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AN INSTANTANEOUS PULSE-SIGNAL ANALYZER

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AN INSTANTANEOUS PULSE-SIGNAL ANALYZER

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March 22, 1949

Approved by:

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ABSTRACT

With particular reference to radio countermeasures, a novel method for the analysis of pulse-type radio signals is described which makes use of a special five-gun cathode-ray tube wherein each sweep is triggered simultaneously by the signal to be analyzed. The range covers signals having (1) pulse widths from 0.25 to 1000 μsecs, (2) repetition rates from 20 to 10,000 cps, and (3) other complex wave forms of a nonlinear nature. Since modulation characteristics are presented instantaneously on the screen of the tube, it is possible to analyze signals of extremely short duration.

After preliminary research, several instruments of this design were completed and used successfully for the analysis of radio signals intercepted by various Naval vessels at sea.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem R06-11R

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AN INSTANTANEOUS PULSE-SIGNAL ANALYZER

INTRODUCTION

In order to provide suitable countermeasures for jamming or otherwise interfering with various types of radio signals it is necessary to determine the characteristics of signals intercepted. In addition, it is frequently desirable, aside from the problem of jamming or deception, to identify and gain intelligence from unknown signals.

Conventional methods of signal analysis and display are dependent upon the reception of radio signals for relatively long periods of time. Continuously pulsed radar signals, for example, usually provide ample time for the analysis of characteristics by means of conventional equipment such as the AN/APA-11 and the RDJ. The methods used in these equipments require a number of adjustments by the operator before the various characteristics can be measured accurately. In some cases it is necessary to adjust the sweep frequency of the cathode-ray tube to synchronize with the repetition frequency of the received signal, or to compare the repetition frequency with an audio tone whose frequency is known.

Although these techniques have been useful, they have been extremely limited in application and are completely inadequate for the analysis of pulse-type signals of very short duration. It is contemplated that future radar systems will be able to measure range to any particular target using a minimum of four pulses with a pulse length of one microsecond and a repetition frequency of 3000 cycles per second. This provides a total signal duration of only approximately 0.001 second. During the last war the Germans introduced a communication signal which transmitted fifteen character messages in 0.3 second. These examples serve to emphasize the importance of developing essentially automatic and instantaneous techniques of signal analysis.

With these requirements in mind, an analyzer has been developed based upon principles comprising a combination of very stable sweep circuits using a division-impulse technique and presentation of signals on a multiple-gun cathode-ray tube. This unit employs five separate gun structures to produce individual electron streams controlled by their individual deflection systems, and all the sweeps are initiated by the incoming signal simultaneously. The display presented on the face of the five-gun cathode-ray tube permits the evaluation of signals having (1) pulse widths from 0.25 to 1000 microseconds; (2) repetition rates from 20 cycles to 10,000 cycles per second; and (3) other complex wave forms of a nonlinear nature.

GENERAL DESCRIPTION

[redacted] and more clearly the presentation of the display on the cathode-ray tube of the indicator, reference is made to Table A.

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TABLE A

Scale	Range	Max. Excursion in μsec.
1	0.25 - 5 μsec.*	[redacted] 5-1/2
2	0 - 50 μsec.	50
3	1 - 10 Kc.†	1000
4	200 - 1500 cycles	5000
5	20 - 300 cycles	50,000

* A half-microsecond delay was introduced so that the leading edge of a pulse would be visible.

† Since the fundamental sweep time is 1000 microseconds, this scale can also be used for pulse-width measurements up to 1000 microseconds.

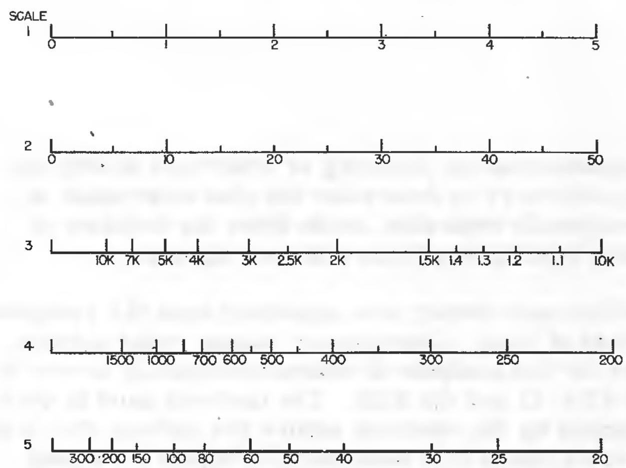

Fig. 1 - Calibration scale

The calibration scale which is placed on the face of the cathode-ray tube as a decalcomania can be seen in Figure 1. The sweep range or the time bases are so chosen that a range of 20 cycles to 10,000 cycles can be analyzed with moderately good accuracy. Also, the scales can be calibrated and the sweep slopes checked for linearity merely by counting five pips from a calibration source. The scale to be read is always the one with the least number of pips, the first pip being used to read repetition frequency.

