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Translation

COMPUTERIZED RADAR OPERATOR TRAINERS

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COMPUTERIZED RADAR OPERATOR TRAINERS

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CONTENTS

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ANNOTATION

This book examines the basic technical principles of building computerized trainers, and it presents the requirements imposed on trainers. Methods for simulating targets and interference on a display with the assistance of a computer are described, as are the principles of signal simulation in trainers.

Some problems associated with operator psychological training are illuminated, the techniques of teaching operators with trainers are described, and the methods for evaluating their preparedness are presented.

The book is intended for military specialists involved in the development and operation of trainers.

INTRODUCTION

Radio engineering troop units and subunits possess the most sophisticated combat equipment embodying the latest achievements of Soviet science. This imposes high requirements on the training level of personnel servicing this equipment.

A high professional level permits operators to successfully assimilate modern radar equipment and automated control systems (ASU), and to competently exploit the combat potentials designed into such equipment.

Life has necessitated a search for ways to train radar operators more quickly.

Reducing specialist training time is only one part of the problem. The other is that of upgrading the quality of work done by operators with combat equipment. Organizing and conducting combat training, commanders, political workers, and staff officers base their efforts on the fact that the continually growing power and complexity of military equipment is intensifying the dependence between the degree to which this equipment is assimilated by the personnel and the effectiveness of its combat use.

The proficiency of radio engineering subunit crews directly influences the accuracy with which antiaircraft missile troops and fighter aviation perform their missions. Therefore one of the most important requirements imposed on crew proficiency should be stated as detecting targets at maximum range, providing radar information with maximum precision, and fully exploiting the possibilities of the combat equipment when determining the composition of airborne targets.

The progress of science and technology in recent years has led to broad proliferation of complex technical systems. The human operator plays the decisive role in such systems, and the complexity of analyzing information and of performing control functions has made it necessary to upgrade operator training and instruction quality. This problem is especially important in radar applications, where operator training based on real systems involves considerable outlays of resources and significant expenditures of material.

Despite the rather broad use of simulators and trainers as technical devices to teach operators the habits of controlling various systems, the effectiveness of their use was inadequate until recently. An analysis of the development of trainers showed that at first, their designers tried to simulate the situation in the air with simplified models with permitted training only within a limited range of operating modes. The requirements on the quality and teaching possibilities of trainers increased, making it necessary to raise the completeness and accuracy of use of dynamic and information models, which necessitated inclusion of electronic computers into the trainers.

Among the merits of computerized stimulators and trainers we should include the possibility for simulating any aerial situation, for making it more or less complex, for changing the target trajectory parameters on a real time scale, for reusing the information models of the aerial situation, for studying such models in parts, and for automatically obtaining an objective score of operator proficiency and monitoring the course of operator training.

These merits and advantages of computerized trainers promote more-effective training, they raise its quality, and reduce its time. The results of operator training sessions can be used as a basis for evaluating how well an operator is suited to controlling a concrete system, and for comparing operators for the purpose of their selection.

THE OPERATOR IN THE RADAR INFORMATION PROCESSING SYSTEM

Operator Selection

A person's aptitude for a particular job depends on the individual features of his intelligence and his capacity for enduring stresses.

Occupational selection has the purpose of determining how well a specific person's capabilities fit the requirements imposed on a particular form of activity. It would be sufficient to recall how meticulously cosmonaut candidates are selected: Not everyone will pass through the fine "sieve" of selection. For example 500 persons were invited to join one of the astronaut groups in the USA, and only 11 persons were taken on following selection.

Selection is just as rigorous in aviation, in rail transportation, and in a number of other sectors.

There are many different techniques for selecting future specialists. Important among them are test-taking and testing with special devices. Such test programs are developed by scientists with regard to the particular features of the future operator's occupational activity.

It cannot be said that all of the problems of selection have already been solved. They are much more complex than may be imagined; however, the requirements on operators in the principal specialties have been defined with sufficient completeness.

For example an operator-controller must have an ample working memory, good diction, and a capability for quick decisions, and he must be maximally attentive, while a radar operator must have the capability for concentrating his attention for a long period of time, and he must have an ample working memory.

The work of a radar operator is distinguished by exceptional intensity and responsibility. Besides fundamental technical knowledge, it also requires firm practical habits associated with detecting airborne targets and determining their coordinates and their motion parameters. An operator's wrong actions may lead to serious consequences such as missing an enemy airplane or causing a friendly airplane to crash within the vicinity of the airfield. High emotional tension experienced by radar operators during their work, especially in a complex aerial situation when the time to reach the right decision is limited, and the feeling of high responsibility for one's actions presuppose selection of willful, technically competent individuals as the radar operators, ones having a full grasp on the habits of working in complex conditions.

After a radar operator is selected, he must be trained. What does training with real equipment involve, what is its effectiveness, and what does it cost?

The activity of a radar operator can be divided into two stages--preparatory and performing. In the first stage the operator turns on the apparatus, tunes and adjusts it as necessary, finds faults, and corrects them. Training a radar operator for work in the first stage is complex and expensive, and use of real equipment in such training reduces its operating life.

The content of the second stage can be summarized as the operator's detection of targets on the background of various sorts of interference, determination of the coordinates and motion parameters of detected targets, and target lock-on and tracking. This stage is rather complex and laborious. Thus for example, to create a complex situation on radar screens, we would need to simultaneously launch a large number of airplanes and direct their flight on particular routes that would ensure their entry into the radar detection zone at given time intervals. The airplanes would have to perform complex maneuvers in course, speed, and altitude, and they would have to create various forms of interference. We need not belabor the difficulty of such a task. Moreover, it is also extremely difficult to evaluate the actions of the operator. And yet, only a specialist with considerable experience in complex situations can become a good, reliable operator.

Thus training operators with real equipment is disadvantageous due to the following shortcomings:

As a rule, training is expensive;

the equipment needed for training is not always available;

the time allowed for training is limited by the specialist training schedules and programs;

a specialist who has completed the training program is forced to supplement his knowledge and improve the habits he has acquired in independent practical work. Sometimes his habits are found to be insufficient, and the specialist makes mistakes in his work, which may lead to serious consequences;

it is sometimes difficult to evaluate the results of such training.

Trainers help us to eliminate these shortcomings, or at least reduce them somewhat.

Trainers for complex machines are usually designed to be as accurate copies of the original as possible. The cost of such a trainer may be very high, approaching that of the machine itself. This is where the computer comes to our rescue: It can be used to create a mathematical model of the machine, one capable of reproducing all situations that may arise during work with the real object. Moreover a computer permits us to vary the training rate. Thus a novice operator can be trained at a slow rate, which can be increased as he acquires experience.

Unique Features of Operator Activity

Irrespective of their type and purpose, automated control systems can be defined as complexes of technical resources that collect, receive, transmit, and process information. Within these complexes, which form a control loop, man is the central unit. Called an operator by tradition, he in a sense closes the circle of information processes within the system, works with the information provided to him, and exercises control (9).

The operation of such a system can be described in general form as successive completion of three basic tasks:

1. Collection and transmission, via communication channels, of information on the object of control--so-called warning information, and its conversion for computer input.

2. Processing information on the object of control in accordance with prewritten algorithms executed by computer program.

3. Output of control information, its conversion, and its transmission to the object of control.

Of course, the degree to which the human operator participates in different systems varies. In principle, some systems may function without an operator in the control loop (Figure 1). Here the individual simply starts up the system, sets its work program, and monitors the correctness of program execution. When trouble arises in the system, the control process is halted until the individual is able to correct this trouble. Such systems are usually called automatic (for example, automatic control systems).

The control loop shown in Figure 2 is typical of systems characterized by a high level of automation. These highly developed control systems are sometimes called semiautomatic--not the best term. The individual is connected in parallel with the system, and he processes some of the information about the object of control. For the most part the operator exercises monitoring functions, and when an unforeseen situation arises, he can make corrections in the control process without stopping the system's work. A production process dispatcher control system is an example.

In systems that are automated in the strict sense of the term (Figure 3), the individual takes a direct and constant part in the control process. The operator receives information from the computer on the status of the object of control, he evaluates it, he works out and adopts a decision, and he feeds control instructions into the system. The computer feeds a processed and ordered set of data on the object of control to the operator, the individual evaluates this information, and he makes a decision on the nature of influence to be exerted upon the object. In this case the operator makes the final decision. Various traffic control systems are examples of systems.

In automated systems working in real time, in which an untimely though correct decision is equivalent to a mistake, extremely high requirements are imposed on the capabilities and occupational skills of the operators.

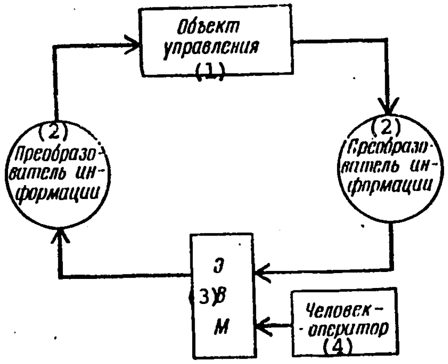

Figure 1. Control Loop in an Automatic
Sys System

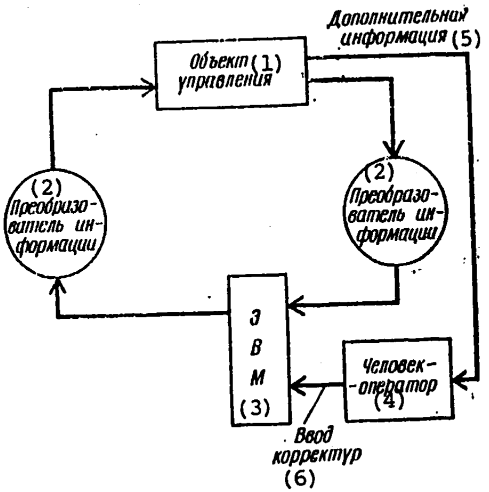

Figure 2. Control Loop in a Semiautomatic System

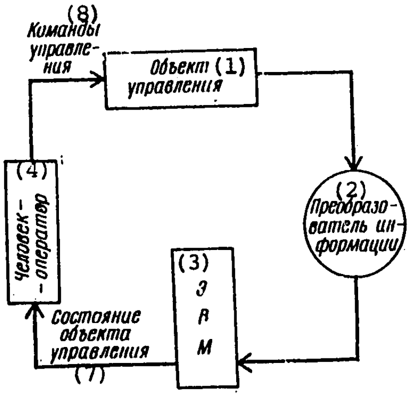

Figure 3. Control Loop in a Traffic Control System

Key:

1. Object of control
2. Information converter
3. Computer
4. Human operator
5. Supplementary information
6. Correction input
7. State of the object of control
8. Control instructions

Preparing information for decision making, evaluating and selecting the alternatives (making the decision, in fact), and executing the decision--in general the basic stages of operator activity--the operator utilizes his knowledge, experience, learned decision making techniques, and habits. These are precisely the components that make up the operator's professional countenance, his psychological, or internal, as psychologists say, resources or tools of activity.

In his work as an operator, the individual uses external technical resources or tools of activity that are created by system designers. The external resources include, first of all, the information display devices (screens, signal panels, graphic panels, indicator instruments), the information (symbolic) models of control processes they display, controls, and communication resources.

Four types of operator activity can be distinguished (9).

1. The operator-production engineer. He is directly included in the control process, he works mainly in an immediate response mode, and he performs controlling actions predominantly, guiding himself by instructions that as a rule cover almost the complete set of situations and decisions he may encounter.

2. The operator-observer--controller (for example a radar station operator, a traffic controller). He deals with a larger amount of information models, conceptual models, and decision making procedures, and he correspondingly possesses somewhat broader control habits (in comparison with the first type). Such activity is typical of operators in most automated systems.

3. The operator-researcher. He makes significantly greater use of intellectual actions and experience embodied within conceptual models. Controls play a still-smaller role for him, and the importance of information models is significantly greater. An example of such an operator is a researcher of any profile: a computer system operator, and so on.

4. The operator-manager. In principle, he differs little from the previous type, but for him, the mechanisms of intellectual activity play the most important role. These are organizers and managers, persons making important decisions and possessing intuition, knowledge, and experience.

Perhaps the types presented here do not fully reflect all aspects of operator activity (it may be suitable to distinguish the activity of an operator-manipulator performing control functions on manipulators--amplifiers of human muscle power). However, this classification simplifies revelation of the specific features of operator activity, and helps us reveal what is most important in the work of different types of operators.

We will subsequently focus our main attention on problems associated with training operators of the first two types.

Actions Taken by Operators in Typical Situations

One of the unique features of operator activity is that the operator is deprived of the possibility for observing the objects of control directly, and he is forced to use information fed to him via communication channels.

The individual's visual system possesses the broadest possibilities in comparison with his other analyzers playing a part in information reception. In this connection most technical signaling resources that transmit information from machine to man are designed for visual reception of signals bearing information.

Hearing is often used for information transmission with the purpose of reducing the load on the visual system. The relatively small number of acoustic signals that man can dependably distinguish is the limiting factor in the use of acoustic signals. Considering the circumstance that sound is one of the strongest stimuli of the orientation reflex, acoustic signals are used mainly as warning signals.

A radar operator's activity consists of a number of successive operations associated with distinguishing and recognizing marks presented on a display. The starting point of this process is the sensation which arises when the visual analyzer interacts with the marks presented on the display.

The first stage of observation involves detection and isolation, from a set of signals, those which are necessary to the task of the operator. From the series of signals he detects, the operator begins to select their most informative properties (characteristics), which transform within him into operational units of perception. The operator errors that arise most frequently in this stage of observation are due to insufficient distinctness of the characteristics of the signals, as a result of which they are confused with each other, becoming unable to support the operator's work. Another cause of errors in this stage is fast supersession of useful information, as a consequence of which the operator fails to identify the signals he needs.

The second stage of observation involves comparison of an isolated signal characteristic with the accepted standard, which is stored in the operator's memory. Here again there is the danger of losing significant signal characteristics, if the wrong standard or unessential characteristics are selected.

In the last stage of observation the operator processes the information he receives in accordance with a prescribed algorithm. This may entail simply decoding and recording the signal, or comparing it with a certain value, recording the comparison results, and so on.

We can mentally subdivide the process of transforming a set of input signals into suitable actions into two stages:

Breaking down situations into classes requiring an identical action (this is commonly called the recognition phase);

selecting actions suited to each of the groups of situations.

An operator's determination of ways to solve problematic situations within a short time interval involves so-called operational thinking.

In a number of cases an operator will use intuition to evaluate a problematic situation and make a decision in a short time interval. Operational thinking and intuition are closely associated with one another, and they are manifested in operators with highly developed spatial and temporal faculties. As a result of this process, the operator arrives at a final decision on controlling the system of which he is a component. The operator's accuracy of perception and the swiftness of his reactions to incoming signals may serve as criteria by which to evaluate his activity.

Radar Information Processing Systems

If we are to automate airspace surveillance and air traffic control, we would need to have complete and continuous information on the coordinates and characteristics of moving aircraft appearing within a given space. This information is acquired as a rule with the help of circular or sector scanning radar.

In the initial period of radar development, the main method for determining target coordinates with the help of a radar set was as follows (12).

Using a circular scanning display, the operator determined the range to the target and its bearing, and then he transmitted this information by telephone. To increase the reading accuracy, electronic range and bearing scale markers were employed, and sector displays showing target blips on a larger scale were used. This method had a number of shortcomings: The accuracy of coordinate determination was still low, depending to a great extent on the training level and state of the operators; the information lost its value when its transmission rate was low.

Such shortcomings on one hand and the great potential radar has for fast detection a of large number of targets on the other necessitated automation of radar information processing--that is, it required the transfer of some or all functions of the human operator associated with radar information processing to computers.

Automation of radar information processing can be partial or complete. Partial automation entails the creation of so-called semiautomatic processing systems. The human operator in a semiautomatic system is its most important organic unit, without which the system cannot work. Such systems are planned with regard to the specific features of human psychology and physiology, such that functions could be distributed sensibly between the individual and the computers.

All stages of processing are delegated to computers in automatic radar information processing systems. The functions of the individual in such systems are basically limited to observation of the system's work, and its technical maintenance.

Both the semiautomatic system and the automatic system are tied in directly with the sources of radar information, and they may perform the following tasks:

Detection of signals (blips) reflected from airborne targets;

determination of the coordinates of detected targets; detection of the trajectories of targets on the basis of the set of blips produced by a number of radar scanning cycles;

computation of target motion parameters (speed, course, and so on) and determination of coordinates on this basis, smoothed and predicted over a certain time interval.

The first two tasks are usually referred to as primary radar information processing. The others have come to be called secondary radar information processing.

In an unautomated system, all of the primary and secondary processing tasks listed above are completed by the operator, with the help of a plan position indicator.

In a semiautomatic processing system, only operations associated with determining target motion parameters and generating anticipated coordinates are usually subject to automation. These are fundamentally computer operations, and they may be performed with the help of both analog and discrete computers. The other processing tasks may be performed in such a system by the operator, visually or with the help of mechanized devices (plotters) that raise the accuracy of visual processing.

In an automatic processing system, both primary and secondary processing are performed with the help of automatic logic devices and computers. In this case as a rule, tasks involving the processing and coding of information obtained during one radar sweep are completed with the help of specialized primary processing computers, and tasks associated with processing target trajectories are completed with the help of electronic computers. The computer memory volume and speed must be sufficient to process data on all targets observed by the radar set, in real time.

Semiautomatic Information Processing

A simplified functional diagram of semiautomatic information processing is shown in Figure 4. The system includes a visual display, a human operator, a coordinate plotter working off the display screen, and a computer intended to calculate the target's motion parameters and to plot its trajectory (6).

The operator records the coordinates from the display and feeds them into the computer by superimposing an electronic marker (blip) produced by the coordinate plotter over the target blips on the display.

Signals (target blips) are fed from the radar receiving channel to the display at discrete intervals defined by the duration of the radar antenna's scanning cycle, T_0. Observing the display, the operator detects the targets, and then he selects, independently or in accordance with target indication data, those of them which need to be processed for automatic tracking.

Lock-on of a selected target involves successive input of the coordinates and detection times of two successive blips into the computer. The operator uses the plotter to feed the target coordinates into the computer. He superimposes the electronic marker created by the plotter over the target blip, after which he presses button K and the marker coordinates (identical in this case to the target coordinates) are fed into the computer. The motion parameters are determined from the first two computer inputs, and the computer begins calculating the anticipated target coordinates. Anticipated coordinates are calculated continually when analog computers are used, and in fixed time intervals when discrete computers are employed. The motion parameters and anticipated (extrapolated) coordinates are transmitted to the users.

In addition the extrapolated range and bearing coordinates, $Д_Э$ and $\beta_Э$ respectively, are used in moving the marker across the display screen. The marker's motion trajectory corresponds to the computed trajectory of the target. When a new blip associated with this trajectory appears, the operator observes the discrepancy between the coordinates of the new blip and the coordinates computed for the moment of observation by the computer. If this discrepancy exceeds a permissible value, the operator makes a correction by once again superimposing the marker over the blip and pressing button K. He stops making such corrections when the true and computed trajectory coincide.

Semiautomatic processing systems enjoy broad use in cases where the number of targets to be tracked is limited and the operator (or group of operators) is capable of tracking each one of them with prescribed accuracy. Moreover semiautomatic systems

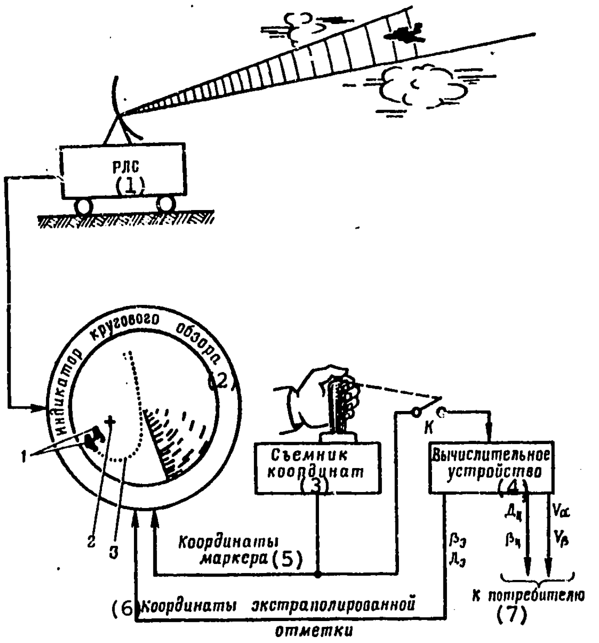

Figure 4. Simplified Functional Diagram of Semiautomatic Radar Information Processing: *1*--target blips in two consecutive sweeps; *2*--extrapolated blip for the third sweep; *3*--marker trajectory

Key:
1. Radar station
2. Plan position indicator
3. Coordinate plotter
4. Computer
5. Marker coordinates
6. Coordinates of the extrapolated blip
7. To user

can be used as back-ups in the event automatic processing systems break down or the latter are overloaded by intense interference.

Psychophysiological Characteristics of the Operator

Each of the components of the semiautomatic system examined above performs fully definite functions: The display presents a visual representation of the information; the plotter provides the current coordinates of targets subject to tracking; the computer determines the coordinates and motion parameters of tracked targets. The functions of the human operator boil down to target detection and mechanical actions associated with recording the blips with the help of the plotter.

All of the components of the system must be tuned and adjusted before they begin work. It is only in this case that the system would function normally and trouble-free.

After displays, plotters, and computers are adjusted, they are intended to operate without further adjustment for a long period of time. In the course of their operation, these components need only be periodically inspected, so as to keep them in working state.

The reliability of the other component of the system, the human operator, is a much more complex issue. The work of the entire system depends on how well the operator is tuned and prepared. This issue is within the competency of psychophysiologists, and their recommendations play an extremely important role in the designing of a semiautomatic system.

The content of operator activity may be reduced to the following.

The main and most difficult task of the operator is to establish the presence of the target on the basis of the results of his observation of marks appearing on the display. How successful he is in this task depends not only on the way the signals are modulated, the type of cathode-ray tube (CRT) and sweep employed, the characteristics of the luminophores, the intensity of screen illumination by external sources, the CRT's operating mode, outside stimuli, the amount of influence exerted by interference, the nature of the targets being detected, and so on, but also to a significant extent on the physiological and psychological features of the operator.

Assume that the operator must constantly observe the airspace represented on the radar display. In this case the periodicity with which airborne targets would appear on the display throughout his entire work shift, 1-2 hours for example, would not be dependent on a particular factor. On detecting an airborne target the operator describes it--that is, he determines its country of origin, coordinates, motion parameters, the quantitative composition of the target, and so on. He may describe the target either vocally or through a set of the appropriate characteristics.

A sample model of a radar operator's actions is shown in Figure 5 (11).

The operator's activity begins with his familiarization with the situation--that is, with perception and the conceptualization of information appearing on the radar display. This requires a certain amount of time t_1. Then the operator performs the current task--he identifies the object and makes a certain decision, which takes an amount of time t_2. Finally the operator performs the necessary actions, which require an amount of time t_3. Such division of the operations is understandably conditional in nature, since it is often difficult to draw a line between perception, decision making, and reactions of the operator; however, this division helps us to systematize the factors influencing the operator's work.

Perception time t_1 depends on many objective causes defining the visibility of target blips, for example on the contrast between the blip and the background, and the intensity and nature of interference. Moreover there are also subjective causes influencing time t_1, ones of the greatest interest to us. They include the operator's training level, his physical and psychological state, the features of his character, and his temperament.

Decision making time t_2 also depends on many variables, for example the problem solving algorithm, the operator's habits of executing similar tasks, and a large number of psychophysiological features of the operator.

The decision execution time t_3 is a function of variables such as the arrangement of the controls, their dimensions and shape, the compatibility of the motor actions required with the operator's accustomed actions, and the degree to which he is trained to perform such actions.

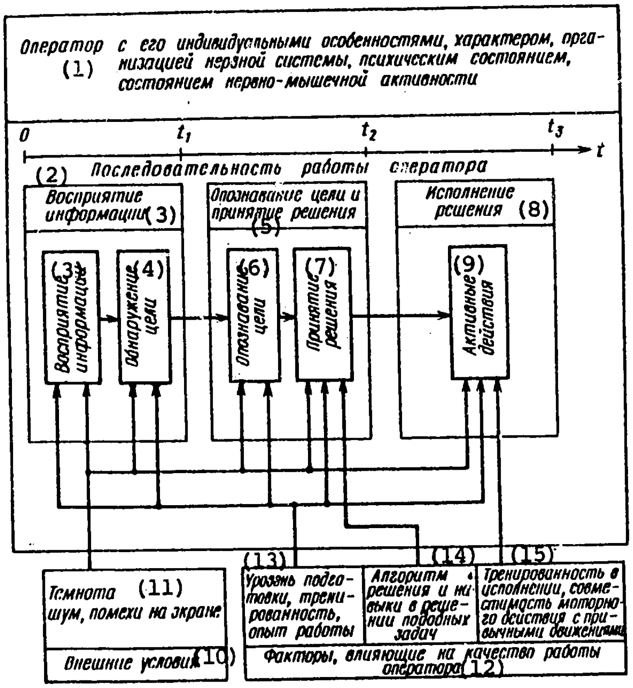

Figure 5. Sequence of Operator Actions

Key:
1. The operator, together with his individual features, character, nervous system organization, mental state, and status of neuromuscular activity
2. Operator work sequence
3. Information perception
4. Target detection
5. Target identification and decision making
6. Target identification
7. Decision making
8. Decision execution
9. Active actions
10. External conditions
11. Darkness, noise, interference on the screen
12. Factors influence operator work quality
13. Training level, work experience
14. Decision making algorithm and habits associated with similar tasks
15. Degree of training in decision execution, compatibility of motor actions with accustomed movements.

If completion of the task by the operator is to be reliable and effective, the sum S of all three times must be a little shorter than a certain time T, by which the operator's activity is rigidly delimited--that is, $S = t_1 + t_2 + t_3 < T$.

Failure to satisfy this inequality would mean a dramatic decline in the reliability of the entire system. We would naturally want to reduce time S by reducing the size of its factors. This can be done by selecting an operator who can make an optimum decision in time $S < T$.

Thus the activity of a radar operator can be divided into three phases: perception, decision making, and execution of an adopted decision.

