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NRL Report 5054

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A SYSTEM FOR RAPID SIGNAL ACQUISITION, ANALYSIS, AND PHOTOGRAPHIC RECORDING

[UNCLASSIFIED TITLE]

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DECLASSIFIED by NRL Contract
Declassification Team
Date: 6 APR 2017
Reviewer's name(s): [redacted]

Declassification authority: NAVY DECLASS GUIDE/NAVY DECLASS MANUAL, 11 DEC 2012
1958 SERIES

January 9, 1958

[redacted]

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ABSTRACT

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For many years, one of the basic countermeasures problems has been to find a method for providing a high probability of signal acquisition, rapid signal identification, and a useful storage of the pertinent information. A system developed at the Naval Research Laboratory for this purpose employs, for acquisition, a high-resolution, high-sensitivity superheterodyne receiver which scans the frequency spectrum at a rate of approximately one octave in two seconds. Received signals are displayed as intensity variations in a time-frequency raster on a long-persistence (P25) cathode-ray-tube screen. Any signal may be analyzed by interrupting the scan and, by use of a potentiometer which controls the servo motor, manually tuning the receiver to the appropriate frequency on the acquisition display. The use of several potentiometers, which may be selected by push buttons, allows any number of signal frequency positions to be stored for later use.

Signals are analyzed from the display on a unified indicator, which presents three time bases, a linear DF indication, and a panoramic trace on a five-gun cathode-ray tube. The fastest time base is exponential, and the other two are each two-decade, approximately logarithmic. The DF display consists of two traces of 180° each, and the positioning of the spot along the traces is effectively direct-coupled to the antenna.

The complete data display (five-gun cathode-ray-tube screen, servo-controlled frequency indicator, true-relative indication, clock, and data card) can be recorded photographically. For either still or motion-picture camera recording on Tri-X film, intensity variations along the individual traces have been minimized, and filters have been designed to equalize light intensities between traces.

It is believed that for the amount of equipment used, this system will provide more useful and reliable data at a faster rate than any comparable system.

PROBLEM STATUS

This is a final report on the rapid signal acquisition and display system, and on problem R06-04. Work is continuing on other phases of problem R06-02.

AUTHORIZATION

NRL Problems R06-02 and R06-04
Projects NE 071 200-2 and NE 071 240-2&4
Bureau Nos. S-1255 and S-1255.7

Manuscript submitted October 22, 1957

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A SYSTEM FOR RAPID SIGNAL ACQUISITION, ANALYSIS, AND PHOTOGRAPHIC RECORDING
[Unclassified Title]

INTRODUCTION

One of the basic problems in electronic countermeasures is to provide a high probability of acquisition of electromagnetic radiations, rapid identification of the acquired signals, and a useful storage of the pertinent information. There are several methods for solving this problem, and numerous organizations have been investigating the various solutions for some time. All practical techniques have revealed certain advantages and disadvantages, and a thorough consideration of these factors by the Countermeasures Branch of the Naval Research Laboratory has led to the development of a system that appears to be a satisfactory compromise in most respects for fulfilling many of the basic requirements.

It was determined that for maximum performance, flexibility, reliability, and efficiency, the system should consist of both a machine and a human being; the design should be based on optimum use of both equipment and operator capabilities (1). Tedious and repetitive operations which can be handled efficiently by electronic circuits or mechanical functions should be performed by the machine, and operations that require judgment or decisions should be handled by the operator. In the system developed, the machine does the work and the operator does the thinking. Laboratory use of this equipment during the past two years has substantiated the validity of the original premise.

Early in 1951, research was initiated on the component units which now comprise this system. The first operating model of the complete system was assembled in the fall of 1954 and was described at the Tri-Service Symposium at New York University in May 1955. Since that time, numerous improvements have been made in circuit techniques and in mechanical configurations, but the basic functions have been retained. The permanent antenna installation was completed in the fall of 1955, and operational evaluations have been performed intermittently since that time.

THE BASIC SYSTEM

Functions

The functions of the NRL Rapid Signal Acquisition and Analysis system are to examine a portion of the radio frequency spectrum for signal transmissions, to determine the operating frequency of the signal, the bearing of the transmitting source, and all identifying characteristics of the signal, and to record the information for later evaluation. The portion of this task delegated to the equipment is to (a) scan a given portion of the radio frequency spectrum at a rate that will provide the maximum probability of signal acquisition consistent with the bandwidth of the receiving equipment used and the types of signals likely to be encountered in that frequency range, (b) provide a visual indication of signal activity which will permit an operator to tune the receiver manually to the frequency of any signals acquired, (c) indicate the frequency to which the receiver is tuned when the receiver is in manual operation, (d) provide push-button-operated resettability of the receiver to any signal to which the receiver was previously tuned,

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(e) produce a display which will permit determination of the bearing of the signal source, the type of modulation on the signal (cw, AM, FM, pulse, noise, single or double sideband, suppressed carrier, frequency shift, or square wave), and the various characteristics associated with pulse signals (pulse width, pulse shape, pulse period, conical scan rate, number of pulses in a train, pulse coding, and modulations of pulse amplitude, width, period, frequency, or position), (f) produce an aural response on signal modulations, and (g) photograph all information given in (c) and (e) and any auxiliary data supplied (time, date, true or relative bearing indication, and operational notations).

The tasks that remain for the operator are to (a) select the radio frequency range to be examined, (b) decide, with the aid of the aural response, whether an indication on the signal activity (acquisition) display is a signal or noise, (c) stop the receiver scanning mechanism and manually tune the receiver to the indication on the signal activity display, (d) adjust receiver gain to the optimum level, (e) either adjust the antenna rotation rate for the best display of signal bearing or manually slew the antenna to the bearing indicated, (f) select the optimum receiver i-f bandwidth for the particular signal, (g) either manually log, or initiate the camera to photographically record, all the information concerning the signal, (h) start the receiver scanning again, and, (i) if desired, push the appropriate button to automatically retune the receiver to the signal previously logged to note any changes in bearing or other characteristics.

Characteristics

The receiver used in this system has a frequency coverage of 1000 to 10,750 Mc in four bands of 1000-2600, 2300-4450, 4300-7350, and 7050-10,750 Mc. For complete coverage of each frequency band, the scanning time is 1.8 seconds. There is an adjustable frequency sector range of 8 to 100 percent of the total scanning range of each band, and the scanning time for any sector is reduced in proportion to the reduction in scanning range. The receiver has noise figures of 18, 20, 22, and 24 db for the four bands, respectively, and there is no loss in sensitivity because of frequency scanning operation. Rejection of all images and spurious responses is at least 60 db. Frequency resolving bandwidths of 20 or 0.6 Mc are available.

The antenna used in this system has a frequency coverage of 1000 to 10,750 Mc in three bands of 1000-2400, 2300-5300, and 5000-10,750 Mc. The antenna rotation rate may be adjusted from 0 to 320 rpm, or the antenna position may be manually controlled. Depending on the frequency, and generally increasing with frequency, the antenna has a gain of 10 to 20 db. Beamwidth decreases from 30 degrees at 1000 Mc to 4 degrees at 10,750 Mc.

Acquisition, analysis, and bearing indications are provided on any types of unmodulated or modulated signals. Single impulses of 0.1 μsec or greater, or repetitive pulses of any rate less than 2 Mc produce acquisition and analysis indications. Retention of the signal activity indications on the acquisition display is at least one minute.

The frequency indication accuracy is better than ±10 Mc, and the frequency resettability is better than ±1 Mc. When bands are switched, the frequency indicator is automatically reset. There is provision for storage of 24 receiver frequency settings for automatic retuning.

A bearing indication is obtained with the antenna either rotating or stationary on any type of signal. Two linear traces of 180 degrees each are used for bearing indication, and the overall instrumental accuracy is ±3 degrees. Either true or relative bearing indications are available.

A 20-Mc-wide panoramic display of the frequency spectrum of the wide-band i-f amplifier in the receiver is produced with a resolution of 0.6 Mc.

Display of analysis information is essentially instantaneous. The pulse width or pulse period measurement scales are calibrated from 0.1 to 50,000 μsec in three concurrently displayed ranges of 0-5, 5-500, and 500-50,000 μsec. An exponential scale is used for the 0-5 μsec range, and approximately logarithmic scales are used for the other two ranges. The accuracy of indication is ±5 percent or ±0.05 μsec, whichever is greater. Measurements can also be made on sine-wave modulation frequencies from 20 cps to 2 Mc, although some waveform distortion is apparent below 200 cps.

The overall video amplifier rise time is less than 0.05 μsec, and the overshoot is less than 5 percent. Droop is less than 5 percent at 500 μsec, and the gain is 60. Aural response is essentially uniform on individual pulses having a width greater than 0.1 μsec, or on pulses or sine waves at any frequency within the range of headphones.

All data displays are located in a common area for easy photographic recording.

Power requirements are 1.4 kva at 115 volts - 400 cps, 700 watts at 115 volts - 60 cps, and 8 amperes at 28 volts dc, for the receiver and indicators, antenna control unit, and relays and KD-2 data recorder, respectively.

Description

The NRL Rapid Signal Acquisition and Analysis system consists essentially of (a) a rotating antenna, (b) a frequency-scanning receiver, (c) an acquisition indicator, (d) a system control, (e) a data display unit, and (f) a photographic recorder. A block diagram of the system (Fig. 1) shows the relationship and basic functions of the six units.

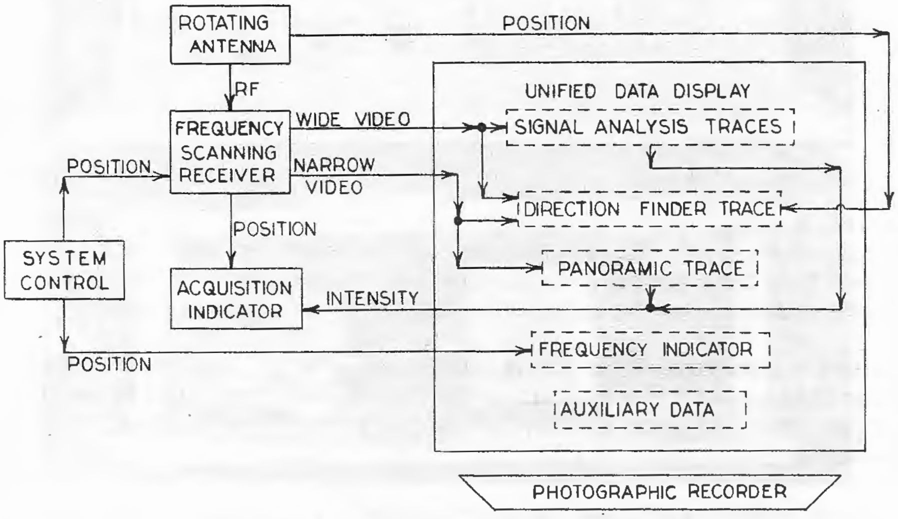

Figure 1 - Block diagram of the basic system

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Radio-frequency energy intercepted by the rotating antenna is detected by the frequency-scanning receiver. A receiver output that is a function of the tuned frequency controls the horizontal position of the spot on the cathode-ray tube in the acquisition indicator. Video outputs from the receiver determine the intensity of the acquisition spot through circuits in the data display unit. The data display unit contains a five-gun cathode-ray tube, a frequency indicator, and an auxiliary data presentation (clock, true or relative bearing lamps, and a data card). Three of the five guns in the cathode-ray tube produce signal analysis traces from the wide-band video output of the receiver. The fourth gun is used for the direction-finder trace, which is positioned horizontally by the rotating antenna; it uses the wide-band video from the receiver for pulse signal indication, and it employs the narrow-band video for indication on cw, AM, and FM signals. A panoramic trace of the narrow-band output from the receiver is displayed by the fifth gun in the cathode-ray tube. Both the frequency indication on the mechanical counter and the tuned frequency of the receiver are positioned by the system control. A photographic recorder registers all the information presented by the data display unit.

Except for the antenna, all equipment is mounted in a console for laboratory use (Fig. 2). This equipment is in experimental form, and no attempt has been made to package it for operational requirements. Construction of the system in a form suitable for shipboard installation is being done by Collins Radio Co. under contract NObsr 64683, and the designation for the shipboard model is AN/WLR-1. Since the contract with Collins Radio Co. has been in effect since April 1955, some of the later ideas incorporated in the NRL model have resulted from suggestions by engineers of Collins Radio Co.

The indicators are located on top of the console (Fig. 2) for easy viewing. At the left is the signal acquisition indicator, and at the right is the unified data display. The control

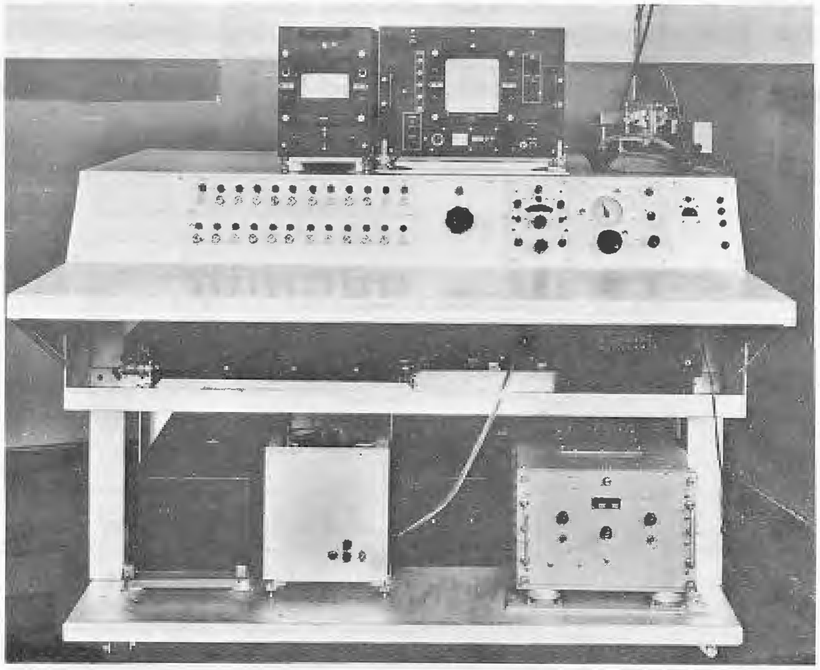

Figure 2 - System console - front view

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panels are, from left to right, the 24-position frequency-setting storage unit, the manual tuning unit, the receiver function unit, the antenna control unit, and the power control unit. The total amount of equipment required in the system is best shown in the rear view of the console (Fig. 3). On the bottom deck (from left to right) are the antenna servoamplifier, receiver tuner switch, antenna servo control unit, and the power supply for the unified data display, acquisition display, and tuner and frequency indicator servoamplifiers. On the second deck are the four tuners for the receiver, the servoamplifier unit for the tuners and frequency indicator, the receiver mixer-amplifier, and the receiver power supply. The additional power supply required for the highest-frequency tuner is located behind the regular power supply. Just to the right of center on the third deck is the tuner servo calibrator, which is required only for maintenance purposes and can be removed during operation. All other items on this deck are associated with the control circuits.

Receiver - For the receiver portion of the system, a modified AN/APR-9 is employed. This superheterodyne receiver has high sensitivity, high resolution, excellent rejection of images and spurious responses, and was readily modified for rapid frequency scanning. Receivers of the fixed multichannel type, which are supposed to acquire any signal instantaneously, are much too large for most operating locations. Also, because of the large number of electron tubes employed in the multichannel receiver, reliability is not good. Receivers employing rapid electronic scanning (such as travelling-wave-tube receivers) or nonscanning devices (such as the wide-open crystal-video receiver) do not have sufficient sensitivity for interception of minor lobe radiation from rotating radar antennas or sufficient selectivity for use in high-signal-density areas. Superheterodyne receivers employing electronic scanning of backward-wave oscillators have no image rejection. Although a mechanical scanning superheterodyne has a poor probability of acquisition for a single burst signal (less than four seconds duration), its superior performance on other types of signals makes it a logical choice.

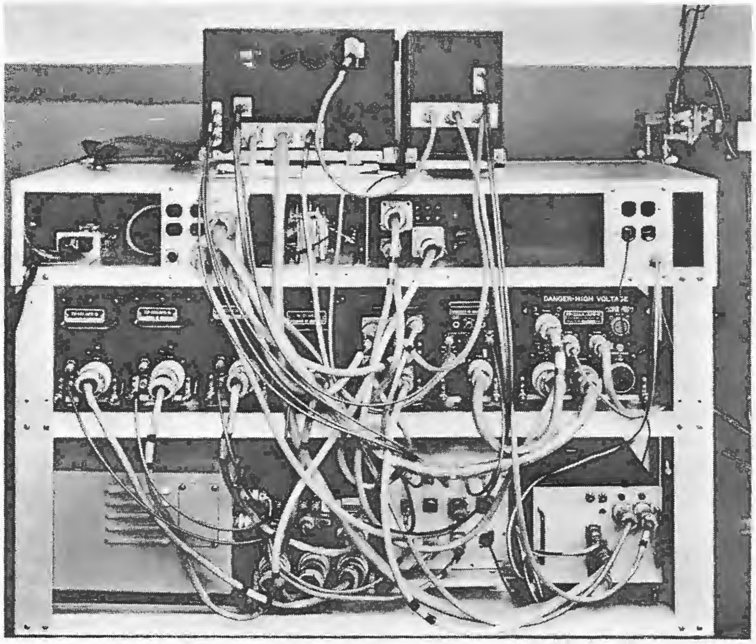

Figure 3 - System console - rear view

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Although this problem was carried on under the sponsorship of the Bureau of Ships, an airborne receiver (the AN/APR-9) was chosen for experimentation because the shipboard version (the AN/SLR-2 or AN/BLR-1) was not available at the time. The AN/WLR-1 equipment being developed by Collins Radio Co. for the Bureau of Ships is based on modification of the AN/SLR-2, which covers a frequency range of 50 to 10,750 Mc. The NRL system could be extended downward in frequency range to 50 Mc by modifying the AN/APR-13 receiver, which covers the range of 50 to 1100 Mc, but an AN/APR-13 has never been available for this purpose.

Modification of the AN/APR-9 receiver for rapid frequency scanning consisted of installation in each tuner of motors and mechanisms which would drive the tuner through its complete frequency range (approximately an octave) in about two seconds. The optimum choice of scanning speed was based on the lowest repetition rate of pulse signals likely to be encountered; this point has been discussed in detail in a previous report (2).

During the years of experimentation, servo control of the receiver has progressed from use of a dc-controlled bidirectional actuator (2) to a carrier-controlled bidirectional actuator (3), and finally to a straight two-phase servo motor drive. Both 60- and 400-cps servo motors were tried for receiver tuning to prove the practicability of the system for either shipboard or airborne applications, since only the servos need be different in the two cases.

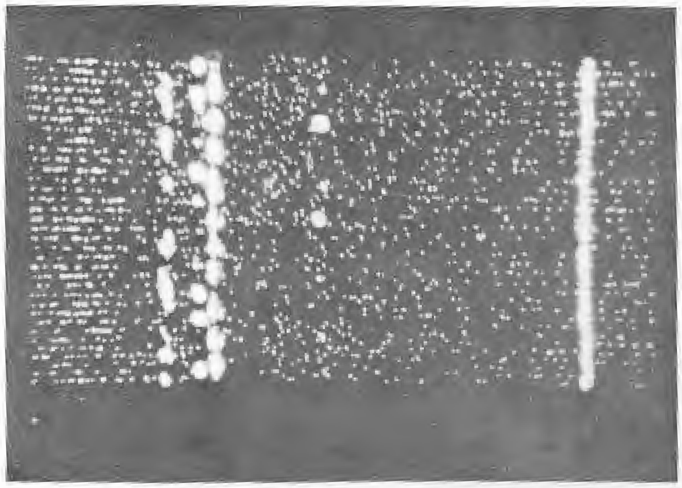
There is really no good reason why different designs should be used for 60- or 400-cps operation. Both shipboard and airborne designs could be based on a 400-cps power source, and a small frequency converter could be employed when only a 60-cps source is available. Frequency converters of the permanent-magnet no-brush type, such as are produced by the Georator Corp., are so small and light that, when added to a 400-cps power supply for the entire system, the total space and weight requirements would be about the same as with a 60-cps power supply alone. Such a device is used in the NRL system, and this 2-kva, 60- to 400-cps converter is only 11 in. in diameter and 15 in. long. The noise level produced by this machine is much less than from any of the air blowers or servo motors in the equipment. Another important advantage of standardizing on a single equipment power frequency and using source converters is that the equipment could also be operated on 50- or 25-cps power sources with a simple change of converter units. Use of similar equipment for both air and ship applications also has obvious advantages in both procurement and maintenance.

Other modifications of the receiver were installation of low-noise preamplifiers in the tuners and redesign of the video circuits. The low-noise preamplifiers were developed by Collins Radio Co. under a Bureau of Aeronautics contract. Details of the video circuit redesign are covered in a later section of this report.

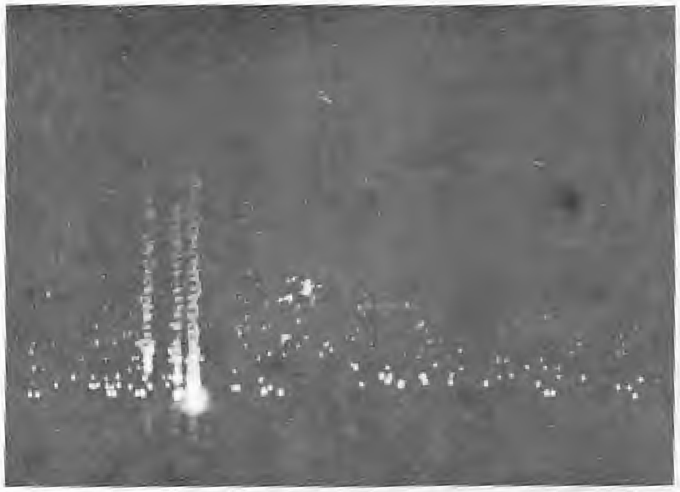
Antenna - The antenna used with this system is the original model of the AN/SLA-3, developed for use with the AN/SLR-2 receiver, and its control mechanism is the only portion of the system that is operated from 60-cps power. The production version of this antenna is the AS-605/SLR, and it is operated from electronic control amplifier AM-825/SLR and control-indicator C-1213/SLR.

Acquisition Indicator - Because of the high speed at which the receiver now scans, the panoramic display normally used with the AN/APR-9 receiver is useless for acquisition. Consequently, an acquisition display that uses a long-persistence (P25 phosphor) cathode-ray tube to present data on a time-frequency raster was developed. In this display, the spot is positioned horizontally by voltages developed in the receiver tuner to give a direct relationship between receiver frequency and spot position. The vertical position of the spot moves slowly downward with time to present a raster. Signals are indicated by intensity modulation, and the amplitude of intensity is a function only of signal amplitude. Photographs (Fig. 4) of the acquisition display indicate typical signals in the presence of a noise background. The first photograph was taken with the camera open for the entire two-minute raster and shows how frequently different signals are acquired. The second photograph is a short exposure and shows the persistence that the operator sees. Unfortunately, much of the noise detail in the original photograph disappears in the process of report reproduction.

A signal is displayed on this acquisition indicator regardless of whether it is AM, FM, cw, or pulse; and even a single 0.1-μsec pulse will produce a spot. Both cw and



(a) Camera open during entire raster scan



(b) Short exposure showing persistence

Figure 4 - Acquisition indicator displays

pulse signals are shown in Fig. 4a, the cw signal being generated from a signal generator, and the pulse signals being live intercepts. The cw signal (at the right of the picture) was received on every scan, since it did not pass through the rotating antenna system. The other four signals were received with different rates of occurrence, depending on the signal strength, rotation rate of the transmitting antenna, and rotation rate of the receiving antenna.

For a tangential or larger amplitude signal, a single dot is usually sufficient to indicate the presence of a signal. If the signal is below tangential level, it may be necessary to observe two dots in the same horizontal location (on the same vertical line) before it is apparent that a signal may have been acquired. Use of the audio output from the unified indicator is a valuable aid in determining if a single dot is noise or a signal. The long persistence of the phosphor allows signals to be viewed about one minute in a reasonably dark room, which is generally sufficient for correlation between spots on an occasional signal.

If a signal occurs near the bottom of the raster, and the spot flies back to the top to start a new raster before the receiver can be tuned to the signal, it is difficult to position accurately on the correct point. Therefore, a three-position switch has been placed below the acquisition display which, when depressed, will hold the trace at the bottom of the raster. If the switch is raised, the trace will be held at the top of the raster. Thus it is also possible to rapidly center the raster on the tube face without waiting the two minutes for the entire vertical scan.

When it is suspected that two signals may be very close together in frequency, narrow-band operation of the receiver may be used instead of wide-band to provide greater resolution in the acquisition display. However, the probability that a signal will be shown on any given scan will then be reduced by the same ratio as the bandwidth is reduced. The signal-to-noise ratio will also be reduced on narrow pulses, although it will be improved on wide-pulse signals.

The first display of this type was a mechanical one using a recording pen and Teledeltos paper (4). To replace the mechanical system with an electronic one, a dark-trace tube was next used for display (5). Both of these systems were operated at the normal receiver scanning rate of about 45 seconds per scan. When the scanning speed was increased, it became apparent that other types of cathode-ray tubes would be more suitable. About that time, the long-persistence P19 phosphor became available, and a successful acquisition indicator using the 5RP19-A tube was developed (2). When the P25 phosphor was released, it was quickly adopted because the cathode-ray-tube accelerating potential required to excite this phosphor was only 5000 instead of 17,000 volts. It was also realized that the power requirements of the tubes used for deflection of the cathode-ray-tube spot could be reduced considerably by use of a magnetic deflection tube instead of an electrostatic deflection one if the proper deflection coils could be procured. Successful procurement of a high-impedance yoke led to the final adoption of the 5FP25 tube.

When the acquisition indicator and unified data display were connected into a combined system, it was realized that there was considerable duplication of circuits in the two units. By adding a small amount of circuitry to the unified indicator unit, it was possible to eliminate most of the circuitry in the original acquisition indicator (2).

<u>System Control</u> - To analyze a signal appearing on the acquisition indicator, receiver scanning must be stopped by pressing one of the 24 storage pushbuttons located at the left of the system control panel (Fig. 2). Receiver tuning is then controlled by a potentiometer which is adjusted by the tuning knob located at the right of the pushbuttons. The knob is

spun until the spot on the acquisition indicator coincides horizontally with the persistence spot that indicated the possible presence of a signal. Any signal at this frequency is then within the passband of the receiver, and an analysis can be made on the unified data display. After an analysis is completed, scanning may be resumed by pushing the acquisition button located at the top of the receiver function panel. At any time that reexamination of a signal is desired, it may be done by again pressing the particular storage button that was used previously.

As many as 24 receiver frequency settings may be stored, because there is a separate tuning potentiometer associated with each pushbutton. The 24 potentiometers are individually connected to the tuning knob through magnetic clutches when the appropriate storage button is pressed. Only one potentiometer can be rotated at a time, while the remaining ones hold their storage positions. Since the potentiometers are 10-turn Helipots and since there is a two-to-one reduction in the magnetic clutch gearing, it is easy to tune the signal into the narrow passband of the receiver.

