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NRL REPORT NO. R-3317

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VIDEO MAPPING FOR THE DATA RELAY NAVIGATION SYSTEM

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VIDEO MAPPING FOR THE DATA RELAY NAVIGATION SYSTEM

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and
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July 14, 1948

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ABSTRACT

The Data Relay Navigation System makes use of combined radar and map video information, both obtained at the ground installation and sent by radar link to all equipped aircraft. Video mapping is the technique of scanning a map by a cathode-ray indicator (flying-spot scanning) and then, by means of a phototube, converting the light pulses to video signals. Many of the refinements required for best resolution of map data are discussed. The best general type of video amplifier at the output of the phototube is indicated. The most adequate type of maps for pilot navigational purposes are also dealt with. A typical mixing circuit is given incorporating a level control, so that the map data will not obscure radar targets.

PROBLEM STATUS

This is a final report on the Video Mapping portion of the Data Relay Navigation System. Work continues on the main problem.

AUTHORIZATION

NRL Problem No. R04-20D

VIDEO MAPPING FOR THE DATA RELAY NAVIGATION SYSTEM

INTRODUCTION

The Data Relay Navigation System employs a shipboard radar to gather information, which is then sent by means of a data link transmitter to all equipped aircraft. Its purpose is to provide navigational information to the pilot for aid in approach, traffic control, and landing on an aircraft carrier.[1] In order to orient the aircraft in respect to geographical points or arbitrary flight paths, or to insert written messages such as weather and other flight data, video mapping is employed. Maps of the area, or desired flight paths appear on the pilot's indicator and so enable him to see his own position in reference to these points. Since it is necessary that the map lines be fine so that radar targets are not lost on the combined display, the resolution of the mapping device must be the best obtainable. The map data must also be free of range errors in order to make it useful for navigational purposes.

Considerable work has been done on video mapping as a device for superimposing certain desired data on radar ground-station indicators. An early system developed was used in the AN/APS-T2 Emerson Trainer. The map used for this device was rudimentary in form and consisted mainly of simple identification markers. Therefore, the resolution requirements of the system were not great. Further investigation of the problems of video mapping were carried on at the Radiation Laboratory, M.I.T.[2] The fundamental design of the equipment discussed in this report is based on that work. However, many of the factors effecting resolution were not investigated there, since the map used was still simple in form, and slight attention was paid to meeting high resolution standards. Flying-spot scanning and phototube pick-up is also used in RCA's Simultaneous Color Television system,[3] where it is desired to reproduce faithfully a detailed image. Consequently, greater efforts were made toward improving resolution. Since the RCA system deals mainly with

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[1] The preliminary investigations and operational trials of the system were conducted with the equipment installed at a ground base.

[2] J. Hexem, "Video mapping" MIT Rad. Lab. Report No. 890, January 1946.

[3] G. C. Sziklai, R. C. Ballard & A. C. Schroeder, Proc. I.R.E., pp. 862-870, September 1947.

television, such factors as map construction, range errors, and mixing of video data, do not arise.

The most comprehensive analysis to date of certain aspects of video mapping has been carried out by the Research Products Division of the Stevens-Arnold Company.[4] This work was carried on concurrently with the NRL investigations discussed in this report. A good portion of their work, however, concerned the suitability of using television techniques in the pick-up of the scanned data, which was not investigated in the work carried out here. Other aspects of the system, such as amplifier design, rotating maps, optimum scanning-tube size, and choice of phosphor are discussed in considerable detail in their report. During the course of this discussion, reference will be made to the similarity or divergence of investigational results with those found in the Stevens-Arnold work. It should be pointed out that many of the problems faced in the design of the equipment described in this report arose largely because it was necessary to use a standard Navy indicator as a scanning device, since it was essential that a working unit be put into the field as soon as possible for an operational trial of the Data Relay system. As will be indicated later, some of the problems would have been considerably simplified, and better results would have been obtained, if certain needed components had been designed for this specific purpose.[5]

METHOD OF VIDEO MAPPING

The video mapping device consists of:

(1) A scanning c-r tube in a standard Navy indicator (VE),
(2) A map negative placed in front of the tube face,
(3) A phototube to pick up the variations in light output, and
(4) An amplifier to raise the level of the phototube output.

The flying spot of the c-r tube completely scans the map placed in front of it. The map data, consisting of transparent lines on an opaque background, or vice versa, cause a variation in the light reaching the phototube which corresponds to the map lines. The phototube converts these fluctuations into video pulses, and the accompanying video amplifier shapes them into rectangular pulses of greater amplitude.

The scanning beam is triggered by the transmitter pulse of the radar, and the deflection coil is rotated in synchronism with the radar antenna. The sweep length of the beam of the scanning tube is made to correspond to the scale of the map being used. Consequently, when map and radar data are superimposed, radar targets will be in the correct azimuth and range relationship to the map.

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[4] J. B. Higley, "Video Mapping Project," Consolidated Report Research Products Division of Stevens-Arnold Co., January 1948.

[5] Since the completion of a greater part of the NRL work, just such components have been made available commercially.

This map video is then mixed with the output of the radar receiver and the combined output modulates a link transmitter. The signals are received in the aircraft, and the composite picture is reproduced on the airborne indicator. The plane also receives transmitted rotational data, so that the airborne indicator is in synchronism with the radar antenna. The basic block diagram is shown in Figure 1. For bench test purposes, an antenna simulator was used. Since the radar associated with this system rotates at 6 rpm, a 6 rpm motor driving a 5G synchro provided the rotational information to the scanning unit.

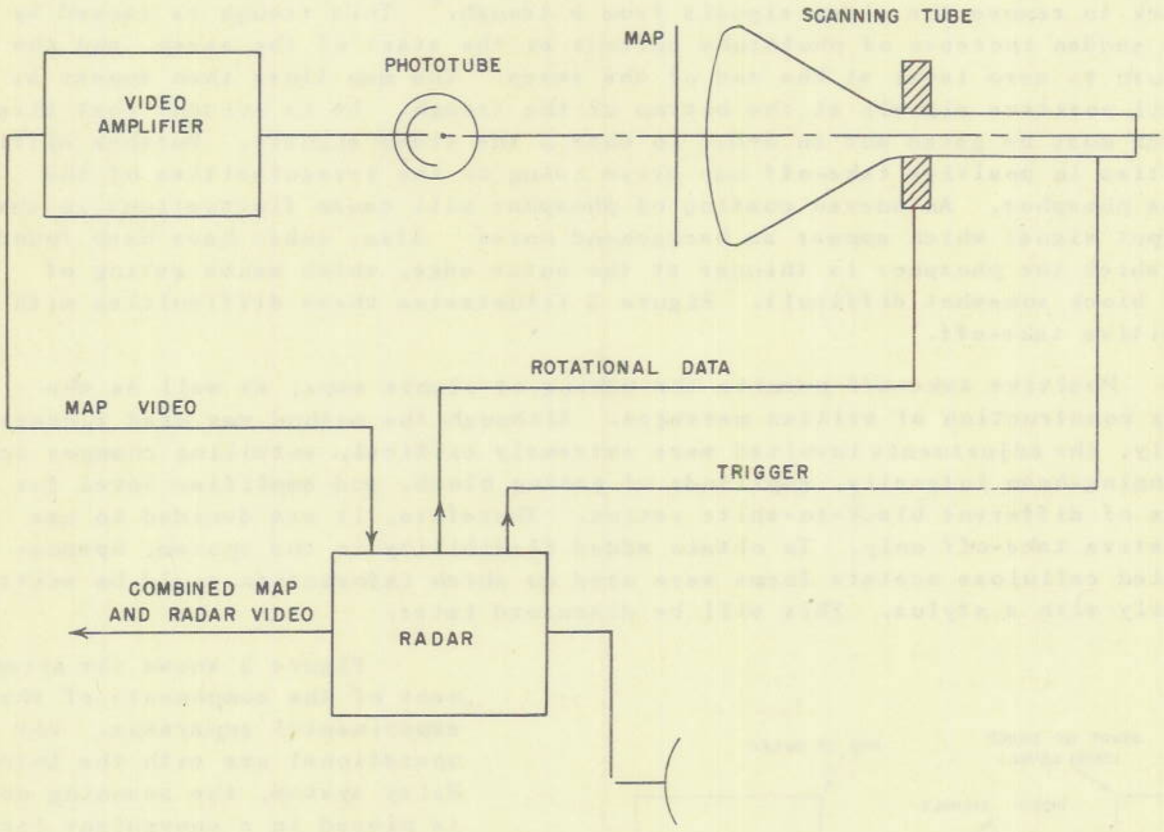


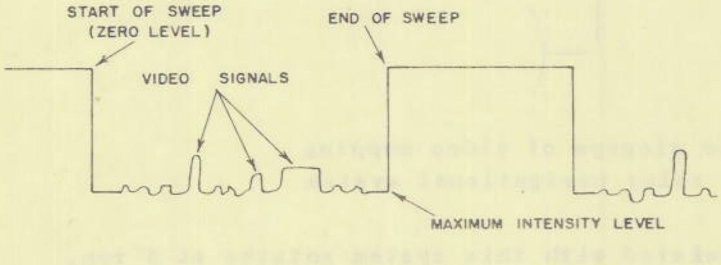
Figure 1 - Basic diagram of video mapping for use in data relay navigational system

An extension of the basic video-mapping pick-up method entailed the use of optical lenses placed between the scanning tube and the phototube. An objective lens focuses the scanning beam onto the map, which has been reduced in size. The light fluctuations are then directed to the aperture of the phototube by a condensing lens. This system, originally used in the Emerson Trainer, was tried and discarded. The technique added a good deal of complexity to the device and experimental results showed little, if any, improvement over the direct method of pick-up. The same conclusions concerning the use of lenses was reached in the Stevens-Arnold report.