The perception phase begins with an information search, as a result of which the operator detects a target. Detection is the starting point of a complex cognitive process. Presence of a signal within the visual field is established at the very beginning of the process. The information search ends with detection only in extremely simple tasks, requiring the operator only to decide whether or not a target exists. In real working conditions, the radar operator must not only detect the target but also reveal maximum information about it (a single or group target, the number of airplanes in the group, and so on). This task is also completed in the perception phase. It is very difficult to draw a sharp line between operations associated with detection and those associated with acquisition of information on the detected target.

The next phase in operator activity involves analysis and processing of the obtained information to be used in decision making, and making the decision itself. The psychological content of this phase is represented by the highest form of cognitive activity--thinking.

The decision making process is followed by the last phase--the operator's actions to execute his decision. Let us assume that motor actions are required of the operator in this phase (for example pressing buttons, turning tumbler switches, and so on). As a rule the movements themselves are not complex, but the effectiveness of the actions of decision execution depends on how they are controlled by the central nervous system, the status of neuromuscular activity, the strength of habits, and so on.

Because it is important for the operator to make the correct decision and to execute it quickly and correctly, he must be capable of reacting quickly, and without error, to all unexpected changes in the aerial situation, and to unforeseen circumstances and events. Moreover the operator must work in specific conditions, and this naturally makes his work significantly more difficult.

The existing methods of operator selection are based on revealing the individual's unique features affecting the effectiveness with which he can work in the given occupation. The main goal of selection is to choose persons with the fastest reactions or with prescribed qualities, and to determine the distribution of test subjects in relation to a given characteristic. Therefore to be able to perform selection, we would need to determine the group of characteristics that should be laid at the basis of a classification of radar operators. They include, first of all, a state of continual preparedness for immediate action throughout the entire time of work; second, prolonged concentration of attention on target search; third, the need for making an accurate and correct target detection decision; fourth, the propensity for stress*; fifth, awareness of high responsibility for making and executing decisions.

Let us examine the following occupational psychological characteristics of a radar operator that are subject to observation and analysis during selection: his powers of observation, attention, memory, and his capability for inductive and deductive reasoning.

An operator's powers of observation can be described as his ability to compare and contrast different objects and phenomena, notice the largest possible number of their features, and establish relationships and the nature of interaction between objects and phenomena.

An operator is said to be capable of inductive and deductive reasoning when he can successfully generalize the information he obtains with the purpose of encoding it in the most economical fashion, and when he is able to distinguish, from an overall background, those elements that are necessary for recognition and identification.

Let us dwell in greater detail on memory, viewed as a mental process and reflected in the capability for retaining and reproducing previous experience. The visual memory is known to be capable of retaining up to 90 percent of perceived information, while the auditory memory can retain only 9 percent. On analogy with a computer memory, human memory is divided into working and long-term. The volume of the working memory which is commensurate with the volume of a single instance of perception consists of five or six elements for a person with average capabilities; as a rule the time an individual retains information in his working memory does not exceed 3 seconds. Ten seconds after information is transmitted, the individual forgets 50 percent of it, and after 18 seconds he forgets 90 percent. Forgetting occurs even more intensively in complex situations.

The state of continual preparedness to act and the quality of concentrating attention over a long period of time may be summarized by the term fitness for work. Fitness for work declines as the result of tiring and fatigue. When the individual tires, his vision worsens, illusions and hallucinations may arise, and attention decreases significantly. Target search itself is especially tiring to an operator. It should be noted that the concept of fitness for work is defined quite specifically in relation to an operator. For example a radar station operator performs no cyclic operations. A considerable part of his working time goes on in a state of seeming inactivity, though in reality this period is occupied by intense observation of the radar screen. An operator's fitness for work is concurrently defined mainly by his readiness to react to emergency situations.

Stress may arise in response to growth in the complexity of the situation, arisal of some sort of conflicts and interference, or a mistake. Emotional and mental strain is the main cause of stress. One of the ways to avert such a state of mental stress in radar operators is to select them on the basis of personal qualities

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*Stress--a state of mental tension arising in an individual working in difficult conditions; it can have both a positive and a negative influence on activity, going as far as its complete disorganization.

reflecting individual features of the nervous system, emotional stability, and the capability for working in extreme conditions. A model of the psychological features of a radar operator's work and of the main mental factors affecting his work is shown in Figure 6 (11).

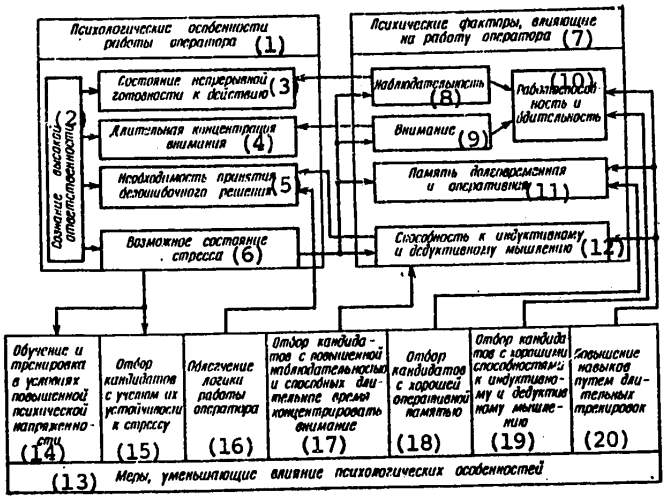


Figure 6. Psychological Features of an Operator's Work

Key:
1. Psychological features of an operator's work
2. Awareness of high responsibility
3. State of continual preparedness for action
4. Prolonged concentration of attention
5. Need for making a correct decision
6. Possible stress
7. Mental factors influencing the operator's work
8. Powers of observation
9. Attention
10. Fitness for work and alertness
11. Long-term and working memory
12. Capability for inductive and deductive reasoning
13. Measures reducing the influence of psychological features
14. Training and exercise in conditions causing higher mental tension
15. Selection of candidates with a consideration for their resistance to stress
16. Simplification of the logic of the operator's work
17. Selection of candidates with higher powers of observation capable of concentrating their attention for a long period of time
18. Selection of candidates with a good working memory
19. Selection of candidates with good capabilities for inductive and deductive reasoning
20. Improving habits through prolonged training

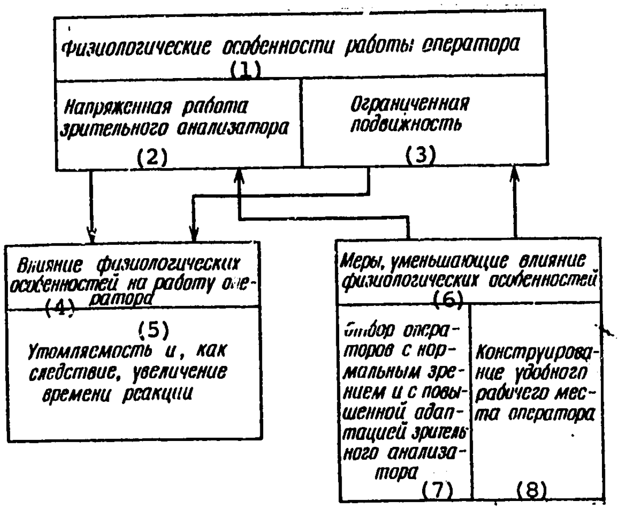


Figure 7. Physiological Features of an Operator's Work

Key:
1. Physiological features of an operator's work
2. Intense work of the visual analyzer
3. Limited mobility
4. Influence of physiological features on the operator's work
5. Tiring and consequent growth in reaction time
6. Measures reducing the influence of physiological features
7. Selection of operators with normal vision and with higher adapatibility of the visual analyzer
8. Design of a comfortable workplace for the operator

Consideration of the operator's basic psychological characteristics is no less important. They include limited mobility during work, and extremely intense work of the visual analyzer (Figure 7). The visual analyzer is a self-tuning system, and it adapts to the concrete conditions of the operator's work. In this case the sensitivity of the eye as an analyzer changes, thus promoting adaptation to concrete conditions. Adaptation is defined by the amount of change in sensitivity and by the time required for such change to occur. The sensitivity of the analyzer is a dynamic characteristic; its range changes with change in the operating stimulus. In a normal person, full adaptation takes a few dozen minutes. A working radar operator requires fast retuning of his analyzer, for example when shifting his gaze from a bright target blip to a dimly lit control panel, and back. If such shifts occur frequently, the operator begins to tire.

Thus the main requirements imposed on selection of a radar operator can be summarized as follows: resistance to stress, high powers of observation, a capability for prolonged concentration of attention, an ample working memory, presence of capabilities for inductive reasoning, and good adaptation of the visual analyzer.

Operator Recognition of Radar Signals

In the general case, recognition can be defined as making a decision establishing the membership of an input signal to one of several previously determined classes by comparison of this signal's properties, which make up its image, with previously known and studied images inherent to the given class.

For a recognition system (biological or technical) to function normally, some information must be available on the given list of signal classes. The system attains this information through learning, in which typical characteristics of signals in each of the classes are selected and memorized.

All recognition systems contain a perceiving unit, a memory block, a comparison unit, and a computer. In biological systems, these components are functionally and spatially integrated as a rule. Thus for example, recognition of signal blips by a radar operator involves the participation of the visual system, the memory, speech, and motion, all brought together under the single concept "central nervous system". In this case the visual system plays the role of the perceiving unit and performs the function of measuring the values of the blip characteristics. The characteristics of different signal classes are stored in the long-term memory, and the operations of comparing observed characteristics with class characteristics, and of generating a decision are performed with the help of operational thinking, involving the use of the short-term memory.

The class of a target detected by a radar station can be determined if we know the characteristics that place a signal in a certain general class and make it different from signals produced by all of the targets that may appear within the range of the radar station. Such characteristics may be determined by analyzing reflected signals.

The effectiveness with which operators recognize radar signal blips depends significantly on the way the situation is presented to the operator. For example information on the aerial situation may be represented in the form of target blips on the screen of a cathode-ray tube, as is done in a radar station, or on a screen on which airplanes are represented jointly by numerical data and their motion parameters, or in tabular form. In all cases the requirement of the information model's adequacy to the evolved situation would be observed. But the operator may require more time for analysis in one case than in another. Therefore the information model must not only reflect reality but also correspond to the individual's capabilities for efficient information processing.

On the basis of his analysis of the information he acquires, the operator creates his own impression of the state of the objects he is observing; this impression is commonly called the conceptual model. The operator needs some time to form it. The closer the information model is to the conceptual model, the higher is the operator's working capacity.

A distinction is made between detailed and integral information models. Detailed models contain detailed information on objects and their parameters, which could be used by the operator to make decisions concerning each object. Integral models permit the operator to make a qualitative evaluation of the situation. Depending on the tasks performed by operators of different display devices, either detailed or integral models are created. Combination of both models on one indicator is also possible.

In some cases this helps to raise the operator's working capacity, because work with an integral model releases the operator from the need to search for the necessary information.

Three particular recognition tasks may be performed in radar detection:

- determination of the class of the detected target; identification of one prescribed target on a background consisting of reflections from terrain features, or interference:
- recognition of terrain images.

To recognize radar targets, the operator utilizes the characteristics of the reflected signals themselves, while to recognize terrain, he uses the characteristics of a sum of reflected signals. In the course of his training, a radar operator is provided information on the typical characteristics of the blips produced by signals reflected from airplanes, ships, vehicles, bridges, and other objects. Special attention should be turned in this case to proper selection of the most typical characteristics for each class of targets.

Characteristics which an operator can use to determine the class of a detected target and to identify one prescribed target from a background of changing reflections include the detection range, the rate of movement of the spot on the screen, the size of the blip, the shape of the blip, and the nature of changes experienced by the size and shape of the blip (pulsations) from sweep to sweep.

Depending on the conditions, some of these characteristics may have decisive significance, while some may have an auxiliary function. Assume for example that the operator of a marine detection radar has detected a target at the station's maximum range. The distance to the target decreases relatively slowly, and the reflected signal hardly changes from sweep to sweep. In this case the operator has the grounds for classifying the detected target as a large vessel. A characteristic such as the size of the blip may be used later by the operator to confirm his hypothesis that he had detected a large vessel, since as the range decreases, the blip from such a target begins to acquire a distinct, stable shape, and its size is somewhat greater than that of a blip produced by medium-sized and small vessels.

The main characteristic used by an operator to recognize blips produced by airplanes is the rate at which the target shifts from sweep to sweep. The nature of pulsations from sweep to sweep, which occur owing to fast change of the target's angle of sight and its reorientation relative to the radar set, serve as a supplementary characteristic in this case.

If special countermeasures are not taken, signals from small ships, vessels, and landmarks are detected at low range, which is a dominant characteristic of their recognition. Low-flying airplanes are also detected at low range; however, fast change in range from sweep to sweep permits the operator to make the right recognition decision.

When the operator detects several targets located close together, he sees a blip of complex shape; this itself can serve as the basis for classifying the detected target as a group target.

The probability that an operator would correctly recognize targets depends on a number of factors: the extent signals reflected from different objects differ; the length of time the operator underwent training, and the degree of his training; the actual capability radar has for picking up targets in the given region; information on the anticipated situation, received by the operator before and during work; use of camouflage and deception by the enemy; the timeliness of target detection; presence of external stimuli, fatigue, and so on.

Trainers for Radar Operators

We can distinguish three basic tasks in the use of trainers to teach operators.

The first task is to create a simulated information model of the aerial situation, similar to a real situation in its influence on the operator.

We know that the image created on the screen of a plan position indicator is characterized by the brightness of different points (areas) on the screen, by the shape and persistence of marks, and by the average brightness of the screen. In addition to useful signals reflected from targets, signals from various sorts of interference are also induced on the indicator screen (12).

For real moving targets, there exists a relationship between their previous and subsequent positions stemming from the inertial properties of real targets and their possibilities for maneuvering. Therefore it can be asserted that following a sufficiently short time, a subsequent blip must be located in the vicinity of a previous one. Moreover we can predict, with a certain degree of precision, the coordinates of the next blip, if we first calculate the speed of the target and the direction of its flight. The smaller the interval between a previous and a subsequent blip, the more strongly these laws manifest themselves. As the interval increases, this relationship weakens as a rule, and it may disappear altogether.

The most probable causes of arisal of false blips are concerned with purely random factors. In view of this, the laws governing the arisal of such blips on the radar display and their locations are different. They manifest themselves mainly as the absence of a relationship between blips from sweep to sweep. False blips appear randomly in different places on the indicator screen, while target blips appear along the trajectory of the target's motion (there is some scatter due to measurement errors).

Simulation of an information model of a sufficiently complex aerial situation within the range of one or several radar stations is possible only with high-speed electronic computers.

The second task is to obtain information on the operator's reactions to input signals transmitted to him. Assume that an operator observing an indicator screen detects new target blips and determines the coordinates off of the indicator screen by superimposing an electronic marker connected to the plotter mechanism over the corresponding blips from the targets. The operator can lock onto new targets for tracking by successively inputting the coordinates of the blips and the moments of their detection into the computer. Inasmuch as the computer memory stores the coordinates of the simulated target blips and the times of their transmission to the indicator screen, when the computer receives the coordinates of the same blips from the operator, it can evaluate the accuracy and swiftness of coordinate plotting.

The third task is to control the training information model of the aerial situation during operator training. It would be suitable to delegate this task to the computer as well; using a learning program, the computer should change the information model of the aerial situation depending on the successfulness of the training.

A trainer is a technical device intended for development of the necessary habits and skills of an individual or a group of people by creating a simulated information model, the complexity of which changes as training proceeds.

A training device which does not possess a well-developed system for monitoring the actions of students, and which can only transmit information from the computer to the radar indicator screen, is called an aerial situation simulator.

Figure 8 shows one of the possible functional flow charts for a computerized trainer.

The trainer consists of a raw data input block, a radar antenna simulating block, a target and interference signal generating block, an indicator, a device that plots coordinates off of the indicator screen, an interlinking block, a trainer control console, and a computer.

The raw data input block is used to set the parameters that remain constant in the course of training.

The computer calculates the current values of the parameters of simulated target and interference signals.

On receiving data from the computer, the signal generating block generates simulated target and interference signals with the help of the antenna simulating block. On being transmitted to a display on the operator's control console, simulated signals form an information model of the aerial situation.

Information on operator reactions, the nature of which is determined with the help of the coordinate plotter, is transmitted to the computer via the interlinking block. The computer evaluates the accuracy and swiftness with which the operator reads the data, and displays scores on the trainer control console. In addition, other information required for management of the training is transmitted to this console as well.

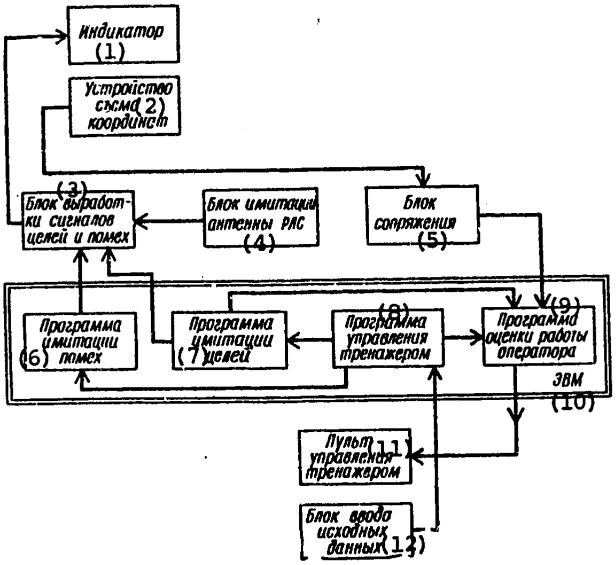


Figure 8. Functional Flow Chart of a Computerized Trainer (One Variant)

Key:

1. Indicator
2. Coordinate plotter
3. Target and interference signal generating block
4. Radar antenna simulating block
5. Interlinking block
6. Interference simulation program
7. Target simulation program
8. Trainer control program
9. Operator evaluation program
10. Computer
11. Trainer control console
12. Raw data input block

COMPUTER MODELING OF A SITUATION

The Principles of Computer Modeling of a Situation

The main information concerning the trajectory of motion of targets within radar range is the spatial coordinates of the target blips, change in which follows the law of target motion in space.

In the general case the trajectory of each target may be described by the coordinates of its center of mass, given in a selected coordinate system.

Let us examine the trajectory of each target beginning with the moment it flies within range of the radar station. Let us describe the initial point by time t_{BX} and coordinates x_0, y_0, z_0, in a rectangular coordinate system, or by variables Д_0, β_0, ε_0 (slant range, bearing, and angle of sight respectively) in a polar coordinate system.

Let us represent the trajectory of a target of arbitrary shape as a set of successive banking turns (including turns at zero acceleration--that is, straight sections of the flight path) in two planes--horizontal and vertical--at a constant velocity (within the confines of a turn) V. Thus to describe the motion of the target, we would need to give the starting point t_{BX}, x_0, y_0, z_0, and a succession of parameters characterizing each turn: τ_B--duration of the turn, V--turning velocity, m and n--normal accelerations in the horizontal and vertical planes respectively.

The motion of the target about its center of mass may be described by its angles of incidence and sideslip, as well as by its attitude, yaw, and roll.

In a real situation, any radar information processing system must deal not with lone targets but with an aggregate of targets with a certain distribution of the moments in time at which they enter within radar range. Such an aggregate is called the target flow. In order to arrive at a mathematical description of target flows, it would be convenient to make use of some premises of queueing theory.

In order to describe a determined flow consisting of N targets, it would be sufficient to assign a succession of vectors $\vec{C}_1, \vec{C}_2, \ldots, \vec{C}_N$ of the form (t_{BX}, x_0, y_0, z_0, V, m, n). However, we have only limited interest in studying the reactions of the modeled system to a determined flow of targets. The fact is that given the presence of unaccounted deviations in the operating factors, the impossibility of maintaining parameters at strictly prescribed values, and instrument error, a target flow must be interpreted as a random flow.

Although a flow of targets of such general form can be described mathematically with the help of the modern machinery of probability theory, to do so would be extremely complex. Research has shown that computer-plotting of multidimensional vectors requires extremely cumbersome calculations. Therefore it would be suitable to use certain approximate, partial procedures available for use today.

The first such procedure for describing a random target flow is the method of realizations. In essence it entails describing a certain random flow of targets by a sufficiently large number of individual realizations. Naturally the aggregate of realizations would represent a set of fully determined flows approximating the sum total of possible realizations of the random flow.

If we are to describe, for example, r realizations of a flow, each of which consists of N targets, we would need to tabulate rN multidimensional characteristics containing the components of vectors C_i. Obviously such description of the target flow would also be cumbersome.

Description of the target flow becomes much simpler when we can approximate the values in the table by elementary time functions for each realization of the flow; in this case each transition from one realization to another would involve change in the values of certain parameters.

The second practically acceptable method for describing a target flow would be its approximate description by means of probability characteristics. For this purpose we would need to know the so-called average flow, the parameters of which are the mathematical expectations of the parameters of the random flow, and we would need to indicate the probability characteristics for deviations of the parameters from their corresponding mathematical expectations.

An average flow may also be described as a fully determined flow by the same procedure used to describe individual realizations of the flow. Deviations of parameters from their mathematical expectations are described by the corresponding distribution laws (joint distribution laws). Some of the flow parameters may be fixed.

Thus we can describe sufficiently diverse flows of targets and insure their compact computer simulation.

We can arrive at an extremely simple computer expression of a broad class of flows in the event that the moments of entry of targets within radar range take the form of a flow of uniform events, and the rest of the parameters are assumed to be independent of the time of entry, and are described by the appropriate distribution laws.

As an example, let us examine simulation of a flow of airplanes flying into the range of a radar station set up at an airfield (6). The coordinates of the entry points of each airplane within the airfield zone, x_0, y_0, z_0, and the parameters of each airplane's motion within the zone are presumed to be random variables following a normal distribution law and described by the corresponding mathematical expectations and correlation matrixes. The moments of entry of the airplanes, t_{BX}, are a flow of uniform events. The distribution law for the flow is presumed to be known. The moment of entry t_{BX} and the initial coordinates are not independent. Their joint description always involves significant difficulties elicited by the need for considering a timetable. Therefore it would be suitable to describe the initial coordinates by their distribution law on the condition that $t = t_{BX}$.

First we model the moment of an airplane's entry into the airfield zone as one event in a random flow of successive uniform events following a given distribution law. Then at a fixed moment t_{BX} we model the initial coordinates x_0, y_0, z_0 for the given airplane as a random vector following a given, conditional distribution law. Next we plot the trajectory of the airplane in the form of a connecting segment of arcs and straight lines depending on the given motion parameters.

Building a Model of the Trajectory of a Simulated Target

The information used to describe a target is its trajectory, given by time functions in current coordinates. A target trajectory may be described by either a determined function of time and parameters, or in the form of a random process with given statistical characteristics. It depends on numerous factors and conditions: the type of target, altitude, velocity, and maneuverability. Moreover a large number of random factors (interference) that distort the trajectory or hinder its detection and reproduction also have an influence on the target trajectory. These include, for example, random oscillations of the target about its kinematic trajectory due to random environmental perturbations, errors made by the target control system, instrumental errors in coordinate measurements by the radar station, returns from terrain features and jamming.

These and some other factors compel us to treat moving targets as processes with parameters varying randomly in time. Obviously if we are to arrive at a statistical description of such processes, we would need to know the distribution laws for the probabilities of the parameters defining these processes. For practical purposes, however, we cannot derive such laws, and therefore we must propose several hypotheses on the statistical characteristics of the target--that is, we need to begin with a more or less plausible statistical model of the target's motion.

The particular model of target motion we select depends on the particular target with which the radar operator will have to deal. If the functions of the operator will entail detecting returns from airplanes and cruise missiles, then the models of their motion would take the form of a set of segments of straight-line movement and maneuvering segments. A so-called polynomial model of motion may be adopted for such targets as the basis. It entails representing change in coordinates within a limited zone of observation by a polynomial.

Let us examine the motion of a target in, for example, a rectangular coordinate system $OXYZ$ or $OXYH$ where H is the target altitude, or in a spherical system of coordinates Д, β, э with its origin at the location of the radar station. In either of these coordinate systems, the target's trajectory may be approximated by temporal polynomials. However, difficulties in modeling transitions from one leg of a trajectory to another arise in polynomial description of a rather complex trajectory (one having straight-line and curvilinear segments). Therefore it would be more advantageous to resort to parametric description of the trajectory, and to use parameters having graphical geometric meaning.

Let us imagine a flat target trajectory (with $H = \text{const}$) in a rectangular coordinate system with the origin located a distance $Д_{\text{макс}}$ away from the radar station's location--the maximum range of the radar station in relation to both coordinate x and coordinate y (Figure 9).

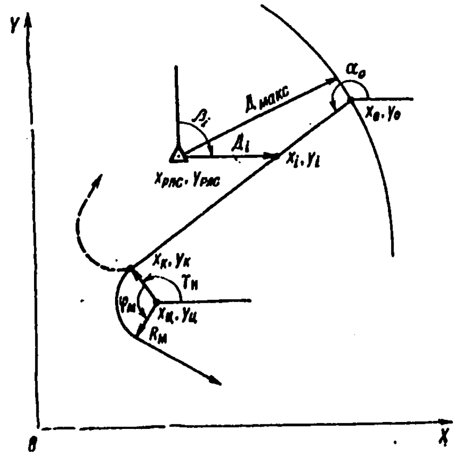


Figure 9. A Model of a Target Trajectory

The first important parameter describing the target trajectory is the point at which it enters within the zone of the radar information processing system. The boundaries of the area inscribed by rotation of the radar's beam pattern must be taken as the system's limits. This zone can be simplified down to a cylinder with base radius equal to the maximum range of the radar station and the generatrix representing the maximum height of the radar scanning zone.

The point at which the target enters within the radar scanning zone is described by:

time of entry t_0;

the rectangular coordinates of the starting point of the trajectory x_0, y_0.

The following are given for segments of the target's uniform and straight-line motion:

the target velocity V_l, where l is the trajectory segment number;

angle α_l between axis OX and target velocity vector V_l;

the number of detection points N_l;

the time interval between detection points Δt.

The initial segment of the trajectory may be said to be linear.

We assume that in all portions of a turn (a maneuver) the target follows the circumference of a circle, and consequently its motion may be described by the following parameters (Figure 9):

The normal turning acceleration n_M;

the depth of the turn ϕ_M, which is defined as the angular amount the target changes its initial course during the turn;

the target's velocity in the turn V_M.