A receiver frequency setting is stored on a potentiometer for the particular tuner in use at the time of storage. When operation is on another tuner, the storage potentiometer will reference a particular frequency in the tuner being operated, but this position is meaningless. It is necessary to adopt some system to indicate the particular tuner that was in use when a frequency setting was stored on a given potentiometer. The NRL system does not have any indicating device for this purpose, so one technique adopted has been to start at the left hand end of the upper bank for one tuner, the right hand end of the upper bank for the next tuner, the left hand end of the lower bank for the third tuner, and the right hand end of the lower bank for the fourth tuner. Since the system being developed at Collins Radio Co. has 9 tuners and only 10 storage positions, a device has been incorporated that will indicate by numbers from 1 to 9 the tuner that was in use at the time of storage.

The optimum number of storage positions required has not been determined, but when all four tuners of the AN/APR-9 are used at the laboratory location, there are times when all 24 positions have signal frequency-settings stored on them. In the present system, 24 storage positions were incorporated because the control system uses a 25-position stepping switch (the 25th position is used for acquisition), and stepping switches with more contacts were not readily available. Reliable illuminated push-button switches of a type that would eliminate the need for a stepping switch are now available, and any number of these switch sections can be ganged to increase the number of storage positions.

Each storage push button has a neon lamp inside which illuminates when that button is pressed. The neon lamp extinguishes whenever another storage button or the acquisition button is pressed. Thus the position controlling the system is readily identified. Each storage button also has a memory or history lamp immediately above it. The memory lamp illuminates the numerals on its face when the corresponding storage button is pressed. This lamp remains lighted until it is deliberately extinguished, thus indicating the particular positions that have been used for storage. To extinguish a memory lamp, the release button over the tuning knob is held down while pressing the storage button corresponding to the particular memory lamp. Pressing the storage button while the release button is held down has no effect on operation of the system other than to extinguish the lamp.

The control technique adopted for this system is essentially an electrical one, employing relays and stepping switches. The control method that Collins Radio Co. intends to use in the AN/WLR-1 is a mechanical one employing latching devices. Although a mechanical system is somewhat more difficult to design, it should have fewer maintenance problems. For the NRL experimental model, it was easier and more expedient to use an electrical system.

After the receiver has been tuned to a signal, receiver gain is set to the optimum level for the analysis display by the gain adjustment at the bottom of the receiver function unit on the control panel (Fig. 2). Two gain controls are used in this system, one to set the level of noise on the acquisition indicator and the other to set the level for analysis of a particular signal. Both gain potentiometers are operated from one knob, the appropriate potentiometer being connected to the control by magnetic clutches when in acquisition or analysis. Thus it is not necessary to reset gain when the receiver is returned to acquisition. The acquisition gain control need be adjusted only when tuners are switched, or when changing from wide- to narrow-band scanning operation.

Also located on the receiver function unit of the control panel are the bandswitch and the sector sweep limit controls to allow selection of the frequency range to be covered. Either normal (20 Mc bandwidth) or narrow (0.6 Mc bandwidth) frequency resolution may be chosen by the wide/narrow bandswitch. For aid in very precise centering of the signal within the receiver passband, the fixed oscillator normally associated with the AN/APR-9 receiver may also be energized from a switch on this panel. The acquisition button is located at the top of the panel, but operational experience has indicated that a better position would be at the right of the storage buttons. The AN/APR-9 crystal current meter, which is normally located on the receiver function panel, has been moved to the power control panel on the right to allow more space for the normal operating controls.

Unified Data Display - To permit rapid identification of a signal, the unified data display (Fig. 5) provides signal analysis information, DF bearings, and a receiver panoramic presentation on a five-gun cathode-ray-tube screen (Fig. 6). Analysis is performed on the first three traces, which use nonlinear slave sweeps. The first is a 0-5 μsec exponential sweep which is triggered in synchronism with the incoming signal. The termination of this sweep initiates the second, which is a 5-500 μsec, two-decade, approximately logarithmic sweep. The termination of the second sweep in turn initiates

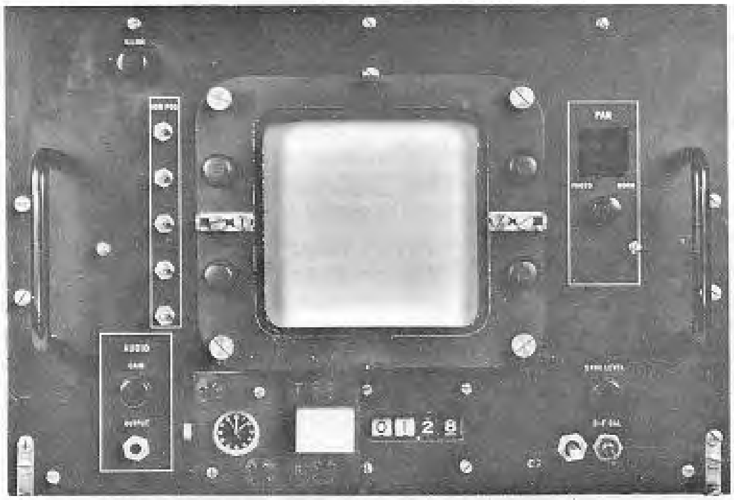


Figure 5 - Unified data display unit

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the third, which runs from 500 to 50,000 μsec and is also a two-decade, approximately logarithmic sweep. The fourth gun in the cathode-ray tube is used for the linear DF display, which consists of two traces of 180 degrees each. The sweep progresses from 0° at the center to 90° at the right of the upper trace, from 90° at the right to 270° at the left of the lower trace, and from 270° at the left to 360° or 0° at the center of the upper trace. Video is displayed downward from the upper trace and upward from the lower trace. The receiver panoramic display is produced by the fifth gun in the cathode-ray tube.

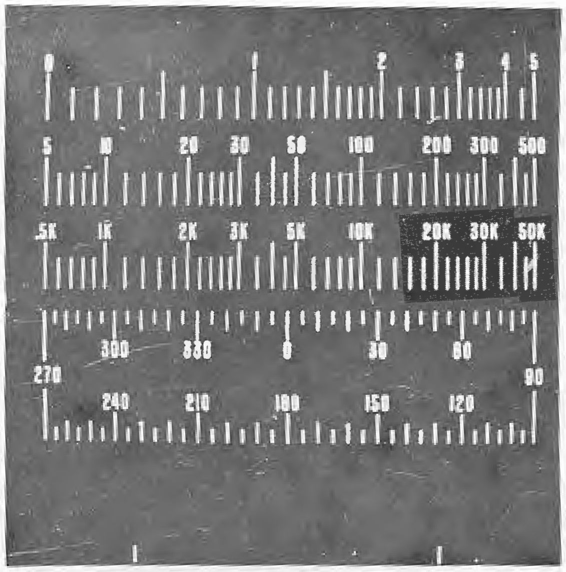

Figure 6 - Unified-data-display scale calibrations

Nonlinear sweeps were chosen for the analysis portion of the unified data display because traces of this type provide the greatest overall accuracy in the minimum amount of space (6). For the two slower sweeps, approximately logarithmic traces were used, since logarithmic sweeps have constant percentage accuracy over the entire scale, and a good approximation to a two-decade logarithmic scale can be developed from circuits where the wave shape is controlled by passive components. Since a logarithmic curve does not start from zero, it was not possible to use the logarithmic shape for the fastest trace, and an exponential sweep was employed. The speed at the end of each sweep is approximately the same as at the start of the following one, so the three traces form a continuous scale.

Each sweep has its own lockout circuit (7), which prevents it from being retriggered before all of its time constants have fully recovered. However, the first sweep may be triggered many times while the second sweep is triggered once, and similarly between the second and third sweeps, so that the integration effects of the phosphor may be utilized. Both intensity and pulse stretching are tailored dynamically as each sweep progresses to produce a uniform display (8). The stability of the analysis circuits has been shown to be good if stable components are used (9).

The analysis circuits provide accurate indication on pulses as short as 0.1 μsec and as high as 2 Mc in repetition rate. Equally good operation is obtained on sine-wave signals down to the lower limit of the video amplifier, which is 20 to 200 cps, depending on the amount of distortion permissible. This indicator is also capable of displaying multiple-pulse signals and signals employing forms of complex pulse modulation. A sync level control is provided on the indicator to synchronize the display on an antenna lobing rate or other similar periodic variation in the signal.

Since a polar DF display is not practical in a type 7YP2 multigun cathode-ray tube, a dual-trace rectangular display was developed (10). Transition between traces is approximately 0.2°. Because the spot position is effectively direct-coupled to the antenna, the indication on the display will be correct even when antenna motion is stopped. Accuracy is maintained at any antenna rotational speed up to 720 rpm, but the antenna in use has a maximum limitation of 320 rpm. Indication is produced by AM, FM, and cw in

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addition to pulse signals. Video for the DF display (analysis displays, also) is direct coupled. Thus on a high-repetition-rate signal, where detection would occur because of pulse stretching, a vertical displacement is produced at the correct bearing even when antenna rotation is stopped. Since the DF display is triggered through the analysis circuits, it is possible to narrow the effective pattern in the display by reducing the sync level, if desired, when the antenna pattern is very broad. Baseline suppression is used in the DF display to provide optimum viewing and photographing. The accuracy of the DF indication is better than one degree between the resolver and the cathode-ray-tube display. There may be another one to two degrees error between the antenna beam and the resolver because of the antenna servo system error and antenna squint. Thus the overall instrumental accuracy of the DF system is within ±3°.

Although bearings are normally taken when the antenna is rotating, the three analysis traces and the panoramic display may be read more easily when antenna rotation is stopped on the bearing of the signal. A switch is provided at the right center of the antenna control panel (Fig. 2) to allow selection of either continuous rotation or manual operation of the antenna. The knob at the lower left of this panel controls the manual position of the antenna, and the dial above this knob provides an indication of the antenna position when in manual operation. This indication is not necessary for operational use, but it can be used to preset the position at which the antenna will stop when switched from rotational to manual operation.

For low-repetition-rate signals, the maximum rotational rate of the antenna may be too fast to permit reception of sufficient pulses during the time the antenna is beamed on the signal to provide an accurate indication on the display. The knob at the lower right of the antenna control panel permits continuous adjustment of the antenna rotational speed for optimum reception of a particular signal.

Bearings may be indicated either with respect to true north or relative to the craft's heading. For true bearings, an additional synchro, controlled by the ship's gyro source, is inserted in the antenna driving train. Selection of either true or relative bearings is controlled by the switch at the upper right of the antenna control panel, and indicating lights are located adjacent to the data card on the unified data display unit (Fig. 5) to show the mode of operation in use.

Circuits to permit switching from relative to true bearing are incorporated in the AM-825/SLR and C-1213/SLR control system used with the AS-605/SLR antenna, and no circuit modifications are required to produce the proper display when this equipment is used. However, if an AN/APA-69 antenna is employed to provide directional information for the DF display, an additional unit must be provided to produce a true bearing indication. The outputs of the antenna resolver must be fed through a low-impedance driving amplifier to another resolver which is driven by a synchro follower on the flux-gate compass line. This heading resolver must rotate at one-half the synchro speed; it will introduce the necessary shift in bearing display when its output is connected into the DF sweep circuit. When using this system for both true and relative bearings, changes in carrier level through the second resolver must be compensated for to maintain the correct display length when shifting between the two positions.

A calibrating circuit for the DF sweep is available in the unified indicator unit. Thirty-degree markers, synchronized from a magnetic pickup in the antenna pedestal, are presented on the scale when the switch at the lower right of the front panel (Fig. 5) is thrown.

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The switch adjacent to the DF calibrator switch removes the narrow-band video from the DF display. Pulse signals having a duty cycle greater than 0.02 will produce a voltage from the narrow-band video that may interfere with the presentation from the wide-band video. Since most pulse signals have duty cycles lower than this value, it is only on rare occasions that it is necessary to operate this switch.

For the panoramic display, narrow-band video is no longer stretched in the AN/APR-9 receiver used in this system. The receiver has been modified to only amplify the narrow-band video to the proper level for the panoramic display. The narrow-band video is then properly stretched in the indicator and directly coupled to the panoramic deflection plates. When the video is adequately stretched and properly shaped, intensity modulation by the video is not necessary for viewing the panoramic display, and the intensity modulation control has been eliminated. However, for photographic purposes, an intensity modulation circuit has been incorporated which permits optional base line suppression.

The frequency indicator of the AN/APR-9 receiver is located below the face of the cathode-ray tube in the unified display unit (Fig. 5) and is servo controlled to the receiver frequency when scanning is stopped. It is not scanned with the tuners because the mechanical counter from the AN/APR-9 does not run readily at such high speeds. It is not possible to read anything when the counter is running at high speed, anyway. Therefore, the frequency indicator is servo controlled to the frequency corresponding to the voltage on the particular storage potentiometer in use. The comparison potentiometer geared to the frequency counter has multiple taps, and the reference voltage supply is switched to a different set of taps for each tuner. Since the counter position is a function of the position on the potentiometer where a given voltage appears, the frequency indicated on the counter is changed automatically each time the tuner is changed, and the manual resetting required with a normal AN/APR-9 receiver is eliminated. This technique was suggested by Collins Radio Co. in their original proposal for modifying the AN/SLR-2 to rapid scan operation, and it was adopted in the NRL model. During scan operation, the frequency indicator is set at the midpoint of the band in use to give minimum average time to reach the correct frequency during analysis.

Also available from the unified indicator unit is an audio output that is stretched to give about 6 db better response than normally obtained from the AN/APR-9 receiver at low repetition rates and on narrow pulse signals. A single 0.1-μsec or longer pulse produces an audible click in the headphones. It is recommended that the audio be used when acquiring signals because the correlation of sound with sight improves the acquisition probability, helps distinguish between signal and noise, and may indicate the presence of two or more signals so closely spaced in frequency that they would appear as a single spot on the acquisition indicator.

The unified data display can be used with any standard AN/APR-9 or similar receiver. It is not necessary to have a rapid scan system to use it. In this case, the additional circuits for the acquisition indicator can be omitted.

Photographic Recorder - The best method of recording the type of data displayed on the unified indicator is by photography. The field of view of the camera should enclose the five-gun cathode-ray-tube face, the frequency indicator, clock, data card, and true/relative bearing indicator, all of which are located together for this purpose. Light output from the cathode-ray tube is sufficient to permit photographing a single trace of the 0-5 μsec sweep. For this purpose it is necessary to use a camera with an f/2 lens and Tri-X film processed for a film speed of 1000. By use of color filters (11), the higher intensity on the slower traces can be recorded without overexposing the film while still permitting visual observation of the afterglow when the flash has passed.

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A data recorder similar to the type KD-2 could be used for single-frame exposures, if modified to incorporate frequency indication and true/relative bearing information into the present data chamber of the recorder. However, the loss in effective speed caused by the dichroic mirror used in this recorder makes photography of single traces on the 0-5 μsec sweep almost impossible.

Prior to the advent of Tri-X film, continuous motion photography of the unified display was not satisfactory because of chopping of the traces by the shutter in the camera. However, the high sensitivity that can be obtained from Tri-X film with proper processing permits photographing the afterglow of the traces, and continuous-motion photography now appears to be practical. For this purpose, it might be desirable to replace the single-frame camera normally used in the KD-2 by a properly designed motion picture camera. Mechanical and electrical operation of the KD-2 would be considerably simplified by this change. However, an f/1 lens is required to obtain a good image on continuous motion pictures with this recorder because of the loss in the dichroic mirror. An attempt has been made to adapt a standard Navy gun camera to the KD-2, but so far it has not been possible to procure the required lens.

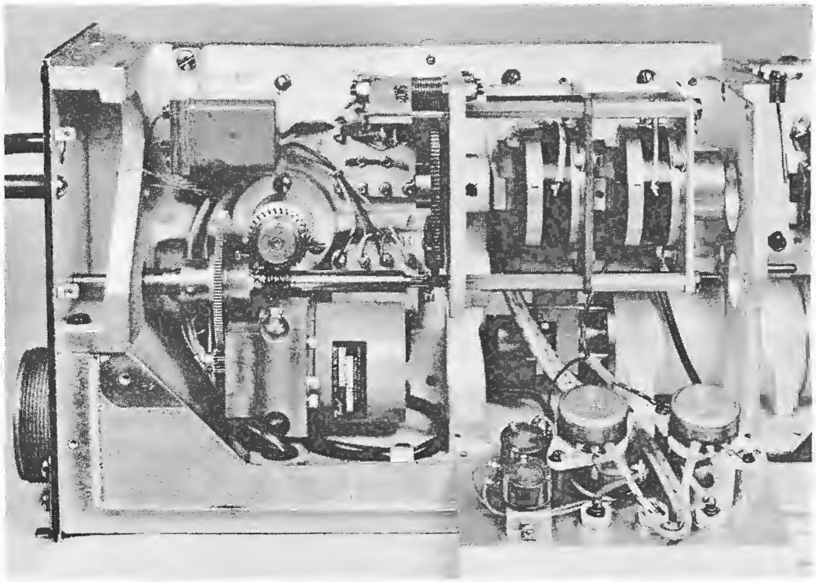
CIRCUIT DETAILS

To understand this section of the report completely, it is recommended that some of the references be reviewed first. In particular, for details on the AN/APR-9 receiver, reference 12 should be consulted. For a discussion of servo operation of the tuners and frequency indicator, references 2 and 3 are applicable. Reference 2 also provides the background information on the acquisition indicator. The unified data display has been extensively described in references 6, 8, 9, and 10.

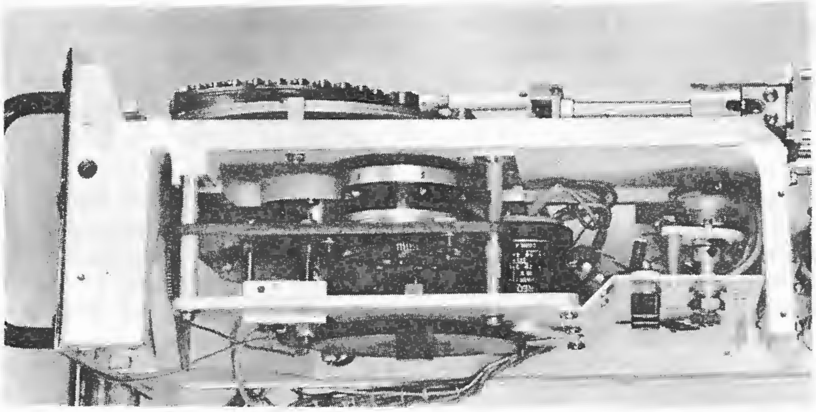
Receiver Tuning System

Tuner Modifications - Each tuner of the AN/APR-9 receiver was stripped of its drive mechanism and reference potentiometers, and a new drive system and precision potentiometers were installed (Fig. 7a). The 400-cps two-phase servo motor used was an Eclipse Pioneer type CK2006-3, which was capable of delivering about 5.8 watts of mechanical power to the load. To scan the complete range of a tuner in two seconds, only about three watts of power were required when the loading springs in the tuners were properly adjusted, but the reserve power was needed for rapid reversal. This motor had the disadvantage that neither winding was suitable for 115-volt operation, so an inductor was installed at the upper left of each tuner to reduce the voltage applied to the line winding.

The Eclipse-Pioneer motor was geared to the tuner countershaft by two sets of spur gears having an overall ratio of 14.73 to one. The mesh on each pair was made adjustable to allow the gears to be set for minimum backlash. On most of the tuners it was necessary to reduce the tension in the clockspring that was used to take out the backlash between the worm gear on the countershaft and the worm wheel. Reducing the tension not only reduced motor loading but also reduced wear on the worm wheel, which was the most vulnerable part of the drive system. On some tuners, it was also necessary to reduce tension of the compression springs on the cam followers because of excessive motor loading. No particular difficulty was encountered with vibration when weaker springs were installed.



(a) **Worm gearing**



(b) **Spur gearing**

Figure 7 - Modified receiver tuner

Operation of these tuners over a considerable period of time revealed that the worm-gear drive wore excessively under continuous scan operation. After about 50 hours of continuous operation, it was no longer possible to align the calibration at the high-frequency end of a tuner, and after about 200 hours it was necessary to replace the worm and wheel. Continuous scanning is not the normal operation of the receiver, since tuning is stopped frequently for signal analysis. Thus under normal conditions, operation would be possible for considerably longer periods. Engineers of Collins Radio Co. realized the limitations of worm gearing and based the design of the AN/WLR-1 on the use of spur gears throughout.

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To permit continued operation of the NRL equipment, the drive system for the tuners was recently redesigned to use spur gears only. A tuner was further stripped and the spur gear system installed (Fig. 7b). Since spur gears are more efficient than worm gears, the power requirements of the drive motor were reduced. A three-watt output motor, such as the BuOrd Mark 8 Mod 1, provides sufficient power. This motor has the advantages of 115-volt windings (thus eliminating the series inductor), a pinion gear on the shaft to simplify the mechanics, and better availability. Servoamplifier power requirements are reduced also.

Only one tuner has been built in this form, to determine design inadequacies and operational life. Consequently, the wiring of this tuner is still in experimental status. Continuous operation on the bench for a period of over 200 hours has shown no noticeable wear in the new spur-gear mechanism. Certain design changes have been made in the drawings of this tuner drive to provide better assembly and maintenance and to reduce the scanning rate from 40 scans per minute to the 33 per minute obtained in the tuners using worm gearing. Unavailability of shop facilities has delayed reconstruction of the four tuners in the NRL system to incorporate the spur-drive mechanism.

The clock spring that was originally installed in the tuner camshaft to remove worm-gear backlash is not required for this purpose in the spur-drive system. However, the compression springs on the cam followers produce a torque on the camshaft which will cause unequal loading of the drive motor in the two directions of motion. Therefore, a clock spring which produces torque in the opposite direction has been installed in the camshaft. It is not possible to balance the two torques at all positions of the scan because of changes in spring tension and cam shapes, but a reasonable amount of compensation can be obtained. The compression springs originally installed in these tuners can be retained when this spring compensation is employed. Proper spring adjustment provides much smoother operation of the tuners and prevents the mechanism from running down to one limit of its travel when motor power is removed.

One of the most critical components in the entire system is the servo reference potentiometer in the tuner. Originally, high-resolution wire-wound potentiometers were used, but even the best available had inadequate resolution for fine control on the X-band tuner. Also, after some length of operation, particles worn from the wire would lodge between turns, thus changing the effective resolution and causing excessive hunting of the servo in some positions. It was necessary, therefore, to clean the potentiometers occasionally. When high-linearity carbon-film potentiometers became available, they were immediately tried in the system. Since resolution is not a problem in the continuous type of potentiometer, servo gain could be raised without the danger of hunting between turns. Fine tuning and resettability to within the narrow passband of the receiver are now readily achieved on X band.

The potentiometers in use are Computer Instruments Model 205. For the servo reference, the linearity (0.05 percent) is the best available in a 2-in.-diameter unit. For the reflector voltage, a standard 0.25-percent linearity control is used. In the design shown in Fig. 7a, the potentiometers were coupled to the potentiometer gear shaft through constant-velocity couplings, and a clock spring at the rear of the potentiometers took out the backlash in the couplings and the backlash between the potentiometer gear and the pinion gear on the countershaft. The newer design (Fig. 7b) used spring-loaded spur gears to minimize backlash.

Occasionally a position would be encountered on the film-type potentiometers where small-excursion high-frequency (about 60 cps mechanically) hunting occurred. No correlation between hunting position and motor or gear positions could be found, and the

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position varied with use of the equipment. A similar occurrence at Collins Radio Co. led them to investigate the characteristics of these potentiometers on a precision turntable. Results indicated that the resistance vs angle characteristic had considerable slope variation in very small increments of angle. A change in resistance slope changes the effective gain in the servo loop, and hunting will occur if the slope is too great. The variations in the potentiometer were still within the linearity tolerance of 0.05 percent, but to meet the resettability requirement of ±1 Mc on the highest frequency tuner, the servo system had to be so sensitive that even these small variations caused difficulty. A linearity tolerance of 0.02 percent would be desirable, but space limitations prevent use of potentiometers large enough to have this order of linearity.

The sensitivity of the servo loop is such that ground currents can cause difficulty. The lead to the arm of the servo reference potentiometer is shielded, and this shield is insulated from ground throughout the cabling. The ground return for the potentiometer is made through this shield, and the only connection to ground is at the input of the servo-amplifier. Failure to maintain an isolated ground lead in an installation is likely to cause hunting.

Two wire-wound trimming potentiometers have been installed in each tuner to adjust the electrical end limits to correspond with the mechanical end limits of motion. Each tuner is aligned against a precision calibrator, so that all tuners will cover the same range of electrical voltages, the raster will not shift on the acquisition indicator when tuners are switched, and the frequency indicator will read properly. In the latest tuner design, miniature 25-turn trimming potentiometers are used to provide the fine adjustment needed.

<u>Tuner Servo Calibrator</u> - The tuner servo calibration circuit (Fig. 8) is a precision resistance bridge. When the tuning mechanism is set at the upper-limit-microswitch operating point (indicated by illumination of a neon lamp on the unified indicator), the calibration selector switch is set for the upper-limit position, and the upper-limit trimming potentiometer is adjusted for a null on the microammeter in the calibrator. Similarly, the lower-limit trimming potentiometer is adjusted when the tuning mechanism is set at the lower-limit-microswitch operating point (also indicated by the neon lamp) and the calibration selector switch is set in the lower-limit position. Since the two trimmers have a slight interaction, it may be necessary to repeat the operation a few times. Variations in the supply voltage for the tuner potentiometers have no effect on the calibration, because the calibrating circuit and all servo reference circuits operate as balanced bridges.

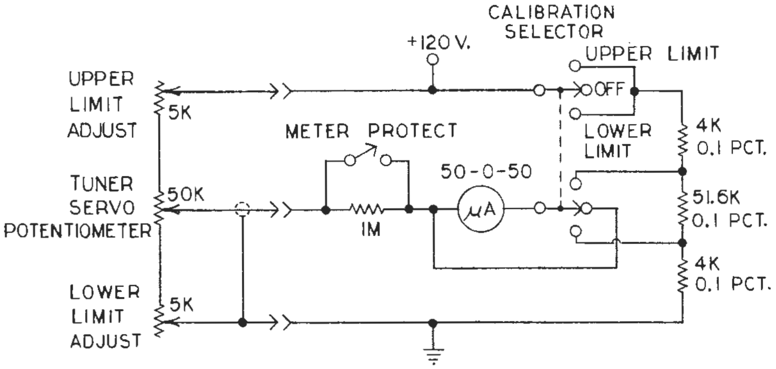

Figure 8 - Tuner servo calibration circuit

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Tuner Servoamplifier - The 400-cps servo system used to drive the tuners is similar in design to the one previously developed for 60-cps operation (3). Basically, the system consists of a modulator, amplifier, and antihunt circuit (Fig. 9). Any difference in dc voltage between the reference input and the potentiometer arm in the receiver tuner produces a 400-cps voltage at the output of the balanced modulator (V3). An electronic modulator was used in this circuit because it does not load the input circuit and is a continuous-function device. However, the electronic modulator does have some thermal drift, which will cause slight shifts in receiver tuning over a period of time. To eliminate the thermal drift, Collins Radio Co. is using a 60-cps mechanical chopper for the modulator in their servo. It had been believed at first (and also stated in the literature) that a chopper would not provide fast enough response because of the sampling action. The engineers at Collins Radio Co. have shown otherwise, since the chopper has proved successful in their servo.

