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RADAR RELAY DATA COMPRESSION SYSTEM

H. W. Chitty, R. E. Brescia,
and
M. F. Williams

Avigation Branch
Radio Division III

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NAVAL RESEARCH LABORATORY

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CONTENTS

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ABSTRACT

A method of reducing the amount of bandwidth required to transmit radar and artificial video over a radio link has been developed. The video obtained from an SP-1M radar and a flying spot scanner, covering a bandwidth of some 1.5 Mc, is compressed to a bandwidth of approximately 15 kc without loss of information. The compressed signal can be broadcast by a slightly modified TDQ Navy vhf transmitter. The receiving terminal consists of a standard vhf receiver and a decoder-indicator and is conventional except for the synchronizing system for the rotational data.

Photographs of the compressed data taken at a receiving station located three quarters of a mile from the transmitter terminal seem to prove conclusively the practicability of transmitting compressed video data over a narrowband link.

PROBLEM STATUS

This is a final report on the Radar Relay Data Compression System as applied to the SP-1M radar. Work on the problem is continuing.

AUTHORIZATION

NRL Problem R04-43
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RADAR RELAY DATA COMPRESSION SYSTEM

INTRODUCTION

The proposal for a PPI Compression System embodies a method for compressing SP-1M radar data into a bandwidth of 10 kc or less. The primary factor governing the amount of bandwidth reduction possible is the inherent redundancy and inefficiency existing in the radar. Another factor governing the amount of reduction that can be incorporated into such a system is the resolution limitation of the indicator. A compromise is effected in the final reduction between the theoretical limit and the actual indicator presentation.

In addition to the actual compression techniques developed in the data reduction problem, components for implementing the transmission of the reduced data over a vhf carrier are necessary. It has been possible to modify existing equipment for this use and to transmit rotation information without using any additional bandwidth by transmitting discontinuous North reference signals at the rate of 6 signals per minute.

It should be noted that the system as described herein applies only to the SP-1M radar and cannot be applied directly to any other unless the general characteristics such as scan rate, and repetition rate are the same. The general techniques, however, are applicable, and it is intended to continue this work and formulate a system which can be applied to a wide variety of search radars.

THEORY OF BANDWIDTH REDUCTION

Bandwidth reduction of the radar data is accomplished by removing the redundancy in the data and by limiting the data to that which can be utilized at the receiving terminal, in this case, a plan-position indicator. Since the azimuth resolution of a radar is limited by the antenna beamwidth, it is possible to transmit one integrated radial sweep per beamwidth and still retain all the inherent azimuth resolution in the radar system. Another factor which is important in accomplishing bandwidth reduction is that, except for very short ranges, range resolution on a plan-position indicator is limited by the indicator spot size. This size is generally taken as approximately 1/150 to 1/200 of the radius of the particular tube in use.[1] Thus, at the limit, the narrowest pulse necessary to transmit is 1/200 of the time of one beamwidth.

When n sweeps per beamwidth are integrated and stretched to one sweep per beamwidth (Figure 1), the net result is to broaden all pulses by a factor n. Thus the bandwidth is decreased by n although this factor may be greater if there is a significant amount of dead time between the time required for the maximum range of the radar and the next

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[1] Ridenour, L. N., ed., "Radar System Engineering," MIT Radiation Laboratory Series, Vol. I, 1st ed., p. 548, New York: McGraw-Hill, 1947

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radar sync pulse. Since the compressed data pulse rate frequency is the radar pulse rate frequency divided by n, the repetition rate frequency is also reduced by the factor n.

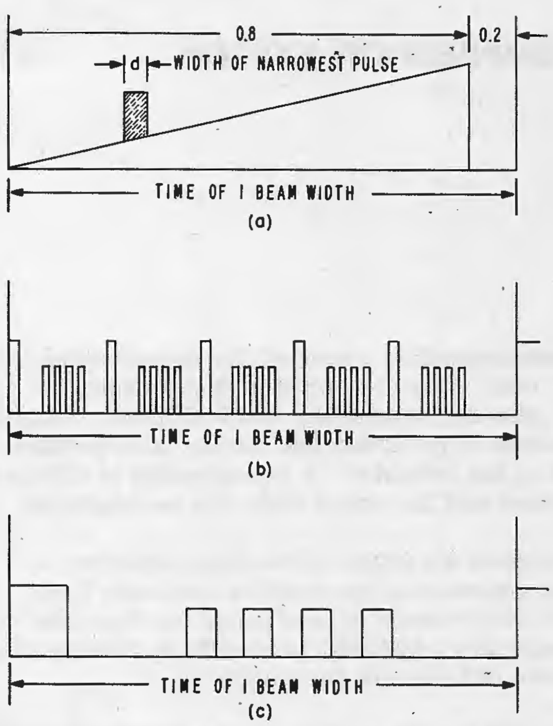

Figure 1 - Amplitude vs.time graph showing (a) the narrowest pulse necessary to transmit all usable information, (b) the original time base of the radar, and (c) the integrated time base after compression

With this information and with the semi-empirical equation, $B = k/d$, where k is a constant from 1 to 2 and d is the width of the narrowest pulse, the bandwidth B required to transmit the information of any radar can be calculated. As indicated above, d equals 1/200 of the time of one beamwidth, multiplied by a factor of about 0.8 to allow for recovery time of the circuits.

The minimum pulse length in seconds in terms of antenna beamwidth and rotation rate of the radar antenna is $d = (1/200)\,(0.8\,\alpha/360)\,(60/R) = \alpha/1500R$ where α is antenna beamwidth and R is the rotation rate in revolutions per minute of the radar antenna. Assuming

(a) one sweep per antenna beamwidth,

(b) 80-percent duty cycle of the circuits,

(c) the range resolution of a PPI is limited to 1/200 of the radius, and

(d) the constant k equals 1.6 (a figure consistent with standard engineering practice),

the maximum bandwidth in kilocycles necessary to transmit the information is $2.4\ R/\alpha$. In this case, using the SP-1M radar, $\alpha = 3$ degrees, $R = 6$ rpm, and thus $B = 4.8$ kc as the bandwidth necessary to transmit all the usable information from the SP-1M radar. However, this gives a picture composed of one radial line every 3 degrees, a spoked picture which will appear quite crude although, actually, it will contain all data inherent to the radar. This picture can be improved in a psychological sense by using one sweep per degree (equivalent to a beamwidth of 1 degree). This requires a 14.4-kc bandwidth which, in this case, can be tolerated since the bandwidth is available.

OPERATION OF THE SYSTEM

The technique used, which evolved from the investigations carried out by Haller, Raymond, and Brown,[2] is shown in block diagram in Figure 2. The normal video bandwidth of the SP-1M radar, consisting of some one and one-half megacycles, is mixed with

[2] "Narrow Band Radar Relaying," Appendix A of "Interim Engineering Report on Radar Facsimile Development, 1300-9," Haller, Raymond, and Brown, Inc., Report No. 1300-9A (Confidential), July 1, 1949

artificial video from a map generator produced by a flying spot scanner. This composite video signal is then presented to a "bandwidth compressor," which reduces the 1.5-Mc video to a bandwidth of approximately 14.4 kc. The output of the compressor is fed to a slightly modified TDQ vhf transmitter and then broadcast. The receiving terminal equipment is conventional except for the synchronizing system for the rotational data. The separation of video and synchronizing information is accomplished on an amplitude basis and passed on to the indicator display.