In addition, using the parameters above, we calculate the radius of the turn with the formula

$$R_м = V_м^2 g_0 \sqrt{N_м^2 - 1},$$

where g_0--free-fall acceleration; N_M--number of detection points along the turn:

$$N_м = R_м \frac{\varphi_м}{V_м} \Delta t.$$

The starting point of a turn coincides with the end point of a segment of linear motion. The sequence of alternating segments of linear motion and turns is known beforehand.

The entire trajectory of the target is represented by a combination of linear segments joined together by circumferential arcs. To plot such a trajectory, we would need to know its parameters at the connecting points (reference points). The set of parameters associated with each reference point is computed beforehand, and recorded in the computer's main memory.

After the reference points are determined, the detection points along the trajectory are plotted in a rectangular coordinate system using the following formulas (6):

a) in a linear segment (beginning with the starting point):

$$x_i = x_{i-1} + V_i \cos\alpha_i \cdot \Delta t;$$
$$y_i = y_{i-1} + V_i \sin\alpha_i \cdot \Delta t;$$

b) in a turning segment:

First we calculate the rectangular coordinates of the center of the turn circle:

$$x_ц = x_к - |R_м| \operatorname{sgn} R_м \sin\alpha_i;$$
$$y_ц = y_к + |R_м| \operatorname{sgn} R_м \cos\alpha_i,$$

where x_K, y_K are the coordinates of the end point of the previous segment of the trajectory;

$$\operatorname{sgn} R_{\text{м}} = \begin{cases} +1, & \text{for a left turn} \\ -1, & \text{for a right turn;} \end{cases}$$

Then we calculate the initial value of angle γ_H;

$$\gamma_{\text{н}} = \alpha_i - \frac{\pi}{2} \operatorname{sgn} R_{\text{м}};$$

the current value of γ_i $(i = 1, 2, \ldots, n_M)$ is computed with the formula

$$\gamma_i = \gamma_{i-1} + |\Delta\varphi| \operatorname{sgn} \varphi,$$

where

$$\Delta\varphi = \varphi_{\text{м}}/N_{\text{м}};$$

$$\operatorname{sgn} \varphi = \begin{cases} +1, & \text{for a left turn} \\ -1, & \text{for a right turn;} \end{cases}$$

the coordinates of a successive detection point in a turn segment are determined with the formulas:

$$x_{\text{м}i} = x_{\text{ц}} + R_{\text{м}} \cos \gamma_i;$$
$$y_{\text{м}i} = y_{\text{ц}} + R_{\text{м}} \sin \gamma_i,$$

corresponding to velocities:

$$V_{x\text{м}i} = \frac{x_{\text{м}i} - x_{\text{м}i-1}}{\Delta t};$$
$$V_{y\text{м}i} = \frac{y_{\text{м}i} - y_{\text{м}i-1}}{\Delta t}.$$

In all cases the radar coordinates of a successive detection point are defined by the formulas:

$$\text{Д}_i = \sqrt{(\Delta x_i^2) + (\Delta y_i^2)};$$

$$\beta_i = \begin{cases} \beta_i' & \text{at } \Delta x_i > 0, \ \Delta y_i > 0, \\ \pi - \beta_i' & \text{at } \Delta x_i > 0, \ \Delta y_i < 0, \\ \pi + \beta_i' & \text{at } \Delta x_i < 0, \ \Delta y_i < 0, \\ 2\pi - \beta_i' & \text{at } \Delta x_i < 0, \ \Delta y_i > 0, \end{cases}$$

where $\Delta x_i = x_i - x_{\text{рлс}}$;

$\Delta y_i = y_i - y_{\text{рлс}}$;

$\beta_i' = \operatorname{arctg} \frac{|\Delta x_i|}{|\Delta y_i|}$.

Thus the essence of plotting the trajectory of a target with the help of a computer boils down to the following. First of all we plot so-called templates of all possible variants of target flight--the target trajectories from the boundary of the radar detection zone to emergence from the latter. These trajectories are recorded in the computer memory as a table containing the starting point, the duration and parameters of the first turn, the duration and parameters of the second turn, and so on. The values contained in the table subsequently serve as the mathematical expectations of the corresponding values used to model a real trajectory. The computer memory also stores the elements of correlation matrixes characterizing random fluctuations in these tables.

The target trajectory modeling procedure entails modeling each successive step: The mathematical expectations of a turn are selected from the table, then random numbers are used to create random deviations from the mathematical expectation, and finally a pair of straight lines or circles representing a model of the trajectory in the given segment is plotted in the appropriate planes. The coordinates of a target at the end point of its turn are assumed to be the coordinates for the starting point of the next turn.

Using special limitations, we check each segment of the trajectory to see if it lies within the tolerances of the trajectory whose parameters are stored in the computer.

Modeling the Process of Arisal of Blips From Simulated Targets, Detection Errors, and Interference

Let us adopt the convention that the moment in time at which the beam of the radar antenna's polar diagram coincides with the direction to the target is the moment of detection of the given target, and that the point on the trajectory at which the target is located at the moment of detection is the target detection point. Were no errors made in measuring the coordinates of the radar station, the coordinates of the detection point could be defined as the coordinates of the point at which the beam of the radar station's polar diagram intersects the target trajectory. A point with such coordinates is called the ideal detection point. In contrast to an ideal point, we will examine simply the detection point arrived at with a consideration for measurement errors.

The process of formation of radar blips from targets within radar range may be described as follows. The beam of the radar's polar diagram rotates uniformly, and it intersects the trajectories of targets within its scanning zone. The resulting points of intersection are ideal detection points.

Thus if we are to model the coordinates of ideal detection points, we would need to jointly solve the equation for the target trajectory and the equation for motion of the radar station's beam pattern, which may be written as:

$$\beta(t) = \beta_0 + (2\pi/T_0)\, t,$$

where β_0 is the bearing of the initial direction (usually $\beta_0 = 0$), and T_0 is the duration of a radar scanning cycle.

However, we could simplify the modeling process by first arbitrarily computing the coordinates of each trajectory and then arranging the resulting values in order of larger (or smaller) range Д and bearing β. Inasmuch as the coordinate for bearing β is uniquely associated with current time, when ordering each pair of coordinates Д_i, β_i, we can ascribe a detection time t_i to each such pair (7).

The detection points obtained in this fashion belong to targets present within the radar station's scanning zone. But not all of these points would in fact be detected in a current sweep. Consequently we would need to account for the probability of target detection as a function of range.

Calculations show that the current probability of detection of the i-th target is

$$p_i \approx \exp(-0{,}68\text{Д}_{0i}/\overline{\text{Д}}),$$

where Д_{0i} is the threshold for the detection range of the i-th type of target, and $\overline{\text{Д}}$ is the average range at which targets of the i-th type are detected.

The value of Д_{0i} is given as the initial point of entry. If, as a simplification, we assume $\text{Д}_{0i} = \overline{\text{Д}}$, the expression above could be written as:

$$p_i = \exp(-0{,}68) \approx 0{,}38.$$

After p_i is computed, the blip detection procedure proceeds as follows: A random number κ, uniformly distributed in the interval [0,1], is selected, and this member is compared with p_i. The blip is said to be detected when the inequality $\kappa \leqslant p_i$ is satisfied.

Solution of the equation system for the coordinates of the starting point requires the assumption that the first ideal detection point is given.

But if the first detection point must still be found, we can adopt, as the starting point, the point of the target's entry within radar range, for which parameters x_0, y_0, z_0 are known.

Thus by solving the equation system we get the coordinates of the ideal detection point for the corresponding moment in time. This procedure is performed successively in relation to all targets within the radar scanning zone.

To move on from ideal to real detection points, we would need to consider the error made by radar stations in measuring coordinates. It is usually presumed that random coordinate measurement errors are independent, and that they have a normal distribution.

Different factors can be included in the error model depending on the modeling objective: random noise, random fluctuations slowly changing according to a particular law, systematic error, and so on. Let us examine, as an example, simulation of only the noise and fluctuation factors of random errors. Both factors are said to be distributed normally.

The error modeling objective in this case is to arrive at random errors $\Delta Д_i$, $\Delta\beta_i$ with a normal distribution, a given standard deviation, and a mathematical expectation of random errors taken equal to zero.

The derived random errors $\Delta Д_i$, $\Delta\beta_i$ are added to the ideal detection points:

$$Д'_i = Д_i + \Delta Д_i;$$
$$\beta'_i = \beta_i + \Delta\beta_i.$$

As a result we get the coordinates of real radar blips.

The interference detection procedure could have been devised on analogy with the method examined above for determining ideal detection points. However, this would have created certain inconveniences connected with selecting undetected interference. Therefore it would be suitable to adopt a procedure for considering noise which would permit us to derive information only on detected interference, and which at the same time would not be too complex. The main possibilities allowed here for simplification, in comparison with the target detection situation, would be superimposing a false blip with the radar station's beam in time, and ignoring measurement errors.

Both a false blip and a real blip will be described by three parameters: coordinates $Д_{\Pi i}$ and $\beta_{\Pi i}$, and the moment of detection $t_{\Pi i}$.

The sequence of operations for modeling false blips boils down to the following pattern:

We model the flow of moments in time $t_{\Pi i}$ in the interval $[0,T]$;

we find the bearing of the false point with the formula

$$\beta_{\Pi i} = n_i \Delta\beta,$$

where $n_i = [t_{\Pi i} \; T_{\Pi}]$ is the greatest integer of the ratio of time interval $t_{\Pi i}$ to the duration of scanning cycle T_{Π}, and $\Delta\beta = (2\pi/T_0)T_{\Pi}$ is the discrete angular scanning space;

we find the range to the false blip with the formula

$$Д_{\Pi i} = c\frac{\Delta t_{\Pi i}}{2},$$

where $\Delta t_{\Pi i} = t_{\Pi i} - n_i T_{\Pi}$;
$c = 3 \cdot 10^8$ m/sec.

The range obtained with the formula is compared with the radar station's maximum range. When $Д_{\Pi i} < Д_{\max}$, it is assumed that the false point is within radar range; in the opposite case, information on it is erased.

The coordinates of other false blips are determined similarly. When inspected separately, a succession of false blips is ordered in terms of the time of their detection. However, when both true and false blips are present, we would need to order them together, so that we could arrive at a combined flow of true and false blips.

Modeling a Sequence of the Moments of Target Entry Into the Radar Scanning Zone

The moments of time at which targets appear at the boundary of the radar scanning zone (the moments of target entry) compose a random flow of events. As an example we will examine the operation of a large airfield in steady state, for which this flow may be represented, over a sufficiently long time interval, as a flow of uniform events following one another with time intervals of $t_1, t_2, \ldots, t_k$. We assume that the distribution law for τ_i--that is, for the times at which the boundary of the radar scanning zone is crossed by the flow of targets--is of the simplest form possible, with a probability density of

$$\omega(\tau) = \lambda \exp(-\lambda\tau), \quad \tau > 0,$$

where λ is a parameter of the flow equal to the mathematical expectation of the number of targets crossing the scanning zone per unit time.

Random numbers τ_i with a distribution density of $\omega(\tau)$ may be obtained with a computer by transforming a sequence of pseudorandom numbers κ', uniformly distributed in the interval [0,1].

In the event of the simplest possible flow, there exists a simple analytical dependence between random numbers κ' and τ_i:

$$\tau_i = -[\ln(1 - \kappa')]/\lambda,$$

which allows us to solve the problem at hand.

Thus simulation of the moments of target entry into the radar scanning zone boils down to selecting a sequence of random numbers κ', uniformly distributed in the interval [0,1], and calculating τ_i with the last formula. Then we determine t_{0i}--the time of entry of each target within range of the radar station (3).

In addition to the moments of entry, we also need to model the angular coordinates of the point of entry of each target into the radar scanning zone. In this case it would be desirable to account for the existing trend in the directions from which the airplanes approach the radar scanning zone. But if there are no predominant approach directions, or if they are ignored, we could presume that the entry points are distributed uniformly along the circumference of a circle with radius Д_{BX} with its center at the location of the radar station. In this case the bearing of the point at which the scanning zone is entered is distributed uniformly within the interval

$$[0, 2\pi], \text{ i.e. } \omega(\beta_{\text{нх}}) = \frac{1}{2}\pi.$$

Now we can use pseudorandom numbers to determine the bearing of the entry point with the formula

$$\beta_{\text{вх}i} = 2\pi\kappa_i.$$

Thus the polar coordinates of the point of entry of the i-th target into the scanning zone are range $Д_{\text{вх}i}$ and bearing $\beta_{\text{вх}i}$. We can get the rectangular coordinates of the entry point for the i-th target with the following formulas:

$$\left.\begin{aligned} x_{0i} &= Д_{\text{вх}}(1+\sin\beta_{\text{вх}i}) \\ y_{0i} &= Д_{\text{вх}}(1+\cos\beta_{\text{вх}i}) \end{aligned}\right\} \text{when } \beta_{\text{вх}i} \leqslant \frac{\pi}{2};$$

$$\left.\begin{aligned} x_{0i} &= Д_{\text{вх}}[1+\sin(\pi-\beta_{\text{вх}i})] \\ y_{0i} &= Д_{\text{вх}}[1-\cos(\pi-\beta_{\text{вх}i})] \end{aligned}\right\} \text{when } \frac{\pi}{2} < \beta_{\text{вх}i} \leqslant \pi;$$

$$\left.\begin{aligned} x_{0i} &= Д_{\text{вх}}[1-\sin(\beta_{\text{вх}i}-\pi)] \\ y_{0i} &= Д_{\text{вх}}[1-\cos(\beta_{\text{вх}i}-\pi)] \end{aligned}\right\} \text{when } \pi < \beta_{\text{вх}i} \leqslant \frac{3\pi}{2};$$

$$\left.\begin{aligned} x_{0i} &= Д_{\text{вх}}[1-\sin(2\pi-\beta_{\text{вх}i})] \\ y_{0i} &= Д_{\text{вх}}[1-\cos(2\pi-\beta_{\text{вх}i})] \end{aligned}\right\} \text{when } \frac{3\pi}{2} < \beta_{\text{вх}i} \leqslant 2\pi.$$

The moment in time t_{0i} and the coordinates of the entry point x_{0i} and y_{0i} describe the initial reference point of the i-th trajectory, and they are used to compute the coordinates of detection points in the radar scanning zone.

A model of the aerial situation is created on the basis of the assumption that targets of different types, differing in speed and altitude, may appear within the radar scanning zone. Differences in target types may be accounted for in the following fashion.

We draw up a table (Table 1) in which we record, for all hypothesized types of targets, their flying speeds within a particular permissible range of altitudes (6).

This table is stored in the computer memory.

Table 1

Тип самолета (1)	Диапазоны высот, км (2) ($\Delta H_m = H_i - H_{i-1}$) при (3) $H_0=0$				
	ΔH_1	ΔH_2	ΔH_3	....	ΔH_m
1	V_{11}	V_{12}	V_{13}	... ..	—
2	—	V_{22}	V_{23}	. ....	V_{2m}
⋮	⋮	⋮	⋮	⋮	⋮
к	—	—	$V_{к3}$	......	$V_{кm}$

Key:
1. Type aircraft
2. Range of altitudes, km
3. At

Next we assume that the distribution of crossings of the outer boundary of the scanning zone by a target of a certain type is probabilistic; therefore we set the probabilities of arisal of the targets indicated in the table (in relation to individual types) on the basis of an analysis of the hypothesized aerial situation. We designate these probabilities as $p_1, p_2, \ldots, p_k$, and we assume that the normality condition, $\sum_i P_i = 1$, is satisfied. Then the procedure for modeling the type target involves comparing random number κ_l', which has a uniform distribution in the interval [0,1], with the values of p_{l-1} and p_l, determined by the formulas:

$$p_{l-1} = \sum_{i=1}^{l-1} p_i, \quad p_l = \sum_{i=1}^{l} p_i, \quad (l = \overline{1, \kappa}).$$

We select that type of target for which the following condition is satisfied:

$$p_{l-1} \leqslant \kappa_l' < p_l.$$

After we select the type target, we find the range of altitude for targets of this type in the table. For example for type 2 targets, the altitude range is H_2-H_m. Then we reassign the probability that the target would fly within different segments of the permissible range of altitudes, and using the method examine above, we find the subrange ΔH_l ascribed to the target being modeled.

The velocity of the target is selected from the table after its altitude is determined. As a result of modeling the type, altitude, and velocity of the target, we get the third coordinate of the starting point of the trajectory, and the modulus of its velocity vector.

Thus the process of modeling the trajectory of a target within the radar scanning zone is as follows.

First we model the moment of entry of the airplane into the scanning zone as a successive event in a random flow of uniform events. Then for a fixed moment t_{BX} we model the planar coordinates of the starting point of the trajectory x_0, y_0, and the airplane's altitude H_0 and velocity V_0. Next we plot the target trajectory in the form of connected segments--linear and curvilinear.

To form a flow of radar blips produced by a set of targets present within the radar scanning zone, we can use all of the operations employed to model a sequence of blips from a single target, adding to this the operation of ordering the blips in relation to detection time.

Modeling the Algorithm for Formation of the Target Blip Sequence

Let us examine, as an example, the block diagram for the modeling algorithm used to form a sequence of radar blips (Figure 10) (3). Let us assume that the initial segment of the trajectory is linear, that the information on the trajectory is processed in polar coordinates, and that detection of the target blip involves comparison of its probability with random number κ_i.

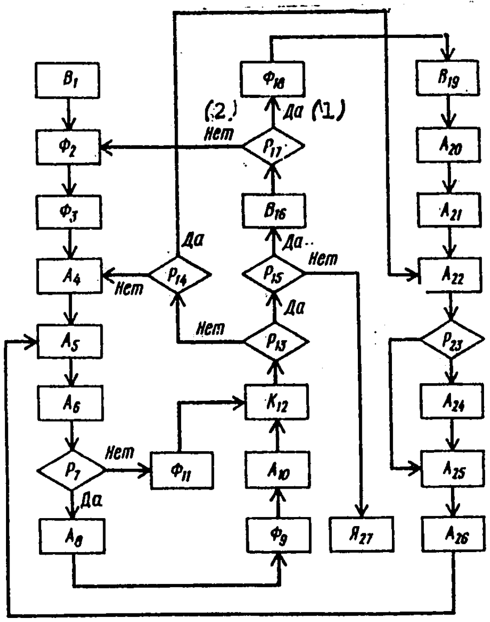


Figure 10. Block Diagram of the Modeling Algorithm Used to Form a Sequence of Radar Blips From One Target

Key:
1. Yes
2. No

The modeling algorithm begins with operator B_1, which inputs the initial segment of the trajectory, described by the coordinates of the starting point $Д_0$, β_0, the velocity V_0, angle α_0, and number of points N_0. Operator Φ_2 forms a "turn absent" tag, since the starting segment is linear by definition, and operator Φ_3 records, in the counter, the number of points N_i in the linear segment of the trajectory. Later on, when the counter assumes its zero state, termination of the process of modeling the trajectory's linear segment is established.

The arithmetic operator A_4 determines the rectangular coordinates x_i, y_i of a successive point on the trajectory, and operator A_5 converts them to polar coordinates, calculating coordinates $Д_i$, β_i.

The arithmetic operator A_6 calculates probability p_i of detecting a target blip with coordinates $Д_i$, β_i, and it transfers control to operator P_7. The logic operator P_7 selects a number uniformly distributed in the interval [0,1], and tests the inequality $\kappa_i \geqslant p_i$. If this relationship is satisfied, control is transferred to operator A_8; otherwise operator Φ_{11} forms a "blip absent" tag in the event that the blip is not detected.

The arithmetic operator A_8 calculates the standard deviation of total coordinate measurement errors, and operator Φ_9 forms random numbers $\Delta Д_i$, $\Delta\beta_i$ with a normal distribution.

The arithmetic operator A_{10} determines the current coordinates and transfers control to operator K_{12}, reducing the contents of the counter sensing the number of detection points in a linear segment by one.

The logic operator P_{13} tests whether or not the contents of the counter are equal to zero. If the contents of the counter are equal to zero, control is transferred to operator P_{15}. Otherwise control is transferred to the logic operator P_{14}, which tests for the turn tag ($n_M = 1$). In the absence of this tag, control is transferred to the arithmetic operator A_4, and when it is present, it is transferred to operator A_{22}.

The operator P_{15} tests for presence of the next segment of the trajectory. If the latter is present, control is transferred to operator B_{16} and if it is absent, its is transferred to stop operator Я_{27}.

Operator B_{16} inputs the next segment of the trajectory, described by parameters Φ_l, R_{Ml}, V_l, α_l, and the logic operator P_{17} tests for satisfaction of the inequality $\Phi_l>0$--that is, it determines whether or not the next segment is a turn segment. If this condition is not satisfied, a "turn absent" tag is formed by operator Φ_2; otherwise control is transferred to operator Φ_{18}, which forms a "turn present" tag.

Operator B_{19} records the number $N_M = N_l$ in the counter, and operator A_{22} successively computes the coordinates of the center of the circle, the initial value of angle γ_H, and the current value of the angle γ_i.

The logic operator P_{23} tests for positiveness of angle γ_i. If angle γ_i is positive, operator A_{25} computes the rectangular coordinates of the point in the turn segment. If angle γ_i is negative, operator A_{24} transforms angle γ_i in accordance with the formula $\gamma(+)=\gamma(-)+2\pi$.

The arithmetic operator A_{26} calculates the components of the target velocity vector for the turn segment, and transfers control to operator A_5.

Stop operator Я_{27} halts the calculations if all segments of the trajectory have been inputed, and if all points in these segments have been read.

A modeling algorithm for formation of a flow of radar blips from a set of targets within the scanning zone of the radar station can be created similarly (6).

Let us introduce the following operators:

A_1--determines the moment in time t_l of the end of a successive radar sweep;

P_2--tests the condition $t_l<T$, where T represents the boundary of the interval [0,1] within which the system's function is modeled;

Φ_3--forms the moment of target entry t_{BX} into the radar scanning zone, and the starting point;

P_4--tests the condition $t_{BX}<t_l$, satisfaction of which indicates that the given moment of target entry is associated with the current sweep cycle;

K_5--counts the number m of targets present within the radar scanning zone;

A_6--memorizes the moment of entry of a target belonging to the next sweep cycle;

P_7--tests the condition $m>0$;

K_8--counts the number of targets subject to detection in the current sweep cycle;

P_9--tests the condition $t_{KB}<t_l$, satisfaction of which indicates that the time of a turn's termination t_{KB} occurs in the current sweep cycle;

A_{10}--determines the coordinates of the point and the moment of termination of the current turn;

Φ_{11}--selects the parameters of the next turn from the main memory;

Φ_{12}--forms random fluctuations in the turn parameters, in accordance with given distribution laws;

A_{13}--determines the target trajectory within the limits of the current sweep cycle;

A_{14}--determines the ideal target blip;

Φ_{15}--forms the error of a circular scanning radar station in determining the target coordinates;

Φ_{16}--forms the real target blip;

Φ_{17}--forms false blips in accordance with a given distribution law;

Φ_{18}--arranges the blips in a series corresponding to the order of their detection;

B_{19}--transmits blips to the indicator screen of a circular scanning trainer;

Φ_{20}--achieves transition to the next sweep cycle;

$Я_{21}$--stop operator.

Figure 11 shows the block diagram for this modeling algorithm.

Operator A_1 causes transition to a new radar sweep cycle. If the condition tested by operator P_2 is not satisfied, then the modeling interval has ended and control is transferred to the stop operator. But if the modeling interval has not come to its conclusion (if the condition tested by operator P_2 is satisfied), then operator Φ_3 forms the moment of entry and the initial point for the next target entering the radar zone in the course of the given sweep cycle. The chain of operators Φ_3, P_4, K_5, A_6 samples all targets entering the range of the radar station within the entire sweep cycle.

The sequence of operators P_7, $K_8, \ldots, \Phi_{16}$ models detection of a target by the radar station. If the current turn does not end within the limits of the given sweep

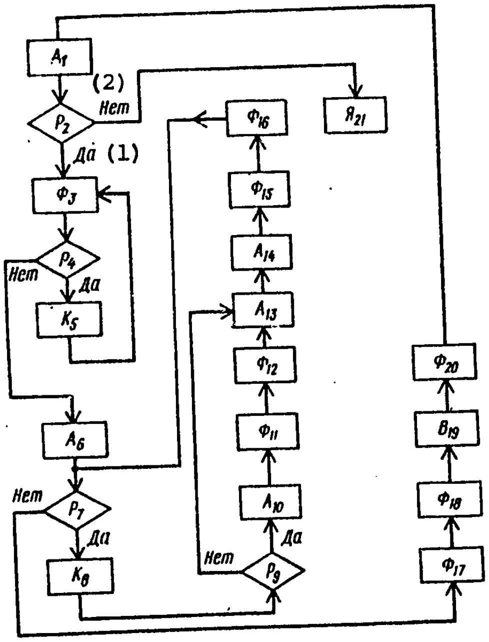


Figure 11. Block Diagram of a Modeling Algorithm for Formation of Radar Blips From a Set of Targets Located Within the Radar Scanning Zone

Key:
1. Yes
2. No

cycle (if the condition tested by operator P_9 is not satisfied), then operators $A_{13},\ldots,\Phi_{16}$ determine the trajectory of the target (A_{13}), compute the coordinates of the ideal detection point (A_{14}), form the measurement error (Φ_{15}), and determine the blip corresponding to the given target (Φ_{16}). But if the turn ends within the limits of the sweep cycle, the end point of the turn is determined by operator A_{10}, the parameters of the next turn are selected from the computer memory by operator Φ_{11}, fluctuations in the turn parameters are formed in accordance with the given probability characteristics, and it is only after this that control is transferred to operator A_{13} for plotting of the target route.

If $m>0$ (operator P_7), then all targets within range of the radar have been detected; in other words for practical purposes the current sweep cycle has already ended, since further movement of the beam of the radar station's polar diagram would not be able to provide any information on new targets within the limits of the remaining part of the sweep cycle. A transition is made to formation of false blips (operator Φ_{17}), and then the blips are arranged in the order of their detection--that is, in the order of increasing detection time (operator Φ_{18}). Information obtained in this fashion during the sweep cycle is fed to the trainer's indicator screen (operator B_{19}). Then a transition is made to the next radar sweep cycle (operator Φ_{20}).

