DESIGN SPECIFICATION FOR A

TERRAIN AVOIDANCE RADAR SYSTEM

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Submitted by:

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Air Arm Division
Baltimore, Maryland.

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SUMMARY

This specification describes a radar which functions as an aid in low altitude flight. A sector in space centered about the aircraft's projected flight path is presented in a three dimensional display. Azimuth and elevation are presented in true perspective. The third dimension, depth or range, is effected by presenting the picture in colors as a function of range. This is the basic display commonly referred to as a transverse profile or "X" Scope. An additional display is incorporated whose use is optional. This display presents a range vs elevation profile of the vertical plane containing the aircraft's flight path. This is commonly referred to as a profilometer or "E" Scope. As an added feature, this profile plane may be positioned at some angle in azimuth with respect to the vertical plane containing the aircraft's flight path to enable exploration in detail of terrain to either side of the flight path. The selected profile can be marked by a line on the transverse profile to enable correlation of the two displays.

Detailed specifications of the system are as follows:

ANTENNA CHARACTERISTICS

Antenna beamwidth:		
	Vertical	1°
	Horizontal	1.5°
Scan Sector:		
	Vertical	10°
	Horizontal	30°
Scan Rate:		
	Vertical	2/3 cps modified sinewave
	Horizontal	16.5 cps linear sawtooth
Drift Angle Stabilization:		To 15° from aircraft centerline in any direction (to correct for drift angle at any bank or roll angle).

TRANSMITTER CHARACTERISTICS

Magnetron Type:	MA-207
Frequency:	34,900 ± 350 MC
Power:	60KW (nominal)
Pulse Width	.25 microseconds
PRF	1365 pulses per second.

RECEIVER CHARACTERISTICS

System noise figure:	12.5 db
Receiver gain:	91 db
Receiver IF bandwidth:	4.2 MC
Klystron type:	Varian VA-97
Receiver Tuning:	Manual or AFC
Local Oscillator frequency:	45 MC above transmitter
Intermediate frequency:	45 MC
Range Gate:	
Minimum range	.25 ±.1 N. Miles
Maximum range	10 or 20 N. Miles, variable ± 25%.

INDICATOR CHARACTERISTICS

Presentation:	Azimuth vs elevation in 3 colors to represent range segments.
CRT Type:	RCA C73703B storage tube with selective erase gun.
Marks:	Aircraft's flight path Horizontal reference.

OPTIONAL PROFILE INDICATOR CHARACTERISTICS

Presentation:	Type C (Range vs Elevation).
CRT Type:	5 UP 7
Marks:	Cursor, 1000 ft. elevation marks. Electronic, 1 mile marks.
Weight:	Basic System 206 lbs. Optional navigators "X" and "C" Scopes 35 lbs.
Environmental Conditions:	$-55^{\circ}C$ to $+55^{\circ}C$ Altitude to 15,000 ft. operating Vibration per mil E-5400

SYSTEM CONSIDERATIONS

In a terrain avoidance radar it is desirable to have high scan rates and narrow antenna beamwidths from the system performance point of view. This involves large antennas which are aerodynamically undesirable and the larger the antenna, the more difficult it is to scan at high rates. These are not the basic limitations in this system, however. A certain minimum number of hits per beamwidth are required to insure detection of small targets. The product of beamwidth and scan rate or beamwidths scanned per second multiplied by the number of hits per beamwidth required determines the PRF. This is the basic limitation. Unless severe restrictions are placed on all three parameters the PRF is so high that, using the minimum pulse width which it is possible to generate with the magnetron, the average power rating of the magnetron is exceeded. Reducing the pulse power is not practical since this leads to difficulty with the magnetron not operating in the desired mode. Attempts along these lines with presently available magnetrons lead to a broad spectrum and unsatisfactory power output at best. Thus, it is necessary that resolution, scan rate and hits per beamwidth be no better than required. This is particularly true if the 6799 magnetron with a .0002 duty cycle is used. The MA-207 with a .0004 duty cycle will allow better resolution or scan rates but its peak power is only 70 KW maximum as compared to 200 KW maximum for the 6799 magnetron. These are the two highest power magnetrons presently available for K_a band. Due to the nature of the targets and the near grazing incidence angles, the return signals will be small. In addition the C Scope type presentation where noise is integrated over a long time or range interval requires a better signal to noise ratio than a radar system using narrow range gates. The minimum detectable signal is not determined by received power but by its ratio to the noise level. Since noise is a function of receiver bandwidth, it can be minimized by using a wide pulse. The PRF is determined by considerations of beamwidth, scan rates and number of hits per beamwidth so that it may be considered independent as far as signal to noise considerations are concerned. Thus the maximum usable pulse width is determined by the maximum power capability of the magnetron. The pulse width may be increased until the maximum permissable average power is dissipated in order to realize minimum receiver noise, assuming that the peak pulse power was made maximum to obtain maximum signal return. Any further increase in pulse width requires that the pulse power be decreased and the signal decreases so that the signal to noise ratio decreases. Thus the magnetron is a primary limitation in this system.

The question of resolution capability involves a compromise between practical antenna size and resolution desired. This resolves into a question of aircraft performance and minimum clearance above terrain obstacles the pilot would desire to maintain. The minimum clearance is determined by flight conditions, type of terrain, the individual pilot concerned and aircraft speed. This is displayed as an angular clearance. Range segments are identified by colors. Range is thus known accurately where the display changes color. If we choose red for the shortest (or most dangerous) range, the pilot must steer to keep all red targets below the aircraft. It is desirable to make the range below which this angular clearance is maintained the minimum consistent with safety. For a given aircraft and speed it is a function of the number of degrees an obstacle will be allowed to extend above the flight path in the preceeding range interval or display color. The minimum angular clearance is limited by antenna beamwidth or resolution. The shorter the range at which the desired absolute clearance can be steered for, the larger the clearance angle becomes and, the wider the permissable beamwidth becomes. For a given beamwidth, the shorter the range at which the desired clearance is maintained, the smaller the desired clearance may be. Two parameters, minimum clearance and maximum angle which an obstacle is allowed to extend above the flight path up to the point where minimum clearance is steered for, must be selected on the basis of expected aircraft performance. Once these are selected, the range at which minimum clearance is steered for can be determined on the basis of ground speed and maximum number of g s turn desired, assuming the maximum constant-speed climbing angle of the aircraft is not exceeded. If a minimum clearance of 150 feet and a maximum angular elevation of an obstacle of 5° above the flight path (the top of the display) are selected then the range at which this clearance is steered for is 9000 feet for an aircraft traveling at 300 MPH if a 1g turn and a linear climb angle of 7.5° is utilized to climb over the obstacle. This allows 2 seconds for pilot reaction, 1.5 sec. scan time and 1 sec. for aircraft response. A 1.5 sec. frame time is the minimum that will allow the desired coverage and resolution without exceeding magnetron capacity. The scan time is 1.5 seconds only at the edge of the display and decreases to .75 seconds at the center. Thus, this scan time is necessary only in the case of an obstacle extending to the limit of the display. It should be noted that this range and minimum clearance can be varied to suit different aircraft by adjusting the range gating of the red display. Thus, to clear an obstacle the pilot must pull up until the desired clearance angle is indicated, then he must hold this climb angle to clear by some distance. If he continues to use the terrain avoidance display to maintain the desired clearance angle, he must continually decrease his climb angle and will steer into the peak of the obstruction. A speed of 300 MPH was chosen as a realistic condition. For a slower aircraft the problem is less severe. For a faster aircraft it is only necessary to lengthen the red range gate.

The resolution required must be determined on the basis of the clearance angle and how close together it is desired to separate two objects. The resolution in terms of beamwidth is a function of the gain and display brightness adjustment. The worst case must be where the resolution is equal to a beamwidth and will be used as the basis to determine beamwidth required. A minimum clearance of 150 feet may be accepted as reasonable. This can be resolved at 1.5 N. Miles or 9000 feet by a 1^{o} beamwidth. Thus, a one degree beamwidth will allow 150 feet resolution at the limit of the red range. This appears adequate for vertical resolution. A narrower beamwidth may be advocated for better display resolution, but the extra capability it would permit is not adequate to justify the additional antenna size and the reduced sector coverage or scan rate necessary to stay within ratings on the magnetron. The possibility of multiplexing two magnetrons to allow higher scan rates was considered, but this would require two complete radars except for a common antenna and indicator. It is not felt that this is practical. A more satisfactory solution would be the development of a magnetron with a higher duty cycle rating. This could not be undertaken within the time span of the present contract. How close it is desired to separate two objects laterally is determined by how narrow a path between two objects it may be desired to fly. If it is assumed two objects must be at least 300 feet apart for an aircraft to fly between them, an antenna beamwidth of 1.5 degrees will allow them to be resolved at 2 miles. Thus, vertical beamwidth of 1.0^{o} and horizontal beamwidth of 1.5^{o} should be adequate. To steer around an object rather than over it is considerably easier in terms of aircraft performance so that the requirements for vertical clearance may be used for horizontal clearance. Closer clearance could be used which would require a narrower horizontal beamwidth if it would increase aircraft capability. It is not necessary to fly as close to an object when flying around it as when flying over it to avoid radar detection so that nothing would be gained by increasing this capability over that set by the 1.5° horizontal beamwidth.

A desirable presentation would be one in which red is used to indicate the nearest or most dangerous range, yellow for medium range and green for maximum range. The red range must extend to 9000 feet or 1.5 N. miles to determine the range at which minimum clearance is steered for. Yellow covers the range over which an object is allowed to extend 5° above the flight path (assuming no possibility of steering around the object). This range should be small so that the range where no restrictions are imposed on aircraft attitude may be large. It should also be small so that a higher effective signal to noise ratio and, consequently, more reliability achieved in this region preceeding the danger zone. A range extending from 1.5 to 3 miles appears reasonable. Thus green represents a range of from 3 miles to the maximum of which the radar is capable.

The horizontal or line scan rate should be made as slow as is consistent with a sufficient number of scans per vertical beamwidth so that the PRF may be as low as possible and still achieve a sufficient number of hits per horizontal beamwidth. The PRF should be low so that the widest pulse possible can be used, consistent with magnetron average power capability. A wider pulse results in less receiver bandwidth and consequently a lower noise voltage and a higher signal to noise ratio. Thus, horizontal scan rate and hits per beamwidth conflict with signal to noise ratio. A horizontal scan frequency of 16.5 cps appears to be about the minimum permissable. This will allow at least 1 scan per vertical beamwidth for a target of zero height. Two scans per vertical beamwidth will be achieved for a target 105 feet high at 1 mile, or 210 feet high at 2 miles. Thus, most targets of interest will be scanned at least twice. This is based on a vertical scan having a maximum speed of .0613 second per beamwidth. This is midway between the maximum slope of a sinewave and a linear scan. This appears to be a reasonable compromise between the desired linear scan and a reasonable drive power requirement during scan reversal.

The PRF should be made the minimum that will insure target detection since the signal equal to the RMS noise level (and consequently having the same probability of being exceeded by noise) is directly proportional to the PRF, since PRF determines maximum pulse width for a given magnetron. Thus, if twice as high a PRF is used to achieve more hits per beamwidth, then twice the signal voltage is required to be detected with the same reliability. The horizontal sector scanned should be 30° wide to present an adequate view of the surrounding terrain. With this coverage a PRF of 1365 cps will be used. This will allow a pulse width of .25 usec., with the MA-207 magnetron. For a zero width target, 4 hits per beamwidth will be achieved.