The 800-cps second harmonic produced by the modulator is rejected by the bridged T network in the plate circuit of this tube. Higher harmonics and noise are greatly reduced by the 90-degree phase-shift network in the amplifier, and the broadly resonant circuit formed by the capacitor across the motor terminals and the inductance of the motor also improves the waveform of the voltage applied to the motor.

Unsymmetrical clipping in the amplifier on large voltages reduced the output capabilities of the final amplifier stage. Therefore, a symmetrical clipping circuit was installed at the grid of V5A. Negative signal excursions are clipped by a silicon diode, and positive excursions by the grid conduction in V5A. The grid resistor of V5A is returned to a positive potential equal to the grid-cathode potential, which puts the correct bias on the diode for symmetrical operation. Only silicon or vacuum diodes can be used in this circuit, because an extremely high reverse impedance is required to maintain proper bias conditions.

Both tachometer feedback and velocity-voltage feedback from the motor winding have been tried for antihunt operation, but the most successful antihunt circuit was the electronic type developed in the earliest work (2). The engineers at Collins Radio Co. have developed a rate-bridge antihunt circuit for use in the AN/WLR-1 which eliminates the two vacuum tubes used in the NRL circuit. However, for proper bridge operation, the frequency of the supply voltage must be maintained within a few percent. The electronic antihunt circuit is independent of supply-voltage frequency.

The first tube (V1) in the antihunt circuit is a device used to produce an output unbalance proportional to the input unbalance, but at a constant average dc level regardless of the absolute magnitude of the dc voltages at the input terminals. Thus the antihunt amplifier (V2) can operate linearly regardless of the position in the scan. The original circuit (2) has been improved by returning the cathode resistor of the antihunt amplifier to -150 volts instead of to ground to increase the dynamic range. The dc antihunt voltage is differentiated with the optimum time constant at the plates of V2 and is applied to the grids of the balanced modulator.

When the tuning mechanism was changed from a worm- to a spur-gear drive, the power required from the output stage of the servoamplifier was reduced. Modification of the output stage of the tuner servoamplifier for use with the BuOrd Mark 8 Mod 1 motor is indicated in Fig. 10.

Sector Sweep - In manual operation, the reference input to the tuner servo is from one of the manual storage potentiometers; in scan operation, the reference input is from the sector-sweep circuit (Fig. 11). Only minor modifications have been made in the

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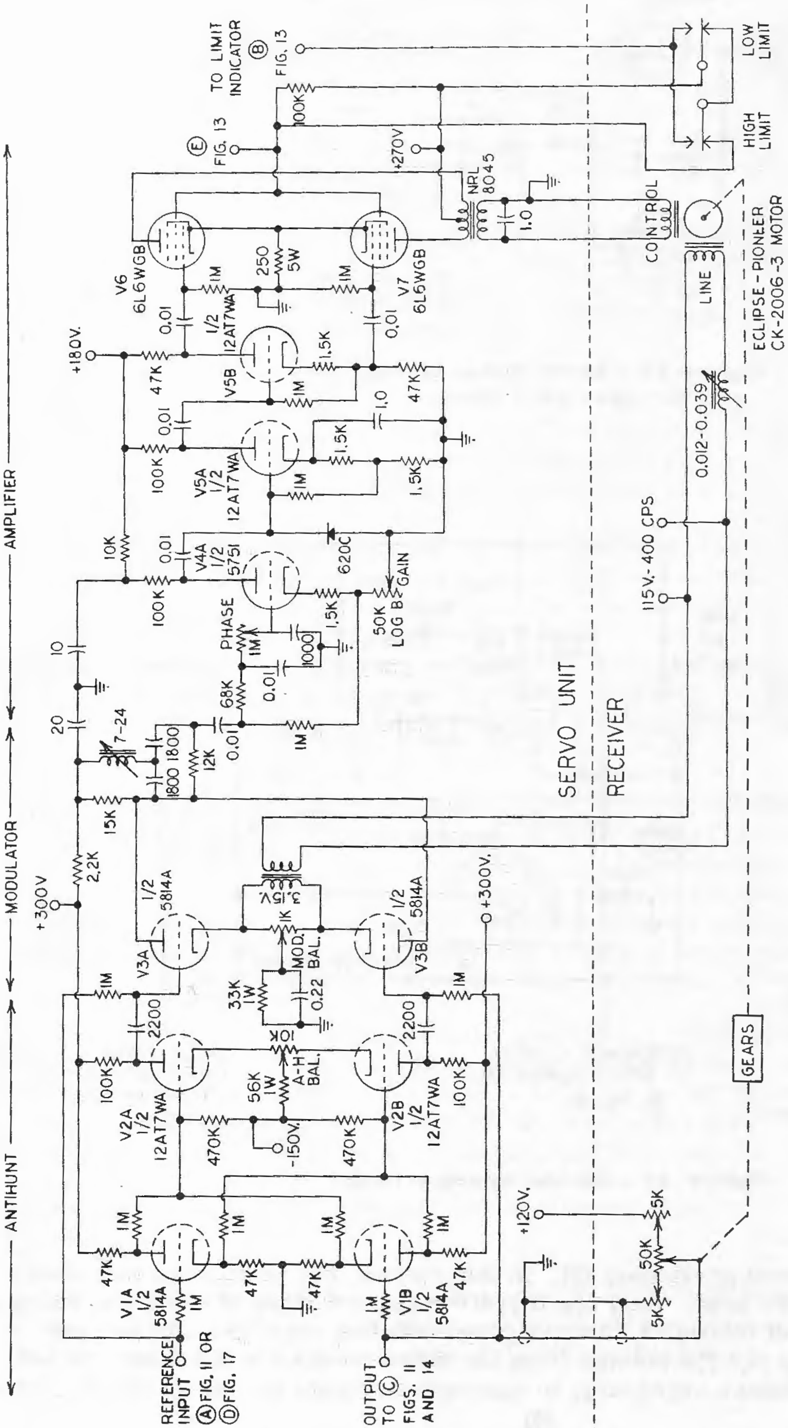

UNITS:

RESISTORS - OHMS. $K=10^3$, $M=10^6$
CAPACITORS - VALUES UNDER 25 IN MICROFARADS, OTHERWISE IN MICROMICROFARADS
INDUCTORS-HENRIES

ABBREVIATIONS:

A-H - ANTIHUNT
BAL - BALANCE
MOD - MODULATOR

Figure 9 - Tuner servoamplifier circuit

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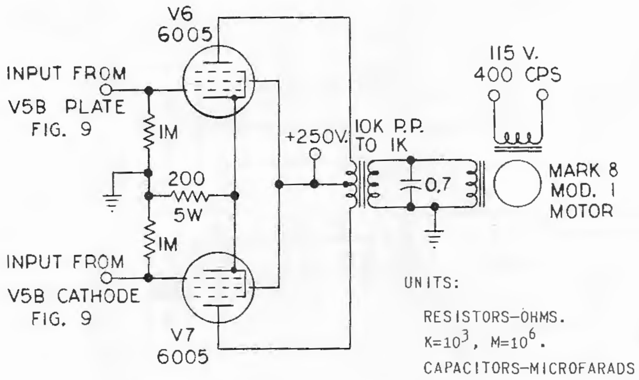

Figure 10 - Servo motor circuit for spur gear drive

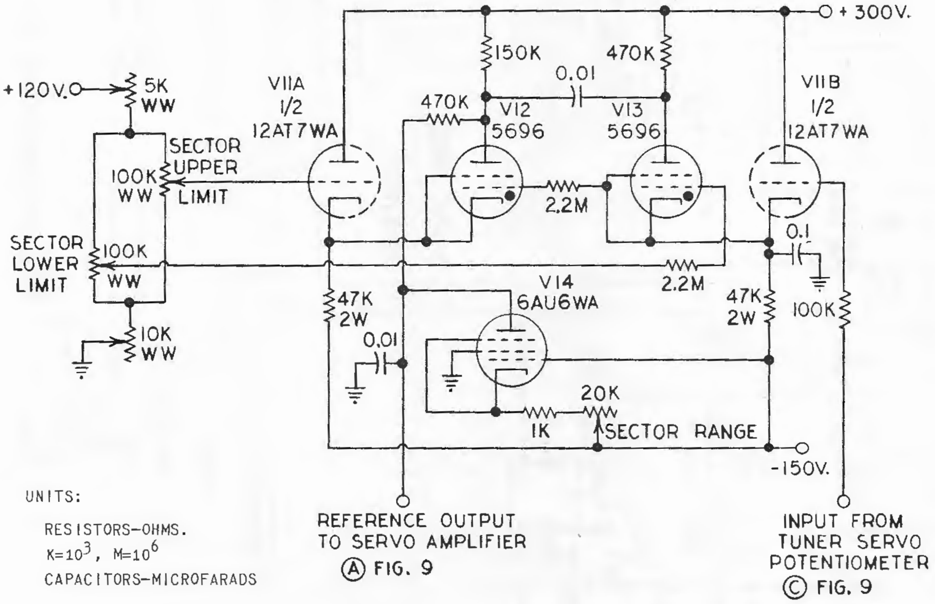

Figure 11 - Sector-sweep circuit

sector-sweep circuit reported previously (3). In this circuit, two thyratrons fire alternately, one at each end of the scan. Only one thyratron is conducting at any time; firing the second turns off the first through a common plate-coupling capacitor. Upper and lower sector-limit voltages and the voltage from the potentiometer in the tuner are fed, through cathode followers where necessary, to appropriate points to control the thyratrons.

The variation in voltage at the plate of one thyratron is changed in absolute value to provide the proper limits of voltage for the reference input to the servoamplifier. Previously, this change in absolute value was made by the drop in voltage through a

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subminiature voltage regulator. The 140-volt subminiature voltage regulator proved to be unstable with time, causing the sector reference voltage limits to fall outside the desired range. The latest circuit uses a pentode (V14) as a constant-current device to change the absolute value. Since the plate current in a pentode is essentially independent of plate voltage if the screen voltage is held constant, the voltage drop in the plate load resistor is essentially constant. Therefore, any change in potential at the plate of thyratron V12 appears as almost the same change in potential at the plate of pentode V14. The voltage at the plate of V14 is used as reference for the tuner servo when in sector-sweep operation.

The total change in reference voltage is about 130 volts, and the absolute value of the limits is set by the sector range control in the cathode of V14. Control of sector range is necessary because of the variation in cutoff characteristics of the 6AU6WA or any other pentode used in this circuit. The range limits are set so that the voltage sent to the servoamplifier for reference is either slightly above + 120 volts or slightly below zero, limits which can never be reached during scan. Thus the servo will sector towards one limit or the other until a thyratron fires to change the reference potential and start the receiver scanning in the opposite direction.

Other modifications of the previously reported sector-sweep circuit (3) were necessary to insure stable operation of the thyratrons. Bypass capacitors were added to the reference output line and the cathodes of V13 and V11B to suppress parasitic oscillations. The dc potential of the heater circuit was reduced from 60 to 38 volts to eliminate a 400-cps oscillation that was apparently caused by gas discharge between the heater and cathode of V12. Several changes were made to insure the extinguishing of V12 when V13 fired. The gate fed to V12 was increased by raising the value of the plate load of V13. The change in grid voltage of V12 caused by the inability of V11B to handle the current surge when V13 fired was reduced by decreasing the cathode resistor of V11B to increase the current drawn and by making the capacitor on the cathode of V11B sufficiently large to provide some energy storage.

Because of similar difficulties, Collins Radio Co. abandoned the thyratron sector-sweep circuit; they are instead using a bistable multivibrator. The triggering points are not as stable with a dc multivibrator as with thyratrons, but this feature is not particularly important, and the possibility of both control tubes firing simultaneously is eliminated. However, no trouble has been experienced with the circuit of Fig. 11 in over a year of operation except for failure of a metallized paper capacitor which was inadvertently mounted under a high-power resistor.

<u>Frequency Indicator</u> - Figure 12 illustrates the mechanics of the frequency indicator. For minimum backlash, all slow-speed gear meshes are adjustable. The counter is one removed from a standard AN/APR-9 and has a maximum speed rating of 200 rpm. In this unit, the counter is being operated at 400 rpm, and no difficulty has

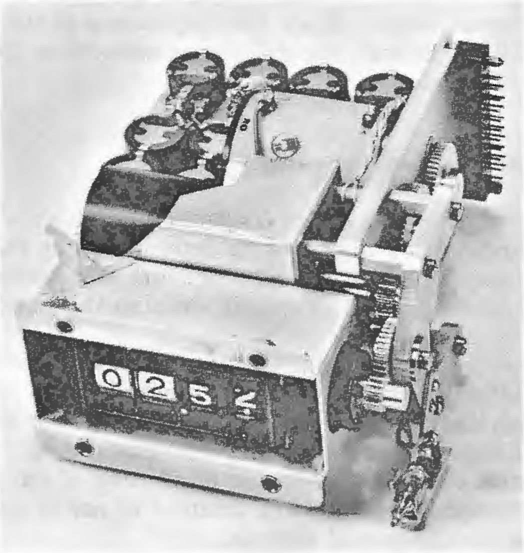

Figure 12 - Frequency indicator

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been encountered. When switching from the top of the X-band tuner to the bottom of the L-band tuner, about 15 seconds are required for the frequency indicator to reach the proper value. This period of time is entirely too long, and a higher-speed counter is desirable. Collins Radio Co. has procured a counter capable of tuning through the entire range of the nine tuners of the AN/SLR-2 in five seconds, which is a satisfactory rate.

The servo motor used in this indicator is a Ford Instrument Co. 1/2-watt, two-phase, 400-cps unit which has a 180-volt control winding. Since the power required by this high-impedance control winding is only one-fourth that required by the line winding, this motor can be driven by a miniature double triode. The mechanical power required from this motor is not determined by the counter load, which is negligible, but by the torque requirements of the frequency reference potentiometer geared to the counter.

The reference potentiometer in the frequency indicator is a special multitap 10-turn unit, Helipot model SAN 652. The maximum possible resistance (400,000 ohms) was incorporated in this potentiometer to provide sufficient resolution. Taps are provided at 477, 612, 1210, 1290, 2218, and 2353 degrees, and connections are made to the appropriate taps for each tuner. This particular potentiometer is applicable only to the four tuners of the AN/APR-9 receiver. A different tap arrangement and a movable decimal point on the counter are required to cover the nine tuners of the AN/SLR-2 or AN/ALR-8 (AN/APR-9 plus AN/APR-13).

A trimmer in series with each connection to the frequency potentiometer permits adjustment of the lower and upper readings on each frequency band to correspond with the limits in the tuners. The trimmers in series with the ends of the frequency potentiometer must always be connected to the voltage source to produce a differential across the unused portion of the potentiometer. Otherwise, when set at one end of the tuning range, there might not be sufficient differential for the servo to move from the unused portion to the "in use" section of the frequency potentiometer when bands are switched.

The frequency servoamplifier (Fig. 13) is similar to the tuner servoamplifier, but because of the lower speed of operation, neither the signal nor antihunt gains need be as great. Also, a dual triode is adequate to furnish the reduced power requirements of the output stage. Since the impedance of the control winding in the motor is large (about 25,000 ohms), the driving transformer (NRL 8274) must also have high impedance at 400 cps.

Acquisition Indicator

Horizontal and Vertical Deflection - The horizontal position of the trace on the acquisition indicator is determined by the voltage from the servo potentiometer in the tuner in operation. To prevent any loading of the tuner servo potentiometer, cathode follower V31A (Fig. 14) isolates the input circuit.

Adjustment of the amplitude control in the grid of deflection amplifier V32 would also affect the position, if a balance control had not been added. The balance control is adjusted so that when a tuner is set at the lower frequency limit, no voltage appears across the amplitude control. The horizontal position and amplitude controls then independently adjust the left edge and amplitude of the raster. The interaction that would occur if the balance control were omitted is not serious because the controls are seldom readjusted after the initial setting.

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UNITS:

RESISTORS - OHMS. K=10^3, M=10^6
CAPACITORS-VALUES UNDER 25 IN MICROFARADS,
OTHERWISE IN MICROMICROFARADS.
INDUCTORS-HENRIES

ABBREVIATIONS:

A-H - ANTIHUNT
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MOD - MODULATOR

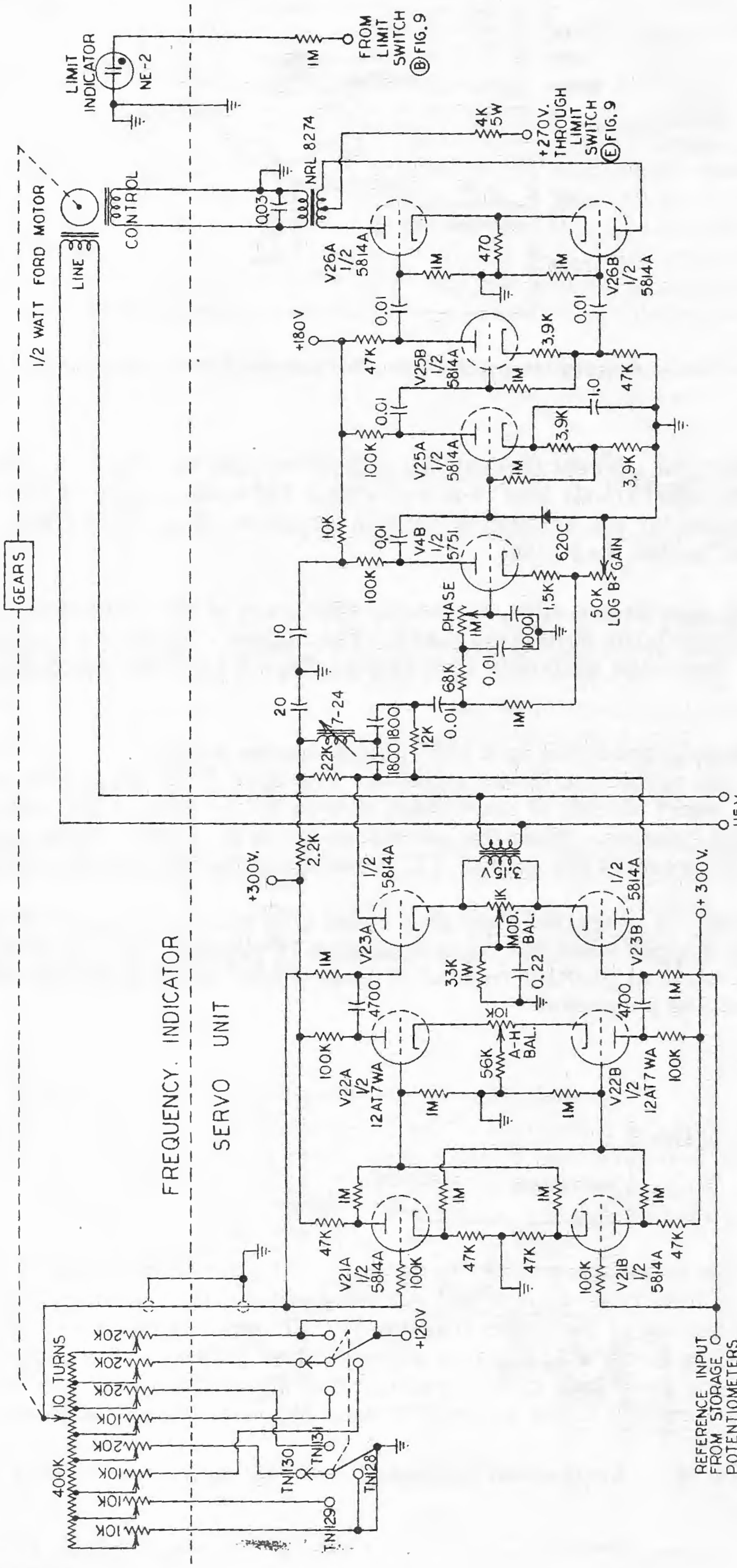

Figure 13 - Frequency servoamplifier circuit

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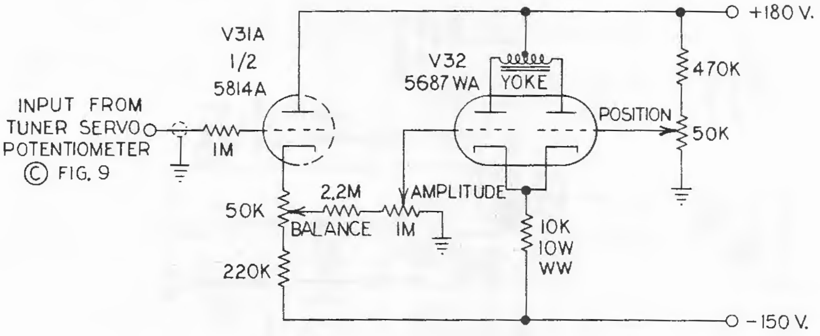

Figure 14 - Acquisition indicator, horizontal deflection circuit

To provide sufficient current through the deflection yoke for the 4-in. horizontal trace, a type 5687WA dual triode was required with a 180-volt supply. A 5814A dual triode was satisfactory for the vertical deflection amplifier (Fig. 15) because only 2 in. of deflection is used in that direction.

Since the sweep speeds are slow, maximum efficiency of the deflection amplifiers is obtained with high-impedance deflection yokes. The highest-impedance commercial yoke that could be located was the Syntronic Instruments Type Y15GG5P, which has proved satisfactory.

The vertical scan is produced by a 358° potentiometer which is run by a timing motor at a rate of one revolution in two minutes. The open 2° of the potentiometer is required to prevent short circuit of the voltage source by the arm of the potentiometer during its continuous rotation. When the potentiometer arm is in the open position, a 10-megohm resistor prevents the grid of V33 from assuming an arbitrary potential.

The driving motor is energized through a relay only when in acquisition operation; the vertical scan is stopped when the horizontal scan is stopped. The vertical position selector allows the vertical position to scan or to be placed at its upper or lower limit for alignment or holding purposes.

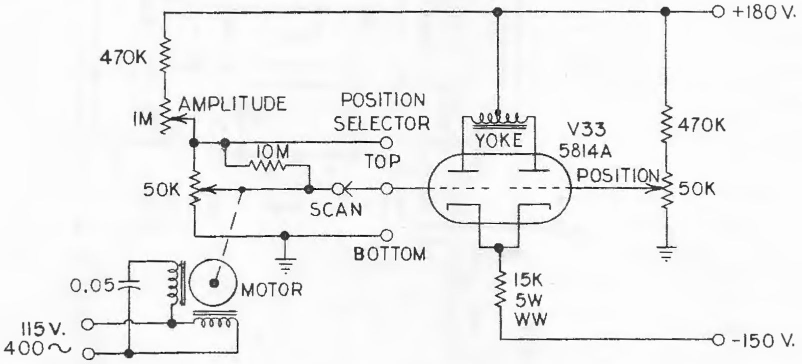

Figure 15 - Acquisition indicator, vertical deflection circuit

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Intensity Modulation - The intensity of the spot on the acquisition indicator is a function of the amplitude of the video signals appearing at the wide- and narrow-band outputs of the receiver. All the circuits for deriving the acquisition intensity gates from these video signals are located in the unified indicator, where many of these circuits are used for other purposes. On wide-band video signals, the acquisition indicator video intensity circuit (Fig. 16) receives its input from the unstretched video output fed to the 0-5 μsec trace on the unified indicator. On narrow-band video signals, the acquisition video is obtained from the circuit that provides narrow-band video to the DF trace on the unified indicator. In the unified indicator, a 500-μsec gate, triggered by the wide-band video signal, is generated by adding the 0-5 μsec and 5-500 μsec intensity gates used in the analysis sweep circuits. This 500-μsec gate is used in the acquisition video circuit to control the maximum time length of the intensity gates.

Cathode follower V201B (Fig. 16) drives the 100-$\mu\mu$f pulse stretching capacitor through diode V41A on wide-band video signals. During a video pulse, discharge tube V41B is cut off by a negative 500-μsec gate, and the stretching capacitor can charge. At the end of the 500-μsec gate, V41B conducts and discharges the capacitor rapidly. Thus a 500-μsec gate whose amplitude is proportional to the video pulse amplitude is generated at the suppressor of gated amplifier V42. If the pulse amplitude is great enough to drive the suppressor positive, the 100K resistor in the suppressor of V42 causes clipping and limits the amplitude.

Production of intensity output by noise is limited because discharge tube V41B is cut off only when gates are received from the trigger circuits in the unified indicator. Thus only noise peaks above the threshold level of the Schmitt trigger circuit in the unified indicator produce 500-μsec intensity gates. Noise is also controlled by the base-line clip adjustment in the grid circuit of V201B. Since direct coupling is employed between V201B and the suppressor of V42, the bias on the suppressor is determined by the grid voltage on V201B. Only noise peaks above the cutoff voltage of the suppressor are amplified by V42. Thus, the receiver gain control determines the noise density in the display by controlling the number of noise spikes that exceed the Schmitt-circuit threshold to produce gates, and the base-line clip control determines the intensity of the noise spikes in the display by controlling the level of noise that exists when the circuit is gated. This method of slicing is quite effective in differentiating between weak signals and noise. The dynamic range between threshold and saturation signals is only 9 db.

It is also possible to gate the signal with a diode instead of a triode for V41B. An advantage of diode gating is that only positive 500-μsec gates are required instead of both negative and positive. A disadvantage is that an additional diode is required to clamp the applied gate unless direct coupling can be employed. Clamping is obtained in the grid circuit of V41B when triode gating is used. For diode gating, the grid of V41B is connected to the plate, and a resistor is inserted between the cathode of V41B and the bias tap (junction of 68K and 15K resistors). A clamping diode is connected across the cathode resistor, and the bias tap is bypassed to ground. The positive 500-μsec gate is capacitively coupled to the cathode. Collins Radio Co. is using a direct-coupled diode gating circuit in the AN/WLR-1.

In the diode gating circuit, V41A and V41B may be replaced by silicon junction diodes of the quick-recovery type (1N627). Germanium diodes cannot be used here because a very large inverse impedance is needed to prevent discharge of the 100-$\mu\mu$f stretching capacitor. Ordinary silicon junction diodes cannot be used for V41A and V41B because the inverse impedance is too low during the recovery period immediately following the termination of the pulse. However, if a 100K impedance is inserted in the cathode of V41B to limit the capacitor discharge during the short interval in which the silicon diode is recovering, then an ordinary silicon junction diode can be used for V41B.

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UNITS:

RESISTORS - OHMS. $K=10^3$, $M=10^6$
CAPACITORS - VALUES UNDER 25 IN MICROFARADS,
OTHERWISE IN MICROMICROFARADS.