An Example of a Model of an Air Raid

The raw data for the model are:

F--Number of targets participating in the raid;
$Y_{\text{макс}}$, $Y_{\text{мин}}$--breadth of the defense, given in rectangular coordinates;
$x_{\text{Н}}$--abscissa of the so-called guidance boundary; when the target crosses it, its trajectory ceases to be modeled;
x_0--abscissa of target detection, signifying initiation of trajectory modeling;
p_{γ}, p_V, p_{V1}--the probabilities of target maneuver relative to course, velocity, and acceleration;
$\gamma_{\text{макс}}$, $\gamma_{\text{мин}}$--possible target turning angles;
$V_{\text{макс}}$, $V_{\text{мин}}$, $H_{\text{макс}}$, $H_{\text{мин}}$--possible limits of target maneuver in relation to velocity and altitude;
T_0--discrete data output interval, representing a radar sweep cycle.

The raw data are summarized on a raw data order blank to permit their input into the computer.

Order Blank for Raw Data to Create an Air Raid Model

Raw Data

Serial No.	Data	Unit of Measurement	Symbol	Value
1	Number of targets	Units	F	
2	Breadth of defense	KM	$Y_{\text{макс}}$, $Y_{\text{мин}}$	
3	Abscissa of boundary of guidance	KM	$x_{\text{Н}}$	
4	Abscissa of target detection	KM	x_0	
5	Probabilities of target maneuver in relation to:			
	course		p_{γ}	
	velocity		p_V	
	acceleration		p_{V1}	
6	Target turning angles:	Radians/min		
	maximum		$\gamma_{\text{макс}}$	
	minimum		$\gamma_{\text{мин}}$	
7	Limits of target maneuver in relation to:			
	velocity	KM/min	$V_{\text{макс}}$, $V_{\text{мин}}$	
	altitude	KM	$H_{\text{макс}}$, $H_{\text{мин}}$	
8	Data output interval	min	T_0	

The raw data are fed into the computer, the model program is started, and reports on the targets are printed out in real time with an update interval of T_0.

The model is built in the following order.

The first step is to set the starting velocities V_{oi} and altitudes H_{oi}, as well as the starting coordinates Y_{oi} of all F targets. This procedure requires generation of random numbers d_{ci}, with a uniform distribution in the interval [0,1]. The initial turning angles γ_{oi} for all targets are assumed equal to zero ($\gamma_{oi} = 0$).

The initial values of V_{oi}, H_{oi}, y_{oi} are interpreted as random variables with uniform distributions in the intervals $[V_{\text{макс}}, V_{\text{мин}}]$, $[H_{\text{макс}}, H_{\text{мин}}]$, $[y_{\text{макс}}, y_{\text{мин}}]$ respectively:

$$V_{0i} = V_{\text{мин}} + d_{ci}(V_{\text{макс}} - V_{\text{мин}});$$
$$H_{0i} = H_{\text{мин}} + d_{ci}(H_{\text{макс}} - H_{\text{мин}});$$
$$y_{0i} = y_{\text{мин}} + d_{ci}(y_{\text{макс}} - y_{\text{мин}}).$$

After the initial values are calculated, the initial coordinates and parameters of all F targets are printed out: x_{oi}, y_{oi}, H_{oi}, V_{oi}, and $\gamma_{oi} = 0$. The time of approach to the guidance boundary is determined from the initial values of V_{0i} and the difference $x_{oi}-x_{H}$, and it is printed out:

$$\tau_{\text{подл}} = \frac{x_{0i} - x_{\text{н}}}{V_{0i}}.$$

The next step is to plot the target approach trajectories.

Let x_{mi}, y_{mi} be the coordinates of the i-th target at time $t + T_o$, and x_i, y_i be its coordinates at time t. Coordinates x_{mi}, y_{mi} may be expressed by the turning angles and velocities (Figure 12):

$$V_{mi} = V_i + dV_i;$$
$$\gamma_{mi} = \gamma_i + d\gamma_i,$$

where dV_i and $d\gamma_i$ are the increment in the velocity and turning angle of the i-th target during time T_o (in this case a positive course maneuver is assumed to be a left turn, and a negative course maneuver is said to be a right turn).

Obviously,

$$x_{mi} = x_i - V_{mi} \cos \gamma_{mi} T_0,$$
$$y_{mi} = y_i - V_{mi} \sin \gamma_{mi} T_0.$$

Let us consider determination of dV_i and $d\gamma_i$.

First let us look at a maneuver in velocity. The raw data given were the probability of maneuver in velocity and acceleration, p_v, and p_{v1}. We assume that the maximum attainable velocity during time T_o is subordinated to an exponential law (Figure 13)--that is,

$$V_{\text{макс}}(t) = (1 - e^{-t})(V_{\text{макс}} - V_{\text{мин}}) + V_{\text{мин}};$$

then

$$dV_{\text{макс}} = (1 - e^{-(t+T_0)})(V_{\text{макс}} - V_{\text{мин}}) - (1 - e^{-t}) \times$$
$$\times (V_{\text{макс}} - V_{\text{мин}}) = (V_{\text{макс}} - V_{\text{мин}})(e^{-t} - e^{-(t+T_0)}) =$$
$$= e^{-t}(V_{\text{макс}} - V_{\text{мин}})(1 - e^{-T_0}).$$

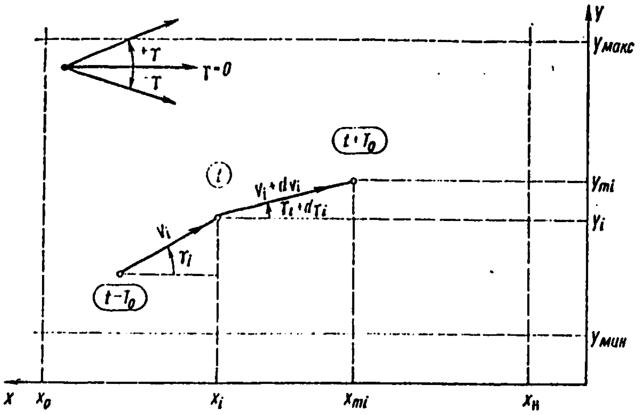


Figure 12. Determination of x_{mi} and y_{mi}

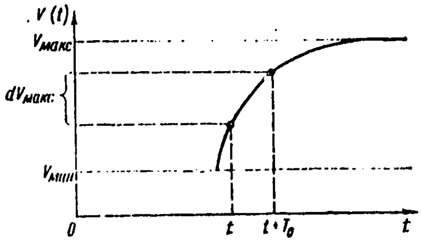


Figure 13. Law of Increasing Speed During Time T_0

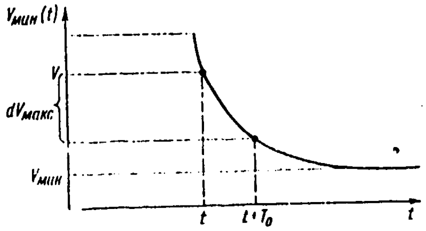


Figure 14. Law of Decreasing Speed During Time T_0

Let us express e^{-t} by V:

$$V = (e - e^{-t})(V_{\text{макс}} - V_{\text{мин}}) + V_{\text{мин}},$$
$$e^{-t} = 1 - \frac{V - V_{\text{мин}}}{V_{\text{макс}} - V_{\text{мин}}} = \frac{V_{\text{макс}} - V}{V_{\text{макс}} - V_{\text{мин}}}.$$

Thus when a maneuver involves an increase in velocity, we get:

$$dV_{\text{макс}\,i} = (V - V_i)(1 - e^{-T_0}).$$

Let us go on to assume that the minimum velocity attainable by the target during time T_0 also follows an exponential law (Figure 14)--that is,

$$V_{\text{мин}}(t) = (V - V_{\text{мин}})e^{-T_0} + V_{\text{мин}},$$

then

$$dV_{\text{макс}} = V - (V - V_{\text{мин}})e^{-T_0} - V_{\text{мин}} = (V - V_{\text{мин}})(1 - e^{-T_0}).$$

Thus when a maneuver involves a decrease in velocity,

$$dV_{\text{макс}} = (V_i - V_{\text{мин}})(1 - e^{-T_0}).$$

Let us assume that the increment in velocity at time t is uniformly distributed in the interval $[0, dV_{\text{макс}}]$--that is,

$$V_{mi} = V_i + \alpha\beta d_{cV_{\text{макс}\,i}} dV_{\text{макс}\,i},$$

where

$$\alpha = 1, \text{ if } d_{\text{ср}V1} \geqslant p_{V1} \text{ and } \alpha = -1, \text{ if } d_{\text{ср}V1} < p_{V1};$$
$$\beta = 1, \text{ if } d_{\text{ср}V} \geqslant p_V \text{ and } \beta = 0, \text{ if } d_{\text{ср}V} < p_V.$$

Now let us examine maneuver in course. The probability of such a maneuver, p_γ, is given for all targets in the raw data. We assume in this case that the probabilities that the targets would maneuver right and left are identical. We assume that the turning angle γ_m decreases exponentially with growth in velocity from $\gamma_{\text{макс}}$ to $\gamma_{\text{мин}}$ (Figure 15):

$$d\gamma_{mi} = (\gamma_{\text{макс}} - \gamma_{\text{мин}})e^{-(V_i - V_{\text{мин}})} + \gamma_{\text{мин}}.$$

We assume that the increment in γ at time t is uniformly distributed in the interval $[0, \gamma_m]$--that is,

$$\gamma_{mi} = \gamma_i + \eta \varkappa d_{\text{ст макс } i} d\gamma_{mi},$$

where

$$\eta = 1, \text{ if } d_{cp} \geqslant 0{,}5 \text{ and } \eta = -1, \text{ if } d_{cp} < 0{,}5;$$
$$\varkappa = 0, \text{ if } d_{cpi} < p_{\text{т}} \text{ and } \varkappa = 1, \text{ if } d_{cp\text{т}} > p_{\text{т}}.$$

The results of this stage of the calculations should be the values of x_m, y_m, V_m, and γ_m for all F targets. These values are printed out.

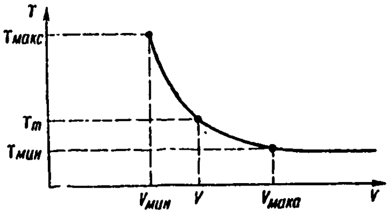


Figure 15. Law of Change in Turning Angle Depending on a Slight Velocity

In the next stage we check for:

The quantity and numbers of the targets which cross the guidance boundary x_{H} from time t to $(t+T_0)$. At $x_i<x_{\text{H}}$, modeling of the flight trajectory of the i-th target ceases;

the quantity and numbers of targets that flew beyond the limits of the defense zone during the same time interval. When $y_i<y_{\text{мин}}$, or $y_i>y_{\text{макс}}$, modeling of the trajectory of this target ceases;

presence of targets within the limits of the defense zone, the trajectories of which continue to be modeled. When the condition $F=0$ is satisfied, the modeling program stops.

The first and second conditions are printed out. An example of a computer print-out of the model is shown on the previous page.

Air Raid Model

Исполнил (1) ______________________________
(дата, фамилия, имя, отчество) (2)

I. Исходные данные (3)

F	$y_{макс}$	$y_{мин}$	$x_н$	x_0	$p_т$	p_v	p_{vt}	$\gamma_{макс}$
10	500	10	50	1000	07	04	06	08

$\gamma_{мин}$	$V_{макс}$	$V_{мин}$	$H_{макс}$	$H_{мин}$	T_0
01	50	10	40	01	1

II. Налет (4)

t	$N_ц$	$H_ц$	$x_ц$	$y_ц$	$V_ц$	τ
0	1	10	1000	010	50	20
	2	20	1000	120	45	24
	3	35	1000	030	40	26
	4	40	1000	470	35	32
. . .	. . .	. . .	. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .	. . .	. . .	. . .
	20	03	1000	245	24	40
1	. . .	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	. . .	. . .	. . .	. . .
2	. . .	. . .	. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .	. . .	. . .	. . .
15	1	10	400	183	43	8
	2	вышла из полосы обороны (5)				
	3	20	240	342	18	4
	4	пересекла рубеж наведения (6)				
. . .	. . .	. . .	. . .	. . .	. . .	. . .
	20	03	32	240	50	05
. . .	. . .	. . .	. . .	. . .	. . .	. . .

Key:

1. Created by
2. Date, last, first, middle names
3. Raw data
4. Raid
5. Left defense zone
6. Crossed guidance boundary

SIMULATION OF A SITUATION ON RADAR INDICATOR SCREENS

The Composition of Target and Interference Simulation Apparatus

The apparatus used to simulate targets and interference on the indicator screen of a radar station contains the following basic blocks: antenna simulation block, bearing and range sweep formation block, plan position indicator, bearing and range determination blocks, matching block, and a computer (Figure 16) (13).

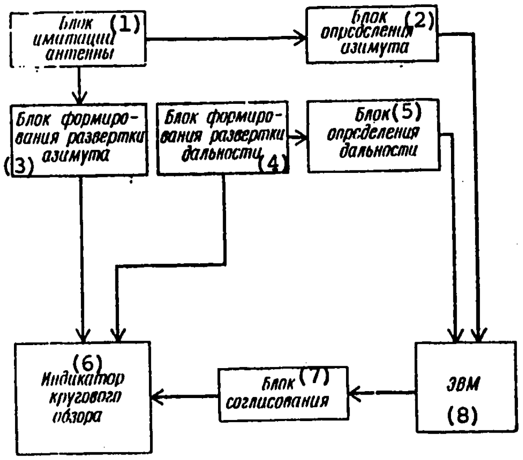


Figure 16. Functional Diagram of Apparatus for Computer Simulation of Targets and Interference

Key:

1. Antenna simulation block	5. Range determination block
2. Bearing determination block	6. Plan position indicator
3. Bearing sweep formation block	7. Matching block
4. Range sweep formation block	8. Computer

The main purpose of the antenna simulation block and the bearing and range sweep formation blocks is to create a PPI sweep on the indicator screen.

The functions of simulating targets and interference are delegated to the computer, into which the coordinates of the target trajectories and interference are fed beforehand. The PPI sweep on the screen of the plan position indicator is synchronized with the computer with the help of the bearing and range determination blocks.

The bearing determination block, which is rigidly slaved to the radar antenna simulation block, reports the bearing of the radio sweep on the PPI screen at each moment in time to the computer. Receiving the coordinate for the bearing of the PPI beam, the computer compares it with the current coordinate for the bearing of the target, stored in the main memory and subject to display on the screen. If the current value does not correspond to the closest target bearing value stored in the computer memory, the computer does not produce any signals. Otherwise the computer runs a subroutine entailing continual interrogation of the range measurement block, and comparison of its readings with the closest value of the range of the target, which is on a constant bearing.

The range determination block, which is mated to the range sweep formation block, measures, at each moment in time, the coordinate for the range of the PPI beam, which is then read by the computer.

As a result of continual interrogation of the range measurement block and comparison of its readings with the range of a target on a constant bearing, at the moment of comparison of these coordinates the computer produces a "Target Present" signal. This signal is fed through the matching block, intended to coordinate the computer output with the indicator input, to the master electrode of the indicator's cathode-ray tube.

Moreover, controlling the matching block by special programs, the computer can change the amplitude of the target signal depending on the range to the target, and modulate this amplitude randomly, simulating fluctuations. Simulating interference with prescribed coordinates, the computer generates a set of signals to represent interference, and to simulate jamming, it produces signals that light up certain areas of the range sweep, the coordinates of which are stored in the computer's main memory.

In all operating modes of the target and interference simulation apparatus, the number of simulated targets and different tactical situations involving interference and jamming is limited only by the possibilities of the computer: its speed and the volume of its main memory.

Formation of the PPI Sweep on the Indicator Screen

Figure 17 shows a PPI screen bearing blips from two targets. Assume that the antenna, the beam pattern of which has a breadth of 2Θ, makes a circular clockwise sweep. During the sweep, first target No 1 is illuminated, the range and bearing of which are $Д_1$ and β_1, and then target No 2, the range and bearing of which are $Д_2$ and β_2. Illumination of target No 1 begins when the beam pattern reaches position *1* and its maximum is at angle $\beta_1-\Theta$. Illumination of this target ends when the maximum of the beam pattern is at angle $\beta_1+\Theta$ (position *3*). Similarly, pulses are reflected from target No 2 during the time that the beam pattern shifts from position *4* to position *6* (from $\beta_2-\Theta$ to $\beta_2+\Theta$). The blip from target No 1 is located between radial sweep lines *1-3*, and that of target No 2 is located between lines *4-6* (2).

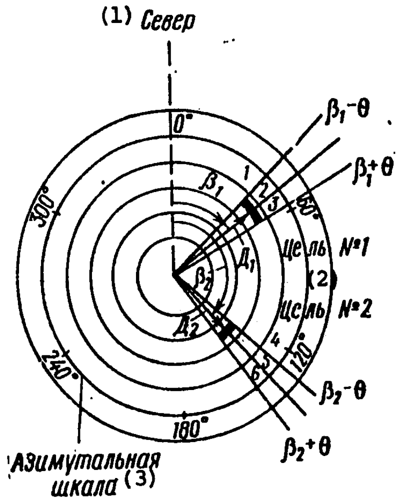


Figure 17. Dependence of the Image on a PPI Screen on the Antenna's Beam Pattern

Key:
1. North
2. Target
3. Bearing scale

As a rule a PPI radar operates in such a way that each target is illuminated several times in the course of a sweep. Owing to this the signal from the target is not a single reflected pulse but a train of pulses of the same range but a different bearing. In the course of a single radial sweep cycle, the antenna manages to rotate a very slight angle (tenths and even hundredths of a degree). Therefore the returns appear continuous, and they have the shape of an arc with an angular width of 2θ. The bearings to the targets are determined from the position of sweep lines 2 and 5.

The location of the radar station corresponds to the center of the PPI screen, and because the origin of the radial sweep coincides with the point of origin of the probing pulse, the range to target $Д_1$, $Д_2$,... may be determined by measuring the distance from the center of the screen to the forward edges of the target blips. It is on this basis that the range scale markers take the form of circles with different radii.

A PPI sweep can be achieved by two methods. In one of them a beam deflecting system with a single pair of coils is powered by linearly varying current (to obtain the radial sweep), and it is simultaneously rotated about the axis of the cathode-ray tube at a rate equivalent to that of the circular sweep, as created by the antenna simulation block. The difference in the other method is that rotation of the electron beam about the axis of the tube is achieved by amplitude modulation of a sawtooth current powering immobile coils; the modulation frequency (in hertz) is equivalent to the number of rotations made by the motor of the antenna simulation block within one second.

A functional diagram of a PPI with a rotating beam deflection system is shown in Figure 18. It contains a triggering pulse simulation block; a range sweep formation block containing a pulse stretcher, a sawtooth voltage oscillator, and a sawtooth current amplifier; a mixing block; a PPI beam forward trace lighting circuit, and a cathode-ray tube with deflecting and focusing coils (17).

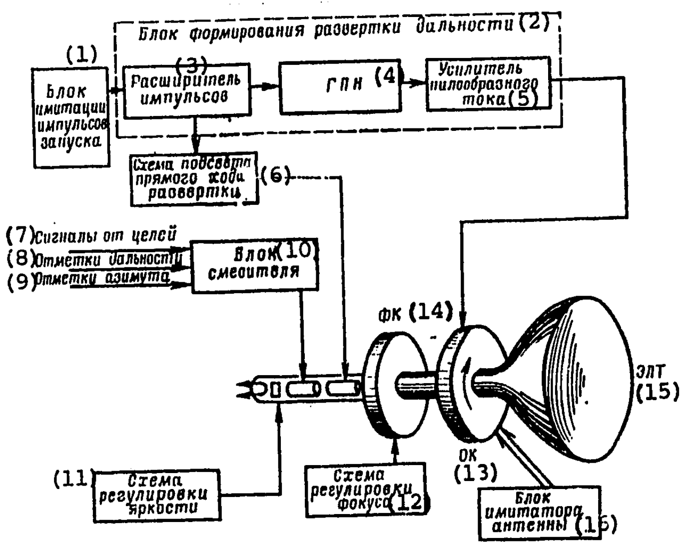


Figure 18. Functional Diagram of a PPI With a Rotating Deflection System

Key:

1. Triggering pulse simulation block
2. Range sweep formation block
3. Pulse stretcher
4. Sawtooth voltage oscillator
5. Sawtooth current amplifier
6. Sweep forward trace lighting circuit
7. Signals from targets
8. Range markers
9. Bearing markers
10. Mixing block
11. Brightness adjusting circuit
12. Focusing circuit
13. Deflecting coil
14. Focusing coil
15. CRT
16. Antenna simulation block

A PPI sweep is formed on the CRT screen in the following fashion.

Because the duration of the forward trace of the sweep is greater than the duration of the triggering pulse, a pulse stretcher--for example a delay multivibrator--is inserted before the sawtooth voltage oscillator. During every other period of transmission of triggering pulses, its negative pulses block the sawtooth voltage oscillator tube for the time of the forward trace.

The sawtooth sweep voltage picked up from the oscillator passes through the sawtooth current amplifier into deflecting coil OK, and the light spot deflects the entire length of the screen's radius.

The lighting circuit changes the polarity and amplitude of pulses from the stretcher in such a fashion that on being applied to the CRT's master electrode, they would cause the screen to glow as required during the forward trace of the sweep.

Circular scanning produced by the radar antenna simulation block must be accompanied by synchronous rotation of the indicator's deflection system about the axis of the CRT. Synchronous transmission with the help of single-phase alternating current induction motors called selsyns are the most suited to this purpose.

Selsyn transmission is diagramed in Figure 19. The rotor of the pick-up selsyn С-Д is mechanically connected to motor Д. The rotor of the receiving selsyn С-П rotates the deflecting coil OK. The ends of the windings on the rotors, as well as on the stators, are connected among each other appropriately. Before we can have synchronous transmission, we also need to connect the rotors to an alternating current circuit.

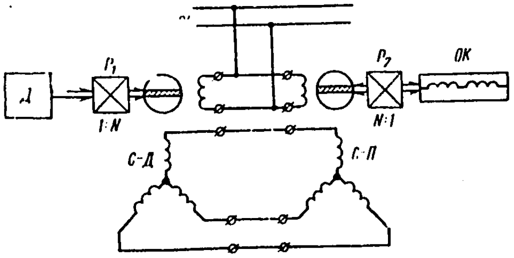


Figure 19. Selsyn-Assisted Synchronous Transmission

The error of pick-up selsyns does not usually exceed 1.5°, while that of receiving selsyns does not exceed 1°. But the accuracy of transmission may be raised significantly by using two reduction gears, one of which (P_1) accelerates while the other (P_2) decelerates transmission by a factor of N. If for example the displacement error in a system without reduction gears is 1°, by having the deflecting coil and antenna simulation block rotate slower than the selsyn rotors by a factor of N in the presence of reduction gears, this error becomes equal to 1°/N. Moreover the displacement error decreases due to reduction of the load imposed on the selsyns.

To achieve a PPI sweep with the help of a motionless deflection system, a linearly varying magnetic field rotating synchronously with the rotation caused by the antenna simulation block would have to be created in the neck of the tube.

A motionless deflection system consists of two pairs of coils located mutually perpendicular to the axis of the cathode-ray tube. Sawtooth currents modulated according to the law of the rotation caused by the antenna simulation block and mutually shifted 90° in phase, pass through these coils. These currents create a synchronously rotating magnetic field, which deflects the cathode beam.

Thus a rotating sweep is created by splitting the sawtooth voltage formed by the oscillator in the range sweep channel into two components shifted relative to one another by 90°; each of these components is modulated in accordance with the law of antenna rotation.

Sine-cosine rotating transformers (SCRT) and sine-cosine potentiometers, which are mechanically reliable and which unload directly onto deflecting coils, are used most often to split and shift the phases.

A functional diagram of a PPI with a motionless deflection system is shown in Figure 20. It differs from a PPI using a rotating deflection system only in relation to the bearing sweep formation block. The SCRT in this block has a rotor winding and two mutually perpendicular stator windings. The rotor is mechanically connected to the antenna simulation block motor, and it turns synchronously with it. The rotor winding serves as the load for the amplifier of the sawtooth current generated by the range sweep formation block. The magnetic flux of the rotor winding, which arises as the sawtooth current passes through, induces electromotive forces in the stator windings, the magnitudes of which depend on the mutual positions of the rotor and stator windings.

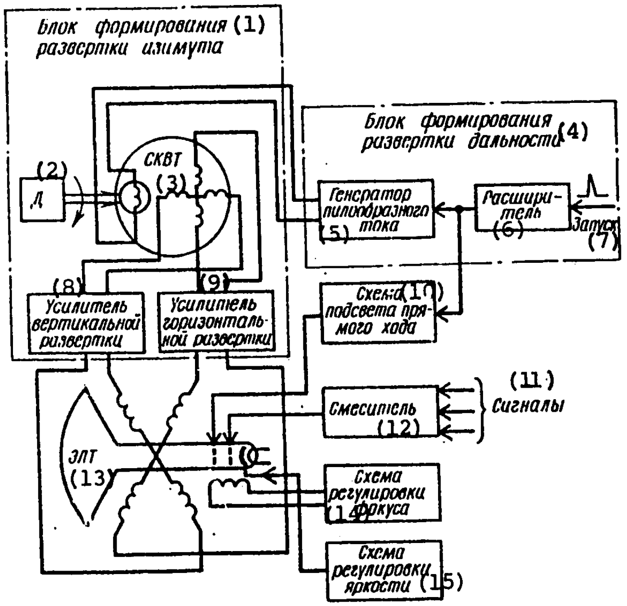


Figure 20. Functional Diagram of a PPI With a Motionless Deflection System

Key:

1. Range sweep formation block
2. Motor
3. SCRT
4. Range sweep formation block
5. Sawtooth current oscillator
6. Stretcher
7. Triggering pulse
8. Vertical sweep amplifier
9. Horizontal sweep amplifier
10. Forward trace lighting circuit
11. Signals
12. Mixer
13. CRT
14. Focusing circuit
15. Brightness adjusting circuit

Measurement of Target Coordinates in Digital Code

The structure of the range determination block, which is intended to form the coordinates for the range of simulated targets in binary code, is based on the dependence of the range on the delay of the target signal relative to the probing pulse,

$$Д = \frac{c\tau}{2},$$

where τ is the target signal delay, and $c = 3 \cdot 10^8$ m/sec (12).

This dependence is used to represent range in the form of a binary number equal to the number of pulses N coming from the counting pulse operator in time τ:

$$N = F\tau,$$

where F is the pulse repetition frequency.

