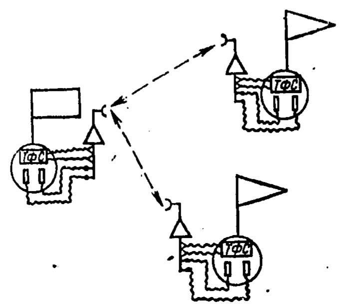


Figure 2.15. Radio-Relay Communications by Net

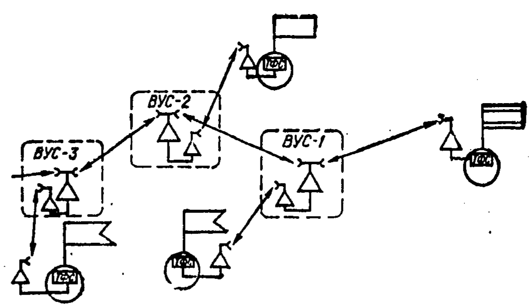


Figure 2.16. Radio-Relay Communications by Main Artery

Elevation of the arbitrary datum level (sea level) at the point of the highest obstacle can be determined with sufficient accuracy for practical purposes with the following formula:

$$Y = \frac{R_0^2}{50}. \qquad (2.5)$$

If after calculations we obtain $\Delta H > 0$, the hop between these stations will be open and communications will be assured. When $\Delta H < 0$ the relay hop will be closed and communications will not be possible; it will be necessary to select a new route.

Figures 2.14-2.16 contain a graphic representation of modes of radio-relay communications.

Line communications in aviation are set up at airfields, within airfield complexes, and at control facilities. Line communications are organized in all cases between control entities within airfield complexes if the situation permits and if manpower and equipment are available.

Line communications are described in Table 2.6.

Table 2.6. Description of Line Communications

Advantages of Line Communications	Drawbacks of Line Communications	Types of Communications and Their Execution
Convenience of communication. High degree of communications security. Little dependence on season, time of day and state of the atmosphere. Capability of obtaining a large number of communication channels in a single circuit with the aid of multiplexing. High throughput capacity of communications routes. High degree of communication channel reliability	Considerable manpower and equipment requirements for constructing (laying) communication lines. Little flexibility in constructing (laying) communication lines. High degree of vulnerability to hostile fire. Complexity of construction (laying) of wire communication lines on enemy-contaminated and difficult terrain	Telephone communications are effected by wire lines, both low- and high-frequency. Telegraphic communications employ high-frequency telephone channels multiplexed by audio frequency telegraphy, as well as single-wire and double-wire communications lines, as well as telephone circuit midpoints multiplexed by hybrid coils. Telecode communications employ telephone channels multiplexed by audio frequency telegraphy equipment. Signal-code communications employ wire lines and communication channels. Television communications employ wire communication lines and channels

There are two possible modes of organizing line communications, depending on situation, available time, personnel and equipment: by route, and by main artery (Table 2.7).

Table 2.7. Description of Modes of Line Communications

Mode	Substance of Mode	Advantages	Drawbacks
Line communications by route	Communications are effected between two control facilities by wire line constructed (laid) directly between them	Simplicity of organization. High traffic capacity. High reliability and security of communications	Considerable manpower and equipment requirements. Little flexibility
Line communications by main artery	Communications between higher-echelon control facility and subordinate entities employ a wire line laid in the direction of displacement of the higher-echelon control facility or one of the control entities of the subordinate units	Smaller manpower and equipment requirements in comparison with the route variant. Capability of obtaining a number of communication channels on one circuit with the aid of multiplexing equipment	Poor communications reliability, high degree of vulnerability to hostile fire. Low traffic capacity

Figures 2.17 and 2.18 contain a graphic representation of line communications modes.

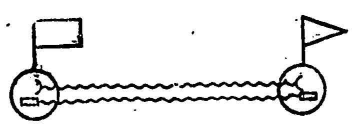


Figure 2.17. Line Communications by Route

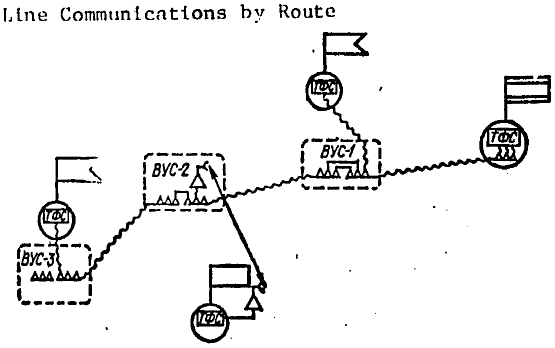


Figure 2.18. Line Communications by Main Artery

2.3. Modes of Signal Communications

Signal communications are employed to perform missions of aircraft control. They are employed at aviation control facilities, air bases, and communications and RTO complexes.

Visual, aural and radio-radar means are employed for signal communications. Table 2.8 lists possible modes of signal communications.

Table 2.8. Modes of Signal Communications

Mode Designation	Potential Area of Employment	Methods of Implementation
Visual means	Control of aircraft in battle dispositions. Aircrew communications with one another and with control facilities (airfields). Transmission of brief commands, reports and aircraft call signals on the battlefield. Mutual identification between aircraft and ground troops, and aircraft target designation. Coordination between aircrews and air subunits and between aircraft and ground troops. Designation of friendly troops and the forward edge of the battle area.	Personal example of the commander in the battle disposition. Employment of aircraft running lights, landing lights, signal cartridges. Signaling with smoke flares, signal cartridges, smoke generators, hand grenades and searchlights.
Aural means	Transmission of signals and commands to place troops and installations on a required combat-ready status. Exchange of information between control facility personnel and aircrews	Aural signals of differing frequency, duration and discreteness
Radio-radar means	Determination of nationality and individual identification of aircraft. Mutual identification and target designation between aircraft and ground troops	Transmission of coded response signals from aircraft on request of troops, at designated points. Issuing of specified signals by ground troops when coordinated-action aircraft approach battle line, on request of aircrews

Chapter 3. MODES OF AIR TRAFFIC CONTROL RADIO-RADAR SUPPORT SERVICES

3.1. Modes of Air Traffic Control Radar Support Services

Ground radar support activities constitute an aggregate of measures directed toward prompt and timely acquisition, collection, processing and issuing to control facilities of information on the location of aircraft in a given airspace area.

The success of ground radar support activities is directly dependent on the quality of information on the location of in-air aircraft, received by control facilities. Radar support services are characterized by a number of parameters, the principal parameters among which are the following: informing points, composition of information, discreteness of information presentation, and information accuracy. These parameters are described in Table 3.1.

Table 3.1. Description of Radar Support Service Parameters

Parameter	Description of Parameter
Informing point	An informing point is a designated point the approach to which by air targets initiates transmission of information to the control facility on the positional location of said aircraft. The required distance to the informing point for providing radar support to fighter units is determined with the formula $$Д_{РВИ} = S_{РВВ} + V_ц T_{потр},\qquad (3.1)$$ where $S_{РВВ}$ -- fighter-interceptor engagement point (determined from scrambling airfield); $V_ц$ -- speed of target; $T_{потр}$ -- time required from initiation of information transmission to interceptor arrival at engagement point. The required time is calculated with the formula $$T_{потр} = t_{зап} + t_{бг} + t_{вб},\qquad (3.2)$$ where $t_{зап}$ -- radar information time lag; $t_{бг}$ -- time required to ready alert aircraft to scramble; $t_{вб}$ -- time required for takeoff and flight to the intercept point

(Table 3.1, cont'd)

Parameter	Description of Parameter
Composition of information	Information includes the following data on aircraft in the designated airspace required by control facility personnel: present position data on each air target (in a polar or rectangular coordinate system); result of overall and individual identification of targets (aircraft); composition of aircraft groups (for concentrated targets); characteristics of possible target action
Discreneness of information presentation	Discreteness of information presentation is determined proceeding from the condition of providing control facilities personnel with the requisite uniformity of picture on the actual location of aircraft in the designated airspace, excluding the possibility of confusion on flight paths and prompt detection and reporting of maneuver and redeployment of group target formations. The least degree of discreteness is established for targets possessing the greatest tactical importance within a given time segment. Discreteness of information presentation is greater for less important targets than for other air targets
Accuracy of information	Accuracy of information depends on the content of control tasks being performed at the control facility and should not diminish control effectiveness. Accuracy of information on the positional location of aircraft should be adequate for well-substantiated combat action decision making and control of aircraft. Meeting of the requirements imposed on accuracy of radar information is secured by employing radars with the best accuracy characteristics and selection of optimal radar support methods

Depending on the concrete situation, there are three possible modes of providing ground radar support activities: plotting board, scope, and automated (Table 3.2).

Table 3.2. Description of Modes of Providing Radar Support Activities

Mode	Substance of Mode	Advantages of Mode	Drawbacks of Mode
Plotting board	Specifies eyeball reading of information on radar scopes and manual information processing with the employment of rudimentary means of mechanizing individual operations. Information is displayed on plotting boards at control facility	Simple in organization. Possesses a high degree of reliability. Enables one to display information on the location of aircraft practically without area size limitation	Poor degree of accuracy of information display and little information capability. Considerable information time lag

(Table 3.2, cont'd)

Mode	Substance of Mode	Advantages of Mode	Drawbacks of Mode
Scope	Consists in utilizing information on aircraft location directly from remote radar displays. Information can be fed to the control facility by cable or radio relay links	Provides a high degree of accuracy and reliability of aircraft position determination. Practically no time lag	Area of determination of aircraft location is limited by the coverage zone of the radar providing the information
Automated	Provides for automated information output from radar displays, automated information processing, transmission and display on special screens and plotting boards at control facilities [14]	Possesses a high degree of accuracy of information display. Enables one to obtain sufficiently high-quality information from distant radar sites. Possesses a high degree of information capability. Provides combining of information acquired by various detection methods, which increases reliability of radar support activities under conditions of jamming	Imposes greater demands on communications channels as regards reliability of information

Implementation of each of the above modes of radar support activities is dependent on the specifications and characteristics of the utilized equipment and their deployment, which determines the structure of the radar field [6].

The radar field is that space within the boundaries of which deployed radar facilities provide determination of the position of aircraft with a probability not below a specified figure.

A radar site in a radar field forms an elementary component within which complete information is obtained on the position of aircraft. Mutual contact or overlapping of complete information zones of adjacent radar sites ensures the establishment of a solid radar field.

The structure, dimensions and shape of a solid or continuous radar field are characterized by quantitative indices called field parameters (Table 3.3).

Table 3.3. Parameters of a Continuous Radar Field

Parameter	Definition of Parameter
Boundary of radar field at given altitude	A closed line obtained by intersection of the field with an imaginary surface equidistant from the surface of the earth (sea) at all points. When plotting field boundaries at low altitudes the altitude of the intersecting surface is figured relative to each topographic relief point. At medium and high altitudes topographic relief has no effect on the shape of field boundaries, and therefore the altitude of the intersecting surface is figured relative to sea level
Altitude of lower boundary of radar field H_0	Minimum altitude figured from terrain relief at which the position of aircraft can be determined by at least one radar at every given moment in time
Altitude of upper boundary of continuous radar field H_B	Maximum altitude relative to sea level at which the position of aircraft is determined by at least one radar at each given moment in time
Coefficient of continuous radar field overlap at a given point K_Π	A whole number corresponding to the number of radar sites, the zones of complete information of which mutually intersect at a given point. The coefficient of overlap characterizes the multilayer nature of a continuous radar field at each point, which increases the reliability of determination of the position of aircraft

3.2. Air Traffic Control Radio and Light Signal Support Services

Radio and light signal support services comprise an aggregate of measures aimed at promptly conveying to aircraft information required by aircrews to determine their positional location.

Presently employed for radio and light signal support services are ground radio, light and signal devices which, in combination with airborne equipment, form the following:

aircraft landing systems;

radio azimuth measuring systems;

radio azimuth-distance measuring systems;

radio distance-measuring systems;

radio difference-ranging systems [Loran].

Table 3.4 specifies the area of application of these systems.

Table 3.4. Area of Application of Radio and Light Signal Support Services

System	Area of System Application
Aircraft landing system	Employed for forming and conveying to aircraft information needed by the aircrew to execute takeoff and departure, approach the destination and to plot a landing approach path
Radio azimuth measuring system	Forming and communication to aircraft of information on the basis of which an aircrew determines its line of position or positional location in the air
Radio azimuth and distance measuring system	Utilized to form and convey to aircraft information with the aid of which aircrews determine their present position coordinates
Radio distance-measuring and difference-ranging systems	Employed for forming and conveying to aircraft information on the basis of which aircrews determine their present position

An aircraft landing approach system is set up on the basis of combined utilization of radars, radio navigation, communication equipment and lights. It provides aircrews with information required to execute takeoff and landing in instrument weather and at night. These facilities are deployed at airfields on the basis of standard arrangements. These arrangements can be varied on the basis of the specific topography adjacent to the airfield.

A radio azimuth measuring system determines the bearing from an aircraft to a ground control facility (station). The system can be one of two variants:

a non-directional radio beacon on the ground and a radio compass on the aircraft (PAR-ARK);

a radio direction finder on the ground and an airborne communications transceiver (ARP-airborne transceiver).

Table 3.5 contains a description of radio azimuth measuring system layout variants.

Table 3.5. Description of Radio Azimuth Measuring System Variants

Variant	Capability to Determine Parameters of Aircraft Position	Advantages of Variant	Drawbacks of Variant
PAR-ARK	Continuous determination of bearing to NDB [non-directional beacon], as well as distance to NDB if the aircraft carries a navigation display.	Simplicity of organization. Capability to solve diversified navigation problems. Unlimited traffic capacity. Comparatively long	Limited utilized frequency capabilities. Effective range determined by nature of underlying ground surface

(Table 3.5, cont'd)

Variant	Capability to Determine Parameters of Aircraft Position	Advantages of Variant	Drawbacks of Variant
	Capability to provide guidance into a designated area, homing to the destination field and determination of final approach course lineup with runway centerline, as well as execution of approach sequence	effective range, little dependent on aircraft's altitude. High degree of reliability, security and resistance to jamming. Capability to determine aircraft position with two NDBs at different locations	and time of day. Poor accuracy of bearing determination, as well as relatively poor accuracy and efficiency of determination of aircraft position from two NDBs
ARP-airborne transceiver	Determination of bearing (azimuth) to aircraft with operating transmitter on the scope of a ground radio direction finder with subsequent communication of this information to the aircraft by radio. Monitoring of aircraft flight path, entry into designated zone, guidance to airfield, as well as execution of approach procedures. Determination of locational position of aircraft	No need for additional airborne equipment. Relatively high degree of security, due to the fact that a ground radio DF operates on receive. Capability to perform all tasks possible with PAR-ARK	Limited traffic capacity. No continuous airborne position line display. Limited vhf-uhf range, determined by aircraft altitude

A radio azimuth and distance measuring system (UDS) forms and conveys to aircraft a considerably larger volume of information than an azimuth measuring system. Utilizing this information, aircrews can monitor their position line and positional location, can guide their aircraft to a designated point or area and, in conjunction with lighting equipment, can land their aircraft in instrument weather and at night.

Figure 3.1 contains a diagram of the effective area of a ground azimuth and distance measuring system.

A radio ranging system forms and conveys to aircraft information which is used by aircrews to handle navigation tasks and bombing missions against small targets beyond ground visual range under the condition that the precise target position data relative to the system's ground stations are known. The system is based on two ground stations positioned 100-300 km from each other,

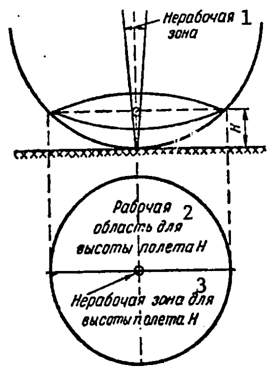


Figure 3.1. Effective Coverage Area of a Ground Radio Azimuth and Distance Measuring System Station

Key:
1. Dead zone
2. Effective coverage area for altitude H
3. Dead zone for altitude H

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which form the system base. With this base it is possible to establish an effective zone which for all practical purposes can be utilized at all aircraft flight altitudes. Figure 3.2 contains a diagram of deployment of radio ranging system ground stations.

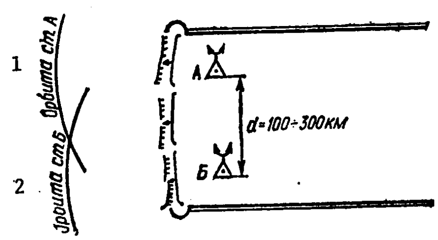

Figure 3.2. Diagram of Deployment of Radio Ranging System Ground Stations

Key:
1. Orbit of station A
2. Orbit of station B

A radio difference-ranging system forms and conveys to aircraft information which is used to determine the positional location of aircraft, to guide them to destination areas, as well as to determine certain navigation elements (drift angle, ground speed).

A difference-ranging system is set up with three ground stations deployed at a distance of 700-1,300 km from one another (Figure 3.3). Station A is the master station and operates alternately with slave stations B and C.

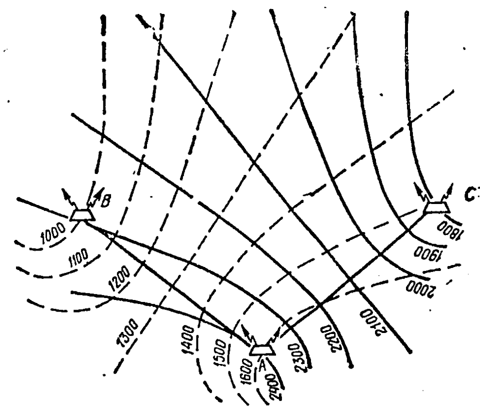

Figure 3.3. Diagram of Deployment of Radio Difference-Ranging System Ground Stations

Signals emitted by the ground stations are received by a special airborne receiver which measures the difference in distances (in time) between the aircraft and the pair of ground stations.

Based on the distance difference obtained from one pair of stations (A and B, for example), one determines the aircraft's position line in the form of a hyperbola all points of which are situated from points A and B at one and the same difference in distances to them.

3.3. Selection of Positions for Deployment of Radio-Radar Support Facilities

The position of any radio-radar support facility should be defined as that site occupied (or prepared for occupation) by this facility to perform radio-radar support activities.

Ground radar sites impose the most rigid demands on position. Radar sites can be divided into two types, on the basis of topography and the presence of local features:

circular positions, which offer normal radar operation in all directions;

sector positions, which provide normal radar operations only in certain sectors.

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Following are the principal characteristics of positions:

radius of return area;

size of local features in return area;

rise (gradient) of return area;

crest clearance angles.

Of all radar facilities, the highest demands are imposed on meter and decimeter-band radar site positions, since the forming of their radiation patterns is closely linked with the reflection of electromagnetic energy from the ground (water) surface.

The radius of the return or reflection area is determined by the height of the antenna's electrical center and the radar's wavelength. The allowable height of terrain irregularities in the area is determined with the formula

$$h_H < \frac{\lambda l}{\Pi h_a}, \quad (3.3)$$

where h_H is the allowable height of terrain irregularities, m; λ -- radar wavelength, m; h_a -- antenna height, m; 1 -- distance from antenna base to terrain irregularity, m; Π -- constant; for a decimeter-band radar -- 16, for a meter-band radar -- 36.

A position rise (gradient) of a few degrees raises the radar detection zone, which in turn affects range of aircraft detection. For example, a flat, horizontal site area with a uniform gradient within allowable limits will promote an increased effective range at low and extremely low altitudes. Correspondingly, a site area with a uniform rising gradient will provide better conditions for detection and tracking of aircraft at high and extremely high altitudes.

Crest clearance or screening angles are formed by local features and terrain relief. They limit the capability of radar facilities to determine the positional location of aircraft at low altitudes.

Maximum allowable screening angles in degrees for specific radar sites can be determined with the formula

$$\varepsilon = 3{,}44\frac{H_ц - h_a}{Д} - \frac{Д}{6}, \quad (3.4)$$

where $H_ц$ is height of the target over the underlying terrain surface, m; h_a -- height of the electrical center of the radar antenna above the ground surface, m; $Д$ -- target detection slant range, km.

The effective range of radar facilities depends on the screening angles, which determine the existence of line-of-sight between radar and aircraft.

Line-of-sight range for various flight altitudes and screening angles α can be calculated with the formula

$$Д_{пр} = \sqrt{\left(\frac{R_э\alpha^0}{57,3}\right)^2 + 2R_э H} - \frac{R_э\alpha^0}{57,3}, \qquad (3.5)$$

where $Д_{пр}$ -- line-of-sight range, km; $R_э$ -- equivalent earth's radius, 8,500 km; H -- aircraft altitude, km.

It is convenient to use the figures in Table 3.6 in practical calculations of line-of-sight range. Calculations have been performed with formula (3.5), with an accuracy to the closest whole number.

Table 3.6. Line-of-Sight Ranges in Relation to Aircraft Flight Altitude and Screening Angles

1 Высота полета, км	2 Дальности прямой видимости, км, при углах закрытия, °								
	0	0,2	0,5	0,8	1	1,5	2	2,5	3
0,2	58	36	17	14	11	8	6	4	4
0,5	92	67	39	31	26	18	14	11	10
1	130	104	69	57	49	35	27	22	19
2	134	153	115	100	88	66	52	43	37
4	200	238	186	168	152	121	98	82	71
6	319	291	248	222	203	167	139	119	103
8	368	340	286	269	249	208	177	152	133
10	418	384	333	310	290	246	211	184	162
12	452	423	371	348	327	280	244	214	189
14	488	459	407	383	362	314	274	242	215
16	522	493	440	416	394	346	303	269	241
18	553	524	471	447	425	379	330	295	265
20	583	554	500	476	453	402	357	319	288
22	611	583	529	505	481	428	382	344	311
25	652	622	569	544	520	488	419	380	344

Key:
1. Aircraft altitude, km
2. Line-of-sight ranges, km, with screening angles

In selecting positions for deploying radar sites one must avoid locations with close-by tracts of forest and large buildings roofed with sheet iron. They strongly distort the radiation pattern.

In those cases where the situation requires placing a radar site near forest and the surveillance sector passes across the forest, the radar must be sited at a distance from the forest which satisfies the following relation:

$$d < 12\frac{h_a}{\lambda}(2h_a + H_0), \qquad (3.6)$$

where d is the distance from radar site to forest, m; h_a -- antenna height, m; H_0 -- height of forest (obstacle), m; λ -- radar operating wavelength, m.

All radars directly involved in servicing air traffic control should be periodically flight-checked.

Radar facility flight checks are subdivided into complete, inspection and preflight on the basis of timetable and degree of detail of the flight check.

Part II. AIR TRAFFIC CONTROL COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

Chapter 4. DESCRIPTION OF RADIO COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

4.1. Parameters Characterizing Technical Capabilities of Radio Communications and Radio-Radar Support Services Equipment

Radio communications equipment and ground air target detection radars, departure and approach radars, as well as ground radio navigation system facilities, which form the basis of air traffic control communications and radio-radar support facilities, differ in construction, principles of operation, function, and design. However, the technical capabilities of these facilities are characterized by essentially identical parameters, which assume a concrete value for each of the enumerated facilities. These parameters are the following: band of operating frequencies, number of operating frequencies in this band, operating mode, transmitter power and receiver sensitivity, type of antenna system and its characteristics, resistance to interference and jamming, weight (size), type of power supply, and power requirements. Table 4.1 lists and describes these parameters.

Table 4.1. Parameters Characterizing the Technical Capabilities of Communications and RTO Equipment

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
Band of operating frequencies	Operating frequency band is defined as that segment of the radio frequency spectrum within the boundaries of which a communications, radio navigation and radar transmitter	VHF-UHF transceivers employed in radio communications with aircraft, operate in the meter and decimeter bands, while high-frequency transceivers practically	Ground radio direction finders operate in the band used by airborne transceivers. Airborne ADFs (radio compasses) operate in the 150-1,300 kHz band.	RTO ground radars operate practically in all parts of the UHF band. Detection and detection-guidance radars can

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
	or receiver can operate. It is described by extreme frequencies -- minimum and maximum. The band of operating frequencies can be continuous or discrete. In the former instance the transmitter (receiver) is tuned to any frequency in the band, and in the latter -- only to certain specified frequencies	throughout the entire shortwave band	DME and azimuth-ranging systems operate in the decimeter band	operate in the meter, decimeter and upper part of the centimeter band. Ground altitude measuring equipment and ATC precision approach radars, in order to obtain better accuracy and resolution, operate in the centimeter band
Number of operating frequencies in band	Number of operating frequencies on which communications, transmission and receiving of radio navigation information, and radar target detection can be performed	Modern transceivers operate in a continuous band of frequencies or at discrete frequencies. In the latter case transceivers are designed for a certain number of specific frequencies which can be used in the specified band with observance of a minimum frequency spacing which ensures operation without mutual interference. Spacing between adjacent frequencies depends on	Ground radio direction finders operate at the frequencies as communications transceivers of the same frequency band. Airborne ADFs (radio compasses) have continuous tuning across their frequency band. DME and azimuth-ranging systems have a group of discrete frequencies within their frequency band	RTO system radars can operate at several frequencies within the band of operating frequencies

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
		the signal spectrum width, absolute frequency instability of the transmitter and receiver local oscillator, receiver passband and the shape of its resonance curve		
Operating mode	Operating mode of communications and RTO equipment is determined by two characteristics: type of oscillations employed and mode of information exchange. Continuous-wave and pulse mode are differentiated with the first characteristic. In radio communications equipment the second characteristic differentiates simplex, duplex, half-duplex modes and relay mode. Simplex mode in two-way radio communications is defined as a mode whereby transmission and receiving on each transceiver are performed sequentially. With duplex mode transmission and receiving on each transceiver are performed simultaneously. With half-duplex mode the	For the most part continuous mode is used in equipment employed on radio communication links with aircraft. All modes determined by method of information exchange are utilized fairly extensively in radio facilities	Azimuth measuring systems are systems with continuous radiation, while distance-measuring and Loran systems employ pulsed radiation. Azimuth measuring and Loran systems are one-way systems (only a receiver or only a transmitter is carried airborne for these systems). Distance-measuring systems always require receiving and transmitting equipment both on the ground and airborne and are two-way systems	RTO radars operate in pulse mode, which is characterized by pulse duration $\tau_{И}$, pulse repetition period $T_{И}$ or pulse repetition frequency $F_{И}$. Repetition frequency and period are linked by relation $F_{И} = \frac{10^6}{T_{И}}$, where $F_{И}$ is in Hertz, and $T_{И}$ is in microseconds. Pulse duration determines the radar's range resolution and, together with

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
	transmitter and receiver are ready to operate, while sequential antenna connection is effected with the aid of an antenna relay control by mike keying. Relay mode provides radio communications via intermediate transceivers for the purpose of extending range. Relaying can be performed automatically, in which case signals are retransmitted immediately after being received. In radio navigation systems the second characteristic is employed to differentiate systems with two-way or with one-way communication between ground and airborne equipment. Radars distinguish on the basis of the second characteristic active radar mode (detection on reflected signal) and operation mode with active response			power, effective range -- for this reason pulse durations in detection radars and air traffic control surveillance radars, where the principal requirement is great range, are greater than in precision approach radars, where where resolution and precision play an important role

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
Transmitter power	Transmitter power is the power put by a radio transmitter into the antenna (or antenna equivalent) at a given frequency. For radio-radar equipment operating on pulse mode transmitter power is characterized by pulsed and average power output. Pulse power $P_И$ is linked to transmitter average power during pulse repetition period P_{cp} by the relation $P_{cp}=P_И\tau_И F_И$, where $\tau_И$ -- pulse duration, s; $F_И$ -- pulse repetition frequency, Hz. Transmitter energy $W_И$ (in joules) for pulse repetition period $T_И$ is equal to $W_И = P_И \tau_И = P_{cp} T_И$, where $\tau_И$ and $T_И$ -- in seconds; $P_И$ and P_{cp} -- in watts	Radio transmitter power is determined by frequency bands, transmitter location and required range. In order to decrease mutual interference, to increase operation security and ensure requisite transmitting altitude, stepwise change in radiated power is provided in airborne transceivers: 100, 50, 25 and 10%. Stepwise change in radiated power is also provided in ground transceivers	In azimuth measuring systems in the form of ground and airborne radio direction finders, where only radio receivers are employed, transmitter power does not figure as a system parameter. In distance measuring systems and distance measuring channels of azimuth measuring and ranging systems, transmitter power is selected to ensure effective line-of-sight range. Transmitter pulse power in Loran systems can reach hundreds and even thousands of kilowatts	Ground detection radars and ground radio altitude measuring systems are high-power systems. Air traffic control surveillance radars and precision approach radars are medium-power units
Receiver sensitivity	Receiver sensitivity is characterized by minimum emf value (in microvolts) or power (in watts) at input at which a voltage (or power) is developed at	Sensitivity of communications receivers is usually a few microvolts. Sensitivity of airborne receivers is	Sensitivity of azimuth measuring system receivers is approximately the same as that of communication receivers	Sensitivity of radar receivers is usually very high, ensuring the specified detection range

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
	receiver output sufficient to reproduce the received signal. In estimating sensitivity one figures the ratio of signal level to noise level at receiver output. In conformity with this, receiver sensitivity is viewed as the minimum useful signal value at input $P_{пр}$ under the condition that one obtains at the receiver output a signal-to-noise ratio sufficient for normal operation of receiver terminal stages and devices. In many cases sensitivity is expressed in decibels in relation to power level at input P_0 at 1 watt or 1 megawatt. In this case sensitivity is figured with the formula $P_{дБ} = 10 \lg \frac{P_r}{P_{пр}}$, $P_{пр}$ -- in watts; $P_{дB}$ -- in decibels	somewhat less than that of ground units		
Type of antenna system and its characteristics	Following are the principal characteristics of antenna systems: type and width of antenna radiation pattern in the horizontal and vertical planes;	Following are employed on modern aircraft: with high-frequency transceivers -- folded-dipole and flush antennas, less frequently rigid	RTO system radio navigation equipment employs the most diversified types of antenna.	Ground radars, altitude measuring equipment and precision approach radars, depending on the

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
	antenna gain (directional effect). The radiation pattern indicates the dependence of antenna field intensity amplitude ($E(\varphi, \varepsilon)$, V/m) or power flux density ($p(\varphi, \varepsilon)$, w/m^2) on direction from the antenna at a constant distance to points of observation, that is: $E(\varphi, \varepsilon)=E_{max}k(\varphi, \varepsilon)$; $p(\varphi, \varepsilon)=p_{max}k^2(\varphi, \varepsilon)$, where E_{max}, p_{max} -- maximum field intensity and power flux density values; φ, ε -- azimuth and angle of elevation; $k(\varphi, \varepsilon)$ -- standardized expression of antenna directivity by field intensity (Figure 4.1). Radiation pattern width -- angle between directions in which the power field density diminishes to half, with field intensity 0.707 of maximum value. Directive gain (KND) of an antenna [$G(\varphi, \varepsilon)$] is that number which indicates gain in power field density or in radiated power given at the point of observation	wire antennas stretched along the surface of the aircraft; VHF and UHF transceivers -- flush and whip antennas; high-frequency transceivers with a medium-frequency unit -- trailing antennas. Ground transceivers employ antennas of the "wave duct" type, symmetrical dipoles, discone, V, T, Z, rhombic and vertical whip antennas	Ground UHF and HF direction finders employ so-called H antennas, while aircraft ADFs employ loop antennas. DME ground stations employ directional antennas consisting of dipoles with metal reflectors, while airborne equipment employs nondirectional whip antennas. Instrument landing system radio beacons employ antennas with parabolic reflectors and of the "wave duct" type, a horizontal loop antenna, etc. Azimuth measuring-ranging system ground equipment employs in the azimuth measuring section directional antennas with parabolic reflector, the ranging section -- antenna arrays	frequency band, most frequently employ the following types of antennas: in the centimeter and decimeter bands -- antennas with parabolic reflectors; in the meter band,-- "wave duct" type antennas (director antennas). Antenna radiation patterns of detection radars and ATC surveillance radars are relatively broad in the vertical plane and narrow in the horizontal plane. Precision approach radar antenna radiation patterns are different for the localizer antenna and the glide-slope antenna. The localizer antenna is

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigaion Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
	by a directional antenna (Figure 4.2): $G(\varphi,\varepsilon)=\frac{P_{\Sigma}(\varphi,\varepsilon)}{P_0}$ when $P_{\Sigma 0}=P_{\Sigma}$ or $G(\varphi,\varepsilon)=\frac{P_{\Sigma 0}}{P_{\Sigma}}$ when $E(\varphi,\varepsilon)=E_0$, where $P_{\Sigma}(\varphi,\varepsilon)$ and P_0 are power field densities produced by a directional and nondirectional antenna; P_{Σ} and $P_{\Sigma 0}$ -- powers radiated by a directional and nondirectional antenna; $E(\varphi, \varepsilon)$ and E_0 -- field intensities generated by a directional and nondirectional antenna. Dependence of directive gain on direction is determined with the radiation pattern by relation $G(\varphi,\varepsilon)=G_{max}k^2(\varphi,\varepsilon)$. The antenna gain factor is the product of directive gain times antenna efficiency η_A $D(\varphi,\varepsilon)=G(\varphi,\varepsilon)\eta_A$		which are nondirectional in the horizontal plane, and airborne equipment -- nondirectional whip antennas	narrow in the horizontal plane and broader in the vertical plane. On the contrary, the glideslope antenna is narrow in the vertical plane and broader in the horizontal plane. Antenna directive gains are determined by antenna dimensions and the radar wavelength, and therefore by the type and width of the radiation pattern.
Resistance to interference and jamming	Resistance to interference and jamming characterizes the capability of communications and RTO equipment to operate under conditions	All methods of increasing the noise immunity of radio communications equipment are based on the	Azimuth or angle measuring systems in the form of ground direction finders possess poor	The effect of interference and jamming on the operation of radars is manifested in decreasing the

(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
	of natural interference and man-made jamming. It depends on operational security and noise immunity. Operating security is determined by the time during which transmitter signals are emitted, as well as countermeasures against hostile intelligence. The noise immunity of communications and RTO equipment is determined by the operating mode of the given unit and the employment of special circuits (devices) working to prevent noise penetration to the input of the receiver terminal device	principle of increasing redundancy in the transmitted message or, which is the same thing, the principle of increasing signal volume V_c: $$V_c = \tau_c \Delta f_c \log_2 \frac{P_c}{P_n}.$$ As is evident from the formula, signal volume can be increased by increasing signal duration τ_c, signal frequency band Δf_c and the ratio of signal average powers P_c to noise P_π. Noise immunity by increasing the frequency band is achieved by employing wideband types of modulation (frequency and all pulse modulations) and when increasing the signal/noise ratio -- by reducing the noise level and increasing transmitter power. In addition, increased noise immunity is achieved	security in view of the necessity of extended transmission of signals from an airborne aircraft, as well as transmission of bearing information to the aircraft. Noise immunity of a DF channel corresponds to that of radiotelephone communications channels. Distance measuring systems with continuous measurement of current range possess poor security, since continuous two-way radio communication between airborne and ground equipment is taking place during the entire duration of system utilization. Systems with periodic distance measurement can have extremely brief periods of communication between ground and airborne aircraft,	signal-noise ratio at receiver input. As a consequence of this, targets are detected with the specified probability at closer ranges or are not detected at all. Usually a radar's noise immunity is estimated on the basis of effective range during interference. The effective range of a radar with noise generated by a jamming transmitter not collocated with the protected object is equal to (cont'd on next page)

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(Table 4.1, cont'd)

Parameter	Substance of Parameter	Description of Parameters as Applied to Radio Communications Equipment	Description of Parameter as Applied to RTO System Radio Navigation Equipment	Description of Parameter as Applied to RTO System Ground Radar Facilities
		by employing noise- and jam-proof codes and special methods of receiving weak signals: periodic signal filtration, storage, narrow-band receiving, employment of a wideband-limiter-narrow band (ShOU) system, etc. As a rule security of radio communications equipment is poor and is secured primarily by organizational-technical measures.	which means they can possess a high degree of operational security. The noise immunity of distance measuring systems can be quite high due to the employment of pulsed transmitting devices, high energy potentials, and encoded interrogation and response. Loran systems possess poor operating security of ground stations and close to absolute security of operation of airborne equipment due to continuous emission of signals by ground stations and employment only of receiving equipment on board aircraft. The noise immunity of these systems is approximately the same as that of distance measuring systems	$Д_{пом} = Д\sqrt[4]{\frac{(4\pi)^2 Д_{пп}^2 P_ш}{g_п G_{РЛС}(\varphi_п, \varepsilon_п) \Delta f_{РЛС} \lambda^2}}$, where $Д$ is the radar's effective range in the absence of jamming, km; $Д_{пп}$ -- distance from radar site to jamming transmitter, m; $P_ш$, $\Delta f_{РЛС}$ -- respectively the noise output in the radar receiver band and its passband, MHz; $g_п$ -- noise output density, w/MHz; $G_{РЛС}(\varphi_п, \varepsilon_п)$ -- radar directive gain in the direction of the jamming transmitter; λ -- radar wavelength, m. If the jamming transmitter is collocated with the protected target, $Д_{пом} = Д^{2}\sqrt{\frac{(4\pi)^2 P_ш}{g_п G_{РЛС\,max} \Delta f_{РЛС} \lambda^2}}$. where $G_{РЛС\,max}$ -- maximum radar antenna directive gain.

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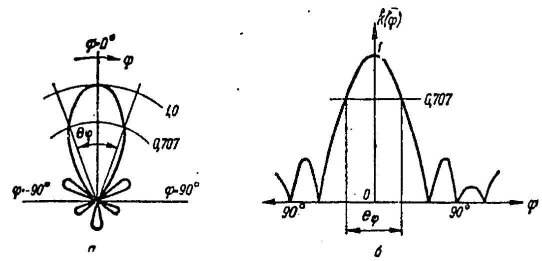

Figure 4.1. Antenna Radiation Pattern in a Polar (a) and Rectangular (б) Coordinate System

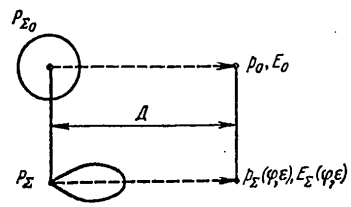

Figure 4.2. Determining Antenna Directive Gain

4.2. Parameters Characterizing Tactical Capabilities of Radio Communications Equipment

Following are the principal tactical parameters characterizing radio communications equipment: range, number of discrete frequencies to which a transceiver can be tuned in advance, time to tune a transceiver from one frequency to another, transceiver cycle of operation, altitude, transceiver, remote control capability, transportability, transceiver capability of operation while moving, deployment time, and size of position required for deployment.

Table 4.2 discusses the above-enumerated tactical parameters.

4.3. Parameters Characterizing Tactical Capabilities of Radar Equipment

Radar equipment in an RTO system includes ground radars for detecting air targets, ground altitude measuring equipment, and approach radars. Employed for identification of detected air targets is equipment for identifying aircraft nationality, as well as additional equipment such as ground direction finders, airborne ATC transponders, and ground equipment of azimuth and distance measuring radio navigation systems.

Table 4.2. Parameters Characterizing Tactical Capabilities of Radio Communications Equipment

Parameter	Substance of Parameter	Description of Parameter as Applied to Aviation Radio Communications Equipment
Range	Range is defined as the greatest distance between stations of a radio communication link at which stable two-way communications are effected under the condition that normal received signal power is ensured at the output of each receiver with an allowable signal-to-noise ratio. Requisite transceiver range is secured by proper selection of frequency band, suitable transmitter power and receiver sensitivity, utilization of effective methods of controlling oscillations, as well as the employment of high-gain antenna systems. Range of radio communications depends to a substantial degree on the conditions of propagation of electromagnetic energy, that is, on the absorbing, scattering, refracting and reflecting properties of the troposphere and ionosphere, which change during the course of a 24-hour period, during the course of the year, and on the ability of radio waves to pass around obstacles	When employing long waves, the conditions of propagation of which vary insignificantly, range of radio communications is practically a constant value. With change in conditions of propagation of short waves, range of radio communications varies over a significant range even with unchanged parameters of receiving and transmitting equipment. Range of radio communications in the VHF and UHF bands is determined primarily by the state of the troposphere and capability of radio waves to pass around obstacles. Therefore range of communications depends on the antenna height of the communicating stations and does not exceed line-of-sight range Д in kilometers: $Д = 4.12\,(\sqrt{h_1} + \sqrt{h_2})$, where h_1, h_2 -- station antenna heights at terminal points of a radio communication link, m
Number of specified pretuned frequencies	This parameter defines the capability to shift frequencies when conducting communications under conditions of deliberate jamming, and provides flexibility and reliability of control of a large number of groups of aircraft from one or several control facilities. In conformity with this, each airborne transceiver is designed so that it can be tuned in advance to a number of specified frequencies and be quickly tuned over to any of them during the flight.	The number of pretuned frequencies for aviation transceivers ranges within broad limits: from dozens to hundreds. The number of fixed fequencies in airborne transceivers is considerably greater than in ground stations

(Table 4.2, cont'd)

Parameter	Substance of Parameter	Description of Parameter as Applied to Aviation Radio Communications Equipment
	Utilization in transceivers of a discrete group of rigidly-fixed frequencies (usually with quartz stabilization) ensures establishment of contact without seek-tuning and conduct of communications without fine-adjustment tuning. All other conditions being equal, this speeds the process of communication and increases its reliability. A specified number of fixed frequencies are also provided in ground radio equipment	
Cycle of operation	This parameter is characterized by the ratio of station operating time for transmitting and receiving. It depends on conditions of cooling and equipment design, power supply, ambient temperature and atmospheric pressure. Radio receivers usually have a capability of around-the-clock continuous operation. Continuous operation time for transmitters and power supplies is limited; their operation for an extended period is secured with a specified ratio of receiving to transmitting time (receiving time exceeds transmitting time by not less than two to threefold). Listening watch is employed to increase transceiver service life and operational reliability. The operator transmits when necessary in the control process	Extended operation is secured under the condition that receiving time exceeds transmitting time severalfold. This ratio is greater with VHF-UHF transceivers than in shortwave transceivers, due to more intensive heating conditions. Aircrews guard the current communication frequency from takeoff to landing on the principal receiver, while at a ground station a special receiver operating on a separate antenna is used for this purpose
Altitude capability	Altitude is one of the important parameters of airborne radio equipment. Air density and pressure gradually decrease with increased altitude. The heat capacity of air decreases with low atmospheric pressure, which can lead to excessive heating and breakdown of	The altitude capability of aircraft transceivers corresponds to the tactical capabilities of modern aircraft as regards operating altitude

(Table 4.2, cont'd)

Parameter	Substance of Parameter	Description of Parameter as Applied to Aviation Radio Communications Equipment
	equipment. Breakdown voltage also decreases with a decrease in air density. All this affects the electrical properties of the mounting of capacitors, coils and a number of other components, which can fail or change values as a result of electrical breakdown. Temperature and humidity of the ambient air decrease with an increase in altitude, which also changes the parameters of radio components (primarily in oscillator and electromechanical systems). Thus with an increase in altitude the operating conditions of radio circuitry worsen. In connection with the above, an altitude limit is specified for transceivers of each type, up to which altitudes they can be utilized for practical operations. This parameter is generally called altitude capability. An increase in the altitude capability of modern radio equipment is achieved by sealing assemblies and individual components, by employing higher-quality dielectrics, by increasing the cooling surface, as well as by employing pressurization and forced-air ventilation	
Remote control capability	This parameter is a principal parameter in resolving the problem of locating ground radio equipment away from control facilities for purposes of concealment, as well as most efficient location of airborne radio equipment elements on board an aircraft and convenience of radio utilization by crew members.	Remote control of ground radio facilities can be effected at a distance of up to several tens of kilometers, and for airborne radio equipment -- up to several tens of meters

(Table 4.2, cont'd)

Parameter	Substance of Parameter	Description of Parameter as Applied to Aviation Radio Communications Equipment
	Remote control of ground radio stations is effected by wire or radio with the aid of individual or group radio station devices. Low-power VHF-UHF transceivers are employed as individual station devices, and radio-relay stations as group equipment. Remote control of ground stations for communicating with aircraft is handled with special remote radio control consoles (RVPU). They are used to set up the required type of operation, to switch from receive to transmit and vice versa, transmitter modulation, signal volume control, tuning to the required communication frequency (change from one frequency to another), service communications with radio facility personnel, as well as switching and adjustment in the console power supply circuits depending on the type of primary supply. Airborne radio equipment remote control devices do the following: switch a transceiver on and off, shift from one discrete frequency to another, adjust signal volume, transmitter power (by discrete values), and provide transmitter operation readings	
Radio equipment transportability and capability to operate while traveling	Ground radio stations employed for ground-to-air communications come in two basic transport versions: truck-deployed and takedown. Employment of these versions depends on the tasks to be performed, basing and geographic conditions. Of great importance for controlling aircrews is the adaptability of a station to operate while	Stations employed with frequent short-distance redeployment of aviation control facilities in an area with favorable geographic conditions and with a good road system are the truck-mounted version. With permanent aircraft basing or with frequent long-distance redeployment of facilities,

(Table 4.2, cont'd)

Parameter	Substance of Parameter	Description of Parameter as Applied to Aviation Radio Communications Equipment
	traveling. Capability to operate during travel is secured by selecting appropriate station operating modes and antenna arrays with optimal radiation patterns	as well as under adverse geographic conditions, the takedown version is employed. Radio communications with aircraft during station travel are secured at a distance of up to several dozen kilometers
Setup time and dimensions of required position	Ground radio station setup time is figured from the moment it arrives at the position to the moment it is ready for communication operations. It is determined primarily by the time to set up the antenna system and station remote control equipment. Minimum station setup time occurs when using compact antenna systems with employment of means of mechanization for setup, with utilization of individual station control equipment, as well as when station personnel are sufficiently well drilled. Selection of position is of great importance in the process of setting up ground radio stations. In choosing a station site one seeks to ensure the least possible number of local signal-blocking features, maximum distance to individual interference sources, observance of electromagnetic compatibility standards, securement of capability to perform engineer activities to shelter the station and personnel for purposes of cover and concealment, with approach roads and conditions for performing radioactive decontamination	Modern ground radio stations can be set up quickly. Setting up a VHF-UHF station takes one half to one third the time required to set up high-frequency facilities. Site size depends on station design (primarily antenna arrays) and designation.

Ground surveillance radars, altitude measuring radars and precision approach radars employ either 360 degree or sector coverage.

The tactical capabilities of this equipment are characterized by such indices as maximum range, detection zone, measured coordinates and accuracy of measurement, resolution and information capability. The substance of these parameters and their quantitative relations are contained in Table 4.3.

Table 4.3. Parameters Characterizing Tactical Capabilities of Radar Facilities

Parameter	Substance of Parameter	Quantitative Relations
Maximum range	Maximum range is the range of detection of air targets in the direction of the radar antenna's radiation pattern maximum. Maximum detection range is determined by the function of the specific radar and depends on radar transmitter power, antenna radiation pattern, target effective reflecting area, and receiver sensitivity	A radar's maximum range $Д_{max}$ (in meters) is determined by the relation $$Д_{max} = \sqrt[4]{\frac{P_и G_{РЛС\,max} \sigma_ц \lambda^2}{(4\pi)^3 P_{пр.\,min}}},$$ where $P_и$ -- power in radar transmitter pulse, watts; $G_{РЛСmax}$ -- radar antenna maximum directive gain; $P_{пр.min}$ -- radar receiver sensitivity, watts; $\sigma_ц$ -- target effective reflecting or echo area, m^2; λ -- radar wavelength, m
Detection zone	A radar's detection zone is that area within the boundaries of which a radar detects targets with a specified probability and measures their coordinates with the required accuracy (Figure 4.3). The shape of a detection zone is determined by the shape of the radar antenna's radiation pattern and the mode of its displacement within the boundaries of the specified radar surveillance zone. The dimensions of the detection zone in a direction away from the radar are determined by maximum detection range, and in directions perpendicular to a line away from the radar -- by the viewing angle in the horizontal and vertical planes. Graphically the detection zone is characterized by two sections: vertical and horizontal planes. Correspondingly these graphs are called detection zones in the vertical (Figure 4. 4.3a) and horizontal (Figure 4.3б) planes.	The detection zones of ground surveillance radars have the shape indicated in Figure 4.3. The detection zone is formed as a consequence of rotation of the radar antenna on its vertical axis (all-round scanning). The detection zones of ground altitude measuring radars are approximately the same as those of surveillance radars. However, due to the specific method of measuring altitude, scanning of the detection zone is performed with rapid rocking in the vertical plane of the antenna's pattern and comparatively slow antenna rotation in the horizontal plane. Two kinds of radar are employed in aircraft instrument landing system -- surveillance radar and precision approach radar. The detection zone of the surveillance radar is similar to that of a detection radar, but as a rule it has a somewhat shorter detection range.