Electronic Scanning
Lens Types

ANTENNA CONSIDERATIONS

There are two basic antenna configurations to choose from. One consists of a so-called pencil beam antenna which focuses the energy into a narrow solid angle. This requires an antenna with a relatively large frontal area. This antenna serves as both a transmitting and receiving antenna. Typical examples are a paraboloid of revolution or a cylindrical parabola fed by a sectoral horn. The other type consists of crossed fan beam antennas. Separate receiving and transmitting antennas are used. One focuses energy into a narrow beam in one plane, but is relatively broad in the perpendicular plane. Another similar antenna rotated 90° is used also. The effective receiving area (or beamwidth) is then the intercept of the two. These antennas are relatively long (length determining beamwidth) and narrow. This type antenna system is commonly referred to as a crossed array, since they usually consist of linear arrays.

A pencil beam antenna is necessary if this system is to have sufficient gain to give adequate range coverage. Crossed arrays achieve a frontal area reduction at the expense of gain.

Without attempting to evaluate target characteristics, an estimate of the antenna gain necessary may be made by interpolation from other K_a band radars designed and built by Westinghouse Air Arm. It may be assumed that system gain, exclusive of antenna gain is comparable except as noted. An experimental terrain avoidance radar has an antenna gain of 40db and an additional gain of about 10db derived from a coherence detector. This detector involves considerable extra equipment and must use standardized video, thus deteriorating angular resolution. For these reasons it is not planned to use it in the present system. Thus the correct relative antenna gain is 50 db for the experimental radar.

ANTENNA CONSIDERATIONS (Cont'd.)

The range for "strong signal" return is approximately 4 miles. Another radar has an antenna gain of 90db plus an additional gain of 25db attained through film integration. Thus the correct relative antenna gain is 115db. This radar has a strong signal range of approximately 18 miles. These points are plotted in Fig. 1 . Interpolation from this graph reveals that an antenna gain of 90db is needed for a range of 10 miles. A pencil beam antenna having a beamwidth of 1° by 1.5° will have a gain of 87db. This indicates a range of about 9.5 miles. These are reliable ranges where good terrain coverage may be expected. Under most conditions larger targets should give returns at ranges up to 20 miles or better.

It may be shown that a crossed array can achieve an area reduction over a pencil beam antenna for a given beamwidth only at the expense of antenna gain. The two-way gain of a crossed antenna array for a given wavelength may be expressed

$$G = \frac{K \text{ Area } 1 \times \text{Area } 2}{\frac{\theta_{V_1}}{\theta_{V_2}} \times \frac{\theta_{H_2}}{\theta_{H_1}}}$$ where subscripts 1 and 2 refer.

to the two crossed antennas and H and V refer to horizontal and vertical. Reference to Fig. 2 will help clarify this. The areas represent the gain of the antennas while the denominator represents the crossing loss or the fractional intercept in the two planes. Since area = length X width and since the angular beamwidths are proportional to the proper linear dimension, this may be expressed

$$G = K \frac{L_1 W_1 \times L_2 W_2}{\frac{L_1}{W_2} \times \frac{L_2}{W_1}} = KW_1^2 W_2^2.$$ Thus the gain varies with area as in

any antenna, provided the proper area is considered. This area $W_1 W_2$ is the intercept area and is independent of the antenna lengths and consequent beamwidth.

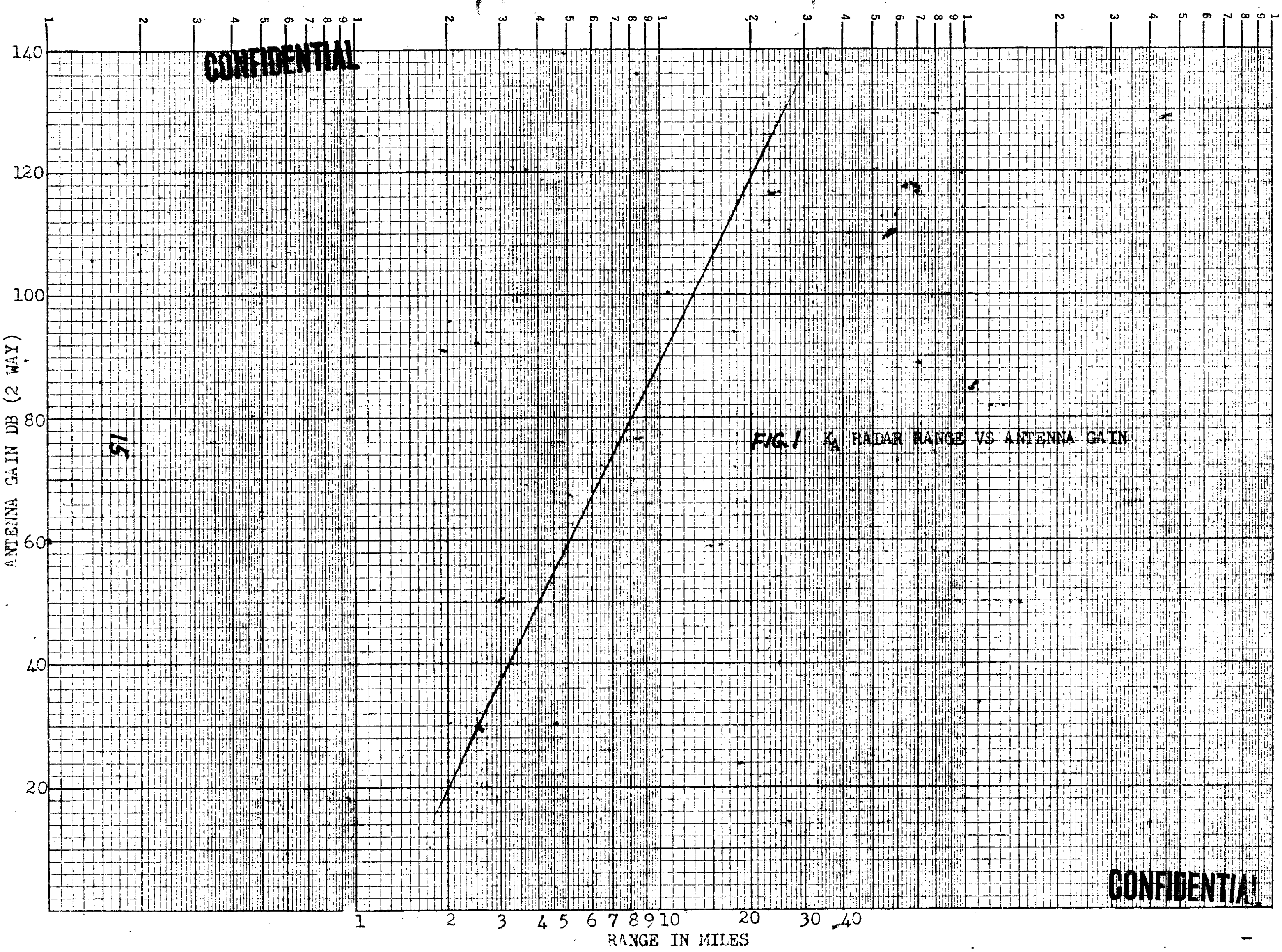

FIG. I K_A RADAR RANGE VS ANTENNA GAIN

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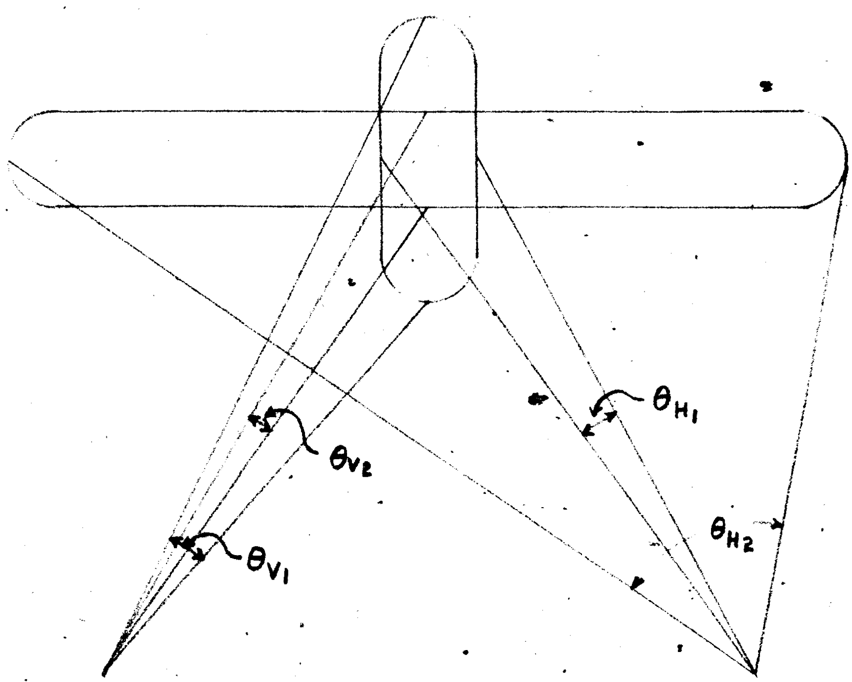

FIG. 2 CROSSED ARRAY ANTENNA PATTERN

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ANTENNA CONSIDERATIONS (Cont'd.)

A family of curves, one for each beamwidth, may be plotted of area vs gain for crossed arrays. Such a plot is shown in Fig. 3 for arrays having two identical antennas. The area vs gain and beamwidth curve for a parabola is shown for comparison. Interpretation reveals that a crossed array having the same beamwidth as a parabola has 10db less gain for the same total area, -21db for ½ the area, and -32db for ¼ the area of a parabola.

A parabola having the desired 87db gain has an effective area of 376 sq. in. A crossed array having the desired $1^\circ \times 1.5^\circ$ beamwidth and 87db gain would have a total area of 564 $in.^2$ but an intercept area ($W_1 W_2$) of only 200 $in.^2$ The only usable configuration would be to make $W_1 = W_2 = 14.1$ in. Thus two antennas 14.1 x 16 and 14.1 x 24 inches would be required. The beamwidths would be $1.68^\circ \times 1.5^\circ$ and $1.68^\circ \times 1^\circ$. This would not be a very practical antenna system since both antennas must be scanned in both planes.

It appears that 70db is about the highest gain obtainable with a crossed array suitable to this system. It would be 2.38 x 16 inches and 12.3 x 24 inches so that one antenna would have a beamwidth $10^\circ \times 1.5^\circ$ and would need to be scanned in only one plane if oriented so the 10° is vertical to cover the desired sector. The other antenna would have a beamwidth of $1^\circ \times 2^\circ$ and would have to be scanned in both planes. This antenna array would have 330 $in.^2$ fromtal area as compared to 376 $in.^2$ for a parabola having the same beamwidth and 87db gain. In all cases no allowance has been made for cross polarization loss with crossed arrays.

It is felt that feed scanning of a sectoral horn represents a satisfactory method of achieving a rapid scan.