Then

$$Д = \frac{c}{2F} N.$$

The range determination block is a converter of linear dimensions to time. It consists basically of a quartz-stabilized time interval generator *1* and a time pulse counter TPC (Figure 21).

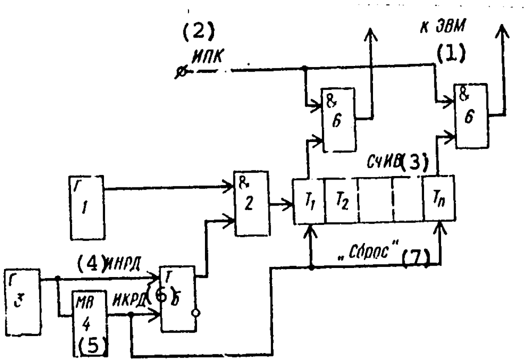


Figure 21. Functional Diagram of a Range Determination Block

Key:

1. To the computer
2. CIP [coordinate input pulse]
3. TPC
4. RSSP [range sweep start pulse]
5. Multivibrator
6. RSEP [range sweep end pulse]
7. "Reset"

Range is determined by the method of dynamic compensation measurement, in which the value of the coordinate Д of the simulated target blip is compared with an auxiliary sweep function Д', and the moment at which Д=Д' is recorded. The balancing function Д', which is formed by the time pulse counter, reflects motion of the scanning beam across the indicator screen, and it changes within the limits of all possible values limited by the time of the measuring cycle. Synchronization between movement of the scanning beam and the balancing function Д' is achieved with the assistance of range sweep start pulses (RSSP) and range sweep end pulses (RSEP).

The simplest method for obtaining such pulses is to use a quartz-stabilized oscillator *3* which produces pulses having a repetition frequency equal to the repetition period of the radar probing pulses, and a delay multivibrator *4*, the time delay of which is equal to the time of the forward trace of the PPI beam.

The time from the beginning of the range sweep to arisal of a computer signal registering the position of the beam on the range sweep is proportional to the range to the target.

Thus the value of coordinate Д is determined as a discrete quantity with the help of a time-pulse system for counting the number of pulses arising in the time interval from the moment the sweep is started by the RSSP to the moment the target appears on this sweep. The beginning and end of pulse counting are determined by control flip-flop *5*, which permits and prevents, under the influence of RSSP's and RSEP's, the passage of counting pulses through (kon"yunktor) [possibly an AND gate?] *2* to the input of the time pulse counter, TPC. The coordinates defining the position of the PPI beam on the range sweep are transmitted to the computer with the assistance of a coordinate input pulse (CIP) from the computer. When this pulse arrives, kon"yunktor's *6* open, and the reading of the time pulse counter is transmitted to the computer.

Let us determine the required time pulse generation frequency and the bit configuration of the PPC, considering their dependence on the resolution of the indicator screen and on the rate of movement of the PPI beam. Taking account of the fact that the accuracy with which the time pulse counter makes its readings must be k times higher than the minimum measureable distance, defined by the resolution of the indicator screen, the frequency of the time pulse oscillator should be

$$F = k\gamma v,$$

where γ is the indicator's resolution and v is the sweep rate.

Thus at a sweep rate of $v = 1000$ mm/sec, a resolution of $\gamma = 2$ lines/mm, and $k = 5$, $F = 100$ kHz. The word length of the pulse counter is determined by the expression

$$n = \frac{\ln N}{\ln 2} = \frac{\ln 10^5}{\ln 2} \approx 17{,}3,$$

where N is the number of pulses with a pulse interval of $T = 10$ µsec ($F = 100$ kHz), entering the TPC in 1 second.

Rounding off n to the nearest integer, we get $n = 17$--that is, the time pulse counter must have a capacity of 17 bits.

Transformation of angular coordinates into a binary code boils down to measuring the antenna's angle of rotation in relation to the angular coordinate being measured, and expressing it in binary units. Inasmuch as the target blip occupies a certain azimuth angle, in most cases the true direction to the target is the arithmetic mean of two readings--the bearing of the start and of the end of the pulse train. Other methods for determining the bearing are possible as well.

The bearing can be determined in binary code by the various methods. If for example the operator trainer is a self-contained device with an antenna simulation block playing the role of the antenna, the bearing can be determined in a way similar to digital determination of range. In fact, given a constant rate of angular rotation, the angle of rotation may be measured indirectly by the time of rotation of the antenna simulation block. As in the case of range measurement, in this case measurements of the bearing boils down to transforming the time interval into a number. The only difference is that the control flip-flop is activated not by a range sweep start pulse, but by a bearing sweep start pulse (BSSP)--that is, by a pulse corresponding to a zero reading.

The operating cycle of such a circuit is defined not by the time interval between radar start pulses, but by the radar station's bearing scanning time. The control flip-flop is reset in its initial state by a bearing sweep end pulse (BSEP).

The simplest method for obtaining BSSP's and BSEP's is to use a pair of cams connected rigidly to the motor of the antenna simulation block (Figure 22). The first cam (*A*) corresponds to the start of the bearing sweep--that is, it closes its contact precisely at the moment the antenna simulation block aligns itself with the zero reading line. The second cam (*B*) corresponds to the end of the bearing sweep. The angle between the cams, which depends on the size of the bearing sweep, may be changed when adjusting the antenna simulation block. One contact group (*a*,*b*) is mounted opposite each cam. These are two normally open contacts that are constantly loaded by a series of pulses of sufficiently high frequency, for example 250 kHz.

At the moment the bearing sweep starts, contact *a* closes and a train of pulses passes to a circuit that isolates single pulses, consisting of amplifier *1* and flip-flop *2*. Inasmuch as flip-flop *1* is in its zero position in its initial state, kon"yunktor *3* is open, and the first pulse of the train passes to the output as a BSSP. Moreover the same pulse passes to the unit input of flip-flop *2*, which blocks kon"yunktor *3*, preventing passage of the rest of the pulses.

After the bearing sweep cycle ends, contact group *b* closes, and a BSEP forms in precisely the same way out of the same train of pulses. The circuit is prepared for isolation of the next BSSP by feeding the bearing sweep end pulse to the zero input of flip-flop *2*, returning it to its initial state. The BSSP circuit performs a similar function in relation to the zero input of flip-flop *5*.

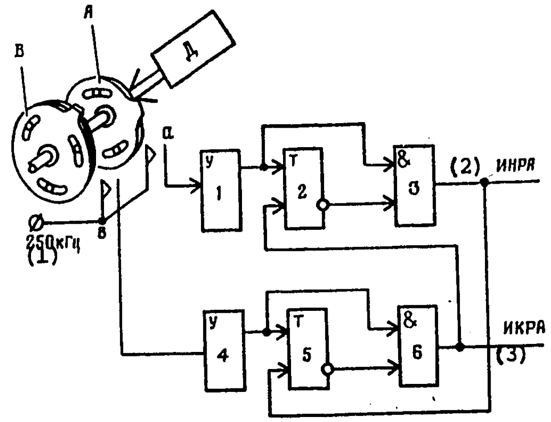


Figure 22. Functional Diagram Describing Formation of Bearing Sweep Start and End Pulses

Key:
1. kHz
2. BSSP
3. BSEP

Another possible method for obtaining such pulses involves photoelectric pulse formation. In this case two holes are drilled through a disc mounted on the shaft of the antenna simulation block's motor. Point light sources and photodiodes are installed opposite these holes. Pulses with parameters required by the computer are formed by a cell schematically diagramed in Figure 23.

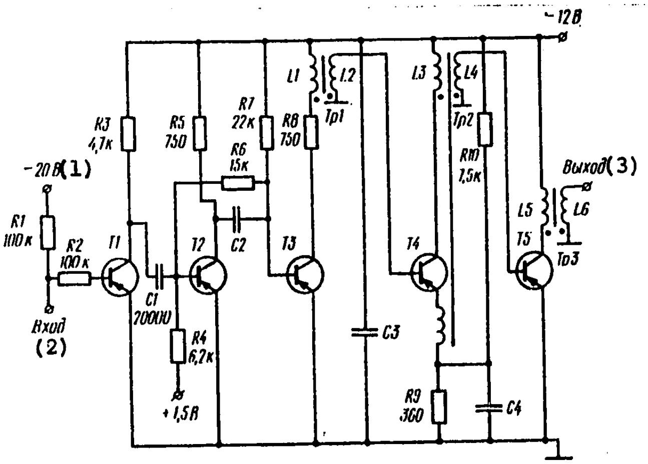


Figure 23. Basic Circuit for Formation of Bearing Sweep Start and End Pulses

Key:
1. Volts
2. Input
3. Output

The cell's first stage is a normally open inverter. Resistor R1 serves as the photodiode's load. Pulses of positive polarity are singled out at resistor R1 and fed through resistor R2 to the base of open transistor T1.

The next two cascades are a univibrator. Transistor T3 is open in static state, since its base is connected by way of resistor R7 directly to a -12 volt power supply. Transistor T2 is closed. To make it resistant to interference, transistor T2 is also closed by a positive constant +1.5 volt bias source by way of resistor R4. Amplified and inverted pulses are transmitted from the collector of transistor T1 through capacitor C1 to the base of transistor T2.

When a negative pulse passes to the base of triode T2, the univibrator shifts to an unstable state, in which it remains until such time that capacitor C3 discharges. A negative pulse forms at the collector of transistor T3. This pulse passes through connecting transformer Tp1 to the input of a two-stage amplifier consisting of transistors T4, T5. In its initial state, transistor T4 is closed by a negative voltage passed to the emitter from divider R9, R10. In response to a negative pulse the transistor opens, current passes through winding L3 of transformer Tp2, and a negative pulse is picked off from the output winding L4, opening transistor T5. A pulse of standard duration and amplitude is formed at the output of the cell.

The bearing coordinate may be determined not only with the assistance of a counting pulse generator but also with the help of current bearing sensors. The main component of a current bearing sensor is a device that converts angles of rotation into a binary code: Converters with coded discs, induction sensors, magnetic drums, and other devices may be used for this purpose.

One of the simplest variants of such a converter involves the use of a slotted disc. Slots corresponding in number to the discrete angle read-out are situated along the periphery of an opaque disc (Figure 24). A light source is positioned on one side of the disc. It creates a narrow beam of light that illuminates only one slot in the disc at any moment in time. A photoelectric cell is mounted on the other side of the disc. The light pulses penetrating through slots in the disc as it is turned by the antenna simulation block's motor are converted into electric pulses by the photoelectric cell.

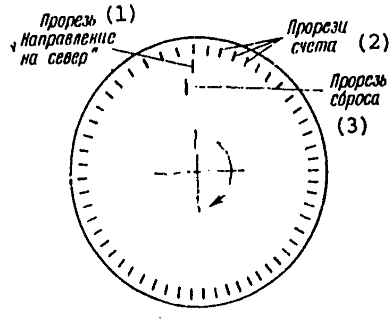


Figure 24. Slotted Discs

Key:
1. "North" slot
2. Counting slots
3. Reset slot

Two more slots are made in the disc to initiate the read-out at the moment the antenna simulation block crosses an arbitrary zero line (the "north" line) and to reset the counter. Additional photoelectric cells are mounted as well.

The work of the bearing coordinate determination block's principal unit is similar to the work of corresponding units in the range coordinate determination block. The main difference is that the operating cycle of the bearing coordinate determination block is about three orders of magnitude longer than the operating cycle of the range coordinate determination block (12).

As slotted disc *1* (Figure 25) mounted on the motor shaft rotates, a bearing sweep start pulse produced by photoelectric cell *3* at the moment the "north" line is sensed passes to the unit input of control flip-flop *5*; this sets the flip-flop in its unit state, thus opening kon"yunktor *6*. The sequence of pulses from photoelectric cell *2*, which reads the bearing marks, passes to the bearing mark counter (BMC), the outputs of which are connected through kon"yunktor's *7* to the computer's input register. In response to a signal from the computer, taking the form of a coordinate input pulse (CIP) that passes to the other input of kon"yunktor's *7*, the readings of the bearing mark counter are transcribed into the computer's input register.

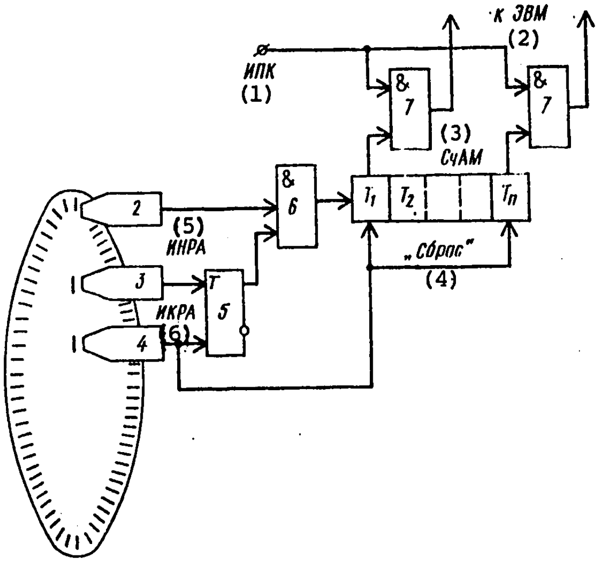


Figure 25. Functional Diagram of a Rotation Angle-Code Converter

Key:

1. CIP
2. To computer
3. BMC
4. "Reset"
5. BSSP
6. BSEP

At the end of a full rotation of the disc, the bearing sweep end pulse formed by photoelectric cell *4*, which reads reset pulses, passes to the zero input of control flip-flop *5*, returning it to its initial state, and to the bearing mark counter reset mechanism.

Direct determination of bearing coordinates by reading the bearing from a coded disc is also possible (1).

A binary code representing angles of rotation is applied photographically to a transparent disc secured directly to the shaft of the antenna simulation block's motor (Figure 26). The disc is divided into a number of sectors and rings. The breadth of the sectors is determined by the bearing determination accuracy required, and the number of rings depends on the quantity of code bits required. The outer ring corresponds to the first bit of the code, the second ring corresponds to the second bit of the code, and so on. A fully determined, nonrepeating combination of light and dark areas corresponds to each rotation angle of the antenna simulation block. Point light sources are situated on one side of the disc, and a screen is located on the other side. Light passes through a narrow slit on the screen to miniature photoelectric cells, the number of which is equal to the number of discs. A light beam passing through the disc produces current pulses in the circuit of a photoelectric cell. Following amplification, the pulses are fed to counting kon"yunktor's, which register the unity code in the appropriate disc positions. If light beams corresponding to other bit positions are blocked by dark areas on the disc, no pulses arise in the amplifier for the given bit positions. A zero code is registered in the bit positions.

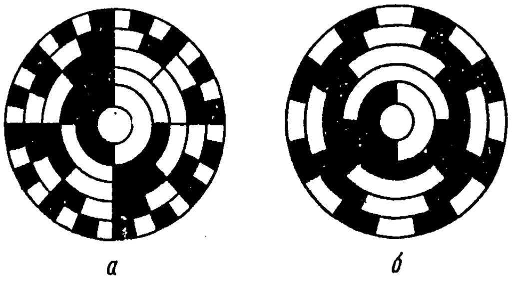


Figure 26. Code Discs to Which Binary (*a*) and Cyclic (*b*) Codes Are Applied

In contrast to the device examined above, this one can measure the disc's angle of rotation irrespective of whether it is rotating, standing motionless, or rocking. This feature is highly significant in trainers in which the operator himself controls the movements of the antenna simulation block.

But a significant shortcoming is inherent to the device shown in Figure 26*a*. It is susceptible to sizeable code reading errors when reading occurs at the boundary between the code combinations of two adjacent angles. For example at the boundaries between numbers 7 and 8 and between numbers 23 and 24, ones and zeros are changed simultaneously in four bit positions, while at the boundaries between numbers 15 and 16 and numbers 31 and 0 such a change occurs in as many as five bits. If the light beams are not sufficiently precise, different combinations of numbers not reflecting the true code of the bearing may form at such boundaries.

To prevent such reading errors, a cyclic rather than a conventional binary code is applied to the disc (Figure 26*b*); in all cases the error it may produce would not exceed the value of the low-order bit.

Table 2

(1) Коды			(2) Разряды			
десятичный (3)	двоичный (4)	циклический (5)	4	3	2	1
0	0000	0000				
1	0001	0001				XXX
2	0010	0011			XXX	XXX
3	0011	0010			XXX	
4	0100	0110		XXX	XXX	
5	0101	0111		XXX	XXX	XXX
6	0110	0101		XXX		XXX
7	1111	0100		XXX		
8	1000	1100	XXX	XXX		
9	1001	1101	XXX	XXX		XXX
10	1010	1111	XXX	XXX	XXX	XXX
11	1011	1110	XXX	XXX	XXX	
12	1100	1010	XXX		XXX	
13	1101	1011	XXX		XXX	XXX
14	1110	1001	XXX			XXX
15	1111	1000	XXX			

Key:

1. Codes
2. Bits
3. Decimal
4. Binary
5. Cyclic

Decimal, binary, and cyclic codes are shown in Table 2 to permit comparison of the different codes. It also shows the cyclic code combinations for 16 positions of a disc. The clear areas correspond to transparent areas on the disc, producing a unit read-out. Areas marked XXX correspond to zero. For convenience, the bits are arranged not as rings but as fixed strips.

We can see from the cyclic code that all bit positions are equivalent, and that when we shift from one binary number to another, a change occurs in only one bit position. Consequently only one of two adjacent numbers can be read at the boundary between two digits. In this case the error would be equivalent to only a small part of one division--that is, just a fraction of a low-order bit.

After the cyclic code is read by a coordinate input pulse, the code is transmitted to the computer, where it is transformed by a simple program into a conventional binary code.

Representation of a Target on an Indicator Screen

Depending on the purpose and design of the trainer, radar signals may be simulated at the carrier frequency, an intermediate frequency, or a low frequency (a video frequency). Most computerized trainers simulate target signals in video frequency. When simulating radar signals, we must account for a number of their typical parameters, and for change in these parameters depending on the coordinates of the target, the nature of its maneuvers, and its physical properties (10).

Typical target parameters may include: the duration of the "reflected" pulse, fluctuation of the "reflected" signal, the shape of the signal envelope depending on the nature of the reflecting surface of the simulated target, the amplitude of the "reflected" signal, and the angular length of the signal on the indicator screen, which depends on the dimensions of the target, its flying radius (the target's course angle), and the breadth of the beam pattern of the simulated radar antenna.

One possible functional diagram of a computerized video-frequency target signal simulator is shown in Figure 27. The system includes indicator *1*, range sweep formation block *2*, bearing sweep formation and antenna simulation block *3*, range marker pulse generator *4*, kon"yunktor *5*, range marker pulse counter *6*, bearing pulse counter *7*, matching block *8*, and computer *9* (14).

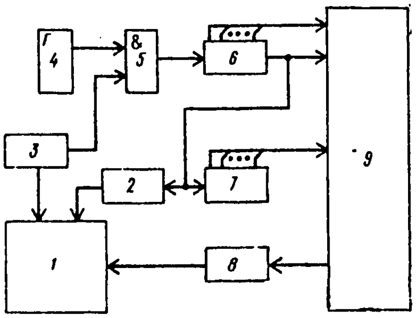


Figure 27. Functional Diagram of a Computerized Target Blip Simulator

Bearing sweep formation and antenna simulation block *3* forms the bearing sweep on indicator *1*, and at the moment it lines up with the bearing read-out start line (the "north" line) it opens kon"yunktor *5*, to the input of which a highly stable oscillator *4* is connected. Range marker pulses pass through kon"yunktor *5* to range marker pulse counter *6* with a capacity of n bits. In addition to counting these pulses, the counter forms the range sweep start pulses, the repetition frequency of which is n times lower than the repetition frequency of the range marker pulses. Thus each cycle of the range sweep always contains the same number of range marker pulses.

Range sweep start pulses picked off from the output of the range marker pulse counter *6* pass to both the input of the range sweep formation block *2* and the input of the bearing pulse counter *7*. By counting the number of range sweep start pulses coming in at any moment in time, the latter registers the angular position of the PPI beam in relation to bearing. Following a complete 360° revolution of the PPI beam, bearing pulse counter *7* is reset, and it once again begins counting pulses arriving at its input. The universality of such a simulation system permits its operation in two modes.

In the first mode, current range and bearing coordinates of the target's trajectory are calculated by the computer beforehand and stored in its main memory. During the system's work in this case, every range sweep triggering pulse passing through the interrupt system into the computer control unit causes the latter to run a subroutine interrogating the contents of the bearing pulse counter *7* and comparing its readings with the closest current value of the target bearing, stored in the computer's main memory.

If the readings of bearing pulse counter *7* do not correspond to the nearest current value of the target bearing, computer *9* returns to the main program, not associated with simulation of target blips. Otherwise it switches to a second subroutine in which the contents of the range marker pulse counter *6* are continually interrogated, and its readings are compared with the closest current value of the range of a target located at a constant bearing.

As soon as the current value of the target range corresponds precisely to the reading of the range marker pulse counter *6*, the computer transmits a signal to matching block *8*, causing it to turn on the first target pulse on the indicator's range sweep. Inasmuch as the number of pulses received by the radar station out of the pulse train from the target is random, and because it is dependent on the antenna's rotation rate and the breadth of its beam pattern, the concrete breadth of the target pulse train is set by the working program of the computer *9*, depending on the specific tactical situation being simulated. To simulate the next target pulses on adjoining lines of the range sweep following the first k-1 target pulses, the computer produces another k-1 signals. causing the target pulse range sweep to turn on at the moment that the current range values equal the readings of the range marker pulse counter *6*.

This system follows the target blip simulation algorithm shown in Figure 28.

The algorithm begins with operator A_1, which interrogates the contents of the bearing pulse counter at the moment the range sweep start pulse (RSSP) arrives. Logic operator P_2 compares the readings of the bearing pulse counter with the closest current value of target bearing, stored in the computer's main memory. If logic operator $P_2 = 0$--that is, if the readings of the bearing pulse counter are not equal to the current value of the target bearing, control is transferred to stop operator $Я_8$. Otherwise (at $P_2 = 1$) control is transferred to operator A_3, which interrogates the contents of the range marker pulse counter.

Logic operator P_4 compares the readings of the range marker pulse counter with the closest values for the range coordinate, recorded at the given bearing and stored in the working memory of the computer. If logic operator $P_4 = 0$, then control is transferred to operator A_3, which interrogates the range marker pulse counter, registering a new value for its readings.

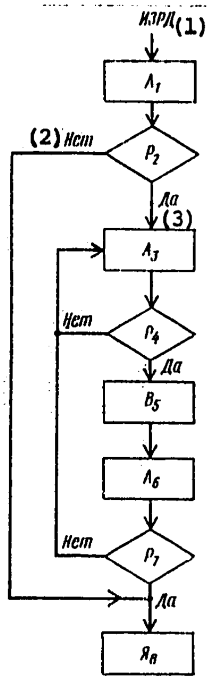


Figure 28. Block Diagram of a Traget Blip Simulation Algorithm Entailing Interrogation of the Range Marker Pulse Counter

Key:
1. RSSP
2. No
3. Yes

As soon as the readings of the range marker pulse counter correspond to the value of the range coordinate--that is, when logic operator $P_4 = 1$, control is transferred to operator B_5. The latter forms and transmits target pulses to the modulator of the indicator's cathode-ray tube. In addition operator B_5 transfers control to operator A_6, which counts the number of pulses produced by operator B_5.

Logic operator P_7 compares the number of target pulses produced by the modulator of the indicator's cathode-ray tube with a constant defining the breadth of the pulse train. If logic operator $P_7 = 0$, then control is transferred to operator A_3, which, together with operators P_4 and B_5, forms and produces the next target pulse. When the quantity of target pulses produced by operator B_5 equals the quantity of pulses defined by the constant, logic operator $P = 1$ [sic], and control is transferred to stop operator $Я_8$.

In the second operating mode, none of the current target coordinates are computed beforehand. The computer's main memory stores only the initial values of the coordinates (bearing and range) for each target, and of their velocities. During the trainer's operation, the computer follows a special program, preparing the current target coordinates for the next scan, and producing them on the display. When it becomes necessary to change the target's trajectory, it is sufficient to change the motion parameters of this target (velocity, or one of the indicated coordinates).

The principle of such programs entails the use of extrapolation algorithms: The coordinates of a subsequent blip are calculated on the basis of the coordinates of previous blips.

In the simplest case the coordinates of an extrapolated blip ($x_{\text{э}}$) in the n-th scan may be computed as follows (12):

$$x_{\text{э}} = x_{n-1} + VT_0,$$

where x_{n-1}--the coordinate of the target in the previous (n-1)-th scan; V--target velocity; T_0--scanning cycle.

In the general case the coordinate of the extrapolated blip is described by the algorithm

$$x_{\text{э}} = \sum_{i=1}^{n} \rho_i x_i,$$

where n--number of blips used in the prediction (the subscript $n = 1$ is assigned to the blip appearing on the last scan); ρ_i--weight factor of the i-th blip.

Weight coefficient ρ_i may be determined by the following formulas:

For a target that is not maneuvering,

$$\rho_{i(\text{нм})} = \frac{6i - 2n - 4}{(n-1)n};$$

for a target that is maneuvering

$$\rho_{i(\text{м})} = \frac{3}{n(n-1)(n-2)}[(n+3)(n+2) - 2i(4n + 7) + 10i^2].$$

As an example, let us determine the extrapolation factors for a nonmaneuvering target on the basis of three successive sweeps ($n = 3$):

$$\rho_{3(\text{нм})} = \frac{6 \cdot 3 - 2 \cdot 3 - 4}{3 \cdot 2} = \frac{4}{3};$$

$$\rho_{2(\text{нм})} = \frac{6 \cdot 2 - 2 \cdot 3 - 4}{3 \cdot 2} = \frac{1}{3};$$

$$\rho_{1(\text{нм})} = \frac{6 \cdot 1 - 2 \cdot 3 - 4}{3 \cdot 2} = -\frac{2}{3}.$$

Thus for a nonmaneuvering target, the extrapolation algorithm used to make a prediction on the basis of three blips appearing in a single sweep would be:

$$x_{\text{э}(\text{нм})} = \frac{4}{3}x_1 + \frac{1}{3}x_2 - \frac{2}{3}x_3.$$

It would not be difficult to show that the weight factors for a maneuvering target would be as follows for the case of extrapolation on the basis of three successive sweeps:

$$\rho_{3(\text{м})} = 3, \quad \rho_{2(\text{м})} = -3, \quad \rho_{1(\text{м})} = 1,$$

and in this case the extrapolation algorithm would have the form

$$x_{\text{э}(\text{м})} = 3x_1 - 3x_2 + x_3.$$

Let us illustrate the use of these algorithms with the assumption that blips with coordinates $x_1 = 6$, $x_2 = 4$, $x_3 = 2$ are obtained from a nonmaneuvering target and blips with coordinates $x_1 = 9$, $x_2 = 5$, $x_3 = 2$ are obtained from a maneuvering target.