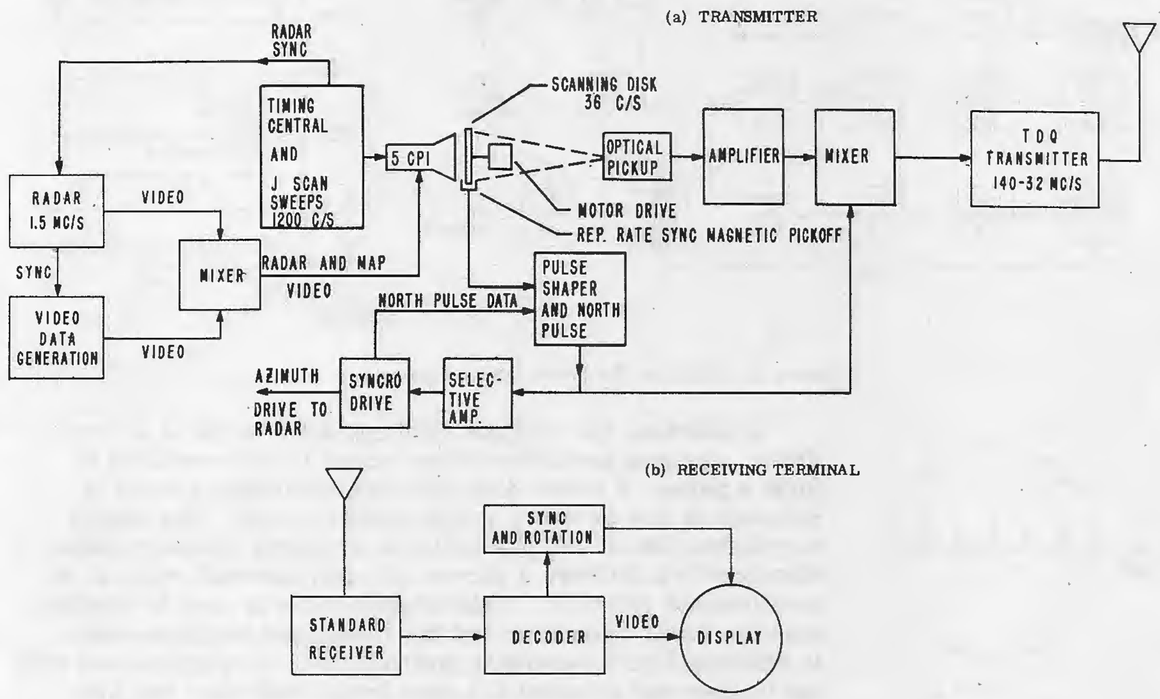

Figure 2 - Block diagram of data compression system

Compression System

Integration and compression of the data are accomplished by the bandwidth compressor (Figure 3). The timing center triggers the radar and supplies sweep voltages to a J-scan cathode-ray tube which is intensity modulated by the radar video and/or the map generator. This video is stored and integrated on the J-scan cathode-ray tube from which it is removed at a slower rate (base-line stretching) by a mechanically rotating opaque disk with a narrow slot which lets light through to a phototube. Synchronizing pulses are supplied for the compressed data by a magnetic circuit actuated by an iron slug on the rim of the disk. The output of the compression system is then amplified and used to modulate a standard Navy vhf transmitter from which it is broadcast.

Timing Element - The central timing element (Figure A1 in the Appendix) of the compression system is a Wien Bridge Oscillator adjusted to a frequency of 1200 cycles per second. This wave is operated on by two phase shifters and amplified in two channels to supply two waves of the same shape and amplitude but differing in time phase by 90°. The two amplifiers are of the push-pull type so that the outputs may be applied to the deflection plates of a cathode-ray tube to produce a circular trace. This is known as J-type scan (Figure 4).

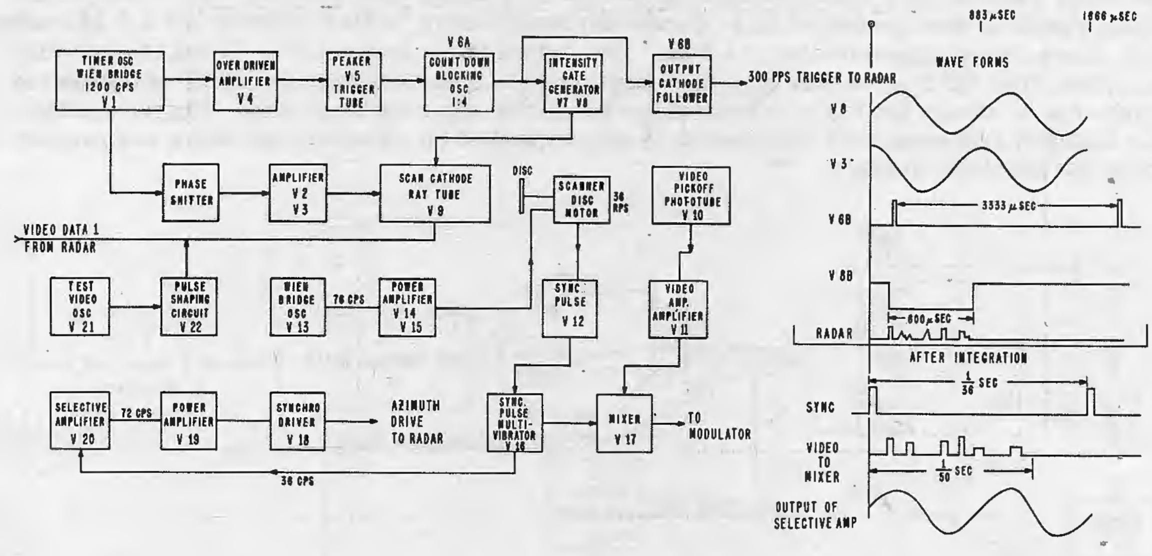

Figure 3 - Block diagram of compressor

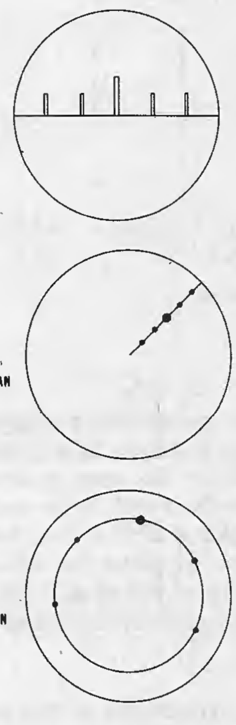

Figure 4 - Various types of radar display

In addition, the original 1200 cps wave is fed to an over-driven squaring amplifier whose output is differentiated to form a pulse. A count-down blocking oscillator circuit is adjusted to fire on every fourth positive pulse. The pulsed waveform, now at 300 pps is fed to a cathode follower output circuit which delivers a narrow (1-microsecond) pulse at an amplitude of 150 volts. This trigger pulse is used to synchronize the radar modulator and the flying spot map generator. In addition, a gate generator multivibrator is synchronized with the trigger and adjusted to a gate length sufficient for fifty nautical miles of video data (approximately 600 microseconds). The gate waveform is used to intensify the J scan on every fourth rotation of the spot. The video information from the radar or flying spot scanner is also applied to the J-scan tube.

Storage on the J-Scan Cathode-Ray Tube - As described in the reports on the Haller, Raymond, and Brown system, data can be stored on the face of a cathode-ray tube. Figure 5 shows how the 25 returns per beamwidth of a theoretical point target affect the light output from a cathode-ray tube. The P-1 phosphor has a decay characteristic that is essentially exponential. The time constant T is approximately 3.6 milliseconds. The radar pulses are of negligible time duration compared with the time constant of the phosphor so that excitation of the phosphor may be taken as impulse. From mathematical analysis of the exponential circuit, it may be shown that 300-pps excitation of the phosphor will yield a peak light output of 1.65 times that produced by single pulse. From this level the light intensity decays to 0.65 of the single pulse value and is then re-energized by the next pulse.