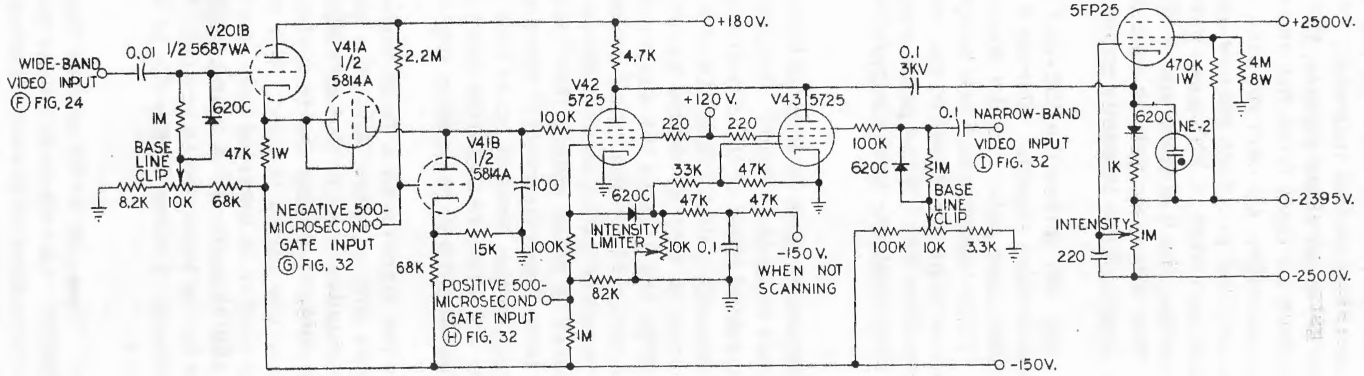

Figure 16 - Acquisition indicator, video intensity circuit

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On high-repetition-rate signals, the stretching capacitor cannot be discharged completely between pulses by V41B, and an average dc voltage appears at the suppressor of V42 regardless of the gating operation of V41B. However, since the control grid of V42 is gated by a positive 500-μsec gate that is synchronized with the negative gate applied to V41B, 500-μsec pulses will appear at the plate of V42 regardless of signal repetition rate.

To produce an indication on a cw signal, the narrow-band channel of the receiver is used. Every time the sweeping oscillator (used to provide the panoramic display) and the signal in the wide-band i-f amplifier are so related in frequency that heterodyne action occurs, a pulse that describes the narrow pass band of the receiver will be produced at the output of the narrow-band detector. The detected video is restricted in frequency response by circuits in the unified indicator to eliminate normal pulse signals but not the wide pulses produced by a cw signal. These wide pulses are applied to the suppressor of V43 to generate intensity pulses for the acquisition display. Base-line clipping is again used to reduce noise, but in this case the noise is cut off completely to prevent degradation of the signal-to-noise ratio on wide-band signals. Since the signal-to-noise ratio is much greater on narrow than on wide band, the sensitivity on cw signals is still greater than on pulse signals, even when the noise is completely cut off.

An intensity level which will not harm the screen of the cathode-ray tube in the acquisition indicator when scanning may destroy the screen when not scanning. To protect the screen when not scanning, an intensity limiter was installed in the control grid circuits of V42 and V43. During scanning operation, the 620C diode connected to the grid of V42 has no effect. When not scanning, a relay applies -150 volts to the network of two 47K resistors and the intensity limiter control to bias the diode. The amplitude of the positive gate on the control grid of V42 is then clipped at a level low enough to prevent screen burn on pulse signals if the intensity limiter control is properly set. At the same time, additional bias is supplied to the control grid of V43 to prevent screen burn on cw signals. A 0.1-μf capacitor connected from the junction of the two 47K resistors in the bias network to ground filters the switching transient when scanning is resumed.

The clamping diode in the cathode circuit of the cathode-ray tube is protected by a 1K series resistor and a neon lamp across the combination. When the power supply is turned on or off, transients can occur because of charge or discharge of the 0.1-μf intensity coupling capacitor. The reverse voltage transient is limited by the ignition potential of the neon lamp. The forward current transient is limited by the 1K resistor, since the voltage drop cannot exceed the ignition potential of the neon lamp. This protection system is used in all high-voltage circuits, and no diode failures have occurred since protection was added.

Cathode-Ray-Tube Characteristics and Operation - The P25 phosphor used in the cathode-ray tube is not as fragile as the P19 used previously, but some care is still required to prevent screen burn. One advantage of this phosphor is that even after a spot has been burned, there is still phosphorescence at that point when excitation is again applied. Since this phosphor is not as sensitive to burn, it can be operated at higher beam current than the P19 and hence will produce the required spot intensity at lower voltages. The 17-kv potential required with the P19 was reduced to 5 kv with the P25. This 5 kv is supplied from the power supply normally used for the unified data display and is split across ground—plus and minus 2500 volts.

Although the P25 phosphor has greater persistence than the P19, the intensity flash is less. Since the flash is yellow and the presistence is orange, an orange filter can be used to successfully mask the flash without affecting the visibility of the afterglow.

[redacted]

A Quam Focalizer Unit type QF-1 was employed for permanent-magnet focusing of the 5FP25. It is possible to obtain a much better focus over the entire face of this tube than of the 5RP19. However, there is some change in focus with signal intensity, and adjustment is made for small spot size on noise or threshold signals even though some defocusing occurs on saturation signals. If focus is adjusted for small spot size on a saturation signal, defocusing will occur on noise, and it is more difficult to distinguish between signal and noise. Since the dynamic range of brilliance of the P25 phosphor is small, spot size is a better indication of signal strength than intensity.

Control Techniques

Receiver Tuning and Storage - Receiver tuning is handled through the storage control circuits (Fig. 17). A 25-position telephone stepping switch determines whether one of the storage positions or the acquisition position is in control. Only storage positions 1 and 24 are shown in the figure to avoid confusion with excess wiring. Positions 2 through 23 are similarly connected.

The position of the stepper is controlled through its homing deck (top deck in the circuit diagram) by the storage and acquisition pushbuttons. When any one of the 25 pushbuttons is depressed, the arm of pole 1 on all pushbuttons becomes grounded through the one that is pressed. All terminals on the homing deck except the one connected to the button that is depressed are then grounded to close the circuit on the stepper. The stepper rotates until it comes to the terminal where power is interrupted by the depressed pushbutton. When the pushbutton is released, the circuit is open on all terminals of the homing deck and no change occurs. If two buttons are pressed simultaneously, the stepper will home to the first open position.

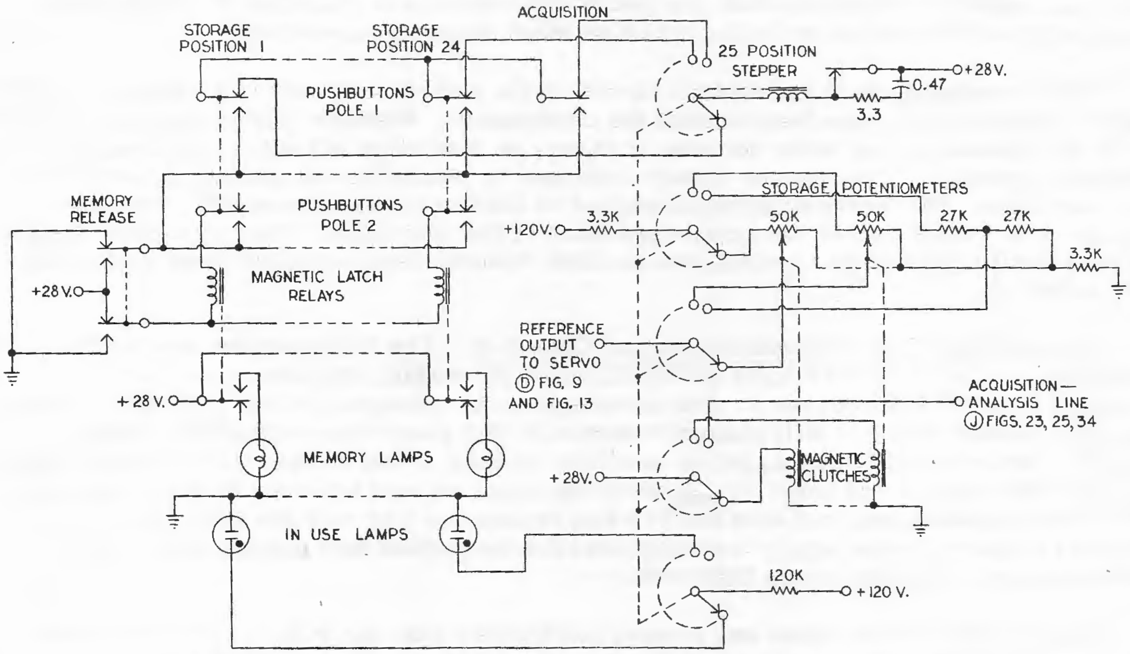

Figure 17 - Storage control circuits

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When any of the storage buttons are pressed, the second pole of the pushbutton energizes a polarized relay which locks in permanently (with a magnetic latch) to light the appropriate memory lamp. If the memory release button is held down, the polarity of voltage supplied to the relays is reversed. Pressing a storage button will then lock the polarized relay in the opposite position and turn off the memory lamp. The memory release button also reverses the polarity on the line feeding the homing deck of the 25-position stepper, so there is no potential difference across the stepper coil, and the stepper does not move when extinguishing the memory lamps.

The second deck of the 25-position stepper applies 120 volts to the appropriate storage potentiometer selected, and the third deck selects the arm connection of the same potentiometer. In the acquisition position, a fixed divider is used instead of a potentiometer, since then the reference output to the servo is applied only to the frequency indicator servo; the tuning servo is switched to the sector-sweep circuit in this position. The fixed divider centers the frequency indicator in the middle of the band, so minimum average time is required for the indicator to reach the correct position when a storage button is pressed.

The fourth deck of the stepper energizes the appropriate magnetic clutch to connect the tuning knob mechanically to the storage potentiometer selected. In the mechanical arrangement of this unit (Fig. 18), the potentiometers are alternately staggered at angles of plus or minus 30° with the horizontal to reduce overall depth. The depth is as short as gearing will allow, but use of smaller diameter potentiometers would eliminate the need for staggering. However, smaller potentiometers must have higher resistance to maintain adequate resolution. Also, a 1/4-in. shaft is required on the potentiometers for mounting the clutch, which eliminates most types of smaller potentiometers from consideration. Double bearings are required to support the clutch gearing adequately, and the type A Helipots used were so modified.

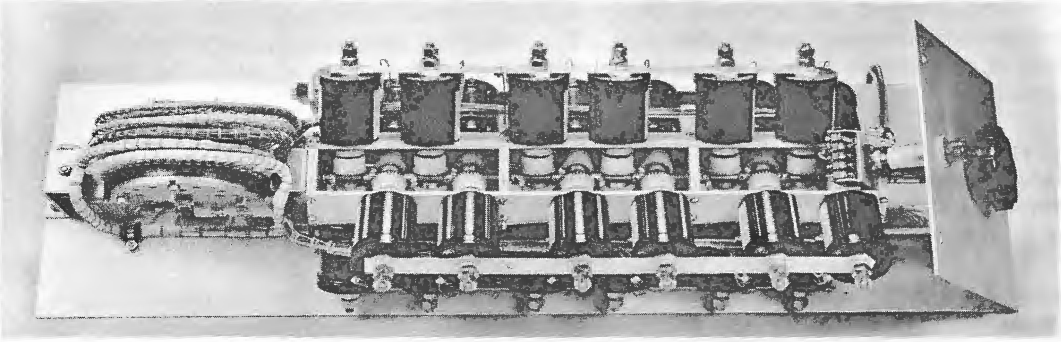

Figure 18 - Storage potentiometer unit

One of the electrical connections to each magnetic clutch is made through the metallic bushing which attaches the clutch to the potentiometer shaft. Therefore, a good electrical connection must be made between the potentiometer shaft and the frame through the potentiometer bearings. Some difficulty was experienced with these potentiometers, and both front and rear bearings were grounded in hopes that at least one would make good electrical contact to the shaft. Contact was still not good, so bronze rods were forced against the rear ends of the shafts and held in place by potentiometer-shaft-locking nuts.

These rods provide positive electrical contact and also add friction to movement of the potentiometer shafts. Without the added friction, energization or de-energization of the clutches caused a slight drift in potentiometer arm positions. A high-torque rather than a low-torque potentiometer is best for this service.

In the acquisition position, the fourth deck of the stepping switch furnishes power to the acquisition-analysis line to operate the numerous relays which must close in this position. On acquisition, the tuning servo reference input is switched to the sector sweep circuit, no intensity limiting bias is furnished to the acquisition indicator, the vertical scanning motor in the acquisition indicator is energized, the unified indicator intensity circuit is blanked, the synchronization level control in the unified indicator is switched to maximum sensitivity, the video bandwidth in the unified indicator is narrowed, the clutch to operate the acquisition gain control from the gain-control knob is energized, and the acquisition gain-control potentiometer is connected to the receiver gain-control line. When the relays are not energized in any of the 24 analysis positions, the tuning servo reference is switched to the manual outputs on deck 3 of the 25-position stepper, bias is supplied to limit the intensity gate on the acquisition indicator, the vertical scanning motor in the acquisition indicator is de-energized, the unified indicator intensity circuit is unblanked, the synchronization level on the unified indicator is switched to the front panel control, the video bandwidth in the unified indicator is switched to maximum, the clutch to operate the analysis gain control from the gain-control knob is energized, and the analysis gain-control potentiometer is connected to the receiver gain-control line.

The fifth deck of the stepper supplies power to the neon lamps located in the illuminated pushbutton switches to indicate the position in use. Only the last button pressed will light; on acquisition, none are lighted.

Tuner Switching - Tuner switching is accomplished through use of BuAer part E-1798-1 rf and power switching unit, which is indirectly controlled by the AN/APR-9 receiver-control-panel bandswitch. Since the frequency indicator must also be switched when tuners are changed, an auxiliary rotary-solenoid switch was installed in the tuner- and frequency-indicator-servoamplifier unit. The receiver bandswitch controls the homing deck of the switch in this servo unit, and this switch in turn supplies the voltage for the homing deck of the rotary-solenoid switch in part E-1798-1.

The portion of the circuits in the tuner switch used for the servo reference potentiometer had to be completely rewired, since shielded leads are necessary for the arm of the servo potentiometer. The shielding had to be isolated from ground, and a separate connection provided in the plugs for the shield lead.

Antenna Servo Switching - In the AN/SLA-3 antenna used with this equipment, the section for the TN-128/APR-9 tuner is oriented 180° in DF position from the other sections in the antenna. Therefore, the antenna servo operation has to be shifted 180° when the TN-128/APR-9 tuner is used. Selection of the TN-128 position on the receiver bandswitch furnishes 28 volts to relays in the antenna servo-control unit to reverse the leads on the synchro motor and the synchro control transformer. If the production version of the AN/SLA-3 (the AS-605/SLR) is used with the AN/WLR-1 equipment, the polarization switch must be manually changed to accomplish the same purpose when the L-band tuner is used.

Antenna Feed Switching - Two antenna sections cover the range of the TN-129/APR-9, TN-130/APR-9, and TN-131/APR-9 tuners. The TN-129 and TN-131 tuners receive signals from the low- and high-frequency sections respectively, but the TN-130 tuner must be switched between the low- and high-frequency antenna sections during the scanning operation. Switching of the three tuners between the two antenna feeds is accomplished by three Transco Products model 11300 coaxial switches, which have a transfer time of 10 milliseconds. High-speed switching is required because of the rapid scan rate.

In the switching circuit (Fig. 19), the low antenna feed is connected to TN-129 and the high antenna feed to TN-131 until TN-130 is selected for operation. The 28 volts from the bandswitch in the TN-130 position energizes SW-1 and SW-2 to switch both antennas to SW-3. TN-130 is then switched between the low and high antennas during the scan by a control voltage developed for this purpose.

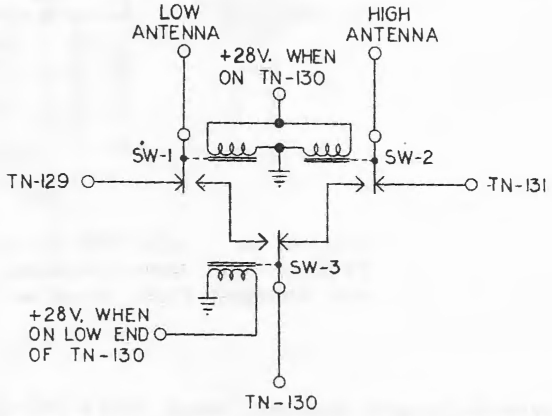

Figure 19 - Antenna switching circuit

To develop the control voltage for the switching function, the sector-sweep circuit normally used in the AN/APR-9 receiver is employed. The voltage from the servo reference potentiometer in the tuner is fed through a cathode follower to the sector-sweep tap lead in the receiver power supply. The voltage for the sector-sweep thyratron anodes is controlled by another deck on the rotary-solenoid switch in the servo unit, so this circuit will function only on the TN-130 tuner. Power to operate antenna feed switch SW-3 is furnished from the relay used for reversing the 28-volt motor in a normal AN/APR-9 receiver. Sector-sweep-limit controls were added and set to switch the antenna feed at the proper frequency.

The tuners employed in the AN/SLR-2 and AN/WLR-1 to cover the range of the TN-130/APR-9 have a switch installed to control the power for antenna changing. Therefore, the additional antenna-switching control circuitry is not required with these shipboard receivers. It was not convenient to add a switch of this type to the TN-130/APR-9.

For efficient operation, the antenna and its feed system must be kept dry. Therefore, an air drier was procured; its output is forced into the X-band wave guide. Several small holes were drilled in the X-band guide just inside the antenna pedestal to allow the air to flow into the radome. Since the radome is practically air tight, the air forced up the X-band guide returns through the S-band wave guide, where the pressure is released. This air system eliminated the condensation difficulties which occurred previously.

Unified Data Display

Receiver Modifications Required - To provide wide- and narrow-band video signals for the unified data display, several modifications were made in the Mixer-Amplifier unit of the AN/APR-9 receiver (12). In the wide-band channel (Fig. 20), the load (R530A) on the second detector was reduced to 1,000 ohms to improve the bandwidth. The diode (CR501A) was changed to a 1N56 for higher rectification efficiency, and parts C526A, L549, L550, R531, C534, and R532 were removed from the receiver (12). Since R530A provides sufficient loading on V509, R527 in the plate of V509 was replaced by a 0.25-microhenry inductor. The output cathode follower (V510A) was changed to a 6AH6 to

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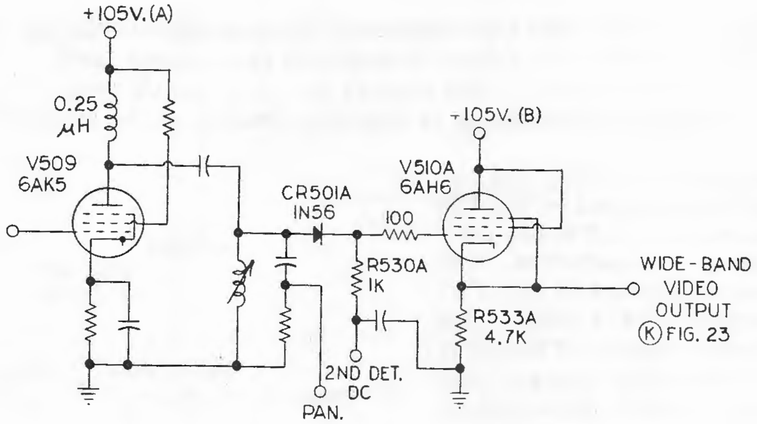

Figure 20 - AN/APR-9 wide-band video modifications. (Values have been purposely omitted from all components not changed from original equipment. See text below.

provide greater dynamic range, and a 100-ohm oscillation suppressor was inserted in its control grid. The cathode resistor of V510A was increased to 4.7K, since all loading is provided by the 91-ohm impedance at the input of the unified indicator. All components in Fig. 20 which are not identified have not been changed from the normal circuit (12). All components which have been changed are identified in Fig. 20 by an A following the part number which appears in the receiver handbook.

Unstretched narrow-band video was preferred for the DF circuit in the unified data display, so the following modifications were made in the narrow-band channel of the receiver. The detector (CR503A - Fig. 21) was changed to a 1N56 for higher rectification efficiency, and its polarity was reversed because an amplifier was added. Since the receiver circuits (12) employing V511, V512, V513, and V514 are not used in this system, the latter three tubes were removed and V511 was rewired as the amplifier. The dynamic range of this amplifier was limited to prevent excessive amplitude on the panoramic

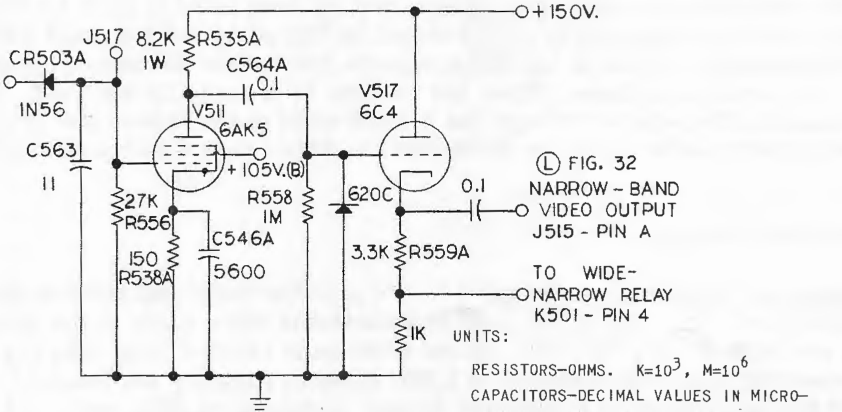

Figure 21 - AN/APR-9 narrow-band video modifications

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display, which also receives its signal from this channel. Since a negative-polarity signal is applied to the grid of V511, the maximum amplitude that can be obtained occurs when the tube reaches cutoff. Thus the output pulse can never exceed the no-signal dc voltage drop in R535A, and the size of this resistor determines the dynamic range. Use of a negative-signal excursion for amplitude limiting prevents overshoots. Cathode peaking was employed to improve the rise time. Clamping was added in the grid circuit of the output cathode follower (V517). The cathode load resistor of V517 was split, and the tap point was adjusted to furnish equal noise outputs from the receiver on narrow and wide bands.

Functional Outline - The functions of the various circuits in the unified data display may be outlined from a block diagram (Fig. 22). Starting at the top of the diagram, the wide-band video signal from the receiver is amplified by V101, V102A, and V103, delayed, and applied through cathode follower V201A to the vertical deflection plates of the 0-5 μsec gun of the cathode-ray tube. The clamped video is also supplied to the various stretcher systems from which video is obtained for the other guns. The stretched video applied to the 5-500 μsec gun by V202A and V202B is dynamically varied as the sweep progresses by control tube V203, which in turn operates from the properly shaped gate developed by sweep deflection amplifier V406. Neutralization is used to minimize the effects of the capacity in V202A. To furnish video to the 500-50,000 μsec gun, the signal from V201A is first prestretched a fixed amount by V204A and V205A, and then further stretched by a 1N627 silicon diode and V206A. This stretched video is dynamically controlled by V207, according to the gate produced by sweep-deflection amplifier V506, in a manner similar to the 5-500 μsec video. The prestretched video from V205A is stretched a fixed amount by a 620C silicon diode and is delivered by cathode follower V204B to the wide-narrow mixer V905 in the DF video switch, through which it is eventually applied to the DF-gun vertical-deflection plates. An audio output is obtained from the pulse stretcher system by use of a 620C stretcher, cathode follower V206B, a mixing network, and amplifier V205B in a circuit similar to that used with linear-sweep analyzer systems (7).

Sync for the 0-5 μsec sweep is derived from the video amplifier through cathode follower V102B. The sync multivibrator, V301, generates a very narrow pulse of constant width and amplitude, which is amplified by V302 and used to trigger timing multivibrator V303. At the end of the period of V303, another pulse is generated to trigger lockout multivibrator V304. The gate from V304 cuts off V302 to prevent another triggering of V303 before the timing multivibrator and sweep generator V305B have recovered. Split-load amplifier V305A, which receives a positive gate from the timing multivibrator, delivers a rectangular positive gate to the mixers for the DF-gun intensity, a shaped positive gate for intensity on the 0-5 μsec gun, and a rectangular negative gate to sweep generator V305B. V305B produces an exponential decay in voltage during the period of the gate supplied by V303, and this voltage is amplified by V306 before being applied to the horizontal deflection plates of the 0-5 μsec gun.

Sync for the 5-500 μsec sweep is derived from the trailing edge of the gate produced by V303. Except for the time lengths involved, operation of V402, V403, and V404 is similar to that of V302, V303, and V304 respectively. Since sweep generator V405B requires a positive rectangular gate instead of a negative one (required for V305B), V405A is a cathode follower instead of a split-load amplifier (like V305A). Other functions of V405A are similar to those of V305A. V405B produces an approximately logarithmic rise in voltage during the period of the gate supplied by V403, and this voltage is amplified by V406 before being applied to the horizontal deflection plates of the 5-500 μsec gun. A portion of the output voltage is used as a stretch gate to control V203, since this voltage has the proper shape for tailoring of the pulse stretching. It is not possible to control the pulse stretching for this gun without introducing some of the stretch gate into the vertical deflection supplied by V202B. Therefore, a compensating gate is supplied to the other vertical deflection plate of the 5-500 μsec gun by V406 to balance out this undesirable effect.

Operation of the 500-50,000 μsec sweep is similar to the 5-500 μsec one except for minor details. Exponential rather than gate-type lockout is satisfactory for this sweep, thus eliminating the lockout multivibrator. Compensation for the stretch gate is not required, because negligible gate is introduced by V207 with the smaller current required for the longer stretch period.

The 10-kc carrier used to produce the DF sweep is generated by oscillator V601A in the DF carrier generator, and its output is maintained constant by an agc circuit operating on controlled amplifier V602. After the signal is further amplified by V603 and V604A, it is fed through cathode follower V604B to the resolver. Inverse feedback is applied through differential amplifier V603 to produce the very low output impedance required to drive the resolver and to maintain the required symmetry in the waveform. The agc voltage is developed by rectifying the signal from V604B in a voltage doubler consisting of V601B and a 620C silicon diode.

The two outputs from the resolver (sine and cosine envelope waveforms) are fed to similar circuits. Cathode followers V701A and V701B drive push-pull rectifiers and the lines feeding to the phase comparator. The output networks of the rectifiers are isolated from the mixing network by cathode followers V702A and V702B. Addition of the rectified sine and cosine envelopes in the mixer produces an almost linear sweep* which is amplified by V703 before being applied to the horizontal deflection plates of the DF gun.

To displace the DF sweep vertically and to reverse the video deflection between the two 180° segments of the sweep, the outputs of V701A and V701B are fed through similar circuits in a phase comparator. Channel one consists of cathode follower V801A, amplifiers V802 and V804, and three sets of clippers; channel two consists of V801B, V803, V805, and three sets of clippers. The outputs of these channels are 10-kc square waves, and sufficient amplification and clipping is provided to produce square-wave outputs even at the resolver nulls. Since the phase of a resolver output reverses when a null is passed, and since the nulls occur 90° apart in resolver position (180° on the sweep), the outputs of the two channels will be either in phase or out of phase. When added in V806, the squared carriers either produce a double output or cancel, depending on the resolver position. The summed carrier is full-wave rectified by two 620C diodes to produce dc to operate switching multivibrator V901 in the DF video switch.

The outputs of V901 in the DF video switch cut off either gated amplifier V903 or V904, depending on whether or not V901 is receiving a dc voltage. Thus the video from wide-narrow mixer V905 is switched from one vertical deflection plate to the other by V903 and V904 to produce either upward or downward deflection. To displace the DF sweep baseline when the video is reversed, V901 also controls the plate voltages of V903 and V904 through cathode followers V902A and V902B respectively.