A simplified laboratory set-up using linear reciprocal feed movement produces the required 30° scan. This set-up is now being extended to test the scanning

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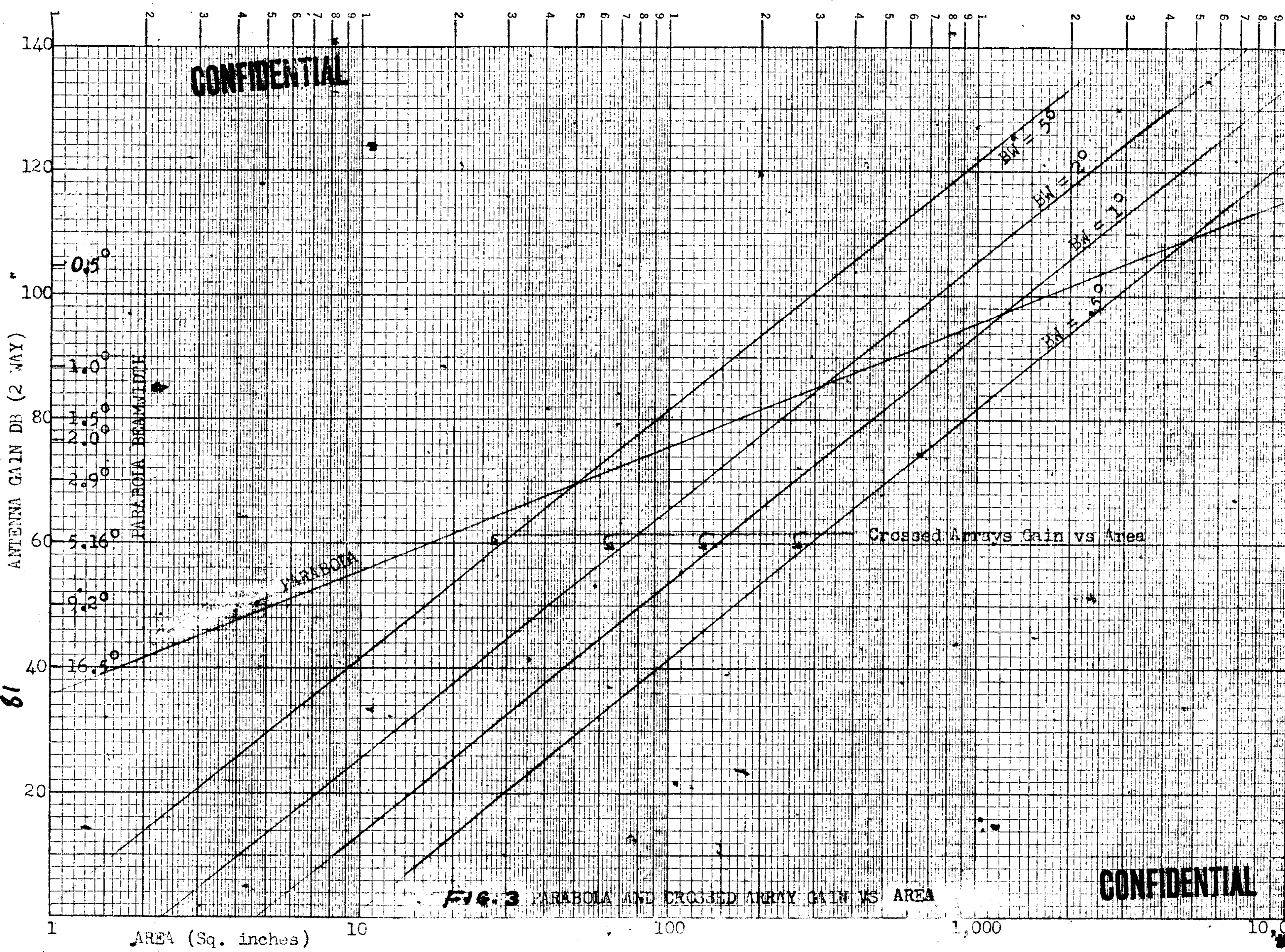

FIG. 3 PARABOLA AND CROSSED ARRAY GAIN VS AREA

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ANTENNA CONSIDERATIONS (Cont'd.)

obtainable with a circular feed mechanism to use simple rotary movement of the feed. This method promises to be simpler and less critical of mechanical tolerances than the moving backwall method of scanning used in a present, experimental model.

PROPOSED SYSTEM SPECIFICATIONS

It is proposed to cover a sector 30 degrees wide horizontally by 10 degrees vertically. This appears to be a reasonable compromise between sector coverage on one hand and scan rate and beamwidth on the other. On the basis of considerations of aircraft performance as previously discussed, an antenna beamwidth of 1° vertically by 1.5° horizontally in the center of the display will be the nominal objective. Some deterioration of the beamwidth at the edge of the display will occur. A scan rate of .67 cps (or an up and down scan in 1.5 sec.) in the vertical plane and a 16.5 cps sawtooth scan in the horizontal plane will be the objective. This will depend on the feasibility of a horn feed scan system covering 30°. If this does not prove feasible, the horizontal scan rate will be made .67 cps and the vertical scan rate 33cps. This will require a horn feed scan through only 10°.

The antenna will consist of a sectoral horn feeding a cylindrical parabola. The rapid scan will be effected by scanning the feed across the throat of the horn. The slow scan will be effected by rocking the entire antenna and receiver-transmitter. An antenna gain of 45db (one way) will be the design objective. It is expected that the parabolic antenna will have a 24 inch x 24 inch frontal area.

It is desirable to control the antenna orientation to compensate for drift angle so that the display is centered about the flight path. It is planned to compensate for a drift angle up to 15° maximum. This correction will be performed when the aircraft is banking also, thus requiring two degrees of freedom. It is planned to allow $\pm 15^{\circ}$ of freedom in the vertical plane so that a 15° drift angle can be corrected for with the aircraft banking at 90°. Provision will be made to allow manual correction for variation of aircraft trim angle with changes in load.

PROPOSED SYSTEM SPECIFICATIONS (Cont'd.)

It is planned to use the MA-207 magnetron for a transmitter. While this magnetron has a maximum pulse power rating of only 70KW as compared to 200KW for the 6799, its duty factor is twice that of the 6799. A pulse width of .25µsec can be used as compared to .1 µsec with the 6799. The relative range may be expressed as:

$$\frac{R_{(6799)}}{R_{(MA207)}} = \sqrt[4]{\frac{P_{p(6799)}\ PW_{(6799)}}{P_{p(MA207)}\ PW_{(MA207)}}} = \sqrt[4]{\frac{200}{70} \times \frac{.25}{.1}} = 1.03$$

Under actual conditions the MA207 with a Phillips cathode will produce a 50 or 60KW pulse for an appreciable life, while the 6799 will not produce 100KW for any substantial period. It produces only about 50 or 60KW for any appreciable time. Thus the MA-207 in practice may be expected to actually have considerably greater range. Even assuming the 6799 may be improved to have adequate life during which it will produce 200KW, it is not felt that the small additional range advantage justifies the extra weight. At least 40 lbs. can be saved in magnetron and modulator weight. If we estimate a possible range of 20 miles for the system with a MA-207, the range would be only 20.6 miles using a 6799.

The transverse profile display (tentatively referred to as an "X" scope on drawings, pending assignment of an official nomenclature) is the basic system display which is presented to the pilot. A flight path profile is also displayed on an "E" scope. This scope will be located at the navigators position along with an additional "X" scope. These two scopes are optional and may be removed from the system at will. Means will be provided whereby the navigator may display profiles to either side of the aircrafts flight path on the "E" Scope. A line will be displayed on the navigator's "X" Scope indicating the location of the profile being displayed.

PROPOSED SYSTEM SPECIFICATIONS (Cont'd.)

It is planned to incorporate means to enable monitoring of system performance. On the basis of experience with another K_a radar it is believed to be feasible to measure altitude up to possibly 1000 feet. This will serve to prove that the radar is operating satisfactorily as well as indicating altitude. This will be displayed by displacing the "E" Scope trace once every vertical (or slow) scan and gating the receiver on during this interval when the receiver is normally off. Sufficient energy should be available from the antenna side-lobe for the altimeter function. An alternative possibility for checking radar performance would be a small antenna and untuned echo-box located so that energy is directed into it at the top of the vertical scan.

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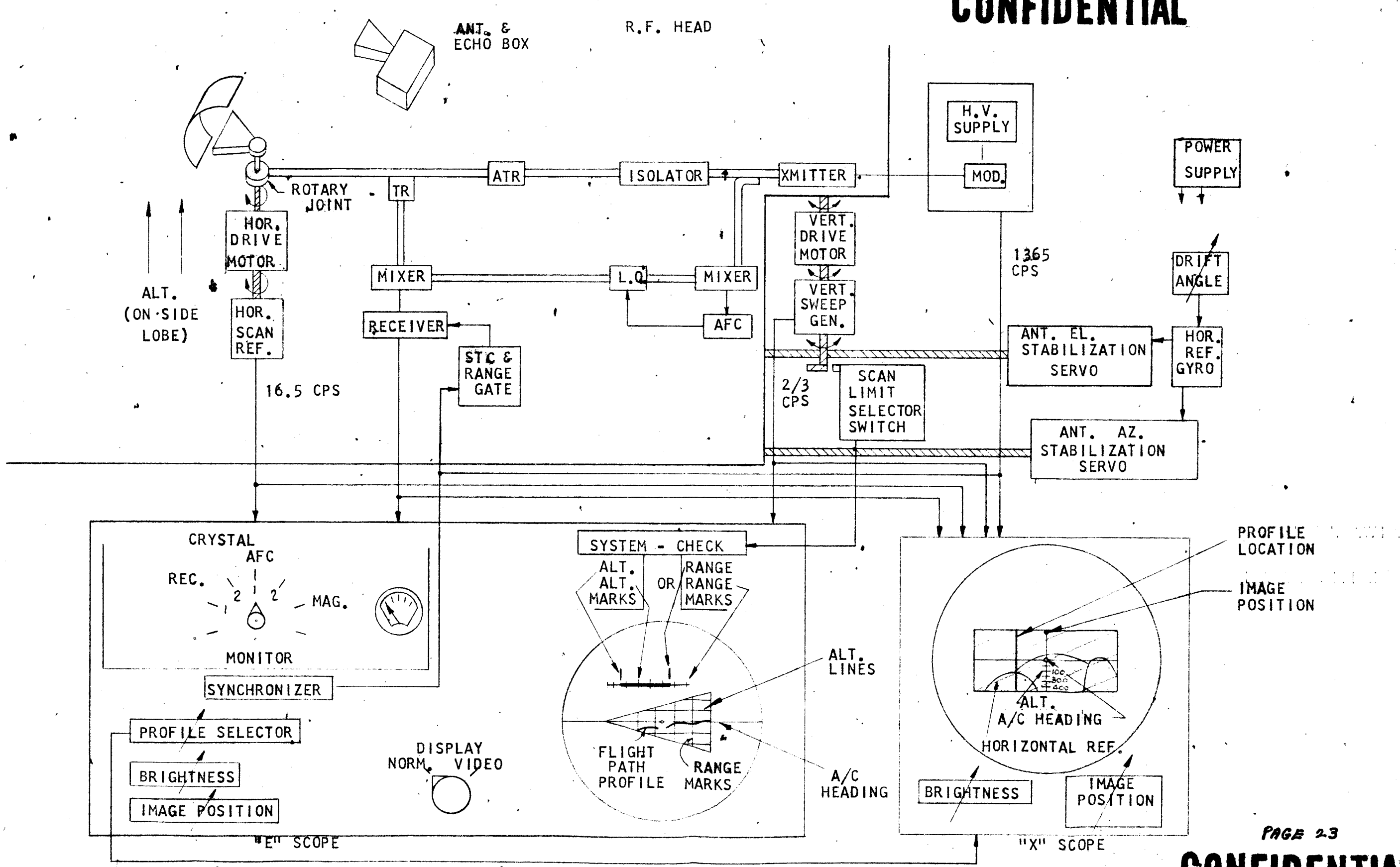