Scanning Assembly - The reading operation is accomplished by rotating a scanning disc between the cathode-ray-tube face and a phototube (Figures 6 and 7). The scanning disk is driven by a small ac induction motor at 2160 rpm or 36 rps. The motor power supply consists of a Wien Bridge Oscillator (Figure A2) operating at 76 cps, driving a pair of 6L6's in push-pull. The output transformer delivers 110-volt power at 76 cps to the motor. Light from the usable portion of the J scan (about 290 degrees because of the mechanical requirements of the motor mount) is focused by means of a Lucite lens on the cathode of a type 931A photomultiplier tube (Figure 8). The output of the phototube is negative-going video and is similar in appearance to the radar video but is presented on a much longer time base. A one-stage video amplifier and cathode follower (Figure A3) invert the signal and deliver it to the transmitter modulator.

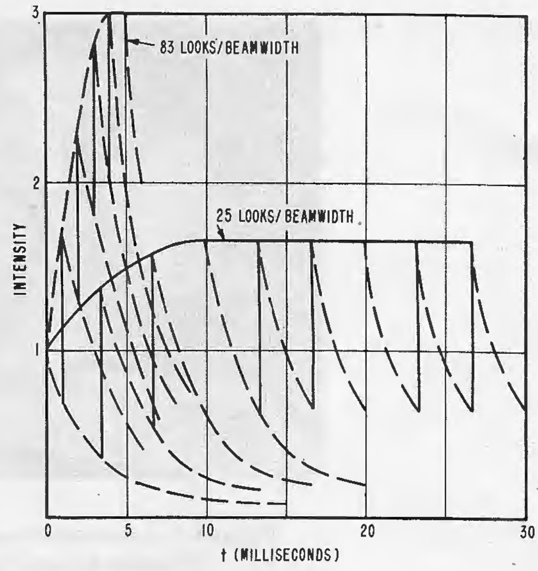

Figure 5 - Decay characteristic of a P-1 phosphor

It should be noted that the time base chosen, 36 cps, does not represent the ultimate in bandwidth reduction but a compromise value that eliminates the objectionable 3-degree separation between spokes. Although the spoked picture contains all of the data inherent in the system, it is disconcerting to untrained observers. For ultimate conservation of bandwidth, the data can be relayed at 12 pps by making some changes in the timing circuits.

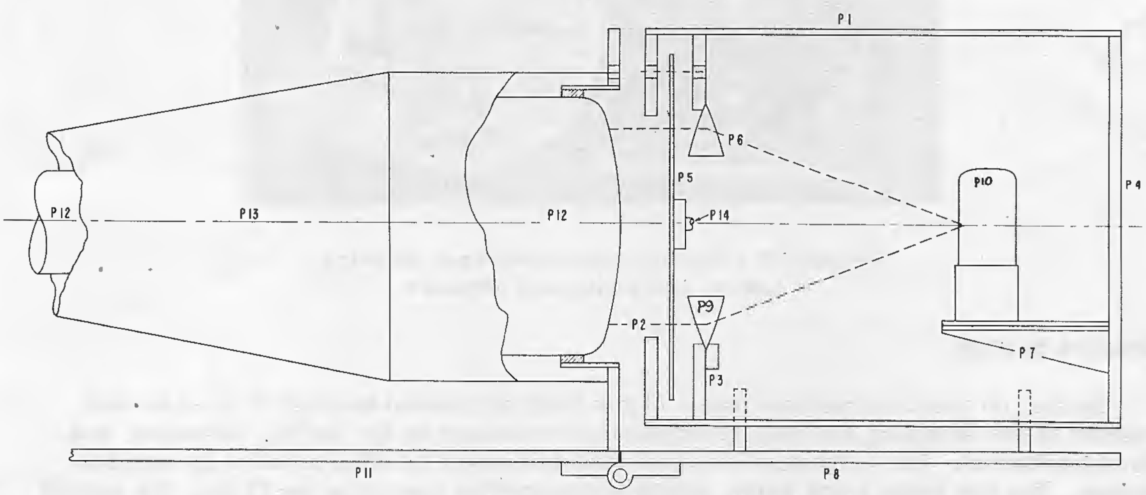

Figure 6 - Scanning assembly showing scanning barrel (P1), barrel head (P2), lens mount (P3), phototube mount (P4, P7), scanning disc (P5), Lucite lens (P6, P9), mounting panel (P8, P11), phototube (P10), cathode-ray tube (P12), mu-metal shield (P13), and motor shaft (P14)

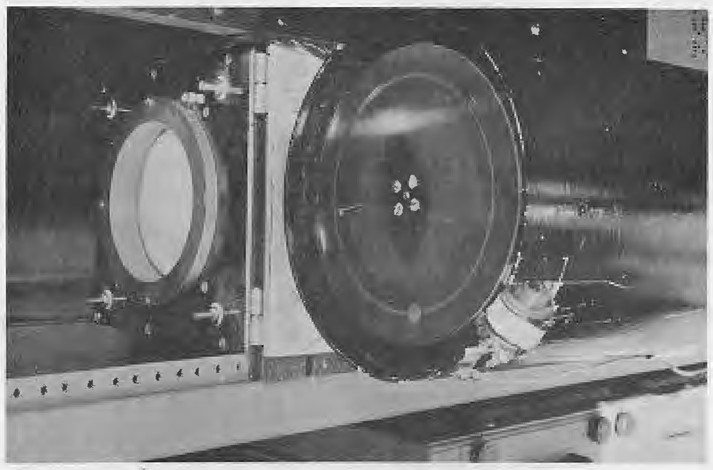

Figure 7 - Scanner assembly open showing face of cathode-ray tube and slotted disc

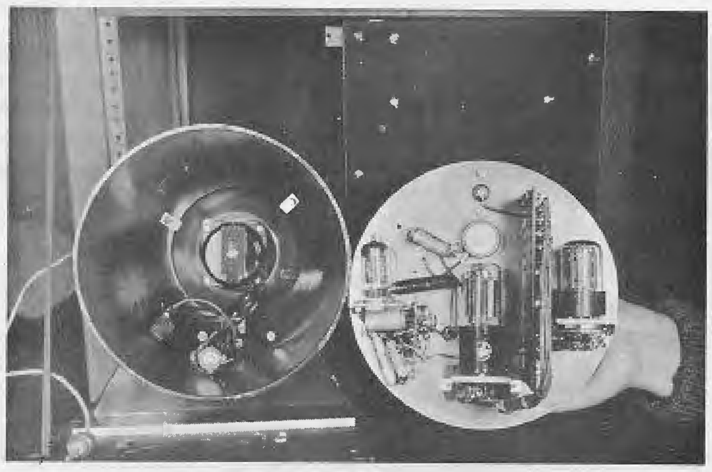

Figure 8 - Scanner assembly open showing motor and phototube mounted

Rotation System

So far, no mention has been made of the rotation system because it is in no way related to the sampling and data compression techniques of the Haller, Raymond, and Brown proposal. The original wire connected equipment handled rotation by synchro means. For the radio relay setup, synchronous motors operating on 72 cps, the second harmonic of the pulse repetition frequency, provide the proper rotation rate. Synchronism is achieved by broadening the sync pulse whenever the radar antenna passes through North. Such a system is limited to simple PPI presentation but has the advantage of using no additional bandwidth for rotational data transmission.