(Table 4.3, cont'd)

Parameter	Substance of Parameter	Quantitative Relations
	The boundary of the detection zone in the vertical plane for ground surveillance radars can be calculated with the formula where k(ε) is the antenna's radiation pattern in a vertical plane	A precision approach radar has a limited detection zone in the direction of the landing approach (Figure 4.4). The radar's detection zone is scanned in sequence by two antennas -- the localizer antenna and the glideslope antenna. The localizer antenna scans the specified zone by continuous rocking of the radiation pattern in a horizontal plane within a scanning sector measured by an angle of approximately 25-30° and by turning in the vertical plane when necessary, within the vertical scanning limits of approximately 9°. The glideslope or glidepath antenna on the other hand covers its scanning zone by rocking the radiation pattern in a vertical plane within limits of an angle of 8-9° and, when necessary, by turning in a horizontal plane within the limits of the scanning zone (25-30°)
Detection zone scanning time	Detection zone scanning time is that time following the lapse of which a radar sequentially illuminates a target. Scanning time characterizes the intensity of input of data on the detected target. Scanning time (in seconds) can be determined with the formula $$t_{\text{обз}} \geq n_{\min} T_{\text{и}} \frac{\varphi_{\text{обз}} \varepsilon_{\text{обз}}}{\theta_\varphi \theta_\varepsilon},$$ where n_{min} is the minimum requisite number of pulses echoed from the target for assured observation of the target return on the radar scope; $T_{\text{и}}$ -- radar pulse repetition period $\left(T_{\text{и}} > \frac{2Д_{\max}}{c}\right)$, , seconds; $\varphi_{\text{обз}}, \varepsilon_{\text{обз}}$ -- scan angles in the horizontal and vertical planes, °;	Scanning time for detection radars and surveillance radars operating in all-round scanning mode is $$t_{\text{обз}} > n_{\min} T_{\text{и}} \frac{360°}{\theta_\varphi}$$ and comprises 10-20 seconds (3-6 antenna revolutions per minute). All-round scanning is usually not employed with ground altitude measuring equipment, which has narrow radiation patterns in both planes, since scanning time is considerable. These radars perform target detection in limited sectors. Precision approach radars, in order to ensure continuous tracking of the descending aircraft, scanning of the entire coverage

(Table 4.3, cont'd)

Parameter	Substance of Parameter	Quantitative Relations
	θ_{φ}, θ_{ε} -- width of antenna radiation pattern in horizontal and vertical planes	zone by both antennas is not employed simultaneously, for the same reason as with altitude measuring equipment. Scanning time for localizer path and glidepath is identical and is approximately 0.3-0.5 s
Coordinates and accuracy of measurement	A radar is capable of measuring three coordinates which fully determine the position of a target in space, namely slant range $Д$, bearing to the target in a horizontal plane -- azimuth φ, and in a vertical plane -- elevation ε. For convenience of utilization of radar data, target altitude is figured from range and elevation. In this instance a radar determines three coordinates -- range, azimuth, and altitude. A radar's accuracy of determination of coordinates is estimated by the magnitude of measurement errors. One utilizes the conventional techniques of probability theory, and for estimating random errors of measurement of coordinates one employs the terms root-mean-square error $\sigma(x)$, mean or probable error x_B and maximum error x_{max}. $$\sigma(x)=\sqrt{\frac{1}{n}\sum_{i=1}^{n}x_i^2},$$ where x_i -- random error of i measurement; n -- number of measurements $$x_B=\frac{2}{3}\sigma(x);$$ $$x_{max}=4x_B\approx 3\sigma(x).$$ Very frequently radar characteristics include error values with 85 or 95% of measurements. In this case $$x_{0,85}=1.44\sigma(x);$$ $$x_{0,95}=2\sigma(x).$$	Ground detection radars determine two coordinates -- range and azimuth. Ground altitude measuring radars also determine two coordinates -- range and altitude (elevation), but target azimuths can also be determined with their assistance. Aircraft instrument landing surveillance radar is also a two-coordinate radar and determines the range and azimuth of the detected target. The precision approach radar as an aggregate is a precision three-coordinate radar. The localizer section determines range and azimuth, with azimuth measured as the aircraft's deviation from the predetermined landing approach course. The glidepath section determines range and elevation, with the elevation measured as the aircraft's deviation in a vertical plane from the predetermined descent trajectory (glidepath). Accuracy of range measurement in ground detection and altitude measuring radars depends on the selected scanning range scale and to a certain degree on the measured range (more precisely, on the signal/noise ratio at receiver input). Accuracy of azimuth measurement by detection radars, instrument landing system surveillance radars and altitude measuring radars is approximately identical and ranges

(Table 4.3, cont'd)

Parameter	Substance of Parameter	Quantitative Relations
	Potential accuracy of radar measurement of coordinates is determined by the following expressions: range, m: $\sigma_0(Д)=\frac{c\tau_и}{2\sqrt{2\pi m_p}}$, azimuth, °: $\sigma_0(\varphi)=\frac{\sqrt{3}}{\pi}\frac{\theta_\varphi}{\sqrt{2m_p}}$, elevation, °: $\sigma_0(\varepsilon)=\frac{\sqrt{3}}{\pi}\frac{\theta_\varepsilon}{\sqrt{2m_p}}$, where $\tau_и$ -- pulse duration, sec; c -- velocity of propagation of electromagnetic waves, equal to the speed of light, m/s; m_p -- coefficient of distinguishability for one pulse; θ_φ, θ_ε -- width of radar radiation pattern in azimuth and elevation, °. Actual accuracy is always worse than potential due to errors of display, propagation of radio waves, and equipment distortions. Actual accuracy can be obtained by multiplying potential accuracy by the corresponding coefficients of worsening of accuracy ($k_Д$, k_φ, k_ε). For modern radars, for example, $k_Д$=1.5-15.	from 1 to 1.5°. Accuracy of altitude measurement by ground altitude measuring radars (in meters) is determined by errors in determining range and elevation: $\sigma(H)=\sigma(Д)\left[\sin\varepsilon+\frac{Д}{R_э}\right]+\sigma(\varepsilon)Д\cos\varepsilon$, where $\sigma(Д)$, $\sigma(\varepsilon)$ -- errors in determining range and elevation, m and rad; Д -- range to target, m; ε -- target elevation, °; $R_э$ -- equivalent earth's radius, m
Resolution	A radar's resolution is its capability separately to observe and measure the parameters of two targets which are positioned close to one another in space. We differentiate resolution in range and angular coordinates (azimuth, elevation). Quantitatively resolution is evaluated by the minimum difference of meausred coordinates (range, azimuth, elevation) of two targets with which they are differentiated by the radar. Resolution in range (in meters) is $\delta Д=\frac{c\tau_и}{2}+\frac{Д_p}{L_p}d_п$,	The resolution range of a detection radar and approach surveillance radar, which as a rule have 360° scan displays, is calculated with the formula $\delta Д=\frac{c\tau_и}{2}+\frac{Д_p}{n_п}$ and is determined basically by the ratio $\frac{Д_p}{n_п}$, where $n_п$ is the number of blips which will fit onto a scope radius. In modern tubes $n_п$=150-200. In altitude-determining radars values δД are

(Table 4.3, cont'd)

Parameter	Substance of Parameter	Quantitative Relations
	where $\tau_и$ -- pulse duration, sec; $Д_р$ -- scanning range scale, m; $d_п$ -- diameter of blip on face of CRT, mm; L_p -- length of scanning line, mm. Resolution in azimuth (in degrees) is $$\delta\varphi = \theta_\varphi + \frac{\varphi_p}{L_p} d_п$$ and in elevation (in degrees) $$\delta\varepsilon = \theta_\varepsilon + \frac{\varepsilon_p}{L_p} d_п,$$ where θ_φ, θ_ε -- width of radiation pattern by azimuth and elevation, °; φ_p ε_p -- size of scanning sector on scope by azimuth and elevation, °; L_p -- linear dimension of scanning by azimuth and elevation, mm; $d_п$ -- diameter of blip on face of CRT, mm	approximately the same as in surveillance radars. Range resolution in precision approach radars is greater as a result of employment of larger scales (smaller $Д_р$) and sector-type scopes with scanning origin displaced to the edge of the scope. Azimuth resolution in detection radars and landing approach system surveillance radars with a plan position indicator is determined with the formula $$\delta\varphi = \theta_\varphi + \frac{57,3}{n_п} \frac{Д_р}{Д_ц - Д_{зад}},$$ where $Д_р$ -- scanning range scale, km; $Д_ц$ -- range to target, km; $Д_{зад}$ -- scanning initiation delay, km. In the absence of delay and with target observation in the middle of scan ($Д_ц \simeq 0.5 Д_р$) azimuth resolution is approximately equal to radar radiation pattern width θ_φ. In altitude determining radars, in place of an elevation resolution value the term altitude resolution (in kilometers) is employed: $$\delta H = \frac{\theta_\varepsilon Д_ц}{57,3 \cos \varepsilon} + \frac{H_p}{L_p} d_п,$$ where $Д_ц$ -- range to target, km; ε -- target elevation, °; H_p -- altitude scanning scale, km; L_p -- linear dimension of altitude scan, mm.
Information capability	Information capability is a synthesized indicator of a radar's target detection capability as a source of information. One possible method of quantitative estimate of information	For radar support system ground radars system of events (x) is two equally-probable statements -- "have target" and "no target" within the limits of the radar's resolution. Therefore entropy

(Table 4.3, cont'd)

Parameter	Substance of Parameter	Quantitative Relations
	capability is the quantity of information which a radar can provide: $I = nH(x)$, where n -- number of observation elements in a radar's surveillance zone; H(x) -- entropy of event x	H(x)=binary unit/element, and quantity of information for such radars is equal to the number of observation elements. Information capability of ground radars in binary units $I = \frac{(Д_{max} - Д_{min})\varphi_{об}\varepsilon_{об}}{\delta Д \cdot \delta\varphi \cdot \delta\varepsilon}$, where $Д_{max} - Д_{min}$ -- radar range observation region, km; $\varphi_{об}, \varepsilon_{об}$ -- observation regions by azimuth and elevation, °; $\delta Д, \delta\varphi, \delta\varepsilon$ -- radar resolutions in range, azimuth and elevation, km and °

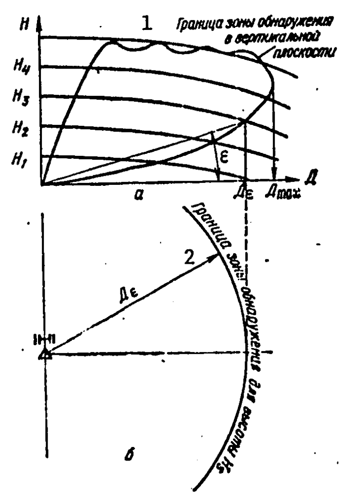

Figure 4.3. Radar Detection Zone in a Vertical (a) and Horizontal (б) Planes

Key:
1. Boundaries of detection zone in vertical plane
2. Boundary of detection zone for altitude H_s

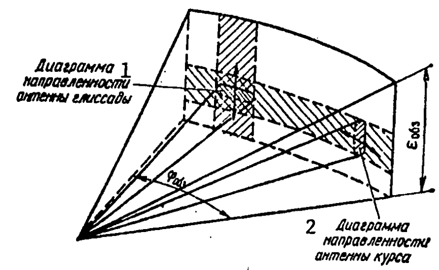

Figure 4.4. Precision Approach Radar Scanning Zone

Key:

1. Glidepath antenna radiation pattern
2. Localizer antenna radiation pattern

4.4. Parameters and Indices Characterizing Tactical Capabilities of Radio Navigation Equipment

Radio navigation systems employed for aircraft navigation make it possible to determine an aircraft's position or navigation elements of a flight through the combined utilization of airborne and special ground equipment. The ground equipment of such systems is called radio navigation equipment of RTO facilities. In addition to ground equipment of radio navigation systems, RTO radio navigation equipment includes the localizer and glideslope radio beacons of aircraft instrument landing systems, which by their principle of operation are azimuth measuring systems.

The positional location of an aircraft in space is established with the aid of a radio navigation system by means of determining the lines (surfaces) of position of aircraft relative to ground facilities the location of which is known.

A line of position (on a surface) or surface of position (in space) is the geometric position of points of the possible position of an aircraft with a constant value of the parameter measured in the system.

The position of an aircraft in space is determined by the intersection of three surfaces of position. In solving a problem on a surface (plane) situated at an aircraft's flight level, its position is determined by the point of intersection of two lines of position.

Following can be parameters measured in a radio navigation system and determining the character of the line and surface of position: the angle between a constant bearing and bearing to the aircraft or to a ground station, or range between aircraft and ground station, or difference or sum of ranges between an aircraft and two ground stations. In conformity with this, systems are angle-measuring, ranging, difference-ranging, or summing-ranging. Some systems measure two parameters simultaneously. Such systems are called combined systems. Essentially such a system can involve any combination of measured parameters. The most common are systems combining measurement of angle and range, which are called goniometric-ranging.

Table 4.4. lists the relationships between measured parameter and line (or surface) of position.

Table 4.4. Relationship Between Parameter, Line and Surface of Position

Type of System	Measured Parameter p	Type of Line of Position	Type of Surface of Position
Ranging system with active response	This system measures double the distance R between a fixed point and an aircraft. Equation of parameter: $p=2R$	Line of position on a plane -- a circle with its center at the point of location of the ground station, of radius R (Figure 4.5). Equation of line of position in a rectangular coordinate system with its center at a reference point: $R^2=x^2+y^2$	Surface of position in space -- a sphere with its center at the location point of a fixed station, and radius R. Equation of surface of position in a rectangular system with center at a reference point: $R^2=x^2+y^2+z^2$
Difference-ranging system	This system measures the difference of distances from two fixed points to an aircraft (Figure 4.6). Equation of parameter: $p=R_1-R_2=2a$	Line of position on a plane -- hyperbola with focal points at location point of ground stations A and B (Figure 4.6) and semiaxes a and $b=\sqrt{\frac{d^2}{4}-a^2}$ Equation of line of position: $\frac{x^2}{a^2}-\frac{y^2}{b^2}=1,$	Surface of position in space -- a hyperboloid formed by the turning of a hyperbola on axis OX. Equation of surface of position: $\frac{x^2}{a^2}-\frac{y^2}{b^2}-\frac{z^2}{b^2}=1$
Sum-ranging system	This system measures the sum of distances from an aircraft to two fixed points (Figure 4.7). Equation of parameter: $p=R_1+R_2=2a$	Line of position on a plane -- an ellipse with focal points at the locations of ground stations A and B (Figure 4.7), and with semiaxes	Surface of position in space -- an ellipsoid obtained by rotating an ellipse on axis OX.

Table 4.4 (cont'd)

Type of System	Measured Parameter p	Type of Line of Position	Type of Surface of Position
		a and $b=\sqrt{a^2-\frac{d^2}{4}}$. Equation of line of position: $\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$	Equation of surface of position: $\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{b^2}=1$, where a and b are semi-axes.
Goniometric System	This system measures an angle in the horizontal and vertical plane. Equation of parameter: a) when measuring azimuth $p=\varphi$; b) when measuring elevation $p=\varepsilon$	Line of position on a horizontal plane (vertical) -- line of equal bearings (equal elevations): $y=x \operatorname{ctg} \varphi$; $z=x \operatorname{ctg} \varepsilon$	Surface of position when measuring azimuth -- a vertical plane, when measuring elevation -- a cone

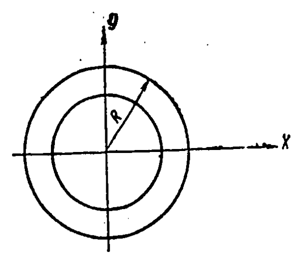

Figure 4.5. Lines of Position of a Ranging System

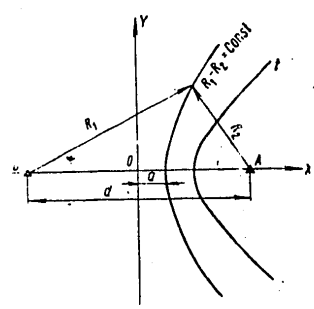

Figure 4.6. Lines of Position of a Difference-Ranging System

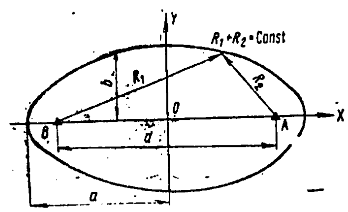

Figure 4.7. Lines of Position of a Sum-Ranging System

Following are the principal tactical indices characterizing effectiveness of employment of radio navigation equipment: effective range, accuracy of determination of parameter, accuracy of determination of line of position, operating zone, throughput, efficiency. Table 4.5 clarifies the substance of these indices and contains relations for calculating their quantitative values.

Table 4.5. Indices Characterizing Tactical Capabilities of Radio Navigation Equipment

Indicator	Substance of Indicator	Quantitative Relation
Effective range	Effective range of a radio navigation system is defined as the greatest distance from ground station to aircraft at which measurement of the system parameter with a specified accuracy is ensured. As a rule the requisite accuracy of parameter measurement is secured by an appropriate signal-noise level at receiver input. System range depends on the frequency band utilized, transmitter power, antenna directivity, and receiver sensitivity	Goniometric systems. Airborne automatic direction finders (radio compasses) are the most common equipment in the medium-frequency band. The effective range of radio compasses in indicating bearing to nondirectional beacons of 400-600 watts is 250-300 km at flight altitudes above 3000 meters. Ground direction finders are most common in the high-frequency band. Their effective range with a sky wave, employment of high-efficiency ground antenna systems and proper selection of operating frequency, may be as much as several thousand kilometers. Both ground and airborne, usually automatic direction finders are employed in the VHF-UHF bands. Their effective range is determined by the conditions of propagation of VHF-UHF radio waves at line-of-sight Д in kilometers: $Д = 4.12(\sqrt{h_1}+\sqrt{h_2})$, where h_1, h_2 -- height of transmitter and direction finder antennas, meters.

Table 4.5 (cont'd)

Indicator	Substance of Indicator	Quantitative Relation
		Ranging systems, as a rule operate in the VHF-UHF band. Their effective range is limited to line-of-sight. Difference-ranging systems operate in various frequency bands. Their effective range is determined by the propagation distance of radio waves in the corresponding band. Goniometric-ranging systems operate in the VHF-UHF band and have the same effective range as ranging (DME) systems.
Parameter determination accuracy	Accuracy of parameter determination is estimated by random errors occurring during parameter measurement -- angle, range, difference of distances.	Accuracy of direction finding by airborne radio compasses is usually 2-3°.
	Accuracy of direction finding (angle determination) depends in large measure on the method of direction finding and the antennas employed in ground or airborne direction finders.	Accuracy of direction finding by ground high-frequency direction finders with the sum-difference method of direction finding is approximately 0.25°, and 2-3° when direction finding by the minimum and aural method.
	Accuracy of determination of distance (or difference of distances) depends on accuracy of time measurement, since distances are measured by the time radio waves require to travel this distance: $D=vt$, where v -- velocity of propagation of radio waves; t -- time.	Accuracy of distance measuring in ranging systems with the employment of special methods of measuring time intervals is 15-20 m.
	Accuracy of measurement of time intervals depends on measurement methods. Indirect measurement methods give greater accuracy than direct methods	Accuracy of measurement of azimuth and range in azimuth-ranging systems is 200-250 m in range and 0.3-0.5° in azimuth [15]
Accuracy of determining	Accuracy of determination of line (surface) of position of an aircraft Δu is determined by distance on the normal between two lines (surfaces) of position corresponding to the true and found parameter	Root-mean-square errors in determining line of position σu in kilometers can be calculated with the following formulas: a) for a goniometric system: $\sigma u=0.01745R\sigma(\varphi)$, where $\sigma(\varphi)$ -- root-mean-square error in determining azimuth, °; R -- distance

Table 4.5 (cont'd)

Indicator	Substance of Indicator	Quantitative Relation
line (surface) of position	values. If error in measurement of parameter p is designated with Δp, error in determining line of position is $$\Delta u = \frac{\Delta p}{\sqrt{(\partial l/\partial x)^2 + (\partial l/\partial y)^2}},$$ while error in determining surface of position is $$\Delta u = \frac{\Delta p}{\sqrt{(\partial f/\partial x)^2 + (\partial f/\partial y)^2 + (\partial f/\partial z)^2}},$$ where p=f(x, y, z) -- equation of parameter in general form	from transmitter to direction finder, km; b) for a distance measuring system: $\sigma(u)=0.15\,\sigma(t)$, where $\sigma(t)$ -- root-mean-square error in measuring time, microseconds; c) for a difference-ranging system: $$\sigma(u) = \frac{0{,}15\sigma(t)}{\sin\psi/2},$$ where ψ -- angle at which the system base can be seen from a moving point, °; $\sigma(t)$ -- root-mean-square error in measuring ground station signal receiving time difference, microseconds
Operating zone	The operating zone of a radio navigation system is that portion of space within which reliable communications are ensured between airborne and ground equipment, while error in determining an aircraft's position does not exceed a certain specified amount. In radio navigation systems an aircraft's position is determined by the point of intersection of two lines of position. If the lines of position are determined with errors Δu_1 and Δu_2, in place of the true position of the aircraft a certain point will be obtained which is displaced relative to the true position by the amount of radial error $$r = \frac{1}{\sin\alpha} \times \sqrt{\Delta u_1^2 + \Delta u_2^2 + 2\Delta u_1 \Delta u_2 \cos\alpha},$$ where α -- angle of intersection of lines of position.	A distance-measuring or ranging system consisting of two ground stations located at the ends of base d, and an airborne DME. Error in determining position (in kilometers) is $$r_\sigma = \frac{0{,}212\,\sigma(t)}{\sin\alpha},$$ where $\sigma(t)$ -- error in measurement of parameter (time), microseconds. Minimum error value will occur when α =90°. Lines of equal accuracy are circles resting on base d and on a chord with central angle 2α and radii $$R_\sigma = \frac{r_\sigma d}{0{,}424\,\sigma(t)} = \frac{d}{2\sin\alpha}.$$ The operating zone is bounded by a region within which the angles of intersection of lines of position α lie within boundaries of from 30 to 150°, and by arcs of a circle with radii equal to the range of reliable communications (Figure 4.8) A goniometric system consisting of two direction finders of equal accuracy, separated from one another by distance

Table 4.5 (cont'd)

Indi-ca-tor	Substance of Indicator	Quantitative Relation
	Since random errors of determination of each line of position are governed by the normal law of distribution, while their appearance can be considered mutually independent, accuracy of determination of position can be estimated by the radius of the root-mean-square circle of dispersion $$r_\sigma = \frac{1}{\sin\alpha}\times \times\sqrt{(\sigma u_1)^2+(\sigma u_2)^2},$$ where σu_1 and σu_2 are root-mean-square errors of determination of lines of position. Knowing expressions σu_1 and σu_2 for a concrete type of system, one can plot the operating zone of a radio navigation system. Usually lines of equal accuracies of position determination, at which position determination error is double its minimum value are selected as operating zone boundaries	d. With an equality of errors in determining bearings, error in determining position (in kilometers) will be $$r_\sigma = \frac{0{,}01745\sigma(\varphi)\sqrt{R_1^2+R_2^2}}{\sin\alpha},$$ where $\sigma(\varphi)$ -- error in measuring bearing, °; R_1, R_2 -- distances from direction finders to aircraft, km. Lines of equal accuracy differ from circles. Minimum error of position determination (in kilometers) is found on a perpendicular to the base and is equal to $$r_{\sigma\,min} = 0{,}01605 d\sigma(\varphi),$$ where d is expressed in kilometers, and $\sigma(\varphi)$ in degrees. The shape of the operating zone is shown in Figure 4.9. Difference-ranging system. With identical accuracy of measurement of time intervals by the airborne equipment, error in determining position (in kilometers) is $$r_\sigma = \frac{0{,}15\sigma(t)}{\sin\alpha}\times \times\sqrt{\frac{1}{\sin^2\frac{\psi_1}{2}}+\frac{1}{\sin^2\frac{\psi_2}{2}}},$$ where $\sigma(t)$ -- error in measurement of time intervals, microseconds; α -- angle of intersection of lines of position, °; ψ_1, ψ_2 -- angles at which system bases are visible, °. The shape and dimensions of the operating zone depend to a substantial degree on the angle between the station bases. If a comparatively poor accuracy of position determination on is allowable, then in order to obtain the largest possible zone it is advantageous to take this angle close to 180°. If it is

Table 4.5 (cont'd)

Indicator	Substance of Indicator	Quantitative Relation
		necessary to achieve the greatest possible accuracy of position determination, the angles between bases should be between 60 and 90° (Figure 4.10). Goniometric ranging system with one radio navigation point. Error in determining position (in kilometers) is $$r_\sigma = \sqrt{\left(R_0\sigma(\varphi)\right)^2 + \left(\frac{\sigma(R)}{2}\right)^2},$$ where $\sigma(\varphi)$ and $\sigma(R)$ are root-mean-square errors of measurement of azimuth and range, radians and kilometers; R_0 -- measured range, km. The operating zone of such a system is a circle with its center at the radio navigation point and with a radius (in kilometers) of $$R = \frac{1}{\sigma(\varphi)}\sqrt{r_\sigma^2 - \left(\frac{\sigma(R)}{2}\right)^2},$$ where $\sigma(R)$ and r_σ are expressed in kilometers, and $\sigma(\varphi)$ in radians.
Throughput or traffic capacity	Throughput or traffic capacity of a radio navigation system is defined as the maximum number of aircraft which can be handled by the system simultaneously. If traffic capacity is equal to 1, for such systems it is indicated how many aircraft are handled in a unit of time	The throughput or traffic capacity of aviation radio navigation systems is determined by the principle of their operation and conditions of utilization. Goniometric systems. In ground beacon-airborne receiver systems (azimuth channel of a goniometric-ranging system) or airborne radio direction finder (radio compass)-ground transmitter system (nondirectional beacon) -- one-way communication link. Traffic capacity is unlimited. In a ground direction finder-airborne transmitter system, traffic capacity is 4-5 aircraft per minute. Distance-measuring systems. In distance-measuring systems where distance is measured by airborne equipment, traffic capacity is limited to the finite number of response signals which can be produced by a ground repeater without a substantial decrease in the power of each.

Table 4.5.(cont'd)

Indicator	Substance of Indicator	Quantitative Relation
		The maximum number of interrogators (aircraft) handled simultaneously, proceeding from the capabilities of the repeater, is $$N = \alpha_{max} \frac{T_и}{t_{код}},$$ where $T_и$ and $t_{код}$ -- response code group repetition period and duration, seconds; α_{max} -- allowable space factor value. Difference-ranging systems have an unlimited traffic capacity, since they involve one-way communication: ground station - airborne receiver. Goniometric-ranging systems have unlimited traffic capacity in the goniometric channel and 50-100 aircraft simultaneously in the DME channel [15]
Efficiency	The efficiency of a radio navigation system is determined by the time expended on obtaining readings, processing and utilizing data. Efficiency increases significantly with employment of simultaneous automatic reading of parameters, high-speed computing devices, as well as automatic command signal input into the aircraft control system	Goniometric systems. In systems of the ground beacon-airborne receiver type (azimuth channel of a goniometric-ranging system), measurement of bearing is automatic, with practically instantaneous azimuth indication, while automatic pilot coupling can be secured with automatic computer data input. Channel efficiency is high. In systems of the ground transmitter (nondirectional beacon)-airborne direction finder (radio compass) type system efficiency is determined by relative bearing indicator reading time (fraction of a second) and time to process two bearings (for determining position). Bearing processing time usually amounts to tens of seconds. In a ground direction finder-airborne transmitter system, efficiency is low as a rule, due to the necessity of transmitting direction finding results by radio channel to the aircraft, and runs 15-20 seconds [15].

Table 4.5 (cont'd)

Indicator	Substance of Indicator	Quantitative Relation
		DME and difference-ranging systems are highly efficient due to automation of the measuring process and measured data computer input. Goniometric-ranging systems are highly efficient due to the capability of practically instantaneous measurement of aircraft range and azimuth and automatic computer input of measured data

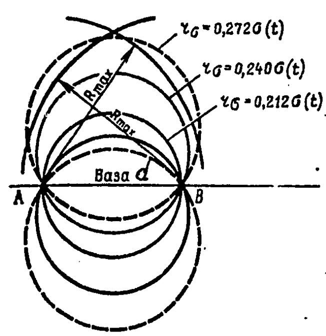

Figure 4.8. Operating Zones of Distance-Measuring System

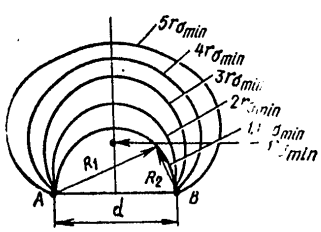

Figure 4.9. Operating Zones of Goniometric System

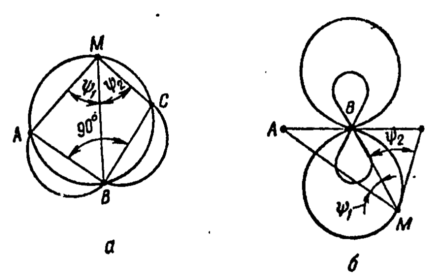

Figure 4.10. Operating Zones of Different-Ranging Systems for Angle Between Bases at 90° (a) and 180° (б)

4.5. Description of Illumination Equipment

Illumination equipment is used to aid aircraft takeoffs and landings, as well as airfield ground traffic. Classified by function, these facilities consist of signal and marker lights, and landing lights.

Lights are placed on the field and on the approach to the field in such a manner as to provide the pilot of a landing aircraft an indication of the direction of the runway centerline, horizon line, and distances to the touchdown point. Depending on the class of the airfield (top-category, first or second class), the total number and intensity of the lights vary, but their general deployment around the runway is identical and is done on the basis of a standard lighting pattern.

Lights are divided by function into the following: approach lights, close-in approach lights, boundary lights, threshold lights, runway far end lights, runway lateral limit lights, landing clearance lights, and departure lights. Following is a brief description of these lights.

Approach lights -- red, continuous or flashing, are placed on the runway centerline extended, from the middle marker (BPRM) toward the outer marker (DPRM) a distance of 1,500 meters, usually with 100 meter spacing. Their purpose is to indicate to the crew of an aircraft on final approach direction to the runway, and to help in transition from instrument to visual flight. Usually approach lights are lens-type high-intensity lights.

Close-in approach lights are red, continuous, running from the runway threshold to the middle marker, spaced every 100 meters. These lights form two rows, forming a continuation of the runway lateral limit lights. To help the aircrew obtain better orientation and to designate the point of initiation of flare, the left row of close-in approach lights is marked by paired lights. The close-in lights are also of the lens type and are fairly high-intensity.

Boundary lights -- red , lens-type or neon -- mark airfield boundaries and establish a light horizon. They are set up at a distance of 400 meters from the end of the runway, perpendicular to the runway axis, with 25 meter spacing.

Threshold lights -- green, lens-type -- mark the runway near end. They are set up at the end of the runway, to the left and right, outside the runway limit.

Runway far end lights -- red -- are employed to mark the end of the runway and to warn against overrun. They are placed on a line parallel to the runway end, 1-5 meters beyond the end.

Runway lights -- white and white-orange -- mark the runway lateral limits and indicate the direction of landing and takeoff roll.

They are positioned along the left and right edges of the runway at 50 meter spacings. Lights with white-orange color filters are located at the beginning and end of the runway, at a distance of 600 meters from the runway ends; the orange color filter is directed toward the runway centerline. This enables the pilot to obtain orientation on the runway end during rollout. Runway lights are placed in such a manner that accidentally running into them will cause no damage to the aircraft. They are mounted flush with the runway or on low, readily-tipping supports.

Landing clearance lights -- flashing, lens-type. Landing clearance lights are green, clearance denial lights are red; placed on the left-hand side of the runway opposite the touchdown point (300 meters from the runway threshold). They signal to the pilot landing clearance or clearance denial, and also mark the touchdown point on the runway.

Departure lights -- red -- are employed to indicate the direction of takeoff roll and provide visual spatial orientation following liftoff; they are placed 400 meters beyond the runway end, in the same configuration as the runway far end lights. In addition, a departure light is placed at a point 1,000 meters from the runway end.

Customarily neon beacons are employed to aid guidance to the airfield. They are placed on the runway centerline extended at a distance of 1,000 meters from the runway threshold. For airfield identification these beacons flash the airfield's call letters -- several (usually two) letters in the telegraph code. All the above-enumerated illuminating equipment, however, may prove insufficient for a sure landing during hours of darkness. Therefore as a rule the runway is illuminated with spotlight-type landing lights. They are mounted on the left side of the runway in such a way as to ensure approximately equal runway illumination along its entire length.

Chapter 5. INFLUENCE OF THE ATMOSPHERE ON OPERATION OF RADIO COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

5.1. Spectrum of Electromagnetic Oscillations

Electromagnetic oscillations occupy a band of frequencies from 3×10^{-3} to 3×10^{20} Hz. This band contains radio waves, infrared rays, visible light, ultraviolet rays, X-Rays, and gamma rays.* Within the spectrum of electromagnetic oscillations, radio waves occupy a band of frequencies from 3×10^{-3} to 3×10^{11} Hz.

Pursuant to an international radio communications agreement, the radio frequency spectrum is subdivided into nine frequency bands, which are designated by whole numbers from 4 to 12 in ascending order, as shown in Table 5.1.

Table 5.1. Spectrum of Radio-Frequency Oscillations

Band Number	Frequency Band (Not Including Lower Limit, Including Upper Limit)	Waveband Subdivision in the Metric System	Letter Designation of Frequency Bands
4	From 3 to 30 kHz	Myriameter	ONCh (VLF)
5	From 30 to 300 kHz	Kilometer	NCh (LF)
6	From 300 to 3000 kHz	Hectometer	SCh (MF)
7	From 3 to 30 MHz	Decameter	VCh (HF)
8	From 30 to 300 MHz	Meter	OVCh (VHF
9	From 300 to 3000 MHz	Decimeter	UVCh (UHF)
10	From 3 to 30 GHz	Centimeter	SVCh (SHF)
11	From 30 to 300 GHz	Millimeter	KVCh (EHF)
12	From 300 to 3000 GHz	Decimillimeter	GVCh [cyrillic designation]

Table 5.2 contains the classification of bands of electromagnetic oscillations adopted in the USSR.

* X-Rays and gamma rays occupy a band of frequencies from 3×10^{15} to 3×10^{20} Hz

Table 5.2. Spectrum of Electromagnetic Oscillations

Наименование диапазона 1	Диапазон, Гц 2		3 Диапазон, м	
	нижняя граница 4	верхняя граница 5	4 нижняя граница	5 верхняя граница
Радиоволны инфразвуковых и звуковых частот 6	$3 \cdot 10^{-3}$	$3 \cdot 10^{3}$	10^{11}	10^{5}
Сверхдлинные волны (СДВ) 7	$3 \cdot 10^{3}$	$3 \cdot 10^{4}$	10^{5}	10^{4}
Длинные волны (ДВ) 8	$3 \cdot 10^{4}$	$3 \cdot 10^{5}$	10^{4}	10^{3}
Средние волны (СВ) 9	$3 \cdot 10^{5}$	$3 \cdot 10^{6}$	10^{3}	10^{2}
Короткие волны (КВ) 10	$3 \cdot 10^{6}$	$3 \cdot 10^{7}$	10^{2}	10
Ультракороткие волны: 11	$3 \cdot 10^{7}$	$3 \cdot 10^{11}$	10	10^{-3}
а) метровые (МВ); 12	$3 \cdot 10^{7}$	$3 \cdot 10^{8}$	10	1
б) дециметровые (ДЦВ); 13	$3 \cdot 10^{8}$	$3 \cdot 10^{9}$	1	10^{-1}
в) сантиметровые (СМВ); 14	$3 \cdot 10^{9}$	$3 \cdot 10^{10}$	10^{-1}	10^{-2}
г) миллиметровые (ММВ) 15	$3 \cdot 10^{10}$	$3 \cdot 10^{11}$	10^{-2}	10^{-3}
Оптические волны: 16	$3 \cdot 10^{11}$	$3 \cdot 10^{16}$	10^{-3}	10^{-7}
а) инфракрасные (ИКЛ); 17	$3 \cdot 10^{11}$	$4 \cdot 10^{14}$	10^{-3}	$7{,}5 \cdot 10^{-7}$
б) видимый свет; 18	$4 \cdot 10^{14}$	$7{,}5 \cdot 10^{14}$	$7{,}5 \cdot 10^{-7}$	$4 \cdot 10^{-7}$
в) ультрафиолетовые (УФЛ) 19	$7{,}5 \cdot 10^{14}$	$3 \cdot 10^{15}$	$4 \cdot 10^{-7}$	10^{-7}

Key:

1. Band designation
2. Band, Hz
3. Band, m
4. Lower limit
5. Upper limit
6. Radio waves of infrasonic and audio frequencies
7. Very low frequency (SDV)
8. Low frequency (DV)
9. Medium frequency (SV)
10. High frequency (KV)
11. Ultrashort waves
12. Meter (MV)
13. Decimeter (DTsV)
14. Centimeter (SMV)
15. Millimeter (MMV)
16. Optical waves
17. Infrared (IKL)
18. Visible light
19. Ultraviolet (UFL)

5.2. Structure of the Atmosphere and Its Influence on Propagation of Radio Waves

In the atmosphere enveloping the earth there are two regions which affect propagation of radio waves: the troposphere, and the ionosphere.

The troposphere is the earth-adjacent layer of atmosphere, which extends to an altitude of 10-15 km and which consists of a mixture of nitrogen, oxygen and argon.

The troposphere is inhomogeneous both vertically and along the earth's surface. In addition, the properties of the troposphere change with change in meteorological conditions: pressure, temperature, and humidity.

Pressure decreases with increasing altitude, initially (up to 10 km) rapidly, and then more slowly. At the earth's surface pressure is 1000 mb, and at an altitude of 10 km -- 270 mb.

The temperature of the troposphere, with normal meteorological conditions, drops uniformly by 5-6°C with each kilometer of increasing altitude and reaches -56°C at an altitude of 10-14 km. With disturbance of meteorological conditions, distribution of temperatures changes with altitude. In this case regions of temperature inversion may form in the troposphere (regions in which the temperature increases with altitude). We must note that the phenomenon of temperature inversion substantially affects the propagation of VHF-UHF radio waves. Air humidity usually decreases with altitude and is highly dependent on meteorological phenomena (rain, fog, wind, etc). When these atmosphere parameters change, the dielectric constant of air changes, as does the related refractive index n. At the earth's surface index n is 1.000338. With a change in pressure, temperature and humidity it can decrease on the average by 4×10^{-6} with each 100 meters increase in altitude. The refractive index changes more substantially with sharp changes in meteorological conditions. This leads to a more pronounced influence of tropospheric refraction on the propagation of radio waves in the troposphere. The trajectory of radio waves can be significantly bent, and the higher the frequency the greater the bending. Therefore tropospheric changes particularly appreciably affect the propagation of decimeter and centimeter waves, which are extensively employed in air traffic control facilities. The troposphere contains local inhomogeneities caused by turbulent (with vortices) air movement, which strongly affect the propagation of VHF-UHF waves.

The ionosphere is that region of the atmosphere lying at an altitude of 60-2000 km above the earth's surface. There takes place in the ionosphere a continuous process of ionization of molecules under the influence of ionizing factors. Ionization is the name given to the process of splitting of gas molecules into positively and negatively charged particles -- ions -- with the release of free electrons.

In addition to ionization, recombination of molecules also occurs in the atmosphere -- the process of joining of ions of opposite signs, that is, the forming of neutral molecules. In the upper layers of the atmosphere the air is highly rarefied, distances between gas molecules are fairly large, and the process of recombination takes place slowly in these layers. It follows from this that the upper (rarefied) layers of atmosphere are highly ionized, and therefore they possess good conductivity.

Ionization of the upper layers of the atmosphere takes place under the influence of a number of factors, the principal factors among which are the following: solar ultraviolet radiation, cosmic rays, corpuscular fluxes emitted by the sun, stellar light, and meteors. Under the influence of any of these factors, an atom's electrons move from one stable orbit into another (atomic excitation), while with sufficient intensity of this factor they detach from the nucleus (atomic ionization). The processes of excitation and ionization are connected with expenditure of energy by the source under the influence of which ionization takes place, that is, with absorption of energy. For excitation or for ionization, for example, a light quantum should possess sufficient energy for transition of an electron from one stable orbit to another. The light quantum value is determined as the product of the light oscillation frequency times the Planck constant: $h=6.626196 \pm 0.000050 \times 10^{-34}$ J·s. Consequently, light activity increases with an increase in oscillation frequency, that is, with transition into the violet and ultraviolet regions of the spectrum. Thus solar ultraviolet radiation and cosmic rays are of the greatest significance for ionization of the atmosphere.

Since the chemical composition of the air changes with altitude, and different gases possess a differing capability to absorb solar radiation of differing frequency, the degree of ionization of the atmosphere will differ from layer to layer. The state of ionization is generally described by the magnitude of electron concentration N, which corresponds to the number of free electrons in one cubic centimeter of gas. Each layer of the ionosphere has an electron concentration of specified magnitude N, which changes in relation to time of day, year, local latitude and the 11-year solar activity cycle.

Ionosphere layers are characterized by the following parameters: electron density at ionization maximum $N_{э\ max}$ or critical frequency f_{kp}, altitude of lower ionization boundary h_0, layer half-thickness, that is, vertical distance from the lower boundary of the layer to the altitude of maximum ionization h_{max}, and by the number of electron collisions with heavy particles ν. As a result of ionosphere investigations it has been established that it consists of regions (layers), which have been given the following designations: D, E, F_1, and F_2.

Table 5.3 presents the principal characteristics of the ionized regions of the ionosphere.

Table 5.3. Principal Characteristics of Ionized Layers of the Ionosphere

Designation of Ionized Regions (Layers)	Principal Properties of Ionized Regions From the Standpoint of Their Influence on Propagation of Radio Waves	Quantitative Characteristics of Ionized Regions				
		Altitude, km	Molecular Density, 1/cm^3	Electron or Ion Concentration, 1/cm^3	Number of collisions, 1/s	Recombination Coefficient, cm^3/s
Region (layer) D	It is the lowest layer of the ionosphere and exists only during the day (disappears at night). The daily cycle of change in electron concentration and altitude of occurrence of the maximum repeat each day. Due to a high density and substantial number of collisions between electrons	60-90 (day)	10^{14}-10^{16}	100-10^3 electrons or 10^6-10^8 ions	10^7 at the lower boundary	10^{-5}-10^{-7}

Table 5.3. Principal Characteristics of Ionized Layers of the Ionosphere

Designation of Ionized Regions (Layers)	Principal Properties of Ionized Regions From the Standpoint of Their Influence on Propagation of Radio Waves	Quantitative Characteristics of Ionized Regions				
		Altitude, km	Molecular Density, $1/cm^3$	Electron or Ion Concentration, $1/cm^3$	Number of Collisions, 1/s	Recombination Coefficient, cm^3/s
	and heavy particles, absorption properties are strongly marked in this region. As a result short, medium and long waves are entirely absorbed in this layer over a path of several kilometers. VLF waves are reflected from it without experiencing great absorption (for this reason the properties of a metal reflector are ascribed to the D layer)					
Region (layer) E	The altitude of this layer is little dependent on time of day or season. The electron density of the E layer shows a patterned seasonal variation: maximum values $N_{\ni max}$ and f_{kp} are observed during the summer months. At night these parameters remain at a constant level. This layer's electron concentration during hours of illumination is unambiguously determined by the magnitude of zenith angle χ, that is, $N = N_{max0}\sqrt{\cos\chi}$ (N_{max0} -- maximum value of N in the given region when $\chi = 0$). The E layer principally affects propagation of medium-frequency waves. From time to time a highly ionized layer is formed at the altitude of the E layer -- "sporadic E layer" (designation E_s), the electron concentration of which several times that of the normal E region. The E_s layer may occur at any time of the day and year, but at the middle latitudes it most frequently forms during the day in the summer months; in the polar regions the E_s layer	95-120	5×10^{11}-10^{13}	During the day 1×10^5-4×10^5, at night 5×10^3-10^4	10^5	Day 10^{-7}, night 10^{-8}

Table 5.3. Principal Characteristics of Ionized Layers of the Ionosphere

Designation of Ionized Regions (Layers)	Principal Properties of Ionized Regions From the Standpoint of Their Influence on Propagation of Radio Waves	Quantitative Characteristics of Ionized Regions: Altitude, km	Molecular Density, $1/cm^3$	Electron or Ion Concentration, $1/cm^3$	Number of Collisions, 1/s	Recombination Coefficient, cm^3/s
	occurs primarily during the hours of darkness, and in the equatorial zone during the day. It is fairly stable in altitude, differing in altitude from the E layer by 5-10 km, and does not last at any one time more than several hours. This layer primarily affects short-distance daylight reflected-wave radio communications.					
Region (Layer) F_1	The F_1 layer is similar in properties to the E layer and differs from it only in a somewhat sharper change in seasonal electron density (its ionization in mid-summer is somewhat greater than at the beginning and end of the year). The electron concentration of the F_1 layer changes synchronously with the height of the sun, and maximum ionization is observed precisely at midday. At sundown it rises and merges with the F_2 layer. F_1 layer is observed primarily at middle latitudes during daylight hours of the summer months and under certain conditions affects shortwave propagation	Day 180-240, at night the layer disappears	$\sim 10^{11}$	2×10^5-4.5×10^5	10^4	4×10^{-9}
Region (layer) F_2	The F_2 layer is an unstable formation of the ionosphere. Electron concentration and altitude of the maximum vacillates considerably from one day to the next. Disturbances frequently occur in this layer. Two sharply-marked conditions are characteristic of the F_2 layer -- winter and summer. The winter N curve is characterized by a high maximum, which	230-400	$\sim 10^{10}$	Winter day -- maximum 2×10^6, summer day -- maximum 2×10^5, winter night -- 3×10^5	10^3-10^4	Day 8×10^{-11}, night 3×10^{-11}

Table 5.3. Principal Characteristics of Ionized Layers of the Ionosphere

Designation of Ionized Regions (Layers)	Principal Properties of Ionized Regions From the Standpoint of Their Influence on Propagation of Radio Waves	Quantitative Characteristics of Ionized Regions: Altitude, km	Molecular Density, 1/cm³	Electron or Ion Concentration, 1/cm³	Number of Collisions, 1/s	Recombination Coefficient, cm³/s
	is somewhat delayed relative to local midday, and a deep minimum during the predawn hours. The summer curve is much flatter, which is due to heating of the atmosphere and rising of air masses. Daily variation of electron concentration in F_2 depends on geomagnetic latitude, while annual variation also depends on the 11-year solar activity cycle. The F_2 layer is of interest, since it determines conditions of shortwave propagation					

5.3. Influence of the Features of Propagation of Radio Waves of Various Bands on Accomplishment of Radio-Radar Air Traffic Control Support Tasks

The operational effectiveness of air traffic control facilities is in direct relation to the conditions of propagation of electromagnetic waves. Radio-radar equipment of various wavebands is employed in the process of radio communications, navigation, detection, identification, guidance and landing approach, from very low frequency to EHF.

Table 5.4 presents the influence of the specific features of propagation of radio waves of the various bands on accomplishment of the missions of radio and radar facilities.

Table 5.4. Employment of Radio Waves of the Various Bands for Performance of Radio-Radar Facilities Tasks

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
Very low frequency and	Waves of this band reflect well from the lowest ionized layer (during the day from the D layer, at night from the lower	Advantages: relative constancy of field strength at the receiving point	Can be employed: for communication with submerged submarines

Table 5.4 (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
Low frequency	boundary of the E layer), and at great distances the field intensity of the sky wave proves greater than that of the ground wave. The mechanism of propagation of these waves is dictated by the presence of a natural waveguide bounded by two semiconducting concentric spheres -- the earth and the ionosphere. Waves of 2,500-3,500-meter length are optimal here, while waves of a length of approximately 100,000 m are critical. A very important property of these waves is their insignificant absorption during passage through the ground or sea. Variations in field strength at the receiving point do not exceed 10-30% of nominal value, and these fluctuations occur fairly slowly. These changes in field intensity have a daily cycle (increase with onset of darkness, and in many cases during the hours of sunrise and sunset). The annual cycle of variation in field strength as well as the influence of the 11-year solar activity cycle are not strongly-marked.	during the course of a 24-hour period, year and 11-year solar activity cycle; insignificant absorption during passage through the ground or sea; insignificant fluctuations in field strength occuring at the receiving point take place slowly, over the course of several tens of minutes and even hours (therefore they do not hinder signal reception). Drawbacks: small frequency capacity of the band; unwieldy antenna structures and high powers are required for radio equipment in this band; some phase instability during the morning and evening hours (when the altitude of reflection of these waves changes)	and underground facilities; for long-range radio communications and radio navigation (primarily in the polar regions); in radio systems for transmission of time signals and weather reports; in phase navigation systems.
Medium frequency	Waves of this band are propagated in ground and sky waves. Therefore three configurations of medium-frequency communications are differentiated. Either only a ground wave or only a sky wave, or a surface and sky wave together arrive at the receiving point.	Advantages: bends well around terrain irregularities; favorable propagation conditions at temperate and northern latitudes of the Northern Hemisphere (signal-noise ratio);	Can be employed: for radio communications in mountain regions (on highly irregular terrain); for radio navigation (homing beacons and other navaids);

Table 5.4 (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
	During the day, with strong absorption in the D layer, or at any time of day or night but at short distances from the transmitter, only ground waves reach the receiving point. They are actively absorbed by the semiconducting earth's surface and therefore provide radio communications at limited distances (approximately 1,000-1,500 km with transmitter powers of hundreds of kilowatts). At night only sky waves reach the receiving point with long-distance communications. At the onset of darkness ground and sky waves may simultaneously reach the receiving point. Depending on the phase difference between these waves, the resultant field may prove to be less or greater than the field of each of the interfering waves. This also causes fading (fading is most sharply marked at frequencies approaching the lower end of the band). Seasonal fluctuations in field strength are expressed in the fact that in the hours of darkness during the summer months one can expect only a slight increase in absorption in comparison with the nighttime hours in the winter month. During daylight hours one observes a clearly-marked relationship between signal level and season (manifested in a substantial decrease in the field strength of sky waves during the summer months in comparision with winter).	occurrence of refraction in the troposphere, which somewhat increases range of propagation of ground waves and has practically no effect on propagation of sky waves. Drawbacks: small frequency capacity of band; comparatively unwieldy transmitting antennas; occurrence of fading, which creates considerable difficulties for radio communications and radio navigation (average duration of fading varies from one second to several tens of seconds); strong influence of nonlinear properties of the ionosphere on propagation of medium waves (this leads to the occurrence of cross modulation of already modulated radio signals)	for radio communications and navigation at temperate and northern latitudes of the Northern Hemisphere; for ground wave radio broadcasting (employing anti-fading antennas)

Table 5.4 (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
	The 11-year solar activity cycle as well as ionospheric disturbances insignificantly affect the propagation of medium-frequency waves.		
High frequency	Can propagate by ground and sky wave. However, as a consequence of strong absorption of shortwaves by the soil, communications range by ground wave is greatly restricted. Long-distance radio communications are effected only with sky waves, which are reflected once or multiply from the ionosphere (mostly from the F_2 layer). Effectiveness of radio communications is determined by the following conditions: the selected signal frequency should ensure wave reflection from the ionosphere; wave absorption in ionosphere layers should not exceed an allowable figure. Optimal operating frequencies for specific radio communication links are selected on the the basis of prior-prepared radio forecasts. Shortwave radio communications are dependent on the state of the ionosphere, or in other words or the time of day, season, direction of radio communication link, and the 11-year solar activity cycle. At night range of communications is greater than during the day, and in winter greater than in summer. As a consequence of the above we differentiate daytime frequencies (from 10 to 25 meters), nighttime frequencies (from 35 to 100 meters), and intermediate	Advantages: long-range communications with comparatively small antennas and low transmitter power; little absorption of radio waves in the ionosphere; high band frequency capacity. Drawbacks: inconstancy of conditions of propagation, due to variability of the state of the ionosphere; occurrence of deep fading, which are much greater than in the medium frequency band; occurrence of skip zones ("dead" zone); occurrence of the phenomenon of signal repetition (echo phenomenon); occurrence of disruptions of radio communications caused by ionospheric disturbances (ionosphere-magnetic storms, sudden flareups of wave absorption, appearance of sporadic E_S layer).	Can be employed: for long-range radio communication between ground stations and with aircraft; for determining bearing to moving objects from the ground; for predicting optimal frequencies (by the oblique-return sounding method)

Table 5.4 (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
	wavelengths (from 25 to 35 m). The best conditions for communications are observed on radio links extending meridionally, with worse conditions on radio links extending latitudinally. Shortwave radio communications are strongly affected by the 11-year solar activity cycle (in relation to periodic degree of ionization). Shortwave radio communications are also strongly influenced by sky wave angle of radiation α. When this angle is greater than critical, the wave passes into space and does not return to earth. Low-angle waves, reflecting from the lowest regions of the ionized layer, reach distant points on the earth's surface (the lower the angle, the greater the range of radio communications). The shorter the wave, the smaller the critical angle and the greater the range of radio communications.		
Very high frequency	Meter waves do not bend readily around the earth's surface, and for this reason the range of their propagation by ground wave only slightly exceeds line-of-sight. Meter waves can propagate great distances both as a result of reflection from regular regions of the ionosphere and from the sporadic E_S layer, and as a result of scattering in the ionosphere. The former phenomenon occurs primarily during years of greater solar	Advantages: long-range radio communications as a consequence of reflection from regular regions of the ionosphere and sporadic E_S layer, and as a result of scattering in the ionosphere; comparative constancy of propagation conditions (approximately the same	Can be employed: for long-range communications between ground stations and communications with aircraft; for secure radio communications in transmitting particularly important information; for line-of-sight communications

Table 5.4 (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
	activity, when the critical frequencies sharply increase (from the F_2 layer and the E_s layer), while the latter occurs during scattering on local inhomogeneities in the region of the D layer (at night in the lower region of the E layer). The phenomenon of ionospheric scattering can be utilized at wavelengths greater than 5 meters. The daily field strength fluctuation cycle is manifested in an increase in field strength during the daylight hours and in the occurrence of a more or or less clearly-marked minimum at 1900-2100 hours local time for mid-route. Ionosphere scatter signals are accompanied by slow changes in field strength and fading. Ionospheric disturbances have no effect here, but there is a strong effect of the phenomenon of absorption in the aurora borealis zone and in the polar cap (wave passage is disrupted). Meter waves are quite readily reflected from the ionized tracks of meteors. Radio waves striking an ionized layer of air are reflected chiefly in that direction for which the angle of reflection is equal to the angle of incidence. Consequently only those meteors which are suitably oriented can be used for communications. Such tracks are formed from time to time. The duration of existence of ionized tracks ranges from 0.1 to 100 seconds, and they are created at altitudes from 80 to 120 km.	as for shortwave communication links with the absence of ionospheric disturbances); possiblity of meteor communications, for which comparatively small power and simple antennas are required. Drawbacks: special requirements on equipment for long-range communications; dependence of conditions of propagation on state of the ionosphere (for the low-frequency end of the meter band); comparatively narrow frequency band usable for long-range communications as a consequence of scattering in the ionosphere, and signal delay with meteor communications	between ground stations, for communications with and between aircraft in flight (at wavelengths in the order of 2-3 m)

Table 5.4 (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of this Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
UHF and SHF	Radio waves in the decimeter and centimeter bands are not reflected from the ionized region of the atmosphere and do not scatter in it. As a consequence of this they propagate short distances above the earth's surface. Some increase in range occurs as a consequence of scattering on inhomogeneities of the troposphere (principally) and to some degree as a result of the directive action of tropospheric waveguides. Radio waves of these bands practically do not refract in ionized regions of the atmosphere and pass easily through the ionosphere. Propagation of these waves is affected by various features on the earth's surface (mountains, hills, forests, buildings); they cause reflection and partial absorption of energy. As a consequence of this the resultant field is determined by the correlation of phases of reflected waves and can be amplified or attenuated. Decimeter-band waves undergo practically no molecular absorption or absorption in hydrometeors. Absorption in hydrometeors becomes appreciable at wavelengths shorter than 3-5 cm. Absorption in water vapor (molecular absorption) becomes appreciable only at a wavelength of 1.35 cm, that is, at the very boundary of the centimeter band. Therefore one can also for all practical purposes ignore molecular absorption of centemeter waves	Advantages: high frequency capacity of band; possibility of building extremely small antennas (including directional); practical absence of influence by atmospheric noise and interference from distant stations; independence of communications from time of day, season and state of the ionosphere. Drawbacks: inconstancy of field strength with communications on broken terrain (due to superimposing of reflected waves with different phases); absorption of waves in forest tracts and in urban buildings; dependence of propagation on weather conditions (appreciable absorption of centimeter waves in hydrometeors)	Can be employed: for communications between aircraft and ground stations and between aircraft and in flight (principally at decimeter wavelengths); for performing radio navigation tasks (for direction finding); for detection and tracking of air targets (for landing approach, identification, intercept and aiming)

Table 5.4 (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
EHF	Propagation of millimeter waves is totally independent of the ionosphere. The troposphere causes bending of the trajectories of these waves. They are strongly affected by hydrometeors in the form of rain, fog, hail, snow, etc (which cause very substantial absorption). Under conditions of heavy rain or fog, millimeter waves for all practical purposes cannot propagate. They also undergo strong molecular absorption in the gases occurring in the troposphere (particularly water vapor and oxygen in the air). Experimental data indicate that there exists a relationship between the absorption coefficient and frequency. In the waveband from 1 to 10 mm there are four "windows" of relatively weak absorption, namely in the region of 1.2 mm (δ=0.7 db/km), in the 2 mm region (δ=0.3 db/km), in the 3 mm region (δ=0.22 db/km), and at 8.6 mm (δ=0.07 db/km). These figures are correct with a relative humidity of 60%. Absorption coefficients climb sharply with increased humidity.	Advantages: large frequency capacity of this band; possibility of building extremely small, highly-directional antennas; favorable conditions of propagation by sky wave beyond the troposphere, in a region lacking thunderstorms and water vapor (in space). Drawbacks: heavy absorption of these waves in hydrometeors (in the form of rain, fog, hail, snow, etc); considerable molecular absorption in troposphere gases (in water vapor and oxygen)	Can be employed: in communication links outside the troposphere, under conditions where there are no electrical storms or water vapor; for close-range radar and communications on the ground in transparency "windows"
Optical Band Radio Waves	Radio waves of this band can propagate both as ground waves and freely propagating waves. Their trajectories are bent under the effect of atmospheric refraction (radius of curvature in the order of 50,000 km as compared with 25,000 km in the lower line-of-sight bands).	Advantages: large frequency capacity of band; possibility of building extremely small, highly-directional antennas; possibility of high energy concentration and transmission	Can be employed: in communication lines beyond the troposphere; for comparatively short-distance ground communications;

Table 5.4. (cont'd)

Designation of Frequency Band	Specific Features of Propagation of Radio Waves of This Band	Advantages and Drawbacks of Radio Waves of This Band	Employment of Waves of This Band to Perform Radio-Radar Tasks in Aviation Communications and RTO
	Passage of these wavelengths is greatly dependent on the presence of hydrometeors in troposphere (rain, snow, fog, hail, etc), and under certain conditions their passage can be totally blocked. Heavy haze can cause considerable absorption of these waves, as a consequence of which range of wave propagation under these conditions is greatly reduced. In the absence of precipitation communications in this band (by ground wave) can be effected at ranges from 0.4 to 20 km, and only in transmissivity "windows" (0.4-0.85, 0.9-1.05, 1.2-1.3, 1.5-1.8, 2.0-2.5, 3.2-4.2, 4.-5-5.2, 8.0-13.5 microns)	in sealed space (achieving isolation from atmospheric precipitation of the environment in which the waves propagate); negligible effect of all types of interference on wave propagation. Drawbacks: heavy absorption in hydrometeors; substantial absorption in smoke and haze	for interference-immune communications in those areas where precipitation is rarely observed

5.4. Physical Properties of Radio Waves and Their Influence on Utilization for Air Traffic Control Communications and Radio-Radar Support Services

The physical properties of radio waves which are affected by the electrical characteristics of the atmosphere and the processes taking place in it determine the area of their application for purposes of air traffic control. Some radio devices and systems utilize the property of radio waves to propagate by the shortest path at a velocity which is practically constant for the entire frequency band. Thanks to this property one can determine the shortest distance between an aircraft and the source of radiation of electromagnetic waves. Other radio devices and systems utilize the properties of directional radiation and directional reception of radio waves. Thanks to this one can determine direction to an aircraft. Therefore the conditions of employment of radio equipment for air traffic control are inseparably linked with the properties of the produced electromagnetic field.