FIG. 4 TERRAIN AVOIDANCE RADAR SYSTEM DIAGRAM

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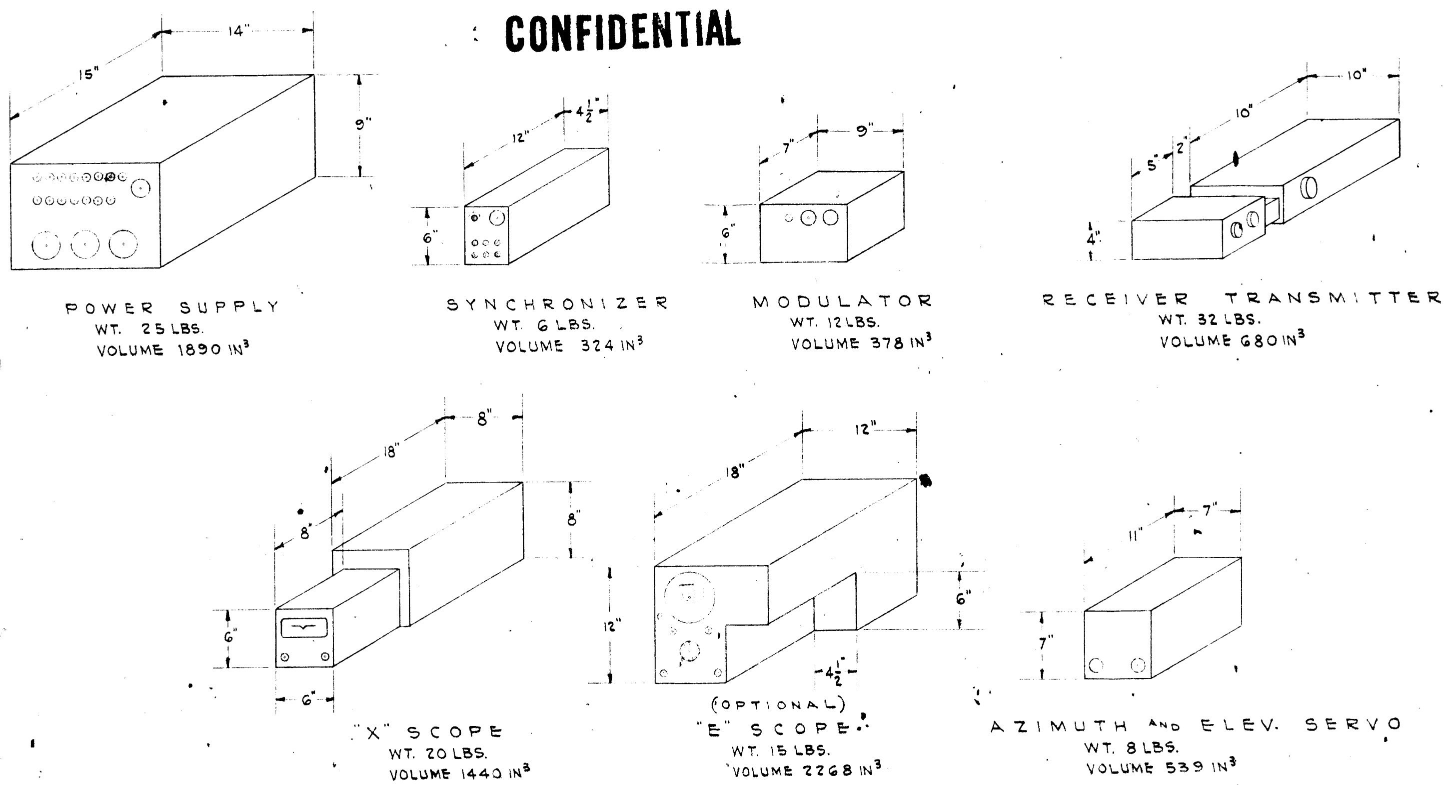

FIG. 5 COMPONENTS OF TERRAIN AVOIDANCE RADAR

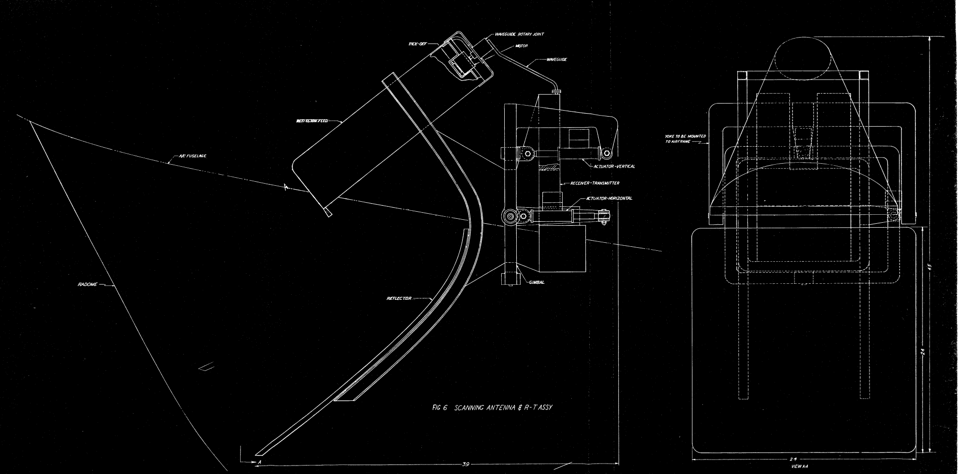

FIG 6 SCANNING ANTENNA & R-T ASSY

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SYSTEM PLACEMENT

The recommended placement of the equipment is shown in Fig. 7. The navigators "X" Scope and "E" Scope with synchronizer attached will be located at the navigators station in a manner dictated by the available space. The exact location of the pilot's indicator is not known at present. It is assumed that some panel space will be available as shown. The optical system shown attached to the front of the "X" scope in Fig. 5 is the basic arrangement which is suitable at least to the navigator's indicator. The image may be projected onto a screen at a greater distance placed at an angle with respect to the indicator if, as seems likely, this is required to fit the indicator in the available space. The possibility of having the indicator head located remotely from the associated circuitry was explored and discarded due to the excess circuitry required.

The power supply, modulator and azimuth and elevation servo will be located in the forward equipment bay in a manner suitable to the available space.

The R.F. head, consisting of the antenna and associated drives, receiver, transmitter and AFC could be located in a chin radome as shown. The exact location of this radome depends upon aerodynamic considerations and the field of view of other radars. Part of this assembly will project into the aircraft to minimize external surface. It is apparent that the frontal area of the antenna does not necessarily represent additional frontal area on the aircraft. Instead it represents a modification of the contour. The feasibility of placing the antenna so as to merge the radome with the radome of another nose radar will be investigated.

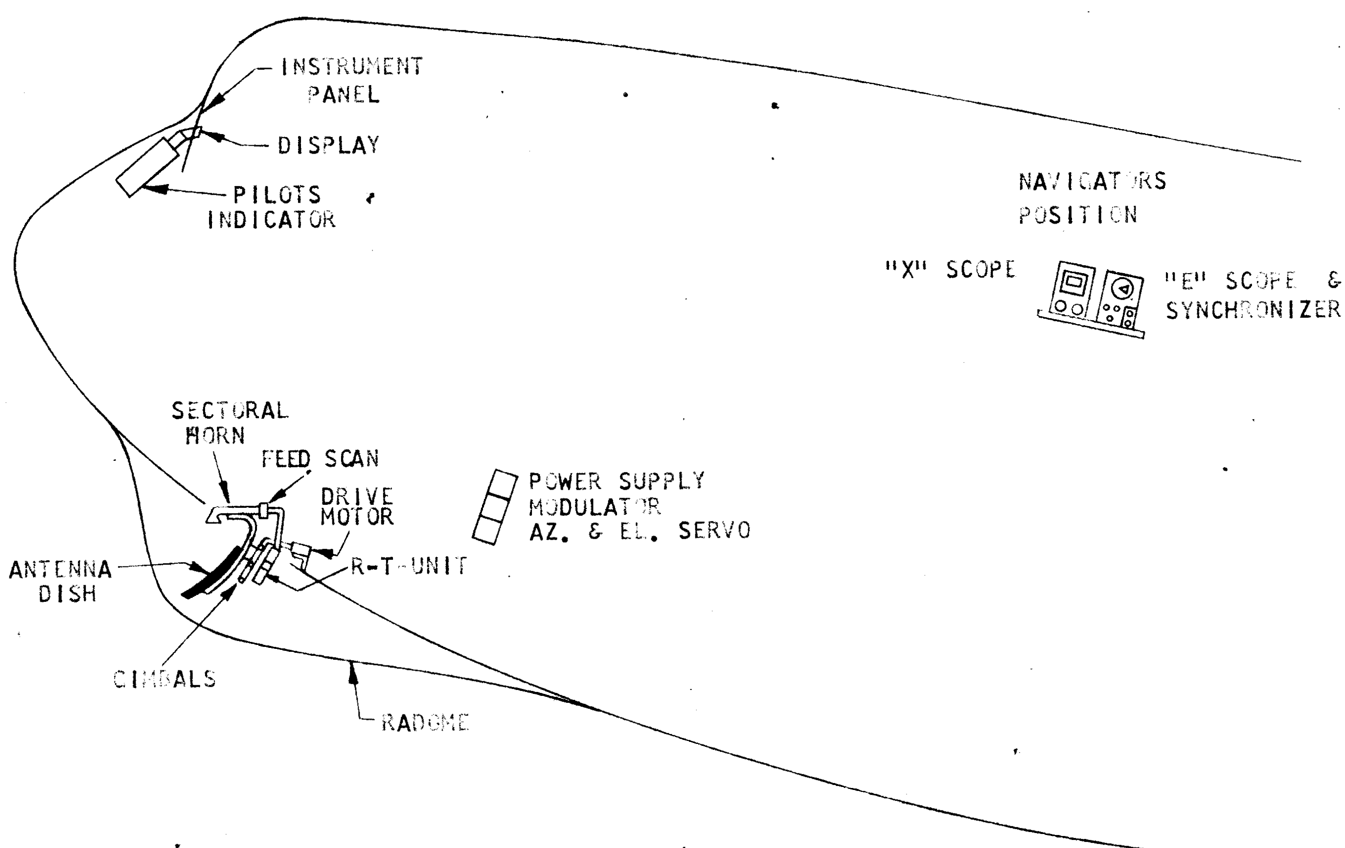

FIG.7 LOCATION OF TERRAIN AVOIDANCE SYSTEM IN AIRCRAFT

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ANTENNA STABILIZATION AND VERTICAL SCAN

It is planned to mount the antenna on gimbals so that it has two degrees of freedom. Hydraulic actuator mechanisms will be used to save weight and size.