CIRCUIT DESCRIPTION

Figure 2 is a block diagram and Figure 3 a circuit schematic of a single channel, of which the components are best discussed individually.

Inverter and Amplifier

Tube V_1 (Figure 3) is used as an inverter tube and amplifier to obtain the proper polarity for the keyer tube when a negative signal is supplied from the intercept receiver. The positive pulse appearing at the plate of V_1 is differentiated through C_2 and R and applied to the grid of the keyer tube (V_2) which is biased to cutoff and will amplify only positive pulses.

Multivibrator

This pulse then plate-keys the multivibrator (V_3 and V_4 in the basic circuit, Figure 4) in a direct-coupled circuit. The high-GM pentode V_2, and the differentiating circuit in its grid, also prevent undesired signals from affecting the multivibrator during its cycle as controlled by the RC product.

The normal operating condition of the multivibrator is such that tube V_4 is conductive and tube V_3 is at cutoff. This condition is achieved by setting the threshold-bias potentiometer of tube V_3 to a potential at least 18 volts less than the potential of the cathode.

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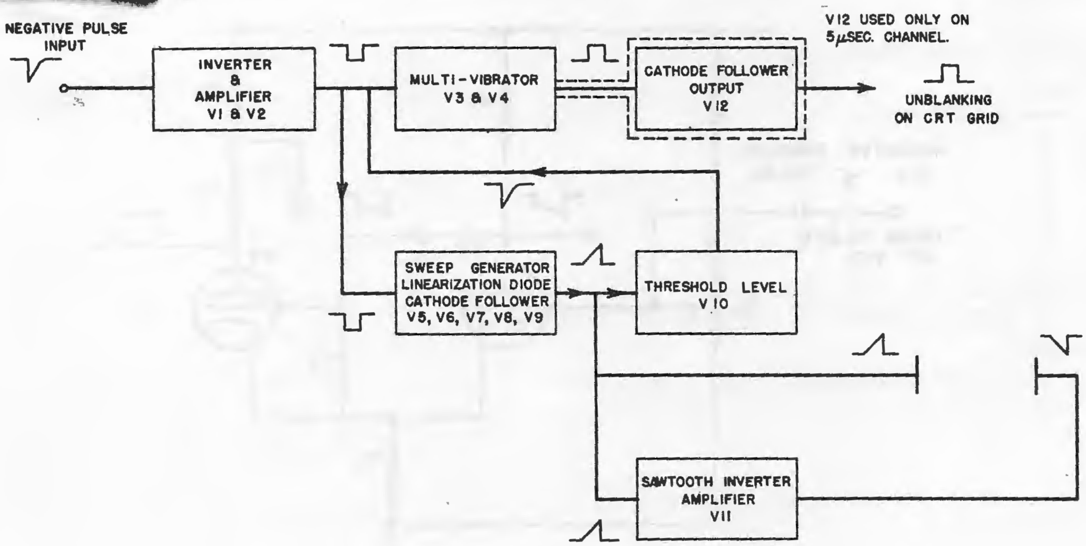