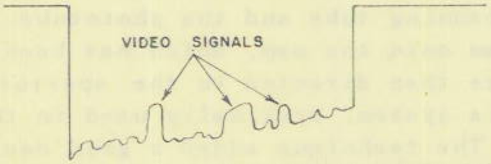
Extensive experimentation was carried out using both positive and negative take-off. Negative take-off refers to the use of an opaque surface on which the map lines are cut out. The phototube output then consists of negative video pulses from a zero intensity light level. In the positive take-off method, a transparent surface is used (or the face of the scope itself) and the map lines are imprinted with some opaque substance. This method is much more difficult to use, since it involves gating out a negative block to remove the video signals from a trough.[8] This trough is caused by the sudden increase of phototube current at the start of the sweep, and the return to zero level at the end of the sweep. The map lines then appear as small positive signals at the bottom of the trough. It is evident that this block must be gated out in order to obtain the video signals. Further difficulties in positive take-off may arise owing to the irregularities of the tube phosphor. An uneven coating of phosphor will cause fluctuations in the output signal which appear as background noise. Also, tubes have been found in which the phosphor is thinner at the outer edge, which makes gating of the block somewhat difficult. Figure 2 illustrates these difficulties with positive take-off.

Positive take-off permits the making of simple maps, as well as the easy construction of written messages. Although the method was used successfully, the adjustments involved were extremely critical, entailing changes in scanning-beam intensity, amplitude of gating block, and amplifier level for maps of different black-to-white ratios. Therefore, it was decided to use negative take-off only. To obtain added flexibility in the system, opaque-coated cellulose acetate forms were used on which information could be written easily with a stylus. This will be discussed later.

Figure 3 shows the arrangement of the components of the experimental apparatus. For operational use with the Data Relay system, the scanning unit is placed in a convenient location near the radar equipment where it can receive the necessary trigger and rotational data. Since the phototube has a cathode follower associated with it, the amplifier need not necessarily be close to the scanning equipment. The best location is near the radar receiver, so that the video map level may be controlled by the operator monitoring the console PPI.



(A) NOISE GENERATION



(B) EFFECT OF UNEVEN PHOSPHOR LAYER

Figure 2 - Difficulties in positive take-off

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[8] Hexem, op. cit.

RESOLUTION FACTORS

A good portion of the development work performed consisted of the investigation of factors affecting the resolution of the system.

Some of these factors considered are as follows:

(a) Type of phosphor of the scanning tube.
(b) Spot size of the scanning beam.
(c) Parallax error due to placement of the map.
(d) Effect of angular velocity of the scanning beam.
(e) Effect of range selection.

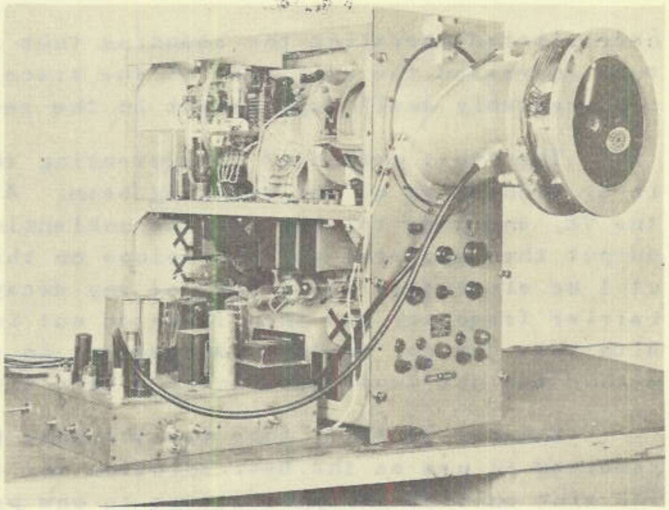

Figure 3 - Bench setup of video mapping generator

Type of Phosphor

As mentioned previously, the prototype equipment was designed for use with a standard Navy VE indicator, and the first experimental work was done with the original 7BP7 c-r tube in the scanning device. The decay characteristics of the P7 phosphor are poor for this application, the time for decay to 1 percent of light output being in the order of two to three seconds. This caused the output video pulse to have an exponential rise and decay, whereas the desired output corresponding to a map line should be a square pulse. The decay characteristic of the tube is improved if it is operated at low beam intensity, since in this case, only the short-persistence blue layer of the cascade phosphor is activated, and the long response of the yellow phosphor is present only to a small extent. An additional factor that permits the limited use of the 7BP7 is the fact that the photomultiplier tubes used, 931A and 1P21, both have maximum response in the blue (S-4) spectrum. Because of this property, it is possible, when the resolution requirements are not great, to use a 7BP7 tube in the scanning device. However, operation at low light levels decreased the signal-to-noise ratio of the phototube output, and adequate reproduction of map data for use in this system was not obtainable without further refinements.

Two additional methods of improving the resolution of the system with the 7BP7 were attempted. The first one entailed the use of optical filters placed between the map and the phototube. The filters used were Corning numbers 5874 and 5113, with polished surfaces. These filters allow only the short-persistence ultraviolet light to reach the phototube, and therefore should eliminate the deleterious effects of a long decay time. However, the filters also absorbed a good proportion of the total light emitted, which necessitated operating the scanning tube at higher intensities. This in turn increased the spot size of the trace, and the overall result was only a perceptably small improvement in the resolution of the map data.

The other method of circumventing the long decay time of the P7 tube is by modulation of the scanning beam. A 1-Mc multivibrator was built in the VE, and used to modulate the unblanking gate. The variations of light output then appeared as an envelope on the carrier. The use of a frequency of 1 Mc eliminated the effect of any decay time greater than 1 μ sec. The carrier frequency was then filtered out in the input to the video amplifier. With this device, decided improvement in resolution was obtained and this method was not superseded until a tube with a better phosphor was obtained.

Finally, a 7BP11 tube was obtained for this specific purpose, and has remained in use as the best solution for the present status of the problem. The zinc sulfide phosphor decays to one percent of its maximum value in 0.005 seconds, and furthermore, has a very high light output. It appears to be the most suitable tube for use in a VE indicator mapping device.

The phosphor with the fastest decay time, zinc oxide (P15), ideal for use in a video mapping system, was not available during the development of the equipment, but has recently been commercially produced in the 5WP15 tube. As will be indicated later, this tube corrects an additional shortcoming in the present equipment, and for a long-range program including the design of a new indicator, would be the logical choice. The second choice would be a 5FP11, a flat-faced tube, which does not require the extremely high operating potentials, 27 Kv, that the 5WP15 requires.

Spot Size

The most obvious factor influencing the resolution of the system is the spot size of the scanning beam, which should be made as small as practicable. The resolution of a PPI scope can be defined in terms of lines, similar to television standards. The line resolution is equal to the tube diameter divided by the spot size. Since spot size is roughly proportional to tube diameter, resolution is essentially the same for all tube sizes. The tube diameter refers to the useful portion of the tube; for a 7BP7, this diameter was set at 5.6 inches. The exact measurement of spot size is difficult and the human eye cannot be relied on as a measuring device. If trace width is measured between the points where brightness is down 50 percent from maximum, the eye cannot judge this 6-db drop, and will usually read a much greater line width.

Reduction of spot size was accomplished by operating the tube at its highest rated potentials. Anode voltage was increased from 5 to 8 Kv by the addition of an r-f power supply built into the VE. Actually, this voltage decreased the spot size only slightly but the increased light output permitted operation at lower beam intensities, which accomplished the desired result. Increasing the voltage on the second grid has an appreciable effect on spot size. In the VE indicator this grid is used for injection of the unblanking pulse, which was raised in amplitude from 275 to 550 volts. In addition it was necessary to place higher potentials on the sweep amplifier and on the focusing coil. To do this a 550-volt power supply was built into the VE indicator. Although the supply was used for both the unblanking and sweep amplifier 807's, since these tubes operated alternately the current drain was not excessive. Figure 4 shows the circuit changes made in the VE for spot size reduction. The nominal spot size of a 7BP7 is 0.8 mm at 200 microamperes beam current. With the tube operated at low intensity, this size is reduced approximately 50 percent. The increased potentials applied to the tube resulted in a further reduction so that the final spot size was in the order of 0.35 mm.