Drift angle must be provided as a shaft position. This can be supplied automatically by a doppler radar or manually by the navigator. Roll angle must also be supplied. The feasibility of obtaining this information from the doppler radar will be investigated. If not available, a reference gyro will be used to furnish this information. To correct for drift angle when the plane rolls (or is banking) requires that drift angle be resolved into components referenced to the aircrafts vertical and horizontal. That is, $\theta_{Vert(AC)} = \sin \theta_{roll} \times \theta_{drift}$ and $\theta_{Hor(AC)} = \cos \theta_{roll} \times \theta_{drift}$. This requires a resolver to operate on the required roll and drift angles to convert to correction voltages. Servos will position the antenna in accordance with these correction voltages. One servo and associated drive will control antenna position in the aircrafts horizontal plane. Fifteen degrees of travel to either side of the aircrafts centerline will be permitted. The antenna must scan 10° in the aircrafts vertical plane at a 2/3 cps rate. A hydraulic actuator will be used to drive the antenna. This scan in the absence of a drift angle will be 5° above and below the aircrafts centerline. A drift angle component in this plane will cause the center of the scan to shift with respect to the aircrafts centerline. This will be performed by the other servo loop. The objective will be $.25^{\circ}$ static and $.5^{\circ}$ dynamic accuracy in the two servo loops.

ANTENNA DESIGN

The design problem is that of obtaining the desired beamwidth and scanning motion while simultaneously maintaining minimum beam distortion. The 1° vertical and 1.5° horizontal beamwidths are to be maintained within 0.5° throughout the 10° vertical scan and the 30° horizontal scan. The beam shape is to be optimized in the straight-ahead position.

The plan for attacking this problem is to design the antenna feed system such that the 30° horizontal scan is obtained by using simple circular motion at a frequency of 16.5 cps. The feed will be of a suitable configuration to beam-shape the power distribution into the required 1.5° horizontal beam. The feed will irradiate a cylindrical parabolic reflector that will shape the energy into a 1° vertical beam. The scanning action in the vertical plane will be obtained by having the feed horn and reflector combination sweep through a 10° angle at the rate of 2/3 CPS.

The following description of a scanning antenna configuration is the direction the antenna design is proceeding.

A simplified view of the feed is shown in Fig. 8. Outline AFBCD is a view of a pair of parallel plates spaced approximately $\lambda/2$ apart. Consider the horizontal beamwidth required and aperature CD is fixed approximately. Bisect CD at G and make 15° angle lines with the bisecting line, GEF. Sketch waveguide feed horn outlines on the $\pm 15^{\circ}$ lines such that the power distribution clears aperature DC at least -12 db down. With G as center, draw arc AFB. Sketch another waveguide feed horn at F on the bisecting line GEF. Its power distribution pattern should clear aperature CD like positions 1 & 2 and all intermediate positions. Far field patterns for all these positions should show little or no distortion of the primary power distribution.

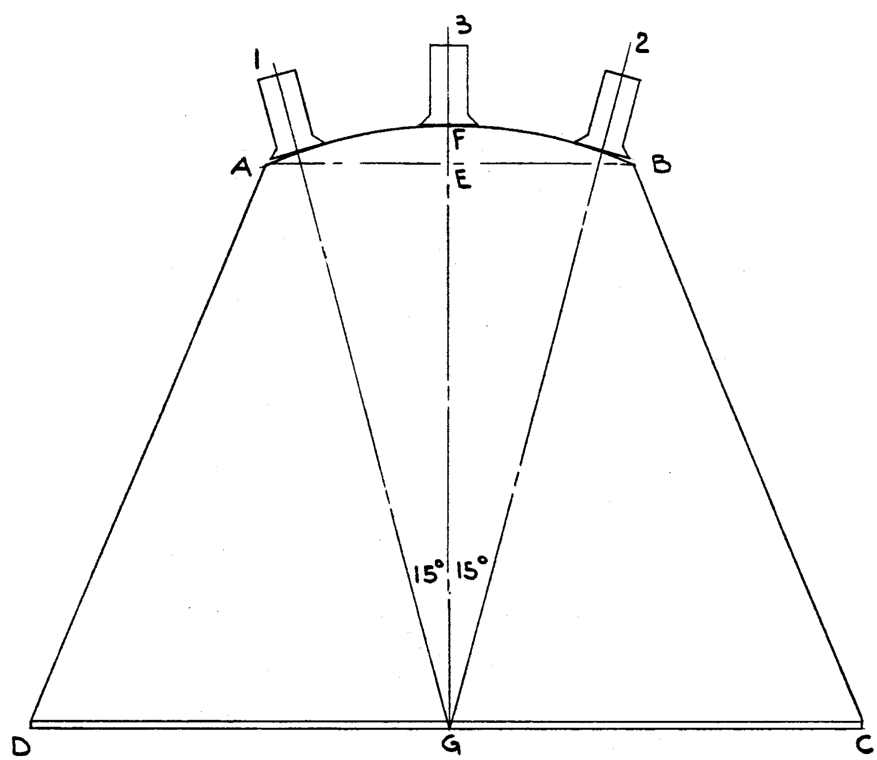

FIG. 8 SIMPLIFIED HORN FEED SKETCH

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Arc AFB is the locus of waveguide horn scan movement. To simplify the waveguide horn scan motion, the parallel plates are folded into a circle at AFB so that A and B join. See figure 9.

Since it is necessary for a 1.5° beam to emerge from aperature CD, beam shaping of the waveguide feed horn power distribution is necessary. For this reason aperature CDG is formed to approximate a parabola and parallel plates DGCH of Figure are placed so as to change the power direction by 90° while narrowing the power pattern in the horizontal plane.

The final feed aperature is CHD as shown in Figure which feeds a cylindrical parabolic reflector narrowing the beam in the remaining vertical plane.

The result is an antenna unit that scans ±15° in the horizontal plane at 16.5 cps. The 2/3 cps vertical scan is obtained by nodding the entire antenna unit.

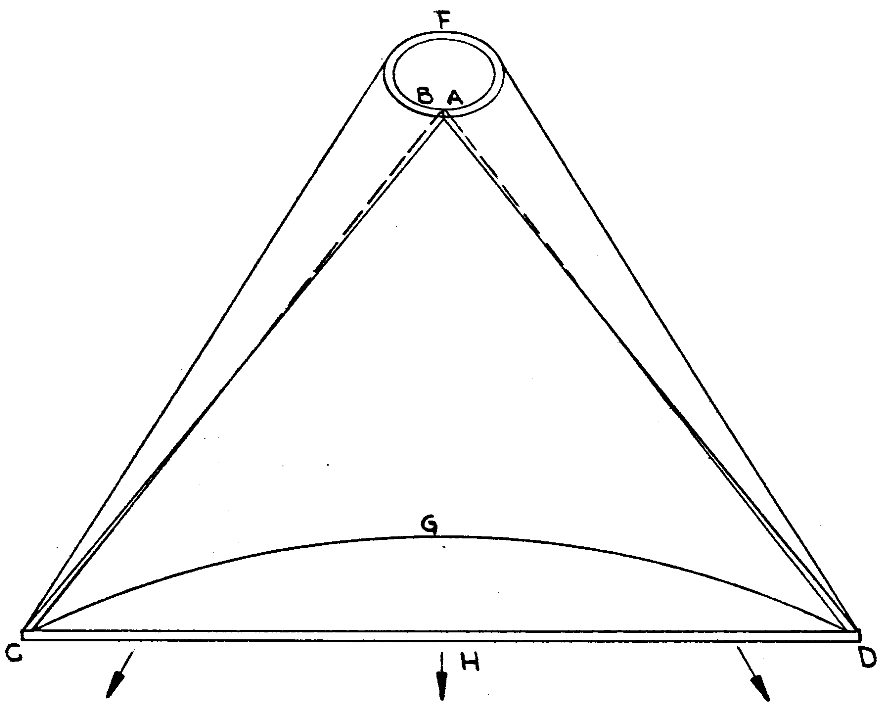

FIG.9 HORN FEED SKETCH

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SYNCHRONIZER

The synchronizer chassis provides the following:

(a) System repetition rate pulses.

(b) Color display switching time pulses.

(c) Stretched video pulses for the X-Scope.

(d) Color display position marks.

(e) Monitor for system voltages, receiver and AFC crystal detector currents, and magnetron average current.

The repetition rate is obtained by means of a crystal-controlled transistorized bistable divider chain which converts the 81.94KC ± .02% crystal oscillator frequency into pulses occurring at a repetition rate of 1365 ± 0.1% pulses per second.

The use of silicon transistors for this function enables considerable weight and power savings.

The color display switching time pulses determine the radar range at which received echos are changed from a red display to a green display on the indicator CR storage tube.

The stretched video pulses enable the storage tube to produce the desirable brilliance from the narrow video echo. Video amplitude variations are preserved in the stretched video so that echo shading is provided in the display. Stretched video is removed during the fly-back time of the horizontal sweep by means of the horizontal reset pulse from the antenna unit.

The color display position marks enable the operator to properly orient the storage tube display with respect to the optical system. These marks are produced when the antenna is in the maximum vertical position and mid-point of horizontal sweep.

SYNCHRONIZER (Cont'd.)

The monitor section provides (by means of a rotary switch and panel meter) rapid checking of all system supply voltages and also of crystal mixer current in both the Receiver IF and AFC IF units. The average value of the magnetron current is also indicated.

Weight of the synchronizer chassis is estimated at 6 lbs. The volume is 325 cu. in.

CONFIDENTIAL

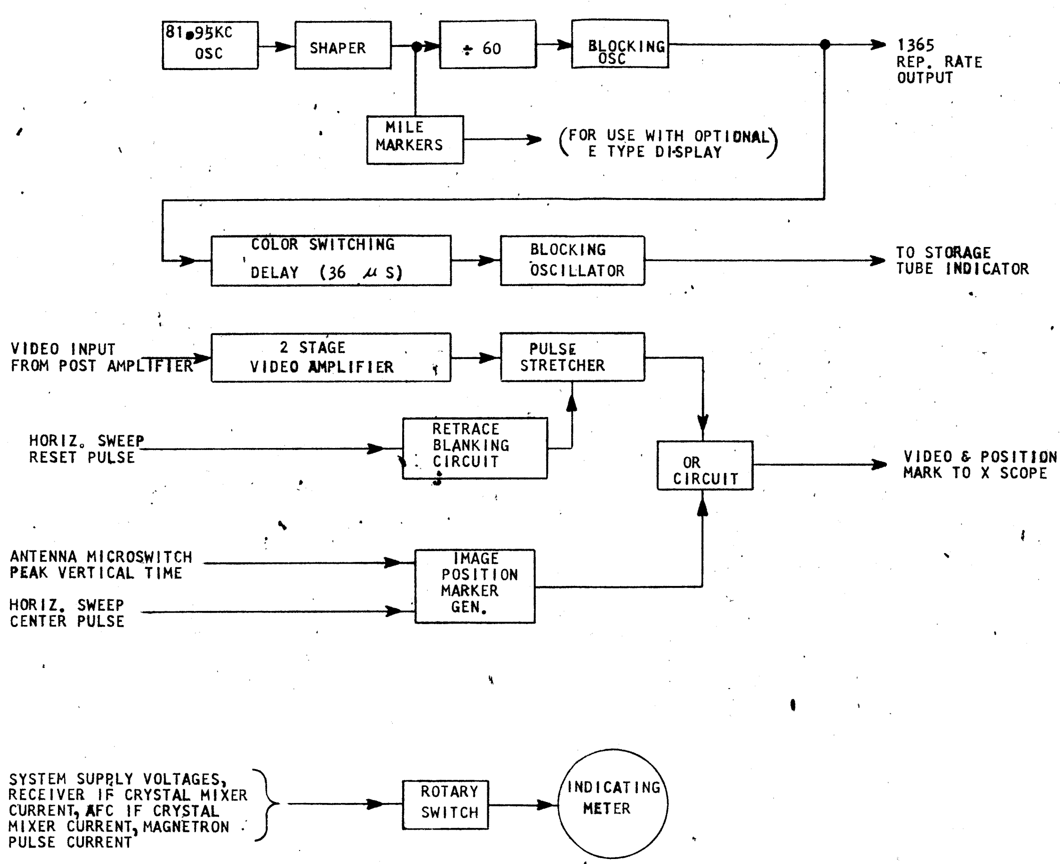

FIG.10 SYNCHRONIZER BLOCK DIAGRAM

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X-SCOPE

A transverse profile display will be provided for the pilot and will be installed on, or near, the instrument panel. This display may also be remoted for the navigator's observation. The transverse profile and display will be a modified "C" scope in which range will be quantized and presented by the use of three contrasting colors. Such displays have often been referred to as type "X" indications.