Then the extrapolated coordinate for the nonmaneuvering target would be

$$x_{\text{э}(\text{нм})} = \frac{4}{3}\cdot 6 + \frac{1}{3}\cdot 4 - \frac{2}{3}\cdot 2 = 8,$$

while the extrapolated coordinate for the maneuvering target would be

$$x_{\text{э}(\text{м})} = 3\cdot 9 - 3\cdot 5 + 2 = 14.$$

An algorithm of this sort is run quite easily in a computer. The only shortcoming is that as the number of blips used to predict a future coordinate increases, the volume of the computer's main memory must increase.

The target blip simulator diagramed in Figure 27 imposes significant restrictions on the effectiveness with which computer time is used, because during the time that the range sweep performs its forward trace, the computer is limited to just the target blip formation task.

In fact, every time that the readings of bearing pulse counter *7* correspond to the current target bearing value stored in the working memory of computer *9*, the computer switches to a subroutine that continually interrogates the contents of range marker pulse counter *6* and compares its readings with the closest current range value of the target, located at constant bearing. Considering that the ratio between the forward and back traces of the range sweep of a typical PPI is about 10:1, we can conclude that the computer will be occupied with just one task for 90 percent of its total working time, and that it will be free for other tasks for only 10 percent of its time.

A functional diagram of a target blip simulator which does not have this shortcoming is shown in Figure 29. It contains PPI *1*, range sweep formation block *3*, antenna simulation and bearing sweep formation block *2*, bearing read-out starting flip-flop *4*, kon"yunkyor *5*, bearing counter *6*, range register *7*, synchronization flip-flop *8*, kon"yunktor *9*, shaper-amplifier *10*, target blip output flip-flop *11*, kon"yunktor *12*, pulse generator *13*, and computer *14*.

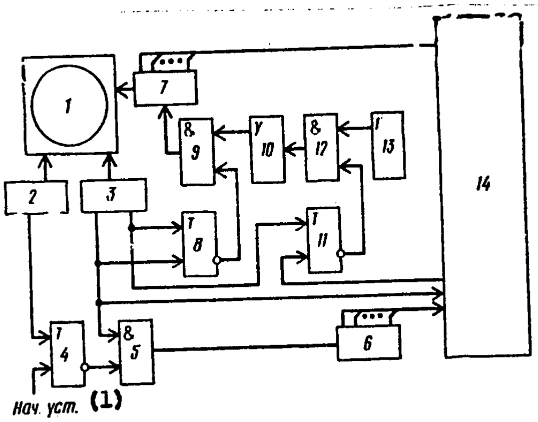


Figure 29. Functional Diagram of a Target Blip Simulator With One Range Register

Key:
1. Initial setting

Antenna simulation and bearing sweep formation block *2* creates, on indicator screen *1* jointly with range sweep formation block *3*, a PPI sweep. The PPI sweep on indicator *1* is synchronized with computer *14* by range sweep start (RSSP) and end (RSEP) pulses, produced in range sweep formation block *3*. RSSP's are fed to kon"yunktor *5*, which is opened by flip-flop *4*, which starts the azimuth read-out, at the moment that the radial-circular sweep passes through the zero point of the bearing read-out. At this moment the bearing read-out initiation flip-flop *4* is set in its unit state by a single from a bearing read-out initiation signal produced by the antenna simulation and bearing sweep formation block *2*.

An RSSP is fed from the output of kon"yunktor *5* to the input of bearing counter *6*, which, by counting the number of incoming RSSP's, determines the angular position of the PPI sweep at any moment in time. Following a complete 360° revolution of the PPI sweep, bearing counter *6* automatically resets, and it once again begins to count pulses arriving at its input. The output of bearing counter *6* is connected to the computer's input register.

To permit information read-out from the bearing counter, each RSSP is additionally fed to the input of the computer control unit interrupt block. On receiving this signal, the computer switches to a subroutine interrogating the contents of the bearing counter and comparing its readings with the target bearing values stored in the computer's working memory.

If the readings of bearing counter *6* do not correspond to the closest target bearing value, computer *14* returns to the main program, which has no relationship to target blip simulation. Otherwise the computer switches to a subroutine forming a target blip at the prescribed range. For this purpose the code for target range corresponding to a fixed bearing is transferred from the computer's main memory to range register *7* as an inverse code, after which the computer produces a signal turning on target output flip-flop *11*. Switching to its unit state, the latter opens kon"yunktor *12* and thus connects pulse oscillator *13* to the input of kon"yunktor *9* via amplifier-shaper *10*.

The work of range register *7* is also synchronized with the PPI sweep on indicator *1*. For this purpose RSSP's and RSEP's control synchronization flip-flop *8*, which opens kon"yunktor *9* at the beginning of the range sweep and closes it at the end.

Inasmuch as kon"yunktor *9* is open throughout the entire time of formation of the range sweep, the succession of pulses from oscillator *13* passes through it, filling range register *7*. As soon as a number of pulses equal to the value of the current range coordinate enters the input of the range register, the first target blip pulse appears at its output. This pulse is then transmitted to the CRT modulator of indicator *1*.

To form a real target blip, consisting of a train of 10-12 pulses, during the return trace of the range sweep the computer rewrites the current range value in the range register by an inverse code 10-12 times, and produces a signal generating a target pulse. As a result of this, target pulses appear in 10-12 successive range sweeps. These pulses simulate a target blip with the given range and bearing coordinate.

This procedure entails the use of the target blip simulation algorithm shown in Figure 30.

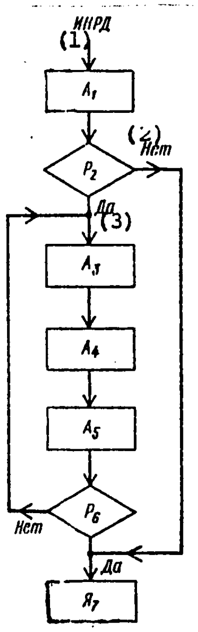


Figure 30. A Flow Chart for a Target Blip Simulation Algorithm Permitting Range Register Control

Key:
1. RSSP
2. No
3. Yes

Upon arrival of an RSSP, operator A_1 interrogates bearing pulse counter *6*, and logic operator P_2 compares the readings of the bearing pulse counter with the closest current value of the target bearing, stored in the computer's main memory. If the readings of the bearing pulse counter do not correspond to the current target bearing, logic operator P_2 transfers control to stop operator $Я_7$. Otherwise, when $P_2 = 1$, control is transferred to operator A_3, which transfers the range coordinates for the target at the given bearing from the computer's main memory to range register *7* by an inverse code.

Operator A_4 forms a signal that turns on target blip generation flip-flop *11* and transfers control to operator A_5 which counts how many times the target blip generation flip-flop was turned on. 'Logic operator P_6 compares this number with a constant defining the number of pulses in a train. If logic operator $P_6 = 0$, control is once again transferred to the succession of operators A_3, A_4, A_5. When $P_6 = 1$, control is transferred to stop operator $Я_7$.

The advantage of such a target blip simulation system is that in the event that the readings of bearing counter *6* equal the bearing value of the target to be simulated, the computer performs just two operations: It transfers the range code of the target corresponding to a fixed bearing from the computer's main memory to range register *7*, and it sets target blip generation flip-flop *11* in its unit state. After this the computer turns to other programs, until the next interrupt pulse appears (RSSP).

But the target blip simulation system examined here cannot simultaneously simulate several targets at different ranges but on the same bearing. This is a consequence of the design of the range register, which is capable of supporting formation of only one target blip on each radial sweep of the beam.

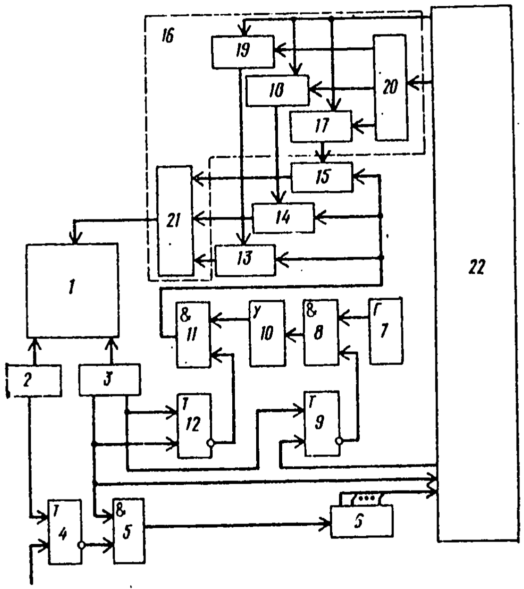


Figure 31. Functional Diagram of a Target Blip Simulator Possessing a Range Register Switching Block

A functional diagram of a target blip simulator free of this shortcoming is shown in Figure 31. It contains indicator *1*, antenna simulation and bearing sweep formablock *2*, range sweep formation block *3*, bearing read-out initiation flip-flop *4*, kon"yunktor *5*, bearing counter *6*, pulse oscillator *7*, kon"yunktor *8*, target blip generation flip-flop *9*, amplifier-shaper *10*, kon"yunktor *11*, synchronization flip-flop *12*, registers *13*, *14*, and *15* storing the current target range coordinates, current target range coordinate switching block *16*, which contains gate groups *17*, *18*, and *19*, switching unit *20*, (diz"yunktor) *21*, and computer *22*.

Working with range sweep formation block *3*, antenna simulation and bearing sweep formation block *2* creates a PPI sweep on the screen of indicator *1*.

The PPI sweep on indicator *1* is synchronized with computer *22* with the assistance of range sweep start and range sweep end pulses generated in range sweep formation block *3*. For this purpose RSSP's are fed to kon"yunktor *5*, which is opened by bearing pulse read-out initiation flip-flop *4* at the moment that the PPI sweep crosses the point of initiation of bearing read-out--that is, when the bearing is 0. At this moment bearing read-out initiation flip-flop *4* is set in its unit state by a bearing read-out initiation signal generated in antenna simulation and bearing sweep formation block *2*.

The RSSP's pass from the output of kon"yunktor *5* to the input of bearing counter *6* which, by counting the number of entering RSSP's, fixes the position of the PPI sweep at any moment in time. Following a complete 360° revolution of the PPI sweep, bearing counter *6* automatically resets, and once again begins counting pulses coming to its input. The output of bearing counter *6* is connected to the input register of computer *22*.

In order to permit information read-out from bearing counter *6*, each RSSP is additionally fed to the input of the control unit of computer *22*. In response to this signal the computer switches to a subroutine interrogating the contents of bearing counter *6* and comparing its readings with the target bearing values stored in the computer's main memory.

If the readings of bearing counter *6* do not correspond to the closest target bearing value, the computer returns to the main program having no relationship to target blip simulation. Otherwise the computer switches to a subroutine to form target blips located at different ranges but at the same bearing.

For this purpose the computer, which controls gate groups *17*, *18*, *19*, successively transfers, in the form of an inverse code, the range code values for targets fixed at a given bearing from its main memory through switching unit *20* to target range coordinate storage registers *14*, *15*, *16*. After this the computer produces a signal turning on target blip generation flip-flop *9*. Switching to its unit state, the latter opens kon"yunktor *7* and thus connects pulse oscillator *8* to the input of kon"yunktor *11* via amplifier-shaper *10*.

The operation of kon"yunktor *11* is controlled by synchronization flip-flop *12*, which opens it at the beginning of the range sweep and closes it at its end. Because kon"yunktor *11* is open throughout the entire time of range sweep formation, the sequence of pulses produced by oscillator *7* passes through it to the inputs of target range coordinate storage registers *13*, *14*, *15*. Inasmuch as the range coordinates of targets at a fixed bearing are stored in these registers in inverse code, after each of the registers is filled with a number of pulses equal to the coordinates of the target ranges, a blip pulse corresponding to each target appears at the output of each of them. The blip pulses from different targets pass through diz"yunktor *21* to the CRT modulator of indicator *1*.

Simulation of Jamming and Interference

In order to create, on an indicator screen, a model of an aerial situation typified by the presence of jamming and interference, it would be suitable to delegate simulation of the latter to the computer.

Figure 32 gives an approximate idea of what radar screens look like when they are affected by jamming and interference (5), and Figure 33 shows one of the possible flow charts for a computerized jamming and interference simulator.

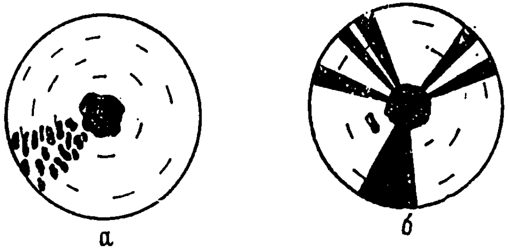


Figure 32. Appearance of the PPI Screens of Radar Stations Subjected to Interference (*a*) and Jamming (*b*)

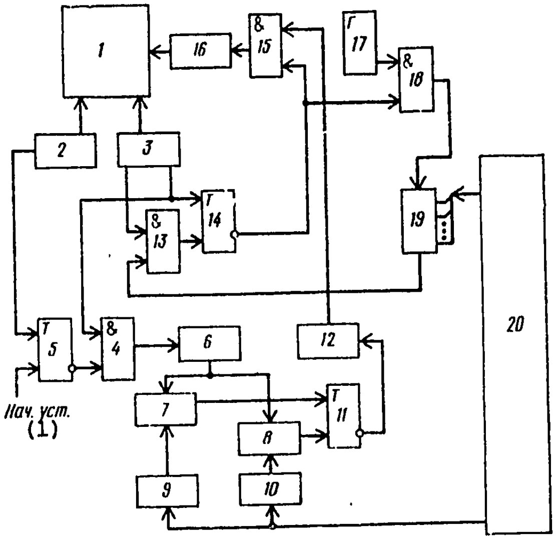


Figure 33. Flow Chart of a Computerized Jamming and Interference Simulator

Key:
1. Initial setting

The simulator contains indicator *1*--a cathode-ray tube with long image persistence, antenna simulation and bearing sweep formation block *2*, range sweep formation block *3*, kon"yunktor *4*, bearing read-out initiation flip-flop *5*, bearing counter *6*, interference bearing start determination block *7*, interference bearing end determination block *8*, interference bearing start storage register *9*, interference bearing end storage register *10*, interference generation flip-flop *11*, interference voltage formation block *12*, diz"yunktor *13*, synchronization flip-flop *14*, analog kon"yunktor *15*, matching block *16*, range marker pulse oscillator *17*, kon"yunktor *18*, register *19*, and computer *20*.

Working together with range sweep formation block *3*, antenna simulation and bearing sweep formation block *2* creates a PPI sweep on the screen of indicator *1*.

To simulate jamming on the indicator screen, shown in one variant in Figure 32*b*, during the back trace of the range sweep the computer transfers the coordinates of the interference bearing start and end coordinates to registers *9* and *10*.

The PPI sweep on indicator *1* is synchronized with computer *20* by means of RSSP and RSEP pulses generated in range sweep formation block *3*. Range sweep start pulses are fed to the input of kon"yunktor *4*, which controls bearing read-out initiation flip-flop *5*. When a "north" pulse, produced by antenna simulation and bearing sweep formation block *2*, appears at the moment the PPI beam passes the azimuth read-out initiation point, flip-flop *5* opens kon"yunktor *4*, and then bearing counter *6* begins fixing the current bearing values by counting the number of RSSP's entering its input.

Blocks *7* and *8*, which determine the start and end of the interference bearing, compare the current bearing values determined by counter *6* with the interference bearing coordinates stored in registers *9* and *10*. As soon as the current bearing value of counter *6* equals the bearing value stored in interference bearing start register *9*, interference bearing start determination block *7* produces a pulse that places interference generation flip-flop *11* in its unit state. The high potential produced by the unit output of flip-flop *11* turns on its current voltage formation block *12*, which produces the range sweep illumination voltage. The illumination voltage passes through analog kon"yunktor *15*, the controlling input of which is connected to synchronization flip-flop *14*, to the input of matching block *16*, and then to the CRT modulator of indicator *1*.

As a result of this, beginning with the initial interference bearing, the screen of indicator *1* would be completely illuminated within the limits of the start and end bearings of the interference. The interference is turned off from the indicator screen by a pulse produced by interference bearing end determination block *8*, at the moment that the current bearing value of counter *6* is equal to the bearing values stored in interference bearing end register *10*. Passing to the zero input of interferenc e generation flip-flop *11*, the pulse produced by intereference bearing end determination block *8* returns the flip-flop to its initial state, and thus turns off interference voltage formation block *12*.

Analog kon"yunktor *15* is needed because in contrast to the situation with jamming, only a part of the range sweep on the indicator screen is illuminated in the presence of passive interference. Figure 32*a* shows the appearance of interference produced on indicator screen *1* by terrain features.

To simulate such interference, computer *20* transmits not only the start and end values of the interference bearing to registers *9* and *10*, but also the range coordinate of the interference, read from the center of the indicator screen *1*; the latter is transferred to register *19* by an inverse code. Range marker pulse generator *17* is connected to register *19* via kon"yunktor *18*, the controlling input of which is connected to synchronization flip-flop *14*.

At the start of the range sweep, synchronization flip-flop *14* opens analog kon"yunktor *15* and kon"yunktor *18*. As a result, the range sweep illumination voltage coming from the output of interference voltage formation block *12* lights up the indicator screen. However, as soon as a number of pulses equal to the value of the interference range coordinate enters register *19*, a pulse arises at the output of register *19*. This pulse passes through diz"yunktor *13* to the zero input of synchronization flip-flop *14*, returning it to its initial state without waiting for the end of the range sweep. As a consequence analog kon"yunktor *15* and kon"yunktor *18* break the corresponding circuits, and formation of interference on this range sweep ends.

COMPUTERIZED TRAINERS

Trainers Used to Teach PPI Radar Operators

A flow chart of a trainer intended to teach operators how to use PPI radar stations is shown in Figure 34 (15). Its composition includes plan position indicator *1*, antenna simulation and bearing sweep formation block *2*, range sweep formation block *3*, bearing flip-flop *4*, bearing kon"yunktor *5*, bearing counter *6*, range flip-flop *7*, range marker pulse oscillator *8*, range kon"yunktor *9*, range counter *10*, target signal amplitude range setting block *11*, target signal amplitude determination block *12*, matching block *13*, semiautomatic coordinate plotting mechanism *14*, marker formation block *15*, marker *x* coordinate register *16*, marker *y* coordinate register *17*, time pulse sensor *18*, time registration flip-flop *19*, time kon"yunktor *20*, time pulse counter *21*, and electronic computer *22*.

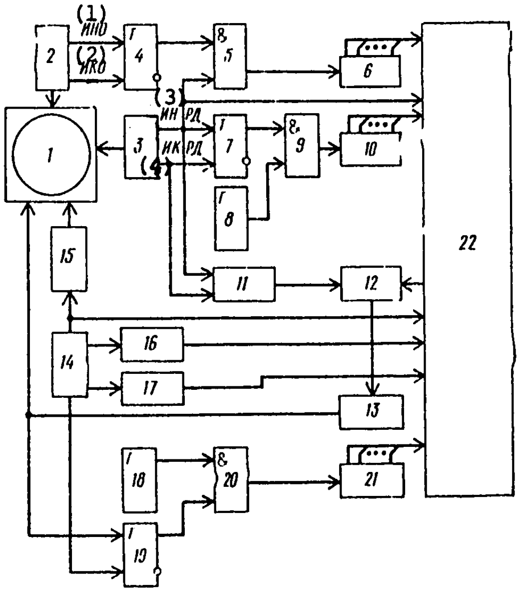


Figure 34. Flow Chart of a Trainer for PPI Radar Operators

Key:
1. SSP
2. SEP
3. RSSP
4. RSEP

The essence of the trainer's operation is as follows.

Antenna simulation and bearing sweep formation block *2* generates scan start pulses (SSP's) and scan end pulses (SEP's), which pass through the unit and zero inputs of bearing flip-flop *4* respectively. At the moment bearing read-out is initiated, an SSP sets bearing flip-flop *4* in its unit state, thus opening bearing kon"yunktor *5*, the input of which receives a constant flow of range sweep start pulses produced by range sweep formation block *3*. RSSP's pass from the output of kon"yunktor *5* to the input of bearing counter *6*, which counts the incoming RSSP's, thus fixing the current bearing values. When the PPI sweep completes a full revolution, a scan end pulse produced by antenna simulation and bearing sweep formation block *2* returns bearing synchronization flip-flop *4* to its initial state. With the start of a new scan, bearing counter *6*, the output of which is connected to the input register of computer *22*, once again begins recording the current bearing values.

RSSP's and RSEP's are also used to synchronize the work of range flip-flop *7*, which is connected to range kon"yunktor *9*; range marker pulse oscillator *8* is connected to the other input of the latter, and range counter *10* is connected to its output. Thus range counter *10* records the current range values from zero to maximum in each range sweep. As with the output of bearing counter *6*, its input is connected to computer *22*.

Target blips and target trajectories are formed in the following fashion. The current bearing and range coordinates of all targets are fed into the computer memory. After the trainer is turned on, each RSSP passes to bearing counter *6*, and simultaneously each pulse is fed through the computer's interrupt channel to the input of its control unit. In response to this signal the computer switches to a subroutine interrogating the contents of the bearing counter and comparing its readings with the value for the first target range coordinate, stored in the computer's main memory.

If the readings of bearing counter *6* do not correspond to the value of the closest target bearing coordinate, the computer returns to its main program not associated with target blip formation. Otherwise the computer switches to a second subroutine forming target blips at a given range; this entails continuous interrogation of the contents of range counter *10* and comparison of its readings with the value of the closest range coordinate of a target at fixed bearing.

As soon as the current target value corresponds to the reading of the range counter, the computer feeds a signal to target signal amplitude determination block *12*, causing it to produce a target pulse on the indicator's range sweep.

The reason target signal amplitude determination block *12* is within the composition of the trainer is that in real conditions, a nonlinear dependence exists between the amplitude of the signal received by the radar station and the range to the target. This dependence is shown in Figure 35 (10). However, because of the action of the automatic gain adjustment circuit in the receiving channel of the radar station and saturation of the receiver at low target ranges, a signal at the output of the receiver increases in intensity only to a certain value; therefore this law is usually simulated approximately in trainers.

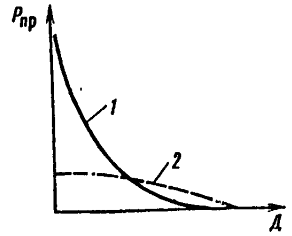


Figure 35. Change Experienced by a Signal at a Radar Receiver Input Depending on Range to the Target *1*, and Simulation of This Change by a Trainer *2*

In the trainer under examination here, the amplitude of the signal received by the radar station is simulated by the target signal amplitude range setting block , one of the possible variants of which is shown in Figure 36. The main component of the block is linearly-falling voltage generator *26*, the input of which is connected to adjustable constant voltage source *25* via analog kon"yunktor *23*, controlled by flip-flop *24*. At the beginning of a range sweep, an RSSP sets flip-flop *23* in its unit state, thus opening analog kon"yunktor *25*, which connects the adjustable constant voltage source to linearly-falling voltage generator *26*, starting up the generator. The magnitude of the constant voltage fed to the input of generator *26* is set such that the law of change of the linearly-falling voltage would be close to the law of change of the signal received by the radar station, depending on range to the target.

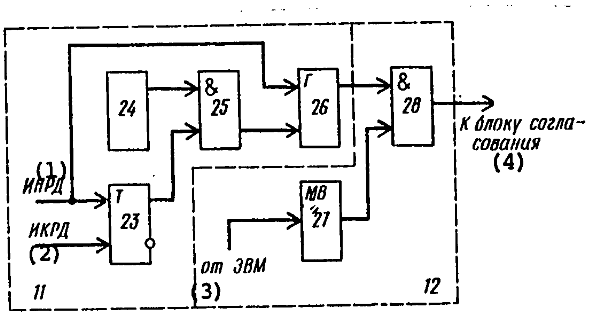


Figure 36. Flow Chart for a Target Pulse Formation Block

Key:

1. RSSP
2. RSEP
3. From computer
4. To matching block

In this case the target signal amplitude determination block *12* (Figure 34) would consist of delay multivibrator *27* (Figure 36), connected to the controlling input of analog kon"yunktor *28*, the other input of which is connected to the output of linearly-falling voltage generator *26*. At the moment a signal requiring production of a target pulse on the indicator's range sweep arrives, delay multivibrator generates a pulse, the duration of which is equal to the duration of the pulse reflected from the target. This pulse passes to the controlling input of analog kon"yunktor *28*, opening it and thus connecting the output of linearly-falling voltage generator *26* to matching block *13* (Figure 34). The latter interlinks the target signal amplitude determination block with the CRT modulator of indicator *1*.

At the end of the range sweep an RSEP returns flip-flop *23* (Figure 36) to its initial state, disconnecting the constant voltage source from linearly-falling voltage generator *26*. When as RSEP appears, the linearly-falling voltage generator starts up once again, and the process of target signal amplitude formation repeats itself.

To simulate successive target pulses on k successive range sweep lines, the computer transmits a target blip generation signal to block *12* (Figure 34) another (k-1) times at the moment the current target range is equal to the reading of range counter *10*.

To simplify the trainer flow chart Figure 34 does not show the jamming and interference simulation blocks, though such interference may be simulated in precisely the same way as the target blip.

Information is read semiautomatically in the trainer with the assistance of semiautomatic coordinate plotter *14*, marker formation block *15*, and marker coordinate x and y registers *16* and *17*.

In principle, coordinates may be read semiautomatically off of various types of conventional radar indicators, for which purpose the indicator must be equipped with a special plotter.

An electron-optic reading method has enjoyed extensive application abroad (12).