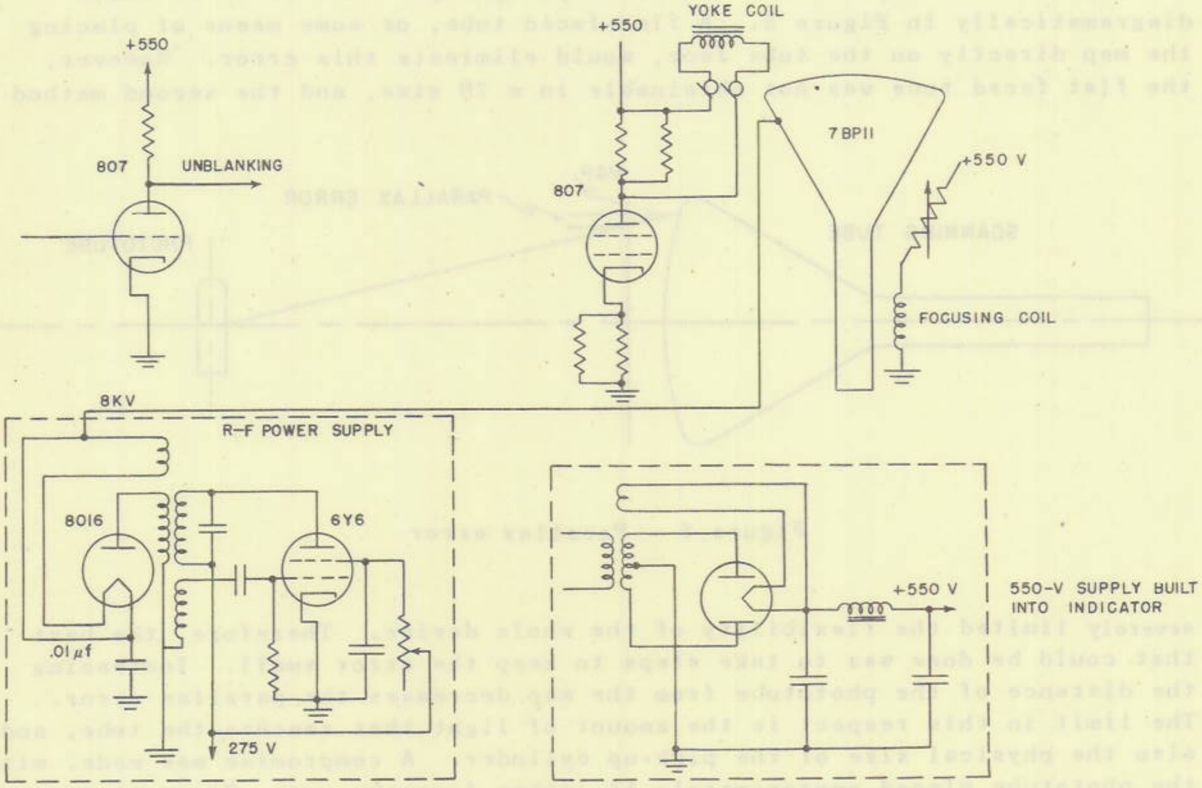

Figure 4 - Circuit changes to VE indicator for spot-size reduction

There is some question concerning the effect of beam intensity on resolution. On the basis of the previous definition of trace width, moderate changes in beam intensity (10-50 µa) show little effect on width.[7] However in respect to the resolution of the system, the definition is meaningless, since the phototube responds to the total light emitted from the screen and does not limit itself to the light level between the 6-db points. In

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[7] Higley, op. cit.

addition, aberration, due to slight misalignment of the gun structure, and space charge effects cause a visually discernable increase in spot size with increase in beam current. Considering these factors, it is advisable to keep the beam intensity as low as possible for best map resolution.

Parallax Error

The map is placed as close as possible to the face of the scanning tube. Unfortunately, the face of the tube used is curved, and since the phototube aperture is much smaller in area than the map surface, the result is a parallax error that makes itself evident as a range distortion and a diffusion of the map data at the outer periphery. This error is shown diagramatically in Figure 5. A flat-faced tube, or some means of placing the map directly on the tube face, would eliminate this error. However, the flat faced tube was not obtainable in a 7B size, and the second method severely limited the flexibility of the whole device. Therefore, the best that could be done was to take steps to keep the error small. Increasing the distance of the phototube from the map decreases the parallax error. The limit in this respect is the amount of light that reaches the tube, and also the physical size of the pick-up cylinder. A compromise was made, with the phototube placed approximately 16 inches from the map. Since the curvature of the tube increases toward the outer edge, and the angle subtended at the photocathode is greater, a further reduction in parallax error can be made by limiting the trace length to some percentage of the full tube radius. A shortening to approximately 2.8 inch radius coupled with the 16-inch placement of the phototube, limited the parallax error to 1.5 percent of the full sweep length.[8] This is the amount of error resulting from the assumption that the sweep as projected on the map is linear.

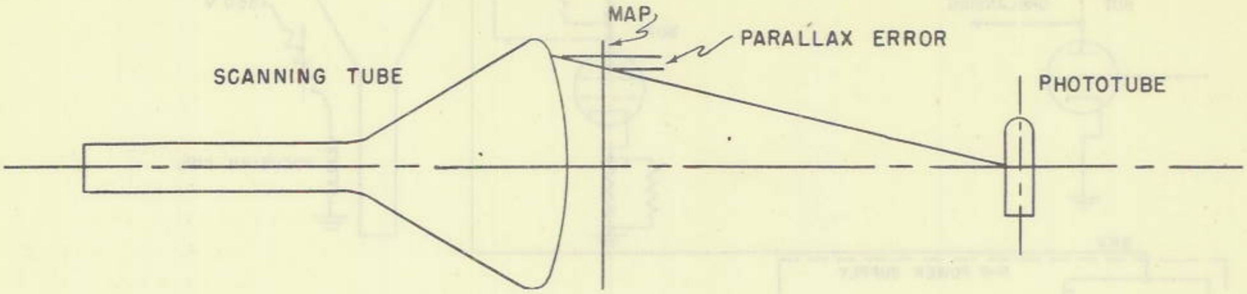

Figure 5 - Parallax error

An attempt was made to reduce this error to zero by increasing the speed of the sweep as it approaches the outer edge, giving it a rising slope

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[8] Hexem, op. cit.

characteristic. If properly adjusted, this sweep compensation will cause the trace projected on the map to be approximately linear. However, the adjustment appeared to be extremely critical, and the resulting distortion in the center of the sweep was sufficient to make its suitability questionable. At present, it is not included in the equipment circuitry.

Another approach to the map-scanning problem involves the use of a monoscope. As in the conventional monoscope, the map data is printed on aluminum foil, and constructed within the tube. The scanning of the map is performed internally, which eliminates the use of the phototube. Parallax error is completely eliminated. Of course, the major shortcoming is the inflexibility of the system, since separate indicators are needed for different maps, and still an additional one for the transmission of written information. However, it is conceivable that when map data is used on the ground for aircraft traffic control purposes, one map, or at the most two, would be sufficient. The use of a monoscope should show a marked improvement over the methods previously discussed in respect to the resolution of the map details. Unfortunately, no test data on it has been completed for inclusion in the report.

Effect of Angular Velocity

Owing to the rotation of the trace beam, the tangential component of velocity increases as the spot travels out to the periphery of the tube. Even though the instantaneous light intensity is the same throughout the sweep, the total light reaching the phototube from equal scanned areas along a radius will decrease with the distance from the center. This is shown in Figure 6 and its effect on map reproduction in Figure 7. This results in less light reaching the phototube from the outer map areas and consequently in a loss in definition and a decrease in the signal to noise ratio. The detect was corrected by the use of a saw-tooth voltage applied to the first grid of the scanning tube. The voltage was derived from the sweep amplifier of the VE, and so had the correct gate length for all ranges. Its amplitude was made adjustable, and the control was brought to the front of the indicator. Figure 8 indicates the changes made to the VE in order to accomplish this correction.

Effect of Range Selection

A cathode-ray tube is essentially an integrating device, and the overall resolution of the system is dependent on the storage effects of the tube. So far, factors involved in the design of the pick-up mechanism have been discussed, but it is obvious that in the final analysis it is the reproducing indicator that determines the resolving ability of the system (discounting the limitations of the human eye). It was previously stated that the spot size of the scan is a limiting factor in the resolution of the mapping device. The overall resolution, however, is a function of range selection, and it will be shown that, on short ranges, a reduction of spot size will be of no help in improving resolution. Optimum resolution occurs when the spot travels its own diameter in the time equivalent of a map line.