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The compressed data synchronizing pulse is generated by an iron insert in the scanning disk which passes over a gap in a magnetic core on which is wound a coil. The coil is in the cathode return lead of a high gain amplifier. The change in reluctance in the magnetic circuit generates a pulse voltage across the coil which is amplified and used to trigger a start-stop multivibrator which in turn generates the 100 microsecond wide synchronizing pulse. Whenever the radar antenna passes through the North position, the grid circuit time constant of the multivibrator is changed by a micro switch to broaden the pulse to 200 microseconds. The sync pulse is fed to the modulator for mixing with the video data.

The sync pulse also triggers a multivibrator whose waveform is selected to contain a high second harmonic content. A parallel T selective amplifier picks out the 72 cps second harmonic and feeds it to a pair of push-pull connected pentodes which deliver 115 volts ac to a synchronous motor geared to an output shaft speed of 25 rpm at 60 cps. Since the actual frequency is 72 cps, the output speed will be 30 rpm. A 1:5 gear reduction drives a 5G synchro generator whose output controls the angular position of the radar antenna (Figure A4).

Transmitter

From the integrator compressed data sync pulses (coded at North) and video are fed to the link transmitter modulator (Figure A5). The modulator built in the TDQ transmitter (Figure 9) did not have sufficient audio bandwidth to handle even the compressed video data so a special modulator was built. The width of the slot on the scanning disk acts as a low-pass filter and determines the width of the narrowest video pulse sent to the modulator. The modulator uses 4 triode-connected 6L6's in a push-pull parallel output amplifier driven by a push-pull 6SN7GT and a phase inverter. The modulator will deliver 20 watts maximum undistorted output and has a frequency response flat within ± 1 db from 20 cps to 30,000 cps.

Figure 9 - Transmitting equipment

Two power supply panels complete the transmitting terminal rack. One supply delivers 425 v dc unregulated up to 300 ma and the other supply delivers 300 v regulated dc up to 250 ma and + 1000 and - 1000 v dc for the integrator cathode-ray tube and the phototube (Figure A6).

Receiver

The receiving terminal equipment (Figure 10) consists of the following component pieces of equipment:

(1) A Standard vhf Receiver, type BC-639A,

(2) A Frequency Meter, type 638A, and

(3) A Decoder-Indicator and Associated power supplies.

The BC-639A receiver was modified slightly to improve the low-frequency response of the output circuit and the stability of the automatic gain control circuit. The changes are shown in Figure A7.

Before describing the operation of the decoder it will be best to review the makeup of the received signal.

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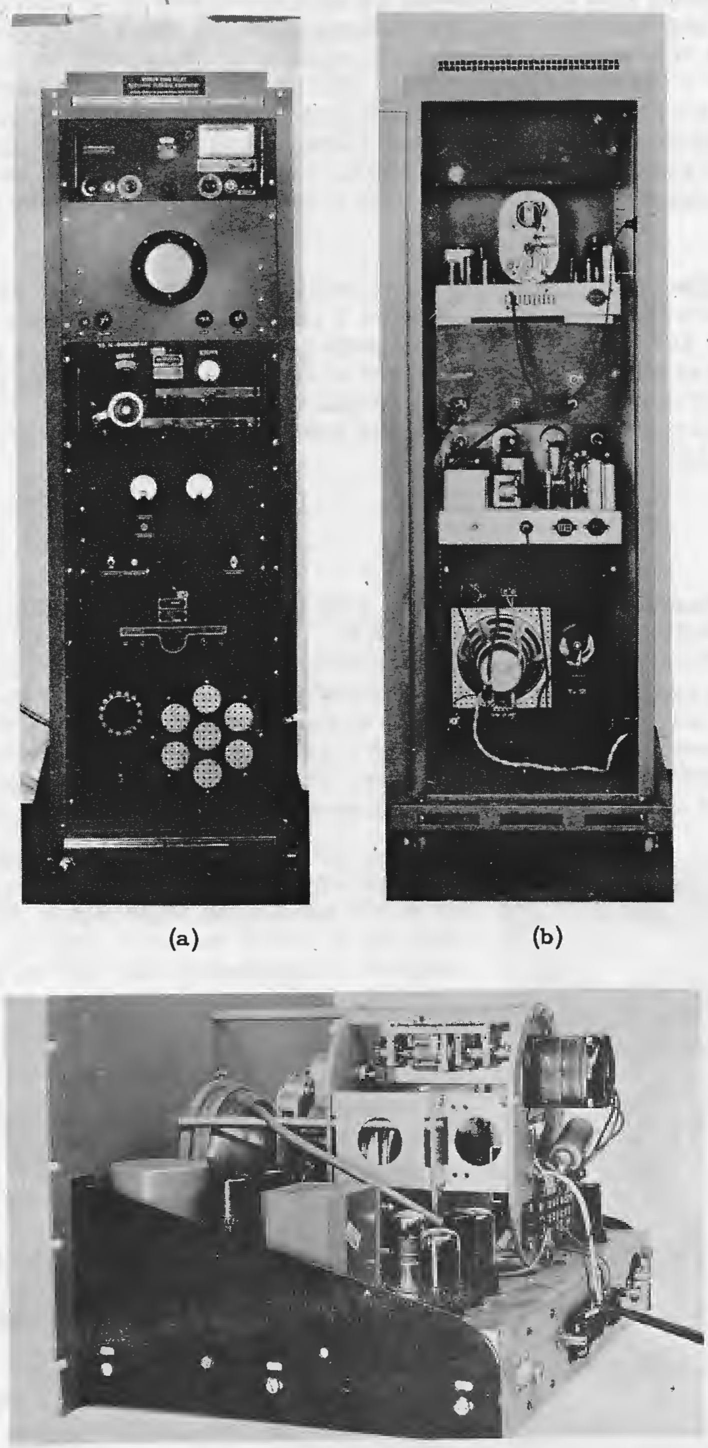

(a) (b)

(c)

Figure 10 - Receiving equipment showing (a) front panel, (b) rear view, and (c) close-up of decoder-indicator

The signal (waveform 1, Figure 11) consists of synchronizing pulses recurring at 36 pps followed by video. In addition, the synchronizing pulse is lengthened from 100 microseconds duration to 200 microseconds duration while the antenna of the radar is passing through North position. The first operation of the decoder is simple amplitude level separation of the synchronizing pulses from the video. The synchronizing pulse is used to trigger a local sawtooth sweep generator. In order to prevent the synchronizing pulse from causing a bright spot at the start of the trace which would burn the indicator phosphor, the sawtooth generator is triggered from the trailing edge of the pulse.