Because of nonlinearities in the cathode-ray tube, there may be a slight horizontal displacement of the trace when the vertical shift is made. To compensate for this shift, an adjustable small portion of the voltage from plate-to-plate of V901 is fed into horizontal deflection amplifier V703.

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*This technique was suggested by Mr. Rambo of Stanford Electronics Laboratory.

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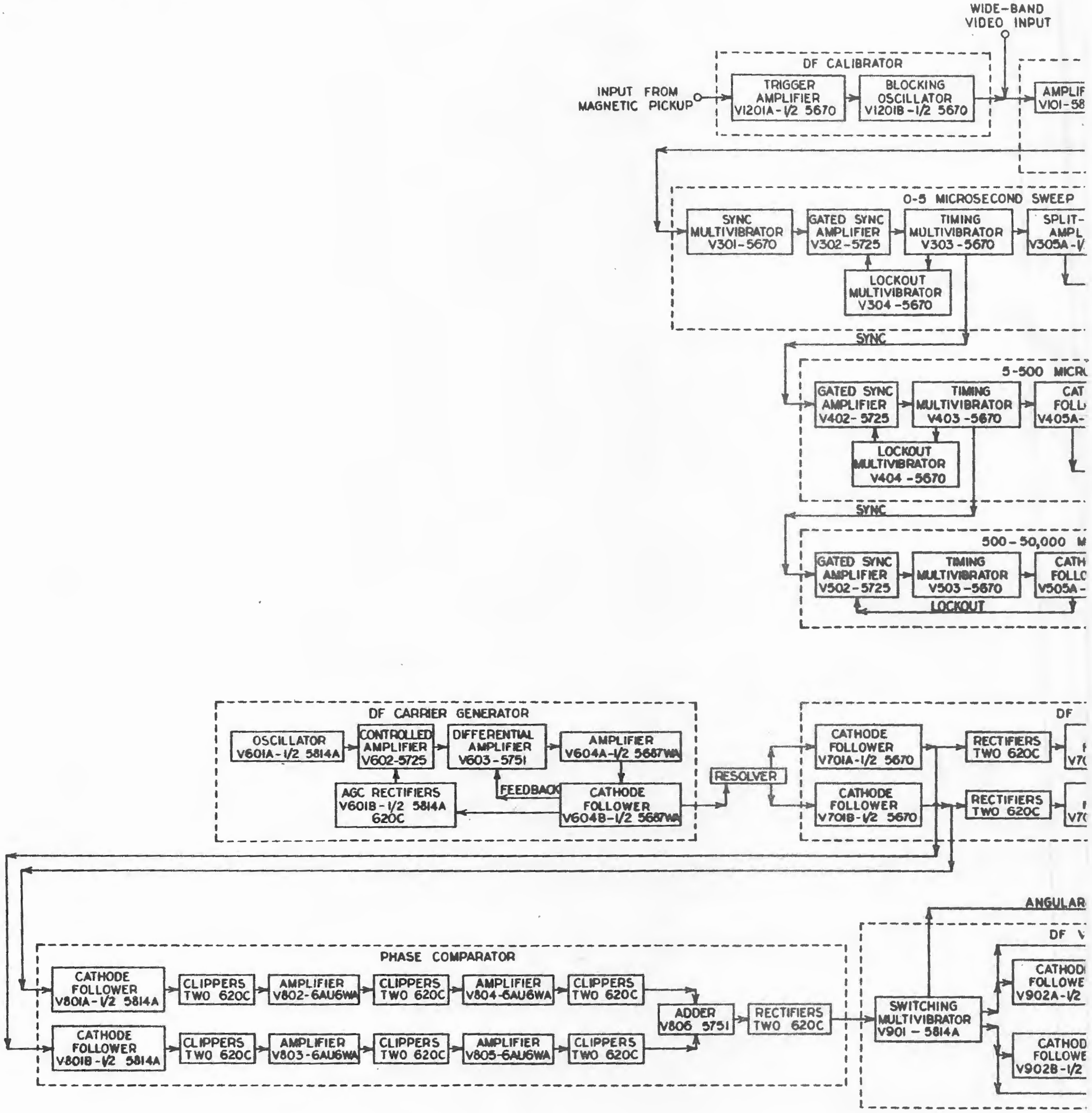

Figure 22 - Unified indicator block diagram

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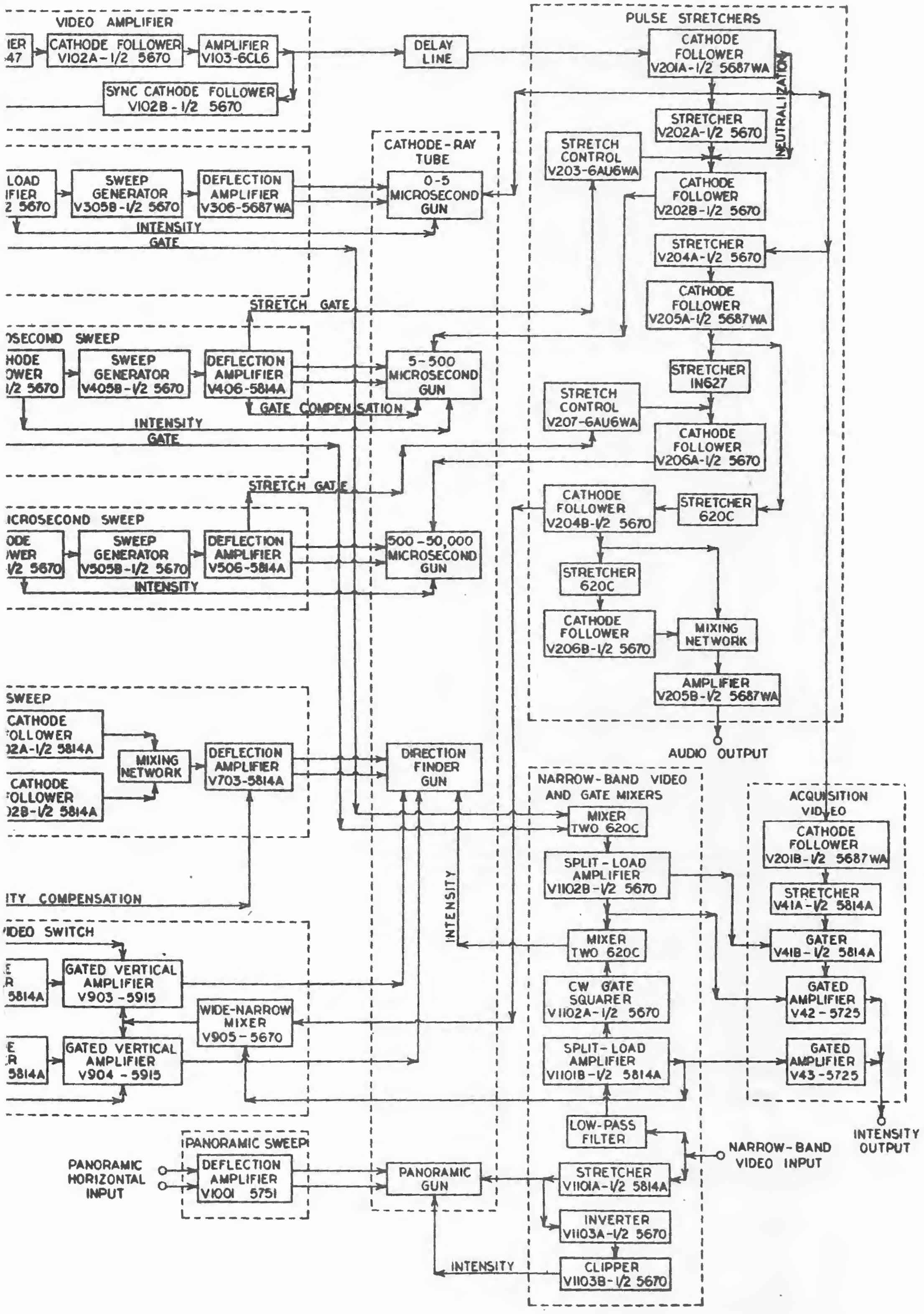
VIDEO AMPLIFIER
IER
47
CATHODE FOLLOWER V102A-1/2 5670
AMPLIFIER V103-6CL6
SYNC CATHODE FOLLOWER V102B-1/2 5670
DELAY LINE
PULSE STRETCHERS
CATHODE FOLLOWER V201A-1/2 5687WA
NEUTRALIZATION
STRETCHER V202A-1/2 5670
STRETCH CONTROL V203-6AU6WA
CATHODE FOLLOWER V202B-1/2 5670
STRETCHER V204A-1/2 5670
CATHODE FOLLOWER V205A-1/2 5687WA
STRETCHER IN627
STRETCH CONTROL V207-6AU6WA
CATHODE FOLLOWER V206A-1/2 5670
CATHODE FOLLOWER V204B-1/2 5670
STRETCHER 620C
STRETCHER 620C
CATHODE FOLLOWER V206B-1/2 5670
MIXING NETWORK
AMPLIFIER V205B-1/2 5687WA
AUDIO OUTPUT
CATHODE-RAY TUBE
LOAD
IFIER
2 5670
SWEEP GENERATOR V305B-1/2 5670
DEFLECTION AMPLIFIER V306-5687WA
0-5 MICROSECOND GUN
INTENSITY
GATE
STRETCH GATE
OSECOND SWEEP
HODE
OWER
1/2 5670
SWEEP GENERATOR V405B-1/2 5670
DEFLECTION AMPLIFIER V406-5814A
5-500 MICROSECOND GUN
GATE COMPENSATION
INTENSITY
GATE
STRETCH GATE
ICROSECOND SWEEP
ODE
WER
1/2 5670
SWEEP GENERATOR V505B-1/2 5670
DEFLECTION AMPLIFIER V506-5814A
500-50,000 MICROSECOND GUN
INTENSITY
SWEEP
CATHODE
OLLOWER
02A-1/2 5814A
CATHODE
OLLOWER
02B-1/2 5814A
MIXING NETWORK
DEFLECTION AMPLIFIER V703-5814A
DIRECTION FINDER GUN
ITY COMPENSATION
NARROW-BAND VIDEO AND GATE MIXERS
MIXER TWO 620C
SPLIT-LOAD AMPLIFIER V1102B-1/2 5670
MIXER TWO 620C
CW GATE SQUARER V1102A-1/2 5670
SPLIT-LOAD AMPLIFIER V1101B-1/2 5814A
LOW-PASS FILTER
STRETCHER V1101A-1/2 5814A
INVERTER V1103A-1/2 5670
CLIPPER V1103B-1/2 5670
NARROW-BAND VIDEO INPUT
INTENSITY
ACQUISITION VIDEO
CATHODE FOLLOWER V201B-1/2 5687WA
STRETCHER V41A-1/2 5814A
GATER V41B-1/2 5814A
GATED AMPLIFIER V42-5725
GATED AMPLIFIER V43-5725
INTENSITY OUTPUT
IDEO SWITCH
E
R
5814A
GATED VERTICAL AMPLIFIER V903-5915
WIDE-NARROW MIXER V905-5670
E
R
5814A
GATED VERTICAL AMPLIFIER V904-5915
PANORAMIC SWEEP
PANORAMIC HORIZONTAL INPUT
DEFLECTION AMPLIFIER V1001 5751
PANORAMIC GUN
INTENSITY

[redacted]

To produce a DF indication on cw signals, the narrow-band video (lower right of the diagram) from the AN/APR-9 receiver is fed through a low-pass filter to eliminate pulses and then through split-load amplifier V1101B to wide-narrow mixer V905. Here the stretched pulse signals from V204B and the cw signals from V1101B are added to produce the video for DF.

On a cw signal, the narrow-band video is a series of wide pulses produced by the heterodyne action between the panoramic-display sweeping oscillator in the receiver and the signal. These long pulses from V1101B are squared in V1102A to provide a cw intensity gate for the DF gun. To provide an intensity gate for pulse signals, the 0-5 and 5-500 μsec gates from V305A and V405A are mixed through two 620C diodes in the gate-mixer unit. After isolation by split-load amplifier V1102B, the pulse gates are mixed with the narrow-band gate through two 620C diodes and fed to the control grid of the DF gun.

The narrow-band video from the receiver is also stretched by V1101A and is used for vertical deflection of the panoramic gun. For horizontal deflection of this gun, sweep voltage from the receiver is amplified by V1001 (lower left of diagram) before being applied to the deflection plates. To produce intensity modulation of the panoramic gun, the stretched narrow-band video from V1101A is inverted by V1103A and clipped by V1103B to produce rectangular gates nearly as wide as the bases of the stretched pulses.

To calibrate the DF sweep, a magnetic pickup and twelve equally spaced vanes were installed in the antenna. The pulse that is produced at every 30° of rotation is fed to trigger amplifier V1201A (upper left of the diagram) in the DF calibrator. The output of V1201A keys blocking oscillator V1201B to produce a calibration marker of constant amplitude and width, which is fed into the video amplifier.

Cathode follower V201A in the pulse stretcher unit (right of diagram) also supplies the signal to the acquisition video (V201B, V41A, V41B, V42, and V43) described previously. The 0-500 μsec gate produced by mixing the 0-5 and 5-500 μsec gates is furnished through split-load amplifier V1102B to V41B and V42. Narrow-band video which has been filtered to pass only the wide pulses generated by cw signals is supplied to gated amplifier V43 from V1101B.

Video Amplifier - Both shunt and cathode peaking are used in the first stage (V101) of the video amplifier (Fig. 23) to provide optimum gain and rise time. Cathode bias is used on both amplifier stages (V101 and V103) for stability. The cathode follower (V102A) between the two amplifier stages isolates the large input capacity of V103 from the plate circuit of V101, thereby allowing twice as much amplification to be obtained from V101. Also, amplifier tubes operated at almost zero bias, such as V103, give better performance when driven from a low-impedance source. Only cathode peaking is used in the final amplifier (V103). The series and shunt peaking following the delay line are for proper termination. A 6CL6 pentode was employed in the output stage instead of the 418A which appeared in the previous circuits (9, 10) because the 418A is larger, more critical, and not as readily procured. The 418A also requires a special type of socket. Although the gain is halved by this change, the overall amplification is still adequate when the AN/APR-9 receiver is the signal source.

For analysis, it is desirable to provide a rise time of less than 0.05 μsec to maintain accurate pulse shapes, especially on narrow pulse signals. However, waveform is of no importance for acquisition. By degrading the rise time on acquisition, noise is reduced without an appreciable effect on pulse peak amplitude. Therefore, the plate load of V101 is switched from a 2.7K resistor in series with a 47 μh inductor on analysis to a 15K

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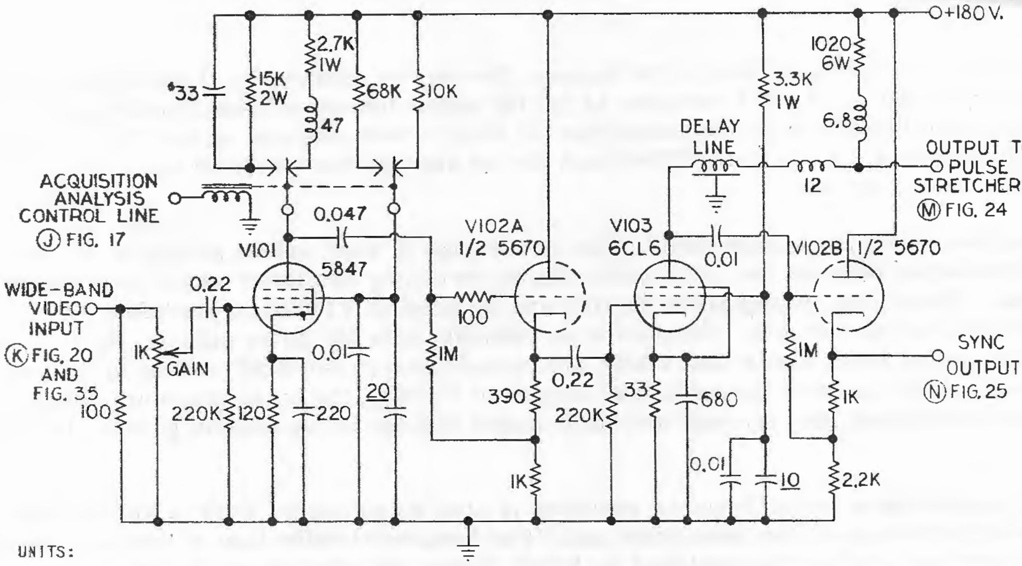

UNITS:

RESISTORS– OHMS. $K=10^3$, $M=10^6$

CAPACITORS–DECIMAL AND UNDERLINED VALUES IN MICROFARADS. OTHERWISE MICROMICROFARADS.

INDUCTORS–MICROHENRIES

Figure 23 - Video amplifier circuit

resistor in parallel with a 33 μμf capacitor on acquisition. The values were chosen so that on acquisition the noise output of the amplifier would remain the same as on analysis and so that the signal-to-noise ratio on a 0.1-μsec pulse would also be the same. On wider pulses an improvement of 6 to 9 db in signal-to-noise ratio is obtained.

When the load resistance in the plate of V101 was increased on acquisition, the voltage drop through this resistor lowered the plate voltage of V101 excessively. To reduce plate current and thus increase the plate voltage, the screen voltage was lowered by increasing the screen-dropping resistor on acquisition also. Since the gain of V101 is a function of plate current, both the plate-load and screen-dropping resistors had to be carefully chosen to provide the correct gain and optimum tube operating conditions.

The RG-65/U cable used for delay lines in video amplifiers developed previously (7, 10) has the disadvantage that the polyethylene insulation softens under temperatures encountered in the equipment. Softening causes the position of the inner conductor to shift with respect to the outer conductor, which changes the characteristics of the line. Frequent rematching of the line is necessary, and eventually the line must be replaced because discontinuities become too bad to match. A search for better delay lines led to development of the type FD164 by Control Electronics Co. This 7/16-in.-diameter by 7-1/2-in.-long stick type line provides a delay of about 0.2 μsec and has characteristics similar to the RG-65/U except that temperature does not change its characteristics. However, variations among the five units purchased were considerably greater than among new pieces of RG-65/U cable. An adjustment of ± 20 percent in terminating resistance and ± 50 percent in matching inductances might be required with this line unless tolerances can be tightened in production units.

Pulse Stretchers - Proper pulse stretching has always been one of the most difficult problems in the indicator design. The present circuit (Fig. 24) shows considerable deviation from the stretcher system reported previously (10). In the video pulse-stretcher system for the 5-500 μsec trace, a portion of the sweep waveform is fed to

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UNITS:

RESISTORS-OHMS. $K=10^3$, $M=10^6$

CAPACITORS-VALUES UNDER 5 IN MICROFARADS, OTHERWISE IN MICROMICROFARADS

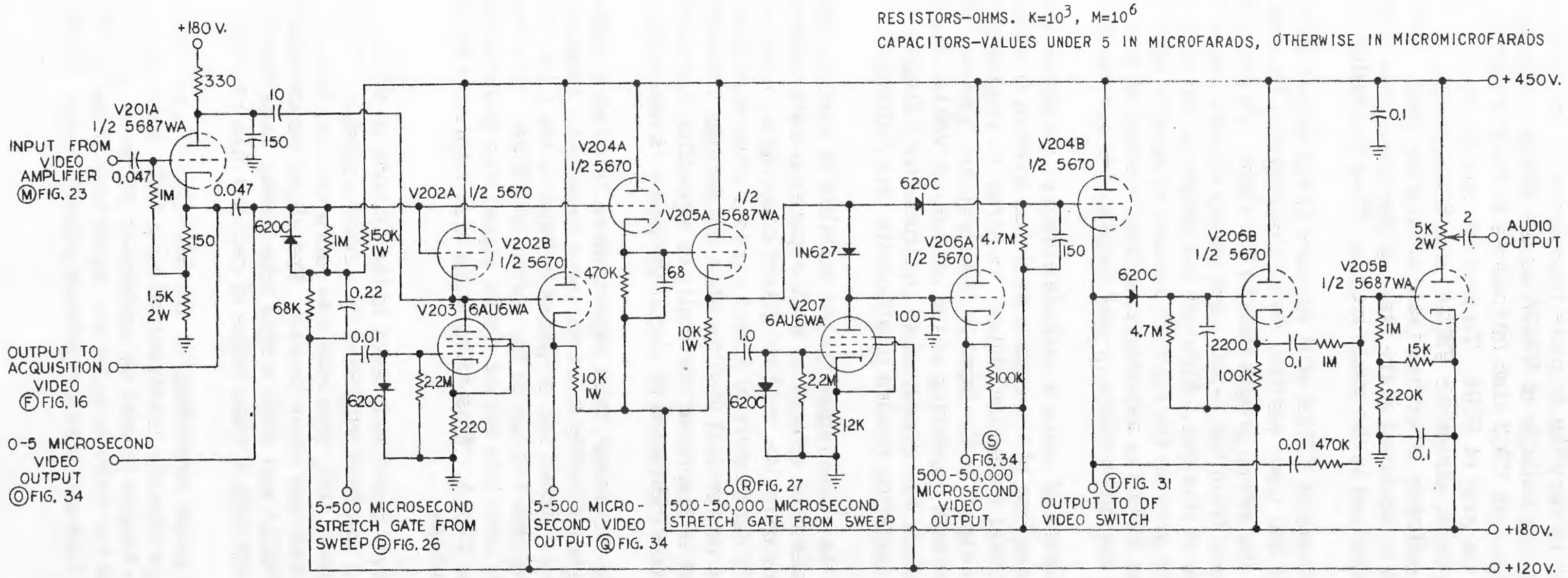

Figure 24 - Pulse stretchers circuit

[redacted]

the control grid of V203 to vary the dc plate impedance of this tube and thus change the stretch time constant at the cathode of V202A as the sweep progresses. Unfortunately, the change in current through V203 also introduces at the cathode of stretcher V202A a gate similar to that at the grid of V203. To prevent introduction of the 5-500 μsec gate into the other video circuits, stretcher V202A, which was formerly a diode, has been replaced by a cathode-follower stretcher that isolates the gate. Previously, the minimum stretch that could be obtained at the start of the sweep was limited by the amount of gate that could be tolerated in the other traces. This limitation no longer exists.

The gate at the cathode of V202A still appears at the output of cathode follower V202B that drives one of the 5-500 μsec vertical deflection plates. This shaped gate causes a rise in the baseline as the sweep progresses to the right. To compensate for this effect, a similar gate is obtained from the 5-500 μsec sweep circuit and is applied to the other vertical deflection plate of this gun. Although the height of the gate supplied to the grid of V203 is adjustable (to provide the correct amount of stretch at the end of the sweep), and hence the gate from V202B is adjustable, a fixed amount of gate can be used for compensation, because the differences in gate heights are too small to be noticed.

An additional advantage of using a cathode-follower stretcher for V202A is that it permits use of direct coupling of the entire stretcher system from driving cathode follower V201A to the vertical deflection plates. In order to employ direct coupling, it is necessary to clamp the signal at the input to the stretcher system. When diode stretchers were used, the gate currents appearing at the cathode of V201A interfered with the clamping action of the 620C diode and produced an unsatisfactory display. The cathode-follower stretcher provides the isolation needed to eliminate this difficulty.

Direct coupling of the video improves the stability of vertical trace positions on burst signals, and rectification effects on high-repetition-rate pulse signals do not cause loss of information. In particular, without direct coupling a signal with high enough repetition rate to rectify completely to direct current when stretched long enough for the DF trace would produce no vertical display when the antenna rotation was stopped. With direct coupling, the spot is displaced vertically to a position corresponding to the peaks of the pulses, so a definite indication of signal presence is obtained.

Similarly to a diode stretcher, tube capacitances in stretch cathode follower V202A feed an uncontrolled signal directly from its input to output. Neutralization was provided previously by developing a small out-of-phase voltage in the plate circuit of cathode follower V201A and feeding this voltage to the output of V202A. However, proper neutralization was not obtained until this out-of-phase signal was integrated by the 150-$\mu\mu$f capacitor at the plate of V201A. This integration also improves the characteristics of V201A as a cathode follower.

The adjustable control previously used in the cathode of V203 to determine the stretch at the start of the sweep has been replaced by a fixed resistor. When diode stretching was used in the previous circuit (10), this bias was more critical because it affected the amount of gate coupling introduced into other traces. The slight variations in initial stretch that occur with changes in V202A and V203 within tube limits have been found to be insignificant in the present circuit with a fixed value of cathode bias resistor.

To produce proper pulse stretching for the 500-50,000 μsec and DF displays, the video from V201A was previously prestretched by a 1N70 diode and a 10-$\mu\mu$f capacitor. However, temperature changes caused by equipment warm-up produced sufficient change in reverse impedance of the 1N70 to upset the stretching at the start of the 500-50,000 μsec sweep. Ordinary high-reverse-impedance silicon diodes, such as the Texas

Instrument type 620C, exhibit a poor recovery characteristic after the pulse that prevents their use for stretching short-duration pulses. Since the only alternative at the time was to use a vacuum tube for prestretching, and since reduction of the loading on cathode follower V201A was desirable, V204A was also made a cathode-follower stretcher.

In the 500-50,000 μsec pulse stretcher, diode stretching was retained because cathode-follower stretching does not work as well for very long stretch periods. The isolation properties of a cathode-follower stretcher are not needed here because for the longer stretch time required, the current drawn by V207 is low even at the start of the sweep, and negligible gate appears at the cathode of the 1N627 stretching diode. The requirement for gate compensation thus disappears on this sweep. Since the 100-μμf stretching capacitor on the cathode of the diode is large compared to the diode capacitance, there is negligible direct feedthru of the pulse, and neutralization is not required.

To prevent changes in stretch with temperature, the stretching diode must be either a silicon-junction type or a vacuum tube. The 620C silicon diode used in most applications in this system does not have fast enough recovery of the back impedance after the termination of the pulse to be used as a stretching diode in the 500-50,000 μsec video circuit. Therefore, a vacuum diode was employed in this application until the recent development of quick-recovery silicon-junction diodes, such as the 1N627.

When an attempt was made to replace the variable bias adjustment on V207 by a fixed cathode resistor, it was found that variations among 6AU6WA tubes in the low-operating-current range were great enough to cause an undesirable change in the amount of stretch at the beginning of the 500-50,000 μsec sweep. However, by adjusting the time constant in prestretcher V204A to provide the desired stretch at the start of the sweep and then choosing a cathode bias resistor for V207 which would limit the initial stretch to a value less than that provided by V204A regardless of the particular 6AU6WA used, satisfactory results were obtained. Thus the stretch at the start of the sweep is controlled by the prestretcher circuit (which is practically independent of tube characteristics) and the stretch along the sweep is determined by the gate amplitude delivered to the control grid of V207.

In the fixed stretcher system for direction finding, it was possible to replace the vacuum diode previously used for stretching by a 620C because the slight loss in amplitude caused by poor recovery of the 620C is compensated for by additional gain later in the circuit. The longer prestretch now provided by V204A also aids in minimizing the loss caused by the recovery characteristics of the 620C.