In the most general case of propagation of radio waves, the amplitude and phase of intensity of this field depend on the azimuth and angle of inclination of the wavefront and angle of polarization, as well as the phenomenon of interference. All this combined substantially affects the employment of radio waves for communications and radio-radar air traffic control support services.

The physical properties of radio waves, their influence and utilization for aviation communications and RTO are presented in Table 5.5.

Table 5.5. Physical Properties of Radio Waves, Their Influence and Utilization for Aviation Communications and RTO

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, or Its Influence
Propagation of radio waves in free space and in homogeneous (isotropic) media takes place rectilinearly and is accompanied by a decrease in density of energy flux with an increase in distance r. Along the earth's surface radio waves propagate following a great circle arc	If space is limited to a certain volume, there will be a certain quantity of energy per unit of area S_1 (volume V_1) at distance r_1, while there will be a smaller quantity of energy per unit of area S_2 (volume V_2) at distance $r_2 > r_1$. With a spherical wave the energy flux density is inversely proportional to the square of the distance r^2 (since with an increase in sphere radius r its surface increases proportionally to r^2). With plane waves energy flux density and field strength amplitude are independent of distance (since the lines of direction of movement of energy are parallel to one another). Radio waves propagate along the earth's surface following the arc of a great circle, which joins the points of radiation and the receiving point by the shortest path	These laws of propagation of radio waves, taking into account that their velocity is finite and extremely constant, form the basis of operation of goniometric radio navigation systems, with the aid of which one determines bearings in space (they encompass two classes of systems: radio direction finders and radio beacons). Radio direction finders employ a radio receiver to determine the direction of radio waves (to the source -- a ground or airborne radio transmitter). In radio beacon systems one determines with the aid of an airborne receiver the bearing to a ground transmitter (or from it) with prior-known coordinates and standard signals
The velocity of propagation of radio waves is practically independent of the medium above which they propagate	The velocity of propagation of light waves in free space is one of the so-called universal constants. The value of this constant is (c=299,931 km/s≈ 300,000 km/s). The velocity of	Distance-measuring and difference-ranging radio navigation devices and systems, in which signal delay

Table 5.5 (cont'd)

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, or Its influence
	propagation of radio waves in the atmosphere or along the atmosphere-earth interface differs somewhat from the above-specified value of the constant, but it is extremely close to it and is little dependent on various conditions. Numerout measurements have established that the velocity of propagation of radio waves is equal to 299,691 km/s, and the relative instability of the velocity of propagation of radio waves is 10^{-4}–10^{-5}.	is measured during signal propagation between the point of emission and point of reception, are based on utilization of the constancy of velocity of propagation of radio waves. The sought distance is determined on the basis of measured delay and the known velocity of radio wave propagation
The Doppler effect is observed when there is a relative displacement of the source of radio emission and its receiver	The Doppler effect consists in the following: the frequency of received radio waves differs from the frequency of emitted waves by the quantity $$F_D \approx f_0 \frac{W_p}{v} = \frac{W_p}{\lambda_0},$$ where f_0 -- frequency of emitted radio waves, Hz; $\lambda_0 = \frac{v}{f_0}$ -- emitted wavelength, m; W_p -- radial component of relative velocity of displacement of transmitter and receiver, m/s; v -- velocity of propagation of radio waves, m/s.	Radio methods of measuring the ground speed of aircraft are based on utilization of the Doppler effect. They consist essentially in measuring Doppler frequency shift. The sought radio component of relative velocity of displacement of the transmitter and receiver is determined on the basis of the measured Doppler frequency shift and the known frequency of emitted waves and velocity of propagation of radio waves.
During propagation of radio waves, on encountering obstacles and discontinuities, radio waves are reflected from them or scattered in all directions	During propagation of radio waves, upon encountering a target and any other discontinuities, the radio waves are reflected from them and partially scattered. The degree of reflection from target is characterized by effective reflecting surface. The latter is determined by the dimensions of the target, its shape, material, and wavelength of the radiation source. Emitted signals can be reflected not only from the targets we are seeking (aircraft, ship, etc) but also from wave splashes, shellbursts, ionized regions formed following nuclear blasts, and other	This property of radio waves is extensively utilized in designing radio altimeters (altitude measuring equipment), radio navigation aircraft groundspeed and drift angle measuring equipment, radio navigation collision-warning devices, etc. Radars which detect and determine the coordinates of objects by illuminating them with high-frequency electromagnetic energy and receiving the energy reflected from

Table 5.5.(cont'd)

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, or Its Influence
	discontinuities. As regards the influence of the earth, a portion of the energy of the emission source strikes the ground and is reflected from it. Therefore two waves are operating at the observation point -- direct and reflected. A portion of the energy is absorbed by the earth thereby.	these objects are based on this property.
The electromagnetic field of radio waves radiated by a transmitting antenna is a traveling wave field. The field phase changes on the path of wave propagation, while amplitude changes relatively mildly	Every radiator generates around itself an induction field and a radiation field. The former exists at a close distance from the radiator, and its intensity changes inversely proportional to the cube of the distance, and at a distance of (2-3) λ from the radiator for all practical purposes becomes zero. As for the second field, with increasing distance from the radiator its intensity in free space changes inversely proportional to the first degree of distance to the radiator. Such a free electromagnetic field moves continuously away from the source which excited it and does not return to that source. In the radiation zone vectors characterizing the strength of the electric and magnetic fields (E and H) are mutually perpendicular and perpendicular to the direction of propagation of electromagnetic energy (to the Poynting vector)	This property of radio waves forms the basis of all radio communications equipment (both between ground stations and with aircraft). Radio communications are achieved with the aid of an electromagnetic radiation field (free field). As regards the induction field, its influence on radio communications is considered when studying the influence of various metal objects on shaping the radiation pattern of an antenna system
Short radio waves, reaching the earth's surface after being reflected from the ionosphere, can be scattered by the earth's surface (N. I. Kabanov effect)	A certain portion of the scattered (by the earth's surface) radiation returns to the source, where it is recorded by oscillograph. The recordings have the appearance of halations, differing in relation to the nature of the reflection surface and propagation trajectory. Backscatter signals can be received from ranges of from several hundred to several thousand kilometers. If the reflecting surface creates a mirror reflection, there will be no backscattered signal	This property is utilized for purposes of predicting conditions of passage of radio waves in given actual atmospheric conditions. This method of radio forecasting is known under the term oblique return probing (VHZ)

Table 5.5 (cont'd)

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, or Its Influence
An electromagnetic field is characterized by the term polarization, which expresses orientation of a wave's electric field in relation to the plane of propagation	We distinguish polarization of the following types: a) normal, when vector $\bar{E}$ lies in the plane of propagation; b) abnormal, when vector $\bar{E}$ forms a certain angle with the vertical plane of propagation relative to the earth; c) an elliptically polarized field, where there is a phase shift between the vertical and horizontal components of electric field strength. The angle of polarization is close to zero when a ground wave is propagating above a highly-conductive surface. Under all other conditions the angle of polarization is not equal to zero, which in receiving electromagnetic energy leads to the occurrence of polarization errors. Most frequently polarization errors arise when, in addition to the normally-polarized ground wave, waves approach the receiving device of a radio system which have been reflected from the upper layers of the atmosphere, and which contain both vertically and horizontally polarized components. Since the parameters of reflecting ionized layers of atmosphere are constantly changing, polarization of radio waves changes, and consequently polarization errors occur	Polarization errors cause disruption in the operation of all types of radio navigation equipment operating in the high-frequency and medium-frequency bands. In the high-frequency band errors occur around the clock (winter and summer). In the medium-frequency band these errors occur principally at night
In reflection of electromagnetic waves from the ionosphere in the high-frequency band, in addition to change in plane of polarization one observes lateral radio wave deflection phenomena	As a consequence of the fact that the reflecting layer has a horizontal ionization gradient which changes on a time axis, the surface of the layer becomes undulating, as it were. As a result fluctuating inclinations appear at any point in the layer, causing lateral deflections of radio waves.	Lateral deflections of radio waves cause change in the angle of inclination of the wavefront and bearing errors in goniometric radio navigation systems. Root-mean-square angles of inclination change approximately

Table 5.5 (cont'd)

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, or Its Influence
	Any inclination of the layer can be broken down into transverse and longitudinal. Lateral deflections of radio waves are caused by transverse inclinations, when the normal to the layer diverges in a plane perpendicular to the plane of the great circle containing the direction of propagation. Longitudinal inclinations (the normal to the layer diverges in the plane of the great circle) cause changes in the angle of inclination of the wave front	inversely proportionally to frequency. The rate of inclination change ranges from 0.4 to 0.5 0.5°/min. During the hours of darkness in summer angles of inclination increase little in comparison with the daylight hours, while in winter during hours of darkness and during ionospheric disturbances these angles may differ by double or more. Fluctuations in layer inclination lead to slow changes in bearing on a time axis with a period of fluctuation of from 1 to 30 minutes and more. In all cases with a number of reflections greater than one, the closer the point of reflection to the receiver, the greater the influence of the reflection at this point on lateral deflection error.
Radio waves can be reflected simultaneously from the E, F_1, and F_2 layers, being reflected once, twice or more. As a result the received signal may consist of a large number of component waves which interfere with one another. This leads to an amplitude and phase change in the resultant	With reflection from any layer there occurs partial scattering of radio waves due to local discontinuities. In addition, there is observed during reflection magneto-ionic splitting into an ordinary and an extraordinary wave. Thus the received signal may consist of a large number of component beams arriving by different paths and interfering with one another (whereby each of the reflected beams is usually accompanied by a bundle of scattered waves). The amplitude of the resultant wave depends on the phase of the component waves. If the interacting waves reached	Fluctuations of bearings in radio direction finders are observed due to interference of radio waves (under particularly unfavorable conditions displacement of the resultant of the radio wave bearing may amount to ±90°). During radio wave interference there also occur changes in the dimensions and form of display of bearings on the CRT of a two-channel radio direction finder -- the linear bearing display becomes elliptical and even circular. Radio wave

Table 5.5 (cont'd)

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, or Its Influence
field and simultaneously to change in its polarization	the point of reception strictly in phase, the amplitude of the resultant wave is maximal and is equal to the arithmetic sum of the amplitudes of the interacting waves. In the general case the amplitude of field strength increases or decreases in relation to the correlation of phases.	interference also has a negative effect on radio communications as a whole (signal fading occurs)
When a radio wave passes a shore line, which separates media with differing conductivity (sea and land), the wave front at the interface undergoes change from normal to inclined, and there simultaneously occurs an electromagnetic field phase change	The passage of a radio wave from sea to land or vice versa is accompanied by the presence of surface irregularities (slope of shore) and change in the electrical parameters of the medium. Both these factors influence the function of wave attenuation, the modulus of which characterizes a decrease in field strength amplitude with distance, while the argument determines the complementary phase of a wave in relation to the phase in free space. During propagation of radio waves perpendicular to the shore line, change in the inclination of the wavefront and increase in the complementary phase takes place at one and the same time in all parts of the wavefront (the direction of the line of equal phases remains unchanged). If the wave intersects the shore line at an angle, the individual portions of the wavefront do not pass from sea to land simultaneously, and phase increase in different parts of the wavefront also takes place not simultaneously but as they intersect the shore line. As a result of this, the line of identical phases is distorted and an error appears in determining the bearing to the radiation source; this error depends on the direction of movement of the wave relative to the shore line. As the wave continues to advance, as the	This property of radio waves indicates that if a shore line separating sea from land (or land from sea) is situated in the vicinity of goniometric systems (radio direction finders), direction finding errors are possible, called errors due to coastal effect.

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Table 5.5 (cont'd)

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, Its Influence
	requisite electric field inclination above the earth is established, phase equalization occurs in all sections of the front, and the direction of the line of equal phases is gradually restored, that is, at a certain distance from the shore line the shore refraction error disappears	
During propagation of short radio waves there forms around an operating transmitter an annular region in which signals cannot be received, that is, a skip zone	A skip zone is that part of the earth's surface located between the terminal point of ground wave reception and initial point of sky wave reception. In a skip zone signal audibility during shortwave communications decreases as one moves away from the transmitter, and at a certain distance from the transmitter the signal is lost entirely, but subsequently at great distances signals again begin to be received, and strong signals. From the standpoint of physics this phenomenon is due to the fact that the transmitter antenna which is operating in the high-frequency band simultaneously radiates ground and sky waves. High-frequency ground waves do not readily bend around obstacles and are strongly absorbed, and consequently their propagation range is short. Sky waves radiated by an antenna at an angle $\alpha<\alpha_{kp}$ travel their entire path in the atmosphere, where those losses to which ground waves are subjected do not occur. In addition, reflections from a corresponding ionosphere layer cause a wave to skip. As a consequence of all the above, their effective range is considerably greater than that of ground waves. The extent of skip zones is determined by wavelength, time of day,	The presence of skip zones exerts considerable influence on organization of shortwave communications. In order to reduce their influence, a careful frequency selection is made on the basis of radio predictions, as well as operation at higher (possible for the given transmitter) power

Table 5.5 (cont'd)

Physical Properties of Radio Waves	Substance of Considered Physical Property of Radio Waves	Area of Utilization of Given Physical Property of Radio Waves, Its Influence
	season, and transmitter power. The shorter the wave and the lower the transmitter power, the broader the skip zone will be. During the day and in the summer, when reflected waves return to a reception point located at a shorter distance from the transmitting station, the width of the skip zone decreases.	
The relatively small absorption experienced by shortwaves during propagation considerable distances enables these radio waves to bend around the earth. Under favorable conditions there have been observed instances of multiple propagation of shortwaves around the earth. This leads to the occurrence of so-called around-the-world radio echo	Depending on the causes of this phenomenon, we differentiate close, round-the-world, and distant echo. Close echo occurs with multiple reflection of shortwaves from higher ionospheric layers. The echo signal lag time relative to the main signal amounts to 0.2-0.3 ms. Distant echo is a consequence of repeat signal reception from a beam propagated to the far upper layers of the ionosphere and back-reflected from electron discontinuities. Round-the-world echo occurs in those cases when radio waves multiply circle the earth's surface. Direct and reverse round-the-world echoes are distinguished. A direct round-the-world echo is a signal which reaches the reception point after circling the earth in a direct direction (lag of 0.13 s). With reverse round-the-world echo, arriving at the reception point in addition to the direct wave is a wave radiated by the antenna in the reverse direction and propagating on a longer path (every thousand kilometers of difference in distance results in a lag of 0.003 s).	The echo phenomenon exerts considerable influence on stability of radio communications. In telegraph communications round-the-world echo causes spurious transmissions, and in telephone communications round-the-world echo is perceived as a persistent reverberation or as an acoustic echo. Facsimile transmissions are also disrupted by echo. The following are employed to combat this phenomenon: frequency selection (frequencies which, propagating on a longer path, either experience substantial absorption or are not reflected at all from the ionosphere), and utilization of transmitting and receiving antennas which are highly directional in the vertical plane and with a radiation pattern concentrated close to the ground

Chapter 6. INFLUENCE OF CLIMATIC CONDITIONS ON EFFICIENCY OF COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICE EQUIPMENT

6.1. Influence of Climatic Conditions on Operational Reliability of Radio Equipment During Flight

Radio equipment carried on board aircraft in flight is subjected to special climatic conditions. They are characterized chiefly by reduced atmospheric pressure, reduced temperature, and change in humidity, in relation to altitude.

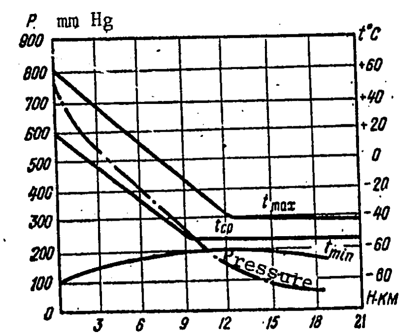

Figure 6.1. Relationship Between Pressure, Temperature and Flight Altitude

We know that with an increase in altitude air density and corresponding pressure as well as temperature gradually decrease. Figure 6.1 contains curves indicating change in pressure and temperature (t_{min}, t_{max}, t_{cp}) in relation to altitude.

The heat capacity of air decreases with a decrease in atmospheric pressure, as a result of which radio equipment can overheat and experience failure. In order to prevent equipment overheating during high-altitude flight, measures are taken to cool equipment (exterior surfaces are painted black, cooling surface is increased by ribbing, and a special ventilation system is employed). In many cases radio transmitter power is reduced, which reduces heating of the transmitter and its power supply.

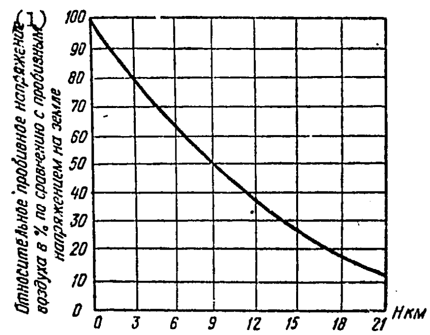

Figure 6.2. Relationship Between Breakdown Voltage and Flight Altitude

Key:
1. Relative breakdown voltage of air as a percentage in comparison with breakdown voltage at sea level

At high altitudes (above 5-6 km) the electric strength of all air gaps in equipment decreases as a result of reduced atmospheric pressure and elevated ionization, and glow discharges occur around conductors which are under high voltage. This leads either to electrical breakdown or to a sharp change in equipment operating conditions. A decrease in air density exerts considerable influence on the electrical properties of air capacitors, relays of various types, and a number of other radio components, since their breakdown voltage is reduced. At an altitude of 10 km the breakdown voltage of air drops by approximately 55% in comparison with the breakdown voltage at sea level, and at an altitude of 18 km -- by approximately 80% (Figure 6.2). Consequently radio equipment operating conditions as a whole become worse with altitude.

The breakdown voltage of each gas gap in radio equipment is a function of the product of gas pressure (air) p times the distance between electrodes d (Paschen's rule), that is, $V_{пр}=f(pd)$. Figure 6.3 shows the relationship between breakdown voltage and product pd for air with brass electrodes. The curve minimum corresponds to the lowest voltage which can lead to breakdown of the gas gap between cold flat electrodes and at the same time determines the distance between electrodes at breakdown.

At high altitudes the danger of gas breakdowns (discharges) forming from the effect of results of ionization and a high-frequency field occurs, as a result of the plasma state of the atmosphere. Breakdown begins with the appearance of a corona discharge, that is, before actual surface flashover occurs. A corona can develop at a significantly lower voltage than sparkover voltage. Figure 6.4 shows relationships between breakdown voltage, altitude and gap (for f=226.8 MHz).

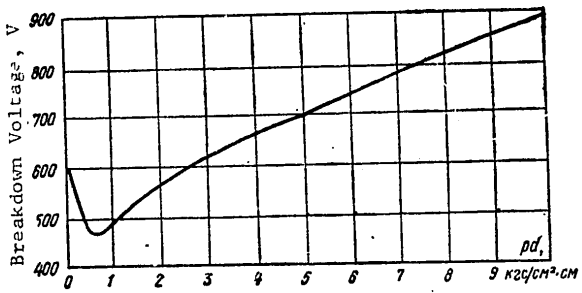

Figure 6.3. Relationship Between Breakdown Voltage and Product pd for Air With Brass Electrodes

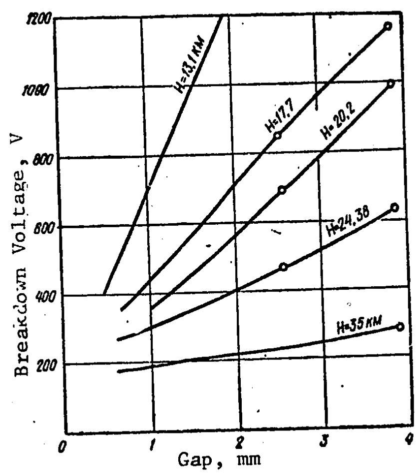

Figure 6.4. Relationship Between Breakdown Voltage, Altitude and Gap at a Frequency of 226.8 MHz

Breakdown voltage also depends on the shape of the electrodes. Figure 6.5 shows relationships between breakdown voltage and gap for two electrode shapes. It is evident from the curves that with rounded electrode ends breakdown voltage is greater than with flat ends.

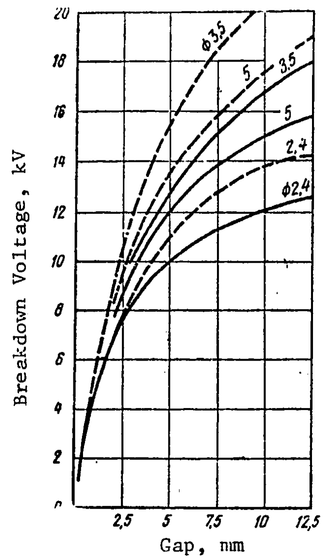

Figure 6.5. Relationship Between Breakdown Voltage and Shape of Electrode Ends (dashed curves -- rounded electrode ends; solid lines -- flat ends)

Relative humidity also does not remain constant from altitude to altitude and from one area to another but varies across an extremely broad range, frequently reaching 95 and even 100% (in fog, in clouds).

Radio equipment is most strongly affected by absolute humidity, which is characterized by quantity of water vapor per unit volume. Radio equipment is most strongly affected by air humidity in ground-adjacent layers close to sources of evaporation, where himidity reaches 7-12 g/m^3. Absolute humidity decreases sharply with an increase in altitude. At an altitude of 10-11 km humidity is negligible -- tenths and hundredths of a gram in a cubic meter. Above the tropopause air moisture content is so small that its effect on radio equipment can be ignored.

Climatic conditions, which change with altitude, exert considerable influence on the working efficiency of equipment operators as well as on the operation of radio equipment electroacoustic terminal components (microphones, throat microphones, headphones). At low temperatures and reduced air pressure there occurs diminished acuteness of perception by operators' sensory organs, efficiency diminishes, attention becomes dulled, personnel become rapidly fatigued, and, what is most important from the standpoint of communications, speech becomes less intelligible, and hearing becomes less acute (this is accompanied by pain sensations in the ear). With increased altitude there occurs a decrease in voice intensity (volume), amounting to one db at an altitude of 3,000 m, 2 db at 5,000 m, 6 db at 10,000 m, and 9 db at 12,000 m. These figures apply to microphone transmission. The decrease in voice intensity is somewhat greater with a throat microphone, particularly at altitudes above 4,000 m. Figure 6.6 contains curves showing decrease in voice intensity at various altitudes when using a microphone (curve 1) and a throat microphone (curve 2). A number of measures are employed to compensate for this attenuation, the most important of which is amplitude clipping.

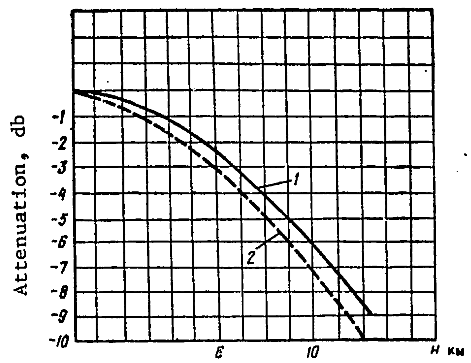

Figure 6.6. Relationship Between Decrease in Voice Intensity and Altitude: 1 -- for a microphone; 2 -- for a throat microphone

The articulation percentage increases substantially as a result of employment of amplitude clipping. The relationship between verbal articulation percentage and amount of clipping in decibels for H=0 and H=10 km is shown in Figure 6.7. As is evident, with amplitude clipping of 30 db, articulation at an altitude of 10 km increases from 40 to 80% (curve 1).

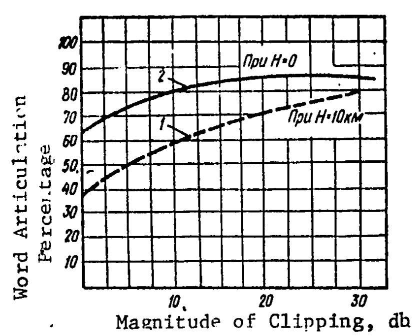

Figure 6.7. Relationship Between Articulation and Magnitude of Amplitude Clipping

Conditions of voice transmission worsen when wearing an oxygen mask, as a rule worn at altitudes above 4 km, since this distorts the voice frequency spectrum (resounding increases at low frequencies -- below 80 Hz), and speech becomes less intelligible, muttering (articulation of syllables drops from 86% to 50%). Speech intelligibility also worsens as a consequence of combined oscillations observed during the interaction of low-frequency speech components (the sound-insulating properties of an oxygen mask decrease sharply at low frequencies) and aircraft noise.

Sound pressure and rate of larynx vibrations decrease at high altitudes (by 2-3 db at 5 km, by 5-6 db at 10 km, by 8-9 db at 12 km). As a result there is a decrease in the emf developed by the throat microphone, and therefore the percentage of modulation. In order to compensate for reduced percentage of modulation at high altitudes, approximately 9-10 db of adjustable amplification is available in the submodulators of radio transmitters and the amplifiers of intercommunication devices.

6.2. Effect of Moisture on Radio Components

Moisture contained in the atmosphere has an adverse effect on radio equipment. There are two principal forms of interaction between moisture and materials employed in radio equipment: in one instance moisture is a chemically bound component of a substance and cannot be removed without destroying it, while in the other instance moisture is not chemically bound to a substance and occupies free cavities in it (in capillaries and cracks) or is held on the surface of a material and on finely-dispersed particles. Moisture leads to the following adverse effects:

accelerates corrosion of metals;

alters the electrical characteristics of dielectrics;

disrupts the structure of dielectrics;

alters the physical-mechanical properties of materials and their linear dimensions;

alters the surface and volume resistance of materials.

The character and essence of these types of effects on radio components are listed in Table 6.1.

(See following page)

Table 6.1. Effect of Moisture on Radio Components

Types of Effects of Moisture on Radio Components	Character and Essence of Different Types of Effects of Moisture on Radio Components: Change in Electrical Characteristics of Dielectrics	Disruptions of Structure of Dielectrics Caused by Penetration of Moisture	Change in Physical-Mechanical Properties of Materials and Their Linear Dimensions Under the Effect of Moisture	Change in Surface and Volume Resistances of Materials Under the Effect of Sorption of Moisture
Moisture, which is always present in the atmosphere, is highly deleterious to radio equipment. It speeds up corrosion of metals, alters the electrical characteristics of dielectrics, promotes thermal breakdown of materials, hydrolysis, growth of mildew, and causes much electrical and mechanical damage to equipment. A harmful effect is caused by moisture (water) which is chemically not bound to a substance, that is, moisture occupying free cavities in a substance (in capillaries, cracks) or	In the presence of water vapor the dielectric constant of air increases with an increase in relative humidity and temperature. This leads to destabilization of devices containing capacitors with an air dielectric. Moisture absorbed by insulation material reduces the resistance of the insulation and the breakdown voltage of the dielectric. These characteristics are determined not only by quantity of moisture but also by how it is distributed within the volume of the material (the less separated a molecule of moisture in the material, the lower the	As ambient temperature rises, with humidity remaining constant, penetration of moisture into a material increases under the influence of two factors: increase in the partial pressure of water vapor in the ambient air and thermal motion of the molecules of the dielectric. The latter circumstance causes the formation of intermolecular spaces, into which water molecules penetrate. This also accelerates their travel into the interior of the dielectric. Intermolecular gaps are those types of disarrangement of structure which are characteristic of organic dielectrics. In the process of a series of periodic moistenings and dryings there occurs a decrease	Absorption of 1% water by many plastics leads to an increase in linear dimensions of approximately 0.2%, and loss of 1% water can shrink linear dimensions by up to 2%. Change in dimensions with change in mass is observed in molded phenol products and aminoplasts in those cases where there takes place an exchange of moisture or volatile substances between objects and the environment. Due to nonuniform change of dimensions (in section) of rigid plastics with small linear expansion, very large internal stresses occur in them, which	Volume absorption of moisture is observed in those materials characterized by shrinking (compounds, waxes) and in materials with a porous structure due to volatilization of solvent (varnishes). This property is also possessed by laminated insulation (cotton, paper) and laminated molded materials (such as resin-hardened paper). In all these materials volume and surface resistivity decreases under the effect of moisture sorption, and the

Table 6.1 (cont'd)

Types of Effects of Moisture on Radio Components	Character and Essence of Different Types of Effects of Moisture on Radio Components			
	Change in Electrical Characteristics of Dielectrics	Disruptions of Structure of Dielectrics Caused by Penetration of Moisture	Change in Physical-Mechanical Properties of Materials and Their Linear Dimensions Under the Effect of Moisture	Change in Surface and Volume Resistance of Materials Under the Effect of Sorption of Moisture
retained on the surface of an object and on finely-dispersed particles	insulation's resistance and breakdown voltage). When a film of water forms on the surface of a material, as a consequence of water's low resistance, dissociation of impurities and contaminants, surface resistance decreases by several orders of magnitude. If disconnected droplets form on the surface of a material, surface resistance decreases insignificantly, while breakdown voltage drops off sharply. A water film absorbed by a material becomes ionized from the action of atmospheric carbon monoxide, salts and sunlight. Surface	in resistance of insulation due to irreversible changes in the material. Absorption of moisture by nonpolar materials is insignificant; their surface is not wetted by water, and therefore their volume and surface resistivities are high. Polar materials are characterized by elevated hygroscopicity and ionic dissociation of impurities in the material, resulting in decreased volume and surface resistance and electric strength. Plastics with hygroscopic fillers in a humid atmosphere can absorb a substantial quantity of moisture -- up to several percent of the weight of the dry material. The electrical properties	sharply alter the original physical-mechanical properties and can lead to warping, surface and deep cracks, and even to failure. The cracks forming on the surface in turn facilitate moisture penetration into the material and decrease its electrical insulation properties. Consequently, the less the capability of given plastics to give off or absorb volatile substances, the less their original physical-mechanical properties will change, and the greater their operational reliability	greater the relative humidity, the greater the reduction. Sorption of moisture by solid organic materials as well as by laminated materials of the glass cloth type, constitutes a slow process of activated diffusion of water vapor into the materials with its partial dissolving. The moisture sorption curves for different materials of the same thickness differ from one another in

Table 6.1 (cont'd)

Types of Effects of Moisture on Radio Components	Character and Essence of Different Types of Effects of Moisture on Radio Components			
	Change in Electrical Characteristics of Dielectrics	Disruptions of Structure of Dielectrics Caused by Penetration of Moisture	Change in Physical-Mechanical Properties of Materials and Their Linear Dimensions Under the Effect of Moisture	Change in Surface and Volume Resistance of Materials Under the Effect of Sorption of Moisture
	resistance drops sharply for a period of 1-5 minutes and then remains at a specific level, determined by the relative humidity	of such materials are directly dependent on the quantity of moisture contained in them		time of onset of an equilibrium state. As a consequence of the above, these materials possess low insulation resistance and have elevated losses. Electrical breakdown in these materials is not determined by the electrical strength of the component elements but chiefly by the content of moisture and ionized impurities. Current passing between contacts located on moist insulation material can attack both the contacts and the insulation material. Contacts enter into a reaction with the oxidizing components of the insulation material. An electrolyte forms either due to solution in water of substances on the surface of the material or due to electrochemical breakdown of certain materials, which yield water-soluble substances

6.3. Effect of Heat and Cold on Radio Components

The effect of heat and cold is caused primarily by climatic conditions and, in addition, by equipment operating conditions. In aircraft operation, with periodic heating and cooling of equipment components, abrupt changes in atmospheric pressure are also possible. The most dangerous conditions occur when heated equipment during a rapid climb encounters atmosphere with low pressure.

An increase in ambient temperature causes both gradual and sudden changes in the physical characteristics of materials, as well as acceleration of chemical reactions in them.

A drop in ambient temperature leads to a decrease in the strength of materials, to substantial shrinkage, brittleness and cracking of molded products and to thickening of lubricating materials.

Cold periodically alternating with above-freezing temperatures is particularly harmful. With sharp temperature fluctuations moisture condenses on the surface of equipment and on its internal parts, which is absorbed through microcapillaries and penetrates into gaps between components. At low temperatures the water filling cracks, pores and gaps freezes and, expanding approximately 10% in volume, causes further enlargement of the pores, cracks and gaps.

Heat and cold lead to the following adverse phenomena:

change in the dimensions of materials;

decreases in the strength of materials (impact and tensile strength);

deterioration of the electrical properties of materials;

disturbance of the nominal electrical properties of materials under the effect of thermal shock;

weakening of the solder used to join components.

The character and essence of the above-listed types of effects on radio components are described in Table 6.2.

(See following page for table)

Table 6.2. Effect of Heat and Cold on Radio Components

Types of Effects of Heat and Cold on Radio Components	Character and Essence of Different Types of Effects of Heat and Cold on Radio Components				
	Change in Dimensions of Materials Under the Effect of Heat and Cold	Decrease in the Strength of Materials (Impact and Tensile Strength) under the Effect of Cold	Deterioration of Electrical Properties of Materials Under the Effect of Heat and Cold	Disturbance of Nominal Electrical Properties of Materials Under the Effect of Thermal Shock	Effect of Heat and Cold on Solder Joining Components
Thermal effect on radio equipment and components can be steady-state, periodic and aperiodic	With a homogeneous material all dimensions of equipment components (parts) receive proportional increments under the effect of heat, and the shape of the component is not distorted. Deformation takes place when the material is inhomogeneous, when temperature differs from one point to another or when a mechanical load is applied to a component	A number of materials (plastics, laminated and fibrous phenoplasts, plastics based on cellulose esters) are characterized by a decrease in impact strength with a drop in temperature. Their tensile strength, static bending strength, compressive strength, and hardness, however, increase by approximately 10-30%.	The electrical insulation properties of polar plastics are significantly dependent on temperature. With a temperature increase there is a sharp decrease in volume resistance and an increase in angle of electrical losses and dielectric constant. There is a particularly substantial increase in angle of losses in materials of the aliphatic group (polyvinyl chloride, polyvinylidene chloride, and chlorinated rubber).	In ceramic materials the lower their coefficient of linear expansion, the greater their resistance to thermal shock. There are, however, materials (lithium ceramic, for example) which even with a negative coefficient of linear expansion do not break down when overheated (thermal shock) to 1200°C and immersed in water.	Tin and tin-lead alloys are employed for soldering. White tin (normal modification) is stable in the temperature range 13-160°C. At temperatures below +13°C white tin slowly transitions to gray, and subsequently, as the temperature approaches -50°C, the rate of this process speeds up sharply (transition to gray tin). This leads to an increase in the metal's volume,

Table 6.2 (cont'd)

Types of Effects of Heat and Cold on Radio Components	Character and Essence of Different Types of Effects of Heat and Cold on Radio Components				
	Change in Dimensions of Materials Under the Effect of Heat and Cold	Decrease in the Strength of Materials (Impact and Tensile Strength) Under the Effect of Cold	Deterioration of Electrical Properties of Materials Under the Effect of Heat and Cold	Disturbance of Nominal Electrical Properties of Materials Under the Effect of Thermal Shock	Effect of Heat and Cold on Solder Joining Components
			In polyvinyl materials containing the hydroxyl group, the angle of losses increases sharply with an increase in temperature and humidity but decreases with an increase in frequency.		and at points of appearance of gray tin there occurs development of the crystalline structure of the metal (its breakdown). The above-described process also occurs when using a lead-tin alloy (but somewhat more mildly). Under the effect of heat and cold stresses always occur in the solder which weaken the bond between solder and material.

Table 6.2 (cont'd)

Types of Effects of Heat and Cold on Radio Components	Character and Essence of Different Types of Effects of Heat and Cold on Radio Components				
	Change in Dimensions of Materials Under the Effect of Heat and Cold	Decrease in the Strength of Materials (Impact and Tensile Strength) Under the Effect of Cold	Deterioration of Electrical Properties of Materials Under the Effect of Heat and Cold	Disturbance of Nominal Electrical Properties of Materials Under the Effect of Thermal Shock	Effect of Heat and Cold on Solder Joining Components
With steady-state thermal effect there occur both gradual and sudden changes in the physical characteristics of materials.	The coefficients of linear expansion differ from one material to another; this leads to the formation of channels between them with a change in temperature. These channels create paths for the penetration of moisture in molded items or items sealed in plastic, and consequently cause all the consequences of the effect of moisture.	At temperatures below freezing considerable shrinkage of molded material can occur, leading to flashovers. Some molded materials become brittle and crack under the effect of low temperatures.		Breakdown of plastic items (dielectrics) takes place with thermal shock considerably exceeding nominal heat conditions. Their electrical conductivity rises exponentially with an increase in temperature. The breakdown voltage of these materials is proportional to their resistance in a degree from 0.34 to 0.14. In addition, the electrical strength of plastics greatly depends on moisture loss or increase.	

Table 6.2 (cont'd)

Types of Effects of Heat and Cold on Radio Components	Character and Essence of Different Types of Effects of Heat and Cold on Radio Components				
	Change in Dimensions of Materials Under the Effect of Heat and Cold	Decrease in the Strength of Materials (Impact and Tensile Strength) Under the Effect of Cold	Deterioration of Electrical Properties of Materials Under the Effect of Heat and Cold	Disturbance of Nominal Electrical Properties of Materials Under the Effect of Thermal Shock	Effect of Heat and Cold on Solder Joining Components
1	2	3	4	5	6
Damage from periodic thermal effects occurs most frequently from repeated deformations of equipment components. The intensity of effects depends on the difference between the highest and lowest temperatures.	Bending and twisting deformations exert considerable influence on the precision of mechanisms and on equipment components (compression and stretching deformations have practically no effect). These deformations increase with a rise in temperature or with a sharp drop in temperature.	As a rule low temperature increases the required start up torque of machines due to thickening lubricant. Mechanisms can jam due to change in clearances between parts the materials of which have different coefficients of linear expansion.	The electrical insulation properties of non-polar plastics, (for example, polyethylene, polystyrene, polyisobutylene, divinyl rubber, etc) are little dependent on temperature. The volume resistivity of these materials remains practically unchanged. Moisture heightens the effect of heat and cold. Water penetrating into a material forces air from pores and cells. The coefficient of heat conductivity of water is 25 times that of air, and therefore even slight moistening of a material causes a sharp increase in its coefficient of heat conductivity, and a a result the heat insulating properties of materials sharply worsen.	Electrical strength of practically the absolute majority of insulating materials initially increases under the effect of heat, while mechanical strength decreases as a consequence of removal of moisture from the material	

Table 6.2 (cont'd)

1	7				
	2	3	4	5	6
Damage from aperiodic effects of heat is connected with the rate of equipment component temperature change (thermal shock). The coefficient of thermal conductivity results from the inertial properties of materials during heat exchange	With the bonding of heterogeneous materials, particularly metals with molding resins, cracking (with cold) or softening (at elevated temperatures) takes place. Compensation for such deformations can be achieved by means of selection of materials and dimensions of components.	Cold periodically alternating with above-freezing temperatures is particularly harmful, due to condensation of moisture, which penetrates into gaps between components. This causes further enlargement of pores, cracks and gaps.		Electrical strength then begins to drop to its original value. The end result is physical breakdown. In thermosetting plastics abrupt temperature changes can produce microcracks, which diminish their moisture-protecting properties.	As a rule solder does poorly with tensile stresses. Therefore during cyclic heatings and coolings, when tensile stresses occur, the solder weakens.
The effect of heat and cold leads: to changes in the dimensions of a material, to worsening of the heat insulating properties of materials, to decreased impact and tensile strength of materials (with decreased temperatures), to worsened electrical insulation properties of materials, and to failure of solder joining components		An increase in time and temperature decreases the mechanical strength of organic materials (they become brittle)		For each group of insulation materials a nominal temperature has been determined which they can withstand for extended periods of time	The higher the operating temperature of an item or the larger the range of temperature change, the more difficult it is to achieve hermetic sealing with the aid of soft solders

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6.4. Effect of Corrosion on Radio Components

Corrosion has a deleterious effect on radio components. It leads to reduced precision and service life of mechanical devices, to decreased electrical characteristics of dielectrics, to failure of contact connections, and in many cases to breaking of fine wires.

We differentiate atmospheric corrosion and corrosion in natural water environments, depending on the environment in which the radio equipment is located. Atmospheric corrosion in turn is subdivided into wet, damp, and dry. The first of these categories occurs when a metal surface is in an environment with a relative humidity close to 100%. The second category occurs under a layer of electrolyte forming on components as a result of moisture condensation on them. The third category of atmospheric corrosion occurs without moisture condensation on radio equipment components. Corrosion in natural water environments is observed primarily when radio equipment is immersed in water, and particularly intensively when the temperature of the equipment is substantially higher than the water temperature. The character and essence of the various types of effect of corrosion on radio components are described in Table 6.3

Table 6.3. Effect of Corrosion on Radio Components

1 Types of Effect of Corrosion on Radio Components	Character and Essence of Various Types of Effect of Corrosion on Radio Components 2				
	Formation of Chemical Condensate Under the Effect of Wet Corrosion 3	Formation of a Surface Film on the Metals of Radio Components Under the Effect of Dry Atmospheric Corrosion 4	Breakdown of Equipment Components Under the Effect of Various Atmospheric Conditions (Accelerating Atmospheric Corrosion) 5	Damage to Equipment Due to Corrosion in Natural Water Environments 6	Damage to Equipment From Contact Corrosion 7
The following have a harmful effect on radio components: atmospheric corrosion, corrosion in natural water environments, and contact corrosion.	Chemical condensate forms with the appearance of a thin layer of moisture on a metal surface and with interaction between moisture and metal. This is due to the fact that water almost always contains a greater or	At a constant temperature gas molecules strike the surface of a metal and, depending on the nature of the surface layer, are adsorbed to one degree or another. These adsorbed gas ions enter into a chemical reaction	The failure of components of equipment installed outdoors is caused by many factors, and particularly precipitation (rain, snow, turbulent currents of damp air), their shock effect, air pollution, difference between the	Damage to equipment or equipment components from corrosion in natural water environments is aggravated when the temperature	In a damp climate, particularly in tropical regions, when one material is in contact with another, there occurs contact electrochemical corrosion, that is,

Table 6.3 (cont'd)

1	2				
	3	4	5	6	7
The damage caused by corrosion of metals is expressed: in decreased mechanical strength of structures, in decreased precision and service life of mechanisms, in breakdown of contact connections, and breakage of fine wires. Corrosion products contaminate components, reduce the electrical characteristics of dielectrics, and mark the external appearance of equipment. Atmospheric corrosion is the most harmful. It is subdivided into: a) corrosion occurring when moisture comes into direct contact with a	smaller quantity of dissolved salts or acids. This type of atmospheric corrosion is similar to the normal case of electrolytic corrosion when metal is fully immersed in an electrolyte and is connected with the action of local microelements. Chemical condensate can also appear due to moisture in the microcapillaries of the metal proper, in gaps and in pores in the oxide film. It is important to note that the smaller the radius of curvature of the concave meniscus in the capillary, the lower the pressure of the vapors in equilibrium with the liquid, and the more readily condensation occurs. The above applies to wet atmospheric	with the metal ions which are released from the space lattice. As a result a surface film develops on the metal, which has an adverse effect on the electrical properties of equipment components (especially contacts). Film thickness, depending on time, increases parabolically (at high temperatures) or logarithmically (at low temperatures). The film is particularly thick in an atmosphere containing sulfur dioxide. The latter, dissolving in the moisture film forming on a metal surface, increases its acidity and electrical conductivity, and thus speeds up corrosion. The rate of the described processes	electrochemical potentials of the employed metals, etc. Rain slows the process of corrosion, while fog speeds it up. Wind promotes rapid evaporation of moisture and slows corrosion. At the same time the process of evaporation affects the mixing of electrolyte (the diffusion layer decreases, oxygen depolarization is accelerated and, consequently, the corrosion process speeds up). Sunlight and air temperature have little effect on the corrosion process. Corrosion under atmospheric conditions begins particularly intensively at a humidity close to 100% (there occurs liquid-droplet condensation of water	of the equipment when immersed is considerably greater than that of the water. Air trapped inside the equipment rapidly cools and compresses, creating reduced pressure within the equipment. Under the effect of the pressure difference, water vigorously penetrates into the equipment and wets components. Upon drying, salts, mineral and organic substances dissolved	electrochemical microcouples are formed. One metal serves as the anode, the other metal as cathode, while the moisture film is the electrolyte. The farther the metals are positioned from one another in the electrochemical displacement series, that is, the greater the difference in potentials between them, the greater the probability of contact corrosion. As the corrosion process advances, the potentials of the metals change as a consequence of polarization, effect of

Table 6.3 (cont'd)

1	2				
	3	4	5	6	7
component (wet corrosion); b) corrosion under a layer of electrolyte forming on components as a consequence of moisture condensation on them (damp corrosion); c) corrosion without moisture condensation on components (dry corrosion). Corrosion in water environments is characteristic of equipment which is subject to brief immersion in water. Contact corrosion is the result of electrochemical processes on contact connections. It occurs in a damp climate, especially in tropical regions	corrosion, which is always connected with formation of a film of electrolyte on the surface of metal	is more rapid in more humid air in the fall and winter. In the summer this process is slowed. The presence of contamination on a metal surface, the presence of dampness in the atmosphere, as well as sharp temperature changes (dew falls) are highly favorable conditions for corrosion. In the morning the temperature of metal components is lower than the air temperature, as a consequence of which moisture can condense on them, and consequently corrosion can occur.	vapor). In principle there exists a certain critical relative air humidity above which, all other conditions being equal, there occurs a sharp increase in the rate of metal corrosion. Corrosion of metal components and contact connections increases when there accumulate inside equipment gaseous substances obtained as a result of the oxidation process of high-molecular resins or the drying of varnish and paint coatings	in the water are deposited on equipment components. In addition, shipboard equipment may periodically receive a seawater dousing. The rate of corrosion in water environments depends on the corroding material, on the composition and physical properties of the water, on the plant and animal organisms contained in the water, and on the degree and periodicity of wetting of the equipment. Corrosion of iron in fresh water is determined by the concentration of oxygen in the water. Water causes corrosion until all the oxygen is consumed. Corrosion intensifies when the water contains bacteria which reduce sulfates (there are many such bacteria in seawater and in damp soil). Iron corrodes more vigorously in soft than in hard water.	environmental conditions, and the influence of corrosion products. Some couples may even change polarity. The effect of corrosion depends on the ratio of the area of the cathode (more noble) metal to the area of the anode (less noble) metal. One should seek to ensure that the area of the cathode metal is as small as possible. Corrosion of soldered seams is viewed as contact corrosion, where the solder (soldered seam) has a substantially smaller surface than the soldered metal.

Table 6.3 (cont'd)

1	2				
	3	4	5	6	7
				Corrosion intensifies on components in contact with snow. Elevated temperature of seawater promotes an increased rate of corrosion, but at the same time it assists the development of protective calcium deposits which retard the corrosion process. Corrosion becomes intensified under conditions of alternating drying and moistening of salt crystals remaining on the metal surface. The rate of corrosion of metals in the tidal zone depends greatly on temperature: in a temperate climate the rate of corrosion is twice that of a tropical climate and four times greater than with complete immersion	In order to increase the service life of a soldered item, a solder is selected with a higher potential than that of the soldered metal. In this case soldered metals will be subjected to negligible damage, and a soldered seam will be protected. The corrosion resistance of solders in a rural area is approximately 50% greater than in industrial areas. One must also bear in mind that contact between certain species of tree (oak, chestnut, etc) and metals causes the latter to corrode. Some grades of plywood, releasing active substances, also cause corrosion in metals (in contact with them)

6.5. Influence of the Biological Environment, Light, Dust, Sand and Conditions of Aging of Materials on Radio Components

The biological environment (primarily mildew), light, dust and sand have an adverse effect on radio components.