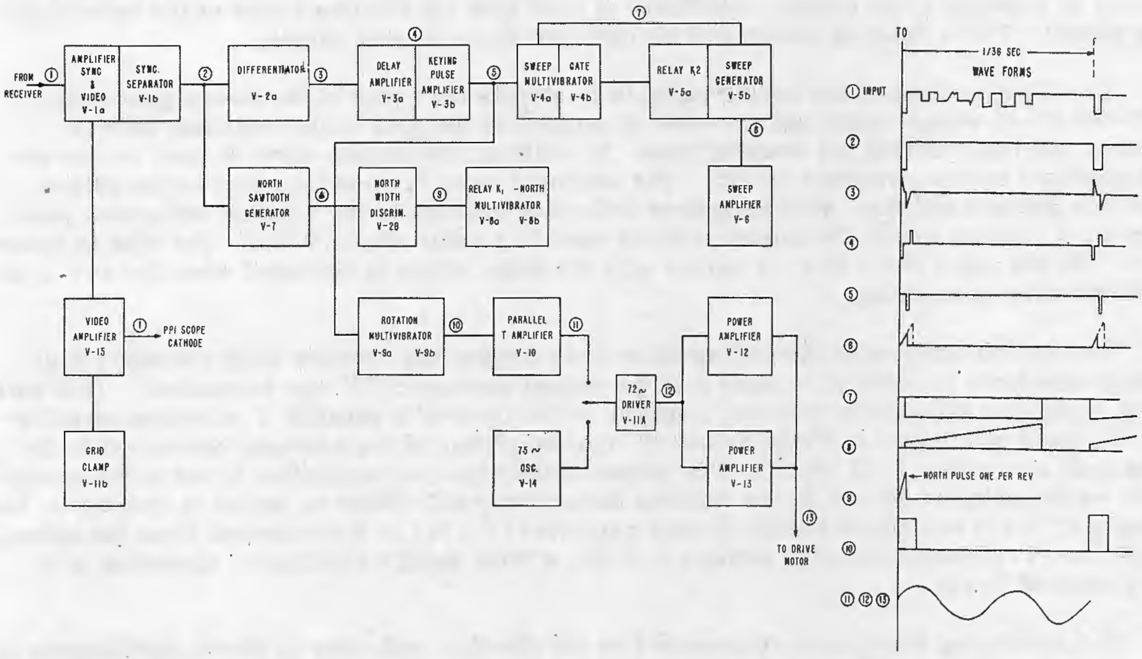

Figure 11 - Block diagram of decoder-indicator

The rotational velocity is inherent in the pulse repetition frequency of 36 pps. The second harmonic, 72 cps, is amplified to drive a synchronous motor which is geared to rotate the deflection yoke at 6 rpm. This portion of the indicator is identical with the servo drive unit of the transmitting terminal equipment so that the rotational rates are equal.

North stabilization is accomplished by two switches connected in parallel in the power circuit to the rotation motor. One switch is operated by a cam on the rotating yoke. It is opened while the trace is passing through the zero azimuth position. The second switch is a relay that is normally open, but is closed by the North broadening of the synchronizing pulse. Thus, the North position is checked once in every revolution.

As shown in Figure 11 and in the schematic (Figure A9) the negative going synchronizing pulses and video are amplified and inverted by a video amplifier (V-1a). The output of V-1a is fed to two channels: (a) a second video amplifier (V-15) whose plate is connected directly to the cathode of the PPI cathode ray tube, and (b) an amplitude synchronizing pulse separator (V-1b). The negative going pulses at the cathode of the indicator tube are of sufficient amplitude to make the fluorescent trace visible. The synchronizing pulse separator (V-1b) is a triode tube with sufficient negative bias to keep the plate current cut off except for the duration of the synchronizing pulses. The output of V-1b is a train of negative going pulses at a repetition frequency of 36 pps (waveform 2, Figure 11).

As mentioned above, it is desirable to start the deflection sawtooth generator from the trailing edge of the synchronizing pulse so that the high amplitude synchronizing pulse will not cause a bright spot at the center of the indicator. To accomplish this, the synchronizing pulses are differentiated and amplified in V-2a, amplified and inverted in V-3a, and clipped and amplified in V-3b (waveforms 3, 4, and 5, Figure 11). The last output waveform is a series of negative going pulses, coincident in time with the trailing edges of the synchronizing pulses. These delayed pulses will be referred to as keying pulses.

The first function of the keying pulse is to initiate the cycle of the sweep gate multivibrator (V-4) whose output square wave is applied to the grid of the indicator tube to unblank the trace during the working time. In addition, the square wave is used to operate the sawtooth sweep generator (V-5b). The sawtooth wave is direct coupled to the grid of V-6, the sweep amplifier, which supplies deflection current to the rotating deflection yoke. The third channel where the square wave is used is a relay stage (V-5a). The tube is biased to cut off and has a relay K-2, in series with its plate, which is operated when the sweep gate multivibrator is working.

The second function of the keying pulse is to trigger the rotation multivibrator (V-9) whose waveform is selected to have a large second harmonic (72 cps) component. This waveform is applied through an isolating resistor to the input of a parallel T selective amplifier (V-10) tuned to 72 cps. A triode driver (V-11a) amplifier is transformer connected to the push-pull amplifier (V-12, V-13). The output of the push-pull amplifier is fed to the synchronous motor which is geared to the rotating deflection yoke. When no signal is coming in, the relay K-2 is not energized and the driver amplifier (V-11a) is disconnected from the selective amplifier (V-10) and connected instead to V-14, a Wien Bridge Oscillator, operating at a frequency of 75 cps.

The remaining function to be provided by the decoder-indicator is North stabilization of the display. The output from V-1b (synchronizing pulses) is fed to V-7. This is a conventional sawtooth wave generator operating on the linear portion of the voltage rise (waveform 6, Figure 11). When the normal synchronizing pulse of 100 microseconds duration is applied to the grid of V-7, the sawtooth plate voltage rises to a peak of approximately 25 volts. When the transmitter equipment is passing through North, the pulses of 200-microseconds duration cause the sawtooth to rise to an amplitude of 50 volts. The sawtooth waveform is applied to the grid of the North pulse synchronizing separator (V-2b). The grid has sufficient negative bias to keep the plate current cut off except during the broadened North pulses. The waveform at the plate of V-2b is a negative going pulse that occurs only when the radar antenna is passing through the North position. These pulses trigger the North relay multivibrator (V-8). V-8 is triggered every ten seconds (6 rpm) and has a switched period of 0.1 second. A relay coil (K-1) is used as the low impedance plate load of the multivibrator. Its contacts (SW-1) are closed for 0.1 second whenever the received signal has the North coding. A microswitch (SW-2) is operated by a cam on the rotating yoke so that its contacts are open while the sweep is passing through the 0° position.

When the power is first turned on at the receiving terminal, the synchronizing pulses coming in operate the sweep gate multivibrator and relay K-2. The 72 cps wave drives the synchronous motor and the deflection yoke. When the yoke reaches the zero position, SW-2 opens and allows a magnetic clutch to disengage the drive motor from the yoke. The yoke remains at zero until a North code comes through, at which time SW-1 will close and engage the clutch. The yoke will rotate around to zero position where SW-2 will open again. This time the North pulse will operate SW-1 and rotation will be maintained. If the signal should fail at any time, relay K-1 will switch the power amplifier over to the 75 cps wave from the Wien Bridge Oscillator, thereby maintaining rotation around to North where the opening of SW-2 will stop the yoke to await the resumption of signal and North pulse. If the signal should be restored before the yoke reaches the zero position, the halt at zero will be momentary. Effectively, the North zero coincidence is checked every revolution.

The clutch is actually a combination clutch and brake assembly that holds the yoke stationary when not coupling it to the drive motor. The rotating yoke indicator is a Sanborn airborne type modified for this installation.

The receiving equipment includes a combination power supply chassis. It supplies + 30 v dc regulated by a series 6AS7-G up to 250 ma; -100 v dc for bias; and + 4300 v dc for the indicator final anode (Figure A8).

PERFORMANCE

Tests were run on the equipment with wire connections to check out the compression circuits. Then the system was operated over a radio link (about one-half mile). Finally, tests were run, relaying from Naval Research Laboratory to Washington National Airport over a radio link. The distance involved was about two miles. Due to lack of a suitable radar site, it was necessary to simulate radar data by means of a flying spot scanner using photographic negative maps and messages. In Figure 12 are shown photographs of the indicator receiving typical messages.