The operation of the target coordinate plotting unit (Figure 37) basically consists of the following. The unit contains guide mechanism *1*, which consists of two slotted yokes situated 90° relative to each other; rod *2*, connected to a handle and plotting button *3*, rocks in the slots. Devices *4* that convert the tilt angles of the rod into a binary number are mounted on the axles of the yoke. As the rod rocks, binary numbers proportional to the rod's tilt angle (x_M and y_M) are picked off from these converters. Passing through a "x,y number-voltage" converter, these numbers are transformed into constant voltages which, acting upon the CRT's deflecting system, determine the position of a luminescent electronic marker on the screen. Rocking rod *2*, the operator moves the electronic marker and superimposes it over the return from the target. When superimposition occurs, he presses plotting button *3*, which is connected to switch *5*. The switch closes the contacts of the x and y binary number output in the computer, and thus marker coordinates x_M and y_M, equal to the coordinates of the target at the moment of superimposition, are transmitted to the computer. This method requires the use of special indicators on which the simulated radar situation is superimposed over secondary signals such as, for example, markers, symbols, and digits.

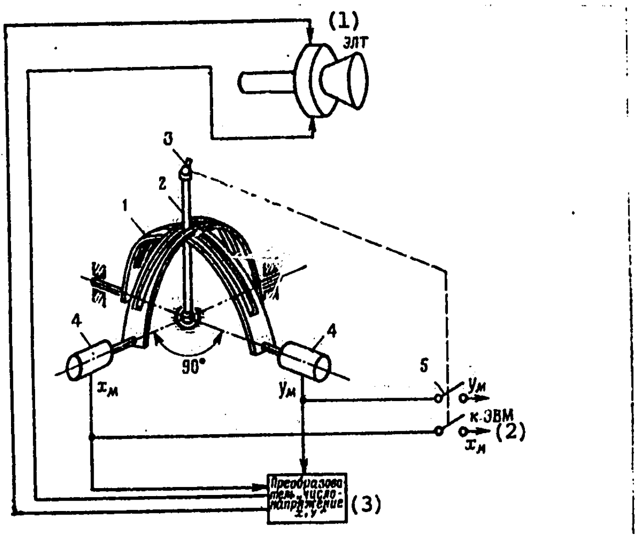


Figure 37. Functional Diagram Explaining the Principle of Electron-Optic Coordinate Read-Out: *1*--guide mechanism; *2*--rod; *3*--plotting handle and button; *4*--devices converting rod tilt angles into binary numbers; *5*--switch

Key:
1. CRT
2. To computer
3. "*x*,*y* number-voltage" converter

The radar situation and the marker can be simulated by the same deflecting system in polar coordinates.

Reproduction of the marker requires interruption of sawtooth voltages to the CRT's deflecting system for long enough to transmit the constant voltages of the marker. The frequency of marker illumination must be such that on one hand the marker would be observed as a nonblinking point, and on the other hand the loss of information caused by interruption of the sweep would be minimal.

In this trainer system (Figure 34), electron-optic coordinate plotting differs from the system shown in Figure 37 in that the coordinate plotter contains a system which converts turning angles in relation to each of the coordinates into a code. The readings of these converters are transmitted to registers *16* and *17* (Figure 34), connected to the computer. In this case when the marker is superimposed over the target blip, the operator presses the plotting button, and a "plot" pulse is generated in block *14*. This pulse passes through the computer's interrupt channel to its control unit, switching the computer to the subroutine interrogating the contents of marker coordinate registers *16* and *17* and comparing their readings with the true coordinates of the simulated targets.

Inasmuch as the true position of the target is recorded in the computer memory in polar coordinates while the marker position is given in rectangular coordinates, the computer transforms the coordinates of the marker from rectangular to polar, and compares them with the target coordinates. As a result of the comparison the computer determines the error made by the operator in measuring the coordinates.

In addition to determining the precision characteristics of the operator, the trainer can also measure and record the temporal characteristics of his work. For this purpose the trainer contains time pulse sensor *18*, connected via kon"yunktor *20* , the controlling input of which is connected to time recording flip-flop *19*, to time pulse counter *21*.

The moment a target blip appears on the indicator screen, the target pulse is passed to time recording flip-flop *19*, placing it in unit state and thus opening kon"yunktor *20*. From this time on, kon"yunktor *20* begins passing time pulses from time pulse sensor *18* to time pulse counter *21*. When the operator reads the coordinates, time recording flip-flop *19* returns to its initial state in response to a "plot" pulse, thus blocking kon"yunktor *20*. Concurrently, because the "plot" pulse is transmitted to the computer at the moment the plot button is pressed, the computer interrogates the time pulse counter and records the result in its memory--the operator's reaction time.

At the desire of the training supervisor the accuracy and time characteristics may be appropriately processed by the computer, and the results can be printed out.

The operator locks onto a selected target for tracking by successively inputting the coordinates and moments of detection of two successive blips into the computer. Using the first two inputs, the computer determines the motion parameters and calculates the anticipated coordinates of this target, which are then used to move the marker across the indicator screen of the trainer.

To calculate the marker coordinates for one or two sweeps ahead, it would be sufficient to use Newton's simple extrapolation formulas (12).

Trainers Used to Teach Guidance and Manual Target Tracking Operators

The task of guidance and manual target tracking radar operators differs from that of PPI radar operators in that they must use target indication data--that is, the target coordinates--to aim the intended system in such a way that the bisector of the scanning sector would intersect the target (Figure 38). The operator observes the aerial situation on a guidance indicator, which looks approximately as shown in Figure 39. This indicator has a scanning pattern similar to that of television; the scanning pattern is created by a scanning motion of the antenna beam pattern (8).

Then the operator superimposes the marker of the slave range system (the horizontal marker) over the target (as a result the target is placed at the intersection of the scanning sector bisector and the horizontal range marker) and sets the antenna control system and the slave range system in manual tracking mode, trying to keep the target at the intersection of the scanning sector bisector and the horizontal range marker.

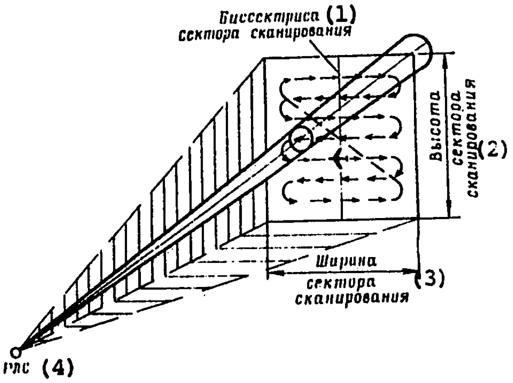


Figure 38. Scanning Pattern of a Guidance Radar Beam

Key:
1. Scanning sector bisector
2. Scanning sector height
3. Scanning sector width
4. Radar station

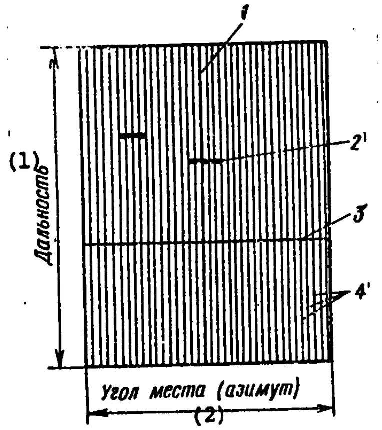


Figure 39. Approximate representation of a guidance indicator: *1*--scanning sector bisector (vertical marker); *2*--target blip ; *3*--horizontal range marker; *4*--range sweep line

Key:
1. Range
2. Angle of sight (bearing)

The flow chart for a trainer used to teach guidance and manual tracking operators is shown in Figure 40 (16).

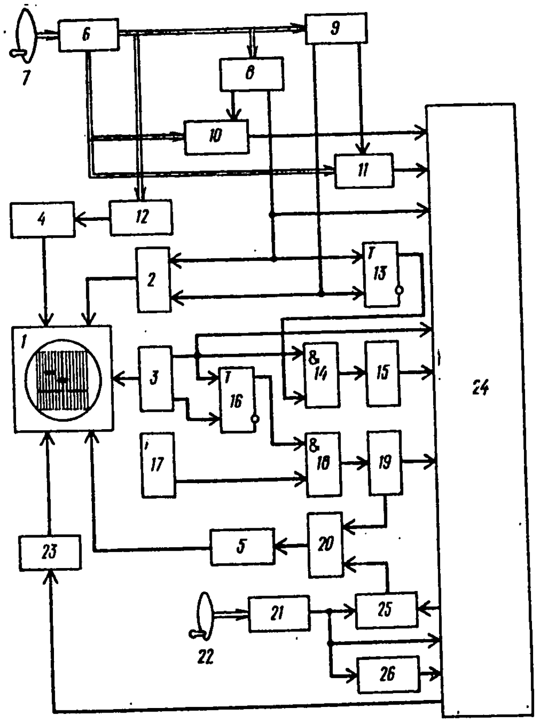


Figure 40. Flow Chart of a Trainer Used to Teach Guidance and Manual Tracking Operators

The trainer consists of guidance indicator *1*, angular sweep formation block *2*, range sweep formation block *3*, vertical marker formation block *4*, horizontal marker formation block *5*, antenna system simulation block *6* connected to angular antenna movement control *7*, scanning sector start pulse formation block *8*, scanning sector end pulse formation block *9*, blocks *10* and *11* measuring the coordinates of the left and right boundaries of the scanning sector respectively, scanning bisector pulse formation block *12*, control flip-flop *13*, angular coordinate read-out kon"yunktor *14*, block *15* which reads the angular coordinates within the scanning sector, range flip-flop *16*, range marker pulse oscillator *17*, range kon"yunktor *18*, range coordinate read-out block *19*, horizontal marker position determination block *20*, block *21* which converts angular movement of the control into a code, manual tracking control *22*, matching block *23*, computer *24*, code switching block *25*, and manual tracking block *26*.

Before the trainer is placed into operation, the program for the target trajectory and interference is fed into the computer's main memory.

After the trainer is turned on, a zebra-striped display is created on indicator screen *1* by blocks *2* and *3*, which form the angular sweep and the range sweep.

The position of the scanning sector of the indicator screen is synchronized with the position of the antenna system by blocks *8* and *9*, which correspondingly form the sector scanning start and end pulses. These blocks are rigidly joined to antenna system simulation block *6*. Controlling antenna system simulation block *6* by control *7*, the operator moves the scanning sector's boundaries, which are indicated by scanning sector start (SSP) and end (SEP) pulses, generated by blocks *8* and *9*.

One of the possible variants of the scanning sector start and end pulse formation systems is shown in Figure 41.

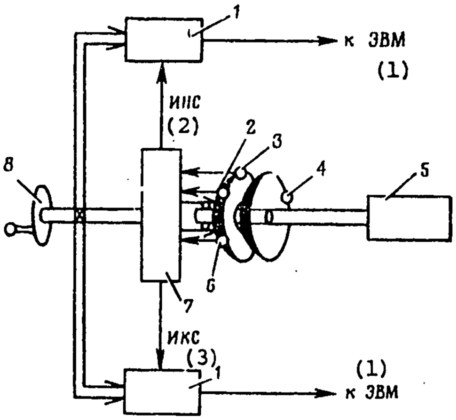


Figure 41. Principle of Measuring Scanning Sector Boundary Coordinates: *1*--rotation angle-code converter; *2*--scanning sector bisector sensor; *3*--scanning sector start sensor; *4*--magnet; *5*--electric motor; *6*--scanning sector end sensor; *7*--current collector; *8*--control

Key:

1. To computer
2. Scanning sector start pulse
3. Scanning sector end pulse

A disc with a magnet mounted on it is rigidly secured to the axle of the electric motor, which rotates at a constant speed. Opposite this disc and mounted coaxially with it is another disc, on which three sensors are mounted: scanning sector start and end sensors, and a scanning sector bisector sensor. The axle of the second disc, upon which the current controller is mounted, is rigidly connected to the scanning sector movement control.

When the disc with the permanent magnet is turned by the electric motor, scanning sector start , scanning sector bisector, and scanning sector end pulses are formed successively in the sensors before the second disc.

Two systems converting rotation angles into a code determine the coordinates of the scanning sector boundaries. The readings of one of them correspond to the position of the scanning sector's left boundary while the readings of the second correspond to the position of the scanning sector's right boundary. When sector scanning begins, a pulse formed by the scanning sector sensor passes through the current collector to the rotation angle-code converter, and the converter's readings are transmitted to the computer's input register. In similar fashion, at the end of sector scanning a pulse formed by the scanning sector end sensor passes through the second rotation angle-code converter, and the coordinates of the scanning sector are once again transmitted to the computer's input register. A pulse defining the location of the scanning sector bisector passes through the current collector through the vertical marker formation block.

Scanning sector start pulses start up angular sweep formation block *2* (Figure 40), while scanning sector end pulses return it to its initial state. Inasmuch as the repetition frequency of scanning sector start and end pulses is 16-24 Hz, an angular sweep is formed on the indicator screen. The range sweep is created on the indicator screen by range sweep formation block *3*, which in turn produces range sweep start (RSSP's) and end (RSEP's) pulses.

In order that the target blips would appear on the indicator screen only after their coordinates are within or on the boundary of the scanning sector, the scanning sector left and right boundary coordinate measuring blocks, which are connected to scanning sector start and end pulse formation blocks *8* and *9*, and to antenna simulation block *6*, record the absolute coordinates of the left and right boundaries of the scanning sector, which are read by computer *24*.

Coordinates within the scanning sector are determined more precisely by block *15*, which reads the angular coordinates within the scanning sector, and by block *19*, which reads the range coordinates.

With this purpose the training sector start and end pulses are transmitted to control flip-flop *13*, which, upon arrival of a sector scanning start pulse, opens the angular coordinate read-out kon"yunktor which connects range sweep formation block *3* to block *15*, which reads the angular coordinates within the scanning sector, and when a scanning sector end pulse arrives, it closes the kon"yunktor.

Thus the readings of block *15*, which records every angular coordinate within the scanning sector, are fed to the computer.

Moreover RSSP's formed by block *3* are fed to range flip-flop *16*, which, upon arrival of an RSSP, opens range coordinate read-out kon"yunktor *18*, connecting the output of range marker pulse oscillator *17* to range coordinate read-out block *19*, and when an RSEP arrives, it closes it. Every range sweep is broken up into discrete intervals by range marker pulses, and at every moment in time, coordinate Д is recorded by range coordinate read-out block *19*, the readings of which are fed into the computer.

The computer controls simulation of target and interference blips on the indicator screen. For this purpose when a scanning sector start pulse reaches the computer, the latter switches to a subroutine interrogating the readings of scanning sector left and right boundary coordinate measuring blocks *10* and *11*, and compares their readings with the current coordinates of targets and interference, stored in the computer memory.

As soon as the operator changes the angular position of the antenna by control *7* in such a fashion that the target and interference coordinates stored in the computer memory are within the scanning sector, the computer switches to its second subroutine, interrogating the readings of block *15*, which reads angular coordinates within the scanning sector, and compares them with the target and interference angular coordinates stored in the computer memory.

As soon as these readings are equal to the coordinates of some particular target or interference source, the computer switches to a third subroutine interrogating range coordinate read-out block *19* and comparing its readings with the range coordinate of the simulated target or interference source. When the latter are equal, the computer feeds a signal to matching block *23*, causing the first pulse from the target or interference source to appear on the range sweep. Inasmuch as the number of pulses received by the guidance radar station from a target pulse train is random and depends on the scanning rate and the breadth of the antenna's beam pattern, the concrete value of the target or interference pulse chain width is picked by the computer program in accordance with the concrete tactical situation being simulated.

To simulate target pulses following the first (k-1) pulses, the computer generates, on k successive range sweep lines, another (k-1) times, a signal turning on the target or interference pulse range sweep at the moment the current values of the target or interference range are equal to the readings of range coordinate read-out block *19*.

Vertical and horizontal markers are formed on the indicator screen to simulate lock-on of tracking systems to the target in relation to angular coordinates (bearing) and range.

The vertical marker is formed by illuminating the mid-line of the range sweep, which corresponds to the position of the scanning sector bisector and divides the scanning sector of the antenna in half. For this purpose block *12* (Figure 40), which forms scanning sector bisector pulses, generates a pulse that passes to vertical marker formation block *4* at the moment the antenna's beam pattern aligns itself with the middle of the scanning sector (when the disc bearing the magnets is opposite the scanning sector bisector sensor, Figure 41). Block *4* illuminates one of the range sweep lines.

One of the possible variants of the vertical marker formation block is shown in Figure 42.

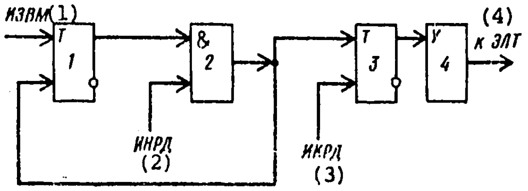


Figure 42. Flow Chart of a Vertical Marker Formation Block

Key:
1. VMSP
2. RSSP
3. RSEP
4. To CRT

The vertical marker start pulse (VMSP) generated by the scanning sector bisector sensor is transmitted to the input of delay flip-flop *1*, setting it in its unit state. The need for a delay flip-flop stems from the fact that because there is no synchrony between scanning sector start pulses and range sweep start pulses, the vertical marker start pulse may appear at any moment during formation of the range sweep. The delay flip-flop delays the vertical marker start pulse until the next range sweep start pulse arrives.

Switching to its unit state, delay flip-flop *1* opens kon"yunktor *2*, to the other input of which range sweep start pulses are constantly fed. The first RSSP following the VMSP passes through kon"yunktor *2* to the input of lighting flip-flop *3*, switching it to its unit state; this pulse simultaneously passes to the input of delay flip-flop *1*, returning it to its initial state.

The high potential picked off from lighting flip-flop *3* is fed through amplifier *4* to the controlling electrode of the CRT, illuminating one of the range sweeps. At the end of the forward trace of the range sweep the range sweep end pulse passes through the zero input of lighting flip-flop *3*, returning it to its initial state and thus shutting off the lighting voltage.

The horizontal marker is formed by block *20* (Figure 40), which determines the position of the horizontal marker. The value of the current coordinate of the CRT's beam position is fed to one input of this block from range coordinate read-out block *19*, while the other receives either the coded value of the position of manual tracking control *22*, formed by block *21*, which converts angular movement of the control into a code, or the coded value of the target velocity from the computer.

Horizontal marker position determination block *20* compares the coded value of the current coordinate of the CRT's beam position with the coded value of the angular position of manual tracking control *22*, or the target velocity, and at the moment of their equality it triggers horizontal marker formation block *5*, which produces a lighting pulse that proceeds to the cathode of indicator *1*'s CRT. Inasmuch as this comparison is made in relation to every bearing sweep line, the succession of lighting signals forms a horizontal marker, which may move across the display screen as manual tracking control *22* is rotated.

When an operator is working with the trainer, first he searches for a target, for which purpose he moves the scanning sector by moving scanning sector angular control *7*, until such time that a target blip appears on the screen. The operator's task is to set the position of the scanning sector in such a way that the vertical marker would divide the target marker in half. Then, moving manual tracking control *22*, the operator superimposes the horizontal marker over the target blip in such a way that the target blip would be at the intersection between the vertical and horizontal markers. After this the operator presses a button which turns on manual tracking block *26*.

At this moment code switching block *25* disconnects block *21*, which converts angular movements of the control into code, from block *20*, which determines the position of the horizontal marker, connecting the latter directly to the computer. A code proportional to the rotation rate of control *22* passes through manual tracking block *26* to the computer, where it is transformed by a special subroutine into a code proportional to the target's velocity; then the code is transmitted through code switching block *25* to horizontal marker position determination block *20*.

Thus by correctly selecting the rotation rates of controls *7* and *22*, the operator is able to keep the target blips continuously superimposed over the intersection of the horizontal and vertical markers.

The flow chart for the algorithm simulating target and interference blips on a guidance indicator screen in shown in Figure 43.

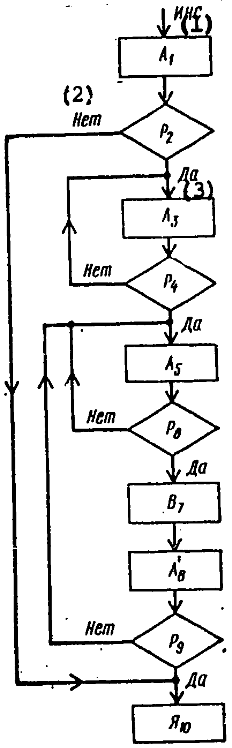


Figure 43. Flow Chart of an Algorithm Simulating Interference and Target Blips on a Guidance Indicator Screen

Key:

1. Scanning sector start pulse
2. No
3. Yes

The algorithm begins with operator A_1, which interrogates the readings of the left and right scanning sector boundary coordinate measuring blocks at the moment a scanning sector start pulse reaches the computer. Logic operator P_2 compares the readings of the scanning sector boundary coordinate measuring block with the closest values of the target bearing coordinates, stored in the computer's main memory. If logic operator $P_2 = 0$--that is, if the target and interference bearing coordinates lie within the scanning sector boundaries, control is transferred to stop operator $Я_{10}$. Otherwise control is transferred to operator A_3, which interrogates block *15* (Figure 40), which reads angular coordinates within the scanning sector. If logic operator $P_4 = 0$--that is, the target and interference angular coordinates do not correspond to the readings of block *15*, control is once again transferred to operator A_3. But if $P_4 = 1$, control is transferred to operator A_5, which interrogates range coordinate read-out block *19*.

Logic operator P_6 compares the readings of the range coordinate read-out block with the closest range coordinate value recorded for the given bearing and stored in the main memory of the computer. If logic operator $P_6 = 0$, control is transferred to operator A_5, which once again interrogates the range coordinate read-out block, setting its reading at a new position.

As soon as the readings of range coordinate read-out block *19* correspond to the total range coordinates--that is, when $P_6 = 1$, control is transferred to operator B_7. The latter forms and transmits a target pulse to the CRT modulator of indicator *1*. In addition operator B_7 transfers control to operator A_8, which counts the number of pulses produced by operator B_7.

Logic operator P_9 compares the number of target pulses transmitted to the indicator's CRT modulator with a constant defining the width of the pulse train. If logic operator $P_9 = 0$, control is transferred to operator A_5 which, together with operators P_5 and B_6, once again forms and transmits the next target pulse. When the number of pulses generated by operator B_7 is equal to the number of pulses defined by the constant, condition $P_9 = 1$ is satisfied, and control is transferred to stop operator $Я_{10}$.

Operator errors are recorded by an operator work precision evaluation program: After target blips are produced on the indicator screen, the angular coordinate and range coordinate of the target are compared with the positions of the vertical and horizontal markers. If the target blip is not at the intersection of the horizontal and vertical markers, a subroutine registers the angular deviation of the target blip from the vertical marker, and its range deviation from the horizontal marker. Concurrently the computer also registers the times at which these deviations were detected.

When the operator finishes work with the trainer, the computer prints out the precision characteristics of the operator's work, in real time.

TEACHING TECHNIQUES APPLIED TO OPERATORS USING TRAINERS

The Techniques of Stage-by-Stage Formation of Actions and Concepts

The theory of stage-by-stage formation of actions and concepts permits us to digress from the traditional forms of training, in which the future specialist is first presented the knowledge he requires, and then he engages in real actions. According to the theory of stage-by-stage formation, training begins not with communicating preliminary knowledge and actions to the student , but rather with furnishing him with an action fundamentals orientation chart--an AFO chart, also called a test card, bearing specific instructions, drawings, graphs, and so on. It indicates the sequence and content of all operations associated with the action the operator is assimilating. Such a chart (test card) must include elements that would account for psychological difficulties encountered by the students.

Using a test card, the student can immediately perform a previously unknown action correctly (though slowly). All directions helping the student to correctly perform an action are involuntarily memorized, together with a large volume of the most diverse information necessary for the performance of this action. Thus the stage in which the student must intentionally learn the material is excluded. As a consequence of this, as well as due to immediate formation of the correct skills and exclusion of unnecessary trials, errors, and the associated loss of time, the duration of the course of instruction decreases significantly as well. As the students assimilate the necessary information, the instructor gradually reduces the number of external cues, and he controls the instruction process in such a way that information contained on the action fundamentals orientation chart would gradually transform into the corresponding knowledge of a new action.

When actions are formed in this manner, qualities the student needs, such as wisdom, flexibility, the ability to make generalizations, and consciousness, permitting him to act correctly in diverse conditions, are developed through proper selection and change of the initial material--that is, those tasks which assist in formation of a new action.