Mildew leads to the most serious destructive effect during the operation of radio equipment in a damp tropical climate. Components break down under the effect of an enzyme, materials corrode under the effect of various acids (citric, carbonic or oxalic), and the surface of transparent materials becomes coated, leading to impairment of their optical properties.

The effect of light on materials reduces to chemical decomposition of organic materials such as plastics, dyes, and fabrics.

The effect of dust is expressed in acceleration of corrosion of metal surfaces, in intensification of the process of absorption of mosture contained in dust by carbonates, sulfates, chlorates and other readily soluble salts. Very frequently a layer of dust becomes a good conductor of electricity (particularly with frequent alternation of the processes of moistening and drying) in disruptive circuits. In many cases this causes surface flashover. Dust also causes diminished precision in the operation of testing instruments and devices. Sand leads to wear on rotating equipment components and to failure of bearings. Aging of materials has a substantial deleterious effect on radio equipment.

The character and essence of the effects of the above factors on radio components are described in Table 6.4.

Table 6.4. Effect of the Biological Environment, Light, Dust, Sand and the Process of Aging of Materials on Radio Components

1 Types of Effects of Biological Environment, Light, Dust, Sand and Aging of Materials on Radio Components	Character and Essence of Effects of Biological Environment, Light, Dust, Sand and Conditions of Aging of Materials on Radio Components 2		
	3 Damage to Equipment by Biological Environment (Mold and Mildew)	4 Damage to Equipment Components by Light, Dust and Sand	5 Damage to Insulation Materials Caused by Change in Physicochemical Properties (Aging)
Effect of the biological environment reduces chiefly to the formation of mold and mildew. Damage caused by mold and mildew is of three types: damage caused by an enzyme, under the effect of byproducts of the action of mold and mildew (various acids), which coat transparent materials (they become opaque). The process of destruction of materials depends on the ambient temperature and moisture, sunlight, air movement,	All natural fibrous materials (textile fabrics, cotton, wool, flax, hemp) are vigorously attacked by mold and mildew. It leads to weakening, impaired resistance to water penetration, and in many cases to fading. Synthetic fibers lose their resistance to the action of mold and mildew under the effect of light and heat. The degree of effect of mold and mildew on plastics is determined by their composition. Mold and mildew gradually destroy the filler and	The effect of light on radio components consists chiefly in the chemical breakdown of certain organic materials (plastics, dyes, fabrics). The effect of light is proportional to the quantity of energy contained in a photon (the energy of a photon is inversely proportional to wavelength), and therefore materials are principally affected by solar ultraviolet radiation. Consequently radiation in a dry tropical climate exerts the greatest effect on materials.	Oxygen in the air is the principal agent which breaks down organic insulation materials (it leads to oxidation). The reaction of oxidation is accelerated under the effect of heat and light, that is, is strongly linked with change in climatic conditions (oxidation of organic materials is a chain reaction, where new centers of attack are continuously forming). The following occurs as a result of oxidation: breakdown of large molecules of

Table 6.4 (cont'd)

1	3	4	5
Precipitation, etc. Mold and mildew contain and hold a large quantity of moisture, forming a water film on a material, promoting chemical decomposition of the material. The effect of light on materials consists chiefly in chemical decomposition of certain organic materials (plastics, dyes, fabrics). It also affects the rate of atmospheric corrosion. Dust, coming into contact with metal parts, accelerates their corrosion, intensifies absorption of moisture, and in many cases creates additional conductivity (impairing the insulation properties of materials). Sand particles cause an abrasive effect. Getting between rotating equipment components, sand particles accelerate their wear or cause bearings to jam. Aging of materials is caused by slow changing of their physicochemical properties in the process of operation or storage	plasticizer making up a plastic, and this increases their brittleness and alters electrical characteristics. Derivatives of aliphatic dicarboxylic acid are the most stable plasticizers. Mold and mildew vigorously attack organic fillers (cotton, paper, rags, etc), natural and synthetic rubber (particularly when rubber is in direct contact with water or earth), as well as wood (under conditions of dampness) and leather (in tropical conditions). Mold and mildew also attack painted surfaces, breaking down the paint layer or causing fading. Mold and mildew cause lenses to become cloudy and lead to spots or granular incrustation caused by leaching and other physical and chemical phenomena. Mold and mildew form on terminal strips, tube receptacles, switch panels and wire insulation. Particularly dangerous are locations in circuitry which create favorable conditions for	The following take place under the effect of solar light: partial chemical breakdown of polymers, breakdown of thermosetting plastics, rapid aging of nitrocellulose plastics, formation of a crust on the surface of rubber and its subsequent cracking, breakdown of natural and nitrile rubber, change in the surface layers of wood, fading and chalking of painted surfaces. The effect of dust on metal components reduces to acceleration of the corrosion process. It can also cause equipment to malfunction; carbonate, sulfate, chlorate, and other readily-soluble salts contained in various dust varieties absorb moisture from the ambient air and therefore promote development of the corrosion process. A layer of dust can become a conductor of electric current along stray paths and lead to surface flashovers. Damp dust catastrophically decreases the resistance of insulation. The dielectric constant of dust is greater than that of air, in connection with which the capacity of an air-gap capacitor increases,	materials, deterioration of the insulation properties of a material, development of additional internal bonds in molecules, which lead to change in the structure of substances (rigidity and brittleness develop). Surface erosion occurs in materials of low molecular weight (in cellulose, for example). One result of the aging of insulating materials is saponification of esters, evaporation of plasticizer, transition of a substance from an amorphous to a crystalline state, and release of chlorine (the above applies to plastics, polystyrene, and polyvinyl chloride). Rubber in a stressed state rapidly loses its elasticity under the effect of high temperature and compression (rapidly ages). Aging intensifies during protracted effect of solar radiation and variable humidity in

Table 6.4. (cont'd)

1	2		
	3	4	5
	establishment of termite colonies (creating short-circuit paths). Termites strongly affect the preservation of wood components. All other living organisms encountered in various physical and physical-geographic conditions have a harmful effect	and the resonant frequency of the circuit simultaneously drops. An increase in the conductivity of a dust layer shunting a circuit lowers its Q. Particles of sand getting between rotating equipment parts accelerate their wear. Sand causes bearings to stick and destroys the lubricating capability of oils and substances of all types (so-called abrasive effect develops in all these cases)	polyamide resins, in plastics with volatile substances, in varnish and paint films, and in polyethylene films. Aging under the effect of climatic factors is less marked in inorganic materials employed in radio components than in organic. Aging of a number of materials (in the styroflex film of polydichlorstyrene) is greatly dependent on the effect of an electrical field on them. With pulse and variable voltage, the effect of temperature on aging of a material
	diminishes. In ceramic materials aging leads to an increase in dielectric losses, a decrease in the resistance of insulation and electrical strength. Aging of ultra-porcelain, steatite, radioporcelain and other such materials, under the effect of high-frequency electric current, takes place as a consequence of ion bombardment in the gas pores of the ceramic body. This weakens these materials, and they easily break down. Considerable aging is observed in TiO_2 cermet dielectric and in ferroelectric ceramic materials		

6.6. Effect of Mechanical Loads on Operation of Communications and Radio-Radar Support Services Equipment

Impacts and vibrations are the principal mechanical loads. These loads are caused by wind gusts, aerodynamic effects, the force of gravity during braking, displacement of mechanical components during transport, etc. Consequences of impact include damped oscillations and large accelerations, which are transferred to system components.

Vibrations can occur both during movement of communications and RTO equipment on the ground and in the process of transport by aircraft. Vibrations particularly affect radio tubes. They are caused by periodic oscillations of aerodynamic origin, by the forces of inertia occurring as a consequence of static and dynamic unbalance of rotating masses in engines, by the impact forces of exhaust streams and ignition blast waves. The frequency of aircraft vibrations affecting radio equipment ranges from 5 to 450 Hz, with an amplitude ranging from 0.005 mm (at high frequencies) to 0.250 mm (at low frequencies). Radio tubes are most seriously affected by vibrations with a frequency of 12-25 Hz, which frequently result in electrode failure.

Shocks and vibrations also lead to loosening of screw and bolt-secured parts, chassis wire breakage (especially at bends and soldered connections), weakening of metal connections (welded, riveted, bolted), circuitry deformation, capacitor and resistor lead separation, and misadjustments.

Mechanical effects are generally estimated on the basis of magnitude of acceleration and are measured in units of acceleration of gravity.

Impact accelerations can be calculated with the following formula:

$$g = \frac{v^2}{2 \cdot 9{,}81 S_y}, \qquad (6.1)$$

where g -- acceleration in relative units (in relation to acceleration of gravitational force); v -- instantaneous velocity at the moment of impact, cm/s; S_y -- displacement at impact or total quantity of elastic and residual deformations of impacting objects, cm.

Acceleration during vibrations (in relative units) is determined with the following formula:

$$g = \frac{4\pi^2 f^2 S_B}{9810},$$

where f -- frequency of oscillations, Hz; S_B -- amplitude of displacements, mm.

The most dangerous vibration frequency ranges under terrestrial conditions are 15-150 Hz and 175-500 Hz. Resonance in the structures proper occurs in the first interval, and in the second -- resonance in vacuum tubes.

We should note that in many cases clumsy actions or carelessness on the part of handling personnel lead to damage of a mechanical nature (for example, excessive force in operating controls and performing tuning and adjustment operations, incorrect handling by equipment operators, careless and negligent handling of units, tubes and other components during preventive maintenance).

Part III. FUNDAMENTALS OF SERVICING AND MAINTENANCE OF AIR TRAFFIC CONTROL COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

Chapter 7. PRINCIPLES OF SERVICING AND MAINTENANCE OF COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

7.1. Substance and Content of Servicing and Maintenance of Communications and Radio-Radar Support Services Equipment

Servicing and maintenance of communications and radio-radar support services equipment is defined as an aggregate of organizational and technical measures performed by personnel for the purpose of:

ensuring that equipment is in operational readiness at all times;

maintaining equipment parameters within the limits of specified tolerances;

preventing equipment malfunctions and failures during operation and storage;

extending operating time between maintenance and service life.

The main feature of servicing and maintenance of communications and radio-radar support services equipment in aviation is the requirement that it possess a high degree of reliability with operations under the most diversified conditions. This is due in the first place to the fact that aircraft are based in the most diversified geographic zones; second, reliable operation of communications and RTO equipment determines not only successful performance of assigned missions but also air safety, particularly aircraft landing operations in IFR conditions.

Following are the principal tasks of technical servicing and maintenance:

prompt and high-quality readying of communications and RTO equipment for operation, equipment operation and training of personnel for independent servicing and operation of this equipment;

maintenance of communications and RTO equipment in an operable state and in continuous operational readiness;

continuous improvement in technical servicing and maintenance methods, with the objective of ensuring a high degree of operational reliability of communications and RTO equipment;

performance of prompt and high-quality repair of communications and RTO equipment, for the purpose of restoring equipment to operation and extending equipment service life;

prompt and complete logistical support of technical servicing and maintenance of communications and RTO equipment.

in conformity with the above-listed tasks, technical servicing and maintenance include the following: readying of communications and RTO equipment for operation, repair and storage, measures to ensure operational reliability of equipment and monitoring of the state of equipment, planning, record keeping and logistical support of technical servicing and maintenance, as well as warranty claims activities.

Scheduled preventive maintenance operations performed on communications and RTO equipment comprise the basis of technical servicing and maintenance (Table 7.1).

Table 7.1. Substance and Content of Servicing Operations (a Variant)

Servicing Procedures 1 (R-1) (First Column)

Performed on equipment operating continuously or with brief interruptions of more than 24 hours, as a rule without taking the equipment off line, as well as on equipment with operation interruptions of not less than 3 days, prior to startup (following interruption).

R-1 procedures are as follows:

determination that communications and RTO equipment is in good operating order and operating efficiently under the specified conditions;

ensuring that operating conditions are in conformity with specifications;

locating and correcting malfunctions which can cause equipment failure.

R-1 specifies performance of the following operations on communications and RTO equipment:

external inspection;

cleaning equipment without opening up;

checking for proper grounding, solid connection of connector plugs and sockets;

check operating efficiency of equipment according to operating specifications with built-in test instruments;

check proper operating condition and efficiency of service communications, remote control and signaling links and lines;

correction of detected malfunctions and deficiencies;

check for presence and proper operating condition of fire-extinguishing and safety equipment;

tidy up work stations and equipment rooms.

Servicing Procedures 2 (R-2) (Second Column)

Performed on equipment operating continuously or with brief interruptions of more than seven days, as well as on equipment with operation interruption with more than three days. At continuously-operating facilities equipment may be taken off line for the period of performance of maintenance procedures, as a rule with mandatory substitution of back-up equipment.

Following are the tasks of R-2:

determination of proper operating conditions and preparedness of communications and RTO equipment to operate under all conditions;

detection and correction of malfunctions.

R-2 specifies performance of the following procedures on communications and RTO equipment:

R-1 procedures;

inspection and, if needed, cleaning of contacts and lubrication of rotating parts, without opening up equipment;

check proper operating condition and efficiency of gasoline heaters;

inspect body of vehicle containing station (equipment room);

inspect antennas and transmission lines; check operating efficiency of equipment in all operating modes with built-in test instruments.

Servicing Procedures 3 (R-3) (Third Column)

Performed on all unit (subunit) communications and RTO equipment in operation, as a rule during equipment servicing days (vehicle servicing days). Following are the tasks of R-3:

thorough inspection and cleaning of equipment, contacts, switches, connectors, component units, etc;

check the operating efficiency of all component items and perform tuning and adjustment procedures.

R-3 specifies performance of the following procedures on communications and RTO equipment:

performance of R-2 procedures;

detailed inspection and cleaning of the entire unit;

check the operating efficiency of all component items with built-in test instruments, and perform necessary tuning and adjustment procedures;

check for presence and proper operating condition of auxiliary equipment;

add missing items to set of spare parts, tools and accessories;

fill in servicing documents.

The R-3 schedule includes the following:

organizational measures (instruction of persons performing R-3, filling out requisition forms for materials and test equipment, distribution of job assignments, etc);

time for work to begin and total time to perform R-3;

procedure of verification of results and quality of performed procedures.

<u>Servicing Procedures 4 (R-4)</u> (Fourth Column)

Performed only on certain communications and RTO equipment operated at permanent communications facilities, when a more detailed inspection is required during the period between R-5 inspections.

Following are the tasks of R-4:

instrument testing of certain parameters;

check the condition of component units, adjustment and control components;

check switching circuits.

R-4 specifies performance of the following procedures on communications and RTO equipment:

performance of R-3 procedures;

testing and, when necessary, replacement of vacuum tubes, equipment components and missing items in the set of spare parts, tools and accessories;

measurement of individual parameters and adjustment to standard.

Servicing Procedures 5 (R-5) (Fifth Column)

Performed on all unit (subunit) communications and RTO equipment in operation, and coincides in time with changing equipment over to winter (summer) operations.

Following are the tasks of R-5:

instrument check on individual parameters;

preparation of communications and RTO equipment for operation in summer (winter) conditions.

R-5 specifies performance of the following procedures on communications an RTO equipment:

performance of R-3 (R-4) procedures;

testing and, when necessary, replacement of vacuum tubes, other equipment components, and items in the set of spare parts, tools and accessories;

measurement of individual parameters and their adjustment to standard;

replacement of lubricants;

servicing of fire extinguishers;

repair and add necessary equipment to places where communications and RTO equipment is stored and serviced.

The R-5 servicing and maintenance schedule includes the following:

date, time of initiation and completion of servicing and maintenance procedures in the subunits;

supervision and monitoring procedures;

procedure for obtaining specialists from other units when needed;

list and sequence of maintenance procedures;

date and procedure of performing operational flight test.

Servicing Procedures 6 (R-6) (Sixth Column)

Performed on all communications and RTO equipment in the unit, according to the plan and schedule approved by the senior officer. As a rule R-6 is combined with performance of regular R-5.

Following are the tasks of R-6:

instrument testing of principal parameters and their adjustment to requisite standards;

determination of the technical state of communications and RTO equipment;

determination of the procedure of subsequent utilization of equipment and facilities.

R-6 specifies performance of the following procedures on communications and RTO equipment:

performance of R-5 procedures;

measurement of principal parameters and their adjustment to standards;

inspection and addition of missing items to set of spare parts, tools and accessories;

inspection of equipment inspection and maintenance sheet and log.

A high degree of efficiency of technical servicing and maintenance is achieved by:

prompt and high-quality preparation of documents on planning servicing procedures and communicating them to executing personnel;

assignment of specific tasks to subunits and individuals on preparation for and performance of servicing procedures;

firm knowledge by personnel of the volume and methods of performing servicing operations and performance of these procedures in strict conformity with the requirements stated in servicing and maintenance documents;

comprehensive and thorough analysis of the causes of failure of communications and RTO equipment and taking prompt measures to prevent them;

continuous supervision and regular monitoring by officials of preparations for, quality of performance, and results of servicing and maintenance procedures;

summing up results of performance of servicing operations, thorough analysis of the actions of personnel, synthesis and dissemination of advanced methods of organization and performance of technical servicing and maintenance of communications and RTO equipment.

Servicing and maintenance of communications and RTO equipment are performed in conformity with a scheduled preventive maintenance system and the calendar principle. An approximate classification of these procedures (conditionally divided into six maintenance inspection sequences) and their substance are described in Table 7.1.

In aviation particular attention is focused on servicing and maintenance of communications and RTO equipment in direct flight operations support services, which includes three stages: preliminary preparation, preflight preparation, and postflight preparation. The substance and an approximate description of servicing and maintenance of communications and RTO equipment with these categories of preparation are described in Table 7.2.

Table 7.2. Substance and Content of Flight Operations Support Servicing and Maintenance of Communications and RTO Equipment (a Variant)

(Columns 1 & 2)

Preliminary Preparation	
Preparation Elements	Character of Servicing and Maintenance
Preliminary preparation is the principal type of preparation of personnel and equipment for flight operations support and is performed on the eve of a day (night) of flight operations. If flight operations are postponed by more than 72 hours, preliminary preparation of personnel and communications equipment shall be repeated. Preliminary preparation includes the following: flight operations support decision and assignment of tasks to individuals; assignment of equipment and designation of duty shifts for flight operations support; instructing of personnel designated for flight operations support; preliminary servicing of equipment designated for flight operations support; verification of readiness of personnel and equipment for flight operations support	Preliminary servicing and maintenance is performed: in the scope of R-1 on all equipment, without exception, designated for flight operations support; in the scope of R-2 with equipment operation interruptions of more than 72 hours (on equipment permanently deployed at an airfield, on main and backup equipment deployed only for the duration of flight operations support activities). In addition to R-1 (R-2), the following are performed: tuning and adjustment of equipment to the desired specifications and operating modes; an accuracy check on the operation of equipment directly involved in aircraft landing operations (position of the localizer and glideslope zones of instrument landing system radio beacons, final approach path and glidepath alignments on precision approach radars, tuned frequency of outer and middle markers, etc); verification of proper working order of remote control equipment, automatic systems for switching over to back-up equipment, operation of lighting equipment; fueling and lubrication of power generator equipment; verification of the operating state and efficiency of self-contained power supply equipment, as well as time of changeover of equipment powering from external sources to self-contained; inspection of emergency set of spare parts, tools and accessories.

Table 7.2 (cont'd)
(Columns 3 & 4)

Preflight Preparation	
Preparation Elements	Character of Servicing and Maintenance
Preflight preparation of duty shift personnel, communications and RTO equipment for flight operations is performed immediately prior to flight activities. The final stage of these preparations is preflight in-air testing of communications and RTO equipment, performed before the day's flight operations begin by the crew of a weather reconnaissance aircraft. With two-shift flight operations a second in-air testing is performed only if there is a change in the landing approach course or underlying surface in the zone of operation of the landing approach radio beacons or if there have been complaints from aircrews. Preflight preparations include the following: preflight briefing of duty shift personnel; preflight servicing of communications and RTO equipment; comprehensive verification of the readiness of personnel and equipment for flight operations support activities; preflight in-air testing of communications and RTO equipment	The following is checked in preflight servicing of equipment: overall state of equipment (verticality of installation and reliability of securement of antenna-mast equipment, secure hookup of antenna transmission lines, power cables, and equipment grounding); correctness and accuracy of equipment tuning in conformity with specified data and operating conditions (with built-in test instruments); proper operating condition of built-in monitoring systems, speed and reliability of changeover to backup sets of equipment. Proper operating condition of portable equipment and objective monitoring devices (tape recorders, photographic, cinematographic and other recording equipment); good working order of control and signaling communication lines and links; fueling and lubrication of self-contained sources of electric power, speed and reliability of their remote and on-site startup, as well as changeover of power supply from external to self-contained sources; complete emergency set of spare parts, tools and accessories on hand. Finally a thorough check is made on readiness of personnel and equipment for flight operations support activities.

(Columns 5 & 6)

Postflight Preparation	
Preparation Elements	Character of Servicing and Maintenance
Postflight preparation is the final stage in flight operations support activities and is performed at the end of each day (night) of flight operations or following a duty shift. Postflight preparation includes the following: sequential servicing and maintenance of communications and RTO equipment; preliminary critique of flight operations support activities. The preliminary critique includes the following: analysis of errors committed by duty shift personnel, as	Postflight servicing of equipment includes the following: inspection of equipment; correction of malfunctions discovered during flight operations and postflight inspection; fueling and lubrication of self-contained electric power generating equipment; performance of record keeping tasks; cleaning equipment and tidying up work stations

Table 7.2 (Columns 5 & 6) (cont'd)

Postflight Preparation	
Preparation Elements	Character of Servicing and Maintenance
well as evaluation of the correctness of their actions in a complex situation; analysis of deficiencies in the performance of flight operations support equipment; communication to personnel of critical comments by the flight operations officer, as well as an overall evaluation of flight operations support activities with communications and RTO equipment; evaluation of the performance of the duty shift personnel of each facility	

Each unit holds equipment and vehicle servicing days in order to assure proper maintenance of communications and RTO equipment and vehicles, as well as to upgrade work stations, vehicle parking and equipment storage facilities. As a rule the following principal tasks are performed on such days:

R-3 servicing of communications and RTO equipment;

servicing and maintenance of communications and RTO equipment vehicles;

upgrading of work stations, equipment shelters and storage sites, as well as access roads to these sites;

holding of demonstration classes for working on personnel practical skills in servicing and maintenance of equipment.

The following are prepared for each such work day: a schedule for preparing for and conducting servicing and maintenance of communications and RTO equipment, as well as scheduled assignments for facility crews.

The schedule of preparation for and conduct of servicing and maintenance of communications and RTO equipment specifies:

date and time of activities to be performed;

activities to be performed;

subunits assigned performance of a given task;

executing personnel;

persons responsible for performance of work;

record of performance.

The facility crew scheduled assignment specifies:

content of task;

responsible individual (rank, last name, initials);

time of task performance;

record of performance.

Performance results are critiqued at the end of a maintenance work day.

7.2. Servicing of Communications and Radio-Radar Support Services Equipment During Flight Operations

Following are the principal servicing operations on communications and RTO equipment during performance of flight operations support activities: operational switching of equipment from one mode to another, equipment monitoring and adjustment, maintaining parameters in conformity with specified standards, as well as procedures in special cases.

Operational switchings are actions by personnel performed on communications and RTO equipment for the purpose of:

tuning equipment from one frequency to another and from one type of operation to another;

switching from one channel to another, from principal to backup equipment;

switching of power supplies, storage batteries, antennas, transmission lines, communication links and lines, keying and control lines.

Operational switchings are performed by facility duty personnel on the instructions of or with the permission of persons in charge of duty shifts, and are recorded in equipment logs.

When performing operational switchings, duty shift personnel must rigorously observe safety rules and regulations.

Equipment monitoring and adjustment should be performed in strict conformity with operation and servicing instructions. During operation of communications and RTO equipment, facility duty personnel shall monitor equipment operation by monitoring instruments (displays), shall compare instrument readings with operating conditions table data, and shall monitor the temperature to which equipment and generators become heated.

Ventilation shall be increased when equipment is heating substantially; if necessary they shall switch over to backup equipment with the permission of the persons in charge of duty shifts.

In addition to monitoring operations, principal equipment parameters shall be periodically measured -- frequency and percentage of modulation, as well as phasing and synchronization (wherever specified by operation procedures).

Equipment shall be adjusted when needed, on the basis of test measurements (on each occasion adjusted to the nominal conditions specified in tables of operation instructions).

Parameters are kept in conformity with specified standards by means of regular comparison of the readings of test instruments with the figures contained in operating condition tables. When nominal values are reached, tuning controls are locked. It is expedient to record in tuning tables the position of tuning controls for nominal conditions at a given frequency and for a given type of operation.

The following procedures are followed in emergency situations, when communications and RTO equipment failure or breakdown occurs:

If backup equipment is available, it is switched on immediately;

when possible, the malfunction causing the failure (breakdown) shall be corrected immediately;

reliable temporary connections and bypass circuits shall be employed (subsequently they should be taken off as soon as possible);

a self-contained power source is employed in case of power failure of the main power source;

available spare tubes, fuses and other consumable materials and tools are utilized for the purpose of correcting malfunctions as quickly as possible.

7.3. Putting Communications and Radio-Radar Support Services Equipment Into Operation

Measures pertaining to putting communications and RTO equipment into operation include the following:

receiving equipment, training and permitting personnel to operate it;

selecting and equipping positions for deployment of equipment, concealing and camouflaging equipment;

checking operational status of equipment under ground and in-air conditions.

The substance of the above-enumerated measures is described in Table 7.3.

Table 7.3. Procedure of Putting Communications and RTO Equipment into Operation (A Variant)

Communications and RTO Equipment Receiving Measures 1	Procedure of Authorizing Personnel to Operate Communications and RTO Equipment 2	Measures Taken For Purposes of Selection and Equipment of Sites for Communications and RTO Equipment 3	Measures for Deployment and Checking of State of Equipment 4
The following procedures are performed when receiving equipment: inspection to ensure equipment is complete; measurement of all parameters with performance of inspection R-6; determination of technical state of equipment. Received equipment is assigned to subunits, and within subunits — to designated responsible personnel. Equipment assignment is recorded in a special log (communications and RTO equipment assignment log).	Personnel are permitted to operate equipment unsupervised when they have successfully passed a test: on knowledge of the operating principle and design of the equipment; on rules of operation and safety measures; on design and utilization of test equipment; on performance characteristics, rules and procedures of record keeping and operational documentation. Personnel shall be tested once each year, as well as persons returning to work following a period off. As a rule a qualifications commission is designated to determine the proficiency qualifications of communications and RTO specialists.	The following are considered in site selection: requirements on sites and terrain specified in technical descriptions, operating instructions and other special documents; equipment concealment and camouflage capabilities; availability of access routes and water supply; conditions of billeting and feeding personnel; possibility of hooking into external power sources; allowable screening angle and terrain slope, as well as nearby sources of radio interference. Engineer equipping of positions includes: site preparation (clearing, leveling and soil packing); construction of embankments, foundations, access roads and footpaths; construction of equipment shelters, covered trenches, dugouts and slit trenches for personnel; digging of water-drainage ditches, trenches, foundation trenches, wells and water-collecting systems; construction of fuel and lubricant storage facilities, fire extinguishing equipment locations, equipment radioactive decontamination areas; site enclosure and designation of assigned zones.	Deployment of communications and RTO equipment includes performance of the following: laying out site for deploying equipment and antenna systems; deployment of equipment and equipment component units; assembly, rigging, raising and alignment of masts and antenna systems; laying out and connecting antenna transmission lines, monitoring instruments, power lines, communications and control lines. Orientation of antenna systems is performed: VHF and UHF radio direction finders, surveillance and air traffic control radars -- by magnetic meridian; HF radio direction finders, close-range navigation equipment, guidance and detection radars -- by true meridian; localizer and glideslope radio beacon precision approach radars, as well as marker beacons and nondirectional beacons -- relative to the runway centerline (directions of landing approach).

Table 7.3 (cont'd)

1	2	3	4
			Ground check of communications and RTO equipment includes: readying of equipment for switching on power; switching on power, adjusting and tuning equipment; check on operable condition of equipment in all modes and all service operations; measurement of principal equipment technical parameters; preparation of tuning tables and operational mode tables. A report is prepared based on results of the ground check, containing the following information: type of equipment, manufacturer's numbers and year of manufacture; conformity between actual equipment deployment and approved layout; list of check procedures performed; principal equipment parameters, discovered defects and malfunctions revealed in the check process. A record of parameter measurements, unit (stage) operating condition tables and equipment tuning tables are attached to the report.

7.4. Methods of Trouble-Shooting Communications and Radio-Radar Support Services Equipment

Following are the principal methods of locating malfunctions in communications and RTO equipment:

1. External inspection method. It includes:

sequential inspection of wiring, cable, components and mechanisms;

inspection by hand probe for heating of electric motors, transformers, reduction gearing, tubes and other components;

inspect by ear the operation of equipment and automatic control devices, listen for sparking in high-frequency connectors and antenna transmission line systems.

2. The isolation method consists in isolating the believed malfunctioning circuits, units or stages from the operating circuitry during the inspection. This method is employed in combination with the other methods described below.

3. The substitution method consists in replacing suspected malfunctioning units, assemblies, and cable connections with corresponding items known to be good.

4. The measurement method calls for checking resistances, insulation, electrical circuits, operating voltages of tubes, relays and other components, input and output voltages of separate units, voltage waveforms and amplitudes in circuits, frequencies of radiated and received oscillations, transmitter output power, consumed current and tube integrity. In evaluating measurement results one employs voltage and resistance cards, oscilloscope patterns and operating condition tables contained in equipment operation and maintenance manuals, as well as operating condition tables prepared when putting equipment into operation.

5. The simulation method consists in substituting for a suspected unit or stage a special device which produces voltages corresponding to those which should be applied by the replaced unit or stage. Standard signal generators, signal generators, meter and centimeter band generators, as well as range calibrators and other signal devices are employed in locating malfunctions by the simulation method.

6. The typical malfunction method consists in analyzing the state of communications and RTO equipment in the process of operation, and then utilizing data on typical malfunctions for a given piece of equipment; at the same time experience is accumulated in repairing the least reliable equipment units, assemblies and parts.

Trouble-shooting is performed in the following sequence:

one determines the malfunctioning unit;

one checks fuses;

one checks supply voltages;

one checks tubes and semiconductor devices;

one checks circuits and contacts for proper operation;

one checks operating conditions of tubes and semiconductor devices;

one performs an external inspection and checks the values of resistors, capacitors and other parts.

In the process of correcting malfunctions it is prohibited to make any changes in the unit which depart from equipment circuits and specifications. They can be performed only in conformity with factory bulletins or servicing information data. The general sequence of performing operations to correct malfunctions is as follows:

secure access to the malfunctioning unit (assemly or part);

protect adjacent units (parts, assemblies) from possible damage during correction of malfunctions;

clean and inspect the surface of the malfunctioning unit (assembly or part);

perform the required procedures to correct malfunctions;

check the quality of repairs performed and, where necessary, perform electrical test measurements;

remove protective devices and tools from equipment;

install unit (assembly, part) and operationally test it.

7.5. Organization of Repair of Communications and Radio-Radar Support Services Equipment

Repair is an aggregate of organizational and technical measures directed toward restoring communications and RTO equipment to service. It is performed for the purpose of correcting failures and malfunctions, bringing technical parameters to specified standards, and renovating equipment.

Repairs are performed by the personnel of communications and RTO subunits and units, by organic maintenance shops and repair agencies.

Depending on the nature of malfunctions and damage, as well as the technical state of communications and RTO equipment, the following types of repair are specified: routine, minor, medium, and major. The first two categories are unscheduled maintenance, while the latter two are scheduled maintenance.

Sets of ZIP [spare parts, tools and accessories] are employed in performing repairs on communications and RTO equipment, sets which, depending on designation and specific features of employment, subdivide into single (ZIP-0), group (ZIP-G), and overhaul (ZIP-R).

Determination of technical state is performed for communications and RTO equipment which have logged the designated maintenance intervals. One determines the possibility of further operation of this equipment or the need for appropriate repairs. On the basis of this, equipment is sent to maintenance facilities for major overhaul. Routine and medium equipment repairs are performed directly at their operational location as well as in special field maintenance shops.

Warranty procedures are an important measure to ensure reliable operation of communications and RTO equipment in the units. It is organized and conducted in conformity with rules and regulations. Principal measures pertaining to organization of repair of communications and RTO equipment are described in Table 7.4.

Table 7.4. Principal Measures Pertaining to Organization of Repair of Communications and RTO Equipment

1 Types of Repair of Communications and RTO Equipment and Their Content	Types of ZIP Employed in Performing Repairs 2	Procedure of Turning Communications and RTO Equipment in for Repairs and Obtaining Them Back 3		Organization of Minor and Medium Repair of Communications RTO Equipment 6	Warranty Claims Procedures 7
		Turning Communications and RTO Equipment in For Repairs 4	Obtaining Communications and RTO Equipment Back From Repairs 5		
The following kinds of repair are differentiated,	The following ZIP sets are employed in performing	After checking the technical state of communications and RTO	Repaired communications and RTO equipment shall	Military unit shops may be employed to perform minor	Warranties cover communications and RTO equipment,

Table 7.4 (cont'd)

1	2	3		6	7
		4	5		
depending on the nature of the malfunctions and damage, as well as technical state of equipment: A) minor -- minimal repairs the performance of which ensures normal operation of equipment until its next scheduled maintenance. With this category of repair, malfunctions are corrected and damage repaired on individual components, mechanisms, devices and units by replacing or adjusting them, for the purpose of restoring communications and RTO equipment to an operable condition. Minor repairs are performed at equipment operating locations by crew members, and when necessary by bringing in unit specialists. B) medium -- consists in	repair of communications and RTO equipment: A) single (ZIP-0) -- supplied with each piece of communications and RTO equipment and designated for keeping that piece of equipment in an operable state by replacement of malfunctioning components or performance of minor repairs. It is divided into emergency (ZIP-0-A) and station (ZIP-0-S). The emergency set is used for replacement of failed repairable and easily-removed nonrepairable components and is kept in the immediate vicinity of equipment. The remainder of ZIP-0 elements form the station set or kit. B) group (ZIP-G) -- provided	equipment, the need for repair is determined. When sending equipment for repairs, the following equipment is left in the unit: backup, auxiliary equipment and tools, portable test equipment, telephone sets, clocks and timers, entrenching and truck tools, typewriters and calculators, blowtorches, packing materials for electrolyte, water, oil and fuel, motor vehicle spare wheels. Communications and RTO equipment being sent for repairs should be given a thorough external cleaning, should be sent complete, all requisite documentation prepared, and be properly packed. Communications and RTO equipment means of transportation should be in good working	be sent by the repair enterprise to those units from which it was received. A duly-authorized unit representative shall check repair results, shall ensure that all equipment was returned, and shall take part in post-repair tests. Discovered deficiencies shall be corrected. Preparation of repaired equipment for shipment, packing, delivery to shipping points, loading and securing shall be performed by repair enterprise personnel. A unit representative shall be present during loading and shall personally verify that the means of transportation is fit for service, shall ensure that the	and medium repairs on communications and RTO equipment directly at their locations. These shops are assigned performance of the following: participation in performance of R-3, R-4, R-5, and R-6 inspection procedures, participation in minor repairs, performance of medium repairs on certain uncomplicated equipment and component parts, minor modification of equipment on the basis of information bulletins and efficiency innovation proposals, fabrication of auxiliary and other devices providing improved quality and faster servicing and repair of equipment. Shop facilities shall include the	separate pieces, items and units, sets of spare parts, tools and accessories both included with equipment and delivered separately, in which the following are discovered during delivery acceptance, storage, run-in, installation, testing or operation within the warranty period: missing items; improper wrapping, packaging and labeling; divergence of parameters from figures specified by standards and specifications if these parameters cannot be restored by adjustment as specified in operating instructions; premature wear and failure of equipment items, assemblies, units and

Table 7.4 (cont'd)

1	2	3		6	7
		4	5		
restoring the operational characteristics of equipment by repairing or replacing worn or damaged equipment components, with mandatory testing of the technical state of all other equipment components and performance of complete adjustment and tuning. Medium repairs are performed by unit specialists. C) major -- consists in complete disassembly and thorough inspection of equipment, repair or replacement of component parts, with subsequent testing and bringing performance characteristics up to standards, as well as complete, comprehensive checking of equipment parameters. Major repairs are performed at repair enterprises in conformity with their assigned equipment list.	separately from the equipment and designated for performance of minor and even medium repair of a group of equipment. It supplements the individual or single ZIP sets and equipment repair by replacement of failed components which are not part of the ZIP-0 set. C) overhaul (ZIP-R) -- supplied separately from equipment and designated for performing major (repair set No 1) and medium (repair set No 2) repairs on a piece of equipment or equipment group.	order and in full complement. The following documents are sent to the repair enterprise: repair work order, document stating condition of equipment and equipment list, complete set of servicing documentation, a statement on the condition of transport equipment, and a list of easily-removed motor vehicle parts. Equipment may be sent on its own vehicle, by rail, water or air transport. If repair of a given piece of equipment proves to be impossible or inadvisable, it shall be transferred to category 5.	equipment is firmly secured and shall inspect to ensure the presence of the requisite seals in conformity with accompanying documents. During repair of communications and RTO equipment, all built-in and attached test instruments shall be checked by the repair facility, regardless of their condition and time of performance of the most recent mandatory check. Repairs on all communications and RTO equipment are guaranteed for the specified warranty period.	following: mobile repair equipment, test instruments, equipment and devices indicated on the equipment list. In addition, a repair shop shall contain work stations for repairing equipment units and racks, work stations for performing general metalwork and machining, stations for checking and testing vacuum tubes, racks for holding repaired equipment and equipment received for repair, as well as cabinets (racks) for storing test equipment, tools, sets of spare parts, tools and accessories, consumable supplies, servicing and repair documentation.	parts, leading to loss of equipment operating efficiency; breakdown or loss of equipment efficiency through the fault of the manufacturer or designer. Warranty claims shall not be honored if restoration of equipment to proper operation can be achieved without breaking seals (by replacing failed parts, without soldering). A representative of the manufacturer shall be summoned by letter or telegram. A warranty claim document shall be drawn up by a commission with the participation of an enterprise representative (bilateral document).

Table 7.4 (cont'd)

1	2	3		6	7
		4	5		
Scheduled medium and major repairs are performed in conformity with equipment maintenance intervals and the actual technical state of equipment				Shop operations shall be conducted on the basis of monthly plans. Equipment received for repair shall be entered in a special log, and an appropriate entry shall be made in this log when the equipment is released	This document shall be submitted to the enterprise after it has been approved. Restoration of equipment to service shall be performed in the unit within the specified period of time. Work performed at the enterprise shall have a deadline specified by the enterprise director jointly with a representative of the customer

7.6. Storage of Communications and Radio-Radar Support Service Equipment

The principal condition ensuring continuous operational readiness of communications and RTO equipment throughout an entire period of storage is correct organization of safekeeping of equipment at storage facilities and in military subunits. Depending on storage specifications, communications and RTO equipment may be kept in heated and unheated areas, under shelter or in the open. Under field conditions equipment may be kept for a short time in temporary facilities under shelter, in dugouts or tents.

Communications and RTO equipment designated to reserve status, shall be placed in extended storage. It shall be maintained as a full set of equipment, in good working order, good for the required number of hours of operation to the next major overhaul. Equipment designated for extended storage shall be protected for storage by one of the following methods:

by sealing, employing moisture absorbing materials;

by sealing, employing moisture absorbing materials and general-purpose volatile inhibitors;

by greasing parts and items subject to corrosion.

Principal measures performed for correct organization of storage of communications and RTO equipment are described in Table 7.5.

Table 7.5. Principal Measures for Storage of Communications and RTO Equipment

Principal Measures Ensuring Safekeeping of Communications and RTO Equipment	Conditions of Storage by Types of Equipment and Elements		
	In Heated Facilities	In Unheated Facilities	Under Shelter and in the Open
Following are the principal measures ensuring safekeeping of communications and RTO equipment during storage: correct layout, equipping, content and utilization of storage facilities; quantitatively and qualitatively thorough procedures of receiving equipment for storage; correct placement and stowage of equipment during receiving and storage; establishment of normal conditions of storage for each type of equipment; correct selection of financially liable individuals; continuous monitoring of the technical and qualitative state of equipment; proper organization of general and fire security of storage facilities and observance of fire safety regulations. Communications and RTO equipment mounted on automotive chassis shall be stored at subunit motor pools (antenna taken down, equipment packed and secured.	The following should be stored in heated facilities: all principal communications and RTO equipment (radio transceivers, transmitters, receivers, radio-relay equipment, etc); sound recording and public address equipment; remote control and signaling equipment; vacuum tubes and semiconductor devices; charging and rectifying equipment; storage batteries, including electrolyte-filled and charged; rubber-insulation power and radio-frequency cables; ZIP for all types of equipment.	The following may be stored in unheated facilities: communications and RTO equipment antenna vehicles; power generators, power-supply units and internal combustion motors; transformers, hookup wire, coil wire, shielded wire and cable; acid and alkaline, dry and dry-charged batteries; wire-laying equipment; field line cable; insulation materials, industrial rubber products; paints and solvents; acids, alkalis and chemicals.	The following may be stored under shelter roofs and in the open: cable for buried communication lines; line equipment for building overhead and buried communication lines; equipment for mechanizing laying of communication lines; mobile light beacons. In field conditions (at maneuvers, exercises) communications and RTO equipment may be briefly stored in temporary facilities, under shelter roofs, in dugouts or tents. Under these conditions spare parts, supplies and tools shall be kept in separate crates if they are not placed inside the vehicle or equipment packing.

Communications and RTO equipment with packing crates shall be stored in subunit storerooms, while other equipment shall be stored in cabinets or on racks.

7.7. Servicing of Radio Communications and Radio-Radar Support Services Equipment by the Calendar-Parametric Method

The calendar-parametric method of servicing is a method whereby servicing is performed on a calendar schedule and depending on the actual technical state of radio equipment, determined by the values of monitored or tested parameters.

With this method, in the process of radio equipment operation, operating personnel check equipment parameters on a regular basis to see if they meet specified standards; if the checked parameters are within the specified limits, no servicing or maintenance is performed.

When a parameter exceeds the allowable limit, adjustment, tuning or repair or equipment is performed. Maintenance of a specified technical state of equipment assemblies and units the operating efficiency of which is not checked with the aid of testing devices shall be achieved by performing specific operations on a calendar schedule.

In conformity with the above, servicing of radio equipment by the calendar-parametric method is subdivided into daily servicing and calendar servicing.

Daily servicing includes the following:

external inspection of equipment for the purpose of spotting and preventing mechanical breakdowns (including checking to ensure equipment is securely mounted and checking tuning and control knob detents);

checking supply voltages for each phase and voltage at rectifier output;

comparison of the readings of the panel gauges of transmitting and receiving devices, as well as the position of tuning and control knobs with check list figures; when the checked parameter exceeds allowable limits, appropriate adjustment, tuning and repair are performed in order to bring parameters back within allowable limits;

inspection of transmission line and antenna mast equipment, for the purpose of discovering and preventing deviation of measured parameters and mechanical damage;

checking to ensure a supply of spare fuses of the proper ratings, as well as a check to ensure proper operating condition of telephone communications, fire extinguishing equipment, security alarms, blackout system, and operation of remote control devices.

Calendar servicing of radio equipment is performed in conformity with prior-specified regulations. The effectiveness of this method of servicing can be substantially increased by adopting improved methods of predicting gradual radio equipment failures. Experience in operating ground radio communications and RTO equipment indicates that the overwhelming majority of failures in this equipment are preceded by gradual deterioration of parameters, not by sudden changes. According to information in foreign publications, as many as

100 gradual failures occur for every sudden failure of permanent-location radio equipment: for ground radars there 91 gradual failures for every nine sudden failures.

Thus the primary task of the calendar-parametric method of servicing is a proper selection of predicted parameters. Obviously the selected parameters should fully characterize the capability of radio equipment to perform its tasks. It is essential that the number of parameters selected for predicting gradual failures be minimal.* The following can be selected, for example, for the transmitters of standard ground radio stations: radiated power, carrier frequency, and percentage of modulation of radiated signal.

The following failure prediction methods exist: functional, the characteristic indication method, high-speed, and extrapolation.

The functional method is employed in those cases where the law of change of predicted parameter П in time is known, that is, the analytical relationship of this function and the value of all its determining coefficients is known. Measured parameter П at moment in time t enables one to select a realization variant which characterizes a given concrete device. After this one can calculate a device's time to failure by solving the following system of equations:

$$\begin{cases} \Pi(t_1) = \Pi_0; \\ \Pi(t_{\text{отк}}) = \Pi_{\text{пред}}, \end{cases}$$

where $\Pi_{\text{пред}}$ -- level of failure (Figure 7.1).

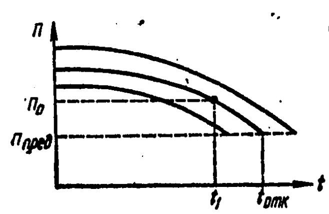

Figure 7.1. Dependence of Parameter П(t) for the Functional Method of Prediction

This method of prediction requires statistical data. The method of characteristic indication is based on knowledge of the behavior characteristics of function П=П(t) in a period of time preceding failure. At these moments function П=П(t) is characterized by a significantly faster rate of change, that is, large value of derivative $\frac{\partial \Pi}{\partial t}$. A substantial increase

* At the practical level selection of prediction parameters is defined as selection of monitored circuit points, that is, locations in the equipment where a given parameter is measured.

in $\frac{\partial \Pi}{\partial t}$, which can be observed in the process of development of failures, is utilized for predicting them. For example, an increase in a resistor's resistance value can indicate that it will soon fail.

High-speed methods of prediction are subdivided into prediction by change in tube plate current and transconductance and prediction on the basis of noise current or noise resistance value.

Experience in operation of radio electronic equipment indicates that for all tubes the ratio of emission current or transconductance and operating time with reduced heater voltage in the process of measurement is always greater than the same ratio measured at normal heater voltage. The greater the distance between normal and reduced heater voltage, the more the curves differ. These relations have made it possible to employ the following method of prediction. To test the quality of a tube, a reduced heater voltage is applied to it, and one of its parameters measured: mutual conductance or emission current. If with a reduced heater voltage the indicated parameter has a greater value than the level of tube efficiency in the given circuit, the tube is considered reliable and is not replaced. If the tube parameter lies below the efficiency level, it is replaced.

Difficulties in measuring tube mutual conductance and emission current directly in an operating circuit led to development of a method of predicting tube failures by the magnitude of their noise current or noise resistance ($R_{ш}$).

We know from noise theory that with a decrease in tube mutual conductance S its noise resistance should increase, since these parameters are interconnected by a ratio of the following type:

$$R_{ш} = \frac{2 \div 3}{S} \quad \text{--}$$

for triodes, and

$$R_{ш} = \frac{I_a}{I_k}\left(\frac{2.5}{S} + 20\frac{I_{g2}}{S^2}\right) \quad \text{--}$$

for pentodes, where I_a -- plate current, I_k -- cathode circuit current, I_{g2} -- screen grid current.

Experimental studies confirm this ratio. With a decrease in heater voltage, $R_{ш}$ will be significantly less than with normal heater voltage.

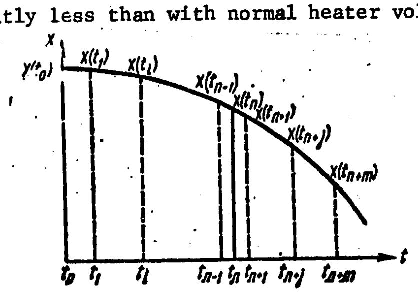

Figure 7.2. Relation of Parameter X(t) for the Extrapolation Method of Prediction

When a maximum value ($R_{ш\ пред}$) is reached, the tube is replaced. Noise resistances can be measured during operation.

The extrapolation method of prediction is based on observation of the behavior of the function X(t) at a certain interval t_0-t_{n+m} with change in the value of parameter X at several points (Figure 7.2).

Prediction of the value of $X(t_{n+m})$ can be performed as a result of calculation by Newton's interpolation formula:

$$X(t_n+mt_n)=X_n+m\Delta X_{n-1}+\frac{m(m+1)}{2!}\Delta X^2_{n-2}+\ldots+\frac{m(m+n+1)}{n!}\Delta X^n_0, \qquad (7.1)$$

where

$$\Delta X_0=X_1-X_0;\quad \Delta X^2_0=\Delta X_1-\Delta X_0;\quad \Delta X^k_0=\Delta X^{k-1}_1-\Delta X^{k-1}_0;$$

$$\Delta X_1=X_2-X_1;\quad \Delta X^2_1=\Delta X_2-\Delta X_1;\quad \Delta X^k_1=\Delta X^{k-1}_2-\Delta X^{k-1}_1;$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\Delta X_{n-1}=X_n-X_{n-1};\ \Delta X^2_{n-1}=\Delta X_n-\Delta X_{n-1};\ \Delta X^k_{n-1}=\Delta X^{k-1}_n-\Delta X^{k-1}_{n-1};$$

$$m=\frac{t-t_n}{t_n}.$$

On the basis of this formula one can solve the inverse problem -- determination of the number of prediction steps until failure occurs. For practical purposes we can recommend the following calculated expression:

$$m=\frac{-(5-6k_1+k_2)\pm\sqrt{(5-6k_1+k_2)^2-16(1-2k_1+k_2)(1-k_{доп})}}{2(1+2k_1+k_2)}, \qquad (7.2)$$

where

$$k_1=\frac{X_{n-1}}{X_n};\ k_2=\frac{X_{n-2}}{X_n};\ k_{доп}=\frac{X_{доп}}{X_n}.$$

Nomograms can be constructed for convenience of employment of formula (7.2). These nomograms present relations $m=f(k_{13}, k_2)$ for various $k_{доп}$.

7.8. Estimating the Operating Condition of Communications and Radio-Radar Support Services Equipment

An evaluation of the operating condition of communications and RTO equipment is performed as a rule on the basis of the following principal indicators:

1. A rating of "excellent" can be given if all equipment, power supply equipment, ZIP and other station equipment meets the following requirements:

a) the equipment is fully operable and is in operational readiness;

b) operating conditions of units and technical parameters as a whole meet standards;

c) there is no dirt, corrosion or mildew on parts and mechanisms;

d) all wooden and metal surfaces are painted (where necessary);

e) mechanisms and parts requiring lubrication are lubricated;

f) the state of station equipment meets technical safety requirements; the heating system meets fire safety requirements; safety and firefighting equipment is operable and in good order;

g) technical documentation is available and is being correctly maintained;

h) there is no missing spare equipment, test equipment and tools, and all items are in good working order;

i) power-supply units are in good working order;

j) DC and AC generators are working without malfunction, commutators and collecting rings are clean, without defects, and brush size and grades are correct for the given type of generator;

k) voltage regulators maintain stable voltage within allowable load limits;

l) all switches, controls, fuses and other devices are in good working order; fuses correspond to the proper ratings, and instrument readings agree with log figures and factory instructions;

m) truck and trailer running gear is properly balanced, wheels and cab windows are protected from damage and are intact:

n) power, radio-frequency and other cables are laid out in conformity with specified requirements;

o) station orientation or alignment errors do not exceed the maximum allowable.

2. A rating of "good" can be given if the same requirements are met as for a rating of "excellent," but lesser marks are given under points d, h, and j.

3. A rating of "satisfactory" is given if the same requirements are met for a rating of "good," but individual failings occur under points g, i, and n.

4. A rating of "unsatisfactory" is given with failure to meet points b, c, e, f, l, and o, regardless of whether the remaining points have been met.

7.9. Safety Measures in Operation, Servicing and Maintenance of Communications and Radio-Radar Support Services Equipment

General

All handling of communications and RTO equipment shall be performed in strict conformity with the requirements of current guideline documents on safety rules and procedures, and in conformity with the requirements of operating and servicing manuals. Observance of safety rules and procedures shall be mandatory in all cases, regardless of conditions and urgency of the job being performed. Following are the principal measures which ensure safe operation and servicing of communications and RTO equipment:

timely planning of measures to ensure safety of performance of all types of operations;

organization and execution of teaching personnel safe operation methods and clearing them for unsupervised handling of communications and RTO equipment;

instilling in personnel a feeling of responsibility for strict observance of safety rules and procedures on the job;

equipping of work stations with safety devices and maintaining them in good working order;

verification of organization of measures ensuring job safety, prompt investigation of accidents and injuries, and elaboration of measures to prevent same.