CONCLUSIONS AND RECOMMENDATIONS

The completion of the system seems to have proved conclusively the practicability and value of transmitting compressed radar data over a narrow band radio link. Possible uses would be convoy duty, harbor control, aircraft early warning, and sonar dunking. The receiving end of such a system would be relatively light, compact and inexpensive and the transmitter would be standard Navy vhf equipment.

However, the experimental system used is inherently inflexible so a more desirable system would be one which would be driven from the radar in use. To that end, further work is being done to develop a flexible system. Certain principles of operation are:

(a) The data compression equipment should require from the radar only such information as is required to operate a repeater (VE, VG, etc.). This means usually a synchronizing pulse, video, and a synchro output to control rotation.

(b) The data storage and integrating device should be capable of processing data at repetition frequencies from 60 pps up to 4000 pps in order to accommodate service radars. It appears that a storage tube of the graphechon or radechon type may satisfy this requirement.

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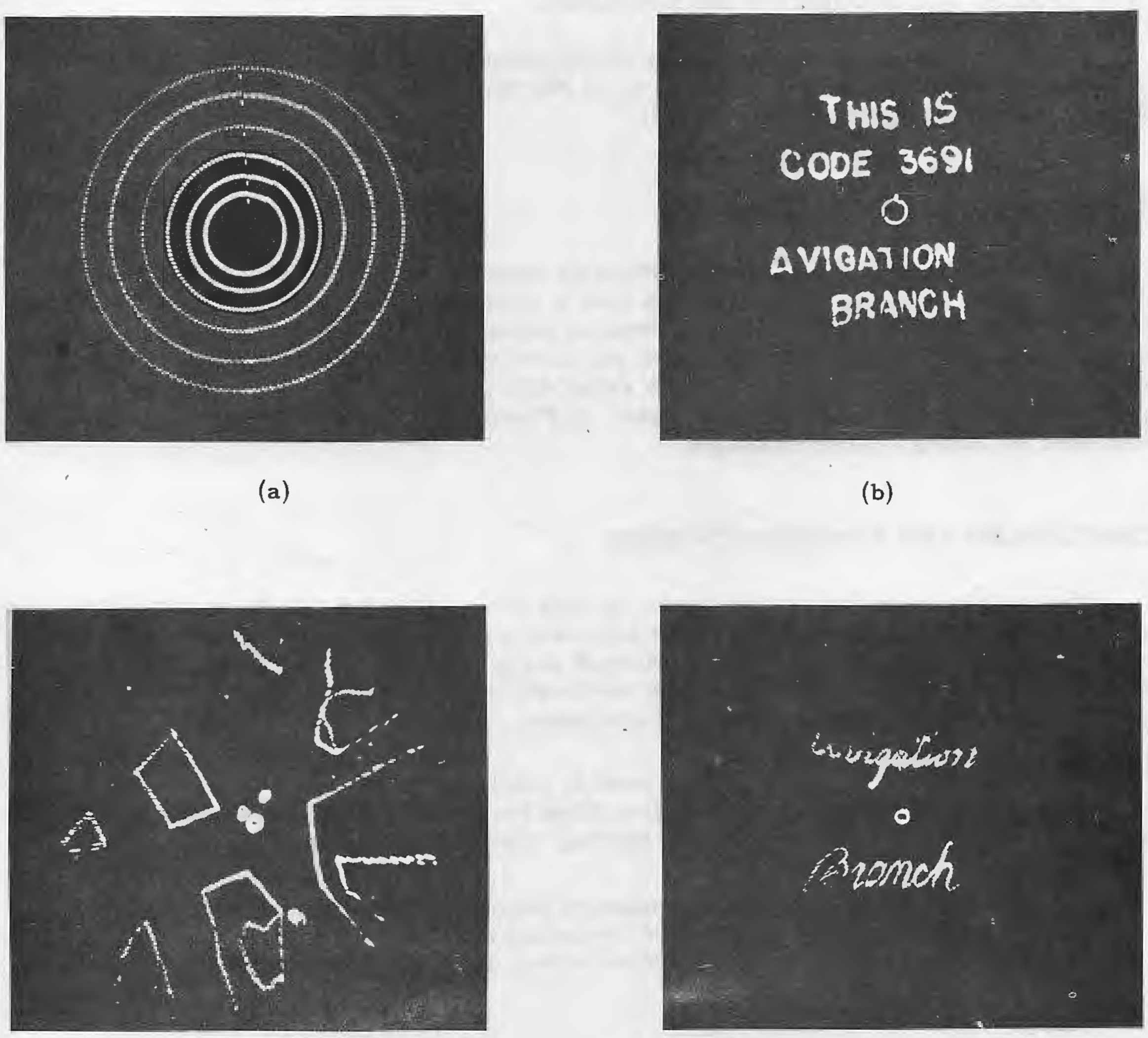

(a) (b)

(c) (d)

Figure 12 - Photographs of test patterns received on the indicator

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(c) It would be most desirable to establish an integral relation between the compressed data repetition frequency and the rotational frequency so as to simplify the azimuth synchronization problem.

The group is now working on some of the aspects of the operation of such a flexible system. The aim is to develop a system that may be connected to a service radar by merely plugging cables into a repeat indicator station.