The basic provisions of the theory of stage-by-stage formation were tested out in many units, to include the Order of Lenin Moscow Antiaircraft District, in which radar operator training was organized in such a fashion that the students performed all of the actions associated with inspecting, turning on, and testing a station, as well as of detecting targets, both with and without interference, from the very beginning of training, slowly but without mistakes (18). Error-free actions were insured by slow,

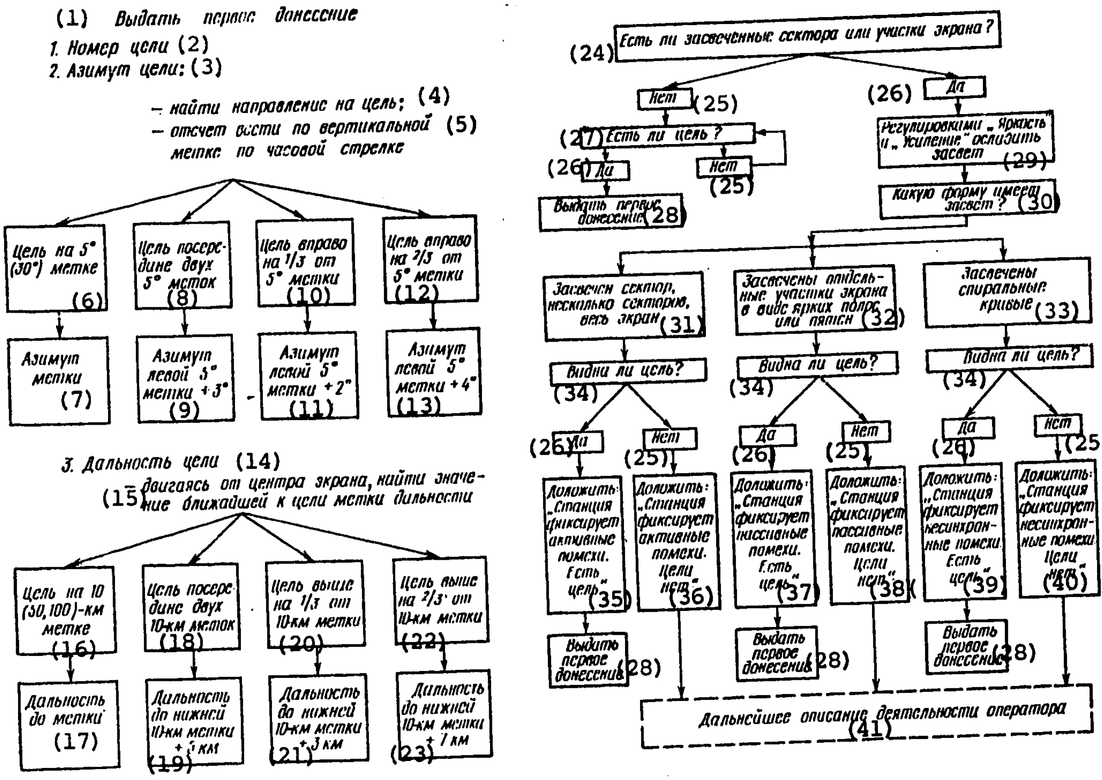


Figure 44. Principle of Organization of a Test Card Used to Teach Radar Operators the Actions of Target Detection

Key:

1. Make initial report
2. Target number
3. Target bearing
4. Find direction to target
5. Read the values on the vertical marker, clockwise
6. Target on 5° (30°) marker
7. Bearing of marker
8. Target midway between two 5° markers
9. Bearing of left 5° marker, +3°
10. Target to right of 5° marker and 1/3 away from it
11. Bearing of left 5° marker, +2°
12. Target to right of 5° marker and 2/3 away from it
13. Bearing of left 5° marker, +4°
14. Target range
15. Moving from center of screen, find range marker closest to target
16. Target on 10 (50,100) km marker
17. Range to marker
18. Target midway between two 10 km markers
19. Range to lower 10 km marker, +5 km
20. Target 1/3 above 10 km marker

[key continued on following page]

21. Range to lower 10 km marker, +3 km
22. Target 2/3 above 10 km marker
23. Range to lower 10 km marker, +7 km
24. Are there illuminated areas or sectors on the screen?
25. No
26. Yes
27. Is a target present?
28. Make initial report
29. Reduce illumination by "Brightness" and "Gain" adjustments
30. What is the shape of the illuminated area?
31. Sector, several sectors, entire screen illuminated
32. Individual areas of the screen illuminated in the form of bright bands or spots
33. Spiral curves illuminated
34. Is target visible?
35. Report: "Station being jammed. Target present"
36. Report: "Station being jammed. Target absent"
37. Report: "Station receiving interference. Target present"
38. Report: "Station receiving interference. Target absent"
39. Report: "Station receiving asynchronous interference. Target present"
40. Report: "Station receiving asynchronous interference. Target absent"
41. See subsequent description of operator activity

successive, step-by-step performance of all operations, with reliance upon the action fundamentals orientation chart.

The AFO chart (test card) places emphasis on the logic of an operator's work. This permits the students to assimilate not only the individual operation contained in activity that is new to them, but also the general principles of its structure.

For example by performing the operations of target detection and tracking, the operator may find himself working both in the absence and in the presence of interference. Therefore the action fundamentals orientation chart must allow the young operator to organize his activities in all situations that may arise at one time or another. In this case the individual elements (branches) of this chart would contain descriptions of successive operations, a complete set of cues for each of these operations, and a system of directions defining how and in what order he is to follow these branches, and how he is to perform each operation.

As with the entire chart as a whole, the individual branches of the chart are set up in such a way that the student would correctly perform each operation as he progresses from one direction to the next, slowly at first (but correctly at the first try!).

The principle of organization of such a chart (test card) is shown in Figure 44. Certain elements of this test card may be made more specific. What we are attempting to show here is only the general principle of organization of an action fundamentals orientation chart, and the way the activity of students may be organized on its basis; this figure also shows the sequence of actions taken by an operator in making his initial report.

Another example of a test card prepared for a lesson in which the student learns to tune the PPI of a P-10 radar station is shown below.

These are the meanings of the symbols employed:

↓ --do perform this operation, and go on to the next;

→Д--do not perform this operation, and report to the instructor (lesson leader);

→ -- independently perform the operations listed in the text.

Test Card for Plan Position Indicator Tuning

1. Set operating mode switch at ECHO + SCALE.

↓

2. Did a narrow, sharp sweep line appear?

↓ → Turn brightness and focus knobs to make sweep line narrow and sharp.

3. Is the start of the sweep precisely at the center of the indicator screen?

↓ → Turning splines marked Center, Vertical, Horizontal, set the origin of the sweep precisely at the center of the screen, so that it aligns with the hole in the center of the graphic scale.

4. Is the image on the indicator screen sharp?

↓ → Set the CONTRAST-OFF tumbler switch at its CONTRAST position, and the mode switch in its ECHO + INTERROGATION position to improve the visibility of signals on the background of terrain features (interference).

5. Is the sweep brightness too high?

↓ → Turning the BRIGHTNESS knob, reduce the sweep brightness to where it is barely visible.

6. Set the GAIN knob at its far right position.

↓

7. Is the image on the screen of normal brightness?

↓ → Turning the spline marked BRIGHTNESS LEVEL, set the required image brightness.

8. Set the mode switch at its SCALE POSITION, and set the scale switch at position 100.

↓

9. Does the second scale marker align with the 10 km division of the graphic scale?

↓ → Turning the spline marked START-100, line up the second scale marker with the 10 km division.

10. Is the 10th marker aligned with the 100 km division on the graphic scale?

→ Turning the spline marked END-100, align the 10th marker with the 100 km division on the graphic scale.

It may appear at first glance that the actions are in a sense made more complex, more cumbersome. But this is only a first impression. In fact, this scheme permits us to organize the training in such a way that a young soldier would be able to perform the appropriate tasks right away, and without mistakes. This is simply a qualitative alteration of the process for forming a needed action.

In order to simulate assimilation of the content of an action by the students, after a certain amount of time (extremely short) the test card is substituted by an abbreviated one. Later on, the operator will be able to work without relying on test cards, since owing to organization of activity in this way, he will quickly assimilate all elements of the test cards.

When working with the test cards, and in his first attempts at working without them, the operator must talk out his actions aloud, laying emphasis in his speech on the significant factors and basic conditions leading to correct performance of the required action. Such verbal accompaniment allows the student to develop conscious performance of each action, with a complete understanding of all of its features and circumstances, and to gradually dispense with external cues provided by the lesson leader, such as the AFO charts, gradually as the actions are assimilated.

As the actions are assimilated, the student progresses to fast and abbreviated mental rehearsal of the individual operations--that is, he mentally recalls what he must do next. Then he begins to mentally rehearse larger operations consisting of several smaller ones. After a while, the need for such rehearsals disappears. From this moment on, the particular action in a sense becomes automatic. Now the operator works silently, and he reports only those data that are required by the appropriate documents. It may be said that this basically ends formation of a new action. What comes next is improvement of the new action in terms of its speed.

Thus while in traditional instruction the operator acts on the basis of knowledge he had acquired earlier, in this case he does not learn the knowledge beforehand, instead receiving it in the form of cues or directions (test cards) explaining what he must do. The operator reads these directions aloud, and then he performs the necessary actions.

It should be noted, however, that if the young operator forms the habits of radar control in relation to some unchanging conditions (constant weather conditions, the same types of targets, and so on), were a change in these conditions to occur, the operator would once again find himself in an unfamiliar situation. In this case his actions would unwittingly slow down, because the operator would not be able to immediately distinguish the concrete ways in which the new situation differs from the customary one, what sort of operation could be carried over from the previous situation to the new one, which operations require some adjustment, and so on.

Therefore, from the very beginning of training, the radar operator must be placed in conditions that would compel him to work in different sectors of the screen, both in the absence and in the presence of interference, while tracking different types of targets, and so on. The possibility of such work is guaranteed by the AFO chart, which permits us to conduct the training not according to the principle of going from the simple to the complex, as is required by traditional didactics, but rather according to the principle of contrast, where tasks of varying difficulty are performed from the very beginning, with simple tasks alternating with complex ones. This promotes maintenance of high student efficiency, raises interest in the training, and keeps the training challenging.

It need not be feared that formation of an action at the very beginning of training in a broad range of conditions is a slow process in such training. The benefits of this approach will appear later on, as the actions are improved and practically utilized.

Comparative data obtained in military units show that this method significantly reduces the time to form the knowledge and habits required of radar operators, beginning with turning on the station and ending with complete control of its functions, and with mastery of target tracking habits equivalent in proficiency to that of a specialist 3d class. In this case half of the training time is used up with detailed test cards, and 30 percent is devoted to abbreviated test cards. The time required to make young soldiers ready for combat crews is decreased by a factor of 1.5-2.

In this method, the role of junior commanders in subordinate training rises significantly, and control over specialist training by commanders and chiefs of all ranks improves. They may determine, at any moment, objectively, and with the least expenditure of time, how well training is proceeding with detailed and abbreviated test cards, reveal the causes of shortcomings, and take efficient steps to eliminate them.

Moreover this method raises the possibilities for individual training right at the workplaces. It is effective in subunits containing individuals in many different specialties. In this case, properly organized independent training reduces, by several times, the amount of training time required to restore the habits of combat duty lost by operators for various reasons.

Training by this method may be performed anywhere: in radio engineering subunits and at training centers; by the group method in training subunits, and individually right with the real radar stations and automatic control systems.

The Unique Features of Instruction Using Trainers

The forms of instruction examined here have one more advantage. The psychological techniques embodied within the test cards for performing the actions of detecting and tracking airborne targets, to include low-altitude targets, permit the use of simulators and trainers to teach the operators.

Practical training with trainers is as a rule preceded by theoretical instructions and demonstration of the work by experienced operators. The training begins with development of sensomotor culture--the operator's functional background. An operator's sensomotor culture is defined as his capability for implementing an adopted decision that may be expressed in the form of a simple sensomotor reaction, a complex sensomotor reaction, and sensomotor coordination.

A simple sensomotor reaction is an operator's fastest possible response to a suddenly arising but previously known signal with a known, simple, solitary movement. All other reactions are complex. Typical complex reactions are: the discrimination reaction (a certain movement must be made in response to one signal, and no movement is made in response to others), the choice reaction (selection of a needed movement out of a large number of possible movements), and the switching reaction (selecting one of several buttons to be pressed in response to a particular signal).

After sensomotor culture is developed, individual procedures are practiced operation by operation, gradually going on to complexes of actions. The student should progress to complexes of action before he forms sound habits associated wtih the performance of individual procedures.

In each stage of training, only those elements of the aerial situation model which the operator requires for the performance of a given procedure are used.

Each complex action is practiced as follows:

The instructor (lesson leader) provides a complete description of the place and significance of the given operation within the overall process of target detection and tracking;

the instructor performs the indicated operation quickly, as would be required in real combat work;

the instructor repeats the entire operation slowly, explaining each action as he performs it;

the instructor once again performs the operation, but this time the student provides all of the explanations by answering the instructor's questions;

the student performs the operation, continually explaining what he is doing and what he intends to do further;

the student practices the given operation, and the instructor scores his performance of each element.

The exercise goes on until the student is able to complete the operation satisfactorily twice.

In the event gross errors arise, the instructor explains their causes, he demonstrates and explains how the student should act, he recreates the situation in which the mistake had been made, and he requires the student to repeat the exercise. Later on the instructor makes the work of the operator more complex by including interference and jamming on the trainer's indicator screen, by increasing the number of targets, and by introducing malfunctions, thus achieving error-free performance of all procedures by the operator.

Operator training ends with a critique. Using computer data obtained during the exercises and relying on his own observations, during the critique the instructor reaches his own conclusions about the successfulness of the students, he notes the errors, he states the objective for the next training exercise, and if certain mistakes were the result of ignorance of the theoretical material, he explains the latter.

Principles of Assessing Operator Training Level

The results of radar operator training must be summarized in accordance with certain training principles embodied within the trainer at the time of its design. Inasmuch as the trainers examined in this book are computerized, they do not impose any sort of restrictions on the nature of the habits that may be developed by the operators. The reason for this is that a computer can run any operator training algorithm.

The overall assessment of the training level of a radar operator and an automated control system operator is the sum of the partial scores awarded for the following stages of the operator's activity:

theoretical knowledge;

knowledge of the rules, instructions, and manuals regulating operator activity in different situations;

the ability to perform individual procedures and equipment maintenance operations in allotted time;

the ability to practically apply acquired knowledge.

Thus an operator's activity may be represented either as a single process following a certain algorithm, or as a set of several procedures and actions. In the first case we would need to award an overall score, and in the second we would have to award partial scores to the individual procedures and operations.

Partial scores must be awarded to operator habits and skills because only this way can we promptly single out and eliminate concrete mistakes influencing the activity as a whole, and preclude reinforcement of incorrect habits.

Finally, this approach is well consistent with the requirements of the operational-integral method of training: At the beginning of training, when individual procedures are being worked out, each of them must be scored separately, and in subsequent stages of the training it would be suitable to score the performance of a number of mutually associated procedures, or the operator's entire activity as a whole.

The following techniques can be recommended for assessing the activity of an operator working with a computerized trainer.

We write out a detailed description of the behavior of a certain ideal operator, using perhaps a master operator of the radio engineering troops, or an operator 1st class as our model. Each step in the activity of a student undergoing training is compared with the behavior of the ideal operator. For this purpose we write a mathematical description of the order of actions of the ideal operator, and feed this description into the computer in the form of a program.

In the course of training, the computer also follows the actions of the student operator, step by step. Assessing the behavior of the student operator, the computer records mistakes and deviations in his actions from the actions of the ideal operator, and in addition it considers the time required to run the algorithm.

In this case the algorithm is defined as a set of elementary information processing acts, and selected logical conditions defining an order of performance of these acts which would lead to the particular objective--complete processing of the information.

Let us illustrate the above with the actions of a radar operator detecting and tracking targets with the assistance of a marker.

We arbitrarily divide the operator's responsibilities into elementary operations-actions A and logic conditions P, which we arrange in the following sequence:

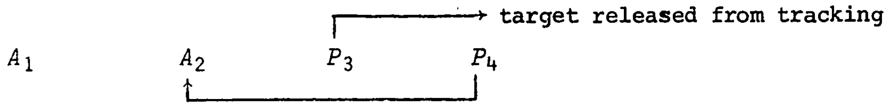
A_1--detection of a target blip on the indicator screen;

A_2--superimposition of the marker over the target blip, and attachment of a serial number to the blip;

P_3--determination of this blip's presence in the next radar scan;

P_4--determination of the coincidence of the target blip and the marker position.

The pattern of operations in the algorithm has the following form:



The terms of the algorithm function in succession, from left to right. In this case if a successive logical condition is not satisfied, the operator must proceed in the order indicated by the arrow.

Operations performed by an ideal operator are thus represented in the form of such a formalized algorithm, which is then recorded in the computer memory, together with the amount of time set aside for the performance of these operations.

The number of operations and logical conditions may reach in the hundreds for an algorithm of moderate complexity. Study of the algorithms of a human operator's action would allow us to evaluate the relative complexity of his responsibilities, and isolate, for individual study, the portions of the algorithms that are the hardest to assimilate.

An algorithm of the activity of radar and automated control system operators is commonly assessed on the basis of intensity, stereotypy, and logical complexity.

Intensity depends on the ratio of the number of operations in the given algorithm to the time allowed for the algorithm.

Stereotypy depends on the number of continuous sequences of operations in the algorithm, and the length of each of these sequences.

Logical complexity is defined by the number of portions of the algorithm containing a continuous sequence of logical conditions, and the number of these conditions in each group.

The more intense the algorithm and the greater its logical complexity, the harder it is to perform. It has been established that those elements of an algorithm which contain a continuous succession of three conditions and more are the most difficult for the operator.

The activity of radar and automated control system operators improves through lengthy and systematic training:

Confusion of similar operations is gradually eliminated;

the time required by the operator to perform the procedures of target detection and tracking decreases and becomes more stable;

elementary habits become grouped together, merging into habits of a higher order;

extra motions are eliminated, and new combinations of motions arise. Visual control over the correctness of motions disappears;

operators concentrate their attention not on the performance of an action, but on its result;

resistance to outside interference arises, tiring and tension decrease, and attention becomes less concentrated.

These factors must be accounted for when evaluating an operator's training level. A direct scoring method is the most suited to the purposes of troop practice. In this method we score the precision and correctness of each procedure or decision of the operators. Experience has shown that a large number of alternative actions and decisions made by radar operators (of the "yes-no" type) may be described exhaustively by "right" or "wrong" scores (with a consideration for the time required to complete them).

The concrete meaning of "action precision" depends on the nature of the given action. The following can be thought of as typical actions of radar and automated control system operators:

a) Reading target blips off of an electronic indicator (blip classification);

b) Isolating a useful signal from noise on an electronic indicator;

c) determining the coordinates of target blips on an indicator screen, with and without auxiliary viewing instruments;

d) reacting to a previously known signal (turning on a required tumbler switch);

e) continuous output of generated data by means of a control stick;

f) discrete output of command information with the assistance of keys, tumbler switches, switches, and so on;

g) tracking a target (superimposing a marker over the return from a moving target);

h) oral reports, commands.

These examples show that the whole typical list of operator actions may be subdivided into three groups depending on the possibilities for automating their assessment.

The first group of habits (a, b, f, g) can in fact be fully described as to the correctness of their execution, inasmuch as these are alternative "yes-no" reactions.

The second group of habits (c, e) may be assessed in terms of the accuracy of their execution--the size of the error made, expressed quantitatively as the difference between the true value of the variable to be determined and the value determined by the operator.

Assessment of the actions in the third group (target tracking for example) requires development of a complex mathematical model, one which is run most easily in computerized trainers.

Mathematical Methods for Assessing Operator Training Level

In cybernetics, we equate man to a complex information system, the activity of which is influenced by many psychological and physiological factors that are hard to account for. Therefore each realization of an action or procedure by the individual is a random event, and in accordance with probability theory, the scores of the results would be random.

If we assume that the quantity of elementary factors influencing the score of operator activity is large, and that the role of each of them in forming a random error is small, then the random error should have a normal distribution.

If a developed habit is to be scored correctly, we would need to subject the results of operator training to statistical treatment, which would require a large volume of calculations. Therefore if we are to score an operator's actions immediately after a training session, we would need to automate these calculations. Such automation is achieved most simply in computerized trainers which record all characteristics of operator activity in the course of training, and display a score for the operator's activity after the training is completed.

Mathematical methods for assessing an operator's training level permit us to objectively describe the quality of the training, and compare different operators among each other. In practice, we often encounter difficulties in determining which operator is best, if they are all able to perform their work-related actions within standard time. How, for example, do we compare operators whose performance just barely satisfies the standard, when one of them must be evaluated on the basis of operation fulfillment time, and the other must be evaluated in terms of the accuracy with which nominal values of a parameter are set?

Finally, how do we evaluate the success of an operator who decides to become an operator 3d class and challenges, to a competition, another operator intending to become an operator 1st class? Assuming both operators meet the challenge, how do we determine which has a better grasp of his specialty, relative to the proficiency required of his class?

One of the most widespread methods for evaluating operator work quality is to calculate the standard deviation, which describes the scatter of concrete results about a mean. We can use it to evaluate the stability of the achieved level: The smaller the standard deviation, the more stably the specialist or crew is working (4). It would not be difficult to calculate this standard deviation if we know the results of the actions of the operator, and the quality of these operators. Then we can find the average result M, and use it to calculate the standard deviation:

$$\sigma = \sqrt{\frac{(M_1 - M)^2 + (M_2 - M)^2 + \cdots + (M_n - M)^2}{n}},$$

where $M_1, M_2, \ldots, M_n$--individual results of the operator; n--number of results; M--average result .

It would be more difficult to compare the characteristics of operators when they are measured in different units, for example volts and seconds.

The solution to this situation is provided by the variation coefficient C, which is used to compare either different characteristics or identical characteristics, the only condition being that the standard deviations must be significantly different:

$$C = \frac{\sigma}{M}.$$

The value of this coefficient is lower for operators who work more stably relative to the average results.

We can compare operators exhibiting different levels of training by using a special normalized deviation coefficient, χ.

This coefficient is calculated on the basis of known standard requirements for the mean M_H and standard deviation σ_H:

$$\chi = \frac{M_H - M}{\sigma_H}.$$

Knowing the requirements imposed on specialists of the particular class, it would not be difficult to establish that the lower the value of the normalized deviation coefficient, the better are the characteristics attained by the students (4).

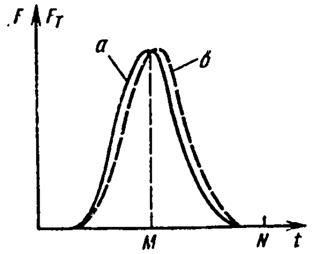


Figure 45. Actual (*a*) and Theoretical (*b*) Distribution of the Results of an Incorrect Training Technique

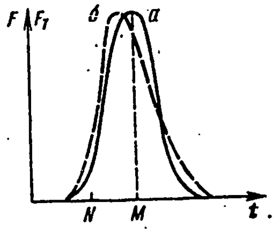


Figure 46. Actual (*a*) and Theoretical (*b*) Distribution of the Results of a Correct Training Technique

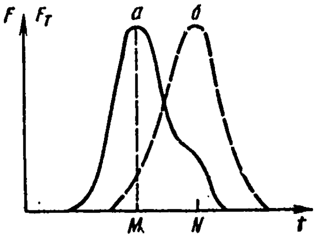


Figure 47. Actual (*a*) and Theoretical (*b*) Distribution of the Best Possible Results

By applying the normal distribution law to the training results, we can reveal whether or not the training process is correctly organized. Let us examine, for example, the case shown in Figure 45, where the horizontal axis represents the average result *M* and the standard characteristic *N*. This mutual location of the actual (*a*) and theoretical (*b*) curves appears when mistakes are made in the work or when the training technique is incorrect.

In another case (Figure 46) the actual and theoretical curves coincide. This means that instruction is proceeding normally, there are no gross errors in work, and the quantity of training sessions should be increased to permit attainment of the standard result.

In the third case (Figure 47) we find that the students have reached the limit of their possibilities. Further growth in the characteristics would be possible only if the work is organized in some other way, for example by redistributing functional responsibilities among the crew members, or changing the sequence of elementary operations.

We can also use the law of rare phenomena and the binomial law in addition to the normal distribution to analyze training.

The law of rare phenomena allows us to establish whether or not mistakes made in the work are a rare event arising owing to objective , to a certain extent unavoidable causes, or due to subjective causes which may be eliminated.

The binomial distribution law is used to analyze so-called alternative events. These are events with only two outcomes possible: One pleases us, and the other does not. For example a crew may either satisfy a standard, or fail it. If training proceeds normally, then the distribution of failures would be subordinated to a binomial law.

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Technical training resources--trainers, simulators, visual aids, classroom equipment, and so on--play an important role in maintaining high combat readiness in the troops. With their help, soldiers study the theoretical principles of the design and operation of modern combat equipment, and they acquire the necessary practical habits of its use, in combat and in the course of daily operation. Broad introduction of simulators and trainers is also significantly promoting economization of the life of combat equipment.

As armament becomes more complex, the existing technical training resources must be constantly updated and improved, and new models must be created. Efficiency experts play a large role in the creation of such equipment. They, the specialists who come into direct content with the combat equipment, and use it, are precisely the ones who must design new, more sophisticated technical training resources.

BIBLIOGRAPHY

1. Anisimov, B. V., and Chetverikov, V. N., "Preobrazovaniye informatsii dlya ETsVM" [Conversion of Information for a Digital Computer], Moscow, Izd-vo "Vysshaya shkola", 1968.

2. Belotserkovskiy, G. B., "Osnovy impul'snoy tekhniki i radiolokatsii" [Principles of Pulse Technology and Radar], Leningrad, Izd-vo "Sudostroyeniye", 1965.

3. Buslenko, N. P., "Modelirovaniye slozhnykh sistem" [Modeling Complex Systems], Moscow, Izd-vo "Nauka", 1968.

4. Grebennikov, N. I., "Innovators in the National Air Defense Forces, and Improvement of Technical Training Resources," VESTNIK PVO, No 8, 1975.

5. Kazarinov, Yu. M., et al., "Radiotekhnicheskiye sistemy" [Radio Engineering Systems], Moscow, Izd-vo "Sovetskoye radio", 1968.

6. Kuz'min, S. V., "Osnovy teorii tsifrovoy obrabotki radiolokatsionnoy informatsii" [Principles of the Theory of Digital Radar Information Processing], Moscow, Izd-vo "Sovetskoye radio", 1974.

7. Likharev, V. A., "Tsifrovyye metody i ustroystva v radiolokatsii" [Digital Methods and Devices in Radar], Moscow, Izd-vo "Sovetskoye radio", 1973.

8. Listov, K. M., and Trofimov, K. N., "Radio i radiolokatsionnaya tekhnika i ikh primeneniye" [Radio and Radar Equipment, and Its Application], Moscow, Voyenizdat, 1960.

9. Maydel'man, I. N., et al., "Otobrazheniye informatsii v avtomatizirovannykh sistemakh upravleniya" [Display of Information in Automated Control Systems], Moscow, Izd-vo "Sovetskoye radio", 1972.

10. Rall', V. Yu., et al., "Trenazhery i imitatory VMF" [Naval Trainers and Simulators], Moscow, Voyenizdat, 1969.

11. Romanov, A. N., and Frolov, G. A., "The Criteria of Operator Occupational Selection," VESTNIK PVO, No 6, 1969.

12. Romanov, A. N., and Frolov, G. A., "Osnovy avtomatizatsii sistem upravleniya" [Principles of Automated Control Systems], Moscow, Voyenizdat, 1971.

13. Romanov, A. N., and Frolov, G. A., "Digital Computer Stimulates a Situation," TEKHNIKA I VOORUZHENIYE, No 10, 1973.

14. Romanov, A. N., "A Device for Simulating the Location of a Target in Space on an Indicator Screen," Author's Certificate No 417808, Bulletin No 8, 28 February 1974.

15. Romanov, A. N., "A Trainer for Operator Training," Author's Certificate No 479144, Bulletin No 28, 30 July 1975.

16. Romanov, A. N., "A Trainer for the Training and Instruction of Guidance Radar Operators," Author's Certificate No 525999, Bulletin No 31, 25 August 1976.

17. "Spravochnik po osnovam radiolokatsionnoy tekhniki" [Handbook on the Principles of Radar Technology], Moscow, Voyenizdat, 1967.

18. S"yedin, S. I., and Ivanov, A. A., "On the Basis of the Stage-by-Stage Formation Technique," VESTNIK PVO, No 4, 1975.

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