The audio stretching circuit is similar to that used in the linear-sweep analyzer (7) except for some changes in circuit values to improve performance at both low and high ends of the audio range. At low repetition rates, the 620C and its time constant provide the long stretching required. At repetition rates high enough to cause rectification in this circuit, the lesser degree of stretching appearing at the cathode of V204B is used directly. One difference between this circuit and the one used previously is that both V205B and V206B have been raised off ground by 180 volts to make use of available tube sections. The cathodes of the other halves of these tubes are about 250 volts above ground, and it is not possible to have a large difference between the two cathode potentials without exceeding the heater-to-cathode voltage rating on one of the sections.

The 0-5 μsec Sweep Circuit - Techniques developed for linear-sweep analysis systems (7) were applied to the nonlinear sweep circuits described in previous reports (8,9,10). In the 0-5 μsec sweep circuit (Fig. 25), only minor changes were required, such as the use of cathode instead of positive return for the second grid of lockout

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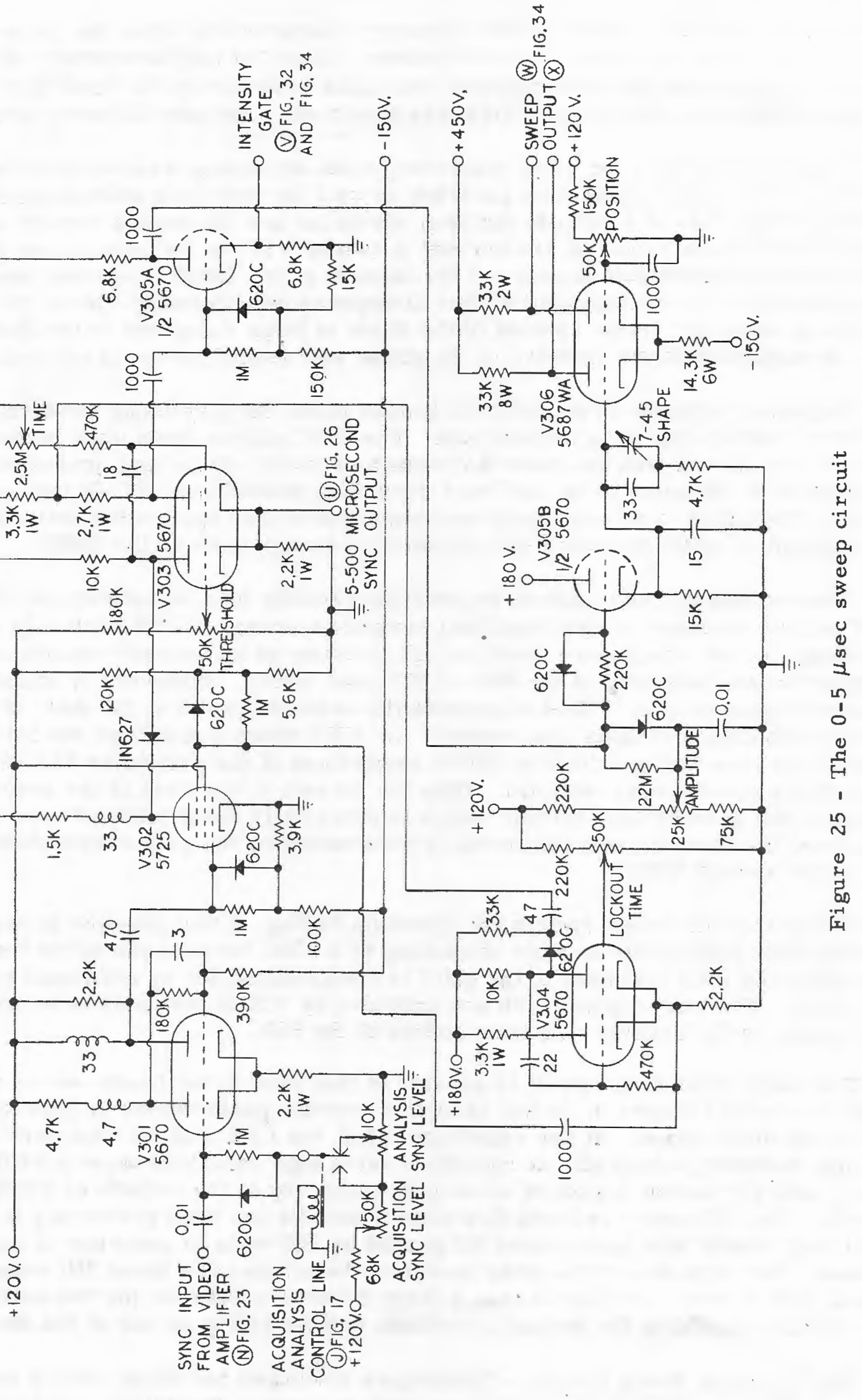

UNITS:
RESISTORS–OHMS. $K=10^3$, $M=10^6$
CAPACITORS–DECIMAL VALUES IN MICROFARADS, OTHERWISE IN MICROMICROFARADS.
INDUCTORS–MICROHENRIES

Figure 25 - The 0-5 μsec sweep circuit

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multivibrator V304 and the adjustment of a few component values. Because of their superior temperature characteristics, silicon diodes were used throughout. Where fast recovery of the diode was required, the 1N627 was installed. Since the silicon diodes have practically infinite inverse impedance, it was necessary to shunt them with fixed resistors in most applications.

In the sync multivibrator (V301), the sync level adjustment for this Schmitt circuit is switched between the acquisition and analysis functions. The acquisition sync-level control, which is only an internal adjustment, is set for optimum threshold of the multivibrator. The analysis sync-level control, which is a front-panel adjustment, is normally set for maximum sensitivity. On certain types of signals, such as lobing radars, where it might be desirable to stop drift of the envelope of pulses, the control setting can be reduced to cause synchronization only on the highest pulse signal in the train.

At high repetition rates (2 to 3 Mc), the recovery characteristics of semiconductor diodes (germanium or silicon) were inadequate to prevent loss of amplitude when used in the damped ringing circuit in the plate of the second section of the sync multivibrator (V301). Consequently, the diode used previously was replaced by a resistor for damping purposes. The damping time constant was chosen so that the positive portion of the second cycle in the train was not large enough to produce a usable output from gated amplifier V302. Since V302 is biased below cutoff, the negative portion of the first cycle in the train cannot appear at the plate of V302, and the positive portion of the second cycle is sliced. After this change was made, no difficulty was experienced with synchronization at rates up to the limit of the available pulse generator (about 3-1/2 Mc).

The diode and capacitor previously used between V303 and V305A to stretch the intensity gate are no longer needed because there is sufficient capacitance in the cabling connected across the cathode of V305A to provide more than adequate stretching. Slightly more stretching is used between V305A and V305B to stretch the sweep gate the proper amount.

The clamping diode in the grid circuit of sweep tube V305B is shunted by a 22-megohm resistor to prevent the grid from acquiring a charge which would require several seconds for dissipation. If this shunting resistor is made too small, clamping will not be adequate, and the position of the start of the sweep will shift at high repetition rates. A satisfactory compromise seems to be the largest stock size of resistor - 22 megohms.

Because the rise time of the deflection amplifier was not good enough to maintain correct shape at the start of the sweep, some error was apparent between the sweep and calibrating marks during the first microsecond. To compensate for this effect, a jump resistor was inserted in series with part of the sweep capacitance. Correction of this difficulty by improving the rise time of the sweep amplifier would have increased power consumption greatly.

The 5814A dual triode previously used for deflection amplifier could not produce a large enough output to permit operation only over the linear portion of its characteristic and have a reserve for cathode-ray tubes with minimum acceptable sensitivity. To furnish as much output as it did, the average plate potential had to be high. Therefore, to minimize the astigmatism in the display, the potential on the second anode of the cathode-ray tube also had to be high, and this value was higher than desired for optimum operation of the other sweeps. Replacement of the type 5814A by a 5687WA dual triode increased the output capability of the amplifier, because the lower internal impedance of the 5687WA tube permitted a greater portion of the plate-supply voltage to be developed

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across the load. Optimum average plate potential is lower because of the lower tube impedance, thus permitting a choice of cathode-ray-tube second anode potential that minimizes astigmatism for all deflection amplifiers. Since the internal impedance of this tube is in parallel with the load resistance across which the output capacitance is effective, the lower internal impedance improves the rise time of the circuit. The load resistance was increased over the value used with the type 5814A, but the rise time is still better. Plate current for the 5687WA tube is approximately the same as for the type 5814A, but heater current is somewhat greater.

The change from a 5814A to a 5687WA tube had an additional effect because of the higher transconductance and sharper cutoff of the type 5687WA. Since less voltage is required at the grid of this tube for a given output while the gate fed in is the same, the rise and fall times of the gate assume a larger proportion of the effective gate width. Thus, the effect of stretching of the sweep is increased. This appeared to be a desirable effect in the present circuit.

When the negative-voltage supply for the indicator was increased from -90 to -150 volts to use the same supply as the servoamplifier, the value of cathode coupling resistor necessary in the push-pull deflection amplifier was increased in all sweeps and, therefore, the balance and operating characteristics of the amplifier were improved.

The 5-500 μsec Sweep Circuit - To improve the operating characteristics of the 5-500 μsec sweep circuit (Fig. 26) over the previous design (8,9,10), numerous changes were made in component values, the lockout circuit was redesigned, and the sweep deflection amplifier was modified. Considerable difficulty was experienced with grid keying of the lockout multivibrator, so plate keying was employed in a circuit similar to that used in the 0-5 μsec sweep. Modification of the sweep amplifier for lower average plate potential resulted in better balance between the two sections and hence better linearity. The plate load of the second section of sweep amplifier V406 has been tapped to provide the compensating gate used in connection with the pulse-stretching circuit. The intensity-tailoring control was found to be unnecessary and has been removed.

The 500-50,000 μsec Sweep Circuit - In the 500-50,000 μsec sweep circuit (Fig. 27), some changes have been made in component values, and silicon diodes have been incorporated. Because of a change in the panoramic-display intensity circuits, the photo-blanking gate is no longer required, and the first section of V505 has become just a cathode follower. The intensity-tailoring adjustment has been removed from this sweep, also.

In the previous circuit (10), sweep shape was adjusted by a 7-45 μμf capacitor whose effective capacitance was multiplied by use of the Miller Effect in the deflection amplifier. An effectively negative capacitance was produced by a fixed capacitor employing the Miller Effect from the opposite side of the push-pull deflection amplifier. Thus, the average value of capacitance added to the sweep circuit was zero, but an adjustment above or below that value could be made to allow for component tolerances. Variations in deflection-amplifier tubes caused difficulty in keeping the adjustment values within the desired limits. Installation of a miniature 10-365-μμf plastic-dielectric variable capacitor which is now available allowed the shape to be controlled by the simple direct method. However, the plastic in this capacitor is not suited for the high temperatures likely to be encountered under some operating conditions; teflon insulation would be desirable. It is likely that the adjustment could be dispensed with altogether if component values could be held within certain tolerances.

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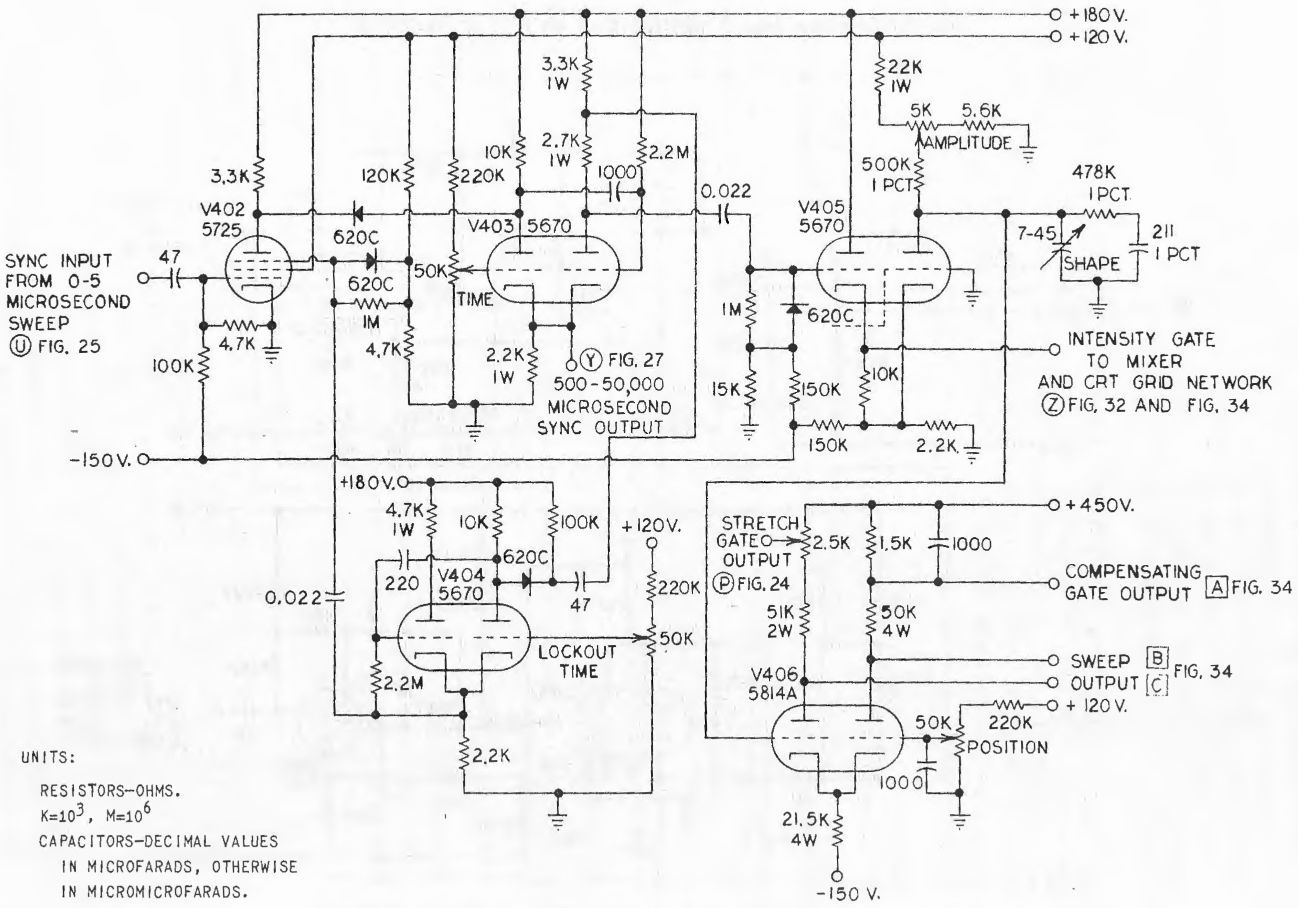

UNITS:

RESISTORS—OHMS.
$K=10^3$, $M=10^6$
CAPACITORS—DECIMAL VALUES
IN MICROFARADS, OTHERWISE
IN MICROMICROFARADS.

Figure 26 - The 5-500 μsec sweep circuit

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UNITS:

RESISTORS-OHMS. $K=10^3$, $M=10^6$

CAPACITORS-VALUES UNDER 2 IN MICROFARADS, OTHERWISE MICROMICROFARADS

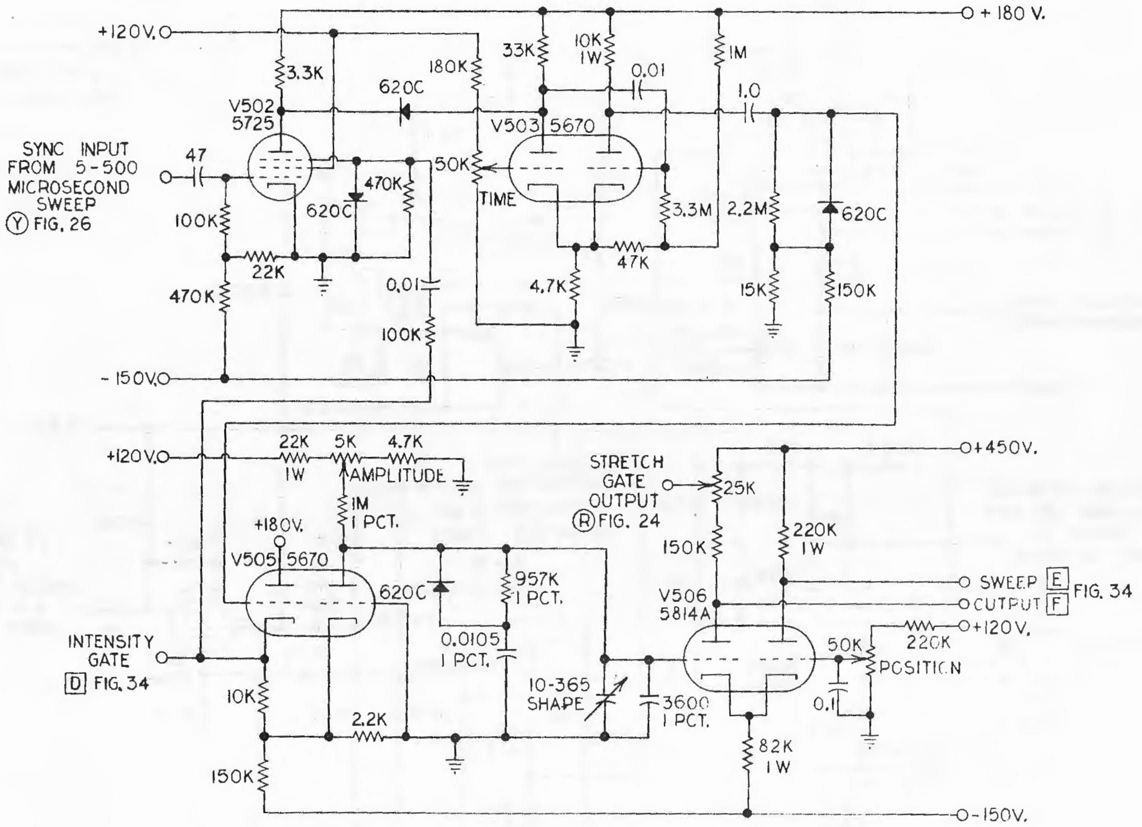

Figure 27 - The 500-50,000 μsec sweep circuit

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In the double-gating technique previously used in the sweep circuit (10), the resting currents and plate potentials of the two gating triodes were different because of the dissimilarity in plate-load resistors. Thus the potential differences for charging the two capacitors in the sweep network were not the same, and the resultant sweep shape deviated from the theoretically calculated value. Apparently the method previously used for adjustment of sweep shape introduced some distortion which corrected for this effect, because the error was not noticed until after the sweep-shape adjustment method was changed. Replacement of one of the gating triodes by a silicon diode in a circuit that allows both capacitors to rest at the same potential improved the sweep shape. A similar technique had been employed in the original circuit development (8), but difficulty was encountered then because a vacuum diode was used, and transition from conduction to nonconduction was not abrupt enough. However, the silicon diode is more suitable because it has a very sharp transition, requires about 0.6 volt potential across it for conduction, and has an inverse impedance high enough not to affect the impedance across which it is connected.

DF Carrier Generator - The original circuit for the DF carrier generator (10) used one television-type adjustable inductor in a Colpitts oscillator and another similar inductor in a resonant circuit to filter harmonics generated in the agc-controlled amplifier. The output amplitude fed into the agc loop was a function of the stability of resonance between these two circuits. Although the agc circuit tends to maintain essentially constant output, it is not perfect, and any reduction in variations in the signal introduced into the loop improves the overall stability.

To improve the carrier generator stability, the redesigned circuit (Fig. 28) employs a hermetically sealed toroid as the inductor in the Colpitts circuit. This inductance need not be variable, since all the DF circuits have been redesigned in terms of fixed components. The resonant circuit in the plate of the agc-controlled amplifier, V602, has been replaced by a low-pass filter of the m-derived type to eliminate harmonics generated in V602. The infinite-rejection frequency is near the second harmonic of the oscillator signal, and attenuation at higher harmonics is more than adequate. Any relative variations in the value of the oscillator toroid and the hermetically sealed toroid in the low-pass filter cause only a slight change in the second-harmonic content of the signal fed into V603 and do not affect the signal amplitude.

To eliminate the cathode followers between the resolver and the demodulators in the DF sweep generator, the input and output windings of the resolver were reversed to provide a low-impedance output. The loss in gain produced by this change was offset by modifying the carrier generator to increase its output amplitude. An additional stage was added to the carrier amplifier by using half of V604 as an amplifier between differential amplifier V603 and the output cathode follower (V604B). The gain in the feedback loop between V604B and V603 was maintained constant by tapping the feedback connection down on the output of V604B. Thus the output voltage available from V604B was approximately doubled. The additional output voltage required was available through adjustment of the amplitude control.

To improve the amplitude stability of the carrier further, the effectiveness of the agc circuit was increased. A 620C diode was added to the agc rectifier to produce a voltage-doubling circuit. This change essentially doubled the gain in the agc circuit.

The DF Sweep Circuit - Two undesirable characteristics that existed in the previously developed DF sweep circuit (10) were important enough to warrant a complete redesign of this circuit. One was the compression of the sweep at the end points and the other was the inability to provide correction for the nonlinearity of deflection in the cathode-ray-tube

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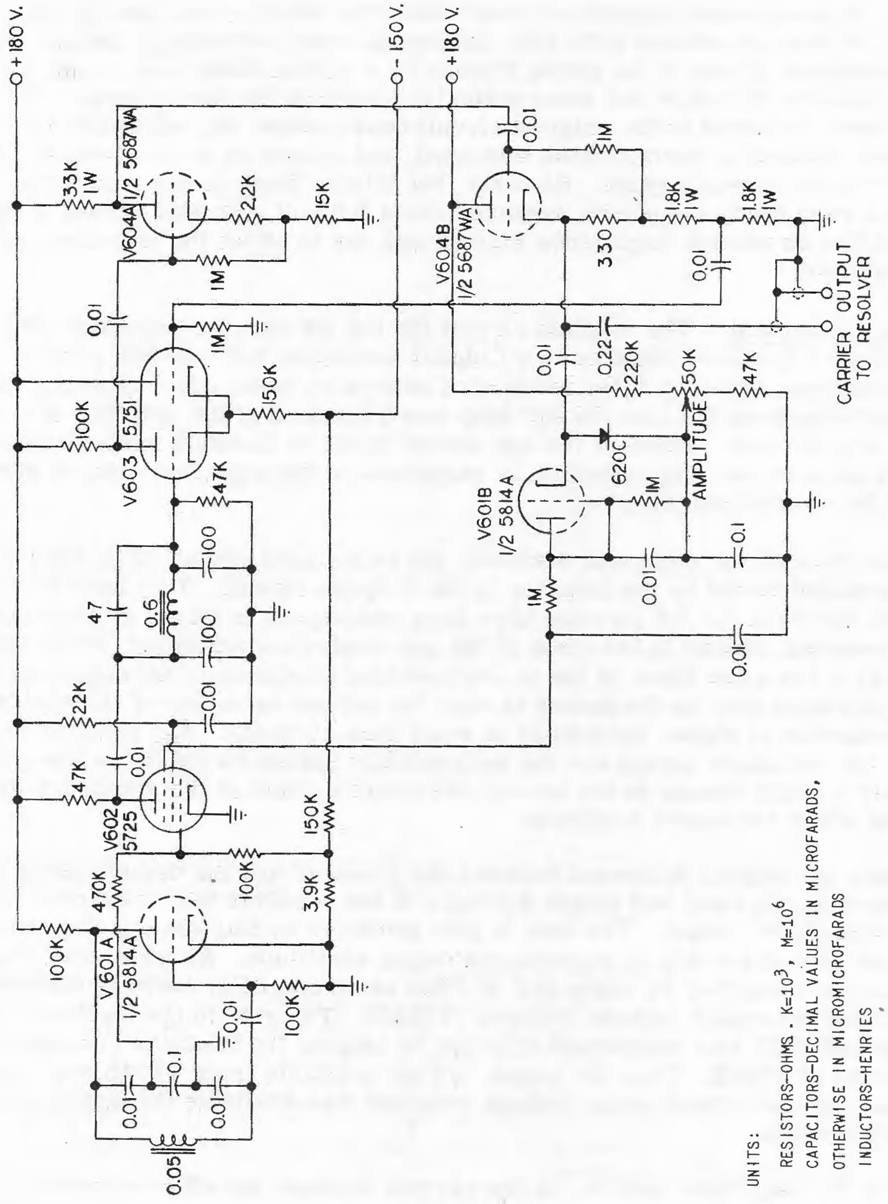

UNITS:
RESISTORS-OHMS. $K=10^3$, $M=10^6$
CAPACITORS-DECIMAL VALUES IN MICROFARADS,
OTHERWISE IN MICROMICROFARADS
INDUCTORS-HENRIES

Figure 28 - DF carrier generator circuit

[redacted]

gun. The new circuit (Fig. 29) overcomes these difficulties and provides an accuracy of indication between the resolver and the mathematically calculated display of ± 1 degree.

In the original circuit, the resolver inputs were fed to transformers which supplied push-pull voltages to cathode followers which, in turn, drove the rectifiers. The present circuit employs the cathode followers at the single-ended inputs to the transformers, thus saving one dual triode which could be employed to better advantage elsewhere in the circuit. The driving impedance reflected through the transformers to the rectifiers is still low.

Silicon diodes provide superior rectification characteristics in the low-voltage regions near the resolver nulls if these diodes are biased properly. A forward bias of approximately two volts has been applied to both pairs of rectifiers, the bias being a positive voltage in the pair associated with one resolver output and a negative voltage in the other pair, since the rectifiers are connected to give opposite output polarities. The use of silicon diodes substantially reduced the compression near the ends of the sweep. The choice of filter capacitor size is also important in obtaining optimum accuracy. If the capacitors are too small, rectification efficiency is poor; if the capacitors are too large, the envelope waveform becomes distorted at high antenna rotational speeds. The values chosen permit antenna speeds up to 720 rpm with a 10-kc carrier for the resolver.

The full-wave rectifier circuit is unique in that each half wave is isolated from the other during rectification and initial filtering and in that the outputs are then added. In the normal full-wave rectifier, the output terminals of the two diodes are common. If the sine wave is not quite symmetrical or if the transformer is not perfectly balanced so that the output of one rectifier is not as large as the other, and if the time constant in the filter is long enough so that the decay between the two half cycles is less than the difference between the two amplitudes, then the rectifier producing the lower output will add nothing to the circuit and the rectification is effectively half wave. By rectifying the two halves independently and then adding the filtered voltages, the output is the average of both half cycles, and rectification is truly full wave. This effect is important in maintaining accurate calibration and in eliminating carrier ripple from the sweep waveform.

Tuned circuits are no longer used for filtering. Adequate filtering is provided by the 1000-$\mu\mu$f capacitors at the grids of V702. Elimination of the adjustments and the need for components of good stability is a definite advantage.

If the outputs of the two channels were added directly, the voltage developed near the maximum of one channel would bias the rectifiers in the other channel when their voltage output was near a null, thus causing errors at the ends of the sweep. Therefore, isolating cathode followers (V702) were used before the addition. The additional dual triode used for this purpose is the one that was saved when the input circuit was redesigned. Addition prior to instead of in deflection amplifier V703 is desirable because the positioning method is simplified, deflection nonlinearity in the cathode-ray tube can be corrected for, and angularity compensation can be added.