The display presented to the observor will be projected data; originating in two images on a single storage cathode ray tube. The optical system is shown in Fig. 11. These time shared images correspond to the video profile data contained in two different range segments and will have the dimensions of azimuth and elevation angle. These images are color filtered, optically combined and then projected into the viewing screen. Normally such a system would yield two colors after projection; but due to a time overlap (as a result of "stretched" video) a third color is produced. The three colors will be red, green and their optic combination - yellow. Near targets will appear in red, far targets in green and those targets in an intermediate range will appear yellow. A storage type CRT is necessary to provide adequate brightness at the slow scan rate used.

In addition to the color profile display, certain navigational indices will be provided. Among these are a set of parallel lines, indicating the aircraft bank angle, and an aircraft heading mark at the center of the display. Another feature may be the indication of altitude. An artist's conception of the indicator is shown in Fig. 12. Since the antenna is wind stabilized, the center of the picture will always represent the terrain directly in the flight path of the aircraft. The flight profile will normally be selected along this line. However, its position may be shifted to the left or right. An electronic marker on the "X" Scope will

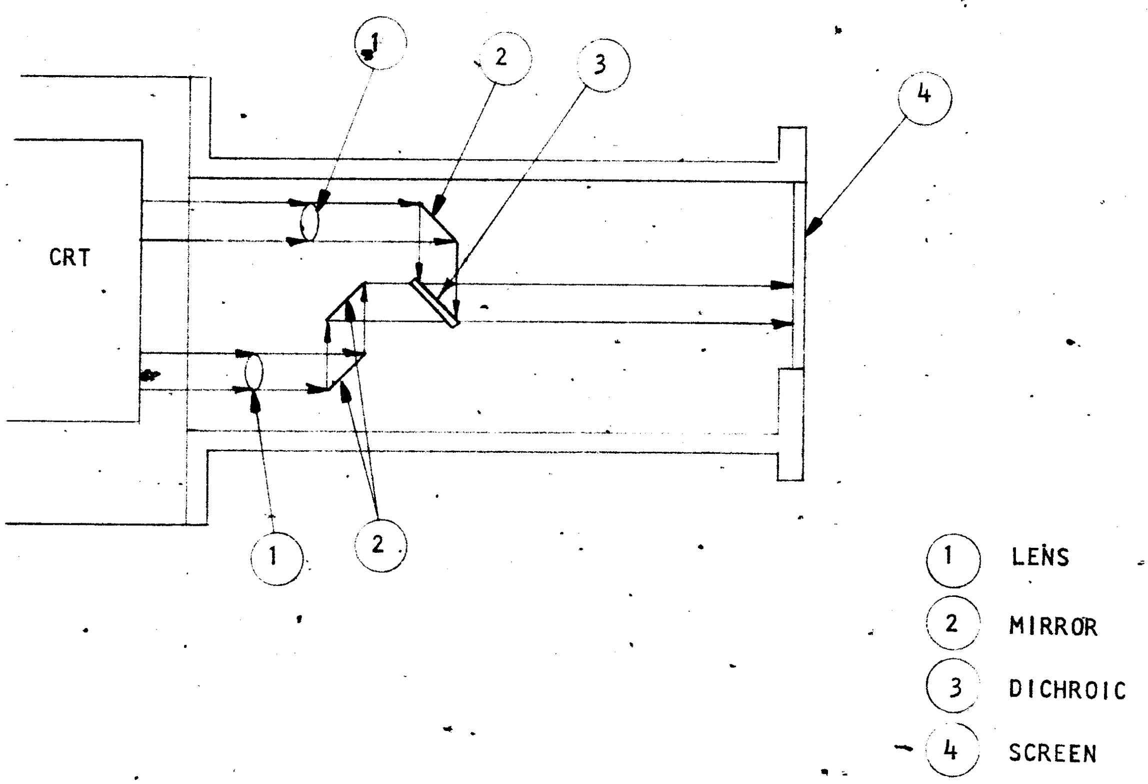

FIG. 11 TRANSVERSE PROFILE DISPLAY OPTICAL SYSTEM

Red - 0-1.5 nm
Y.l 1.5-3
Green 3-

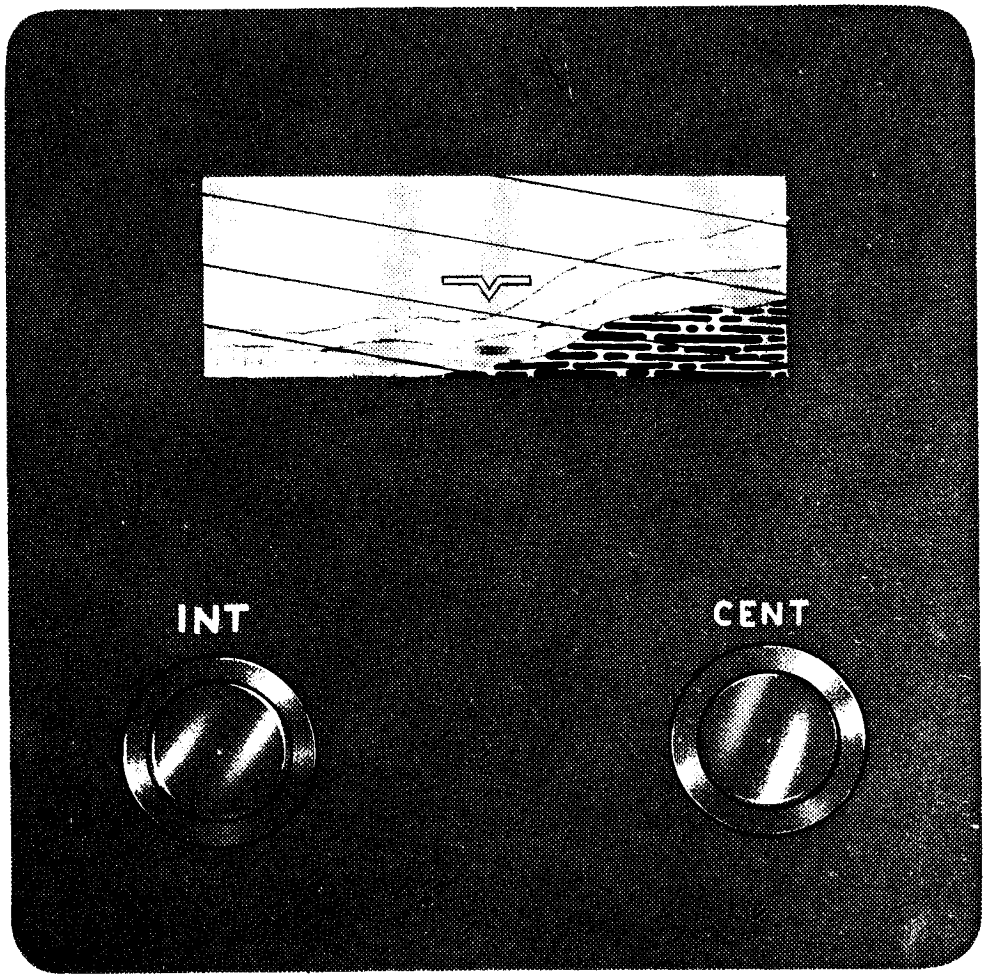

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Figure 12 Pilot's Profile Display

X-SCOPE (CONT'D.)

indicate the profile selected. It is not felt desirable to display this on the pilot's scope, however the two "X" scopes are identical and it may be displayed on either or both.

The block diagram of the "X" scope is shown in Fig. 13.

The RCA Type C73703B is a developmental 2-writing gun storage tube. The viewing gun is used somewhat conventionally; however, one of the writing guns is used for erasure. Both guns are driven by the same deflection signals with a phase shift between the two in the vertical direction. This allows erasure just prior to writing which conserves storage but elliminates flicker.

The vertical deflection signal is a DC signal derived from a pot located at the antenna. A trigger pulse at the start of each horizontal scan actuates the start of the horizontal sweep. The phase shift between the horizontal writing and erase signals is synchronized by pulses from the antenna at the extreme excursions of the antenna. Video signals and blanking pulses are amplified by the video amplifier and applied to the cathode ray tube.