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APPENDIX A

Circuit Diagrams

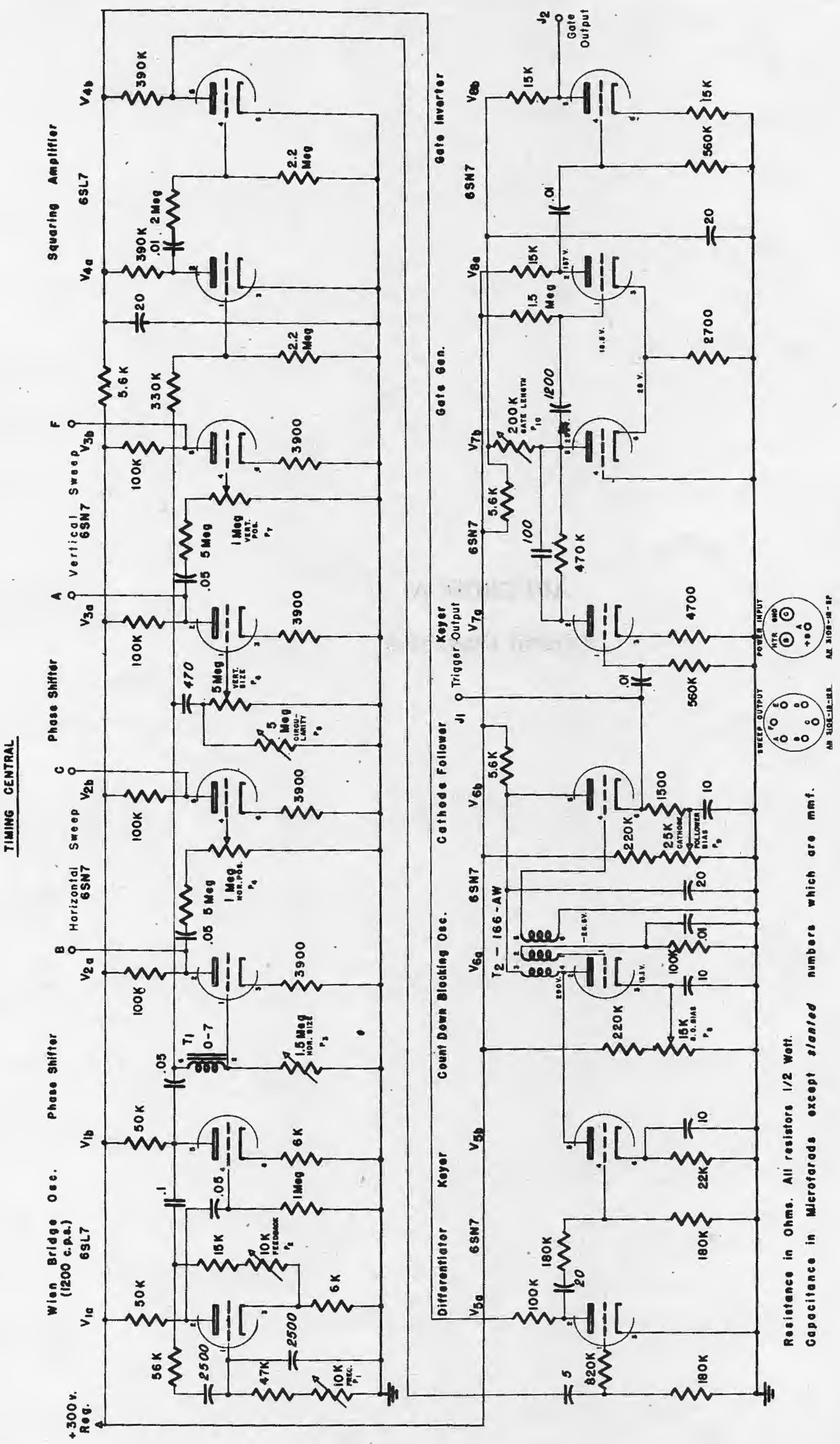

Figure A1 - Compressor timing center

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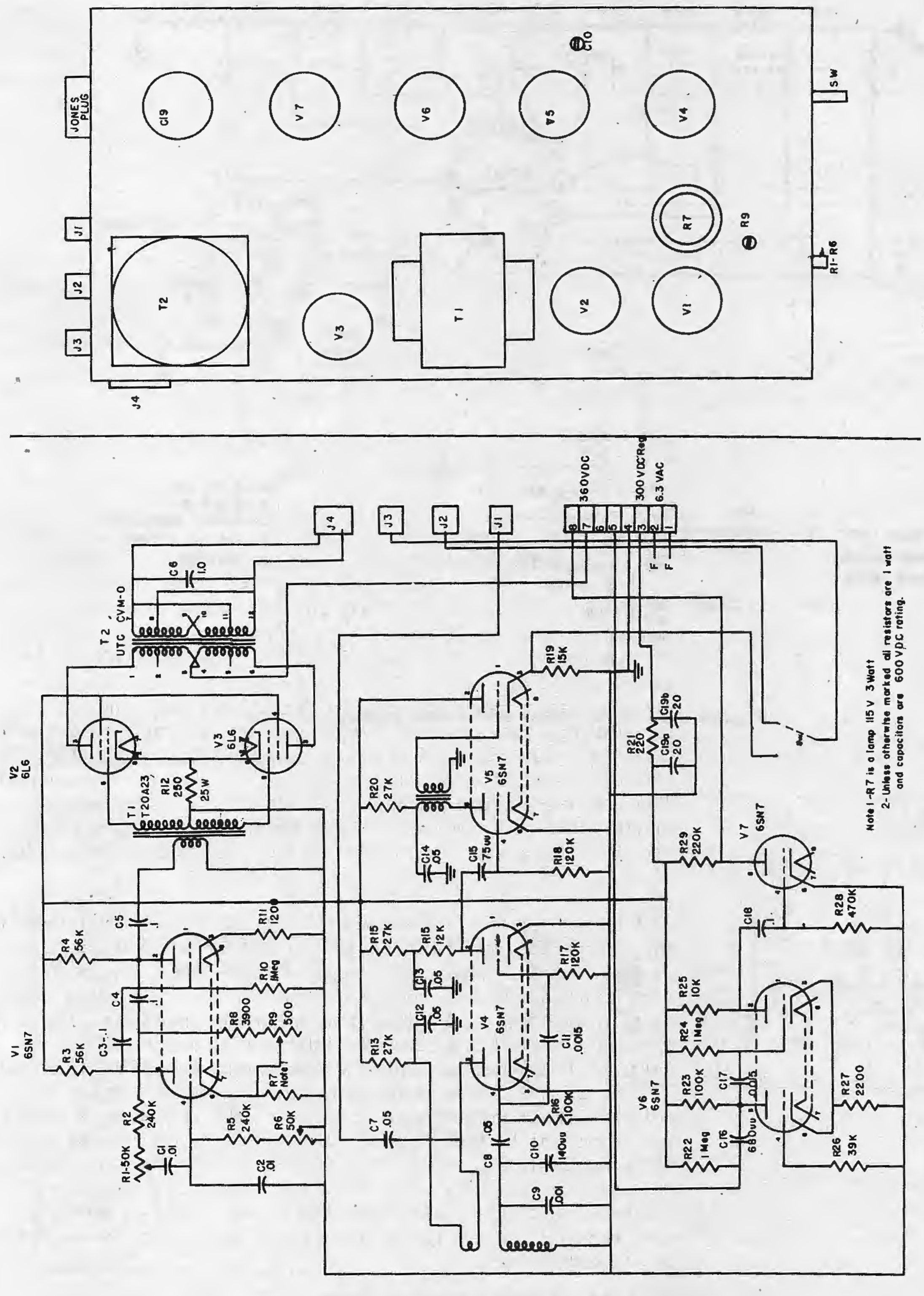

Figure A2 - Scanning-disk-motor driver

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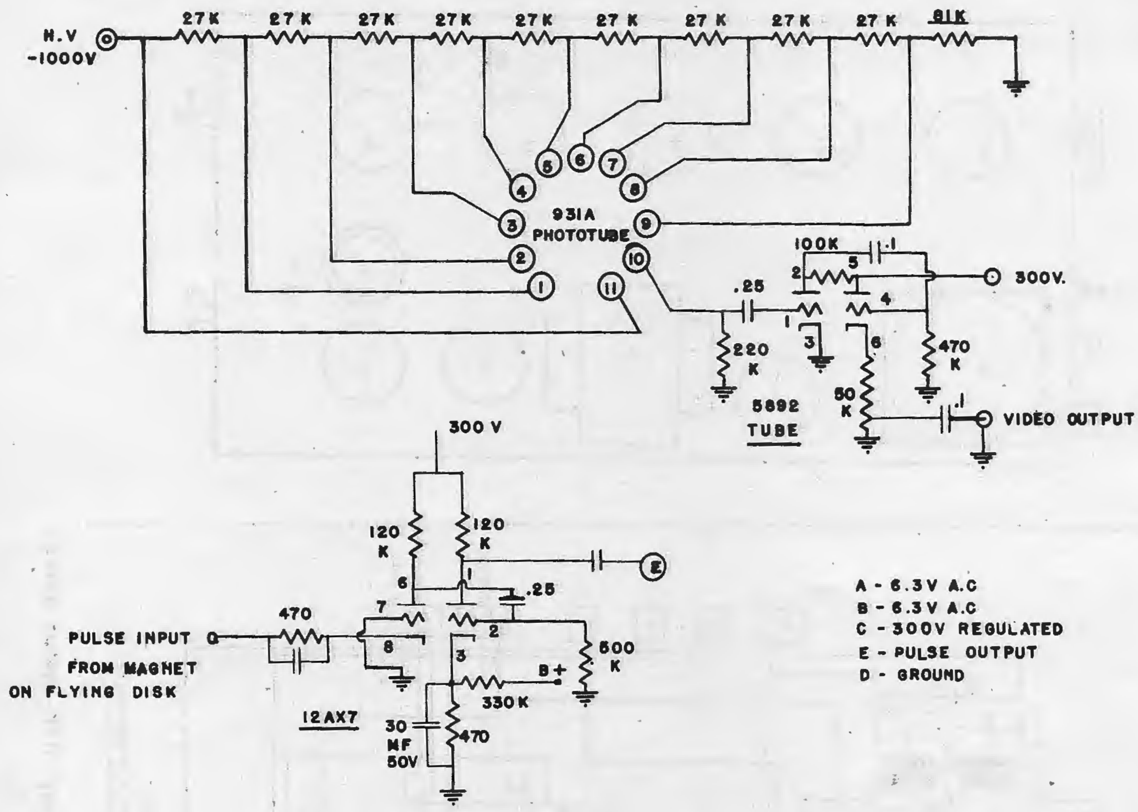