Personnel operating or servicing communications and RTO equipment must be familiar with and must strictly observe specified safety rules and procedures and must be able to administer first aid to casualties.

Teaching personnel safety rules and procedures shall be performed with the following types of briefings:

a) introductory briefing, performed for the purpose of acquainting newly-arrived personnel with safety rules in the unit area (airfield), as well as the dangers which can arise during operation and servicing of communications and RTO equipment; this briefing shall be given by a safety inspector or other person designated by appropriate order;

b) briefing at work station is performed for the purpose of study, reinforcement and testing of knowledge on safe work procedures at a given work station; this briefing (primary and periodic) shall be given by the subunit commander individually with each man at his work station in conformity with current regulations;

c) briefing before work begins (daily) is performed for the purpose of reminding personnel of the principal rules and procedures of safe job performance (stressing the most dangerous operations) and procedure of employment of protective devices in emergency situations; this briefing shall be given by the immediate superior or work supervisor;

d) unscheduled briefing is performed when changes are made in instructions and operational sata, at the request of inspecting personnel, as well as in cases of violation of safety regulations and procedures.

Personnel shall be permitted to operate and service communications and RTO equipment power generating equipment upon earning an electrical safety qualification group designation (from I through V), in conformity with current regulations.

Qualification group I is designated following the introductory briefing and primary briefing at the work station, without indicating authorization to operate and service. Award of the remaining qualification groups (from II through V) shall be made by a commission for authorization for unsupervised operation and servicing of communications and RTO equipment, or by a specially appointed qualification commission.

Commissions consist of three persons possessing qualifications not below group V or IV (one commission member is a power supervisory inspector). It is empowered to award a qualification group not higher than that possessed by its members. Test results shall be formally recorded in the safety regulations and procedures knowledge test log; at the same time the individual shall be certified in writing as authorized to operate and service communications and RTO equipment.

Persons who have violated current safety regulations and instructions shall be specially tested.

The following should be present at all times with communications and RTO equipment: instructions of safety regulations and procedures, requisite protective devices, accident prevention posters, fire extinguishing equipment, tools and devices ensuring work safety.

Danger of Electric Shock

Electric current, affecting the human organism, leads to various impairment of functions. For example, with a current of 1-3 milliamperes, one feels a slight tickling on the skin of fingers touching a wire. With a current of 3-5 ma, the entire hand feels a stimulating sensation; a current of 8-10 ma, alongside strong irritation of sensitive nerves, causes involuntary contraction of the muscles of the hand and wrist. With a current of 15 ma involuntary muscular contractions increase, and it becomes impossible to unclasp the hand: the victim seems to be securely gripped to the wire (a current of this force is called "nonreleasing" in medicine). The effect of such current is initially not potentially lethal, but when the victim remains longer in contact with the electrical circuit, the effect of the current intensifies as a result of decreased resistance of the body due to electrical breakdown of the skin or perspiration. Application of a stronger current (25-50 ma) causes convulsive contraction not only of the muscles of the hands and arms but also of the trunk, including the chest muscles, which take part in the breathing process. This effect of current leads to difficulty or cessation of breathing. The irritating effect of a current of 25-50 ma causes narrowing of the blood vessels and consequently increase in arterial pressure and makes it more difficult for the heart to work (the victim loses consciousness, and death may occur.

The amount of current passing through the organism is determined both by circuit voltage and by body resistance, which differs with dry and damp skin. Consequently the degree of affection will also vary.

The most frequent cause of injury by electrical shock is accidental contact with just one conductor, directly connected to a live circuit. Serving as ground is the earth (or floor) on which the victim is standing, the cases of electrical instruments, apparatus, water and sewer pipes, as well as any other metal objects in electrical contact with the earth. High-voltage shock can occur without direct contact with a conductor, across a spark gap when one is close to a conductor. Injury by shock can also occur upon contact with an object which is not part of the power line or generator unit but which is in contact with them as a result of malfunctions in electrical generating equipment.

In order to avoid injury by electric shock it is necessary thoroughly to learn safety regulations. Table 7.6 contains the principal safety regulations pertaining to operating and servicing various radio and electrical equipment.

Table 7.6. Safety Rules

1 General Rules	2 When Operating or Servicing Radio-Radar Equipment	When handling or Servicing Power-Supply Units 3	4 When Handling or Servicing Storage Battery Equipment	5 When Handling or Servicing High-Voltage Power Generating Equipment (Above 1000 Volts)
1. Facilities should be provided with safety equipment (rubber mats, grounded discharge rods, insulating boots, rubber gloves, protective goggles, tools with insulated handles, etc). They should all be tested for insulation capability. 2. When equipment is on, it is prohibited to: connect and disconnect cables and wires; remove units and replace tubes and fuses; perform soldering and rewiring; artificially close block contacts; inspect and repair equipment when power is on. 3. Protective grounding shall be provided on all facilities with voltages of 115 volts and more. All	1. The following requirements must be observed: energize equipment only after thoroughly verifying that lightning arrestors and grounding devices are in proper working order; do not touch wires and waveguides of the antenna and earth screen of an operating station; use caution and wear protective goggles when replacing cathode-ray tubes; wear rubber gloves when opening up high-voltage units; after unit is opened, all high-voltage components should be discharged with a grounded rod.	1. All power generating equipment shall meet the following requirements: electric motor generator winding and inverter leads, as well as rotating parts of machinery shall be securely covered; insulation shall be placed between leads under voltage and protective covers; it is prohibited to remove protective covers when equipment is operating; generator,	1. The following requirements should be observed in battery rooms: suction-and-exhaust ventilation is mandatory; it is prohibited to clutter aisles with any objects; smoking and eating are forbidden; acid and alkaline batteries should be housed separately (in different rooms).	1. The following equipment at power generating plants and substations must be grounded: housings of generators, transformers, oil circuit breakers, etc; leads of electrical disconnectors; secondary windings of current and voltage transformers; distribution board and control panel frames; metal structures, cable boxes, cable terminal cases, metal cable sheathing.

Table 7.6 (cont'd)

1	2	3	4	5
metal structures shall be securely grounded (by bolted connection, welding or soldering). Grounding device resistance shall not exceed 25 ohms for mobile equipment and shall not exceed 10 ohms for stationary facilities. 4. When working on metal structures with electric hand tools, the tool housing must be connected by wire to the body of the metal structure. During operation the tool power cable must not come into contact with hot surfaces or with surfaces coated with petroleum products. Electric tools used in damp and crowded quarters shall not operate at a voltage greater than 36 volts. 5. In performing all types of control operations or during equipment maintenance one must: disconnect from all power sources; make sure that there is no voltage on the de-energized equipment (with the aid of a test bulb or voltmeter). 6. The following operations may be performed on energized equipment: cleaning and wiping cabinets; replacement of burnt-out fuse cartridges.	2. The following are essential when working on antennas and antenna masts: servicing personnel shall be raised to masts by winch or hoist only after checking for proper operating condition the braking mechanism, brake band, cable integrity, and solid securement of hoist and hoist cradle; do not release the winch handle until hoisting is completed; mast servicing is prohibited during thunderstorms, during high winds, icing and heavy rain; transmitting and receiving antennas which are not operating shall be grounded (HF and MF bands). 3. Personnel are prohibited from working in fields of strong microwave radiation. When such work must be done, personnel should wear protective suits and masks and should employ absorbing and shielding coatings. Motor vehicle bodies, working and living quarters should be equipped with absorbing and shielding materials, which reliably protect personnel	electric motor, inverter and starter housings shall be reliably protected and grounded. 2. The following is essential during performance of equipment servicing and maintenance: electric motors, generators, inverters, gasoline and diesel motors shall be shut down; commutators shall be cleaned and dressed and slip rings polished on rotating equipment only at reduced rpm; when performing these operations one should wear protective goggles and display particular caution; no loose clothing should be worn, and sleeve cuffs should be securely buttoned; personnel must	2. Storage batteries should be serviced by persons with a qualifications group not below III. All battery servicing and maintenance operations should be performed by personnel wearing rubber aprons, gloves and protective goggles. 3. When preparing electrolyte one should first pour the water and then gradually add acid (alkali), continuously mixing the solution with a glass rod, keeping the solution from excessive heating. An open flame is prohibited in the vicinity of a storage battery during charging. 4. The door to a battery room should carry the following warnings:	2. The following rules must be observed during routine servicing of high-voltage electric power equipment: do not go beyond protective barriers or enter distribution system (RU) rooms without protective barriers; upon discovery of grounding of any high-voltage current-carrying element, personnel approaching the damage location must wear rubber boots, gloves and an insulating rod (as a rule one may approach to a distance of not less than 4-5 m); routine switching should be performed in rubber gloves, with the aid of an insulating rod, and mandatorily with a second person present. Installation and removal of

Table 7.6 (cont'd)

1	2	3	4	5
These operations must be performed with observance of safety procedures (employing safety goggles, insulating gloves, rubber boots, insulating mats).	from excessive levels of microwave radiation. 4. Exhaust gases from operating engines, fuel and lubricant vapors, and carbon monoxide fumes from heating equipment shall not be permitted to enter equipment rooms, working and living quarters. The latter shall be continuously aired, and if necessary they shall be equipped with forced-air ventilation	wear insulating gloves when taking up, deploying and moving portable connecting cable lines carrying current. 3. Foreign objects which can cause short circuiting should not be allowed in the vicinity of electric motors, converters, and generators. Knife switches and all other switching equipment should be protected against accidental contact with their current-carrying components.	DO NOT ENTER WITH FLAME, EXPLOSION HAZARD	fuses in circuits with voltage exceeding 1000 volts shall be performed with the aid of insulated pliers. 3. The following rules shall be observed when performing servicing and maintenance of high-voltage equipment: work on high-voltage electric power equipment shall be done on the basis of work orders specifying location, time, job conditions, composition of work team and persons responsible for job safety; jobs by work order shall be performed by not less than two persons assigned to the given equipment; when readying a work station, perform the requisite disconnections and take measures preventing voltage from being mistakenly applied to the work location. 4. Work with high voltage should be performed under the supervision of a responsible individual (work foreman or superintendent). The latter may not combine supervision with other tasks. Duty personnel are prohibited from making any changes in the power equipment circuits without the knowledge of the job supervisor if such changes would alter the working conditions specified in the work order from the standpoint of safety rules.

Chapter 8. ELECTRICAL MEASUREMENTS EMPLOYED IN COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

8.1. Principal Data on Metrological Support in Communications and RTO Units

Metrology, in the general definition of the term, is the science of measures. Its principal tasks are establishment of units of measurement, reproduction of these units of measurement in the form of highly-accurate specimens (standards), and elaboration of methods of precise measurement. Metrological support activities are conducted in the military for the purpose of practical implementation of the principal tasks of metrology.

Metrological support is an aggregate of organizational-technical measures directed toward ensuring uniformity and reliability of measurement of the parameters of communications and RTO equipment, with the objective of maintaining combat readiness and effectiveness of utilization of this equipment at the required level.

All test equipment employed at all stages of operation and maintenance of communications and RTO equipment is encompassed by a single common term -- technical monitoring means (TSK), regardless of the place of their employment, principle of construction and mode of employment.

All technical monitoring means designated for monitoring specific items and built as a single unit are called "special instruments" (PS). If they are all contained in an aggregate of test instruments, they are called "monitoring and testing equipment" (KPA).

All technical monitoring means employing the principle of automatic monitoring of parameters are called automatic. In conformity with this we differentiate between special automatic instruments (APS) and automatic monitoring and testing equipment (AKPA). Technical monitoring means designed on the principle of test equipment and servicing-maintenance consoles designed for testing and tuning individual items, units, channels, etc, are called servicing-maintenance panels or consoles (ERP). General-application technical monitoring means are subdivided into:

electrical testing instruments (EIP);

radio measurement instruments (RIP);

other measuring instruments (designated by the letter П, followed by the capital letters of the quantity to be measured).

All measuring devices and test circuits designed to monitor the parameters of communications and RTO equipment and built directly into the monitored equipment are called "built-in monitoring" (VK) equipment. The monitored parameters and their extent are determined proceeding from stages of operation and maintenance in the process of which these parameters are monitored. Servicing and maintenance of ground communications and RTO equipment is broken down from the standpoint of inspection monitoring into the following stages:

prior to operation;

during operation;

during daily equipment check;

during weekly equipment inspection check;

during monthly equipment inspection;

during quarterly equipment operation inspection;

during semiannual equipment operation inspection;

during annual equipment operation inspection;

during inspection in the process of changing over from summer to winter operations and vice-versa.

General requirements on test measurement of parameters for all the above stages of servicing and maintenance are as follows:

minimum volume of tested parameters and quantity of utilized technical monitoring means;

checking operation of all units and equipment as a whole without emitting signals into the air.

Signal power level across dummy loads and absorbing screens should not exceed the figures specified in current standards as regards requirements on communications security, blackout and noise concealment.

Operation tolerances of two types are established for equipment parameters:

operational monitoring tolerance $\delta_{эк}$ (indicated on servicing cards on the basis of which equipment setup is performed);

Operation preventive maintenance tolerance $\delta_{\text{эп}}$ (indicated on servicing cards used for performing tuning and adjustment operations).

If the measured value of a parameter is beyond the limits of tolerances $\delta_{\text{эк}}$ or $\delta_{\text{эп}}$, the piece of equipment is considered failed, and the event corresponding to this -- failure.

A most important characteristic of results of test measurements is reliability, which expresses the property of information during inspection, reflecting the actual state of the inspected item. We differentiate method reliability and instrumental reliability.

Method reliability characterizes the degree of adequacy of information taken from the inspected item with selected methods and technical monitoring means for evaluating its technical state. Method reliability is estimated quantitatively by coefficient $k_{\text{МД}}=\frac{n}{N}$ (N -- total number of inoperable states of the tested item, n -- total number of inoperable states of this item discovered by monitoring means).

Value $k_{\text{МД}}$ should comprise:

during preliminary preparation of equipment $\geqslant$ 0.8;

during performance of adjustment procedures $\geqslant$ 0.95.

Instrumental reliability characterizes the degree of conformity between test results and the actual state of the equipment. Quantitatively this reliability is estimated by the probability of undetected malfunctions $P_{\text{НО}}$ (error of the first category) and probability of spurious malfunction $P_{\text{ЛО}}$ (error of the second category).

If a testing device measures more than one parameter, instrument reliability is characterized by the allowable probability of occurrence of a spurious failure in at least one parameter:

$$P_{\text{ЛО}\,\Sigma} = 1 - \prod_{i=1}^{m}(1 - P_{\text{ЛО}\,i}), \qquad (8.1)$$

where $P_{\text{ЛО}i}$ -- value of probability $P_{\text{ЛО}}$ when checking i parameter; m -- number of checked parameters.

The overall allowable value of quantity $P_{\text{ЛО}}$ when checking the parameters of communications and RTO equipment should not exceed 0.1. Of great importance in metrology is the question of standardizing test equipment. All employed measuring instruments are characterized by largest allowable basic errors under normal conditions and greatest allowable secondary errors.

Basic error is error inherent in an instrument operating under normal conditions. Normal conditions are those where ambient temperature is +25±10°C, relative humidity 65±15% (at a temperature of +25±5°C), and atmospheric pressure 750±30 mm Hg.

Secondary instrument error is an error which occurs with deviation of one or several influencing factors from normal or from operating conditions.

Normal instrument operating conditions are conditions whereby the greatest values of these types of error do not exceed allowable values in probability of spurious malfunction $P_{\text{лп}}$ of the item being tested ($P_{\text{лп}}$ is indicated in the specifications and technical description of a piece of equipment).

Technical monitoring means (TSK) should meet certain reliability requirements. Following are the principal criteria: operating time to failure T and probability T(t) that metrological (accuracy) characteristics will remain within specified limits during required time t. Table 8.1 contains operating time to failure for instruments employed to test communications and RTO equipment [12].

Table 8.1.

Degree of Complexity of TSK	T, hours
Simple instruments (number of components in circuitry approximately 500)	Not less than 2000
Instruments of medium complexity (number of components in circuitry approximately 1000)	Not less than 1500
Complex instruments (number of components in circuitry approximately 2000)	Not less than 1000

Quantity T includes duration taking into account sudden and metrological malfunctions. Probability that metrological (accuracy) characteristics P(t) will be retained is estimated for the period between regular mandatory TSK checks.

8.2. Measurement Errors

Any measurement, no matter how painstakingly it is performed, is accompanied by errors. They are subdivided into three groups according to the criterion of pattern of occurrence:

1. Systematic errors, which remain constant or varied in the process of measurement according to a specific pattern. They are divided into instrument errors, which occur as a consequence of limited instrument accuracy; subjective, which occur as a consequence of imperfect sensory organs of the observers; external, which occur as a consequence of changes in environment parameters (temperature, humidity, pressure, etc), and errors of method, caused by imperfection of method or incomplete knowledge of all circumstances attending a given measurement.

These errors affect the correctness of performed measurements. They should be eliminated by eliminating their causes or by introducing corrections.

2. Random errors, which inevitably arise with all types of measurements, exert considerable influence on their accuracy. They are taken into account analytically by determining root-mean-square calculated error of mean arithmetic value

$$\sigma_p = \pm \sqrt{\frac{\sum_{i=1}^{n} \varepsilon_i^2}{n(n-1)}}, \qquad (8.2)$$

where $\varepsilon_i = a_i - a_{cp}$ -- residual error; a_i -- instrument reading; a_{cp} -- arithmetical mean of a number of measurements

$$a_{cp} = \frac{\sum_{i=1}^{n} a_i}{n};$$

$\sum_{i=1}^{n} a_i$ -- sum of separate measurements of one and the same quantity; n -- number of repeated measurements.

3. Gross errors resulting from measurement errors. A measurement where $\varepsilon_i > 3\sigma_p$ is considered a gross error. These errors should be discarded; their absence determines validity of measurements.

The following indicators are used for quantitative evaluation of measurements: absolute error, relative error, and reduced error.

Absolute error of measurement Δ is expressed as the difference between instrument reading a_i and the actual value of the measured quantity x, that is,

$$\Delta = a_i - x. \qquad (8.3)$$

In this instance correction is defined as absolute error taken with reverse sign:

$$-\Delta = x - a_i, \qquad (8.4)$$

Relative error is expressed (as a percentage) by the ratio of absolute error to the actual value of the measured quantity, that is,

$$\delta = \frac{\Delta}{x} 100 = \frac{\Delta}{a_i} 100. \qquad (8.5)$$

With a sufficiently small quantity, it is convenient to express relative error directly in relative quantities, such as $\pm 5 \times 10^{-4}$.

Relative error can also be expressed in decibels:

$$\delta = 10 \lg \left(1 + \frac{\delta}{100}\right). \qquad (8.6)$$

Table 8.2 contains relative error values which are frequently encountered in practice.

Table 8.2

δ, %	0,2	2,3	3,5	4,7	12,2	20,2	25,9	31,8	41,3
δ, дБ	0,01	0,1	0,15	0,2	0,5	0,8	1,0	1,2	1,5

Reduced error is expressed (as a percentage) by the ratio of absolute error to the upper (nominal) value a_H of the readings of a given instrument, that is,

$$\delta_{пр} = \frac{\Delta}{a_н} 100. \qquad (8.7)$$

with direct, one-time measurements, for estimating error one utilizes error specified in the test instrument's operating and servicing manual.

With indirect measurements, when the result is determined by means of calculations on the basis of direct measurements of auxiliary quantities, error is estimated with the formula

$$\delta = \pm \sqrt{\sum_{k=1}^{m} \delta_k^2}. \qquad (8.8)$$

where δ_k -- error of measurement of one of m auxiliary quantities.

For example, in measuring voltage with a vacuum tube voltmeter with a voltage divider let there be two independent errors: basic error δ_0 (±3% of the upper limit of the 500 volt scale) and voltage divider error $\delta Д$ (±2% of the measured quantity at 400 volts). These errors and the total error will be equal to:

$$\delta_0 = \pm \frac{3 \cdot 500}{100} = \pm 15 \text{ V}; \quad \delta_д = \pm \frac{2 \cdot 400}{100} = \pm 8 \text{ V};$$

$$\delta = \pm \sqrt{\delta_0^2 + \delta_д^2} = \pm \sqrt{15^2 + 8^2} = \pm 17 \text{ V}.$$

The result of measurement in this example will be written as E=400±17 V.

8.3. Technical Standards and Measurement of Principal Parameters of Communications and Radio-Radar Support Services Equipment

During servicing and maintenance of radio communications and RTO equipment it becomes necessary to measure the values of a number of equipment electrical parameters for the purpose of determining their conformity with specified standards. The degree of divergence of parameters from these standards in the process of operation influences the nature and type of servicing. Quantitative characteristics of technical standards for radio transmitting, radio receiver and antenna-transmission line devices are contained in Table 8.3 [12].

Table 8.3. Technical Standards of Principal Parameters for Radio Transmitting, Radio Receiving and Antenna-Transmission Line Devices

Parameter and Its Definition 1	Method of Measuring Parameter 2	Allowable Deviations of Measured Parameter 3	Remarks 4
	Radio Transmitters		
Rated transmitter output, that is, the power a transmitter can put at a given frequency into a matched load (determined by the type of transmitter and established by the manufacturer)	Measurement of output power is performed as follows: VHF-UHF transmitters -- by type IBM-1 high-power meters or similar instruments; HF transmitters -- photometrically.	The readings of final-stage instruments and transmission line indicators should agree with tuning	Transmitter rated ouput is checked not less than once each year, and in addition

Table 8.3 (cont'd)

1	2	3	4
	Transmitter power is continuously monitored by control console instruments	table figures, with the following tolerances: for grid current ±20%; for general cathode current from -20% to +10%; for current in transmission line or voltage at transmission line input (from the average value of both indicators) ±10%	after each occasion transmitter repairs are performed
Transmitter frequency stability; characterized by frequency deviation from a specified value in relation to operating band, not to exceed the amounts specified in Table 8.4	Frequency stability is checked with a frequency meter. Frequency stability is checked when tuning transmitters to the operating frequency	Allowable deviations for transmitters of all categories are listed in Table 8.4	
Requisite bandwidth, that is, the minimum bandwidth, adequate with a given type of radiation to ensure transmission of messages at a rate and with the quality required for a communications and RTO system under specified conditions	Test equipment consists of a radio receiver of the appropriate band (with a passband adequate for the bandwidth to be checked), a heterodyne frequency analyzer connected to the receiver intermediate-frequency stage, and an oscilloscope connected in parallel to the heterodyne frequency analyzer or to the output of the receiver's amplitude detector. The oscilloscope is used to analyze the signal waveform and to set zero metering level at the level of the unmodulated (unkeyed) carrier by means of preliminary measuring equipment calibration from the high-frequency local oscillator.	Table 8.5 lists requisite frequency bandwidth standards for various classes of emissions	Receiver passband and frequency analyzer band coverage width should be broader than the calculated values of the requisite bandwidth: fivefold for emissions of Type A1, threefold for A2, and 1.5-2-fold for all others

Table 8.3 (cont'd)

1	2	3	4
Occupied emission bandwidth, that is, emission bandwidth including allowance for expansion beyond standard required bandwidth	Measured in the same way as for the requisite emission bandwidth: $B_{зан} = B_H(1+\Delta B)$, where $B_{зан}$ -- occupied band, Hz; B_H -- requisite bandwidth, Hz; ΔB -- allowance for increasing bandwidth	Table 8.5 contains standards for occupied frequency bandwidth	
Power of spurious emissions, which can be generated in a transmitter simultaneously with rated power	Measurement is performed by the substitution method. The transmitter being tested is switched on at rated power output. Spurious emissions field intensity is measured with the aid of a test receiver, interference measuring equipment or comparator circuits. Then the transmitter is switched off, and an auxiliary signal generator is connected to the transmission line, tuned to the spurious emission frequency and output power adjusted until field intensity at the same test point is equal to the transmitter field intensity at the spurious emission frequency. In this case spurious emission power of the transmitter being tested is equal to the power output of the auxiliary oscillator (assuming constant amplification of the test receiver)	Table 8.6 contains spurious emission standards for radio transmitters of various categories and functions. Spurious emission field intensity measured at a distance of 100 km and more from the transmitter should not exceed: 2 microvolts/m at frequencies below 465 kHz; 1 microvolt/m -- 30 MHz at 465 kHz. At frequencies above 30 MHz (at any distance from the transmitter), field strength of spurious emissions should be 60 db below emission at the fundamental frequency	
Non-linear harmonic distortion coefficient, that is, a quantity characterizing divergence of the waveform of the modulating signal at the transmitter output from its waveform at input	It is determined from non-linear distortion meter readings or from an amplitude characteristic obtained with the aid of a modulation meter and an audio frequency generator	The non-linear harmonic distortion coefficient is determined at a frequency of 400 Hz at 90% modulation and should be not more than 10% with these conditions	Testing of the non-linear harmonic distortion coefficient is performed once a year

Table 8.3 (cont'd)

1	2	3	4
Frequency characteristic, that is, characteristic in the band of frequencies specified in the transmitter's operating and servicing data	Obtained by type KIS-2 test equipment rack instruments or with the aid of an audio frequency generator and modulation percentage meter. A voltage is applied from the audio frequency generator to the modulator input at a frequency of 1000 Hz, at a level establishing modulation at 50%. Keeping this level constant, generator frequency is changed within specified limits at 100 Hz intervals, measuring percentage of modulation. A frequency characteristic curve is plotted from these measurements, from which one determines deviation of the level at extreme frequencies at the level corresponding to a frequency of 1000 Hz. This deviation should be within specified limits	Deviation from a level corresponding to a frequency of 1000 Hz at 50% modulation should not exceed 40% (by ±3 db)	Frequency characteristic is checked once a year
Noise background level, that is, parasitic low-frequency modulation	Noise background level is measured with the aid of a modulation meter, output indicator, and audio frequency generator. Two measurements are taken to determine noise background level: the first -- at a modulation frequency of 1000 Hz with an output meter connected to the output terminals of a modulation meter (one determines output voltage corresponding to 100% transmitter modulation), and the second -- with the audio frequency generator disconnected, with one carrier frequency (one determines voltage E_{oct}, corresponding to parasitic modulation). Noise background level is determined as the ratio $\frac{E_{oct}}{E_{100\%}}$, expressed in decibels, or as the ratio $\frac{E_{oct}}{E_{100\%}}$ 100, expressed as a percentage	The noise background level should not exceed: 40 db or 1% during frequency-shift keying; 25 db or 5% during amplitude manipulation; 40 db or 1% during telephony operation	Noise background level is checked once a year
Frequency deviation, that is, the greatest divergence of frequency from a mean value	Checked with a wavemeter or with the aid of a first-class radio receiver	The greatest frequency deviation from a mean value should not exceed 5%	Frequency deviation is checked once each duty shift

Table 8.3 (cont'd)

1	2	3	4
Signal waveform distortions, that is, distortions caused by transient processes during amplitude manipulation	Checked with the aid of an oscillograph	Distortions should not exceed 15%. The telegraph signal waveform should be correct, with a steep and uniform (without discontinuities) leading and trailing edge	Signal quality is checked with the aid of an oscillograph when preparing monitoring data
	Radio Receivers		
Sensitivity, that is, the ability of a radio receiver to receive with minimal signal voltage at input, providing normal output power or voltage and a specified signal-noise ratio. Input voltage is determined by type of radio receiver and is established by the manufacturer	Measured with the aid of a standard signal generator, output meter and audio frequency generator at three frequencies in each sub-band -- a mid, an upper and lower frequency. The upper and lower frequencies should be located 10% from the edge of the sub-band.	Maximum allowable worsening of sensitivity during receiver operation is 20%	Sensitivity is checked once a year, as well as whenever one can aurally detect a decrease in the received signal level and an increase in the receiver noise level
Passband, that is, that band of frequencies at the boundaries of which sensitivity drops to 50% of that at the resonance frequency	During measurement the noise limiter and AGC circuits are disconnected. The intermediate and low frequency passband controls are set to the narrowest passband, while the low-frequency gain control is set for maximum gain. Measured with a standard signal generator and output meter	Deviation from standard specified by manufacturer should not exceed 10%	The passband check is performed once a year
Internal noise level, that is, output voltage with shorted radio receiver input terminals. Determined by the class of radio receiver and specified by the manufacturer			Internal noise level is checked once a month, as well as whenever there occurs a noise level increase apparent to the ear
	Antenna-Transmission Line	Equipment	
Transmission line traveling wave ratio (KBV) $K_б$, characterizing its operating conditions, is	Measured with a type INF-1 measuring loop	Traveling-wave ratio should be: not less than 0.65 for standard	Traveling-wave ratio is checked during initial

Table 8.3 (cont'd)

1	2	3	4
determined as the ratio of voltage E_y at the node to voltage $E_п$ at the loop: $K_б = \frac{E_y}{E_п}$		ground station antenna (permanent site); not less than 0.3 for broadband antennas	transmitter tuning to operating frequency and each time following antenna or transmission line maintenance
Antenna-transmission line system coefficient of asymmetry δ_a, characterizing its geometric symmetry, is determined with formula $\delta_a = \frac{V_1 - V_2}{V_1 + V_2}$, where V_1 -- potential of one transmission line conductor at loop, B; V_2 -- potential of other transmission line conductor at same section, V	Measurement of potential V_1 and V_2 is performed by a type INF-1 measuring loop	Coefficient of asymmetry should not exceed: 10% for transmitting antennas; 5% for receiving antennas	Coefficient of asymmetry is checked following antenna maintenance
Antenna-transmission line system insulation resistance is measured relative to transmitter connection points	Resistance is measured at transmission line input	Resistance should satisfy the following inequalities: in dry weather: $R > \frac{1000}{l_ф + 50}$; in damp weather: $R > \frac{100}{l_ф + 50}$, where R -- antenna-transmission line system insulation resistance, ohms; $l_ф$ -- length of transmission line, m	Checked twice a year (spring and fall), and after every thunderstorm

National standards have been established for the most important radio communications and RTO equipment parameters affecting their electromagnetic compatibility during combined operation. These include the following standards: allowable transmitter frequency deviations (Table 8.4), frequency bandwidth for various classes of emissions (Table 8.5), and spurious emissions power for transmitters of all categories and functions (Table 8.6).

Table 8.4. National Standards for Allowable Frequency Deviations for Radio Transmitters of All Categories and Functions [17]

1 Категории радиостанций	2 Допустимые отклонения частоты (в миллионных долях от частоты (N · 10⁻⁶) или в герцах) — 3 Полоса частот (включая верхний и исключая нижний пределы): 10—535 кГц I	10—535 кГц II	535—1605 кГц I	535—1605 кГц II	1605—4000 кГц I	1605—4000 кГц II	4—29,7 МГц I	4—29,7 МГц II	29,7—100 МГц I	29,7—100 МГц II	100—470 МГц I	100—470 МГц II	470—2450 МГц I	470—2450 МГц II	2450—10 500 МГц I	2450—10 500 МГц II	10,5—40 ГГц I	10,5—40 ГГц II
Фиксированные станции: (4)																		
— в полосе 10—50 кГц;	1000	10 Гц	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
— в полосе 50—535 кГц;	200	10 Гц	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
— мощностью 50 Вт и менее;	—	—	—	—	—	—	—	—	—	—	50	20	—	—	—	—	—	—
— мощностью более 50 Вт;	—	—	—	—	—	—	—	—	—	—	20	10	—	—	—	—	—	—
— мощностью 100 Вт и менее;	—	—	—	—	—	—	—	—	—	—	—	—	300	50	300	50	—	—
— мощностью более 100 Вт;	—	—	—	—	—	—	—	—	—	—	—	—	100	50	100	50	—	—
— мощностью 200 Вт и менее;	—	—	—	—	100	50	—	—	50	20	—	—	—	—	—	—	—	—
— мощностью более 200 Вт;	—	—	—	—	50	20 Гц	—	—	30	20	—	—	—	—	—	—	—	—
— мощностью 500 Вт и менее;	—	—	—	—	—	—	50	50 Гц	—	—	—	—	—	—	—	—	—	—
— мощностью более 500 Вт	—	—	—	—	—	—	15	20 Гц	—	—	—	—	—	—	—	—	—	—
Сухопутные станции (5)																		
— мощностью 15 Вт и менее;	—	—	—	—	—	—	—	—	50	30	—	—	—	—	—	—	—	—
— мощностью более 15 Вт;	—	—	—	—	—	—	—	—	20	10	—	—	—	—	—	—	—	—
(6) а) береговые станции:																		
— мощностью 200 Вт и менее;	500	500	—	—	100	100	—	—	—	—	—	—	—	—	—	—	—	—
— мощностью более 200 Вт;	200	200	—	—	50	50	—	—	—	—	—	—	—	—	—	—	—	—
— мощностью 500 Вт и менее;	—	—	—	—	—	—	50	50	—	—	—	—	—	—	—	—	—	—
— мощностью более 500 Вт (до 5000 Вт);	—	—	—	—	—	—	30	30	—	—	—	—	—	—	—	—	—	—
— мощностью более 5000 Вт	—	—	—	—	—	—	15	15	—	—	—	—	—	—	—	—	—	—
(7) б) стационарные станции воздушной подвижной службы:																		
— в полосе 10—535 кГц;	100	50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
— в полосе 100—470 МГц;	—	—	—	—	—	—	—	—	—	—	50	20	—	—	—	—	—	—

Table 8.4 (cont'd)

1 Категория радиостанций	2 Допустимые отклонения частоты (в миллионных долях от частоты ($N \cdot 10^{-6}$) или в герцах) 3 Полоса частот (включая верхний и исключая нижний пределы) 10—535 кГц I	10—535 кГц II	535—1605 кГц I	535—1605 кГц II	1605—4000 кГц I	1605—4000 кГц II	4—29,7 МГц I	4—29,7 МГц II	29,7—100 МГц I	29,7—100 МГц II	100—470 МГц I	100—470 МГц II	470—2450 МГц I	470—2450 МГц II	2450—10 500 МГц I	2450—10 500 МГц II	10,5—40 ГГц I	10,5—40 ГГц II
— мощностью 500 Вт и менее;	—	—	—	—	100	20Гц	100	10 Гц	—	—	—	—	—	—	—	—	—	—
— мощностью более 500 Вт	—	—	—	—	50	20Гц	50	10 Гц	—	—	—	—	—	—	—	—	—	—
в) базовые станции:(8)																		
— мощностью 5 Вт и менее;	—	—	—	—	—	—	—	—	—	—	50	20	—	—	—	—	—	—
— мощностью более 5 Вт;	—	—	—	—	—	—	—	—	—	—	20	10	—	—	—	—	—	—
— мощностью 500 Вт и менее;	—	—	—	—	—	—	100	30	—	—	—	—	—	—	—	—	—	—
— мощностью более 500 Вт	—	—	—	—	—	—	30	10	—	—	—	—	—	—	—	—	—	—
Подвижные станции: (9)																		
— в полосе 470 МГц—40 ГГц;	—	—	—	—	—	—	—	—	—	—	—	—	300	100	300	200	500	300
— мощностью 5 Вт и менее;	—	—	—	—	—	—	—	—	100	40	—	—	—	—	—	—	—	—
— мощностью более 5 Вт	—	—	—	—	—	—	—	—	50	30	—	—	—	—	—	—	—	—
а) судовые станции:(10)																		
— в полосах 10—535 и 1605—4000 кГц;	5000	5000	—	—	200	200	—	—	—	—	—	—	—	—	—	—	—	—
— с излучением класса A1; (11)	—	—	—	—	—	—	200	50	—	—	—	—	—	—	—	—	—	—
(12) — с излучением других классов (кроме A1)	—	—	—	—	—	—	50	50	—	—	—	—	—	—	—	—	—	—
б) судовые станции и станции спасательных средств: (13)																		
— станции спасательных средств; (14)	5000	5000	—	—	300	300	200	200	—	—	—	—	—	—	—	—	—	—
— в полосе 156—174 МГц;	—	—	—	—	—	—	—	—	—	—	20	10	—	—	—	—	—	—
— вне полосы 156—174 МГц;	—	—	—	—	—	—	—	—	—	—	50	50	—	—	—	—	—	—
— судовые аварийные передатчики (станции (15)	5000	5000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
в) станции воздушных судов (16)	500	100	—	—	100	20Гц	100	20 Гц	—	—	50	30	—	—	—	—	—	—
г) радиомаячная станция, указывающая место бедствия (17)	—	—	—	—	300	300	—	—	—	—	—	—	—	—	—	—	—	—

Table 8.4 (cont'd)

1 Категории радиостанций	2 Допустимые отклонения частоты (в миллионных долях от частоты (N · 10⁻⁶) или в герцах) — 3 Полоса частот (включая верхний и исключая нижний пределы): 10—535 кГц, I	10—535 кГц, II	535—1605 кГц, I	535—1605 кГц, II	1605—4000 кГц, I	1605—4000 кГц, II	4—29,7 МГц, I	4—29,7 МГц, II	29,7—100 МГц, I	29,7—100 МГц, II	100—470 МГц, I	100—470 МГц, II	470—2450 МГц, I	470—2450 МГц, II	2450—10 500 МГц, I	2450—10 500 МГц, II	10,5—40 ГГц, I	10,5—40 ГГц, II
д) сухопутные подвижные станции: (18)																		
— в полосе 1605 кГц—29,7 МГц;	—	—	—	—	200	50	200	50	—	—	—	—	—	—	—	—	—	—
— мощностью 5 Вт и менее;	—	—	—	—	—	—	—	—	100	40	50	20	—	—	—	—	—	—
— мощностью более 5 Вт	—	—	—	—	—	—	—	—	50	30	20	10	—	—	—	—	—	—
Станции радиоопределения (19)	100	100	100	100	100	50	—	—	200	100	50	50	—	—	—	—	—	—
Станции радиоопределения:																		
— с кварцевой стабилизацией; (20)	—	—	—	—	—	—	—	—	—	—	—	—	—	100	—	100	—	500
— без кварцевой стабилизации (21)	—	—	—	—	—	—	—	—	—	—	—	—	—	500	—	1200	—	3000
Радиовещательные станции (22)	10 Гц	10 Гц	10 Гц	10 Гц	20	10 Гц	15	10 Гц	—	—	—	—	—	—	—	—	—	—
Радиовещательные станции (кроме телевизионных): (23)																		
— в полосе 100—470 мГц;	—	—	—	—	—	—	—	—	—	—	20	10	—	—	—	—	—	—
— мощностью 50 Вт и менее;	—	—	—	—	—	—	—	—	50	50	—	—	—	—	—	—	—	—
— мощностью более 50 Вт	—	—	—	—	—	—	—	—	20	20	—	—	—	—	—	—	—	—
Радиовещательные станции (телевизионные, звук и изображение): (24)																		
— мощностью 1000 Вт и менее;	—	—	—	—	—	—	—	—	500 Гц	400 Гц	500 Гц	400 Гц	500 Гц	400 Гц	—	—	—	—
— мощностью более 1000 Вт	—	—	—	—	—	—	—	—	500 Гц	100 Гц	500 Гц	100 Гц	500 Гц	100 Гц	—	—	—	—
Радиовещательные станции, работающие в режиме синхронизации частоты (25)	0,01 Гц	0,01 Гц	0,05 Гц	0,01 Гц	—	0,01 Гц	—	0,05 Гц	—	—	—	—	—	—	—	—	—	—

Key to Table 8.4 on preceding pages:

1. Transmitter categories
2. Allowable frequency deviations (in millionth fractions of frequency ($N \times 10^{-6}$) or in Hertz)
3. Frequency band (including upper and excluding lower boundary)
4. Fixed stations
5. Land stations
6. Shore stations
7. Permanent-site air traffic control stations
8. Base stations
9. Mobile stations
10. Marine shipboard stations
11. With class A1 emission
12. With emission of other classes (other than A1)
13. Shipboard stations and rescue service stations
14. Rescue service stations
15. Shipboard emergency transmitters (transceivers)
16. Aircraft stations
17. Crash locater beacon
18. Land mobile stations
19. Radio-localization stations
20. With quartz stabilization
21. Without quartz stabilization
22. Radio broadcasting stations
23. (other than television)
24. (television, audio and video)
25. Radio broadcasting stations operating in frequency synchronization mode

кГц -- kHz
МГц -- MHz
в полосе -- in band
мощностью -- power
Вт -- watts
более -- more than
и менее -- and less than
до -- up to
вне -- outside

Notes: 1. In column I -- allowable frequency deviations for operating radio transmitters and radio transmitters going into operation prior to 1 January 1985
2. In column II -- allowable frequency deviations for radio transmitters going into operation after 1 January 1985 and radio transmitters modernization of which began after 1 January 1976

Table 8.5. Occupied Frequency Bandwidth Standards [18]

Type of Radio Communications and Designation of Emissions Class 1	Formula for Calculating Requisite Frequency Bandwidth 2	Examples of Calculation of Requisite Frequency Bandwidth 3		Allowable Out-of-Band Emission β/2 for figuring occupied frequency bandwith, % 6
		Modulation Parameters 4	Requisite Frequency Bandwidth, Hz 5	
	Amplitude Modulation			
Continuous-wave telegraphy, A1	$B_H=kB$ k=5 -- for radio communication links subject to	B=20 Baud	100	0.5

Table 8.5 (cont'd)

1	2	3		6
		4	5	
	fading; k=3 -- for radio communication links without fading	B=20 Baud	60	0.5
Audio frequency telegraphy, A2	$B_H=2F_M+5B$	$F_M=900$ Hz B=20 Baud	1900	0.5
Audio frequency telegraphy, single sideband, suppressed carrier, A2J	$B_H=5B$	B=20 Baud	100	0.5
Audio frequency telegraphy, single sideband, full carrier, A2H	$B_H=F_M+5B$	$F_M=650$ Hz B=40 Baud	850	0.5
Radio broadcasting, double sideband, A3	$B_H=2F_B$	$F_B=10$ Hz	20,000	0.12
Radio broadcasting, single sideband, attenuated carrier, A3A	$B_H=F_B$	$F_B=6$ kHz	6000	0.5
Telephony, single sideband, reduced carrier, A3A	$B_H=F_B$	$F_B=2700$ Hz	2700	0.5
Radio broadcasting or telephony in two independent frequency bands, reduced or suppressed carrier, A3B	Radio broadcasting in two independent frequency bands, $B_H=2F_B$.	$F_B=6$ kHz	12,000	0.5
	Telephony in two independent frequency bands, $B_H=2F_B$.	$F_B=3.4$ kHz	6800	0.5
	Telephony in four independent frequency bands, $B_H=4F_B$	$F_B=3$ kHz	12,000	0.5
Telephony, single sideband, full carrier, A3H	$B_H=F_B$	$F_B=2.7$ kHz	2700	0.5
Telephony, single sideband, suppressed carrier, A3J	$B_H=F_B-F_B$	$F_B=2.7$ kHz $F_H=0.35$ kHz	2350	0.5
Telephony, double sideband, A3	$B_H=2F_B$	$F_B=3400$ Hz	6800	0.5
Facsimile transmission with subcarrier frequency carrier modulation, double sideband, A4	$B_H=2F_n+3F_B$	$F_n=1.9$ kHz Drum diameter 70 mm five lines per mm n=60 rpm N=1100 Hz $F_B=550$ Hz	5400	0.5

Table 8.5 (cont'd)

1	2	3		6
		4	5	
Facsimile transmission with subcarrier frequency carrier modulation, single sideband, attenuated carrier, A4A	$B_H=F_n+1.5F_B$	n=120 rpm N=220 Hz F_B=1100 Hz	3550	0.5
Television -- video and audio transmission, A5C and F3	Frequency band regulated by GOST 7845-72, "Black-and-white television. Principal parameters of television broadcasting system"	Number of lines -- 625. Total video signal bandwidth 7.625 MHz; audio FM bandwidth, including guard-band, 0.375 MHz	8 x 10^6	–
Multichannel audio frequency telegraphy, single sideband, attenuated carrier, A7A	$B_H=F_B$, F_B -- upper frequency of single-band channel	F_B=3.4 kHz	3400	0.5
Multichannel audio frequency telegraph, single sideband, suppressed carrier, A7J	$B_H=F_B-F_H$; F_B and F_H -- upper and lower single-band channel frequency respectively	F_H=0.3 kHz F_B=3.4 kHz	3100	0.5
Complex emission in two independent sidebands, suppressed or attenuated carrier A9B (one sideband -- telephony, the other -- multichannel audio frequency telegraphy)	$B_H=2F_B$; F_B -- upper frequency of single-band channel	F_B=3.4 kHz	6800	0.5
Frequency Modulation				
Telegraphy, F1	Fixed-location and mobile service transmitters. Aircraft transmitters $B_H=2.6D+0.55B$ for $1.5\leq m<5.5$	B=200 Baud D=500 Hz m=5.0	1410	0.5
	$B_H=2.1D+1.9B$ for $5.5\leq m<20$	B=50 Baud D=200 Hz m=8.0	515	0.5
Radio broadcasting, F3	(monophonic channel) $B_H=2D+2F_B$	F_B=3.4 kHz	$30.8\cdot10^3$	0.5
Telephony, F3	$B_H=2.4D+2F_B$ ($B_H=3.4D'+2F_B$)	F_B=3.4 kHz D=10 kHz D'=7.07 kHz	$30.8\cdot10^3$	0.5
Facsimile transmission with frequency modulation of carrier and photosignal in pulse form, F4	Transmission of half-tone and color image $B_H=(2m+1.7)F_B$ for $0.14\leq m\leq 0.77$	n=120 rpm N=2200 Hz F_B=1100 Hz D=500 Hz m=0.45	2880	0.5

Table 8,5 (cont'd)

1		2	3: 4	3: 5	6
		$B_H=(2m+2.46)F_B$ for $0.77\leq m\leq 1.7$	n=120 rpm F_B=1100 Hz D=1500 Hz m=1.36	5700	0.5
		$B_H=(2m+3)F_B$ for $1.7<m\leq 2.75$	n=60 rpm N=1100 Hz F_B=1500 Hz D=1500 Hz m=2.75	4650	
	Transmission of black-and-white facsimile (text) image	$B_H=2F_B$ for $0.14\leq m<0.77$	n=120 rpm F_B=1100 Hz D=500 Hz m=0.45	2200	0.5
		$B_H=4F_B$ for $0.77\leq m\leq 1.7$	n=120 rpm F_B=1100 Hz D=1500 Hz m=1.36	4400	0.5
		$B_H=8F_B$ for $1.7<m\leq 3.14$	n=60 rpm F_B=550 Hz D=1500 Hz m=2.75	4400	0.5
Two-channel telegraphy (four-frequency), F6	Synchronized channels	$B_H=2.2D+2B$	Separation between adjacent instantaneous frequencies 1000 Hz D=1500 Hz	3700	0.5
	Unsynchronized channels	$B_H=2.2D+4.5B$	B=200 Baud	4200	0.5

Symbols:

B_H -- requisite bandwidth, Hz; B -- telegraphy rate, Baud; F_M -- keying frequency, Hz; F_B -- maximum modulation frequency, Hz; F_H -- minimum modulation frequency, Hz; F_π -- subcarrier frequency, Hz; D -- maximum frequency deviation, Hz; k -- numerical coefficient, which changes during emission and which is dependent on allowable signal distortion; D' -- maximum deviation, established by the root-mean-square value of sine wave signal, Hz; m -- frequency modulation subscript; n -- rate of phototelegraphy, rpm; N -- maximum possible number of black and white picture elements transmitted per second, Hz.

(see following page for Table 8.6).

Table 8.6. Spurious Emissions Output Power Standard* [19]

1 Radio Transmitter Main Frequency Band	2 Standards for Transmitters Installed Prior to 1964	Standards for Newly-Installed Transmitters (Designed Prior to Ratification of Current Standards), Transmitters Installed After 1964, and Transmitters Design of Which Began Prior to 1 January 1972 3	Standards for Transmitters Design of Which Began After 1 January 1972 4
Below 30 MHz	40 db less than power of principal emission, but not more than 200 mw	40 db less than the power of transmitters at base frequencies, up to 500 watts.[1] ** Not more than 50 mw for transmitters with a power at base frequencies of more than 500 watts (up to 50 kw).[2] 60 db less than fundamental emission power for transmitters with a power of more than 50 kw at the base frequency	40 db less than base emission power for transmitters with a power at base frequencies up to 500 watts.[1] Not more than 50 mw for transmitters with a power at base frequencies of more than 500 watts.[2, 3]
30-235 MHz	40 db less than power of fundamental emission for transmitters with a power at base frequencies of 25 watts and less.	40 db less than power of fundamental emission but not more than 25 microwatts for transmitters with a power at base frequencies of 25 watts and less.[4]	40 db less than power of fundamental emissions, but not more than 25 microwatts for transmitters with a power on base frequencies of 25 watts and less.[4]
	60 db less than power of fundamental emission, but not more than 10 mw for transmitters with a power at base frequencies of more than 25 watts	60 db less than power of fundamental emission for transmitters with a power on base frequency of between 25 watts and one kilowatt.[4] Not more than 1 mw for transmitters with a power at base frequencies of more than 1 kilowatt	60 db less than power of fundamental emission for transmitters with a power at base frequencies of between 25 watts and 1 kilowatt.[4] Not more than 1 mw for transmitters with a power at base frequencies of more than 1 kilowatt
235-960 MHz	-	-	60 db less than power of fundamental emission for transmitters with a power at base frequencies of between 25 watts and 20 kilowatts.[5, 6]

Table 8.6 (cont'd)

1	2	3	4
			Not more than 20 mw for transmitters with a power at base frequencies of more than 20 kw.[6]
235–470 MHz	–	–	Not more than 25 microwatts for transmitters with a power at base frequencies of 25 watts or less.[5]
470–690 MHz	–	–	In transmitters with a power at base frequencies of 25 watts or less, steps should be taken to achieve maximum reduction in level of spurious emissions

* These standards do not apply to transmitters installed at rescue stations, to emergency (backup) airborne and marine transmitters, and to transmitters installed at radio-localization stations.

** For explanations to superscripts 1-6, see below.

Radio transmitter spurious emission or radiation is defined as radiation at frequencies outside the frequency bands authorized for transmission of useful information, the level of which can be reduced without detriment to emitted useful information signals. Spurious radiation includes the following:

emissions at harmonic frequencies -- emissions at frequencies which are multiples of the assigned frequencies;

parasitic radiation -- emissions randomly generated at frequencies independent of the base frequencies and at frequencies occurring in the course of formation of the base frequencies;

intermodulation components, which include emissions at frequencies arising as a consequence of intermodulation between two or more fundamental or harmonic radio transmitter emission frequencies.

Spurious radiation power is defined as power applied to an antenna or antenna equivalent when under the given conditions the transmitter is putting out rated power at the base frequency.

Explanations to Table 8.6:

1) A 30 db reduction in spurious radiation power is allowable for portable transmitters with a power of less than 5 watts in view of the difficulty of obtaining a 40 db suppression.

2) For mobile transmitters any spurious radiation should be 40 db less than the power of fundamental emission but should not exceed 200 mw when it is difficult for practical purposes to reduce power to 50 mw.

3) For transmitters with an average power output of greater than 50 kw, it is not mandatory to reduce spurious radiation to 50 mw in the frequency range of approximately an octave or higher. It is essential, however, to ensure minimum attenuation of 60 db and to seek to ensure that a maximum of 50 mw is not exceeded.

4) For marine mobile service FM radiotelephone equipment, the average power of any spurious radiation caused by modulation products and entering any other international marine mobile service channels should not exceed 10 microwatts, and the power of any other spurious radiation at any discrete frequency within the international marine mobile service band should not exceed 2.5 microwatts. In exceptional cases, when transmitters with an average power of more than 20 watts are employed, these limits can be increased proportional to average tansmitter power.

5) For rescue stations operating at a frequency of 243 MHz, the lowest level of spurious radiation corresponding to equipment of a given type should be achieved.

6) These standards may not provide adequate protection of radio astronomy receiving eqipment; more severe limits may be proposed in each individual case, taking into account the geographic location of the facilities in question.