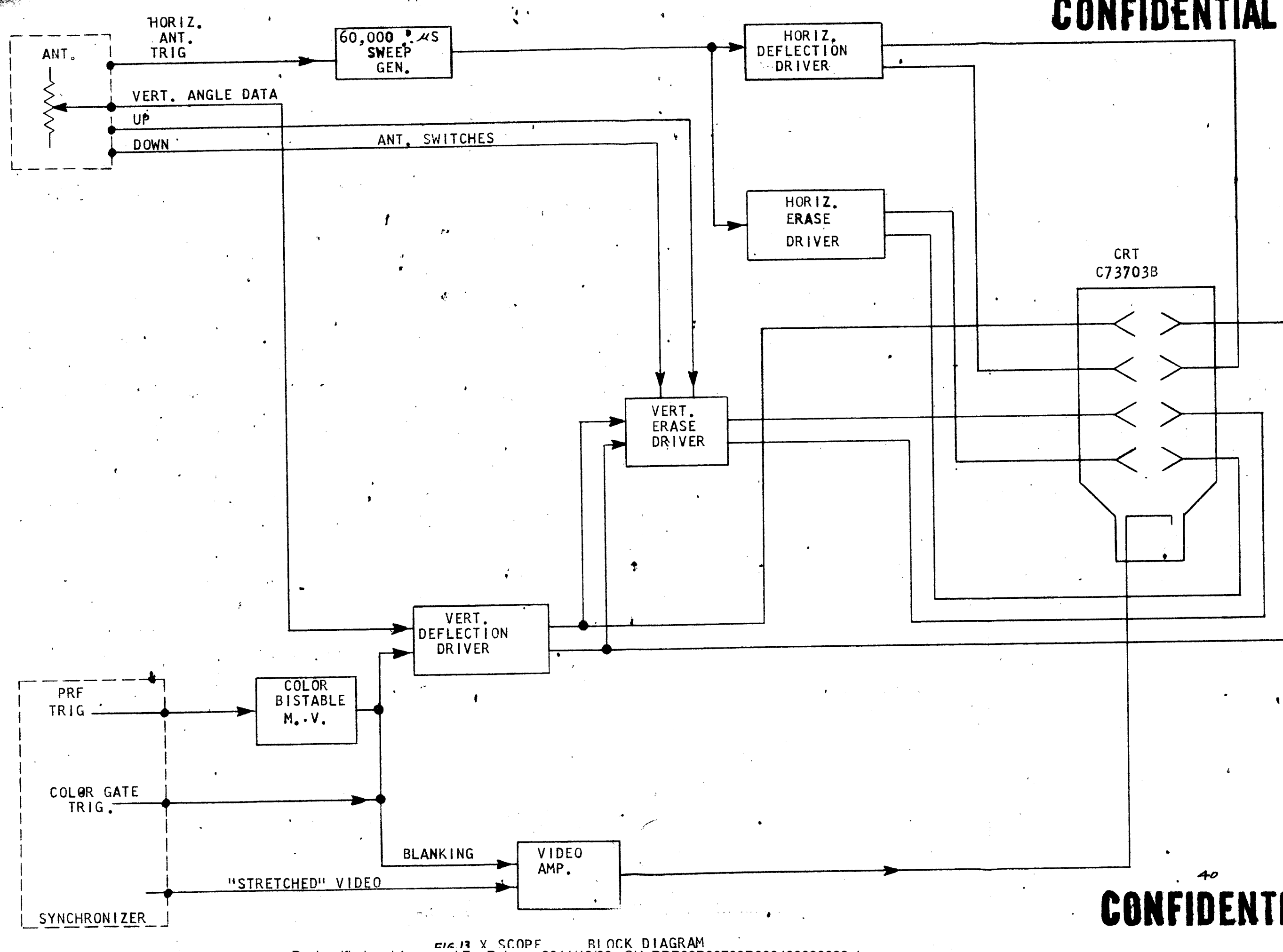

FIG. 13 X SCOPE BLOCK DIAGRAM

E SCOPE UNIT

The E Scope or Profilometer is an auxillary unit which will provide the system with additional information, which could be utilized by a copilot or navigator.

The E Scope unit contains a 5 inch Cathode Ray tube which displays aircraft altitude information and terrain profile information. It also provides video for use with a companion X Scope unit.

The face of the E Scope contains cursor marks which indicate altitude for both the altitude and terrain displays. The altitude display cursor consists of a horizontal line in the upper half of the tube face which is marked in intervals of 100 feet. The profile display cursor consists of horizontal elevation lines which indicate heights in intervals of 1000 feet for objects in the profile display which appear either above or below the aircraft altitude. The corresponding radar range of these objects are indicated electronically by means of markers occurring at appropriate intervals during each sweep.

The aircraft altitude information is displayed once during each vertical cycle of the antenna when the antenna is at its maximum depression angle.

The terrain profile information is displayed by sampling the echo returns from any one sector of the antenna's azimuth coverage. The azimuth sector sampling is subject to operator control by means of a calibrated "Profile Selector" dial.

The azimuth sector which is being displayed is continuously indicated on the companion X scope by means of a brightened vertical line. With this provision, the operator may observe the X scope while turning the profile selector dial on the E Scope unit until the brightened vertical line coincides with the terrain to be observed. Altitude and range information for objects in the selected terrain sector may then be obtained from the terrain profile display on the E Scope.

The E Scope may also be used to monitor certain test points in the system by rotating the display switch on the E Scope unit.

CIRCUITRY (Refer to Block Diagram Fig. 14)

All inputs (except the antenna vertical sweep voltage) are supplied automatically to the E Scope unit whenever the synchronizer unit is plugged into its receptacle in the E Scope unit. The only electrical output of the E Scope unit is the video which supplies information to the companion X Scope.

With reference to the block diagram, it is seen that the horizontal sweep gate controls all displays on the E Scope. This horizontal sweep gate is started whenever the and circuit receives two inputs simultaneously. One of these inputs is the rep. rate pulse and the second input may be either the altitude display gate or the profile display gate. This arrangement guarantees synchronization of display sweeps with the rep. rate.

When the gate is started it unblanks the E Scope and starts the horizontal sweep generator. The horizontal sweep generator drives the horizontal deflection amplifiers which in turn apply the horizontal sweep voltage to the E Scope.

It is planned to provide for switching on either a 10 mile short range or a 20 mile range gate for long range surveillance. The 10 mile gate is preferable for close-up use as it provides better resolution.

The gate also enables the vertical sweep generator which converts the voltage from the antenna vertical sweep potentiometer into a linear sawtooth sweep voltage which is then applied to the vertical deflection amplifiers which in turn supplies the vertical sweep voltage to the E Scope.

By moving the display switch from the "normal" position to the "video" position, the vertical sweep is removed from the vertical deflection amplifiers and input video signals are substituted. This permits observation of video from

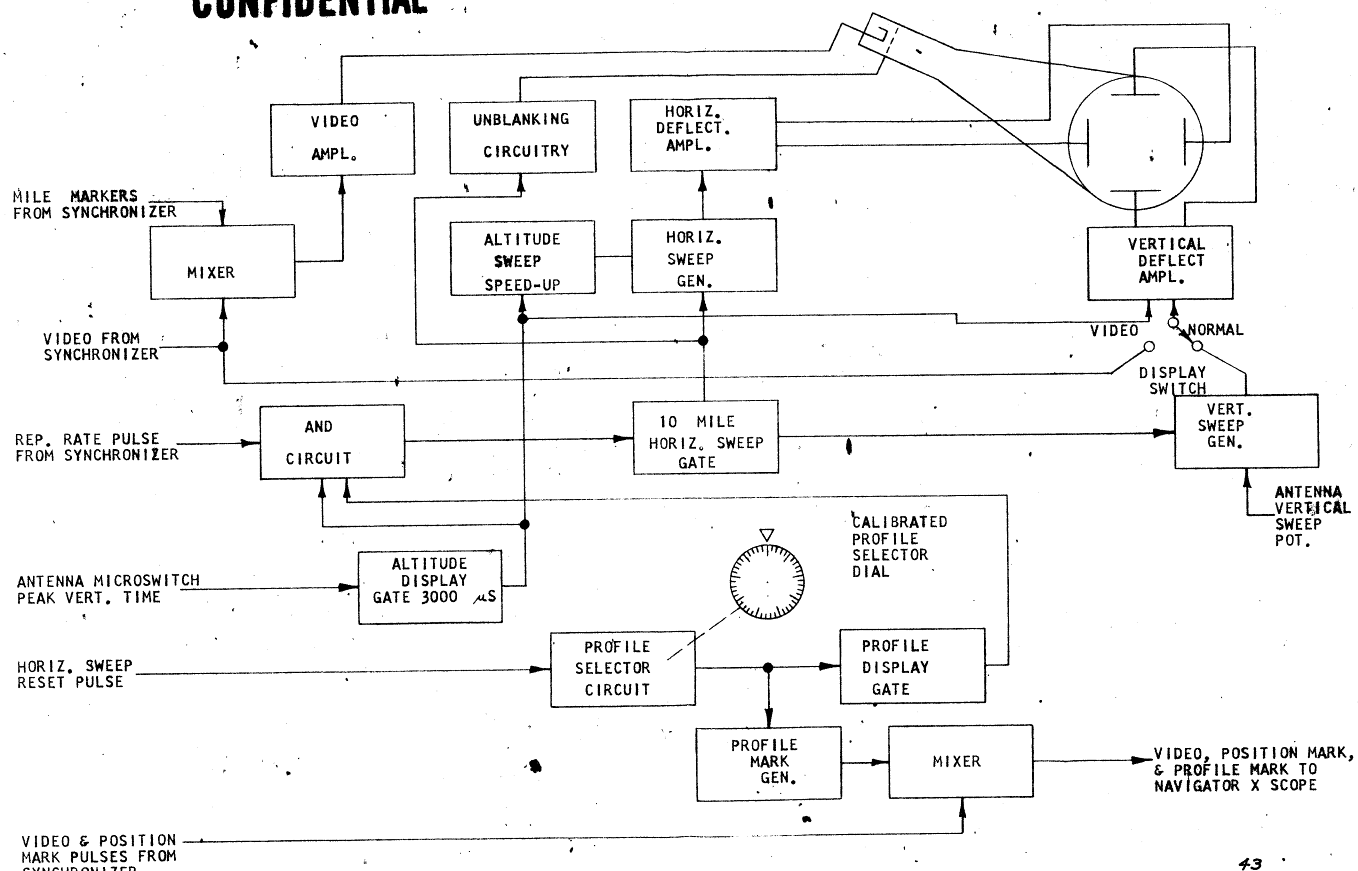

FIG. 14 E SCOPE BLOCK DIAGRAM

receivers or other system test points when connected to the video input jack of the synchronizer unit.

When the antenna moves to the extreme vertical position, the altitude display gate is triggered by a microswitch on the antenna assembly. When the altitude display gate is triggered, a step is applied to the vertical deflection amplifier which causes the sweep to be positioned in the upper portion of the E Scope. The altitude display gate enables the 10 mile horizontal sweep gate and, since the altitude display gate is approximately 3000 microseconds wide, four display sweeps at the rep. rate frequency are produced on the E Scope. The altitude display gate also triggers the altitude speed up circuit which in turn causes the horizontal sweep generator to produce a much faster sweep. This is necessary because the altitude information display on the E Scope requires a 2µs sweep to display 1000 feet of altitude.

The profile selector circuit produces a linearly variable delay which can be controlled by the operator by means of a calibrated dial. The profile selector circuit is triggered by the horizontal sweep reset pulse from the synchronizer unit. This reset pulse occurs at the beginning of each horizontal sweep of the antenna.

The profile selector circuit triggers the profile display gate and the profile marker generator. The profile display gate (approximately 3000µs wide) enables the horizontal sweep gate to produce four sweeps at the rep. rate frequency as previously noted. The profile marker generator produces a pulse which is added in the mixer to the video and position marks from the synchronizer unit. This mixer output becomes the signal input to the companion X Scope. Hence by means of the profile selector dial, a profile mark appears on each horizontal sweep of the X Scope and these individual marks form a brightened vertical line on the X Scope presentation.

The mile markers and the video signals from the synchronizer are mixed and continuously applied to the cathode of the E Scope. The unblanking circuit operation permits these signals to appear as bright spots on the tube face.