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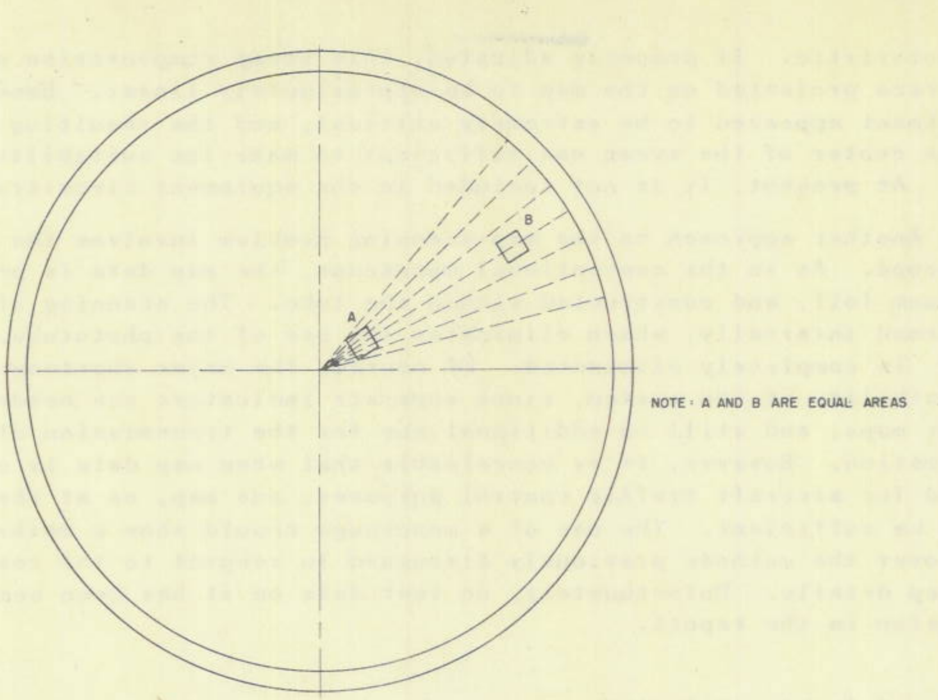

Figure 6 - Loss of light at periphery due to angular velocity of scanning beam

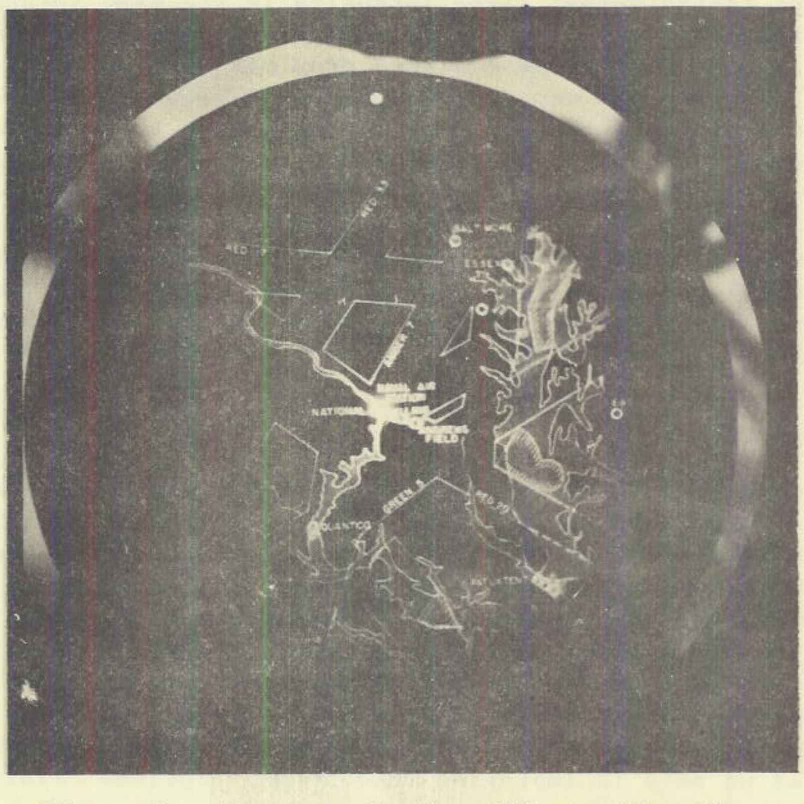

Figure 7 - Map reproduction illustrating the falling off of light intensity due to angular velocity of scanning beam

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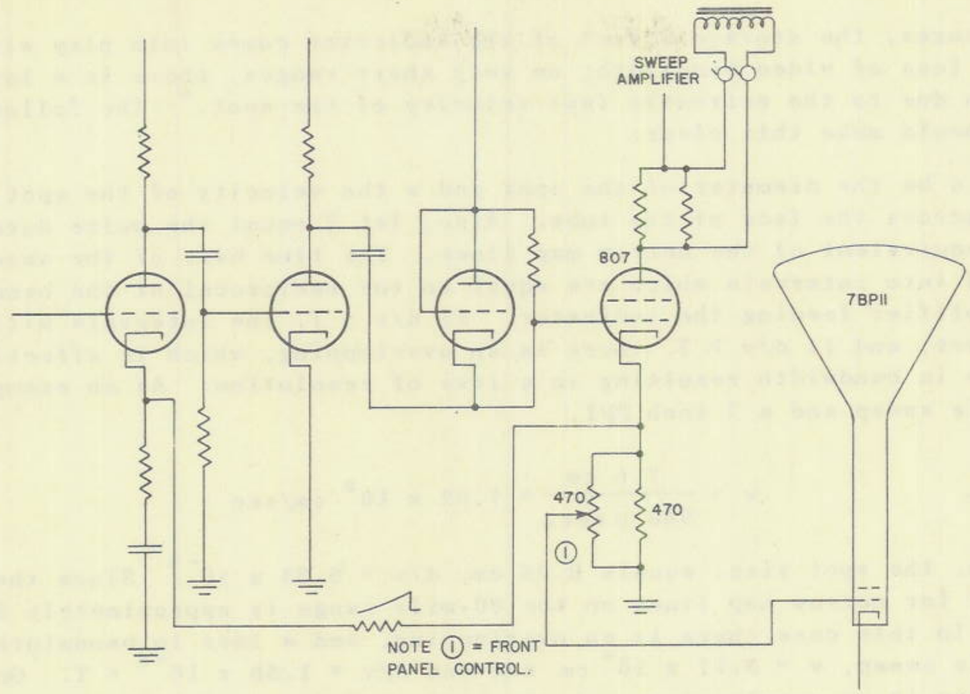

Figure 8 - Method of compensating VE for effect of angular velocity

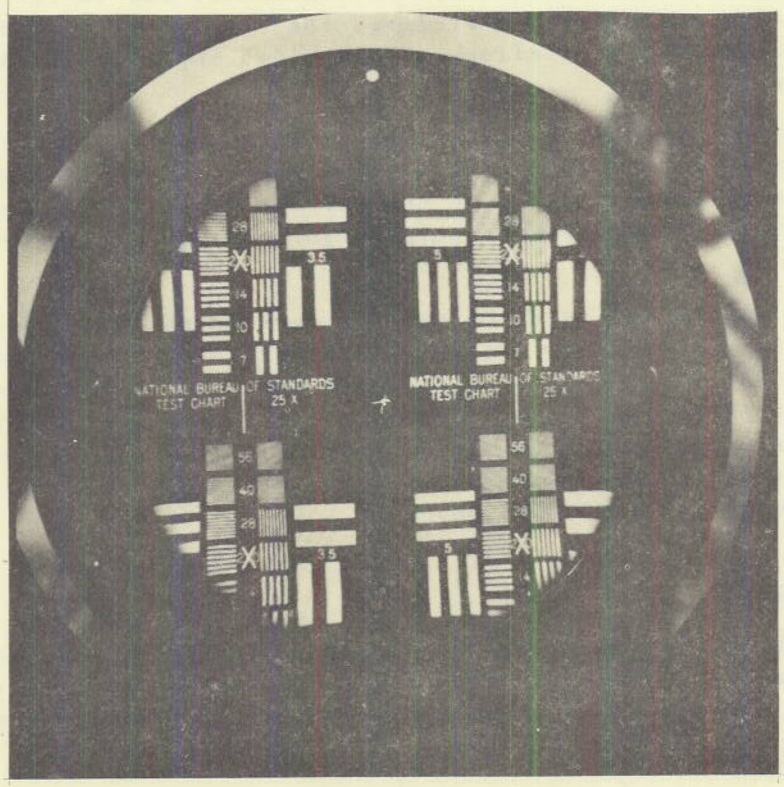

Figure 9 - Reproduction of resolution chart on the 50-mile range

On long ranges, the storage effect of the indicator comes into play with a resulting loss of video bandwidth; on very short ranges, there is a loss of definition due to the extremely fast velocity of the spot.[9] The following example should make this clear:

Let d be the diameter of the spot and v the velocity of the spot as it is swept across the face of the tube. Also, let T equal the pulse duration, the time equivalent of the narrow map lines. The time base of the sweep can be divided into intervals which are equal to the reciprocal of the bandwidth of the amplifier feeding the indicator. If $d/v < T$, the intervals will be spread apart, and if $d/v > T$, there is an overlapping, which is effectively a decrease in bandwidth resulting in a loss of resolution. As an example, on the 80 mile sweep and a 7 inch PPI,

$$v = \frac{7.6 \text{ cm}}{960 \ \mu\text{sec.}} = 7.92 \times 10^{3} \text{ cm/sec}$$

If d, the spot size, equals 0.05 cm, $d/v = 6.33 \times 10^{-6}$ Since the pulse duration T for narrow map lines on the 80-mile range is approximately 3×10^{-6} $d/v > T$. In this case there is an overlapping, and a loss in bandwidth. On the 20-mile sweep, $v = 3.17 \times 10^{4}$ cm sec and $d/v = 1.58 \times 10^{-6} < T$. On this range, there is no overlapping, and the indicator does not limit the overall bandwidth of the system.

The effective video bandwidth of the indicator due to the storage factor, can be defined as v/d. Therefore, the indicator bandwidth is greater on short ranges, and any limitations of the video amplifier bandwidth will make itself evident.