8.4. Metrological Expert Appraisal of Communications and Radio-Radar Support Services Equipment

Metrological expert appraisal of communications and RTO equipment is defined as examination of the aggregate of factors which provide effectiveness and reliability of monitoring and inspection of their technical state, performed in the process of design, testing, manufacture, operation and maintenance.

In military communications and RTO units metrological expert appraisal of facilities is performed in the process of their operation and maintenance. Following are the input materials for metrological expert appraisal:

operating and servicing manuals for communications and RTO equipment to be inspected, as well as test equipment;

technical standards documentation covering all types of inspection and testing procedures;

statistical data on results of monitoring and testing equipment parameters during the entire period of its operation.

The following types of procedures can be included in the program of metrological expert appraisal of communications and RTO equipment following extended operation in military units:

testing of continued effectiveness of test and monitoring equipment during a protracted period of operation;

verification that operating and servicing manuals for a facility as well as test equipment are in conformity with the requirements of the military units in question and the level of qualifications of operating and servicing personnel;

verification that standards of time parameters and periodicity of performance of inspection and various test procedures are in conformity with actual conditions of facility operations as well as test equipment.

Table 8.7. List of Tested Parameters and Test Equipment Employed in Metrological Expert Appraisal

№ № по пор.	Наименование контролируемого параметра	Номинальные значения и допуски по ТУ $\delta_{ТУ}$, ед. изм.	Номинальные значения и допуски в эксплуатационной документации $\delta_э$, ед. изм.	Этапы эксплуатации, на которых контролируется параметр	Используемые контрольно-измерительные средства (10)		Используемые согласующие, присоединительные и переходные устройства	Место (точка) подключения прибора к проверяемому блоку. Тип блока	Достоверность контроля (11)			(12) Примечания (в каком измерительном комплексе находится прибор и другие сведения)
					Тип. Погрешность (класс) прибора ε, ед. изм.	Используемый диапазон технических данных и режимов прибора			$\delta_{ТУ} = \frac{\varepsilon}{\delta_э}$	$P_{ЛО\,min}$, $P_{НО\,min}$	$P_{ЛО\,max}$, $P_{НО\,max}$	
1	2	3	4	5	6	7	8	9	10	11	12	13

Key:

1. Serial number
2. Designation of tested parameter
3. Rated values and tolerances according to technical specifications: $\delta_{ТУ}$, units of measurement
4. Rated values and tolerances in operating and servicing manuals: $\delta_э$, units of measurement
5. Stages of operation or servicing at which parameter is tested
6. Type. Instrument error (class) ε, unit of measurement
7. Employed range of technical data and instrument modes
8. Employed matching, connecting and adapting devices
9. Place (point) where instrument is connected to unit being tested. Type of unit
10. Employed test equipment
11. Test reliability
12. Comments (instrument testing set and other data)

A list of tested parameters and test equipment employed in servicing and maintenance is prepared using the form contained in Table 8.7. In filling in this table, one should be guided by the following:

column 2 indicates the parameters which are tested at all stages of preparation and servicing, including in-flight monitoring or testing (with built-in monitoring-test systems); rated values of tested parameters and tolerances (column 3) are taken from the technical specifications for the equipment and are recorded both for standard ($\delta_{ТУ}^{НУ}$) and for specific climatic conditions ($\delta_{ТУ}^{НУ}$);

rated parameter values and tolerances (column 4) are taken from current operating and servicing manuals, recording test tolerance $\delta_{ЭН}$ and preventive maintenance tolerance $\delta_{ЭП}$;

testing of parameters by stages of operation is recorded in column 5; the following stages are covered: in flight, preflight, during preliminary preparation, and all types of servicing and maintenance procedures;

columns 6-9 indicate types of employed test equipment, equipment error (according to utilized characteristic or mode), segment of utilized portion of scale (for pointer-type instruments) or ranges of utilized characteristics and operating modes of multiple-function instruments of the matching, connecting and adapter type device employed in testing, as well as data on point where test instrument is connected;

columns 10-12 contain parameter testing instrument accuracy figures (probability of undetected malfunction $P_{НО}$ and probability of false malfunction $P_{ЛО}$ on testing, as well as relative measurement error tolerance value η_δ).

The method of calculating test instrument reliability consists in the following:

1. Initial data are determined (values of one half tolerance zone value $\delta_э$ and one half the value of practically maximum measurement error dispersion field ε); they are taken from columns 4 and 6 in Table 8.7. Calculation reduces to determination of minimum and maximum values of probabilities $P_{НО}$, $P_{ЛО}$ and η_δ.

2. If the laws of distribution of functions f(x) and $\varphi(\tau)$ are unknown, all other conditions being equal, in determining measured parameter x and measurement error τ by normal patterns, value $P_{НО}$ and $P_{ЛО}$ will be minimum, while value $P_{ЛО}$ and $P_{НО}$ will be maximum with distribution by the laws of equal probability. This applies to the majority of laws of distribution of x and τ which occur in practice.

3. The sequence of calculation is as follows:

relative allowable measurement error value $\eta_\delta = \frac{\varepsilon}{\delta_э}$ is determined and entered in column 10 of Table 8.7;

the values of probabilities $P_{ЛО\,min}, P_{ЛО\,max}$, are determined by the graph in Figure 8.1, and they are also entered in columns 11 and 12 of Table 8.7;

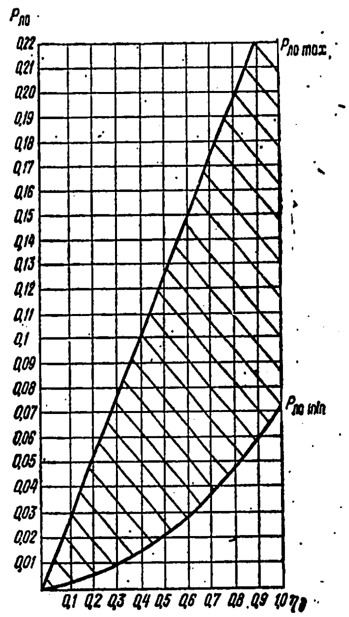

Figure 8.1. Dependence of Probabilities $P_{ЛОmin}$ and $P_{ЛОmax}$ on Relative Allowable Measurement Error η_δ

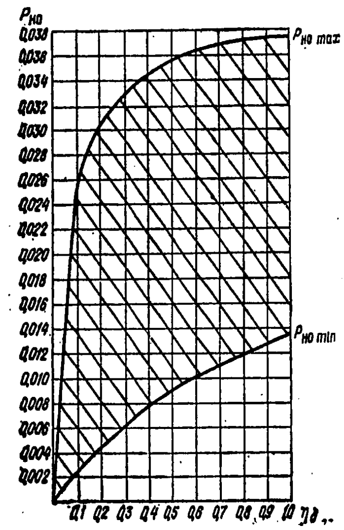

Figure 8.2. Dependence of Probabilities P_{HOmin} and P_{HOmax} on Relative Allowable Measurement Error η_δ

the values of probabilities $P_{HO\,min}$, $P_{HO\,max}$, are determined by the graph in Figure 8.2, and they are also entered in columns 11 and 12 of Table 8.7.

The graphs in figures 8.1 and 8.2 are plotted for the case of dispersion of tested parameter x through tolerance zone 2δ, when the probability that the value of parameter x falls outside the tolerance zone is P=0.05. If the distribution of parameter x and measurement error τ differ from normal and equal probability, the true values of probabilities $P_{ЛО}$ and P_{HO} will fall within the bounds of minimum and maximum values calculated with this method.

Chapter 9. RELIABILITY OF COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

9.1. Quantitative Characteristics of Reliability

Reliability is defined as the capability of an item to perform specified functions, retaining its operating indices within specified limits during the course of a required period of time or required number of hours of operation. The reliability of an item is determined by the degree to which it is "trouble-free," its "repairability," "shelf life," as well as the "longevity" of its components.*

It follows from this that reliability is an internal property of equipment, invested in it in the process of design and manufacture and realized in the process of operation.

The above definition of reliability applies in full measure both to radio equipment and to its component parts -- systems, devices, units, subunits, assemblies, and components. A radio equipment component is defined as a part of a device (system, unit, etc) which performs specific functions but which does not have an independent operational function (for example, a capacitor, resistor, functional assembly). Components in equipment may be joined in series, in parallel, and mixed.

When components are connected in series, the failure of any one component causes failure of the entire device as a whole. When components are connected in parallel, failure of the device occurs following failure of the principal and backup components. A mixed arrangement is characterized by a combination of the properties of series and parallel connections.

We distinguish between sudden and gradual (deterioration) failures by the character of change of radio equipment (component) parameter prior to the moment a malfunction occurs A sudden failure is caused by a sudden change in the value of one or seve al basic radio equipment (component) parameters. In most cases such a change is caused by latent defects in materials and

* The terms in parentheses are defined in Table 9.1.

components. The electrical or mechanical damage to a component which occurs with failures of this type makes it totally unfit for further utilization. By character of manifestation, such a failure leads to loss of radio equipment capability until such time as it is corrected, that is, it is a terminal failure. In contrast to the above, in practice one also encounters intermittent sudden failures, whereby radio equipment operation is periodically restored.

Gradual failure occurs as a consequence of gradual change in the values of one or several operating parameters of radio equipment (component). These failures occur under the influence of the following factors: change in ambient temperature, humidity, supply voltages, as well as with the passage of time (aging of components).

A number of terms are employed in reliability theory, terms which are defined by GOST 13377-67. Table 9.1 contains a list with definitions of the principal reliability terms, the indices which express them, and analytical expressions for calculating these indices.

Table 9.1. Terms and Quantitative Indices of Reliability

Term as Specified in GOST 13377-67 1	Definition According to GOST 13377-67 2	Indices and Their Definition 3	Analytical Expression of Indices 4	Characteristic of Quantities in Analytical Relation of Index 5	Comments 6
Rabotosposobnost' [Efficiency, capability to operate]	State of an item whereby it is capable of performing specified functions with parameters established by service data requirements	Coefficient of technical utilization K_T is expressed by the ratio of total time of system (equipment) serviceable operation to total time of operation and forced down time within a single calendar period. It indicates the percentage of total operating time and shutdown time equipment is in good working order, ready for practical utilization. Coefficient of down time $K_П$ expresses the relationship between total forced down time and total time of good operation and forced down time during the same period of operation	$K_T = \frac{t_{cymm}}{t_{cymm} + t_{pem} + t_{o6cл}}$	t_{cymm} -- total hours logged; t_{pem} -- total hours down for repair; $t_{o6cл}$ -- total hours off line for servicing.*	In the general case total forced down time includes time spent on locating and correcting malfunctions, tuning and adjusting equipment, down time due to lack of replacement components, and time spent on servicing and maintenance procedures.

* Here and elsewhere in this table time values and analytical expression will be stated in hours.

Table 9.1 (cont'd)

1	2	3	4	5	6
			$K_{П}=1-K_{T}$	K_T -- coefficient of technical utilization	If total down time includes only time spent on performing preventive maintenance procedures, the down time coefficient characterizes relative time expenditures on preventive maintenance. In this case it is called preventive maintenance coefficient or standard
Neispravnost' [Malfunction, fault]	State of an item whereby it fails to meet at least one of the requirements specified in the operating and servicing manuals	Coefficient of effectiveness of preventive maintenance $K_{эп}$ is characterized by the ratio of the number of faults discovered during preventive maintenance procedures to the number of failures occurring during operation and to the number of faults discovered during preventive maintenance	$K_{эп}=\frac{n'}{n'+n''}$	n' -- number of faults discovered during preventive maintenance procedures; n'' -- number of failures occurring during equipment operation	We should distinguish between faults which do not lead to failures and faults (and their combinations) which cause failures. The better elaborated the system of preventive maintenance procedures, the higher the $K_{эп}$

Table 9.1 (cont'd)

1	2	3	4	5	6
Narabotka [logged operating hours]	The duration or volume of work performed by a piece of equipment, measured in hours, kilometers, hectares, cycles, cubic meters, or other units	Operating time to failure T is characterized by the average number of equipment operating hours between two successive failures during a specified period of operating time. We distinguish the following variants of this indicator in relation to period of operation: "sutochnaya (mesyachnaya) narobotka" [Daily (monthly) hours logged], "narobotka do pervogo otkaza" [hours to first failure], "narobotka mezhdu otkazami" [hours logged between failures] etc.	$T=\frac{T_p}{n}=\frac{\sum_{i=1}^{n} t_i}{n}$, where $T_p=t_1+t_2+\dots+t_v=\sum_{i=1}^{n} t_i$. For the period from moment t_1 to moment in time t_2, operating time to failure can be determined with the following approximate equation: $T\approx\frac{t_2-t_1}{m_{cp}(t_2)-m_{cp}(t_1)}$, where $m_{cp}(t)=\frac{\sum_{i=1}^{N} m_i(t)}{N}$	T_p -- total equipment operating time during a specified calendar period; $\sum_{i=1}^{n} t_i$ -- sum of operating time intervals between successive failures; t_i -- interval of good operation between (i-1) and i equipment failures; n -- number of failures during calendar period; $m_i(t)$ -- number of failures of each item up to operating time t; N -- number of items	The greater the quantity of statistical data utilized in calculation, the greater the accuracy of determination of time to failure (T)
Otkaz [failure]	An event consisting in breakdown of capability to operate	The probability of failure Q(t) of a system (component) characterizes the probability that failure will occur during a specified time interval, that is, time of good operation of a system (component) will be less than prescribed	a) For a system $Q(t)=1-P_{сист}(t)=1-P_1(t)\times P_2(t)\dots P_N(t)$ or $Q(t)=1-[1-q_1(t)]\times[1-q_2(t)]\dots[1-q_N(t)]$ In a particular case where reliability of system	$P_{сист}(t)$ -- probability of system failure-free operation; $P_1(t)$, $P_2(t)$, ... $P_N(t)$ -- probabilities of	With very small probabilities of component failures, the probability of system failure during a brief period of

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Table 9.1 (cont'd)

1	2	3	4	5	6
			components is identical: $Q(t)=1-[1-q(t)]^N$. b) For element $q(t)=1-P(t)=P\{t_{испр} \leqslant t\}$	system component failure-free operation; $Q(t)$ -- probability of system failure; $q(t)$ -- probabilities of failure of system components; N -- number of system components; $t_{испр}$ -- component good operating time; t -- designated component operating time	time is approximately equal to the sum of probabilities of failures of system components during that same period of time, that is, $$Q(t) \approx \sum_{i=1}^{N} q_i(t).$$ With identical reliability of components $Q(t) \approx Nq(t)$
Bezotkaznost' [trouble-free operation]	Property of a piece of equipment to maintain its operating capability during a certain number of operating hours without forced interruptions of service	Following can serve as trouble-free operation indices: "probability of trouble-free operation," "intensity of failures" (the definitions and analytical expressions for these are given below in the terms "probability of failure-free operation" and "intensity of failures")			
Dolgovechnost' [longevity, durability]	The property of a piece of equipment to maintain its operating capability to a maximum state with requisite interruptions for servicing and maintenance	The service life of an item is characterized by the time calculated from initiation of operation of the item to the point it reaches a "limiting state." The latter is determined by the impossibility of further operation of the item due to diminished efficiency or failure to meet safety requirements. Service life -- allowable period of equipment operation during which it retains rated specifications. In practice service life is characterized by average, that is, average service life (t_{cp})	$t_{cp} \approx \frac{1}{n}\sum_{i=1}^{n} t_i$	n -- number of items of the same type; t_{cp} -- average item service life; t_i -- service life of each item	

Table 9.1 (cont'd)

1	2	3	4	5	6
Remontoprigodnost' [correctability, repairability]	Property of an item consisting in its adaptedness to prevention, detection and correction of failures and malfunctions by performance of servicing and maintenance procedures	Probability of restoration $V(\tau)$ is characterized by the probability that equipment will be restored within a specified time τ following failure and under specified conditions of repair. Average equipment restoration time T_B expresses the mathematical expectation of a random quantity -- restoration time. Intensiveness of restoration μ is characterized by number of restorations per unit of time	$V(\tau) = P(T_B < \tau) = 1 - e^{-\frac{\tau}{T_B}} = 1 - e^{-\mu\tau}$; $T_B = \frac{\sum_{i=1}^{n} \tau_i}{n}$; $\mu = \frac{n}{\sum_{i=1}^{n} \tau_i}$	T_B -- average item restoration time; $\mu = \frac{1}{T_B}$ -- intensity of restoration; τ -- prescribed item restoration time; n -- number of failures in a specified period of equipment operation; $\sum_{i=1}^{n} \tau_i$ -- sum of intervals of time expended on detection and correction of failures during a given period of operation; τ_i -- time expended on locating and correcting i failure	In many cases repairability also characterizes average cost of servicing and maintenance
Sokhranyayemost' [shelf life]	The property of an item to retain specified operating indices during and after the period of storage and transport specified in the equipment's technical data	Average shelf life is the period during which an item retains rated operating indices (corresponding to the guaranteed values of indices in the technical documentation)			

Table 9.1 (cont'd)

1	2	3	4	5	6
Resurs [service life]	Equipment operation to the limiting state specified in the technical documentation	The following indices are employed in practice: "service life to first repair," "service life between repairs," and "designated service life." They are characterized by total time of equipment failure-free operation in hours to (or during) designated states. Frequently the "average service life" indicator is also employed (see the term "dolgovechnost'")			
Gamma-protsentnyy resurs [gamma-percent service life]	Service life equalled and exceeded on the average by a specified percentage (γ) of items of a given type	Specified percentage of items (γ) is a stipulated probability $P(t_\gamma)$. If, for example, γ=90%, the corresponding service life is called "90% service life"	$P(t_\gamma) = \frac{\gamma}{100}$	t_γ -- gamma percent service life; $P(t_\gamma)$ -- probability of failure-free operation during period of operation t_γ; γ -- specified percentage of items	
Naznachennyy resurs [designated service life]	Period of equipment operation upon reaching which operation should be terminated regardless of condition of the equipment	The indicator of this is total equipment operating hours logged, obtained from considerations of safety and economy (indicated in technical documentation)			
Srok sluzhby [calendar service life]	Calendar duration of equipment operation up to the moment of occurrence of a limiting state specified in the technical documentation, or until equipment is retired from service for age, obsolescence or other reasons	Indices are the following: "service life to first major (medium) overhaul," "service life between major overhauls," "service life to retirement," "average service life," etc. They are characterized by equipment trouble-free operating time up to (or in the period of) the specified categories of overhaul.			
Srok garantii [warranty period]	Period during which the manufacturer guarantees and ensures that equipment performance requirements are met, under the condition that the purchaser observes proper operating procedures, including proper storage and transport procedures.	The warranty period (in months, years) is specified in the operating and servicing manuals or in agreements between manufacturer and customer			

Table 9.1 (cont'd)

1	2	3	4	5	6
Garantiy-naya narabotka [warranted hours of operation]	Equipment hours of operation up to which the manufaturer guarantees and ensures that equipment will meet specified performance standards under the condition that the customer observes proper operating procedures, including proper storage and transport procedures	Warrantied hours of operation are specified in operating and servicing manuals or in agreements between manufacturer and customer.			
Narabotka na otkaz [operation to failure]	Average time of operation by a repaired item between failures	Indices are the following: "operation to failure," and "mean time between failures." Operation to failure T is determined for the period from hours of operation t_1 to hours of operation t_2. Mean time between failures T_{cp} is characterized by the ratio of the total time of equipment operation to occurrence of the first failure in each piece of equipment to their total number.	$T \approx \frac{t_2 - t_1}{m_{cp}(t_2) - m_{cp}(t_1)}$ where $m_{cp}(t_1) = \frac{\sum_{i=1}^{N} m_i(t_1)}{N}$; $m_{cp}(t_2) = \frac{\sum_{i=1}^{N} m_i(t_2)}{N}$; $T_{cp} = \frac{\sum_{i=1}^{N} t_i}{N}$	$t_2 - t_1$ -- period from hours of operation t_1 to hours of operation t_2; $m_i(t_1)$, $m_i(t_2)$ -- number of failures of each item of a single type to hours of operation t_1 or t_2; $m_{cp}(t_1)$, $m_{cp}(t_2)$ -- mean number of failures up to hours of operation t_1 or t_2; N -- number of items of the same kind; t_i -- time of trouble-free operation of item i	
Sredneye vremya vosstanovleniya [mean restoration time]	Mean time of forced unscheduled down time, caused by finding and correcting one malfunction	Mean restoration time T_B as an indicator expresses the mathematical expectation of a random quantity -- restoration time	$T_B = \frac{1}{m} \sum_{i=1}^{m} t_i$	$\sum_{i=1}^{m} t_i$ -- total time expended on finding and correcting m malfunctions; m -- number of malfunctions/failures; T_B -- mean item restoration time	

Table 9.1 (cont'd)

1	2	3	4	5	6
Koeffitsiyent gotovnosti [coefficient of readiness]	Probability that an item will be capable of operation at an arbitrarily selected moment in time during the intervals between performance of scheduled servicing and maintenance	Coefficient of readiness K_Γ as an indicator is the ratio of total time of good operation of a piece of equipment to the sum of good operating time and total restoration time taken for one and the same period of operation	$K_\Gamma = \frac{T}{T+T_в}$	T -- time of operation to failure	
Koeffitsiyent tekhnicheskogo ispol'zovaniya [coefficient of technical utilization] K_T	Ratio of unit operation in units of time for a certain period of operation to the sum of this operating time and all down time for servicing and maintenance during the same period of operation		$K_T = \frac{t_{сумм}}{t_{сумм}+t_{рем}+t_{обсл}}$	$t_{сумм}$ -- total unit good operating time; $t_{рем}$ -- equipment down time for repairs; $t_{обсл}$ -- down time for servicing	
Verovatnost' bezotkaznoy raboty [probability of trouble-free operation] P(t)	Probability that equipment failure will not occur within a given time interval or within limits of specified operating hours logged		$P(t) = e^{-\lambda(t)t}$ For a system consisting of a number of sequentially-connected components: $P(t) = P_1(t) \cdot P_2(t) \cdots$ $\ldots P_N(t) = \prod_{i=1}^{N} P_i(t)$	$\lambda(t)$ -- intensity of failures (its expression is given below in the term "intensity of failures"); t -- operating time logged; $P_1(t)$, $P_2(t)$, ..., $P_N(t)$ -- probability of trouble-free operation of system components	
Intensivnost' otkazov [intensity of failures]	Probability of failure of an unrepaired item in a unit of time following a given moment in time under the condition that failure has not occurred up to this moment	Intensity of failures as an indicator is expressed by the ratio of number of failed pieces of equipment in a unit of time to the average number of pieces of equipment which continue to operate correctly	Statistical value of intensity of failures for time interval Δt is determined with the formula $\lambda(t) = \frac{n(t)}{N(t)\Delta t}$	n(t) -- number of equipment items failed during the time from $t - \frac{\Delta t}{2}$ to $t + \frac{\Delta t}{2}$; Δt -- examined time interval; $N(t) = \frac{N_{i-1}+N_i}{2}$, where N_{i-1} -- number of properly operating equipment items at the beginning of interval Δt; N_i -- number of correctly operating equipment items at end of interval Δt	

Table 9.1 (cont'd)

1	2	3	4	5	6
Srednyaya chastota otkazov [mean frequency of failure] (parameter of flow of failures	Mean number of failures of repaired piece of equipment per unit of time, taken for a specified moment in time	Mean frequency of failures $f_{cp}(t)$ as an indicator expresses the ratio of number of failed pieces of equipment per unit of time to the number of pieces of equipment in operation at a given moment	$f_{cp}(t) = \frac{n(t)}{Nt}$	n(t) -- number of pieces of equipment breaking down during operating time t; N -- number of pieces of equipment in operation; t -- operating hours logged by item	
Reservirovaniye [redundancy]	Method of increasing reliability by introduction of backup components which are redundant in respect to the equipment's minimum functional structure essential and adequate for performance of prescribed functions				

9.2. Redundancy in Communications and Radio-Radio Support Services Equipment

Redundancy is viewed as a means of increasing equipment reliability. It is based on the principle of izbytochnost' [redundancy, excessiveness], that is, redundant components (assemblies, units) are provided for operating equipment, which are not functionally essential but are utilized only to replace counterpart components (assemblies, units) in case of their failure. We distinguish the following methods of redundancy: redundancy by substitution, and continuous redundancy. With the former method, if a component fails the equipment is switched to the backup element, while with the latter method redundant components are connected to the principal elements during the entire time of equipment operation and are under identical operating conditions.

With redundancy by substitution one employs switches, to disconnect a malfunctioning component and to connect a backup component; this replacement process can be either automatic or manual.

With continuous redundancy equipment circuitry is not retuned when components fail, and the failed component is not disconnected. Redundancy is continuously connected in, which ensures uninterrupted equipment operation.

These redundancy methods can be implemented by employing common, separate or mixed connection of redundant components.

Common redundancy consists in redundancy of the entire equipment as a whole. We differentiate independent and non-independent switch-in of redundant equipment. In the case of independent in-switching, the redundant equipment has its own input and output, as well as independent power supplies.

Separate redundancy specifies replacement of large assemblies and units as well as separate components.

With mixed redundancy, both individual equipment devices and certain primary components are redundant.

We differentiate the following types of redundancy according to the conditions of operation of backup components up to the moment they are switched in: hot (under load), warm (light-load), and cold (no-load).

In hot backup, redundant components are under identical operating conditions with the equipment's principal components; service life of backup components is being expended from the moment the equipment is switched on. This offers the greatest probability of equipment failure-free operation, with probability independent of what moment in time the redundant components are put on line.

With warm backup the external conditions affecting the equipment up to the moment it comes on line are eased. In this case backup component service life begins to be expended from the moment the entire equipment is switched on, but intensity of service life expenditure is considerably less than under normal operating conditions up to that moment when it comes on line to replace a failed component.

On cold standby backup components begin to expend their service life only at the moment they come on line to replace failed components.

Light-load or no-load standby with fractional frequency is called sliding standby.*

Tables 9.2, 9.3, and 9.4 present the substance of redundancy by the methods of substitution, continuous standby, and restorable redundancy respectively.

* The number of backup equipment items standing in reserve for a given principal equipment item determines the multiplicity of redundancy. If a group consisting of n components is designated for backing up m operating equipment components of the same type, and each of the standby components can take the place of any operating component (if the latter fails), this type of redundancy is designated with fractional frequency n/m.

Table 9.2. Redundancy by Substitution

Principle of Equipment Redundancy	Probability of Failure-Free Operation With Hot Standby	Probability of Failure-Free Operation With Warm and Cold Standby	Optimal Number of Redundancy Sections	Influence of Character of Failures of Switching Devices on Probability of Failure-Free Operation of Redundant System
1	2	3	4	5
Redundancy by Substitution is characterized by the capability to utilize warm and cold standby with mandatory employment of switching devices. The practical expediency of employment of this method of redundancy is determined by the reliability of switching devices. The latter can be incorporated at the input and output of each unit (main and backup) or at the input and output of a group of units (common switching devices are employed). Switches are controlled by special control devices. Figure 9.1 contains a diagram of redundancy with separate switching devices, and Figure 9.2 -- with common switching devices	In general form: $P_ц = P_{П_{вх}} P_Б P_{П_{вых}}$, where $P_ц$ -- probability of failure-free operation of any circuit; $P_{П_{вх}}, P_{П_{вых}}$ -- probabilities of failure-free operation of input and output switches; $P_Б$ -- probability of failure-free operation of the main or any one of the backup units. Probability of failure-free operation of a redundant assembly $P_y(t)$, consisting of one operating and m backup circuits, for an assembly with separate switching devices, is equal to $P_y(t) = 1 - \prod_{i=1}^{m+1}\left[1 - P_{П_{вх} i}(t) \times P_{Б_i} P_{П_{вых} i}(t)\right]$. For an arrangement with common switching devices $P_y(t) = P_{П_{вх}} P_{П_{вых}}\left[1 - \prod_{i=0}^{m}(1 - P_{П_i} P_{Б_i})\right]$, where P_{π_i} -- probability of failure-free operation of the components	With redundancy by substitution, standby components may be on light load (warm) or even no-load (cold) up to the moment they are put on line. This can be done only in those cases when equipment operating conditions permit operation interruptions requisite for switching over from the main to the backup component. For these conditions, probability of failure-free operation of redundant equipment (consisting of one main and m backup components) will be equal to	Maximum equipment reliability is achieved when equipment is divided into a certain optimal number of separately redundant units ($n_{опт}$) with specified probabilities of switch failure and redundancy multiple. $n_{опт} = m \frac{Q_0}{q_П}$, where m -- redundancy multiple; Q_0 -- probability of failure of equipment without redundancy; q_π -- probability of switch failure. With a number of redundant	Switch failures are subdivided into dynamic and static. Dynamic failures occur when it is necessary to switch in a stand-by unit or take off line a failed main unit. Static failures occur in the absence of switching necessity and constitute spontaneous switching. Probability of failure-free operation of an equipment assembly taking into account the nature of switching device failures is equal to

Table 9.2 (cont'd)

1	2	3	4	5
	of input and output switches, failure of which affects only the circuit of i unit; $P_{Б_i}$ -- probability of failure-free operation of i unit. If individual redundant n assemblies in a system are identical and connected in series, probability of failure-free operation is equal to: a) for an arrangement with separate switching devices $P(t) = P_y^n(t) = \{1 - [1 - P_\Pi(t) \times P_Б(t)]^{m+1}\}^n$; b) for an arrangement with common switching devices $P = P^n_{\Pi\,вх} P^n_{\Pi\,вых} \{1 - [1 - P_\Pi P_Б]^{m+1}\}^n$	$P(t) = 1 - e^{-\lambda t}\left[1 + \lambda t + \frac{(\lambda t)^2}{2!} + \ldots + \frac{(\lambda t)^m}{m!}\right]$, where λ -- intensity of failures of main and backup components. With cold and warm redundancy, a substantial gain in probability of failure-free operation is achieved. This gain increases with an increase in the redundancy multiple and time of failure-free operation	sections equal to n_{onT} probability of equipment (system) failure is minimum. Figure 9.3 shows the dependence of minimum probability of redundant system failure Q_{min} on unredundant system failure probability Q_0 with different values of switch failure probabilities q_Π.	$P_y = P_\Pi P_Б P_{Б_1} + P_Б(1 - P_{Б_1})^{\alpha_1} + P_{Б_1}(1 - P_Б)^{\alpha_2}$, where P_Π -- probability of failure-free switch operation; $P_Б$, $P_{Б_1}$ -- probabilities of failure-free operation of main and standby units; α_1 -- probability that a switch either will not fail or its failure will be expressed in

the fact that the backup unit will not come on line in place of the main unit; α_2 -- probability that a switch either will not fail or its failure will be expressed in spontaneous coming on line of a backup unit in place of the main unit. If $P_Б = P_{Б_1} = P$, $\alpha_1 = \alpha_2 = \alpha$, then $P_y = P_\Pi P[2\alpha + (1 - 2\alpha)]$.

Expediency of backing up a given equipment unit is determined from the following inequality:

$$P < \frac{2\alpha - \frac{1}{P_\Pi}}{2\alpha - 1}.$$

Unit redundancy is not advisable when this inequality is not observed

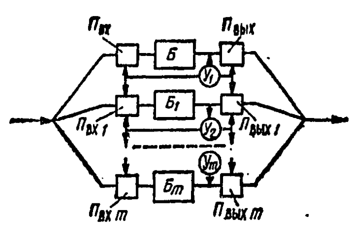

Figure 9.1. Diagram of Redundant Assembly With Separate Switching Devices: Б -- main unit; $Б_1$, ..., $Б_m$ -- backup units; $П_{вх}$, $П_{вх_1}$, ..., $П_{вхm}$ -- input switches of main and backup units; $П_{вых}$, $П_{вых_1}$, ..., $П_{выхm}$ -- output switches of main and backup units; $У_1$, $У_2$, ..., $У_m$ -- adjoining unit switch control devices

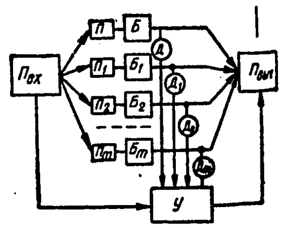

Figure 9.2 Diagram of Redundant Assembly With Common Switching Devices: Б -- main unit: $Б_1$, $Б_2$, ..., $Б_m$ -- backup units; $П_{вх}$, $П_{вых}$ -- common input and output switches; П, $П_1$, $П_2$, ..., $П_m$ -- switch elements applying to separate units; Д, $Д_1$, $Д_2$, ..., $Д_m$ -- switch control system sensors; у -- switch control device

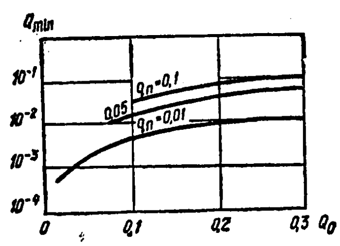

Figure 9.3. Dependence of Minimum Probability of Redundant System Failure Q_{min} on Unredundant System Failure Probability Q_0 with different values of Switch Failure Probability $q_п$

Table 9.3. Redundancy by Continuous On-Line Back-Up

Principle of Equipment Redundancy 1	Switching Element Redundancy 2	Redundancy by Sampling from a Set 3	Calculation of Reliability Parameters With Continuous Redundancy 4
With this method of redundancy, backup components are on line during the entire time of equipment operation and are operating under the same conditions as the working components. The redundancy	Continuous redundancy of switching elements is dictated by the necessity of preventing interruptions and short circuits (failures); it ensures the requisite probability of	Continuous redundancy in control circuits comprised of electron tubes can be effected by sampling from a set. It consists in the following: the initial state of a certain component (unit) is determined by the state of the majority of its outputs (Figure 9.4a). The input signal is applied to the input of three identical devices, the	For a system in which all components are identical in reliability and each assembly in the system consists of n series-connected components, probability of failure-free operation of a system with common redundancy

Table 9.3 (cont'd)

1	2	3	4
arrangement is set up in such a manner that failure of the main component does not disrupt operation of the equipment as a whole. Failure in this case can occur only when, in addition to the main component, the backup components also fail. This method of redundancy involves primarily a simple parallel or series connection of one or several backup units or components to the main unit. The units or components are connected in such a manner that failed sections do not affect the operating capability or efficiency of the equipment	system (equipment) actuation, which is expressed as $P = \sum_{n=0}^{m} A_n P^n \times (1-P)^{m-n}$, where A_n -- number of combinations, subsets, corresponding to a closed path; m -- number of contacts in circuit layout; n -- number of subset-forming contacts requisite for closing the circuit; P -- probability that a single contact is closed. Probability of system failure Q=1-P	outputs of which are connected to circuit M. It is quite obvious that failure of any of the units (short circuits, open circuit) will not disrupt operation of the entire circuit. Redundancy of majority decision circuits can be obtained by repeating this structure (Figure 9.4b). Probability of correct response of such circuits is as follows: $P = \sum_{k=\frac{1}{2}(n+1)}^{n} \frac{n!}{k!(n-k)!} \times P^k (1-P)^{n-k}$, where n -- total number of set sample circuit inputs (always uneven); P -- probability that one component is in good working order. This method of redundancy (sample from a set) has the weakness that the sample components themselves must be backed up. It is sufficiently effective only for protecting units against gradual and sudden failures, as well as short-duration malfunctions	is $P_{об} = 1 - (1 - P^n)^{m+1}$, where P -- probability of component failure-free operation. For a system with separate redundancy, probability of failure-free operation is $P_{разд} = [1 - (1-P)^{m+1}]^n$, where m -- redundancy multiple. It follows from these expressions that with an increase in the redundancy multiple system reliability increases. To sum up, if one eliminates the influence of circuit section failures, one can design highly-reliable systems with the aid of continuous redundancy

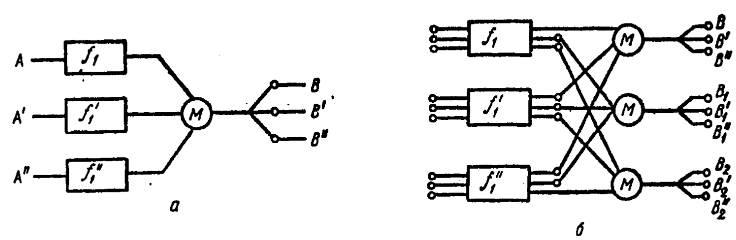

Figure 9.4. Diagram of Device Employing Logical Decision by the Majority

Table 9.4. Reliability of Communications and RTO Equipment With Restorable Redundancy

Essence of Task of Providing Reliability of Equipment With Restorable Redundancy	Expressions for Quantitative Evaluation of Reliability of Equipment With Restorable Redundancy		Expressions for Quantitative Estimate of Equipment Reliability Taking Into Account Restorability and Availability of Replacement Components	
	Coefficient of Readiness	Coefficient of Forced Down Time	Determination of Average Number of Replacement Components	Determination of Guaranteed Number of Replacement Components
With restorable redundancy, backup is continuously being replenished with restored units. In this case a failed unit is restored immediately upon failure, and its mean restoration time will always be less than mean trouble-free operation time. It is quite obvious that under these conditions the probability of failure of the entire equipment (system) as a whole is considerably reduced. Thus an important feature of this method of increasing reliability is the capability of restoring failed units to service while the equipment is in good operating order and is performing its functions	$K_r = \frac{\sum_{K=0}^{M}\left(\frac{NT_B}{T_{01}}\right)^K}{\sum_{K=0}^{M+1}\left(\frac{NT_B}{T_{01}}\right)^K}$, where N -- number of main units; M -- number of backup units; K -- number of failed units; T_{01} -- mean hours logged to failure by a single unit; T_B -- mean restoration time. With a number of restored units equal to or greater than M+1, the coefficient of readiness of equipment with redundnacy is $K_r = \frac{\sum_{K=0}^{M}\frac{(N\rho)^K}{K!}}{\sum_{K=0}^{M+1}\frac{(N\rho)^K}{K!}}$, where $\rho = \frac{T_B}{T_{01}}$ -- down time indicator	This criterion characterizes probability that the number of failed units exceeds the number of backup units (K>M) $K_n = \frac{\left(\frac{NT_B}{T_{01}}\right)^{M+1}}{\sum_{K=0}^{M+1}\left(\frac{NT_B}{T_{01}}\right)^K}$. In the absence of redundancy (M=0): $K_n = \frac{N\frac{T_B}{T_{01}}}{1+\frac{NT_B}{T_{01}}}$. For all practical purposes $\frac{NT_B}{T_{01}} \ll 1$, whereby $K_n \approx (N\rho)^{M+1}$. Figure 9.5 contains dependence $K_\pi = f(\rho)$. To determine K_r one must utilize relation $K_r = 1 - K_\pi$.	The probability that equipment will perform its functions during time t or with z backup components is equal to $P_z(t) = \frac{(\Delta t)^z}{z!} e^{-\Delta t}$ $(z = 0, 1, 2, \ldots, \infty)$. The average number of expended backup components during operating time t will be $z_{cp} = \Delta t$	To ensure the prescribed guaranteed probability of equipment good operating order P, backup components are required as follows: $z_p = K_3 z_{cp}$, where K_3 -- coefficient of backup components. Figures 9.6, 9.7 contain relations $P = f(z_{cp})$ and $K_3 = f(z_{cp}$ The total operation number of backup components is $z_0 = z_p + z_{np} + z_{xp} + z_{Tp}$, that is, one figures in expenditures of components for preventive maintenance, during storage, transport hauls, etc.

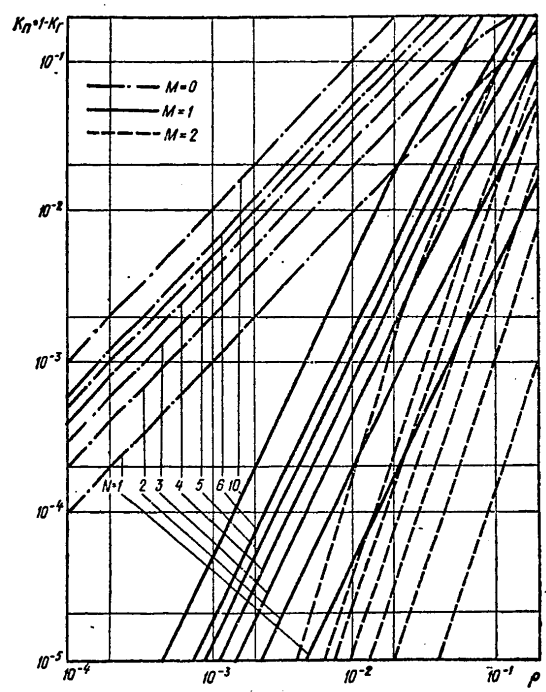

Figure 9.5. Dependence of Coefficient of Forced Down Time K_{Π} of Equipment on Down Time Indicator ρ With Restorable Redundancy

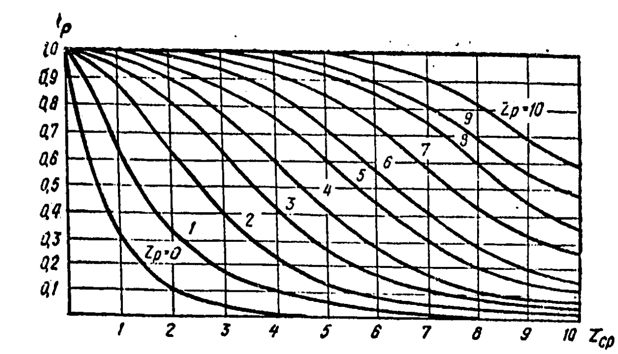

Figure 9.6. Graph of Dependence of Guaranteed Probability of Equipment Good Working Order P on Number of Expendable Replacement Components z_{cp}

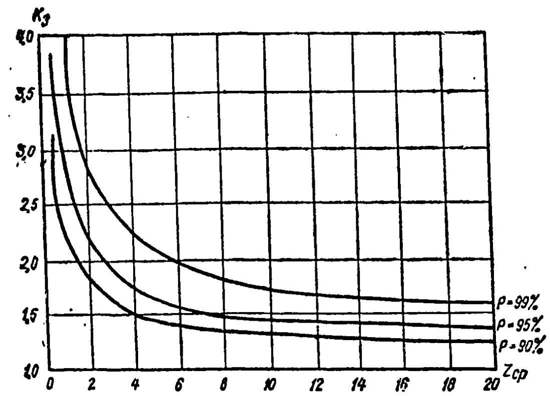

Figure 9.7. Graph of Dependence of Backup Coefficient K_3 on z_{cp} With Different Values of Guaranteed Probability of Equipment Good Operating Condition P

Part IV. OPERATION OF AIR TRAFFIC CONTROL COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT UNDER CONDITIONS OF RADIO INTERFERENCE AND JAMMING

Chapter 10. PROTECTION OF COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT AGAINST RADIO INTERFERENCE AND JAMMING

10.1. Factors Determining Protection of Communications and Radio-Radar Support Services Equipment Against Radio Interference and Jamming

The radio signal generated by all communications and RTO equipment is characterized by frequency, amplitude, phase, polarization, direction of propagation, and other parameters. Each of these parameters can be a specific function of time, and useful information can be contained in each of them (or in several at the same time). Distortions can be caused by disparity between transmitter and receiver parameters and the transmitted signal, as well as various electrical disturbances of internal and external origin, called interference.

Interference, which always accompanies signals, is subdivided into regular and random. Regular interference is the designation given to disturbances the laws of change of which constitute specific functional relations. Their parameters may be determined or prescribed. Elimination of regular interference presents no difficulties. Power supply AC hum is an example of regular interference. This hum is eliminated with the aid of various circuits.

Electrical disturbances of external and internal origin which, depending on specific case, assume different values with specific probabilities, are called random interference. The effort to eliminate random interference is a major problem of radio reception, involving considerable difficulties. If voltage at receiver input can be represented in the form of a sum of signal plus noise, this interference is called additive. Additive interference also occurs in the absence of a useful signal, which is a characteristic feature of this type of interference. So-called multiplicative interference is manifested differently. It can be detected only in the presence of a signal.

Based on origin, interference is subdivided into natural (non-deliberate) and artificial (deliberate and accidental) interference. Interference of natural origin is engendered by various types of fluctuations, that is, random deviations of certain physical quantities from their mean values, by operation of close-by electrical and electronic equipment, by reflections from the earth's surface and local objects. For example, the trajectory of radio wave propagation can fluctuate as a consequence of random changes in the properties of the medium

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(humidity, temperature, ionization, etc): attenuation of radio waves on the path of their propagation can fluctuate under the effect of the same factors; current fluctuates in a resistor in a vacuum-tube or semiconductor device circuit; parameters of the receiver itself also fluctuate (gain, phase, shifts, etc).

Artificial interference or jamming is produced with the aid of special electronic devices and is intended to disrupt normal operation of a communications channel or RTO equipment.

In order to ensure stable operation of communications and RTO equipment under conditions of interference (unintentional, and especially deliberate jamming), protection is provided both to individual equipment and the entire communications and RTO system from radio interference. Protection of communications and RTO equipment against interference and jamming consists of organizational and technical protection measures.

Organizational measures are based, in the first place, on reducing probability of creation of interference and jamming of communications and RTO equipment, secondly on increasing reliability of a communications and RTO system by means of redundancy (performance of identical functions by equipment of different bands, operating principles, etc) and, third, on increasing personnel skills in employment of communications and RTO equipment under conditions of interference and jamming.

Technical measures to protect communications and RTO equipment against jamming can be subdivided into two groups.

The first group includes measures which either impede the arrival of interference signals or which boost the signal-noise ratio at receiver input. They are based on space, polarization and frequency selection effected prior to receiver input.

The second group includes measures employed within the receiver and aimed at boosting the signal-noise ratio at receiver output in comparison with the signal-noise ratio at receiver input. These measures employ techniques of combatting overloading of receiver circuits, various adjustments of receiver parameters, and methods of selection (separation) of interference and useful signals. Useful and interference signal separation arrangements are based on differences in the structure (parameters) of useful signal and interference. In this case time, frequency, amplitude and phase selection are employed.

We shall examine in general form the significance of all the above-enumerated types of useful signal selection employed both ahead of receiver input and within the receiver itself.

Space selection is based on utilization of directional antennas and can be employed in those cases where useful signals and interference arrive at the receiving point from different directions. The ratio of signal power P_c to interference power P_π at receiver input increases G_c/G_π times, where G_c and G_π are receiving antenna directive gains in the directions toward the transmitting station and source of interference.

Time selection is employed when there is a substantial difference either in moments of arrival of signal and interference or in their duration. Operation of circuitry for protection against pulse-type interference is based on this. In particular, time selection is utilized for protection of voice-frequency callup receiving systems against call-up frequency brief-duration oscillations contained in interference and the information signal.

Amplitude selection is based on a difference in the amplitudes of signal and interference and can be utilized only when $P_c > P_{\pi}$. It is utilized, for example, in FM receiver clipper circuits and in noise suppressor circuits, as well as in automatic control systems of phase-modulated signal receivers, which switch off the receiver when useful signal is weak or absent. In addition, amplitude selection is employed in controlling summing amplifiers which add two signals which are separated in space, and consists of two amplifiers with a common load. Amplifier gain depends on the signal-noise ratios at the amplifier input: the amplifier with a higher ratio at input has a higher gain. Amplitude selection is also performed by an operator by ear when receiving signals.

Frequency selection is most extensively employed. It is based on differentiation of the frequency spectra of signal and interference and is effected with the aid of the receiver's resonant circuits. Improved selectivity is achieved by employing additional filters between antenna and receiver.

Polarization selection is possible in those cases where signal and interference have different polarization, that is, the vectors of the electrical field intensities of signal and interference are positioned in different planes.

10.2. Methods of Protecting Radio Communications Equipment Against Radio Interference and Jamming

Radio communication links can be jammed; effectiveness of jamming depends on the ratio of useful signal and interference level at the receiving point. One way to increase the jamming resistance of radio communication links is performance of measures aimed at boosting the useful signal level at the receiving point, that is, at increasing the signal-noise ratio.

Such measures include the following: increase of radiated power, selection of type of antenna system and antenna height above the ground, and selection of operating frequency.

An increase in radiated power P_{Σ} leads to an increase in electrical field intensity E_c at the receiving point and therefore to improvement in the signal-noise ratio. One must bear in mind, however, that there is a square-law relationship between E_c and P_{Σ}, that is, in order to double the E_c/E_{π} ratio it is necessary to increase radiated power fourfold.

Correct selection of antenna arrays at the terminal ends of a radio link can substantially increase electrical field intensity at the receiving point, and consequently can substantially improve the signal-noise ratio at receiver input. The greater the directive gain of the transmitting antenna, the greater the field intensity. Directivity of the receiving antenna improves the signal-noise ratio at receiver input both as a consequence of increase in the useful signal level and attenuation of the noise level (space selection).

The criterion for antenna selection is antenna radiation pattern. Selection of type of transmitting antenna is determined by the condition of generating the greatest field intensity at the receiving point, while selection of type of receiving antenna is determined by conditions of obtaining the greatest signal-noise ratio (that is, the greatest amount by which signal exceeds noise).

In shortwave communications the initial quantity which determines selection of the required types of antenna is angle of radiation $\varepsilon_{\text{изл}}$. Angle of radiation $\varepsilon_{\text{изл}}$ is defined as that angle in relation to the horizon at which there should occur emission of radio waves capable of reflecting from ionized layers of the ionosphere and reaching the destination point. Angle of departure depends on the length of the communication link and the effective altitude of the reflecting layer. At small communication distances angle of radiation $\varepsilon_{\text{изл}}$ will be large, while this angle will decrease as distance increases. For example, at communication distances of 250 km the radiation angle is approximately 55-70°, and at distances of 1,500 km -- 11-25°.

The most effective antenna is one in which the radiation pattern maximum in the vertical plane has an angle with the horizon close to the radiation angle. In contrast to shortwave stations, VHF-UHF ground stations employ omnidirectional antennas, while directional antennas can be used for communications between ground control facilities.

Correct selection of communications operating frequency. For communications in a given shortwave radio link, one can employ operating frequencies the bandwidth of which is limited by the maximum usable frequencies (MPCh) and by the lowest usable frequencies (NPCh). The upper boundary (MPCh) is determined by the possibility of reflection of radio waves from ionized layers of the ionosphere and is determined only by the state of these layers. The lower boundary, connected with absorption of the energy of radio waves in the process of their propagation, depends on the state of the ionosphere, technical parameters of the equipment, and noise level at the receiving point. The degree of absorption of energy of radio waves in the process of their propagation depends on communications frequency. One can assume with a certain degree of approximation that the absorption coefficient is inversely proportional to the square of the frequency. Consequently, the higher the communications operating frequency, the less the absorption, and consequently the greater the electrical field intensity at the receiving point. Therefore communications operating frequencies, from the standpoint of resistance to interference, should be selected close to the MPCh (optimal operating frequency ORCh $\approx$ 0.85 MPCh). Operation at the optimal frequency, from the standpoint of reception, will ensure a maximum useful signal level, and consequently a favorable signal-noise ratio.

Operation frequency for a specified communication link can be selected by various methods, but mandatorily on the basis of considering the state of the ionosphere. It is quite obvious that the broader a radio set's band and the more discrete frequencies in this band, the more precisely one can approximate operating frequency to optimal communication frequency and ensure a maximum useful signal level at the receiving point.

Selection of communication operating frequency for a VHF-UHF line-of-sight radio link has practically no effect on field strength at the receiving point. As regards field strength at points beyond the horizon, in this case lowering frequency leads to an appreciable decrease in field strength. The further the receiving point is beyond the horizon, the greater the effect of wavelength on field strength at this point.

Therefore in order to increase interference immunity in VHF-UHF radio links which extend beyond line-of-sight, it is necessary to select lower frequencies in the band.

Communications interference immunity can also be increased by improving the signal-noise ratio at receiver output. This is achieved by selecting an optimal receiver passband (band change is usually effected in the IF stages).

An optimal receiver passband should be selected taking into account the type of received signal, the character of jamming, and receiver and transmitter tuning stabilities.

The greater the receiver tuning stability and the greater the transmitter frequency stability, the narrower the receiver passband can be, and the greater the jamming resistance of the radio communication link.

With high transmitter frequency and receiver tuning stabilities, the receiver passband is selected approximately equal to the frequency band occupied by the spectrum of the received signal.

Selection of an optimal receiver passband in conformity with the type of received signal is an important measure to protect radio communication links against jamming.

An important measure aimed at increasing the jamming resistance of radio communication links is utilization of the most jamming-resistant types of operation for message transmission.