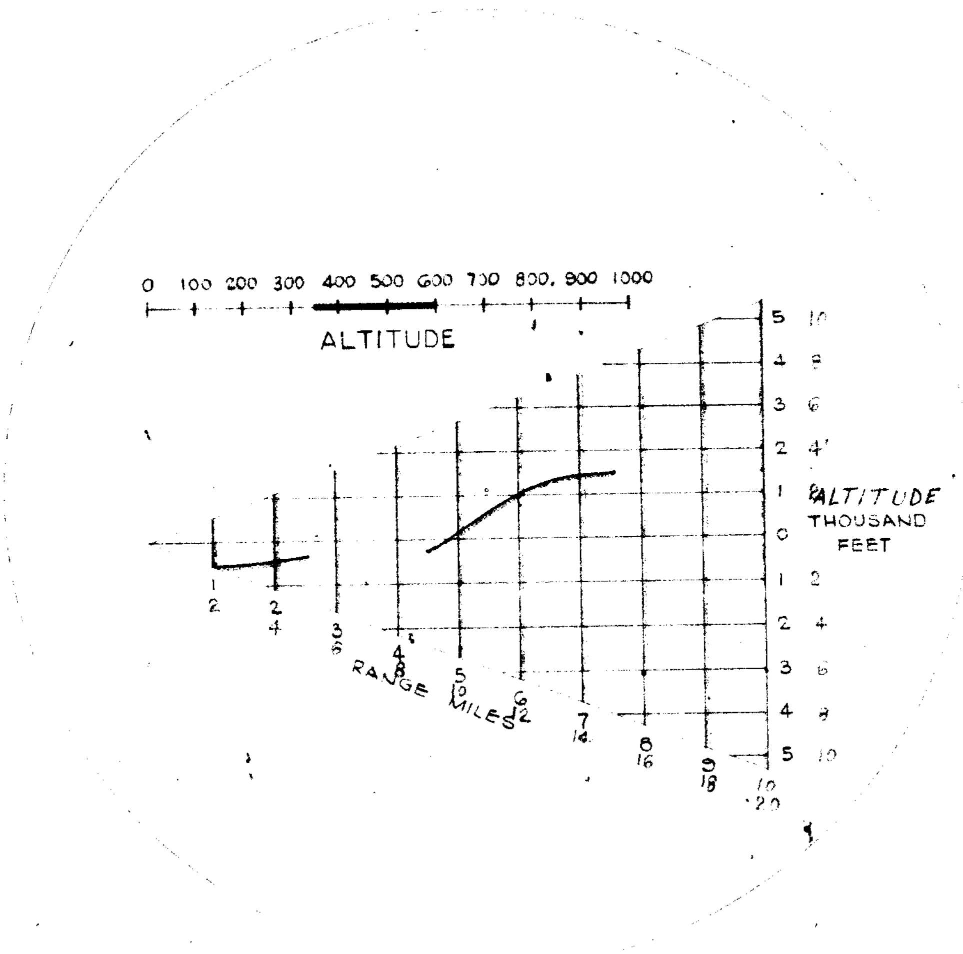

FIG. 15 PROFILE DISPLAY

MODULATOR

The modulator is a line type resonant charging pulser driving the MA207 magnetron through a 4:1 step up transformer. The repetition rate is 1365 pps, while the pulse width is 0.25 µs. The input power is 3ϕ at 115V and approximately 1 amp per line. The power supply designed to deliver 4KV at 35MA consists of a 3ϕ plate transformer, delta primary, star secondary, and a bank of silicon rectifiers with a 6ϕY connection. Filtering consists of an 0.5uf condenser. Resonant charging is achieved with a 16.5h choke.

The discharge circuit consists of an E-36(5956) thyratron and a 38 ohm network. The thyratron driving pulse is derived from an imput trigger pulse of 30 volts amplified by a modified blocking oscillator.

It is estimated that by careful packaging the size can be maintained less than 400 inches and the weight less than 12 pounds.

The transmitter consists of high voltage and plumbing compartments and the MA207 magnetron.

The high voltage unit contains a 4:1 pulse transformer and a magnetron filament transformer in addition to the various components associated with the magnetron current metering circuit.

The plumbing compartment contains the duplexer, consisting of the 6546ATR and the 6545TR tubes, a waveguide load isolator (KA131), the L.O. (VA97) and the receiver and AFC units.

The power input consists of 115V 3ϕ, +400VDC, +150VDC and -150VDC. The high voltage pulses from the modulator are 3KV at 80 amps. The peak pulse RF power output is 60KW (max.) with a 0.25µs width and 1365pps rate.

BALANCED MIXER, CRYSTALS AND IF AMPLIFIER

The crystals used are matched reversible pairs (D938MR). The crystals are used with a "rat race" type of balanced mixer. The balanced mixer and crystal holders can be used either for the reversible matched pairs or the normal matched pairs. However, the input coil of the IF amplifier is designed as a single ended input and requires that only reversible matched pairs be used.

The input stages of the amplifier are subminiature triodes (5718's) and make up a low noise (1.5 db @ 45 mcs) capacitance neutralized cascode circuit. The cascode circuit is followed by five subminiature pentode (6205) stages of amplification. The interstage coils are stagger tuned and comprise three maximally flat two pole networks in cascade with the wider bandwidth transitionally coupled input transformer. The manual gain control (MGC) and sensitivity time control (STC) voltages are applied to the control grids of the first three pentode amplifier stages.

The second detector is followed by a 5718 cathode follower output stage which drives a 90Ω coaxial cable.

The crystal currents are individually monitored by means of an external milliammeter.

The amplifier has a 3 db bandwidth of 4.2 mc, nominal operating gain of 91 db and a system noise figure (including TR and duplexer losses) of not more than 12.5 db.

STC AND RANGE GATE

The positive trigger (t = 0 yds) is used to trigger a variable delay multivibrator with a nominal delay of 2 to 4 usec. The output triggers another multivibrator that generates a positive range gate that is variable from 90 to 150 usec maximum range. An additional range will be available which may be selected. This will be variable from 200 to 300 usec.

The STC exponential waveform is variable in amplitude and duration and is mixed with the range gate.

Every one and one half seconds an altitude check is made by bypassing the 2 to 4 usec delay multivibrator. The variable range gate now starts at t = 0 yds and the receiver is turned on to amplify the ground return and main bang. Normally the main bang is blanked out by the 2 to 4 usec delay before the range gate is applied.

AFC

The AFC consists of an IF amplifier and discriminator and a diode-transitron control circuit. The IF section is a stagger tuned three stage amplifier with a bandwidth of 10MC centered at 46.5 MCPS approx. The Weiss discriminator circuit peak-to-peak separation is 6MCPS with the cross over point at 46.5 MCPS. This point can be adjusted to compensate for overall loop gain variations so that L.O. lock-up occurs at 45MCPS. The discriminator output, after being amplified by a video stage is fed to the control circuit. This consists of a search stopping diode detector and a phantastron. The plate voltage of this tube sweeps until positive pulses appearing at the input are rectified by the diode detector producing a negative bias. At this time the phantastron (or transitron) acts as a normal d-c amplifier with a gain of approximately 50. The plate voltage determined by the magnitude of the positive pulses then supplies the correct klystron repeller voltage for a 45 MCPS I.F.

Since this is not a null seeking device and operates on a certain error signal, the resultant IF signal can not be maintained exactly. Under most conditions the difference will not be in excess of 1 MCPS resulting in only minor system loss. If a true null seeking system were utilized, a disproportionate increase in size,weight and complexity would occur.

The klystron chosen for this application is the Varian VA-97. This tube is small, rugged and operates on readily available voltages. The electronic tuning range of 60 MCPS for the most part determines the pull-in range

AFC (Cont'd.)

of the AFC. The power output of 10 MW provides adequate excitation of the receiver and AFC mixer crystals.

POWER SUPPLY

The power supply will require three phase 115V, 400 cycle and +28DC volt inputs. The three phase voltage will be rectified, filtered, and regulated to provide outputs of +400, +300, +150, -300, and -150 volts. The +28 volts will be dropped and regulated by a transistorized power supply to furnish a +22 volt output. Filament power will be transformed from the 115V, 400 cycle line in each major unit to avoid the distribution of this relatively high current from a central source.

Rectification will be accomplished with three phase silicon bridge rectifiers. Each complete bridge will have dimensions on the order of 1½" x 2½"x 4½" or roughly the size of one rectifier tube. Since five D.C. voltages are required, and each would need at least three tubes, this results in a substantial space reduction. Utilization of three phase full wave rectification tripples the ripple frequency over that of a single phase full wave rectification and hence considerably reduces the filter requirements.

Series regulation will be performed with type 6080WA dual-triodes, and the reference voltage furnished by Zener diodes. Error amplifiers with gain on the order of 10^6 should provide regulation greater than 0.1%.

Series regulator tubes are quite bulky, relatively heavy, and require a large quantity of filament power. Recently Texas Instruments announced the availability of a junction silicon transistor type 2N389 which shows promise in this application. Though the savings in weight, space, and power would be substantial, immediate utilization would be pre-mature. Therefore, design is going ahead with conventional components to insure the existance of a suitable supply when needed. However, every consideration is being given to layout and design

POWER SUPPLY (Cont'd.)

so that these units may be incorporated with a minimum effort should they prove feasible. This consists primarily of mounting the transformers, time delays, filters, and other unaffected items on one chassis, and the regulators on a separate chassis. Utilization of a transistorized version would require only the construction of a small regulator to replace the original vacuum tube model.

The conventional system would occupy a cube roughly 9" x 15" x 14" and weigh on the order of 25 pounds. If the transistored version proves practical, the dimensions could be reduced to perhaps 9" x 12" x 14" and weight to about 20 pounds.

Line power required for the entire system will be on the order of 1500 volt-amperes.

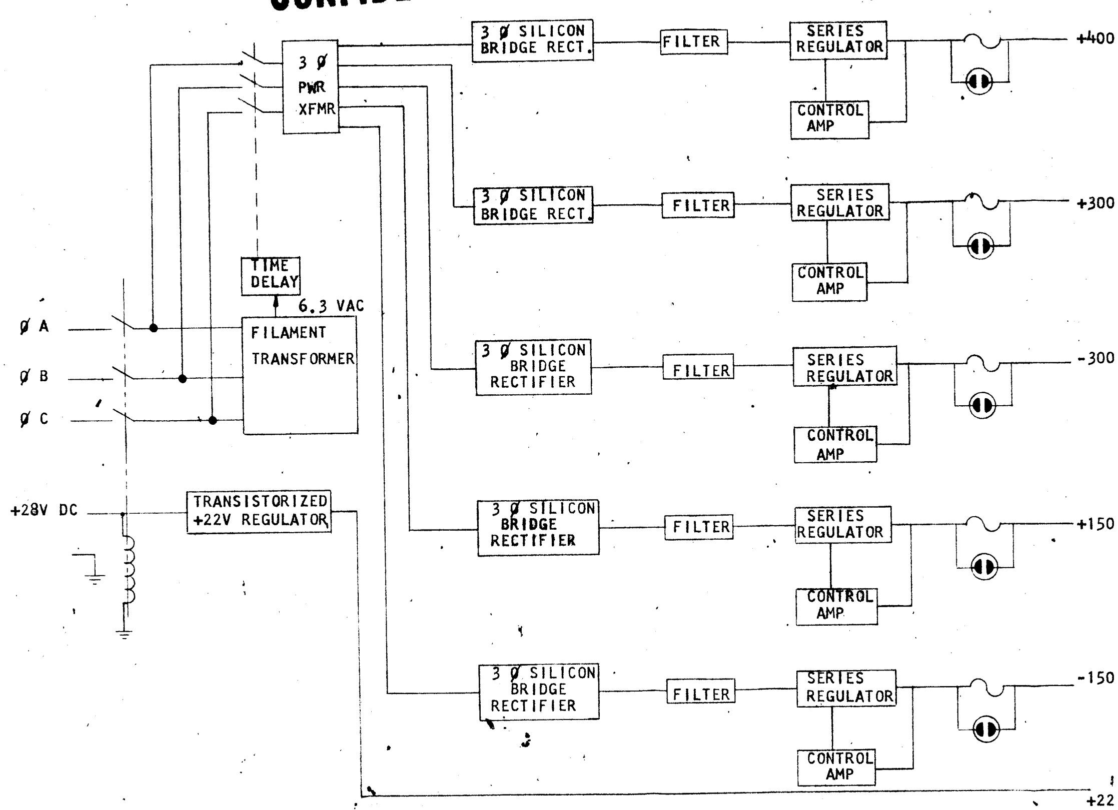

FIG. 16 POWER SUPPLY BLOCK DIAGRAM