Figures 9 and 10 show the appearance of a resolution chart with the indicator operating on the 50- and 20-mile ranges. It can be seen that the definition appears to be inferior on the shorter range. A further improvement in resolution can be obtained only by increasing the video-amplifier bandwidth.

Operation of the indicator on short sweeps makes apparent other distortions inherent in the system: (a) the nonlinearity of the scanning-tube sweep causes a distortion that is most noticeable in the reproduction of written map data (Figure 11), and (b) any lag or unevenness of the servo drive system also causes distortion in the reproduced data. All factors considered, it can be expected that the relative accuracy of the reproduced data will become poorer as the sweep range is made shorter.

PHOTOTUBE ASSEMBLY

The phototube used is a 931A multiplier. Provision was made for the use of as many as four tubes in parallel. After comparative tests, one tube, operated at its maximum rated potentials, showed the lowest noise level and

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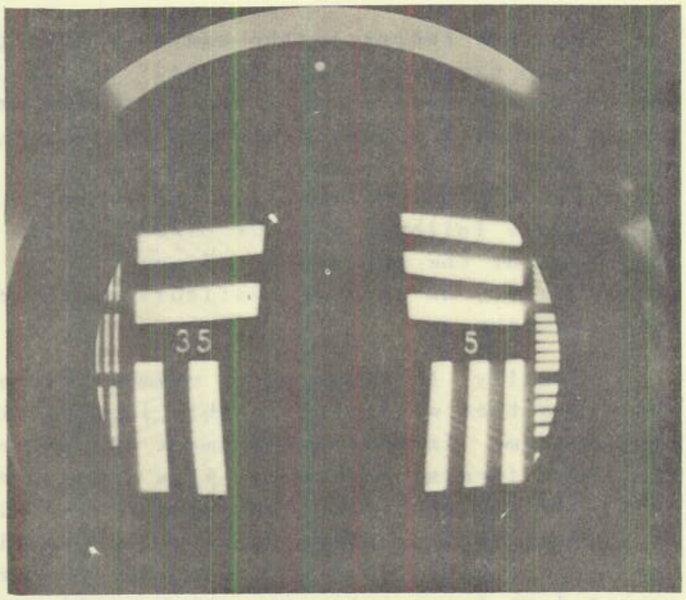
[9] L. N. Ridenour, "Radar systems engineering" Sec. 2-11, McGraw Hill, 1947.

Figure 10 - Reproduction of resolution chart on the 20-mile range



at the same time provided sufficient input to the amplifier. A 1P21 tube was also tried. This tube is similar in all respects to the 931A except that it has a much higher current amplification. The tube seemed to generate much more noise than did the 931A, and so was not used. Higley[10] also preferred a 931A, but rejected the 1P21 because its performance did not warrant its additional cost. It is conceivable that in other equipments, where for purposes of minimizing parallax error the phototube is placed very far from the map, a 1P21 phototube would prove to be of considerable advantage. The phototube is placed along the center axis of the scanning tube. Any deviation from the axis will cause the parallax error from one sector of the map to be greater than the average amount.

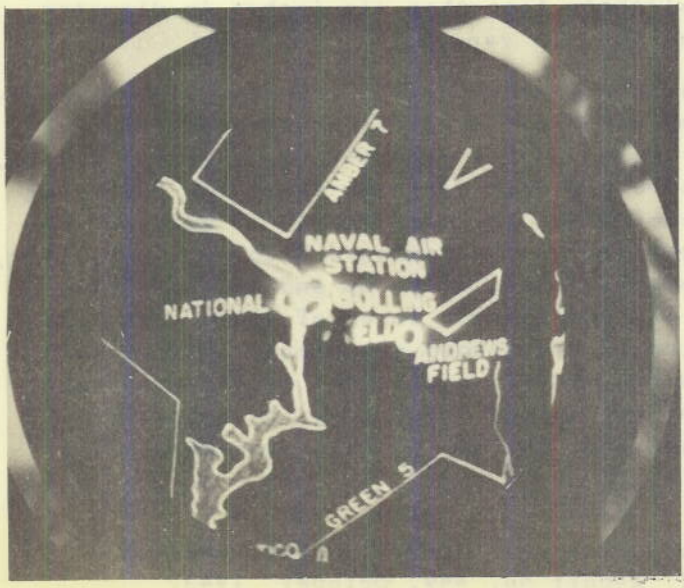


Figure 11 - Reproduction of map on short range showing distortions caused by nonlinearity of sweep

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[10] Higley, *op. cit.*

Another factor in the use of a 931A phototube is the increase of noise level with a rise in temperature. In this assembly, a 6AG7 cathode follower was originally placed near the phototube inside the pick-up cylinder. It was felt that the heat given off by this tube could be contributing to the noise level of the output of the phototube since this tube operates best at low ambient temperatures. In the improved barrel assembly being constructed, the cathode follower will be placed on the outside where it cannot affect the operation of the phototube. Since the new assembly is not ready for experimental trial, no data is available on the extent of improvement such placement may make.

Finally, there is under commercial development a new type of multiplier phototube that will considerably improve the performance of the entire mapping system. In this development the photo-cathode surface completely covers the front face of the tube. If a five-inch-diameter tube of this type were available for mapping use in conjunction with a seven-inch scanning tube, it is evident that parallax error would practically disappear. Furthermore, the current amplification is exceedingly great, and the scanner could be operated at lower intensity which would mean reduced spot size.

The pick-up assembly is constructed so that the maps can be placed very close to the scanning tube face with the map holder easily removable for purposes of changing maps without undue delay. The barrel is hinged and can be swung up out of the way when it becomes necessary to calibrate the sweeps, change tubes, etc.

MAP CONSTRUCTION

The maps were taken from the U. S. Coast and Geodetic Survey Aeronautical Charts. These charts use the Lambert conical projection, which for an 80-mile range have a negligible error. The use of Mercator-projection maps would in itself cause a 1.5 percent error for the same range, at 50° latitudes.[11] The map data desired was drawn from the charts and then photographed and reduced to negatives slightly less than six inches in diameter. Maps were made for both the 80- and 50-mile ranges.

The basic problem that arose in map construction concerned the investigation of the type of data that the pilot or navigator would find most useful. The equipment is capable of reproducing a map with considerable detail, but care must be taken that excessive map data does not cause the obscuring of radar targets. The more map lines used, the more likely it will be that radar echoes will be lost when appearing on the combined display. Many maps, containing various amounts of information were drawn up and operationally tried in the system. Figures 12, 13, and 14 show three of these maps, all centered around the present location of the ground equipment. Figure 12 shows water areas, large cities in the sector, airfields, danger areas and the major airways. This map is the extreme in respect to the amount of information included. It is obvious that the map contains too many white

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[11] N. U. Mayall, The identification of signals on PPI photographs for construction of radar maps," M.I.T. Report No. 449, October 1943.