Figure A3 - Sync pulse and video pickup circuits

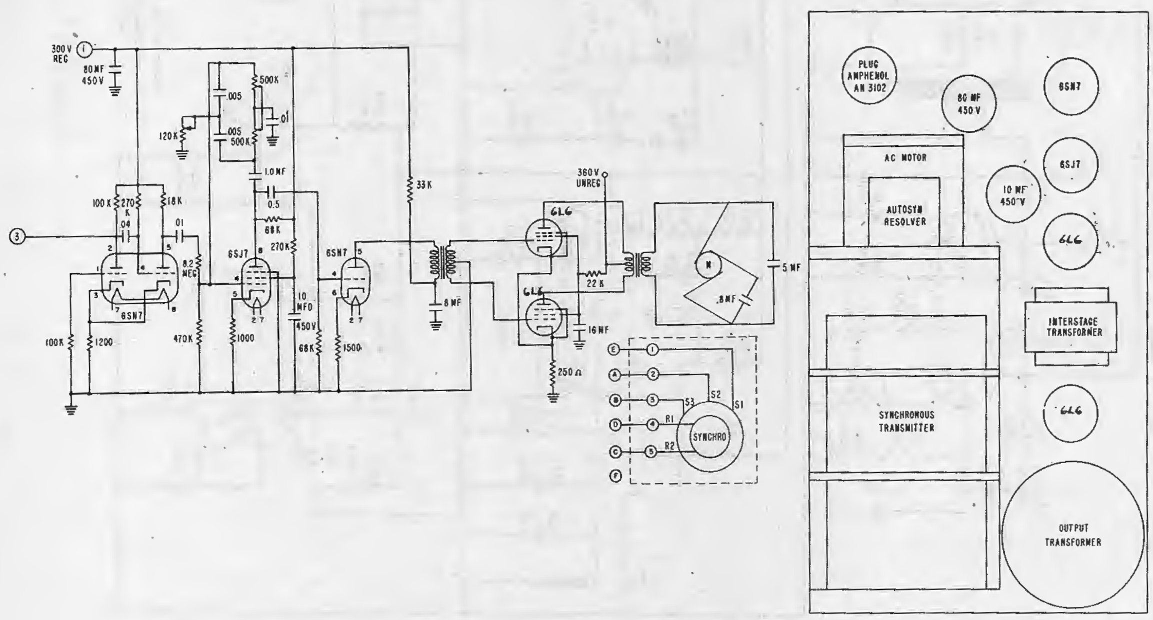

Figure A4 - Antenna synchro drive

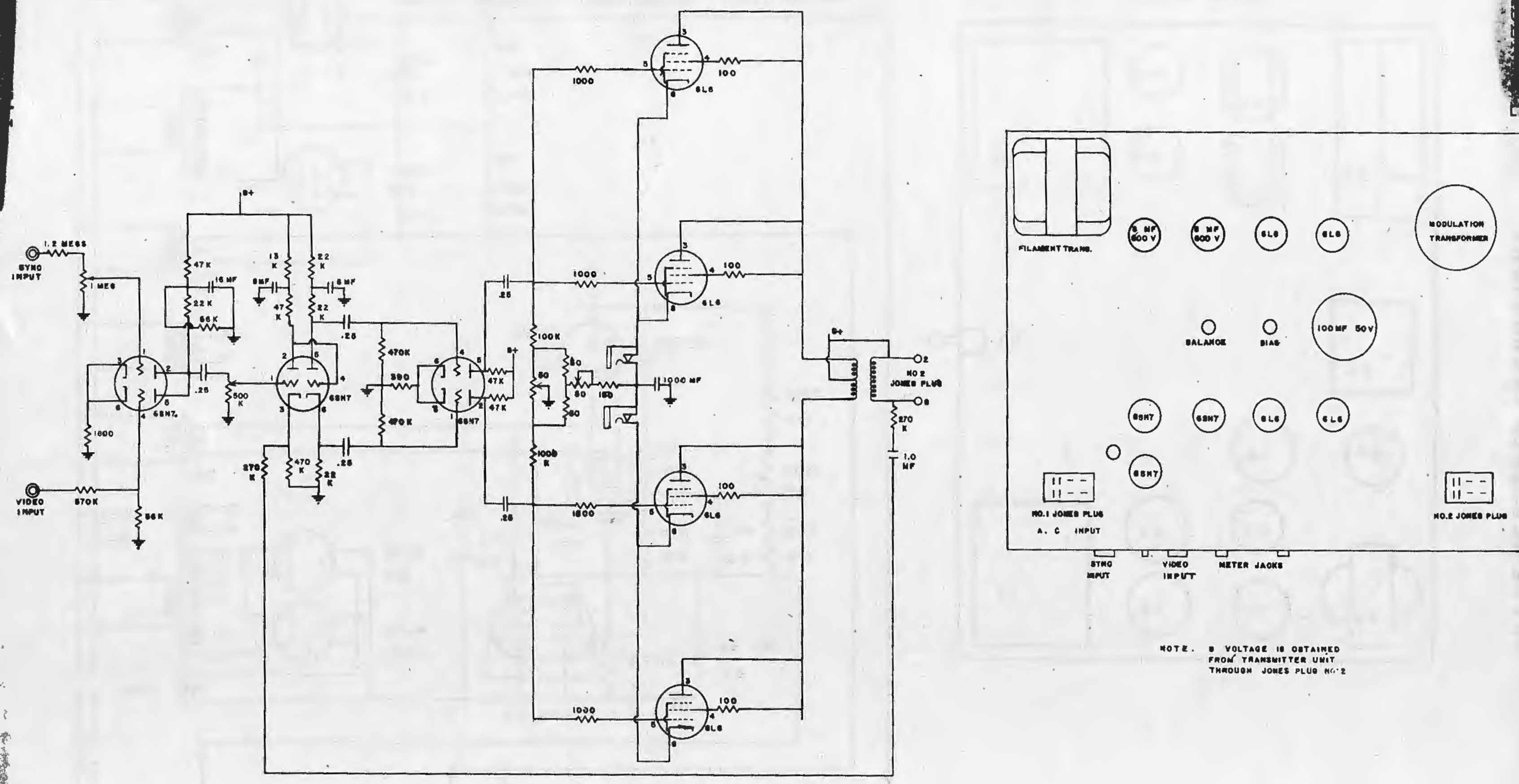

Figure A5 - Modulator