Radiotelephone messages can be transmitted with the aid of various modulation methods. The most widely used methods in HF radio sets are amplitude tlf-AM) and single-sideband modulation (tlf-OM). As regards frequency modulation (tlf-ChM), it has very limited application in the HF band, and even then with a small modulation index (narrow-band modulation). This is connected with the fact that with frequency modulation the spectrum width of the transmitted signal is very large, and consequently a wideband voice channel is obtained. Of the two types of radiotelephone communications, with amplitude and single-sideband modulation, single-sideband is the most jamming-resistant. This is due to the fact that with single-sideband modulation the power of the transmitter output tube is utilized more efficiently, the receiver passband narrows, and conditions of radio wave propagation improve. All this ensures a higher signal-noise ratio at receiver output, and consequently jamming-free reception.

Just for the first two reasons (more efficient utilization of transmitter output tube power and narrowing of the receiver's passband approximately in half), single-sideband operation, from the standpoint of jamming resistance, is equivalent to amplitude-modulation voice communications with a transmitter power of 8 times that of a single-sideband transmitter. In addition, with single-sideband modulation there is a sharp decrease in distortions occurring in the process of radio wave propagation. The latter is connected with the absence, with single-sideband modulation, both of a carrier frequency (and therefore also distortions caused by its selective fading), and a second sideband. The absence of a second sideband eliminates distortions caused by selective fading and fluctuations of the phase components of this band. As regards fluctuations of the amplitudes of the components of the transmitted sidebands, they are perceived as change in reception strength, while fluctuations of the phases of these components, which cause changes in the audio-frequency phase, are not perceived by the human ear. This decrease in distortions also increases the signal-noise ratio at receiver output.

The overall maximum (theoretical) gain in signal-noise ratio at receiver output with changeover from amplitude to single-sideband modulation is approximately fourfold, which is equaivalent to a 16-fold increase in the power of a transmitter with amplitude modulation. For practical purposes it is assumed that single-sideband operation produces a power gain of 8-10-fold.

Of practical application for increasing the jamming resistance of radiotelephone communications with single-sideband modulation is single-sideband signal amplitude limiting (clipper circuit). This circuit compresses the dynamic range of the high-frequency signal, which reduces this signal's peak factor.*

Reduction of the peak factor of a single-sideband signal increases efficiency of utilization of a transmitter's output tubes, since the average power of a single-sideband signal will increase:

$$P_{cp.en} = \frac{P_{max}}{p^2}.$$

Clipping, that is, decreasing the dynamic range of a high-frequency single-sideband signal, usually is performed in the circuit where the upper sideband is formed after the first ring mixer, that is, at the comparatively low intermediate frequency. Normally utilized for this purpose is a band limiter consisting of a quartz band filter, amplifier and amplitude clipper-limiter. As a result of inclusion of a clipper circuit, the signal peak factor is reduced and approaches a value of 1.41, while the quality of communication (intelligibility) does not drop very appreciably. This is due to the fact that when limiting a single-sideband signal a considerable portion of the spectrum of nonlinear distortions lies far beyond the boundaries of the initial signal spectrum frequency band.

* Peak factor p of a complex oscillation is a coefficient characterizing the relationship between peak P_{max} and average P_{cp} powers of complex oscillation:

$$p = \sqrt{\frac{P_{max}}{P_{cp}}}.$$

The average power of a single-sideband signal with operating clipper circuit increases 4-5-fold, thus increasing the jamming resistance of a single-sideband voice communication radio link.

As a result of employment of radiotelephone signal limiting with single-sideband modulation, it is also possible to increase range of communications by approximately 50%.

Of great significance for increasing the jamming resistance of radio equipment in voice communication mode (particularly VHF-UHF equipment) is employment of a low-frequency signal dynamic range limiter. Operation of a limiter consisting of a low-frequency amplifier and diode amplitude clipper-limiter boosts the average percentage modulation and thus substantially increases the signal-noise ratio at receiver output.

Employment of a limiter increases a link's jamming resistance by 3-5-fold. A clipped signal, however, is more poorly perceived by the ear than an unclipped signal, since distortions appear as a consequence of clipping, worsening speech intelligibility. Therefore it is advisable to switch on the limiter only when comparatively strong interference is present. In this case the deficiencies inherent in a clipped signal are manifested insignificantly, and the jamming resistance of radio reception increases. Switching on the limiter in the absence of interference, that is, when speech intelligibility is fairly high, leads to an appreciable worsening of intelligibility, and the gain produced by the limiter is insignificant.

A ShOU system is sometimes used for protection against pulse interference (high amplitude and brief duration). In this case the receiver, consisting of a wideband limiter, a maximum limiter and narrow-band filter, suppresses pulse interference automatically as it appears.

Primarily amplitude (tlg-AT) and frequency-shift (tlg-ChT)keying is employed for transmission of radiotelegraph messages in shortwave equipment.

Amplitude keying, which as a rule is employed with key transmission and aural receiving, is less resistant to jamming than frequency-shift keying. Changeover to frequency-shift keying with the same quality of communications is for all practical purposes equivalent to a power gain of 4-9-fold in comparison with amplitude keying. This is due to the fact that with frequency-shift keying the transmitter continuously generates high-frequency oscillations with maximum power, the frequency of which varies insignificantly (by the amount of frequency shift) with current and currentless pulses of driving voltage, and an amplitude clipper and counter connection of positive and negative impulse rectifiers are employed in the receiving device. Frequency-shift keying is employed both in teleprinter and key transmission with aural reception.

The jamming resistance of aural telegraphic communication links with frequency-shift keying is greater than that of links with printer reception.

Two-channel frequency telegraphy (DChT) can also be used in addition to single-channel frequency telegraphy. Due to broadening of the receiver passband in receiving DChT signals, jamming resistance is somewhat diminished (in comparison with single-channel frequency telegraphy). In order to retain identical jamming resistance of ChT and DChT systems, transmitter power in a DChT system should be increased by 15-20% over transmitter power in a ChT system.

10.3. Methods of Protecting Radio-Radar Support Services Equipment Against Radio Interference and Jamming

Differing-structure active jamming can be generated to counter radio-radar support facilities, just as communications equipment, and in addition, in contrast to communications equipment, so-called passive jamming can be employed against a large group of radar support facilities -- radar stations -- that is, interference appearing at radar input terminals as a consequence of reflection of radar signals from reflecting objects which are not desired radar detection targets.

Methods of protection against active jamming of radio navigation facilities fully coincide with the measures discussed in 10.2 on protecting communications equipment against radio interference and jamming. Therefore what was stated above in 10.2 also fully applies to radio navigation systems operating in continuous radiation mode.

Methods of Protecting Radars Which Prevent Interference From Entering the Receiver

Space selection as a means of combatting radar jamming consists in employing highly-directional antenna arrays with small side lobes. In order to reduce the level of interference signal reception (both active and passive), radars employ special circuits for suppression (compensation) of side lobes, which substantially reduce the interference signal level, and therefore improve the resistance of radars to jamming.

Polarization selection is employed in centimeter-band radars (in instrument landing radars, for example) to attenuate interfering reflections from atmospheric water vapor. Polarization selection involves placing at the radar antenna exciter output a polarization array, with the aid of which the linear-polarized radiator field is transformed into a circular (or elliptical) polarization field. Differing change in polarization occurs during reflection of radar pulses from hydrometeors and aircraft. As a result the signals reflected from hydrometeors, altering their direction of rotation with circular polarization, are suppressed by the polarization array, while signals reflected from an aircraft, retaining their direction of rotation, pass through to the receiver input terminals. Maximum attenuation of returns from hydrometeors can be achieved by means of selection of polarization array angle of rotation.

Polarization selection can also be used to combat active jamming which differs from reflected signals in polarization characteristics. In this instance, radiating elliptically polarized waves and tuning the antenna-waveguide circuit to the polarization parameters of the useful signal, one can substantially boost the signal-noise ratio. For example, with identical signal and interference field power at the antenna, their ratio at the receiver input terminals will be

$$\frac{P_n}{P_c}=\frac{2}{1\pm\frac{4k_nk_c}{(1+k_n^2)(1+k_c^2)}+\frac{(1-k_c^2)(1-k_n^2)}{(1+k_c^2)(1+k_n^2)}\cos(\theta_c-\theta_n)}, \tag{10.1}$$

where k_c, k_n -- coefficients of ellipticity of signal and interference fields; $\theta_c - \theta_n$ -- angle between major axes of ellipses of polarization of signal and interference fields.

A "plus" sign is placed between the 1 and fraction in the denominator of formula (10.1) when the directions of rotation of the signal and interference fields coincide, and a "minus" with opposite direction of rotation.

Frequency selection prior to radar input terminals consists in the capability of frequency-tuning radars. Frequency tuning can be continuous, discontinuous with shift to prior-determined frequencies, and discontinuous with random change from one frequency to another. Rate of frequency retuning can involve slow manual tuning and fast automatic tuning, including from one radar operating cycle to the next (retuning from pulse to pulse). Radar retuning from pulse to pulse is the most effective means of protection against active jamming, which practically eliminates the effect of response jamming by frequency.

Methods of Protecting a Radar Receiver From Interference Reaching Its Input Terminal

These methods are based on combatting receiver circuit overloading and on employing special useful signal and interference selection circuits, which utilize differences in their spectral composition, amplitude, phase, duration, and pulse repetition rate.

In conformity with this, we differentiate frequency, time, phase, and amplitude selection. All types of selection other than amplitude are extensively employed in ground radars. Amplitude selection has not enjoyed widespread application in radars, since a large dynamic range of useful signal change and fluctuation in magnitude of reflected signals can totally obliterate differences in the amplitude relationships between interference and signal.

Phase selection is a particular case of time selection, since the selection parameter is the time shift between interference and signal, which for high-frequency oscillations is manifested in a phase shift between them. Phase selection is extensively employed in radars with selection of moving targets for suppressing passive jamming.

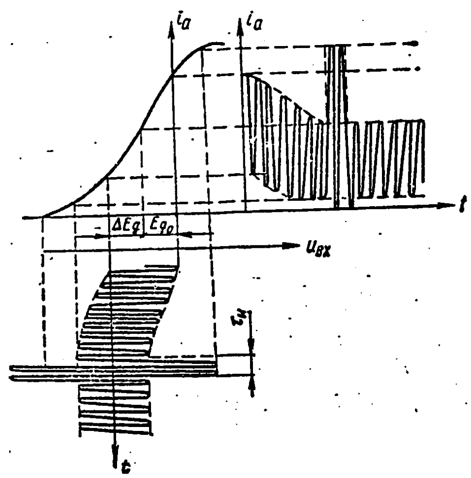


Figure 10.1. Illustration of MARU Circuit Operation

Combatting receiver circuit overload. Receiver protection against overload both by ground clutter and by active jamming boils down to increasing its dynamic range. Receiver overloading can occur in the various stages: in the IF amplifier, in the detector, and in the video amplifier. Various devices with nonlinear amplitude characteristics are employed to combat overloads. A brief description of these devices is given below.

Broadening dynamic range of IF amplifier. Customarily overloading occurs primarily in the final stages of the IF amplifier. The dynamic range of an IF amplifier can be broadened by employing higher-power tubes and by applying higher plate and screen grid voltages to the IF amplifier tubes. To increase dynamic range one can reduce gain in the IF amplifier channel and increase it in the video channel. Employment of this method, however, is limited by the necessity of a certain voltage on the detector to ensure linear detection (usually in the order of 1 volt).

Instantaneous automatic gain control (MARU) makes it possible to maintain a high gain for short-duration useful pulses of small and medium amplitude and sharply to reduce the gain of pulses of large duration and amplitude. Such a circuit makes it possible to attenuate ground clutter, interference from regions of passive jamming and from active pulse jamming of large duration and amplitude.

The operating principle of instantaneous AGC is as follows: when large-amplitude interference appears on the tube grid of a controllable IF amplifier stage, additional bias is applied, equal in magnitude to the amplitude of the interference, moving the operating point considerably to the left of normal receiving conditions. This eliminates signal suppression by the interference,

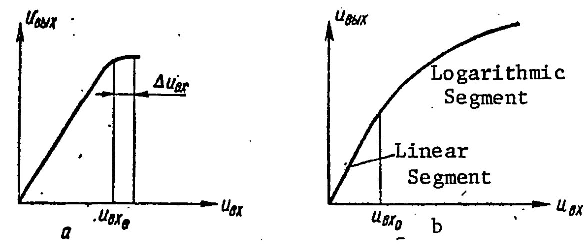


Figure 10.2. Amplitude Characteristic Curve of a Linear (a) and Linear-Logarithmic IF Amplifier (b)

which is amplified on the linear segment of the tube characteristic curve (Figure 10.1). A differentiating circuit with a short time constant is sometimes placed between detector and video amplifier to suppress long pulses remaining beyond the instantaneous AGC.

Employment of an IF amplifier with a linear-logarithmic amplitude characteristic curve. The amplitude characteristic curve of a conventional (linear) receiver has the appearance as shown in Figure 10.2a. Such a receiver becomes easily overloaded, that is, upon attaining input voltage u_{Bx0}, further voltage increase does not produce an increase in output voltage. In a receiver with logarithmic IF amplifier, the characteristic curve for small-amplitude signals (u_{Bx0}) is linear (Figure 10.2b), while for strong signals it has the shape of a logarithmic curve. As a result an increase in input signal within broad limits does not lead to overloading the receiver and makes it possible to observe weak signals on a strong noise background (or alongside strong interference). Usually the ratio of output to input voltage for such IF amplifiers has the form

$$u_{\text{вых}} = u_{\text{вх}_0} k_0 \left(\ln \frac{u_{\text{вх}}}{u_{\text{вх}_0}} + 1 \right), \qquad (10.2)$$

where u_{Bx0} -- input voltage at the end of the linear segment of the characteristic curve; k_0 -- gain on the linear segment of the characteristic curve; u_{Bx} -- input voltage.

Time automatic gain control (VARU). In ground radars, and particularly in landing approach radars, it is desirable to have receivers which provide equal observation on the scope of identical targets located at various distances from the radar site. The power of a reflected signal is inversely proportional to the fourth power of the distance. Therefore when one is monitoring with the aid of a precision approach radar a descending aircraft from a distance of 20 km to touchdown at a distance of 2 km from the radar, the power of the reflected signal will change by a factor of 10,000. Naturally with the same receiver amplification in the process of approach, the difference in observability of the aircraft at the beginning and end of the approach process will be substantial. In order to eliminate this phenomenon and to protect the receiver from being overloaded with a high-power pulse from the transmitter and powerful returns from nearby objects, a time automatic gain control circuit is employed.

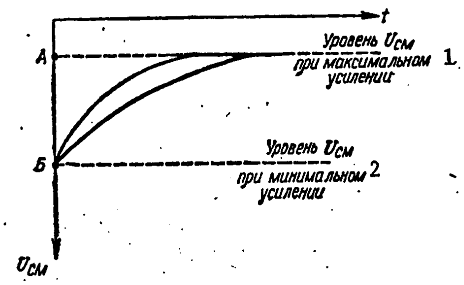


Figure 10.3. Change in Bias Voltage in IF Amplifier With Instantaneous AGC Circuit

Key:
1. U_{cm} level with maximum gain
2. U_{cm} level of minimum gain

Operation of a time AGC circuit is as follows: simultaneously with transmission of a pulse by the radar transmitter, a circuit is activated which sharply reduces receiver gain by applying a large negative bias voltage to the IF amplifier tube grids during the time powerful returns arrive from nearby objects. Then gain increases exponentially and reaches a maximum value at the moment reflected signals are received from more distant targets (Figure 10.3). Decreasing receiver gain when signals are being received from nearby objects, the VARU circuit also attenuates signals received from the lateral and rear lobes of the antenna radiation pattern. By selecting VARU circuit parameters (capacitor discharge time constant), one can alter the rate of change of the control grid bias voltage, that is, alter the rate of receiver gain increase.

Methods of protection based on signal and interference parameter selection. Useful signal and interference frequency spectrum selection (frequency selection) is based on utilizing the selective properties of various kinds of filters. Employment of the optimal filtration method can be the most effective means of protecting pulse radars against jamming. This method consists in the following: signal and interference are applied in the receiver to a special filter, which possesses the ability to pass only the frequency spectrum components of a useful signal, blocking the remaining frequency components of the receiver's passband. In this case the useful signal passes through the filter unattenuated, while the interference signal, the power of which is distributed among all the frequency components of the receiver's passband, will be attenuated to a substantial degree. The amplitude-frequency characteristic of an optimal filter is proportional to the ratio of signal spectrum amplitudes to the energy spectrum of the interference.

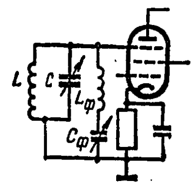


Figure 10.4. Diagram of Rejection Filter

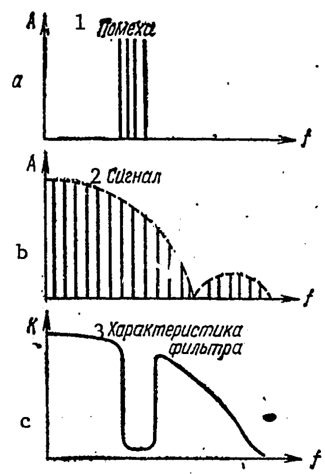


Figure 10.5. Graphs (a, b, c) Showing Rejection Filter Operation

Key:
1. Interference
2. Signal
3. Filter characteristic curve

The greater the amplitude of the signal components and the less the intensity of interference, the greater the degree to which an optimal filter passes frequency spectrum components. The greater the degree to which the signal spectrum differs from the interference spectrum, the greater the signal-noise ratio at filter output. With a uniform interference spectrum, the filter's amplitude-frequency characteristic curve coincides with the amplitude-frequency composition of the signal. Rejection and comb filters are examples of circuits based on optimal filtering.

Rejection filters are employed to suppress narrow-band interference, that is, interference signals the spectrum of which is narrower than that of the useful signal (unmodulated interference or interference with simple types of modulation). With the aid of a rejection filter, the band of frequencies in which the interference is located is removed from the receiver's overall passband. Figure 10.4 contains a sample diagram of a rejection filter, and figure 10.5 -- amplitude-frequency diagrams which explain the operating principle of a rejection filter, which has a sharp decrease in gain K at the interference signal frequencies.

Comb filters can be employed to remove pulse signals from noise interference. Figure 10.6 contains graphs showing filter operation. The top graph (a) depicts the energy spectrum of a noise signal which, as is evident from the figure, is continuous and almost constant in amplitude. The middle graph (b) shows the energy spectrum of a useful signal -- a clipped train of video pulses (a packet of pulses reflected from a target) with a repetition rate of $F_{и}$. The bottom graph (c) contains an amplitude-frequency characteristic curve of a comb filter. It is clearly evident from the figure that with this filter characteristic curve the entire energy of the pulses will pass through the filter, while the interference will be passed only in part, only within the boundaries of the comb filter's elementary passband.

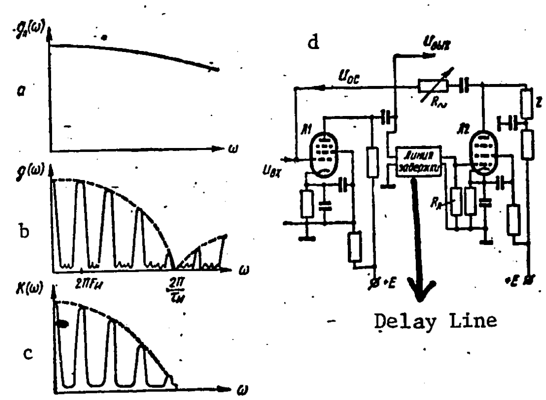


Figure 10.6. Showing Operation of a Comb Filter (a, b, c), and Diagram of Comb Filter (d)

In order to obtain an undistorted signal, a filter should pass the bulk of the signal spectrum, which is concentrated in the band

$$\Delta f_{\phi} = \frac{1}{\tau_{и}}.$$

If a filter contains n elementary bands Δf_i in width, the voltage gain in the signal-noise ratio will be approximately $\Delta f_{\phi} / n \Delta f_i$ times.

An amplitude-frequency characteristic curve close to that of a comb filter can be obtained with an amplifier with feedback through a delay line with a delay of the pulse repetition period $T_{и}$. The line is loaded by resistor $R_{л}$, equal to its characteristic impedance. The Л2 stage amplifies signal taken from the delay line. Plate load Z can be resonant or aperiodic (depending on whether pulses at the intermediate frequency or video pulses are being amplified). Feedback voltage u_{OC}, controlled by resistor R~, is applied from the plate of tube Л2 to the control grid of Л1. Output voltage $u_{вык}$ is taken from the plate of tube Л1.

A comb filter can also be employed to protect a radar from nonsynchronous pulse interference.

Employment of the storage method is one variation of the method of optimal filtering. The storage method is based on periodicity of a useful signal in time, differentiating the signal from interference. This is essentially a variation of the comb filter method, but examined from a time standpoint. Technical implementation of the storage method is substantially simpler, and therefore this method of protection against noise jamming is extensively employed in radars.

Target returns comprise a limited periodic sequence of pulses. There exists no regularity for noise jamming. Therefore if one performs small m-times (within a single packet of reflected pulses) adding of signals received in adjacent radar operation cycles, the amplitude of useful signals, since their appearance is rigorously specified and coincides in time in adjacent cycles, will also increase m times, while noise signals, since their appearance is random, will increase by only $\sqrt{m}$ times. As a result the signal-noise ratio at storage circuit output increases m times in power.

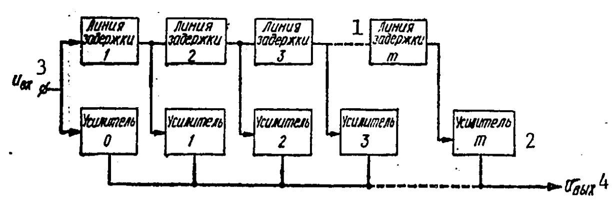


Figure 10.7. Block Diagram of Storage Circuit With Delay Lines

Key:
1. Delay line
2. Amplifier
3. Input voltage
4. Output voltage

Adder circuits with delay lines, CRT tubes with storage of charges (beam storage tubes), with dark trace, and various integrating circuits can be employed as storage devices in radar equipment. Figure 10.7 contains a block diagram of a storage circuit with delay lines. The signal is applied to the amplifier input through delay lines with a delay of the pulse repetition period, while the amplifier outputs are applied to a common load. With this circuit arrangement, following a number of pulse repetition periods equal to the number of delay lines m, the output signal will correspond to storage for m pulse repetition periods.

With a sufficiently large number of storage cycles, these circuits make it possible fairly effectively to segregate weak reflected signals on a noise jamming background. Storage circuits have one shortcoming, however -- the need for time for storing pulses. A spectral analysis of the operation of storage circuits indicates that their amplitude-frequency characteristic curve has the form of a comb filter, and the greater the number of storage cycles, the closer its characteristic curve is to an ideal comb filter.

Selection by signal duration is one kind of time selection and is employed in radars to attenuate interference the duration of which differs from radar pulse duration. The simplest circuit for selection by duration is a differentiation circuit consisting of a capacitor and resistor connected in series (Figure 10.8). As is evident from the time diagrams, in selecting differentiating circuit time constant $\tau = RC \ll \tau_и$ (customarily $\tau < 0.1\tau_и$) two short pulses of different polarity are formed from the useful and interference signals at the circuit output, and the amplitudes of these pulses are determined by the rate of voltage buildup in the input signals. Since customarily large-duration pulses have a sloping leading edge, the output pulses of a differentiating circuit will have less amplitude than when differentiating useful signals. Following a clipping circuit, only pulses of positive polarity are applied to the scope.

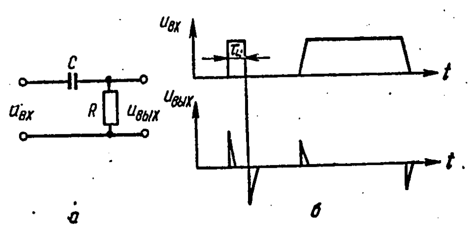


Figure 10.8 Differentiating Circuit: a -- circuit; б -- time diagram

Such a circuit enables one to attenuate the interfering effect of active pulse jamming with long-duration pulses, and also partially to remove from the radar scope strong reflections from chaff as well as clutter. Employment of a differentiating circuit is the most common method of protecting ground radars against jamming.

The most sophisticated method of protecting against active pulse jamming where jamming pulse duration is not equal to that of the radar pulses, is a pulse duration selection circuit. Figure 10.9 contains a block diagram of such a circuit and time diagram depicting its operation. Received signals of duration $\tau_и$ and t (line 1) are fed, following amplification in the video amplifier, to an RC differentiating circuit. Two short pulses with intervals between pulses $\tau_и$ and t appear at circuit output (line 2); these pulses are fed to two channels. The first channel consists of a cathode follower, which passes pulses only of positive polarity, leaving their polarity unchanged, and a delay line with a delay of radar pulse duration $\tau_и$. Present at the input of this channel are single pulses displaced by time $\tau_и$ relative to the leading edges of the input signals (line 3). The second channel contains a grid-clipping amplifier, which amplifies negative-polarity pulses and reverses their polarity to positive (line 4). Signals from the outputs of both channels are fed to a gate circuit which produces a pulse of negative polarity when signals from the outputs of both channels coincide in time. Thus in our example there will be only one channel at the selection circuit output which corresponds to the trailing edge of the radar pulse (line 5). In other words only those signals the duration of which is equal to a radar pulse duration will be applied to the scope, while jamming signals, differing in duration, will not pass through the selection circuitry. These pulse duration selection circuits usually effectively suppress that jamming with pulse duration differing from useful signal by not less than 50-100%.

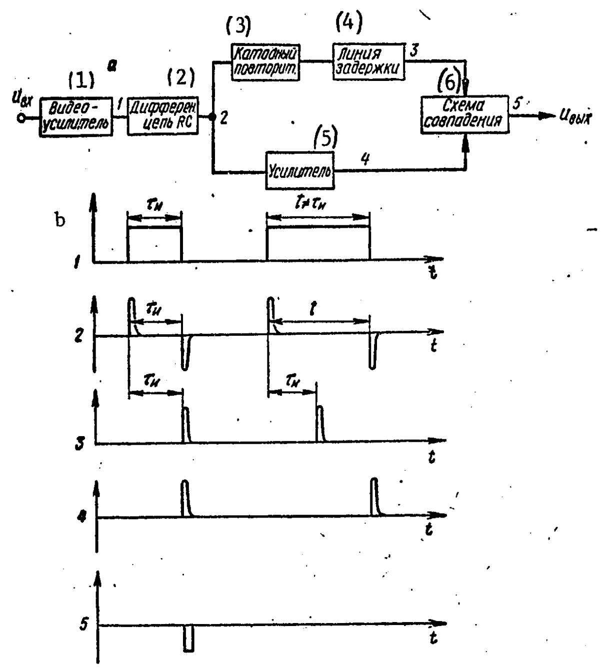


Figure 10.9. Selection by Pulse Duration: a -- block diagram; b -- time diagrams

Key:

1. Video amplifier
2. RC differentiating circuit
3. Cathode follower
4. Delay line
5. Amplifier
6. Gate circuit

Selection by pulse repetition frequency is also a variant of time selection and is employed to protect radars against pulse nonsynchronous interference, which can be interference from neighboring radars or from other pulse devices, as well as deliberate jamming.

Operation of a pulse repetition frequency selection circuit is based on comparison of received signals in two adjacent radar operating cycles. A comparison circuit separates out only those signals of two adjacent cycles which coincide in time of arrival at the circuit. Therefore signals which do not correspond to the radar pulse repetition frequency will not time-coincide in adjacent cycles and will not pass through the comparison circuit. Useful signals, separated by the pulse repetition period, will coincide in adjacent cycles and will pass through the comparison circuit.

Figure 10.10 contains a simplified block diagram of a repetition frequency selection circuit with delay line and time diagrams illustrating its operation. Circuit operation is similar to that of the above-discussed selection by duration circuit. A gate circuit separates out only target-reflected signals the repetition period of which, $T_и$, is equal to delay line passage time. In many cases, in place of a delay line with a repetition period delay (usually an ultrasonic delay) and gate circuit, circuits with cathode ray tubes with charge storage are employed, which also store signals for the repetition period and compare them. Circuits with beam storage tubes are more stable and more effective than circuits with ultrasonic delay lines.

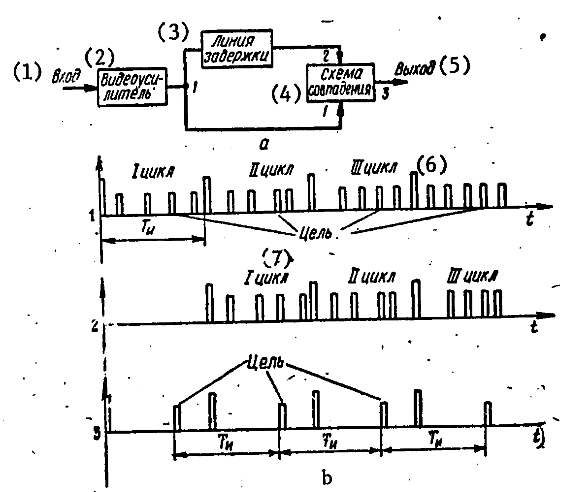


Figure 10.10. Selection by Pulse Repetition Frequency: a -- block diagram; b -- time diagrams

Key:
1. Input
2. Video amplifier
3. Delay line
4. Gate circuit
5. Output
6. Cycle
7. Target

Moving target selection (SDTs) in ground pulse radars is employed to protect against passive interference occurring both with reflection from the earth's surface and with jamming with chaff. When a SDTs circuit is switched on, a radar changes to coherent-pulse radar mode, which makes it possible, in addition to a target's coordinates, to determine its radial velocity in relation to the radar. Radial velocity is determined by utilization of the Doppler effect: with reflection of radio waves from objects with radial velocity V_r(m/s), the frequency of reflected signals received by the radar f_{OTp} (Hz) will differ from the frequency of radiated signals by quantity

$$f_{отр} - f_{изл} = F_д = \frac{2V_r}{\lambda}, \qquad (10.3)$$

where λ -- wavelength of radiated oscillations, m.

Value $F_д$ is called Doppler frequency or Doppler frequency shift.

Doppler frequency in a reflected signal can be obtained and measured if the direct and reflected signal observation time significantly exceeds the Doppler frequency period. This condition practically corresponds to continuous radiation mode.

In pulse radars in which duration of the reflected signal is very short (microseconds and fractions of a microsecond), during a single pulse the Doppler effect is manifested in an additional phase shift of reflected oscillations from the moving target. One can see this from the following.

Let a target be illuminated by a signal the instantaneous value of which is $u=U_m \sin 2\pi ft$ (U_m -- signal amplitude, f -- frequency, t -- time, product $2\pi ft$ -- current oscillation phase) A signal reflected from a target at distance D will return to the radar with a delay of $t_1=\frac{2D}{c}$, and its instantaneous value will be $u_{OTp}=U'_m \sin 2\pi f(t+t_1)$. If the target is stationary, in each operating cycle lag time t_1 is constant, and the difference of direct and reflected signal phases is also constant and equal to:

$$\varphi_{неподв} = 2\pi f(t+t_1) - 2\pi ft = 2\pi ft_1 = \text{const}.$$

If the target is moving at a radial velocity V_r, in the first operating cycle lag time $t_1=\frac{2D}{c}$, in the second $t_2=\frac{2(D+\Delta D)}{c}$, in the third $t_3=\frac{2(D+2\Delta D)}{c}$, etc. In other words, lag time from cycle to cycle changes by quantity

$$\Delta t = \frac{2\Delta D}{c} = \frac{2V_r T_и}{c} \left(T_и = \frac{1}{F_и}\right.$$ -- radar pulse repetition period).

The difference in signal oscillation phases (direct signal and return from moving target) changes from one radar operating cycle to the next. The additional phase shift of direct and reflected signals in two adjacent cycles

$$\Delta\varphi = 2\pi f \Delta t = 2\pi f \frac{2V_r}{c} T_и = 2\pi F_д T_и \qquad (10.4)$$

is determined by the target's radial velocity.

Thus a signal reflected from a stationary target will in all radar operating cycles have a constant phase shift relative to the radiated signal, while a signal reflected from a moving target will be continuously changing the phase shift relative to the radiated signal from one radar operating cycle to the next.

Utilization of the above-examined phase shift in SDTs circuits to discriminate moving targets from background interference is done by comparing in a phase detector the voltage of reflected signals with voltage coherent to transmitter oscillations.

In performing phase detection, these phase shifts are easily converted into amplitude changes. In this case the amplitudes of signals reflected from stationary objects (the earth, chaff) will have the same value in adjacent cycles, while those from moving targets will have a different value. Then mutual compensation of pulses of constant amplitude (reflected from stationary targets) and segregation of pulses from moving targets are accomplished by comparing the signals of two adjacent radar operating cycles in a cancelling circuit (so-called period-jump compensation) [15].

SDTs circuits can have internal and external coherence, depending on what determines coherent voltage frequency.

In circuits with internal coherence, coherent voltage is linked by frequency and phase to radar transmitter oscillations, and therefore in pure form such SDTs circuits are capable of suppressing signals only from genuinely stationary targets. Under actual conditions of protection against passive jamming as well as against reflections from hydrometeors, in precision approach radars, for example, interfering objects also have radial velocities relative to the radar, and their reflected signals will not be compensated by a SDTs circuit with internal coherence without adjustment. Either circuits with external coherence are employed for compensation of such reflected signals, or coherent voltage phase adjustment for translational velocity of interfering objects (wind and antenna rotation compensation) is introduced in circuits with internal coherence. Such compensation is performed automatically in circuits with external coherence, since coherent voltage is synchronized by the reflected signal from the leading edge of distributed reflectors and carries information on their radial velocity.

Delay by the pulse repetition period and period-jump subtraction in SDTs circuits can be performed just as in repetition frequency selection circuits, either in ultrasonic delay lines and tube cancelling circuits or in cathode ray tubes with charge storage (most frequently in beam storage tubes). In the latter case, in order to increase the circuit's effectiveness multiple period-jump cancelling (usually double or triple) can be performed. However, even with single cancelling, employment of beam storage tubes possesses a number of advantages over circuits employing ultrasonic delay lines, such as the capability of readily changing radar pulse repetition frequency, the absence of a special delay line excitation generator and related additional components, smaller circuit weight and size, etc.

The actual configuration of SDTs circuits is quite diversified, but their general operating principles are approximately the same and can be understood with an example of a very simple SDTs circuit with internal coherence and a beam storage tube cancelling circuit as shown in Figure 10.11. For comparison of the phases of the direct and reflected signals, the SDTs circuit employs a coherent oscillator -- an oscillator generating continuous sinewave oscillations rigidly bound in phase with the phase of radar transmitter oscillations. For this the coherent oscillator operates at the intermediate frequency and is phased (rigidly phase-linked with the transmitter phase) by a transmitter pulse converted with the aid of the receiver's local oscillator in a phasing mixer to the intermediate frequency. Comparison of phases at the intermediate frequency does not alter previously derived relations, but it simplifies design of a radar and its SDTs circuit.

Signals reflected from a target and converted by local oscillator into intermediate-frequency oscillations are phase-compared with the coherent oscillator voltage in a phase detector the output voltage of which is determined by the phase difference of high-frequency oscillations applied to its input. As a result video pulses are formed at the phase detector output, with constant amplitude and polarity when reflected from stationary targets and amplitude and polarity changing from one radar operating cycle to the next when reflected from moving targets.

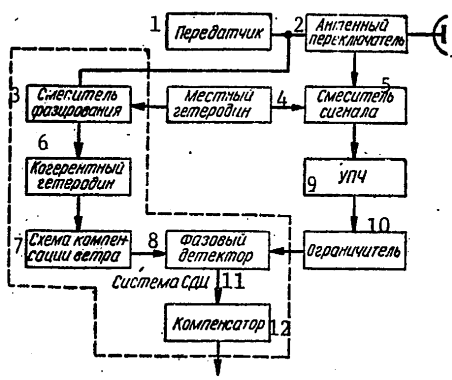


Figure 10.11. Block Diagram of Radar With SDTs System

Key:

1. Transmitter	7. Wind compensation circuit
2. Antenna switch	8. Phase detector
3. Phasing mixer	9. IF amplifier
4. Local oscillator	10. Limiter circuit
5. Signal mixer	11. SDTs system
6. Coherent oscillator	12. Compensator

Thus in the phase detector of a radar with SDTs, the difference in the phase shift of reflected signals is converted into an amplitude difference of video pulses from stationary and moving targets. This means that pulses are for all practical purposes mutually separated. However, in order to eliminate the appearance on scopes of video pulses from stationary targets, it is necessary to keep from feeding them to the scope. Employed for this is a compensating device, which effects period-jump cancellation of video signals at the phase detector output, whereby video signals with constant amplitude are suppressed, while pulses the amplitude of which changes from one period to the next are discriminated.

The operating principle of the SDTs circuit is such that with target radial velocities which produce during each radar operating cycle phase shift $\Delta\phi$ of a whole number of periods $2\Pi n$, the difference in phases of the direct and reflected signal will be identical in all radar operation cycles. Targets with such radial velocities are perceived by the SDTs circuit as stationary, signals from them are compensated, and the targets will not appear on the scope. These radial velocities are called SDTs circuit "blind" velocities. The magnitudes of "blind" velocities are determined by equality

$$V_{r\,слеп} = \frac{\lambda}{2} n F_{и}. \qquad (10.5)$$

As is evident from formula (10.5), a radar may have several "blind" velocities, since n=1, 2, 3,..., etc. The slowest velocity will be at n=1.

In order to avoid "blind" velocities, ground radars employ a variable pulse repetition frequency. If a velocity is "blind" for one repetition rate, it is not "blind" for another, and consequently the target can be detected. Repetition rate can change both continuously and discontinuously.

The best results of compensation of reflections from interference displacing under wind effect are achieved in radars with a two-frequency method of SDTs. In these radars one antenna emits radio-frequency pulses at two frequencies simultaneously in a single radiation pattern. Reflected signals also arrive simultaneously at two frequencies and are received separately by two receiver channels. Reflected signals are fed from the intermediate-frequency amplifier output to a phase discriminator.

In the phase discriminator of the two-frequency radar, reflected signals are compared not with coherent voltage but with one another. As a result video pulses are formed at the discriminator output, the envelope of which changes with the difference Doppler frequency (beat frequency):

$$F_б = F_{д1} - F_{д2} = \frac{2V_r}{\lambda_1} - \frac{2V_r}{\lambda_2} = (f_1 - f_2)\frac{2V_r}{c}, \qquad (10.6)$$

where λ_1 and λ_2, f_1 and f_2 are the wavelength and carrier frequency of the first and second radar channels.

Employment of two channels in the first place increases protection against jamming and, secondly, improves performance of the passive interference protection circuit, especially during radar operation in the decimeter and centimeter bands.

Methods of Combatting Mutual Interference

For receiving weak reflected pulses without significant distortions, radars have highly-sensitive receivers with a fairly broad passband. This decreases the radar's noise immunity, since it opens the way to penetration of external interference signals.

In addition to deliberate jamming, such external interference signals may also be interference from other radars or from other equipment operating in the same frequency band. In order to eliminate or substantially to reduce mutual interference, it is essential scrupulously to meet the requirements of electromagnetic compatibility (see Chapter 11).

Applicable to radar and radio navigation equipment, basic electromagnetic compatibility measures can consist in the following.

When several radars operating in the same and different bands are located in the close vicinity of one another, in order to exclude the influence of mutual interference it is advisable to effect synchronized triggering of all radars from one synchronizing unit (one radar). If this is not possible, it is essential correctly to select the position of each radar taking into account the possible influence of adjacent radars, to disperse in space the operating sectors of individual radars, to determine operating frequencies taking mutual interference into account and, finally, maximally to utilize the radar equipment's interference protection circuitry.

Radar positions must be selected in such a manner as to eliminate the mutual influence of radar emissions, particularly radars operating in the same band. In designating operating sectors, one should avoid the possibility of direct orientation of radar antennas toward one another. Pulse duration and repetition rate selection circuitry can be successfully utilized to combat mutual interference, as well as retuning a radar to other operating frequencies. In addition, for this same purpose one can sometimes resort to radar servicing adjustments -- adjustment of receiver gain, brightness, focus, scanning rate and frequency.

10.4. Method of Estimating the Influence of Radio Interference and Jamming on Operation of Communications and Radio-Radar Support Services Equipment

The technique of estimating the effect of radio interference on the operation of communications equipment as a rule consists in plotting on a map, with known (or presumed) location in space of the useful signal transmitter and source of interference (jamming source), boundaries of the zone of assured reception of communications transmitter signals with a specified reliability (probability). Probability of reliable reception of useful information is determined by the ratio of useful signal voltage to interference signal voltage at the receiver's input terminals. The minimum signal-noise ratio at receiver input at which reliable reception with the designated reliability is ensured is called the coefficient of reliable reception:

$$q_{\text{НП}} = \frac{U_{\text{сигн}}}{U_{\text{пом}}} \text{ при } P_{\text{над. прм.}} = \text{const}. \qquad (10.7)$$

Values $q_{\text{НП}}$ depend on the type of communication link (amplitude-modulated telephone, AM telegraph, FM telegraph, etc), type of interference signal (noise, pulse, keyed, etc), and required probability of reliable reception under interference conditions. Naturally the greater the requisite probability of reliable reception, the higher $q_{\text{НП}}$ will be for one type of communication link and type of interference signal. The greater the potential noise immunity of a communication link, the lower $q_{\text{НП}}$ will be for different types of communication links, one type of interference and one probability of reliable reception.

Values $q_{\text{НП}}$ are usually determined experimentally, applicable to a given type of communication link and given type of interference. Plotting the boundary of a reliable reception zone consists in finding in space the geometrical position of points at which the preselected $q_{\text{НП}}$ value is assured. Determination of these points in turn is connected with calculation of the field strength of useful and interference signals at a given point in space. With considerably different conditions of propagation of radio waves from a useful signal transmitter and jamming transmitter to the receiving point, the problem of plotting the boundary of the reliable reception zone becomes for all practical purposes difficult to solve. In this instance usually the inverse problem is solved -- determination of the probability of reliable reception at points oriented in a certain manner relative to the communication station and interfering station. For this one calculates, from the station's distances and energy potentials, the interference and signal field strength at the receiving point, and probability of reliable reception is determined on the basis of their ratio.

Then, when the conditions of propagation of radio waves from the communication station and interference station are identical or can be assumed identical, which in the majority of cases is correct when estimating the influence of interference on ground and air communication links in the VHF-UHF band or shortwave band involving only ground-wave propagation, it is possible fairly simply to determine the boundary of the reliable reception zone from the specified parameters of the jamming station and communication station. The location, type and dimensions of the reliable reception zone are dependent with specified probability on energy coefficient K, which is equal to the product of the coefficient of reliable reception $q_{\text{НП}}$ times the ratio of energy potentials of the jamming station ($A_{\text{ПП}}$, w) and communications station (A_c, w):

$$K = q_{\text{НП}} \sqrt{\frac{A_{\text{ПП}}}{A_c}}. \qquad (10.8)$$

where

$$A_{\text{ПП}} = P_{\text{ПП}} G_{\text{п}} \frac{\Delta f_{\text{прм}}}{\Delta f_{\text{п}}} k_{\text{п}},$$

$P_{\text{ПП}}$ -- jamming transmitter power, watts; $G_{\text{п}}$ -- directive gain of jamming transmitter antenna; $\Delta f_{\text{прм}}$, $\Delta f_{\text{п}}$ -- receiver passband and band of radiated jamming signals, kHz; $k_{\text{п}}$ -- coefficient which takes into account the variance in polarization between jamming and useful signals ($k_{П}$=1 when polarization coincides, $k_{П}$=0.5 with circular-polarization interference and linear-polarization signal); P_c -- communication link transmitter power, watts; G_c -- communication link transmitter antenna directive gain.

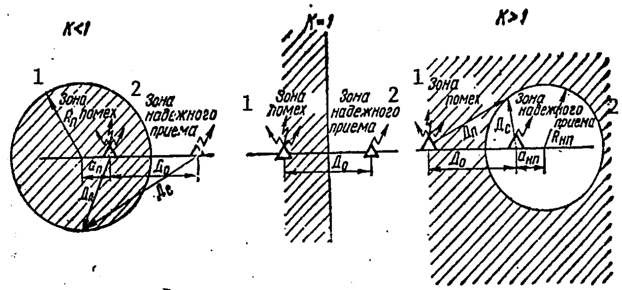


Figure 10.12. Type of Zones of Reliable Reception and Interference Zones With Different Values of Energy Coefficient K

Key:
1. Interference zone
2. Reliable reception zone

In those cases where the communications link transmitter and jamming transmitter have omnidirectional antennas ($G_п$=G_c) with identical polarization, while jamming is selective in frequency with a band coinciding with the receiver's passband $(\Delta f_п = \Delta f_{прм})$, value K can be determined with the formula

$$K = q_{НП} \sqrt{\frac{P_{пп}}{P_c}}. \qquad (10.9)$$

The equation of the boundary of reliable reception in a bipolar coordinate system (Figure 10.12) has the form:

$$D_п = KD_c. \qquad (10.10)$$

Depending on quantity K, the reliable reception zone varies in appearance (Figure 10.12).

When K<1 (which corresponds to a high degree of communication link jamming resistance or considerably less jamming transmitter energy than that of the communications station), the zone of reliable reception exists with specified probability throughout the entire effective zone of the useful signal transmitter, with the exception of an interference zone around the jamming transmitter position. The interference zone comprises a circle of radius

$$R_п = D_0 \frac{K}{1-K^2}, \qquad (10.11)$$

the center of which is displaced along a line radio set-jamming transmitter beyond the jamming transmitter a distance of

$$a_п = R_п K. \qquad (10.12)$$

When K=1 all space is divided by a perpendicular to the middle of the base (a line linking the jamming transmitter useful signal transmitter) into two parts: in the direction of the useful signal transmitter -- a reliable reception zone, and in the direction of the jamming transmitter -- an interference zone.

When K>1 (which corresponds to a low degree of communications link jamming resistance or jamming transmitter energy considerably exceeding that of the useful signal transmitter), the reliable reception zone, with a specified probability of signal reception, comprises a circle of radius

$$R_{\text{НП}} = D_0 \frac{K}{K^2 - 1}, \qquad (10.13)$$

the center of which is displaced along the base line beyond the useful signal transmitter by quantity

$$a_{\text{НП}} = \frac{R_{\text{НП}}}{K}. \qquad (10.14)$$

Thus in order to estimate communications reliability one must determine value $q_{\text{НП}}$ from the characteristic of the communication link, estimate of the enemy's jamming capability, and allowable probability of reliable reception. Then one calculates the value of energy coefficient K, proceeding from the figures on the communications set and enemy's jamming transmitter. One determines $R_{\text{П}}$ or $R_{\text{НП}}$, $a_{\text{П}}$ or $a_{\text{НП}}$ from the value of coefficient K and the distance between the communications set and possible position of the jamming transmitter (D_0) and plots a reliable reception zone boundary on a map. Figure 10.13 contains an example of such a plot [2].

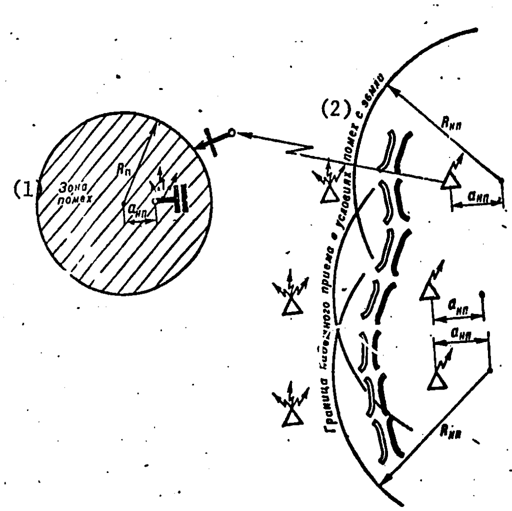


Figure 10.13. Example of Estimating Effect of Jamming on Radio Communication Link

Key:

1. Jamming zone
2. Boundary of reliable reception under conditions of ground jamming

The technique of estimating the effect of active jamming on the operation of ground radars consists in determining the boundaries of the detection zone (with a specified probability) for targets being protected by jamming. The probability of spotting a target return on a noise interference background is determined by the ratio of the power of the target return P_C to noise power $P_П$ at radar receiver input. The minimum $P_C/P_П$ ratio at which a specified probability of detection is ensured is called, on analogy with estimate of the effect of jamming on a communication link, coefficient of reliable detection q^2_{HO} (in a number of sources this quantity is called coefficient of discrimination) [16]. The value of the coefficient of reliable detection depends in turn on the limiting threshold established in the radar receiver-display circuit and the number of target returns which the radar receives during each detection cycle (in each antenna rotation for a 360° surveillance radar). The established limiting threshold is usually characterized by probability of so-called false alarm ($P_{ЛТ}$), that is, the probability that a random interference signal blip will be perceived by the operator to be a target return.

Customarily these relations are contained in radar equipment operating and servicing manuals in the form of detection curves. Figure 10.14 contains a family of detection curves for pulse signals on a noise interference background [14]. One can determine the value of reliable detection coefficient q^2_{HO} from these or similar curves for a given false alarm probability value, having specified the requisite detection probability value $P_{ОЦН}$. For such an estimate it is necessary to determine in advance the number of accumulated pulses during one detection N, which is equal to:

$$N = 0{,}7\,\frac{F_И \theta_\varphi}{6 n_A}, \qquad (10.15)$$

where $F_И$ -- radar pulse repetition rate, Hz; n_A -- antenna rotation rate, rpm; θ_φ -- radar antenna radiation pattern width in a horizontal plane, °.

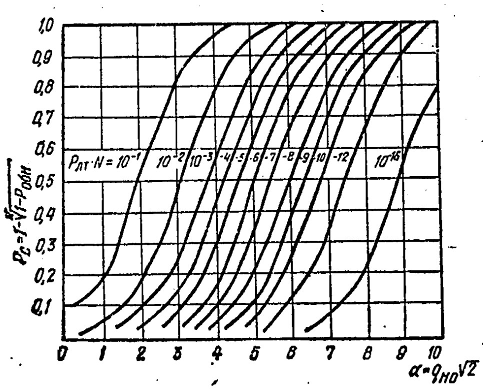


Figure 10.14. Detection Curves

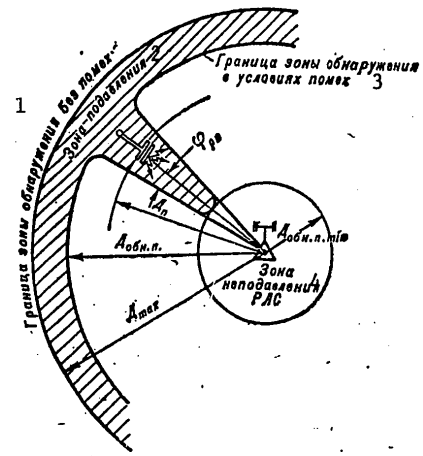


Figure 10.15. Effect of Jamming on Radar Detection Zone

Key:

1. Boundary of detection zone without jamming
2. Suppression zone
3. Boundary of detection zone under jamming conditions
4. Radar nonsuppression zone

When ground radars are jammed by airborne jamming transmitters, each interference source, located at a distance of $Д_П$ from the radar, creates within the boundaries of the radar detection zone a region in which jamming coverage is provided (radar suppression zone) for targets with a specified effective reflecting area $\sigma_Ц$ (Figure 10.15). The following expression is an equation of the boundary of the area of jamming coverage in a polar coordinate system:

$$Д_{обн.п} = \sqrt[4]{\frac{P_и G_{p\,max} \Delta f_п \sigma_ц Д_п^2}{4\pi P_{ПП} G_п \Delta f_{РЛС} k_{пол} k^2(\varphi_{рп}) q^2_{НО}}}. \qquad (10.16)$$

where $Д_{обн.п}$ -- range in meters to boundary of detection zone under conditions of jamming with a detection probability $P_{обн.п}$ and false alarm probability $P_{ЛТ}$;

$q^2_{НО}$ -- coefficient of reliable detection for the same conditions as $Д_{обн.п}$;

$\frac{P_и G_{p\,max}}{\Delta f_{РЛС}} = g_{РЛС}$ -- spectral density of power radiated by radar, w /MHz;

$P_И$ -- power in radar pulse, watts; $G_{p\,max}$ -- maximum radar antenna directive gain; $\Delta f_{РЛС}$ -- radar receiver passband, MHz;

$\frac{P_{ПП} G_п k_{пол}}{\Delta f_п} = g_п$ -- spectral density of power radiated by jamming transmitter, w /MHz;

$P_{пп}$ -- jamming transmitter power, watts; $G_п$ -- jamming transmitter antenna directive gain (average value within boundaries of radiation pattern width); $k_{пол}$ -- coefficient taking into account disparity between polarization of jamming signal and signal reflected from target ($k_{пол}$=1 when polarization coincides; $k_{пол}$=0.5 with linear polarization of reflected signal and circular polarization of jamming signal); $\Delta f_п$ -- jamming frequency spectrum width, Hz; $\sigma_ц$ -- effective reflecting area of covered target, m^2; $Д_п$ -- range from radar to jamming source (transmitter), m; $k(\phi_{рп})$ -- normalized radar radiation pattern by field strength in a horizontal plane; $\phi_{рп}$ -- angle between direction of radar radiation pattern maximum (at moment of target detection) and direction to jamming source (Figure 10.15).