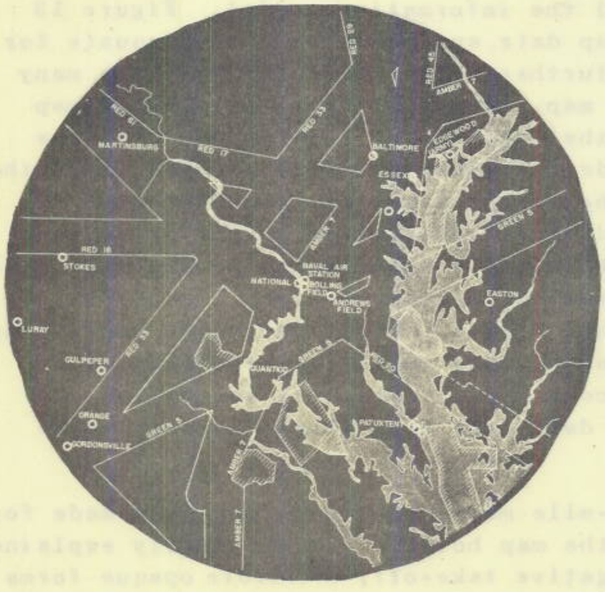


Figure 12 - Map negative containing a maximum of information

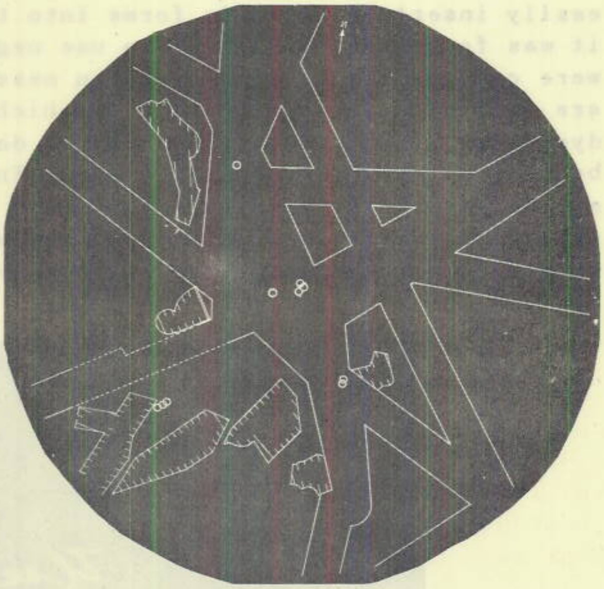


Figure 13 - Map negative with the amount of data reduced

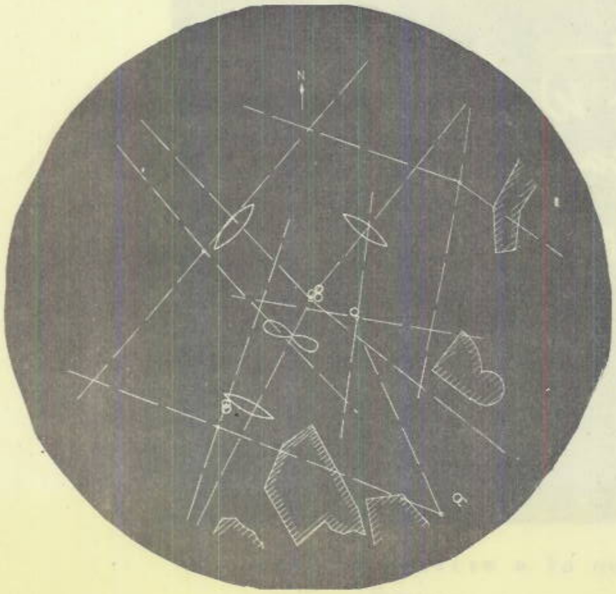
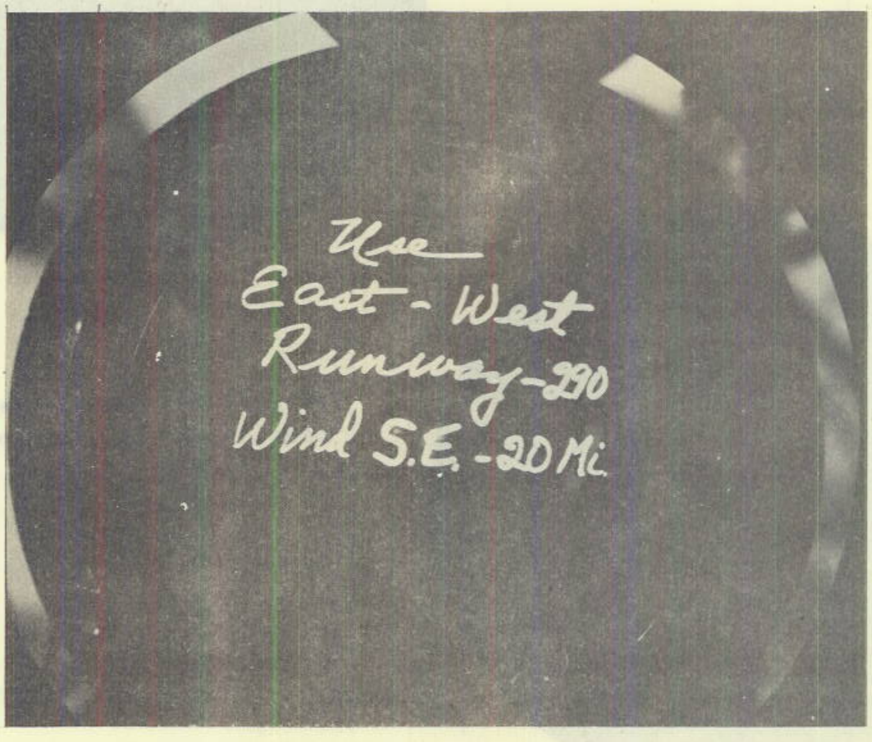


Figure 14 - Map negative considered most acceptable

areas, although the pilot may find all the information useful. Figure 13 shows an attempt to cut down on the map data and still make it adequate for air navigational purposes. However, further tests indicated that too many obscuring areas still remained on the map. Figure 14 was the type of map finally chosen as the one containing the most useful information with the minimum number of lines. The airfields are shown as small circles, with the legs of the radio ranges as lines. The danger areas are included as being of considerable importance. For added range information to the pilot, the legs of the radio ranges are broken at ten-mile intervals. It was felt that name identification of the airfields was not necessary since the pilot received that information from the range signal. Final decisions concerning the data to be placed on the map cannot be made until the reactions of a number of pilot navigators have been considered. From the standpoint of readability of combined map and radar data, the form chosen appears to be the most adequate.

Besides the standard 50- and 80-mile maps, provision has been made for easily inserting write-in forms into the map holder. As previously explained, it was found most expedient to use negative take-off; therefore opaque forms were constructed on which written messages could be inscribed. The forms are made of cellulose acetate on which is placed a coating of Durol black dye mixed with tallow. The coating does not harden, and a blunt stylus can be used as the writing instrument. The ease of message construction allows a wide variety of written information to be sent up to the pilot. Such data as wind direction and velocity, special flight instruction (Figure 15) and warnings can be transmitted and appear visually before the pilot.



Use
East - West
Runway - 290
Wind S.E. - 20 Mi.

Figure 15 - Reproduction of a written message

VIDEO AMPLIFIER

The amplifier must be able to accomplish an important compensating function. As the flying spot of the scanning beam travels from a dark area to white and then to dark again, it is desirable that the output of the phototube be a sharp rectangular pulse. The widths of these pulses, obviously, vary according to the width of the map lines being scanned. However, due to the decay characteristics of the phosphor, the light reaching the phototube has an exponential rise and decay, as shown in Figure 16.

Figure 16 - Phototube output of a scanned line

This figure may at first appear erroneous, since it is known that the build-up time of the phosphor is almost instantaneous, and only the decay is exponential. On careful analysis, it can be seen that the exponential rise is due to the movement of the spot in time. As the spot travels from an opaque to a transparent map line, the light reaching the phototube will at first be the maximum instantaneous output of the excited phosphor. As the spot moves, the light output then becomes the sum of the initial maximum brightness plus the decay output of the area just scanned.[12] Therefore the light build-up as a function of time as the spot moves, is proportional to the integral of the decay characteristic of the phosphor. If the decay of the phosphor is an exponential of the form e^{-t}, then the light build-up can be expressed as $1 + e^{-t}$, which is proportional to the definite integral of e^{-t}.

The amplifier must provide some means of compensating for this exponential wave form in order to produce clear, square pulses in its output. Two different types of amplifiers were constructed, each accomplishing this compensation by a different method. The first amplifier employed base-line clipping and limiting to produce the desired square pulses. The circuit is shown in Figure 17. V2 operates near cut off and therefore accomplishes the necessary clipping. V3 is at zero bias and acts as a limiting amplifier. V4 is a cathode follower whose input is clipped further by a bleeder bias arrangement in the grid circuit.

The second amplifier circuit, Figure 18, employing equalizing networks, is based on a design used with a P15 phosphor. In our case, however, the design of the networks was more difficult because of the P11 phosphor in the scanning tube. The decay characteristic of a P11 phosphor is not exponential, but rather a power law (t^{-n}) decay; therefore the optimum compensating network cannot be a single r-c circuit. The P11 phosphor decay curve must be fitted with a combination of exponentials and the two or three used, placed in different stages of the amplifier.[13] On the other hand, the decay curve

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[12] Sziklai, op. cit.

[13] Brückersteinkuhl, "The persistence of phosphor and its meaning for flying spot scanning," A. G. Fernseh, pp. 179-186, August 1939.

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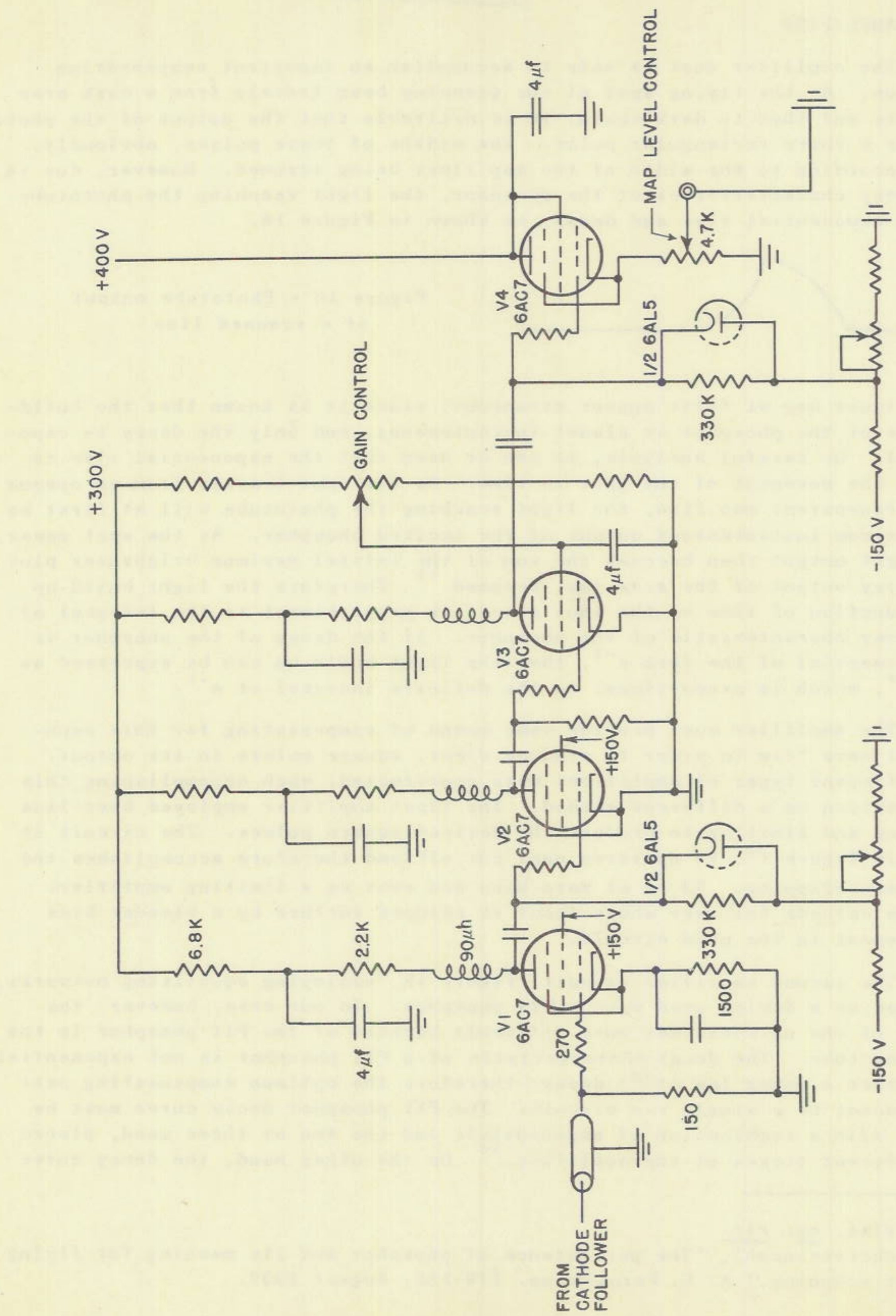