Since the polarities are opposite at the grids of V702A and V702B, the operating range of the two sections is different and distortions in these cathode followers add. By choosing the proper value of cathode resistors, the waveform distortion introduced can be used to partially correct for the nonlinearity of the cathode-ray-tube gun. The additional correction required is obtained by unbalancing the plate-load resistors of deflection amplifier V703 in the same manner as in the analysis sweep circuits.

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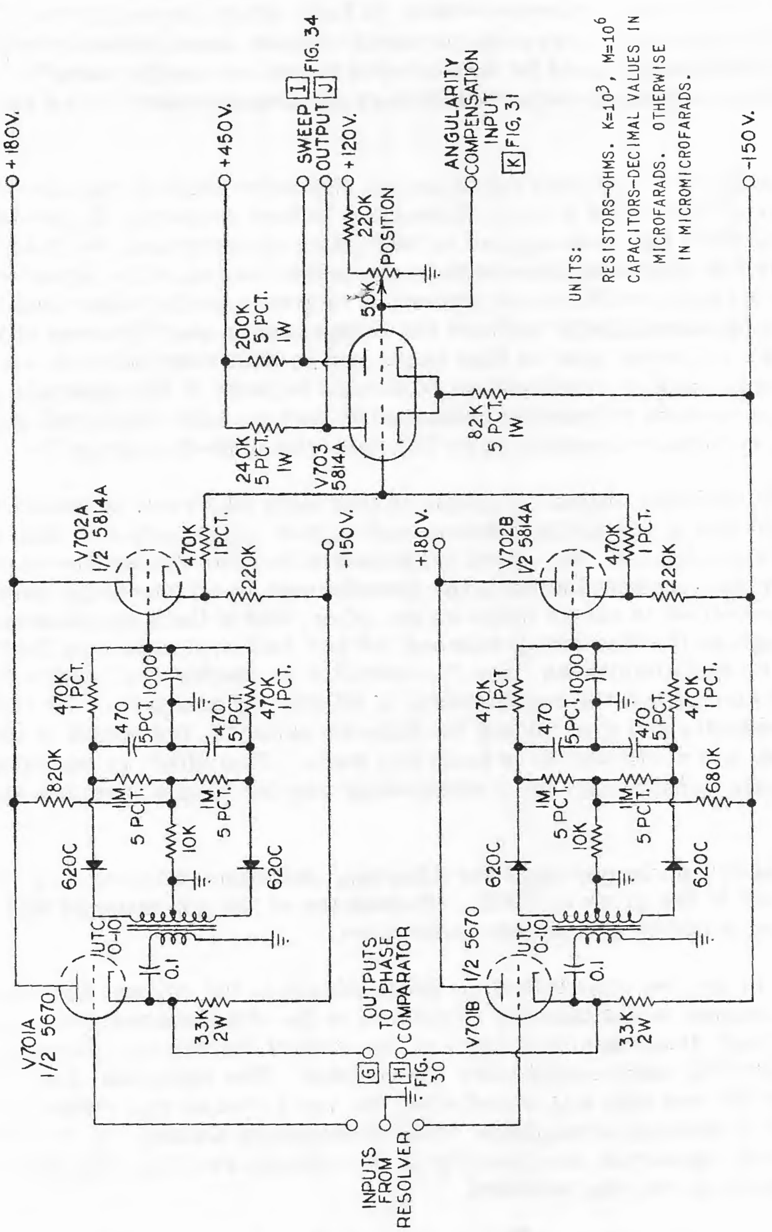

Figure 29 - DF sweep circuit

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Phase Comparator - Modification of the phase comparator circuit (Fig. 30) has consisted mainly of changes in component values to provide optimum performance. Increasing the clipping resistor between V802 and V804 to 100K raised the gain by increasing the effective load impedance for V802 and provided clipping about 2-1/2 times farther into the null. Replacement of the vacuum diodes by silicon ones saved space and power and provided better rectification characteristics. Since silicon diodes do not conduct until the voltage across them exceeds about 0.6 volt, no bias is required on them when they are used as clippers. Time constants in the circuit were reduced to produce smaller envelope delay times. The input cathode-follower tube was changed to a type 5814A because the dynamic range of the 5670 tube was insufficient to handle the input signal without distortion. The output tube (V806) was changed to a 5751 dual triode to provide greater gain, and hence greater output, for better operation of the Schmitt circuit in the DF video switch.

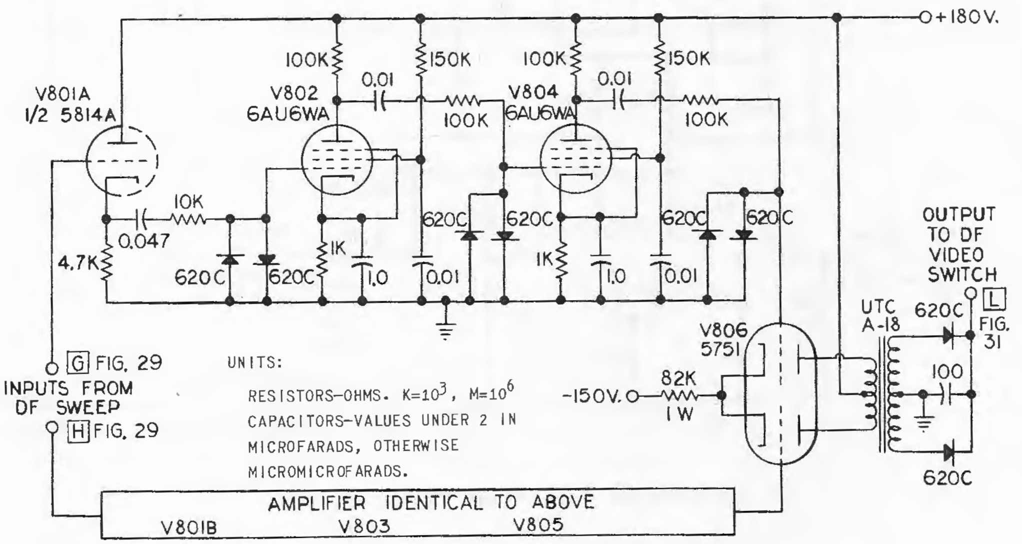

Figure 30 - Phase comparator circuit

DF Video Switch - Minor changes were made in the DF video switching circuit (Fig. 31) to produce optimum threshold sensitivity in the Schmitt circuit (V901), reduce current consumption, and provide the same average vertical-deflection-plate potential as in the other revised circuits. A balanced system of position adjustment was adopted, and the angularity compensation circuit (suggested by Collins Radio Co.) was added. The wide-narrow mixer, previously located with the pulse-stretcher circuit, has been transferred to this unit. This circuit has been suitably modified for direct-coupled wide-band video.

In this circuit, the amount of separation between the two DF baselines is a function of the currents through V903 and V904, and these currents are determined by the bias on the control grids of these tubes. Since these grids are direct coupled from the wide/narrow mixer (V905), the separation is controlled by the relative grid voltages of the two sections of V905. The grid voltage of the wide-band section of this tube is fixed by direct

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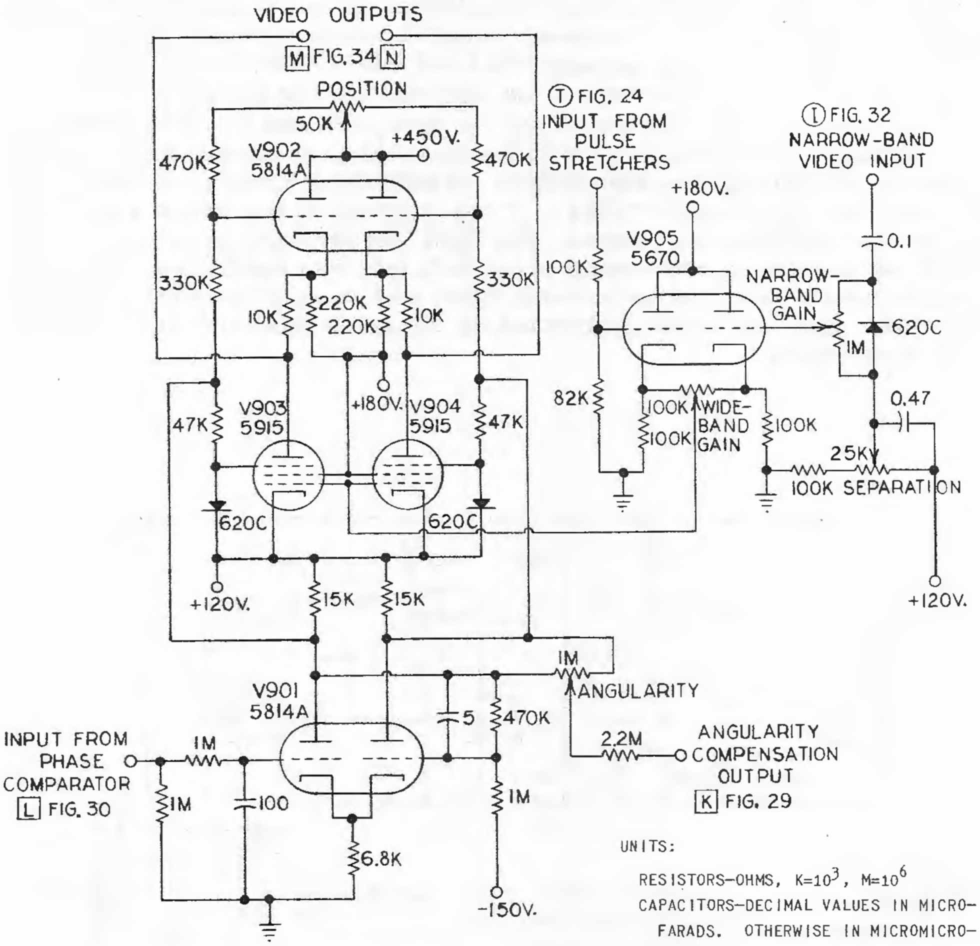

UNITS:
RESISTORS—OHMS, $K=10^3$, $M=10^6$
CAPACITORS—DECIMAL VALUES IN MICROFARADS. OTHERWISE IN MICROMICROFARADS

Figure 31 - DF video switch circuit

coupling from the pulse stretcher circuits. Therefore, separation is adjusted by controlling the grid voltage of the narrow-band section.

Since the wide-band gain control also affects the narrow-band gain, the baseline separation, and the vertical position, this control is adjusted first for the desired wide-band gain. The narrow-band-gain and baseline-separation controls may then be adjusted independently. The separation control adjustment may have a slight effect on vertical position, so the vertical position control is adjusted last.

Narrow-Band Video and Gate Mixers - The circuits required to furnish narrow-band video to the DF and acquisition displays, intensity gates to the DF display, and video to the panoramic display have been completely redesigned for improved performance with fewer tubes (Fig. 32). Added to this circuit are provisions for development of the control gates for the acquisition-indicator video-intensity circuit and a new method for control of intensity of the panoramic baseline during photography.

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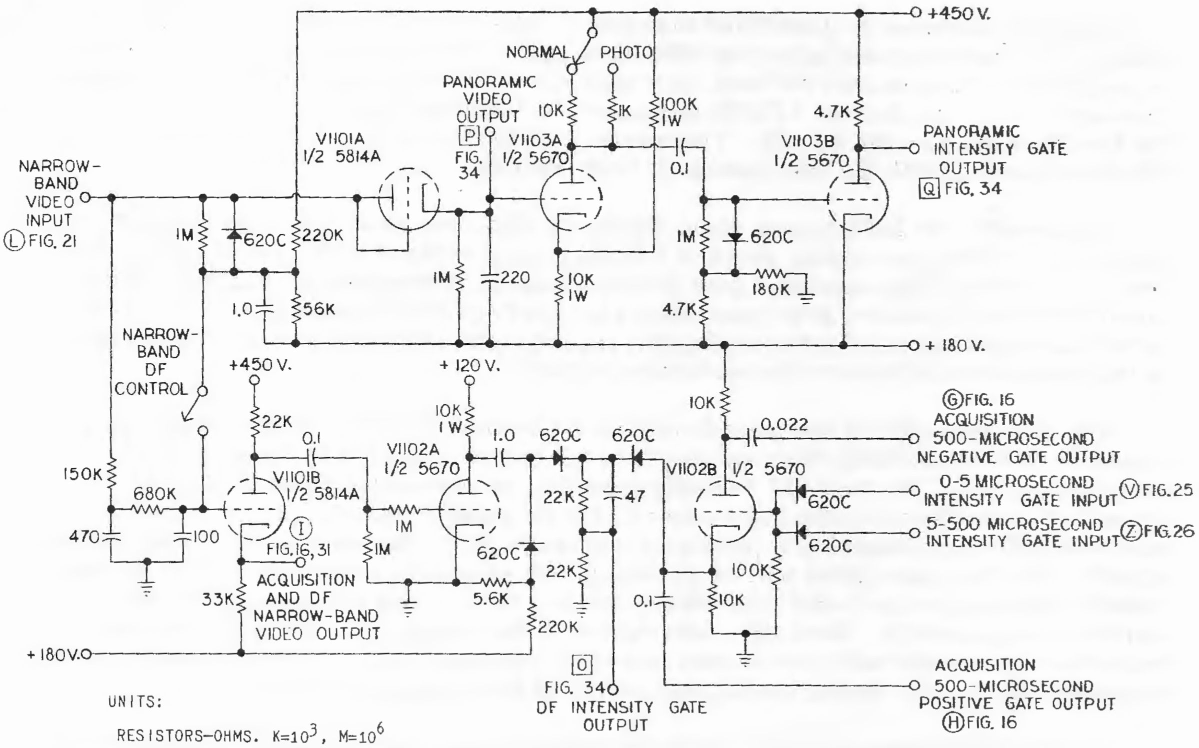

UNITS:

RESISTORS-OHMS. $K=10^3$, $M=10^6$

CAPACITORS-VALUES UNDER 2 IN MICROFARADS.
OTHERWISE IN MICROMICROFARADS.

Figure 32 - Narrow-band video and gate mixers circuit

The time constants in the filter between the high-level narrow-band video input from the receiver and the grid of V1101B were chosen to prevent loss of amplitude on a cw signal regardless of which tuner in the AN/APR-9 was scanning and in which direction the tuner was scanning with respect to the panoramic scan. On a cw signal, the output from the narrow band of the receiver is a pulse formed by the heterodyne action between the panoramic sweeping oscillator in the receiver mixer-amplifier and the signal. The width of this pulse is a function of the width of the passband and the sweeping rate of the 108- to 128-Mc panoramic oscillator when the receiver tuning is stopped on a signal. On acquisition, when the tuner is scanning also, the width of the pulse is also determined by the scan rate of the tuner in megacycles per second per second and by the relative direction of tuner scan with respect to the panoramic oscillator sweep. For the scan rates involved in this system, the output on cw can have a width between about 0.0008 and 0.077 second across the base of what might be assumed to be a half sine wave. Thus the frequency-response band needed to pass the cw indication is about 13 to 1250 cps. The low-pass filter was designed to pass a 1250-cps sine wave without appreciable attenuation. Since most pulse signals have widths considerably narrower than 800 μsec, the filter is quite effective in removing pulse signals from the narrow-band video. Only signals having a duty cycle greater than 0.02 produce any appreciable output from this narrow-band channel, and signals of this type are rare. For the rare signal, such as a square-wave modulated transmission, the narrow-band DF control switch can be operated to remove the narrow-band response completely if the double signal appearing in the DF display from both wide and narrow channels causes confusion.

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Since the receiver was modified to produce high-level output from the narrow-band channel, the signal appearing on the cathode of split-load amplifier V1101B is adequate in amplitude to furnish narrow-band information to both the DF and acquisition displays. The signal from the plate of V1101B is squared in V1102A to produce the intensity gate for the DF display on cw signals. The output of V1102A is clamped to the proper potential for dc mixing with the 500-μsec gate from V1102B.

To intensify the DF trace on pulse signals, a 500-μsec gate is formed by addition of the 0-5 and 5-500 μsec timing gates in a diode mixing network which isolates the gates from each other. This combined gate is fed to a split-load amplifier, V1102B, which isolates the load from the gate-generating circuits to prevent loss of rise time. The split-load amplifier also furnishes the two opposite-polarity gates required for control of the acquisition-indicator video-intensity circuit.

The 500-μsec gate at the cathode of V1102B is mixed with the gate produced by a cw signal in another isolating diode-mixing network before being fed to the grid of the cathode-ray tube. The final DF intensity gate may be of several different lengths, depending on the type of signal intercepted. On cw signals, only the output from the narrow-band video channel will produce an intensity gate. On low-repetition-rate pulse signals, only 500-μsec gates will be produced. On repetition rates high enough to cause lockout operation in the 5-500 μsec sweep circuit, both 5- and 500-μsec gates will appear in the intensity. Since the video pulses in the display are stretched somewhat more than 5 microseconds, the 5-μsec intensity gates will illuminate only the top portion of pulses which occur during the lockout period of the 5-500 μsec sweep.

For the panoramic vertical display, the narrow-band video is stretched at high level by V1101A and direct coupled to the deflection plates. The signal at the plate of V1101A is clamped to the optimum potential for minimum astigmatism in the display. Since V1101B and V1101A are in the same envelope, and since it is undesirable to have the cathode potentials widely separated in the sections of a dual triode, the cathode of V1101B has been raised above ground by the required amount. This type of operation also permits direct coupling between the two narrow-band channels.

One of the problems encountered in photographing the unified display has been film fogging from the baseline of the panoramic trace. Previously, the 500-50,000 μsec gate was used for intensity modulation of the panoramic display on photography, but this technique has an advantage only on time exposures. Therefore, video intensity modulation was used on the panoramic display and the baseline was suppressed in a manner similar to the DF display. The circuit (Fig. 32) for intensity modulation differs from the type normally used in the AN/APR-9, AN/SLR-2, and AN/BLR-1 receivers in that the maximum amplitude of intensity is limited and is reached on a very small signal level, so the intensity of the pulse is almost uniform during its duration.

The stretched narrow-band video from V1101A is inverted by V1103A and clipped by V1103B to produce rectangular gates nearly as wide as the bases of the stretched pulses. Since signals appearing at the clamped grid of V1103B are negative, the output from V1103B will be limited when the signal exceeds cutoff bias for this tube. A relatively sharp-cutoff triode was chosen for this purpose. The height of the intensity pedestal is controlled by the size of resistor in the plate circuit of this tube.

The gain of phase inverter V1103A is changed between the normal and photo positions to change the height of the panscope grass level at which intensification begins. Under normal conditions, the gain is such that noise will produce essentially a complete baseline as though no intensity modulation were present. In the photo position, the gain is reduced so that only the peaks of noise and signals of this amplitude and greater are intensified. Thus the baseline is practically removed. If a very light baseline is desired for reference in photographs, it can be produced by proper adjustment of the dc intensity control.

The Panoramic Sweep Circuit - Adoption of direct coupling between the panoramic sweep outputs from the receiver and the deflection amplifier (Fig. 33) eliminated some bulky components, reduced the variations in display between the two directions of sweep, and reduced the position shift of the display when sweep operating direction is reversed upon change of tuners. The dual gain control used previously (10) has been replaced by a single control which adjusts cathode degeneration in both sections of the push-pull deflection amplifier simultaneously. Since direct coupling is now used in the grid circuit, the position control has been transferred to a balancing position in the cathode circuit. The 100-$\mu\mu$f capacitor between deflection plates eliminates pickup of gates in the long leads to the cathode-ray tube.

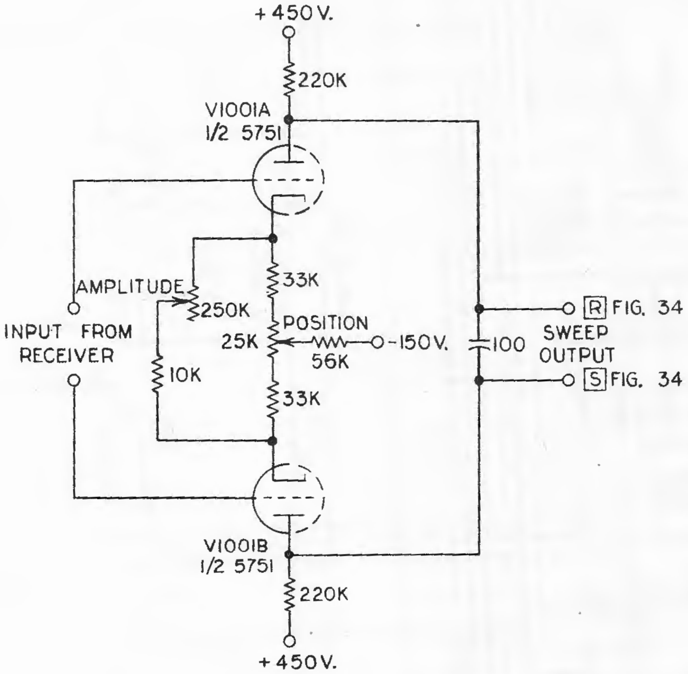

Figure 33 - Panoramic horizontal sweep circuit

Cathode-Ray-Tube Circuits - Slight changes have been made in the time constants of the intensity-tailoring networks for the 5-500 μsec and 500-50,000 μsec guns of the cathode-ray tube (Fig. 34). These modifications intensify the baselines more than is desired at the right-hand ends of the sweeps but they increase the intensity of the pulses to the desired level. The vacuum diodes previously used for clamping have been replaced by silicon diodes that are suitably protected by 1000-ohm resistors in series with the diode to limit forward current and a neon lamp across the combination to limit reverse voltage. This protection is not necessary on the 5-500 μsec gun, because the intensity-coupling capacitor for this gun is small enough to limit the energy supplied to the diode when the power supply is switched on or off. Clamping has been removed from the

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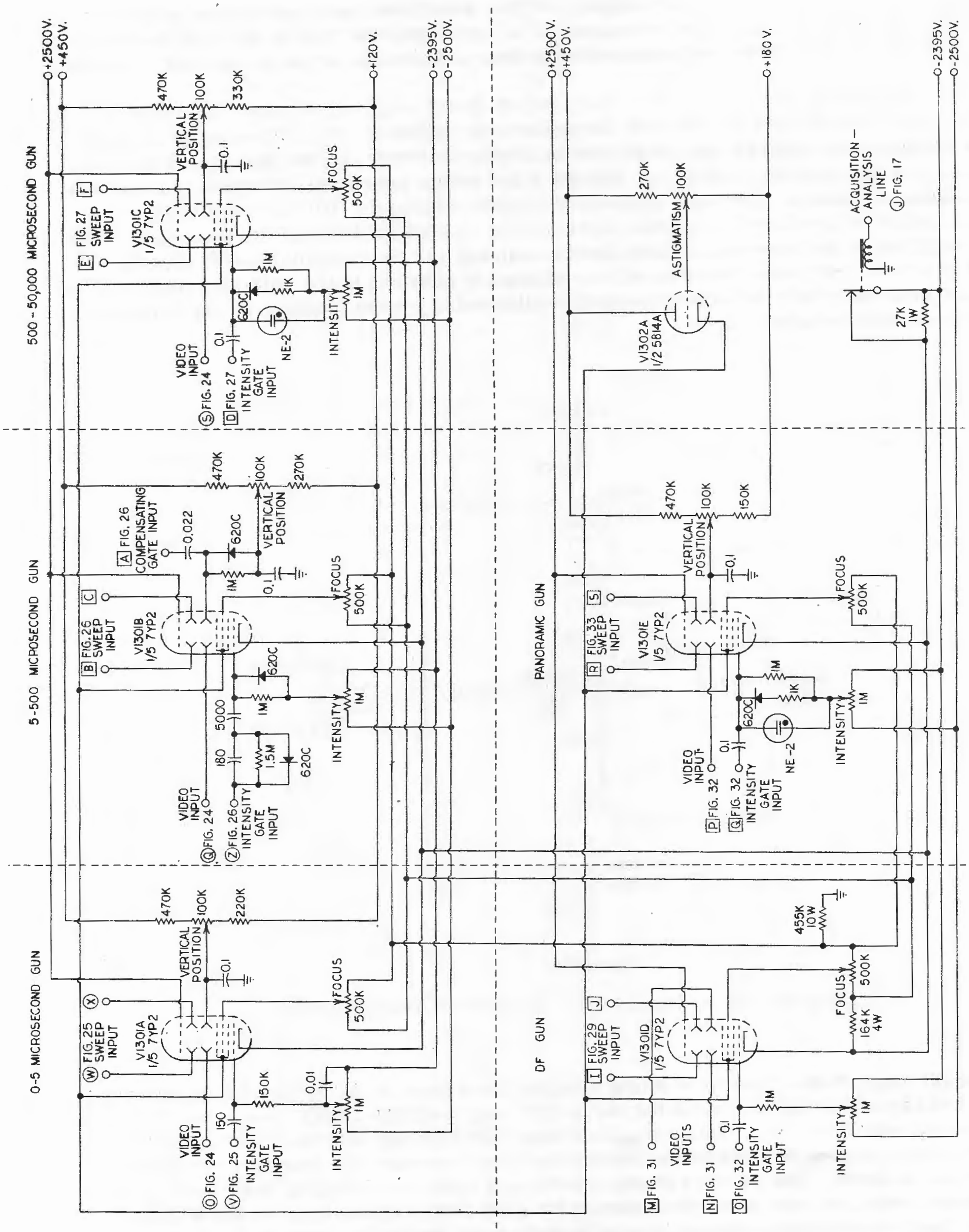

Figure 34 - Cathode-ray-tube circuits

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intensity circuit for the DF gun because at high repetition rates, the energy delivered to the cathode-ray-tube screen was sufficient to burn a hole in the screen when antenna rotation was stopped. Without the clamping diode, the averaging effect at high repetition rates reduces the intensity to a value sufficiently low to protect the screen.

On the panoramic gun, the size of the intensity-coupling capacitor has been reduced considerably, because the new intensifying circuit does not require the transmission of long gates. Switching of intensity controls between the photo and normal positions is also eliminated in the new circuit.

When direct coupling was incorporated into the video for the analysis displays, the dual vertical-positioning controls were necessarily replaced by single controls, and the second astigmatism control was omitted. The first astigmatism control now provides voltage through a cathode follower (V1302A) to minimize interaction between the guns that can exist with a high impedance in the second-anode circuit.

When the system is operated in the acquisition condition, flashing of the traces on the analysis indicator is annoying to the operator, and the analysis display becomes uselessly cluttered. Therefore, the cathode circuit of the cathode-ray tube in the analysis indicator has been modified to cut off the intensity during acquisition by use of a relay operated by the acquisition-analysis line. The simple expedient of adding cathode bias in the bleeder circuit permits turning the intensity off and on without delay or introducing transients into the circuit.

DF Calibrator - The pulse produced by the DF calibrator (Fig. 35) has been narrowed by reducing the time constant in the grid of the second section of blocking oscillator V1201, since a narrower pulse provides more accurate calibration; the pulse is still wide enough to be seen easily.