In expression (10.16) all quantities are constant for a given situation; angle $\varphi_{рп}$ (value $k(\varphi_{рп})$ in the formula) is the independent variable of the quantity (argument), while quantity $Д_{обн.п}$ is the current radius vector. For given radars, jamming transmitter and target, the dimensions of the cover zone are determined by the distance from the radar to the jamming transmitter ($Д_п$), whereby the size of the cover zone decreases with an increase in $Д_п$.

To establish a cover zone with one jamming transmitter (or several sited at approximately the same point), it is necessary to be able to go from angle $\varphi_{рп}$ to value $k(\varphi_{рп})$. This can be accomplished most simply by having a normalized radiation pattern in a horizontal plane, taken experimentally or calculated from an approximate formula

$$k^2(\varphi_{рп}) = \begin{cases} \exp\left[-0{,}7\left(\frac{2\varphi_{рп}}{\theta_\varphi}\right)^2\right] \text{ для (for) } 0 < \varphi_{рп} < \frac{\theta_\varphi}{2} \\ k^2(\varphi_{бок}) \approx 0{,}06\left(\frac{\theta_\varphi}{\varphi_{рп}}\right) \text{ для (for) } \frac{\theta_\varphi}{2} < \varphi_{рп} < 180°. \end{cases} \qquad (10.17)$$

where θ_φ -- width of radar antenna radiation pattern in a horizontal plane; $k^2(\varphi_{бок})$ -- power level of side lobes with the boundaries of angles φ from $\frac{\theta_\varphi}{2}$ to 180°.

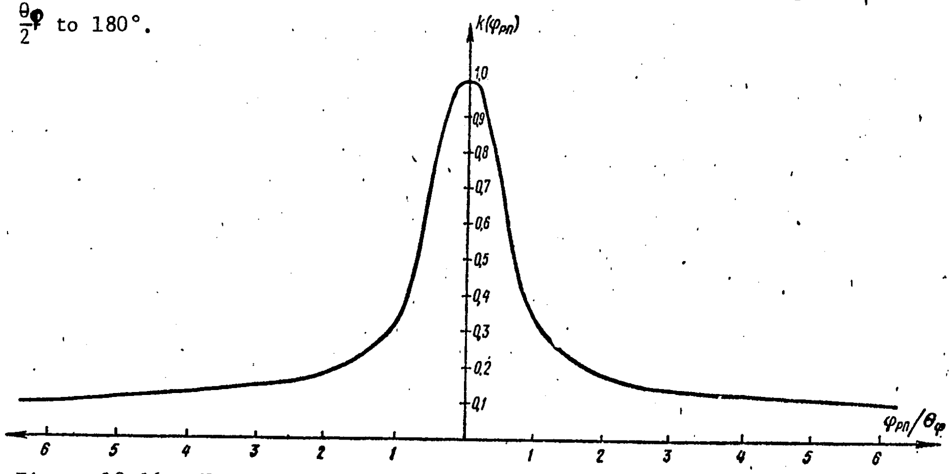


Figure 10.16. Normalized Radar Antenna Directional Response Pattern

Figure 10.16 contains a normalized radar antenna radiation pattern plotted according to formula (10.17), in relative units ($\frac{\varphi_{p\pi}}{\theta_\varphi}$ ratios).

The minimum range up to which an ECM aircraft can cover a target located in the immediate vicinity of the jamming transmitter (that is, when $Д_{обн.п} = Д_п$ and $\varphi_{pп} = 0$) will be:

$$Д_{обн.п.min} = \sqrt{\frac{g_{РЛС}\sigma_ц}{4\pi g_п \cdot q^2_{НО}}}. \qquad (10.18)$$

Expression (10.18) is the equation of a circle which constitutes the boundary of a radar nonsuppression zone (Figure 10.15). In other words, beginning with range $Д_{обн.п.min}$ and closer to the radar, jamming transmitter energy (g_x) is insufficient to screen a target with an effective reflecting area of $\sigma_ц$. Within the circle $R_{НП}=Д_{обн.п.min}$, with jamming of density $g_п$, in the worst case for a radar -- coinciding of jamming transmitter and target -- detection is possible with a probability greater than that for which calculation $q^2_{НО}$ was performed.

Finally, when jamming from several points in the radar's effective coverage zone, detection range at a specified altitude for a target beyond the jamming coverage zone will diminish somewhat due to the summary effect of the jamming transmitters on the side lobes with a level $k^2(\varphi_{бок})$. In other words the entire radar detection zone, if we consider the side lobe level beyond the boundaries of the major lobe of the radar antenna constant, becomes somewhat "compressed," as it were. This compression of the detection zone can be taken into account by coefficient $k_{сж}$, which is equal to the ratio of detection range taking into account the summary effect of jamming on the side lobes $Д_{обн.п}$ to maximum detection range at this altitude ($Д_{max}$) with equal probability (or more precisely, with the same coefficient of reliable detection $q^2_{НО}$). The value of this coefficient is

$$k_{сж} = \frac{Д_{обн.п}}{Д_{max}} = \sqrt[4]{\frac{(4\pi)^2 Д^2_{п\,min} P_ш}{g_{п\Sigma} G_{p\,max} k^2(\varphi_{бок})\lambda^2 \Delta f_{РЛС}}}, \qquad (10.19)$$

where $g_{п\Sigma}$ -- overall jamming spectral density, calculated by effectiveness for a transmitter at minimum range $Д_{п\,min}$; $P_ш$ -- internal noise power converted to radar receiver input; $k^2(\varphi_{бок})$ -- side lobe power level value.

$g_{п\Sigma}$ can be determined in turn for n transmitters located at distances $Д_{пi}$ and each possessing power spectral density $g_{пi}$, with formula

$$g_{п\Sigma} = g_{п1} + \sum_{i=2} g_{пi}\left(\frac{Д_{п\,min}}{Д_{пi}}\right)^2. \qquad (10.20)$$

where $g_{пi}$ -- spectral density of jamming transmitter at minimum range $Д_{min}$ from the radar.

Now, having calculated coefficient $k_{сж}$, one can delineate on a map or diagram, knowing the radar detection zone without jamming, the boundary of the detection zone with jamming for a given altitude and with a specified probability, utilizing relation

$$Д_{обн.\,п} = k_{сж} Д_{обн.б.п}. \qquad (10.21)$$

Thus estimate of the effect of jamming on the performance of ground detection and guidance radars should be performed as follows.

Analyzing ground radar jamming capabilities, one determines the areas from which jamming may originate, taking into consideration ranges $Д_{пi}$ and jamming radiation power densities from these areas $g_{пi}$. Then one calculates $g_{п\Sigma}$ with formula (10.20), quantity $k_{сж}$ with formula (10.19), and $Д_{обн.п}$ for flight altitudes of interest with formula (10.21). The obtained ranges are utilized in normal fashion for placing on the map (diagram) target detection limit lines under conditions of jamming. Then one determines with formula (10.18) radar nonsuppression zone radius $R_{НП}$ for jamming level $g_{п\Sigma}$.

Finally, for a more thorough estimate of the effect of jamming from a given area on a given radar, one can plot, utilizing expression (10.16), the coverage areas of jamming transmitters within the boundaries of the radar detection zone. It is more convenient to plot the coverage area with formula (10.16), solved relative to $k^2(\varphi_{рп})$:

$$k^2(\varphi_{рп}) = \frac{g_{РЛС} \sigma_ц Д_п^2}{4\pi g_п q^2_{НО} Д^4_{обн.\,п}}, \qquad (10.22)$$

specifying values $Д_{обн.п}$ from $R_{НП}$ (Formula 10.18) to $Д_{обн.п}$, calculated with formula (10.21).

One calculates for each range with formula (10.22) the normalized radiation pattern power value $k^2(\varphi_{рп})$, and one determines from the diagram (graphically) or with formula (10.17) angle $\varphi_{рп}$ (Figure 10.16) for a given range. The points of intersection of range $Д_{обн.п}$ and corresponding angle $\varphi_{рп}$ are the boundary of the cover area, which can also be placed on a map or diagram (Figure 10.17).

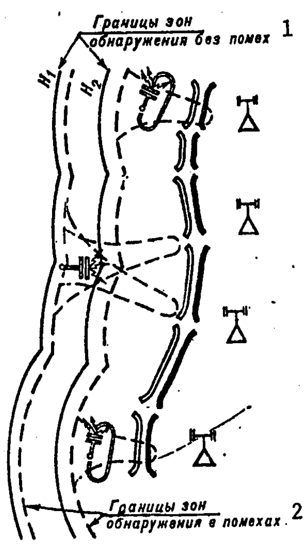


Figure 10.17. Example of Estimate of Effect of Jamming on Radar System

Key:
1. Boundaries of detection zones without jamming
2. Boundaries of detection zones with jamming

Chapter 11. ELECTROMAGNETIC COMPATIBILITY OF RADIO ELECTRONIC EQUIPMENT

11.1. General Information on Electromagnetic Compatibility of Radio Electronic Equipment

One of the problems arising with the operation of radio electronic equipment (RES) is that of ensuring their compatible operation with other equipment which produces interfering radio-frequency emissions. The possibility of mutual influence of RES is dictated by the fact that all such equipment, in spite of a diversity of performed functions, utilizes circumterrestrial space as a medium in which electromagnetic oscillations carrying essential information are propagated. All methods of selection, that is, selecting from the entire aggregate of electromagnetic oscillations radiated by various RES only those which carry information we require, are imperfect. As a consequence of this, the bulk of the radiations of various RES penetrate into a receiving device to one degree or another, and in the final analysis introduce distortions into the received information. It is quite obvious from this that under conditions of a steady increase in quantity of RES in operation and the limited capabilities of utilizing the radio-frequency spectrum, one of the most critical problems today is that of ensuring compatible, simultaneous and mutually independent operation of various radio electronic equipment; It is called the problem of electromagnetic compatibility (EMS).

Electromagnetic compatibility is defined as securing the simultaneous operation of an aggregate of radio electronic equipment, whereby the emissions of any equipment in this aggregate do not disrupt the normal operation of other equipment. Mutual interference in the output devices of radio receivers does not exceed allowable limits thereby [8].

Mutual radio interference between RES can occur both as a result of emission and reception on the principal frequencies of transmitter and receiver, and due to the effect of principal, spurious and out-of-band emissions of transmitting devices into the spurious and out-of-band reception channels of radio receiving equipment [18, 19].

Under normal conditions radiation and reception are secured within the boundaries of the requisite frequency bandwidth, which is defined as the minimum bandwidth sufficient in the given emission category to ensure transmission of messages with the rate and quality required for radio electronic equipment utilized under specified conditions. The middle of the designated frequency band coincides with the frequency assigned to the given transmitter, while its width is determined taking into account double the absolute allowable frequency deviation.

Out-of-band emission is defined as a class of nonfundamental emissions in frequency bands adjacent to the transmitter's required emission band. They are caused by the process of modulation in the transmitter. This means that modulation of principal emissions can be a useful process, essential for transmission of information of a given type, or harmful, occurring with parasitic background action, fluctuation noise, etc. Out-of-band receiving channels affect frequencies adjacent to the main channel, chiefly in the form of cross interference and useful signal blocking.

Cross interference occurs in modulation of useful signal by the modulating voltage of an interference signal, the carrier frequency of which lies outside the receiver's passband. It occurs only when a useful signal is present, which is a characteristic feature of this type of interference, and occurs with interference signals which are strong in comparison with them.

Blocking of useful signal involves reduction in its level or in complete suppression in the amplifier stages with the action of a very strong interference signal at a frequency outside the receiver's passband.

Spurious emissions characterize a broad class of nonfundamental transmitter emissions, the frequency and levels of which are determined by nonlinear processes which occur during the passage of high-frequency currents in these devices, or by other high-frequency processes of a random nature. Spurious emissions include the following: emissions at harmonics, emissions at subharmonics, combination emissions, parasitic emissions, and intermodulation.

Emissions at harmonics are transmitter spurious emissions in bands which include frequencies which are multiples of the transmitter's basic transmitting frequency. High-frequency stages operating with an angle of current flow $\theta < 180°$ are sources of such harmonics in transmitters.

Emissions at subharmonics are viewed as transmitter spurious emissions in frequency bands the values of which are a whole number of times less than the value of the basic emission band frequencies. Some harmonics are characteristic of transmitters in which frequency multipliers are employed for the purpose of forming the principal emission at quartz-stabilized lower-frequency oscillations. In spite of the fact that the resonant circuits at multiplier output are tuned to higher frequencies than the input oscillation frequency, in most cases it is not possible substantially to attenuate the subharmonic. In estimating the harmful effect of this type of spurious emissions one must bear in mind that oscillations at the output of multipliers are modulated by subharmonic voltages both in amplitude and phase and that the number of subharmonics increases with an increase in the number of multipliers.

Combination emissions are spurious emissions occurring both at the transmitting and receiving end of a radio link. At the transmitting end they arise during the formation of principal emission oscillations under the effect of nonlinear transformations of auxiliary oscillations. Combination emissions at the transmitting end are characteristic of a band transmitter, the driver of which secures any operating wave from the grid of a discrete set of waves produced by a system of band-quartz frequency stabilization.

At the receiving end combination spurious emission channels occur as a result of interaction between the voltage of the interference signal and its harmonics with the voltage of the local oscillator and its harmonics in conformity with equation

$$pf_к \pm qf_г = f_{пч},$$

where f_k -- frequency of combination receiving channel; $f_г$ -- local oscillator frequency; p, q -- whole numbers 1, 2, 3 ...; $f_{пч}$ -- receiver intermediate frequency.

The number of possible parasitic channels increases if the local oscillator frequency in turn is formed by the combination method, that is, by adding the frequencies of several primary oscillators and their repeated multiplying. In this case the following frequencies can enter the mixer:

$$f_1,\ f_2,\ f_1+f_2,\ 2f_1,\ 2f_2,\ 2(f_1+f_2)\quad, \text{ etc.}$$

All these frequencies and their harmonics, interacting with the frequencies of the interference signals, can form the intermediate frequency.

There is a particularly large number of combination channels in receivers with poor preselector selectivity (for example, in receivers in which the received signal is applied directly from the antenna array to the mixer).

Parasitic emissions apply to the group of spurious emissions which do not involve the formation of carriers. In many cases they are due to random causes, when self-excitation conditions are unintentionally met in a portion of the circuitry and parasitic oscillations occur either simultaneously with the main oscillations or during deexcitation. Most frequently parasitic emissions are caused by the distributed nature of passive components in oscillation circuits as well as by the formation of unintentional resonant circuits (oscillation circuit components in combination with various circuit reactive components).

Intermodulation emissions are spurious emissions occurring in a transmitter under the effect of emissions from other transmitters. They are especially intensive when there is a functional or structural link between simultaneously operating transmitters, such as when two or more transmitters are operating on a single antenna. The stronger the coupling between transmitters and the greater their power, the more substantial the level of intermodulation emissions can be. The greatest interference can be produced by oscillations at summed and difference frequencies close to the main frequency of one of the transmitters. Often intermodulation emissions of the third order of magnitude prove to be sufficiently strong, such as in the case of the simultaneous operation of three transmitters on one antenna when $|2f_1-f_2|=f_3$.

At the receiving end intermodulation channels arise as a result of interaction of the voltages of several interfering signals and their harmonics with the voltage of the local oscillator and its harmonics in conformity with expression

$$n_1 f_{\text{к}1} \pm n_2 f_{\text{к}2} \pm n_3 f_{\text{к}3} \pm \ldots \pm q f_r = f_{\text{пч}},$$

where n_1, n_2, n_3, ..., q -- whole numbers 1, 2, 3...

One feature of these spurious channels lies in the fact that they occur only when there are two (or more) interference signals present at the mixer input with levels sufficient for development of nonlinear properties of the circuit.

In order to eliminate interference caused by the above-enumerated factors, it becomes necessary to take measures to ensure the electromagnetic compatibility of RES. Obviously in practice such measures involve analysis of combined employment of RES and determination of conditions for interference-free operation by potentially incompatible equipment.

Potentially incompatible radio electronic equipment includes radio electronic equipment which by frequency band, energy relationships and conditions of simultaneous utilization can exert an interfering effect on one another.

In the most general statement of the problem, electromagnetic compatibility can be viewed as a component part of the overall problem of ensuring the noise immunity of a communications and RTO system, which includes protection both against deliberate and nondeliberate interference of all types, including from other simultaneously operating radio electronic equipment. In connection with this, from a quantitative standpoint the problem of electromagnetic compatibility reduces to finding an optimal correlation whereby expenditures for technical execution of all elements of a communications and RTO system which are acceptable from an economic standpoint provide adequate accuracy of reproduction of useful information. Obviously the criterion of fidelity can constitute such a synthesized indicator, a criterion which estimates deviation of output message m from transmitted message y. In each individual instance, proceeding from the functional designation of the communications and RTO system and the conditions of its operation, a specific criterion of fidelity can be selected in the form:

$\varepsilon^2 = \int_a^b [m(t) - y(t)]^2 \, dt$ -- standard deviation;

$\varepsilon_{\text{абс}} = \int_a^b |m(t) - y(t)| \, dt$ -- absolute deviation;

$\varepsilon_{\max} = \max |m(t) - y(t)|$ -- maximum deviation.

With the above conditions the achieved level of interference immunity of a communications and RTO system can be estimated by the quantitative level of selected criterion of fidelity, that is,

$$P_{\text{верн.}} = P\{\varepsilon(t) < \varepsilon_0\}. \quad (11.1)$$

Probability of faithful reception of a transmitted communication will be defined as the probability that the actual value of fidelity criterion $\varepsilon(t)$ will not exceed the required ε_0 value for a given communications and RTO system. In light of the above, radio electronic equipment, including a communications and RTO system as a whole, can be considered electromagnetically compatible with other emission sources if they do not interfere with other equipment and systems operating in a given electromagnetic environment (EMO) of the area in question.

In a certain sense the electromagnetic environment for any communications and RTO system is composed of sources of interference (their frequency and energy radiation spectra) located at any point on earth. For practical purposes, however, we consider as EMO components only those sources of emissions which deliver sufficient energy to the location of radio receiving equipment to affect the quality of reproduction of useful information.

In some instances the problem is simplified to an even greater extent, by considering only the mutual influence of quite specific RES and systems. In this sense the term electromagnetic compatibility can be given the following definition. EMS is the state of a functional aggregate of RES whereby the emissions of any of the equipment within this aggregate do not disrupt the normal operation of other equipment in the group. Mutual interference is either absent or its level at terminal device input does not lead to intolerable distortions of transmitted useful information.

11.2. Method of Estimating Electromagnetic Compatibility of Radio Electronic Equipment

In the most general form the problem of ensuring the electromagnetic compatibility of any communications and RTO system reduces to determining the following:

what emission sources can affect the criterion of fidelity of transmission of information within the given system, and to what degree;

what effect is exerted by a given system on the radio receiving equipment of other RES;

what measures must be taken to reduce these influences to a tolerable level.

In conformity with the above-enumerated questions, the method of estimating the electromagnetic compatibility of radioelectronic equipment includes the following three stages: estimate of the electromagnetic environment, determination of the degree of effect of sources of interfering emissions, and estimate of the compatibility of radio electronic equipment. We shall examine the sequence of performing these component parts of the overall method.

Estimate of the Electromagnetic Environment (EMO)

This stage of the method of evaluating electromagnetic compatibility includes the following: preparation of a list of interfering emissions, determination of the frequency characteristics of the employed radio receiver equipment, and determination of the frequency characteristics of sources of interfering emissions. One then performs a comparative analysis of obtained frequency characteristics and estimates the degree of influence of sources of interference on the operation of the communications and RTO system being studied.

Preparation of a list of interfering emissions. This list contains all known ground and airborne radio electronic equipment located in the siting area of the communications and RTO system being examined. One should consider all radio electronic equipment located at one's airfield and at neighboring airfields, as well as civilian communications system radio electronic equipment (broadcasting stations, radio relay link stations, TV stations, etc) located in this area and operating in a band one order of magnitude higher and lower than the assigned frequency band of the system being examined. The list may also include nearby stationary sources of industrial interference.

The list should be prepared following the form illustrated in Table 11.1.

Table 11.1.

1 № по пор.	2 Наименование источника мешающих излучений (или условное обозначение)	3 Удаление от исследуемой системы, км	4 Средняя мощность, дБ	5 Отведенная полоса частот для мешающего источника излучений. МГц	6 Специфические сведения

Key:

1. Serial number
2. Designation of source of interfering emissions (or identifying symbol)
3. Distance from system being examined, km
4. Average power, db
5. Assigned frequency band for interfering source of emissions, MHz
6. Specific data

The column "Specific Data" specifies the emission class and data on modulation of interfering signals (pulse duration, frequency, telegraphy rate, etc).

Determination of the frequency characteristics of radio electronic equipment employed in the system being examined* (performed in relation to whether this equipment has been assigned one frequency or a band of frequencies).

* Radio receiver frequency characteristic is defined as the relationship between its maximum actual sensitivity and the frequency of signal applied to the input terminals with tuning frequency unchanged.

If a piece of equipment has one assigned frequency, the procedure of obtaining the frequency characteristic is as follows:

a) the receiver is tuned to the assigned frequency and its maximum actual sensitivity is measured in the conventional manner at this frequency; then the signal is set sequentially at -100 db, -80 db, -60 db, -40 db, and in each instance signal generator frequencies are determined (on both sides of the authorized frequency); signal strength at receiver output is sought as in measuring maximum actual sensitivity, that is, the generator frequency is tuned for maximum signal at the receiver output;

b) measurements are performed for all levels in the entire frequency band of interest to us and are entered in a table (Table 11.2).

Table 11.2

1 № по пор.	2 Частота, МГц	3 Чувствительность приемника, настроенного на присвоенную частоту, дБ	4 Восприимчивость приемника для интересующего класса излучений

Key:
1. Serial number
2. Frequency, MHz
3. Sensitivity of receiver tuned to authorized frequency, db
4. Receiver's sensitivity to the given class of emission

Maximum actual receiver sensitivity is defined as the greatest of the minimum interfering signal levels which should be applied to an antenna equivalent simultaneously with the useful signal to the receiver's input terminal to obtain at receiver output a signal-noise ratio resulting in intolerable distortions of the transmitted information.

A table (card) is made up for each frequency band and then presented in the form of a graph. If the equipment operates in a frequency band (continuous or discrete frequencies), the frequency characteristic is obtained at three frequencies: at mid-frequency in the band, and the 2 extreme frequencies in the band. For receivers with discrete frequencies, additional measurements can be taken at frequencies close or equal to the frequencies of potential sources of interfering emissions.

Receiver susceptibility should also be measured at all frequencies of the out-of-band and parasitic channels of sources of interfering emissions. The interference signal frequency is set at the frequency of the secondary channel being checked, and modulation -- corresponding to the class of emission of the interference source operating at this frequency. In conformity with this, susceptibility to interference should be characterized, in addition to a quantitative value in decibels, by frequency and class of emission (for example, 56 db, 153 MHz, A1).

We should note that for a comprehensive, objective appraisal of electromagnetic compatibility of a communications and RTO system it is necessary to know the susceptibility of receivers not only with a useful signal value close to actual sensitivity but also with change in level of useful signal throughout the entire dynamic range of its possible values under actual operating conditions. This is especially important when analyzing electromagnetic compatibility for ground-aircraft communication links. Such characteristics should be obtained for all parasitic reception channels with various types of modulation of interfering signals.

Together with determining frequency characteristics, one should measure and calculate the radiation patterns of the radio receiver antenna array (in a horizontal and vertical plane -- for the principal receiving sectors in directions of possible radio communication with aircraft).

Determination of frequency characteristics of sources of interfering emissions. The following should be measured to obtain a frequency response curve: distribution of radiated power within the occupied frequency band, energy spectrum of out-of-band emission, and spurious emissions.

The frequency response curve of each source of interfering emissions is measured throughout the entire radio frequency spectrum of interest to us and is recorded in a form corresponding to Table 11.3.

Table 11.3

1 № по пор.	2 Средняя частота основного или неосновного излучения, МГц	3 Эффективная излучаемая мощность на средней частоте, дБ	4 Ширина занимаемой полосы излучения, МГц	5 Спектр излучения

Key:
1. Serial number
2. Average frequency of principal or secondary emission, MHz
3. Effective radiated power at middle frequency, db
4. Width of occupied emission band, MHz
5. Emission spectrum

It is also convenient to draw a frequency response curve on a ribbon of transparent materials separately for each band, on the same scale, along the axis of frequencies as was done for the frequency response curve of the radio receiver being examined.

In addition to a frequency response curve for each source of interfering emissions, one should determine the antenna radiation pattern separately for each principal and spurious emission. For purposes of analysis, the frequency response curves of sources of interfering emissions are sequentially compared band by band with the frequency response curve of a receiver of that same band. During comparison one determines the occupied frequency bands of principal and spurious emissions of interference sources (by comparison with the useful information receiving band). Results of the comparison are entered in Table 11.4.

Table 11.4

1 Частота основного или побочного канала приема f_1, МГц	2 Чувствительность (восприимчивость) на частоте f_1, дБ	3 Средняя частота источника помех f_n, МГц	4 Занимаемая полоса частот источника помех, МГц	5 Мощность излучения источника помех, дБ	6 Класса излучения источника помех	7 Коэффициент усиления антенны в направлении, соединяющем передатчик и приемник, дБ	
						приемник исследуемой системы 8	9 мешающий передатчик

Key:

1. Frequency of principal or parasitic receiving channel f_1, MHz
2. Sensitivity (susceptibility) at frequency f_1, db
3. Average frequency of interference source f_n, MHz
4. Interference source occupied frequency band, MHz
5. Radiated power of interference source, db
6. Emission class of interference source
7. Antenna gain in direction linking transmitter and receiver, db
8. Receiver
9. Interfering transmitter

One enters in the table all interference sources the frequency band of which contains at least one frequency from the receiver's frequency response curve, that is, if there are at least minimal areas where the interference emission band and reception band coincide. The evaluation of electromagnetic compatibility is performed by means of sequential analysis of the frequency channels listed in Table 11.4 along which interference sources can affect transmission of useful information in the communications and RTO system. This analysis is customarily called evaluation of duel situations.

One then groups channels by probability of simultaneous operation of interference sources and evaluates the simultaneous effect of a group of channels on the communications and RTO system.

Analysis of the obtained results makes it possible to reach a general conclusion on whether the communications and RTO system can operate normally in the given electromagnetic environment.

Determination of Degree of Effect of Sources of Interfering Emissions on a Communications and RTO System

This part of the method is based on utilization of an analytical relation which expresses the degree of influence of interference on the principal criterion of effective operation of a communications and RTO system (fidelity of information reception), determined by the energy and spectral parameters characterizing the sources of interference and the distance between interference sources and system receiving equipment. One utilizes the following equation:

$$P_{пр} = P_{п} + G_{п} + G_{пр} - L_{с} - \beta, \qquad (11.2)$$

where $P_{пр}$ -- transmitter signal power at the receiver antenna location site; $P_{п}$ -- average transmitter power; $G_{п}$ -- transmitter antenna gain in the direction of the receiver; $G_{пр}$ -- receiver antenna gain in the direction of the transmitter; L_c -- total losses in the communications and RTO system connected with propagation of radio waves; β -- coefficient expressing useful signal attenuation as a consequence of inaccuracy and instability of receiver and transmitter tuning frequencies.

All quantities in equation (11.2) are expressed in decibels.

Quantities $P_{п}$, $G_{п}$, $G_{пр}$ are determined experimentally or are specified in the equipment operating and servicing manuals. Calculation of quantity L_c presents the greatest difficulty. Available analytical expressions of calculation of L_c are given for idealized conditions of propagation of radio waves, for a smooth, ideal conducting surface, and with utilization of isotropic radiators for communications. In an actual situation not one of these connections is observed to such an extent that it can be ignored. In addition, actual conditions of propagation are not constant but depend on season, time of day, and the electrical conductivity and dielectric constant of the earth's surface.

In connection with the above, in practice one utilizes refined data of the International Radio Consultative Committee, obtained on the basis of experimental studies being conducted in many countries. The graphs recommended by the IRCC express the relationship between electromagnetic field strength and distance to the transmitter for various wavelengths and conditions of propagation.

Subsequently, utilizing the analytical expression available for a given frequency band, we determine total losses L_c for specified distance and wavelength values. For example, in the frequency band below 10 MHz we utilize expression

$$L_{с} = 12{,}45 + 20 \lg f - E, \qquad (11.3)$$

where f -- operating frequency; E -- field strength value for specified f and R (determined from IRCC graphs), db.

The following expression is utilized for the band from 40 to 250 MHz:

$$L_{с} = 15{,}85 + 20 \lg f - E. \qquad (11.4)$$

For the band from 250 to 1000 MHz, under the condition of additional consideration of the phenomenon of field attenuation as a consequence of wave interference between the direct wave and wave reflected from the earth's surface (Lobing phenomenon), the following expression is utilized:

$$L_e = L_f + L_e = 20 \lg \frac{4\pi d}{\lambda} - 10 \lg (1 - k^2 - 2k \cos\Omega),$$

where L_f -- en-route losses under the condition of radio-wave propagation in free space; L_e -- magnitude of losses caused by the Lobing phenomenon; k and Ω -- coefficients determining the dependence of reflected wave intensity at the receiving point on the mutual location of transmitter and receiver and the electrical properties of the earth's surface: $k=\rho D$; $\Omega=\delta+\gamma$; ρ and γ -- modulus of reflection factor and reflection angle; δ -- equivalent earth's radius, which is expressed by the formula

$$\delta = 2\pi \frac{r_1 + r_2 - r_0}{\lambda}.$$

Quantity D is determined with the formula

$$D = \left[1 + \frac{2d_1 d_2}{da \operatorname{tg} \psi}\right]^{-\frac{1}{2}}, \qquad (11.5)$$

where a -- earth's radius.

The remaining quantities are indicated in Figure 11.1.

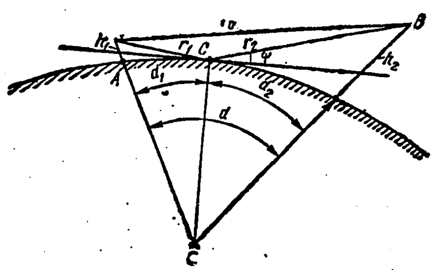


Figure 11.1. Diagram of a Ground-Aircraft Communication Link for Determination of Lobing Phenomenon

For a final quantitative assessment of a duel situation within the framework of a problem of electromagnetic compatibility, one can write the following system of equations:

$$\left.\begin{aligned} P_{\text{пр}} &= P_{\text{п}} + G_{\text{п}} + G_{\text{пр}} - L_e \\ P_{\text{пм}} &= P_{\text{м}} + G_{\text{м}} + G_{\text{пм}} - L_{\text{см}} \end{aligned}\right\} \qquad (11.6)$$

where $P_{\text{пм}}$ -- power of signal from interference-generating transmitter at receiver antenna location point; $P_{\text{м}}$ -- average power of interfering transmitter; $G_{\text{м}}$ -- interfering transmitter antenna gain in direction of receiver;

$G_{ПМ}$ -- receiver antenna gain in direction of interfering transmitter; L_{CM} -- total route losses from interfering transmitter to receiver of communications and RTO system.

We ignore quantity β in our calculations, as it is small.

On the basis of equations (11.6), the equation for a duel situation will have the following form:

$$P_{пр} - P_{пм} = (P_п - P_м) + (G_п + G_{пр} - G_м - G_{пм}) - (L_c - L_м). \quad (11.7)$$

This equation should be considered the principal equation in the area of electromagnetic compatibility.

The following standard problems can be solved with the described method of calculating degree of effect of sources of interfering emissions on a communications and RTO system:

a) determine the required distance of an interfering transmitter from a communications and RTO system receiver ensuring a tolerable level of useful information;

b) determine the required frequency separation between communications and RTO system receiver and interfering transmitter frequencies in order to ensure a specified accuracy of transmission of useful information;

c) determine the magnitude of error introduced into a message transmitted by a communications and RTO system by interfering radiation.

Estimate of Compatibility of Radio Electronic Equipment

This part of the method includes the following elements: selection of criterion of fidelity, analysis of duel situations, and formulation of operating cycles of all sources of interference emissions during a calendar period.

Selection of fidelity criterion. It was stated above that there is presently no uniform scientifically substantiated criterion of fidelity for all types of information systems. The following criterion is the most commonly used in application to a communciations and RTO system:

$$\varepsilon_{абс} = \int_a^b |m(t) - y(t)|\, dt.$$

It characterizes the average value of absolute deviation obtained at the output of a useful communication receiver from that message which is transmitted by a communications and RTO system channel. Fidelity of transmission will be estimated by the probability

$$P_{верн} = P\{\varepsilon(t) < \varepsilon_0\}.$$

Fidelity can be estimated with the following parameters:

a) for radio communications equipment -- number of incorrectly received words (symbols) at a specified rate of transmission;

b) for radio navigation and radar equipment -- error in measurement of bearing or range when determining the coordinates of an aircraft or airfield;

c) for other special radio signal equipment -- correct transmission and deciphering of signals.

Estimation of the fidelity of message transmission in communications and RTO systems under actual conditions of operation presents significant difficulties, and therefore one does not go beyond determining the criterion under laboratory conditions (utilizing various ground simulators). For determination of fidelity characteristic, useful signal and interference signal are applied simultaneously to the radio receiver input terminals through a matching device. The magnitude of signals is established in such a manner as to ensure various signal-noise ratios with different initial useful signal levels.

Initially one records a fidelity characteristic with interference with modulation similar to that of the transmitted useful signal, and frequency equal to the useful signal frequency. Then fidelity characteristics are taken with interference and signal frequency difference Δf, equal to the frequency separation of adjacent channels.

The fidelity characteristic is taken in the following sequence:

useful signal level is set equal to the receiver's actual sensitivity;

the interference level is set by a simulator or other means;

the following signal-noise ratios are set in sequence: 0.7, 0.3, 0, -0.3, -0.7, -1, -1.3, -1.7, -2 db, and one measures the absolute deviation of output signal value from the value established in the absence of interference;

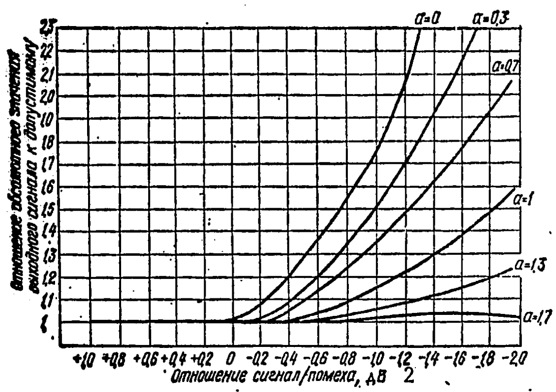
a sufficient number of measurements is performed at each point for a reliable statistical estimate of results, and average fidelity criterion values are determined;

the following useful signal levels are set: 0.3, 0.7, 1, 1.3, 1.7, and 2 db relative to the receiver's actual sensitivity, and measurements analogous to the above are taken;

a family of reception fidelity characteristic curves with a given type of interference emission modulation is plotted from the results of the measurements.

Similar characteristic curves are plotted for other typical types of interference emission modulation. As an illustration we have presented a family of fidelity characteristic curves for interference modulation corresponding to the type of useful signal modulation for an interference and signal frequency difference Δf=0.7 MHz (Figure 11.2). Here parameter $a=10\ \lg\frac{U_c}{U_{чувств}}$ (db).

1



2

Figure 11.2. Radio Receiver Fidelity Characteristic Curves for Various Values of Parameter a for Interference Modulation Corresponding to the Type of Useful Signal Modulation (Δf=0.7 MHz)

Key:
1. Ratio of absolute value of output signal to tolerable value
2. Signal-noise ratio, db

Thus, having calculated the actual signal-noise ratio and knowing the type of modulation and frequency of the signal and interference, one can determine with the fidelity characteristic curves the magnitude of error introduced by the interference into a transmitted message.

Analysis of duel situations is performed on the basis of Table 11.4. It is important thereby to estimate the aggregate effect of all sources of interference emissions on an operating receiver. In conformity with this one groups channels by probability of simultaneous operation of interference sources with communications and RTO channels in the bands of interest to us. The following table is prepared for the purpose of analysis (Table 11.5).

Table 11.5

1 № по пор	2 Диапазоны средств, функционирующих в системе связи и РТО, МГц	3 Диапазоны мешающих излучений, МГц	4 Разнось по частотным диапазонам, МГц		7 Заключение о выполнении требований по ЭМС
			реальный разнос по частоте 5	6 допустимый разнос по частоте	

Key to Table 11.5 (on preceding page):

1. Serial number
2. Frequency bands of equipment operating in communications and RTO system, MHz
3. Frequency bands of interfering emissions, MHz
4. Frequency spacings in bands, MHz
5. Actual frequency separation
6. Allowable frequency separation
7. Conclusion on satisfaction of electromagnetic compatibility requirements

---

On the basis of the data in Table 11.5 a conclusion is reached on whether a communications and RTO system can function normally in the given electromagnetic environment. If necessary, measures are elaborated which are aimed at diminishing the effect of interfering emissions on the fidelity of transmitted messages.

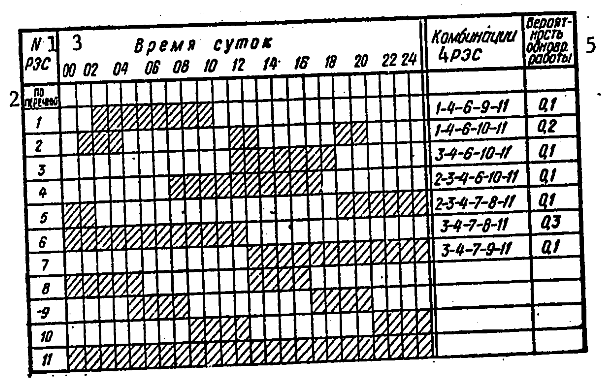


Figure 11.3. Illustrative Graph of Operating Cycles of Utilized Radio Electronic Equipment

Key:

1. Piece of equipment number
2. As listed
3. Time of day
4. Combinations of radio electronic equipment
5. Probability of simultaneous operation

Listing of operating cycles of all sources of interference emissions during a calendar period. They are drawn up for the purpose of determining the probability of simultaneous operation of sources of interfering emissions with radio electronic equipment in an operating communications and RTO system.

Figure 11.3 contains a sample graph of operating cycles of utilized radio electronic equipment.

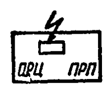
Probability of simultaneous operation is calculated for various combinations of equipment as a ratio of the period of time when this combination is operating simultaneously with a communications and RTO system to this system's total operating cycle. After this one experimentally determines in a quantitative expression the effect of designated equipment combinations on fidelity of transmission of information in a communications and RTO system. The signal level of each piece of equipment as applied across the receiver input terminals is established in conformity with prior-performed calculations.

In conclusion one estimates the overall probability of various levels of diminished equipment operating efficiency over the course of a 24-hour period.

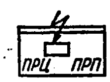
Appendix 1. COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES SYMBOLS

Communications and RTO Facilities

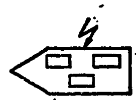
Communications center.



Radio receiving center



Radio receiving center set up in a shelter (protected)



Radio receiving vehicle

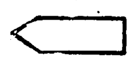
Radio transmitting center

Radio transmitting center set up in a shelter

Radio monitoring station

Technical monitoring station

Telegraph station

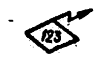


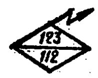
Communications equipment vehicle

Communications and RTO reserve personnel and equipment

Mobile radio set


Portable radio set

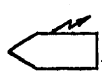

Tank radio set

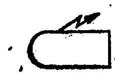

Two radio sets carried in a tank


Communications ship (craft)


Airborne radio set


Radio relay aircraft

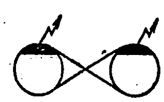

Truck-mounted radio set


Radio set carried on armored personnel carrier

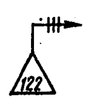

Stationary radio transmitter


Radio set with power amplification unit

Relay facilities:


VHF-UHF


HF


Tropospheric and ionospheric communications station

Radio link

Radio net

Television transmitter

Television receiver

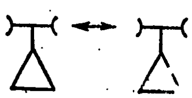
Radio relay communication facilities

Mobile radio relay station

Stationary radio relay station

Radio relay station with omnidirectional antenna

Radio relay station -- one terminal set

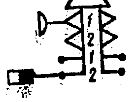


Radio relay communications link

Portable radio relay station

Designation of radio relay station channels: triangle -- telephone; line with dot -- telegraph.


Radio technical equipment


Multichannel radio relay station


Radar station


Stationary radar station


Radar altimeter

Type OSP precision approach radar system:


mobile


stationary


Precision approach radar system (type SP-50)


Combined instrument landing system (OSP with KGG)


Combined instrument landing system (OSP with RSP and KGG)


Combined instrument landing system (OSP with RSP)


Terminal area radio navigation system station


Pulse radio beacon

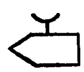

Localizer-glideslope group


Localizer beacon


Glideslope transmitter


Marker beacon


Mobile omni system station


Truck-mounted omni system station


Helicopter-mounted omni navigation system station


Mobile nondirectional beacon


Truck-mounted nondirectional beacon

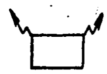

Airborne nondirectional beacon


Stationary nondirectional beacon


Compass locater

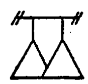

Light beacon


Searchlight station


Long-range radio navigation system station

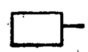

Radio technical observation and communications post

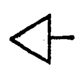

Weather station


Radar post

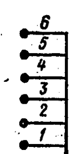
Telegraph and telephone equipment

Telegraph equipment:

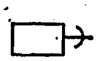

start-stop

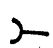

facsimile

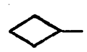

Single-channel audio frequency telegraphy equipment (indicate type of equipment inside box)

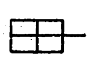


Multichannel audio frequency telegraphy equipment


Midpoint telegraphy


Telephone set


Telecode communications

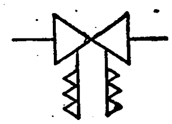

Signal-code communications

Telephone switchboard, line concentrator (specify type of switchboard, line concentrator inside box)

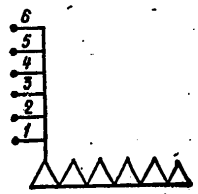
Single-channel high-frequency telephony equipment

Multichannel high-frequency telephony terminal equipment

High-frequency telephony intermediate equipment

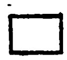


Channel separation equipment

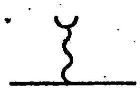


Multichannel audio frequency telegraphy equipment connected into a high-frequency telephone channel

Low-frequency telephone amplifier (intermediate)



Test station (place number inside box)



Telephone monitoring post

Amplifier stations:

manned

unmanned

Terminal loudspeaker

Multichannel interphone headset equipment

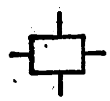
Headset

Communication lines


Two-conductor field cable line


Cable crossover


Mast crossover


Four-way branch box on permanent overhead communication lines


Branch box on permanent overhead communication lines


Permanent cable laid in buried conduit


Underground (underwater) cable

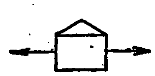
Cable distribution box

Cable box

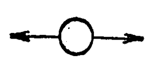
Junction box

Cable manhole

Courier-postal service centers and stations


Courier-postal service center

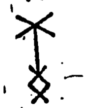

Courier-postal service station


Courier-postal service center exchange point


Car or truck

 Motorcycle

 Liaison aircraft

 Liaison helicopter

 Runner

 Landing site

Appendix 2. SOME UNIVERSAL CONSTANTS

Наименование величины 1	Обозначение 2	3 Значение величины	4 Единица
Физические постоянные 5			
6 Скорость света в вакууме	c	$(2{,}997925 \pm 0{,}0000004) \cdot 10^{8}$	м/с
7 Ускорение свободного падения	g	9,80665	м/с²
8 Давление атмосферное нормальное	p_0	$1{,}01325 \cdot 10^{5}$	Па
9 Элементарный заряд	e	$(1{,}60210 \pm 0{,}00007) \cdot 10^{-19}$	Кл
10 Масса покоя электрона	m_e	$(9{,}109558 \pm 0{,}000054) \cdot 10^{-31}$	кг
11 Масса покоя нейтрона	m_n	$(1{,}674920 \pm 0{,}000011) \cdot 10^{-27}$	кг
12 Масса покоя протона	m_p	$(1{,}672614 \pm 0{,}000011) \cdot 10^{-27}$	кг
13 Постоянная Больцмана	k	$(1{,}380622 \pm 0{,}000059) \cdot 10^{-23}$	Дж/К
14 Магнитная постоянная	μ_0	$4\pi \cdot 10^{-7}$	Г/м
15 Электрическая постоянная	ε_0	$\frac{1}{36\pi} 10^{-9}$	Ф/м
16 Постоянная Планка	h	$(6{,}626196 \pm 0{,}000050) \cdot 10^{-34}$	Дж · с
17 Удельный заряд электрона	$\frac{e}{m_e}$	$(1{,}758796 \pm 0{,}000019) \cdot 10^{11}$	Кл/кг
18 Первая космическая скорость	V_1	7,91	км/с
19 Вторая космическая скорость	V_2	11,186	км/с
Астрономические постоянные 20			
21 Средний радиус Земли	$R_з$	$6{,}37 \cdot 10^{6}$	м
22 Средняя плотность Земли	$G_з$	5500	$кг \cdot м^{-3}$
23 Масса Земли	$m_з$	$5{,}96 \cdot 10^{24}$	кг
24 Радиус Солнца	$R_с$	$6{,}95 \cdot 10^{8}$	м
25 Масса Солнца	$m_с$	$1{,}97 \cdot 10^{30}$	кг
26 Радиус Луны	$R_л$	$1{,}74 \cdot 10^{6}$	м
27 Масса Луны	$m_л$	$7{,}3 \cdot 10^{22}$	кг
28 Среднее расстояние от Земли до Солнца	$R_{зс}$	$1{,}495 \cdot 10^{11}$	м
29 Расстояние от Земли до Луны	$R_{зл}$	$3{,}8 \cdot 10^{8}$	м

Key to Appendix 2 on preceding page:

1. Constant
2. Symbol
3. Value of constant
4. Unit of measurement
5. Physical constants
6. Speed of light in a vacuum
7. Acceleration of gravity
8. Normal atmospheric pressure
9. Elementary charge
10. Rest mass of electron
11. Rest mass of neutron
12. Rest mass of proton
13. Boltzmann constant
14. Magnetic constant
15. Electric constant
16. Planck constant
17. Electron specific charge
18. Orbital velocity
19. Escape velocity
20. Astronomical constants
21. Average radius of the earth
22. Average density of the earth
23. Mass of the earth
24. Radius of the sun
25. Mass of the sun
26. Radius of the moon
27. Mass of the moon
28. Average distance from earth to sun
29. Distance from earth to moon

Appendix 3. SOME DATES FROM THE HISTORY OF DEVELOPMENT AND UTILIZATION OF COMMUNICATIONS AND RADIO-RADAR SUPPORT SERVICES EQUIPMENT

Essence of Development in Field of Communications and RTO 1	Authors 2	Date 3
Discovery of radio	A. S. Popov	7 May 1895
First radio telegraph communications between balloon and ground	A. S. Popov with the participation of P. N. Rybkin and D. S. Troitskiy	July 1899
Development and adoption of radio direction finders	N. D. Papaleksi	1903
Construction of first Soviet airborne electron tube radiotelegraph transmitter, AK-21	A. I. Kovalenkov	1921
AK-23 improved airborne radio transmitter built	A. I. Kovalenkov	1923
Development of single-commutator airborne generator, wind turbine powered	A. I. Kovalenkov	1923
Airborne radio receiver developed	A. V. Panov	1924
AKP airborne radio set built and utilized for communications	A. I. Kovalenkov and A. V. Panov	1924
Airborne radio direction finder developed and utilized	N. A. Korbanskiy	1926
Airborne radio sets developed and utilized for communications: 13S (for bombers), 14S (for artillery observers), and 15S (for fighters)	Industry engineers	1926
3D, 4D, and 11D ground radio sets developed and utilized for communications with aircraft	Industry engineers	1926
Direction-finding radio beacon developed and utilized	N. A. Korbanskiy, L. Ye. Shtillerman, I. K. Sadovskiy, V. I. Bazhenov, A. N. Plemyannikov	1930
Improved airborne radio sets built and utilized: 11SK (for heavy bombers), 13SK (for light bombers), 14SK (for artillery observers), and 15SK (for fighters)	Industry engineers	1931
11AK and 11AKM ground radio transceivers built and utilized for communications with aircraft	Industry engineers	1931
Radio aircraft instrument landing system developed and utilized	N. A. Korbanskiy; tested by pilot G. F. Baydukov	16 October 1932

Appendix 3 (cont'd)

1	2	3
RSVS-1 command radio transceiver developed and utilized on long-range bombers	I. S. Ryabov	1936
Improved airborne radio transceivers developed and utilized for communications: RSI-3 and RSI-4 (for fighters), RSR-1 (for reconnaissance aircraft), RSB-bis and RSB-Mbis (for bombers)	Industry engineers	1938
Ground radio transceivers developed and utilized for communications with aircraft: RAT, RAF-KD, RAF-KV and RSB-F	Same	1938
RPK-2 airborne radio compass and PAR ground nondirectional radio beacon developed and utilized	Same	1938
"Redut," first Soviet radar, built	B. A. Vvedenskiy, Yu. B. Kobzarev	1939
"Pegmatit" improved ground radar developed	Yu. B. Kobzarev, P. A. Pogorelko, N. Ya. Chernetsov, Yu. K. Korovin	1941
"Gneys-2" airborne detection radar developed and first utilized	Industry engineers	1941
PS-6 light beacon developed and utilized	Same	1941
PM-9 light beacon developed and utilized	Same	1943
Improved radio equipment developed and utilized for communications: RSI-3M1 (transmitter), RSI-6M and RSI-6MU (for fighters), RSR-2bis (for reconnaissance aircraft), and RSB-3bis (for bombers)	Same	1943
RV-2 (low altitudes) and RV-10 (high altitudes) radio altimeters developed and utilized	Industry engineers	1942-1943
Ground radio transceivers developed and utilized for communications with aircraft: RAF-KV-3, RAF-KV-4, RAT-44, RSBF-3, and RUK-42 mobile communications center	Same	1943
RSIU-1, RSVS-5 and RSIU-2 airborne VHF transceivers developed and utilized	Same	1943
"Pchela" high-power homing stations, carried in railroad cars, developed and utilized	Same	1943

Appendix 3 (cont'd)

1	2	3
RPKO-2 (for multiseat aircraft) and RPKO-10 (for single-seater aircraft) airborne radio compasses and PAR-3 and MPAR ground homing stations developed	Same	1943
PKV-43 and 55-PK-3A (modernized combined-arms radio direction finder) ground radio direction finders developed and utilized	Same	1943
RST-1 radio teleprinter equipment developed and utilized	Team of engineers under the direction of I. M. Malev	1944
"Signal" radio relay station developed and utilized for ground communications	Same	1944
RAP-150 radar-directed searchlight stations developed and utilized in the antiaircraft illuminating service system	Industry engineers	1944
Mirror attachments for the PM-9 light beacon developed and utilized for daylight operations	Same	1945

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