Figure 17 - Video amplifier employing clipping and limiting

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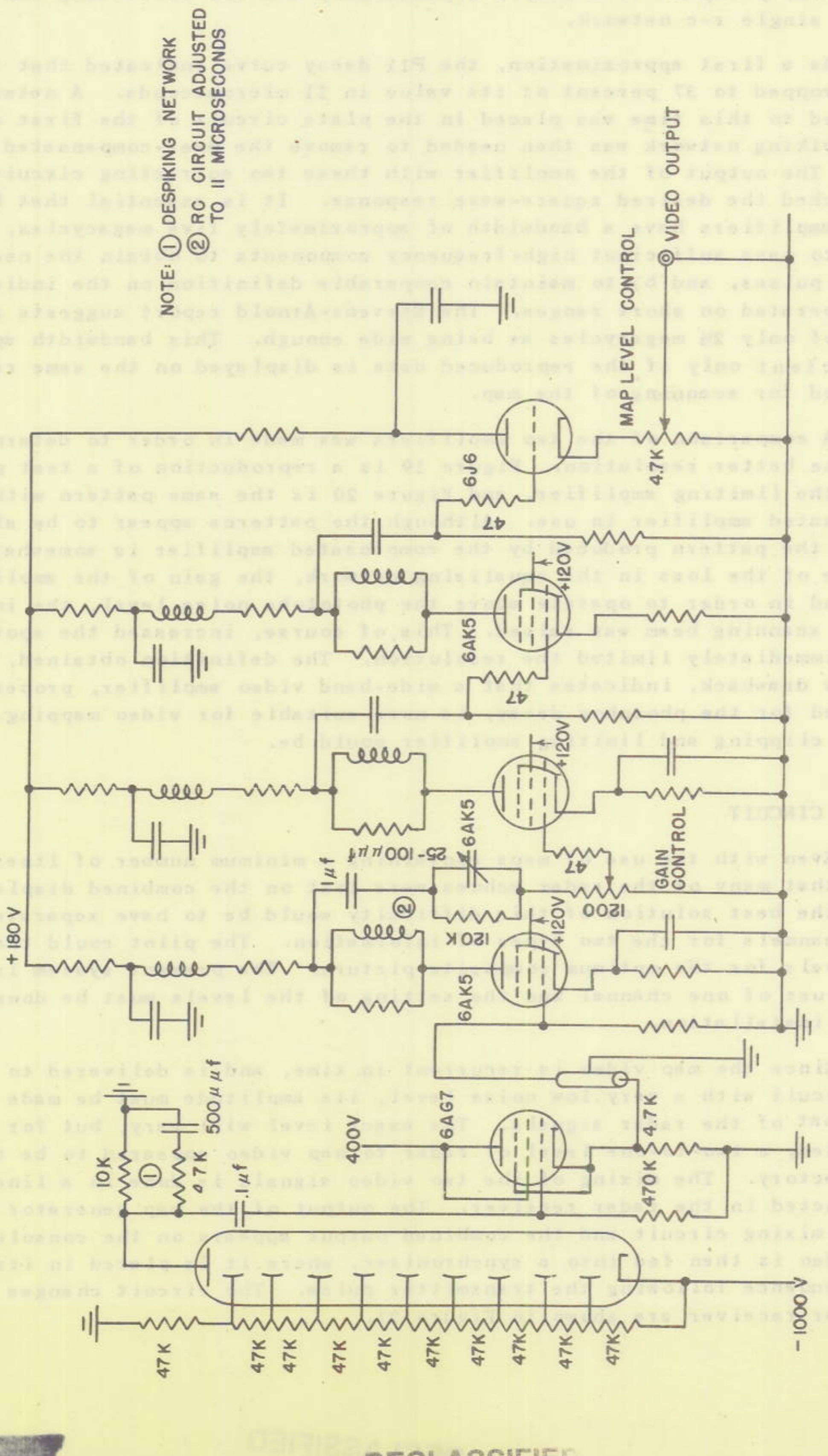


Figure 18. Phosphor-compensated video amplifier

of the P15 phosphor is a simple exponential, and the correcting can be done with a single r-c network.

As a first approximation, the P11 decay curve indicated that the phosphor dropped to 37 percent of its value in 11 microseconds. A network adjusted to this time was placed in the plate circuit of the first stage. A de-spiking network was then needed to remove the over-compensated leading edge. The output of the amplifier with these two correcting circuits approached the desired square-wave response. It is essential that both of these amplifiers have a bandwidth of approximately five megacycles, a) in order to pass sufficient high-frequency components to obtain the necessary square pulses, and b) to maintain comparable definition on the indicator when operated on short ranges. The Stevens-Arnold report suggests a bandwidth of only 2½ megacycles as being wide enough. This bandwidth appears sufficient only if the reproduced data is displayed on the same range employed for scanning of the map.

A comparison of the two amplifiers was made in order to determine which gave the better resolution. Figure 19 is a reproduction of a test pattern using the limiting amplifier, and Figure 20 is the same pattern with the compensated amplifier in use. Although the patterns appear to be almost alike, the pattern produced by the compensated amplifier is somewhat better. Because of the loss in the equalizing network, the gain of the amplifier is low, and in order to operate above the phototube noise level, the intensity of the scanning beam was raised. This, of course, increased the spot size, which immediately limited the resolution. The definition obtained, in spite of this drawback, indicates that a wide-band video amplifier, properly compensated for the phosphor decay, is more suitable for video mapping purposes than a clipping and limiting amplifier would be.

MIXING CIRCUIT

Even with the use of maps containing a minimum number of lines, it was found that many of the radar echoes were lost on the combined display. Probably the best solution of this difficulty would be to have separate r-f link channels for the two types of information. The pilot could then adjust the levels for the optimum composite picture. The present system is limited to the use of one channel and the setting of the levels must be done at the ground installation.

Since the map video is recurrent in time, and is delivered to the mixing circuit with a very low noise level, its amplitude must be made smaller than that of the radar signals. The exact level will vary, but for the tests conducted, a two-to-one level of radar to map video appeared to be the most satisfactory. The mixing of the two video signals is done in a linear mixer constructed in the radar receiver. The output of the map generator is fed to the mixing circuit and the combined output appears on the console PPI. The video is then fed into a synchronizer, where it is placed in its proper time sequence following the transmitter pulse. The circuit changes in the SP radar receiver are shown in Figure 21.