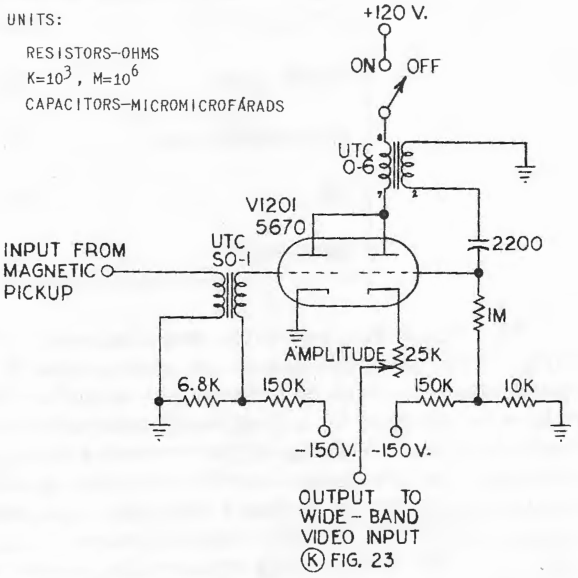

Figure 35 - DF calibrator circuit

Power Supply - A complete power supply has been developed to furnish the well-regulated voltages required for the acquisition indicator, the unified data display, and the two servoamplifiers. Since some of the regulator circuits are unique, the circuit diagram of the power supply has been included (Fig. 36). Although the differential-amplifier regulator circuits used in the four low-voltage supplies provide excellent regulation, some care is needed to prevent spurious oscillations at frequencies up to several megacycles. In the +450-volt, +180-volt, and -150-volt supplies, phase-correcting capacitors were added to prevent these oscillations. A large capacitor across the output of each supply also helps. A considerable change in the normal average load may require adjustment of a phase-correcting capacitor, and physical layout of the circuit will definitely affect the size of the capacitor needed and the position in the circuit at which it must be placed.

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Photographic Techniques

For both visual observation and still-frame photography, it is desirable to use a multisection filter in front of the unified data display (11). By proper choice of filters, the high intensity of the initial flashes can be reduced without any noticeable effect on the visual persistence. The filters most suitable for photography have also proved to be satisfactory for visual observation. For this function, Wratten optical filters that have low-pass frequency characteristics were investigated. Filters of the low-pass type in the range considered were Wratten numbers 8, 9, 12, 15, 16, 21, 22, 23A, 24, 25, 26, and 29, the higher numbers indicating increasing attenuation of the display. Photographs of typical displays indicated that the choice of filters listed in Table 1 provides approximately optimum results. Slight variations do not affect the results appreciably, and the final choice is probably one of individual preference. The filter requirements for the KD-2 data recorder differ from those for a simple 35-mm single-lens reflex camera, such as the Praktica, because of the spectral characteristics of the dichroic mirror in the KD-2. Tri-X film was used in these tests; films having different spectral sensitivities will require different filters.

TABLE 1
Wratten Filter Sections for the Unified Data Display

Trace	Filter Number	
	KD-2 Recorder	Praktica Camera
0-5 μsec	none	none
5-500 μsec	15	16
500-50,000 μsec	21	23A
DF	16	21
Panoramic	15	16

The KD-2 data recorder has a number of limitations when used with this system. First, there is no provision for photographing the frequency indication. If a small high-speed counter could be obtained, it would be desirable to replace the present frame-indicating counter by a frequency-indicating counter. The servo drive for this counter could be mounted on top of the recorder and connected to the counter by a flexible cable. However, the mechanics involved in this modification would be intricate, and a better solution might be to design a new data recorder which would photograph the counter now located below the display. Second, there is no provision for indication of true or relative bearing. The coding lamp system that exists in the data recorder could be modified easily to provide this indication. Third, the scale illumination is too bright compared to the signal patterns in the photographs. In the recorder on hand, a resistor was inserted in series with the scale illumination lamps to reduce the intensity for best picture contrast, but then illumination was insufficient for visual observation. Provision should be made for reducing either the time or intensity of illumination when a picture is being taken. Fourth, this data recorder is limited to single-frame photography. At the Laboratory and in Fleet operations, it has been found more satisfactory to use continuous motion-picture photography for displays of this type. An attempt has been made to procure a

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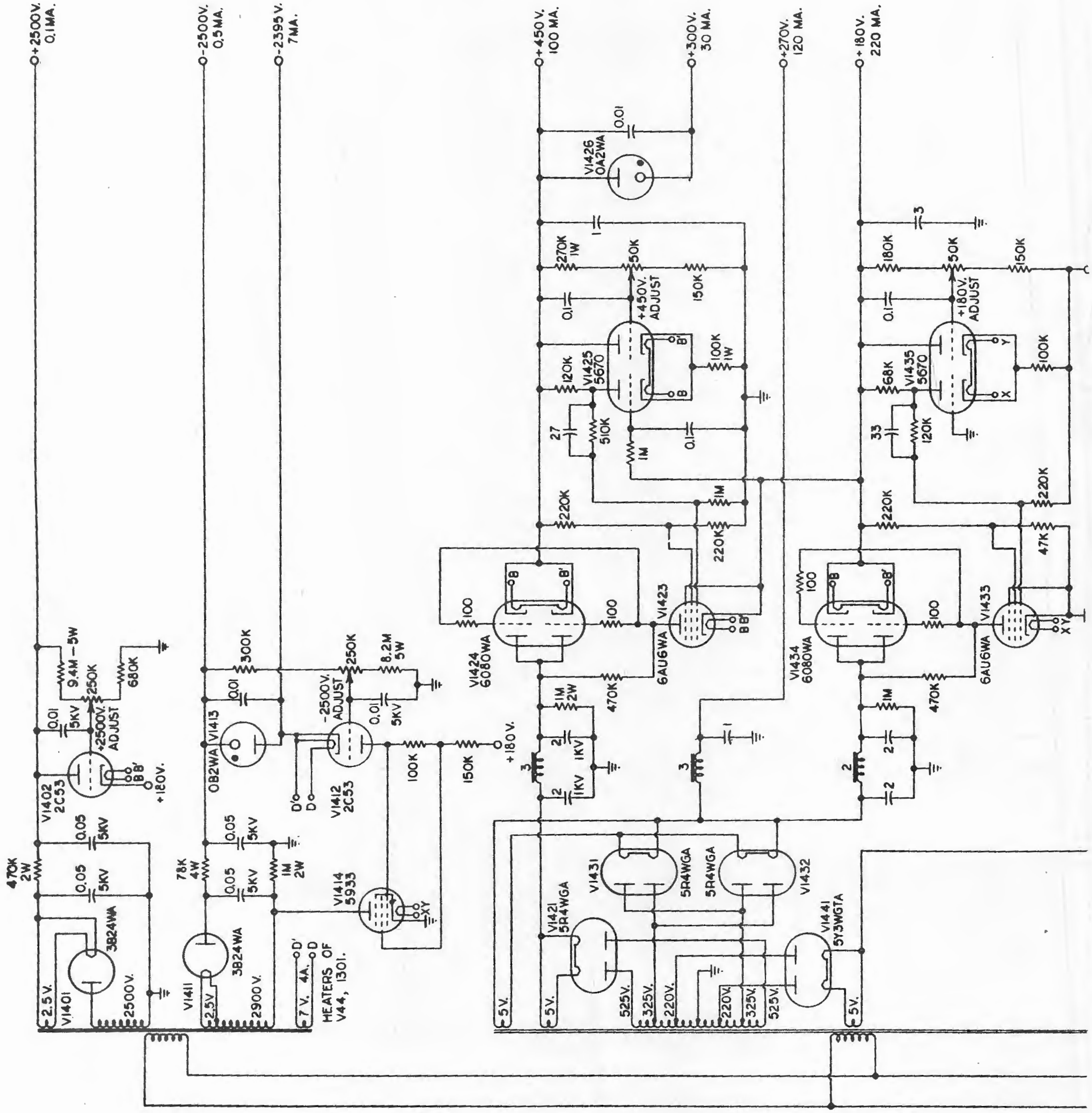

Figure 36 - Power supply

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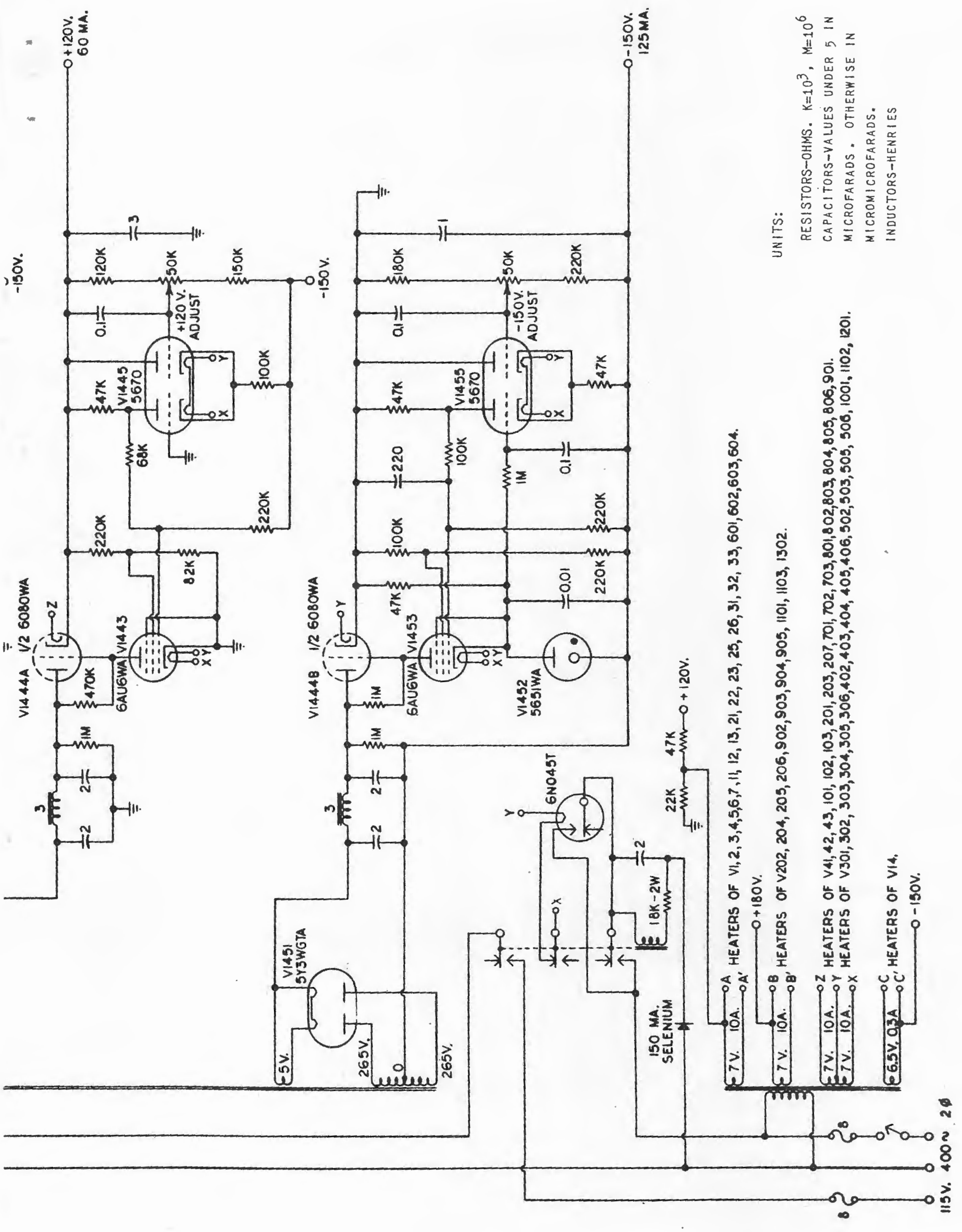

UNITS:
RESISTORS—OHMS. $K=10^3$, $M=10^6$
CAPACITORS—VALUES UNDER 5 IN MICROFARADS. OTHERWISE IN MICROMICROFARADS.
INDUCTORS—HENRIES

circuit

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suitable lens for the standard Navy gun camera to permit continuous-motion photography when this camera is attached to the KD-2 instead of the present camera. Assuming 50-percent efficiency for the dichroic mirror in the KD-2, Tri-X film developed for a speed of ASA 1000, a 130° shutter angle, and frame speed of 16 per second, an f/1 lens is required to photograph the persistence of the phosphor adequately. Since the highest speed lens that it appears possible to procure for this physical arrangement is f/2, a better solution might be the design of a completely new camera that uses a wider shutter angle to reduce the time between frames. Use of a wider shutter angle reduces the requirements on lens speed. Improvements in film speed, which may be possible in the near future, will also reduce requirements on the shutter and lens characteristics.

In summary, the cameras available for photographically recording the data presented by this system are the single-lens reflex type, such as the Praktica used with the AN/SLA-1 equipment, or the KD-2 data recorder used with the AN/SLA-2 and AN/APA-74 equipments. Neither type is satisfactory for recording all of the data at a fast enough rate. To record adequately the information that can be supplied by the unified display unit, a continuous motion-picture camera capable of viewing all the data and having a suitable lens and shutter should be developed.

OPERATIONAL EXPERIENCES

Sufficient time and personnel have not been available to evaluate this system fully, but enough experience has been obtained on operational aspects to draw some conclusions regarding the capabilities of the system. Some of the signals observed have been reported (13), but many types cannot be described within the classification level of Confidential. Photographs taken with a Praktica 35-mm single-lens reflex camera of some typical signals are shown in Fig. 37.

Many of the signals regularly received at the NRL intercept site are not simple pulse signals, and the future trend appears to be toward more complex transmissions. The versatility of the NRL system is a definite asset in the acquisition and analysis of complex signals.

To extract adequate information from the machine on some signals, a reasonable amount of intelligence must be exercised by the operator. The reasoning process required cannot be performed by any automatic device known at the present time, but can be done by an operator with a little experience.

On a number of signals that have been acquired, it has been impossible to get a bearing. To be certain of obtaining a bearing, the minor lobes of a rotating transmitting source must be received. In general, the ratio between major and minor lobes of the receiving antenna is much less than of the transmitting antenna. Thus although the major lobe of the receiving antenna may not be capable of acquiring a signal from the minor lobes of the transmitting antenna, the minor lobes of the receiving antenna may intercept the major lobe of the transmitting antenna. In this case the display will indicate a signal in the direction the receiving antenna is pointing when the major lobe of the transmitting signal passes, and will not indicate the direction of the transmitter. In some cases, use of the narrow-band capabilities of the receiver will increase sensitivity sufficiently to obtain a bearing on the minor lobes of the transmitter.

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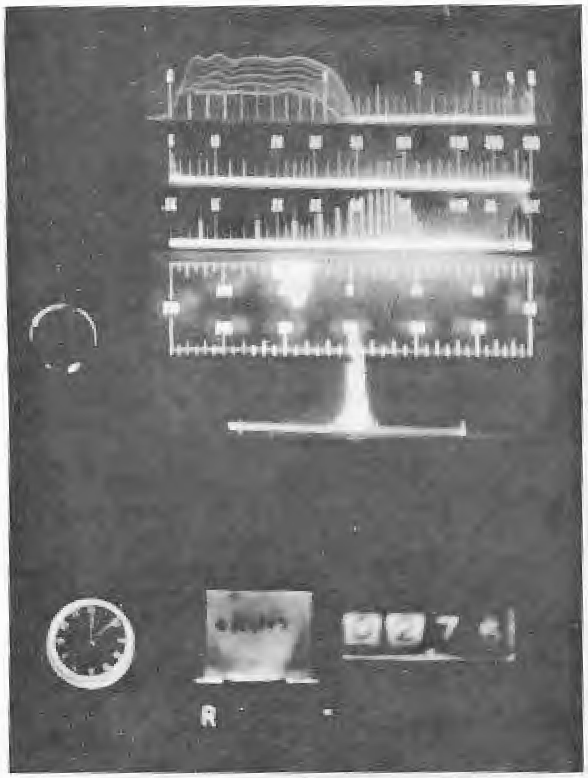
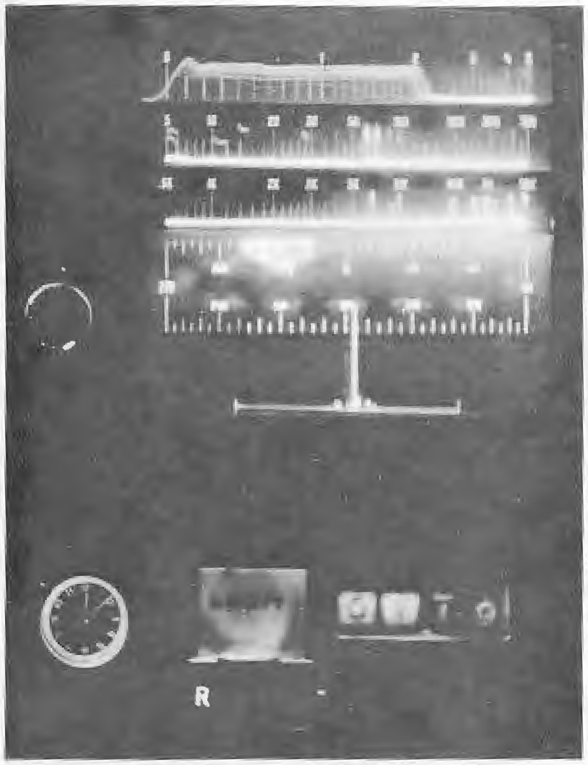


(a) Conical scanning radar - pulse width 1.1 μsec, period 810 μsec, bearing 336° relative, frequency 2.75 kMc



(b) Multiple pulse signal with responses - pulse width 2.0 μsec, second pulse at 60 μsec, third pulse at 70 μsec, basic pulse period 10,000 μsec (Note pulses at 10,000 20,000, 30,000, 40,000, and 50,000 μsec. Other nonrelated pulses are responses), bearing 332° relative, frequency 1.19 kMc

Figure 37 - Unified data display of typical signals

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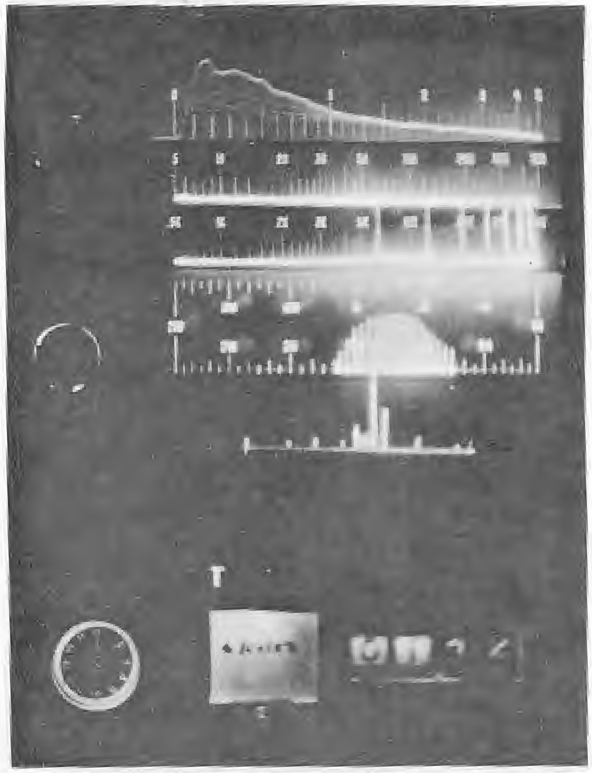
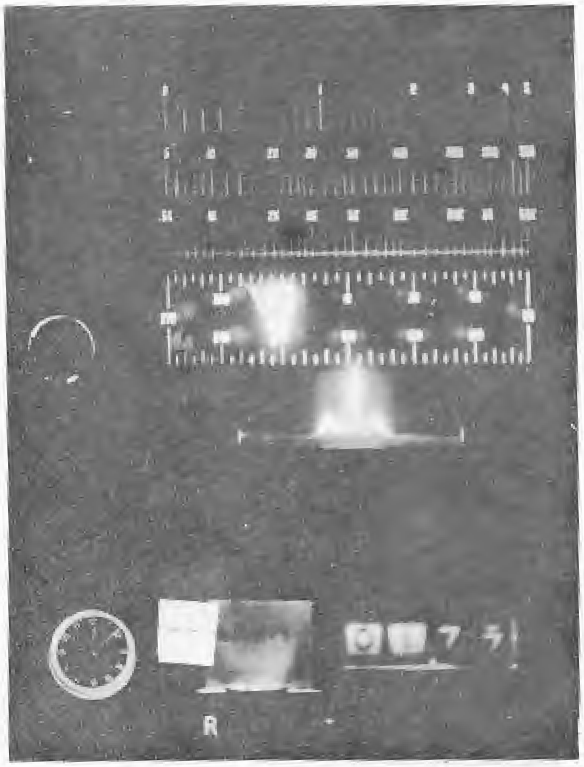


(c) Sawtooth pulse signal - width at base of pulse approximately 5 μsec, pulse period 6200 μsec, bearing 162° true, frequency 1.32 kMc



(d) Frequency-modulated signal - bearing 329° relative, frequency 1.77 kMc, deviation approximately ± 2 Mc

Figure 37 - Unified data display of typical signals

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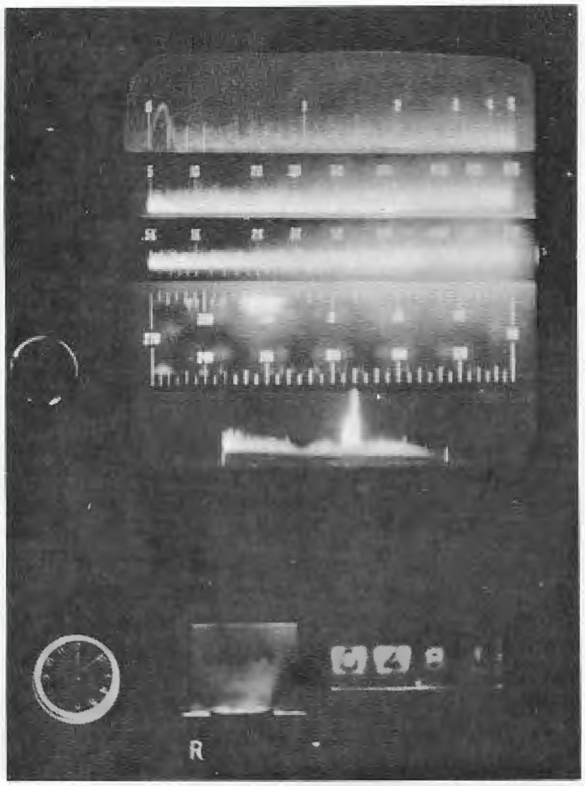
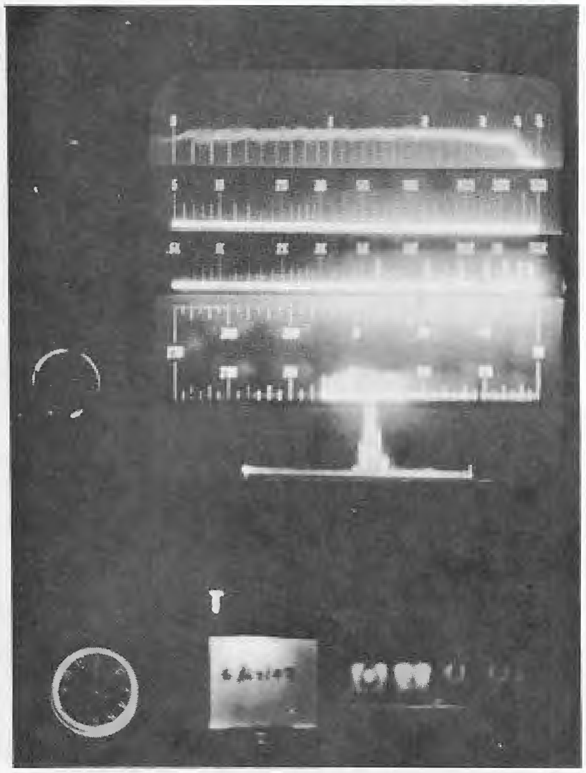


(e) Noise-modulated signal - bearing 329° relative, frequency 4.81 kMc



(f) Pulse signal - pulse width 4 μsec, period 6200 μsec, broad bearing about 175° true, frequency 1.00 kMc

Figure 37 - Unified data display of typical signals

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CONCLUSIONS AND RECOMMENDATIONS

From both theoretical considerations and operational experiences, certain advantages and limitations of the system have become apparent. The system does have the disadvantage of a frequency-scanning receiver in loss of probability of reception on short-burst signals. Another type of receiver is needed for this purpose. However, at the scan rate used, a maximum of four seconds is required (two seconds average) for signal acquisition, and only a few more seconds are required to tune the receiver to the signal. For the large majority of existing signals, frequency scanning does not appear to be a serious limitation.

For the i-f bandwidth used, sensitivity of the system is the highest available at the present time. This high sensitivity of a superheterodyne receiver is an important advantage. However, the sensitivity is still not great enough for some applications. It is recommended that consideration be given to use of active low-noise preamplification at the signal frequencies.

The high resolution available in the narrow-band i-f amplifier of the receiver has been extremely valuable for signal separation, detection and analysis of modulation components, and increased sensitivity on wide-pulse signals. However, for better acquisition of signals where the density is great in a small frequency range, it would be desirable to extend the narrow-band capabilities of the receiver by limiting the scan range and expanding the display on the acquisition indicator by a factor of ten. A technique for doing this has been described (1) and should be incorporated into the system at some future date.

The inability to obtain a bearing on some signals which have been acquired indicates the need for a sensitive nonrotating DF system. Consideration should be given to the use of multiple fixed antennas and a technique for obtaining bearing information from these antennas through a highly sensitive receiver.

The essentially instantaneous cathode-ray-tube display with very stable synchronization has provided excellent analysis information about certain types of signals that would be difficult to obtain by other means. The fact that the number of complex signals being transmitted is continually increasing indicates the need for a signal analyzer having the capability of the type employed. Multiple-pulse signals, pulse-within-a-pulse signals, pulse modulations of various sorts, modulations purposely hidden in noise, and specially shaped pulse trains will all produce useful indications for identification purposes, and in some cases furnish enough information to determine what auxiliary equipment should be added to the system to extract the intelligence from these signals. Other advantages of this type of display are the high confidence factor concerning results obtained and the good reliability of operation.

The lack of suitable photographic recording devices is a handicap to optimum operation of the system. It is recommended that a continuous motion picture camera capable of producing a satisfactory record of all the data presented be developed.

Although the system developed is not the ultimate for signal acquisition, analysis, and recording, it is a considerable improvement over equipment now in use in the fleet. It provides a good compromise between information-gathering ability and size and weight, and it appears to be more practical for reconnaissance on most types of signals than any other system being considered at the present time. The full capabilities of this system cannot be realized until one has operated the equipment and observed the performance.

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ACKNOWLEDGMENTS

Appreciation is expressed to the many former members of the Intercept Section of the Countermeasures Branch who have contributed their efforts in the solution of the many problems involved in the development of this system - to W. F. Hoffmann for the original work on the servo systems; to Bruce Wald for the original work on the acquisition display; to R. J. Solem for the original work on practical circuits for the nonlinear sweeps; to A. H. Hendrickson for the original work on the DF display, complete unified indicator, combination of analysis and unified displays, and assemblage of the first operating system; to C. E. Birgensmith for much of the assemblage of the present equipment; and to G. M. Bullock for comments on the operational aspects in assembly and use of the equipment. Acknowledgment is especially made to H. K. Weidemann, who directed the program and supplied many of the ideas incorporated into the system.

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