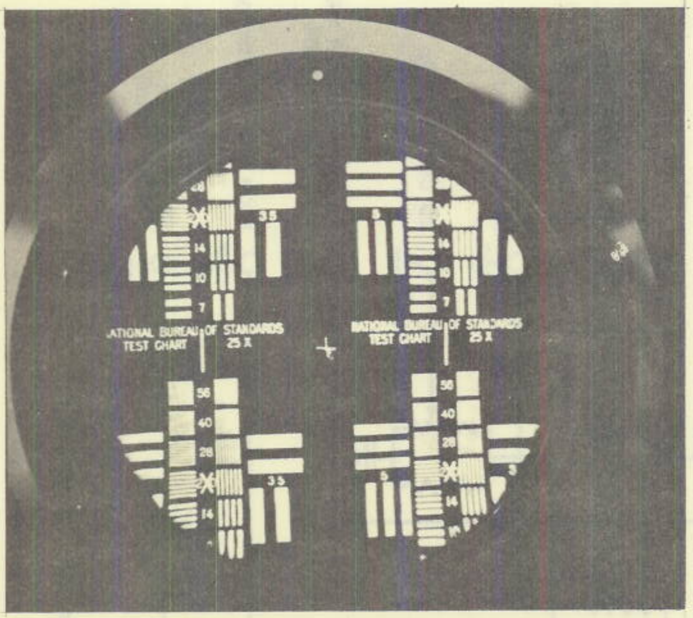


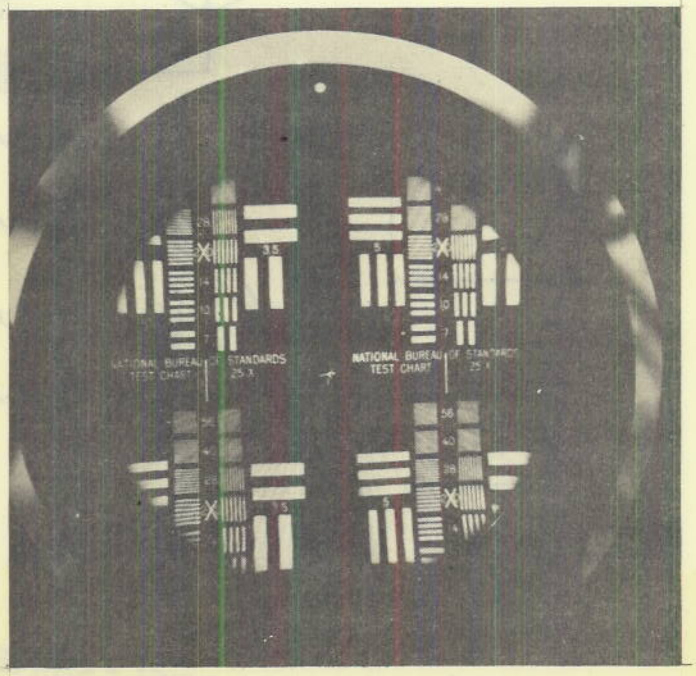
Figure 19 - Reproduction of resolution chart using the clipping and limiting amplier

CONCLUSIONS

Some of the design considerations for best performance of a video mapping system are as follows:

(1) A direct pick-up system without the use of optical lenses appears to be the most satisfactory and simplest device. Lenses do not improve the resolving ability to any extent and the added components make mechanical adjustment difficult.

Figure 20 - Reproduction of resolution chart using the phosphor-compensated amplifie



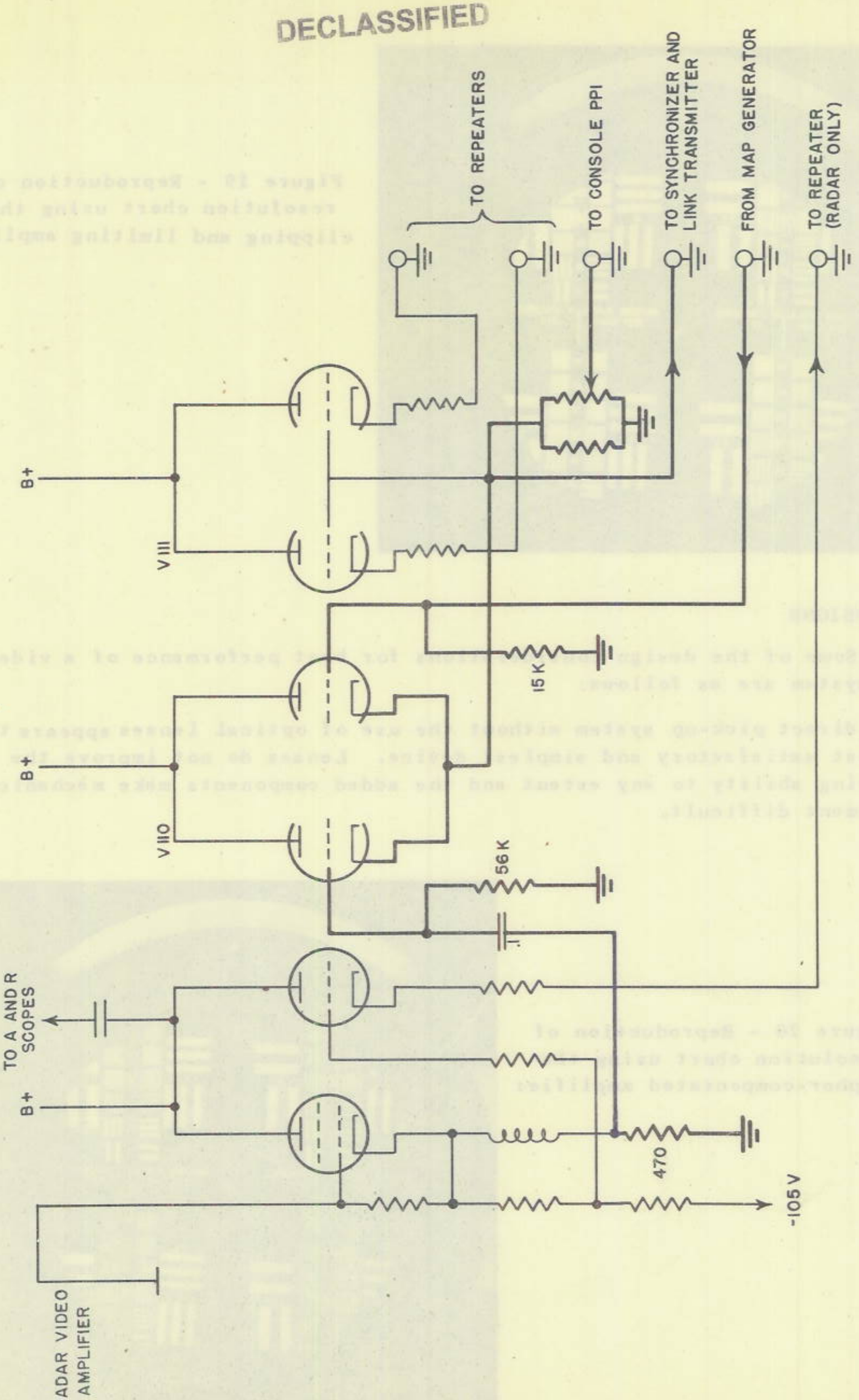


Figure 21 - Video mixing circuit in SP radar receiver

(2) It is essential that the scanning tube have a phosphor with an extremely fast decay time in order to obtain good resolution. Of the phosphors available for use during this investigation, P5 had the fastest decay time, with the P11 next in order. The P11 phosphor was used since its light output was much greater than the P5, and it was felt that this factor would be important in keeping down the noise level of the phototube. As mentioned previously, a tube with a zinc oxide (P15) phosphor has recently been developed and would obviously be the first choice in the consideration of decay time.

(3) To eliminate any parallax error with its resulting range distortion, a flat-faced scanning tube is needed. At present, only 5 inch, or smaller, flat-faced tubes are available. The optimum choice of tubes is then limited to the 5WP15 or, as a second choice, to the 5FP11.

(4) Photomultiplier tubes were the only kind of phototubes investigated for use in this system. Because of the low light output of the scanned map, it was essential that the phototube have a high sensitivity in order to provide an adequate signal-to-noise input to the amplifier. A 931A tube appears more suitable than a 1P21 for the present design of the equipment. It has sufficiently high sensitivity and less inherent noise than a 1P21. The newly developed phototube previously mentioned should be given first consideration when made available. Having a 5-inch photocathode aperture, its sensitivity is probably higher than a 931A. Furthermore, its structure will aid greatly in the elimination of parallax error.

(5) Although it is possible to provide for the interchangeable use of positive and negative take-off by providing a means of reversing video polarity in the amplifier, and also by use of a gating multivibrator, it is deemed advisable to use negative take-off only. The opaque write-in forms remove the only serious limitation in the use of negative take-off. The clarity of the presentation is decidedly superior, and furthermore does not involve the added adjustments that the positive take-off method requires.

(6) The photographs of the resolution charts (Figures 19 and 20) clearly show the added resolution obtained by the use of a phosphor-compensated amplifier in preference to the clipping amplifier. In addition, a clipping and limiting amplifier will cause a range error on the display, which can be equal to half the width of a map line being scanned. On the shorter range sweeps, this error is an appreciable percentage of the full sweep. If a P15 phosphor is used in the scanning tube, the compensating network of the amplifier is a simple RC circuit. A P11 phosphor can also be adequately compensated for by using a pair of RC networks placed in two stages of the amplifier.

(7) In order to give the pilot full control over the combined radar and map data appearing on his indicator, two r-f link channels are called for. He could then adjust the input levels for optimum clarity of the presentation. Since the present Data Relay system employs only one link channel, the mixing of data must be accomplished at the ground installation. The radar receiver circuits provided the components for a linear mixer, and mixing at this point, made it convenient to monitor the combined display on the console PPI. The map video level, which must be set to some percentage of the radar video depending on map density is adjusted by the ground operator.

A video mapping system employing flying-spot scanning and phototube pick-up can be made to have sufficient resolution to reproduce detailed maps. By the use of the techniques of the Data Relay System, these maps can be transmitted and displayed on the pilot's indicator. For thorough evaluation as a navigational aid in approach, traffic control and landing of aircraft on a carrier, the system must await complete operational trials.

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