Fig. 2 - Basic diagram of a single channel

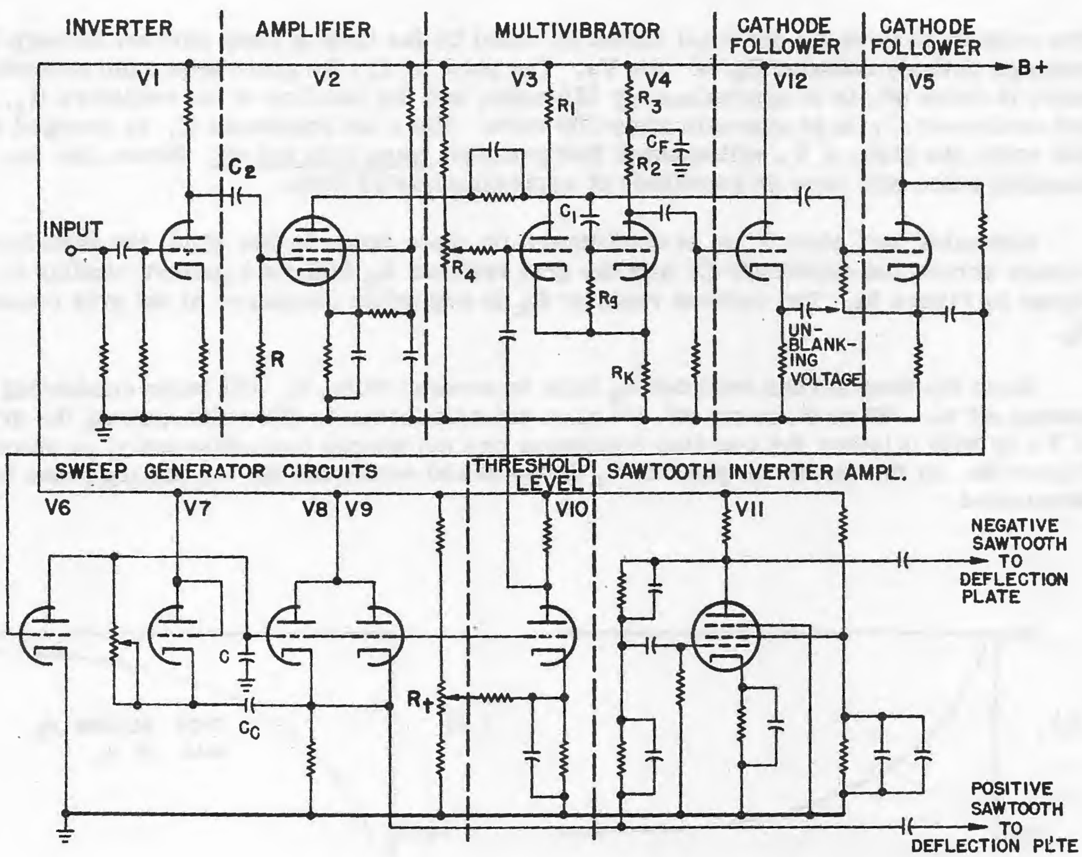

Fig. 3 - Circuit of a single channel

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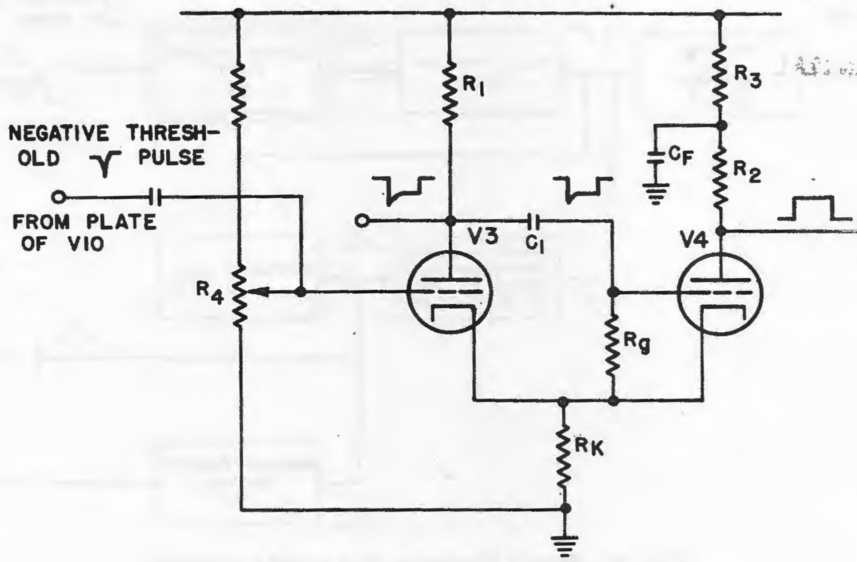

Fig. 4 - Multivibrator circuit

The cathode derives its potential (about 50 volts) by the flow of plate current through the common cathode resistor R_k of tube V_4. The plate of V_4, the point where the unblanking pulse is taken off, is at approximately 150 volts; and the junction of the resistors R_2, R_3, and condenser C_f is at approximately 200 volts. Since the condenser C_f is charged to 200 volts, the plate of V_4 will assume that potential when it is cut off. Hence, the unblanking pulse will have an amplitude of approximately 50 volts.

Assuming that when V_3 is in equilibrium its plate drops to 200 volts, the variation of voltage across the condenser C_1 and the grid resistor R_g follows a pattern similar to that shown in Figure 5a. The cathode resistor R_k is negligible compared to the grid resistor R_g.

When the drop across resistor R_g falls to several volts, V_4 will begin conducting again, cutting off V_3. When V_3 is cut off, its plate potential rises to 350 volts, pulling the grid of V_4 up with it (since the coupling condenser can not charge instantaneously) as shown in Figure 5b. At this point the plate of V_4 drops to 150 volts, and the unblanking pulse is terminated.

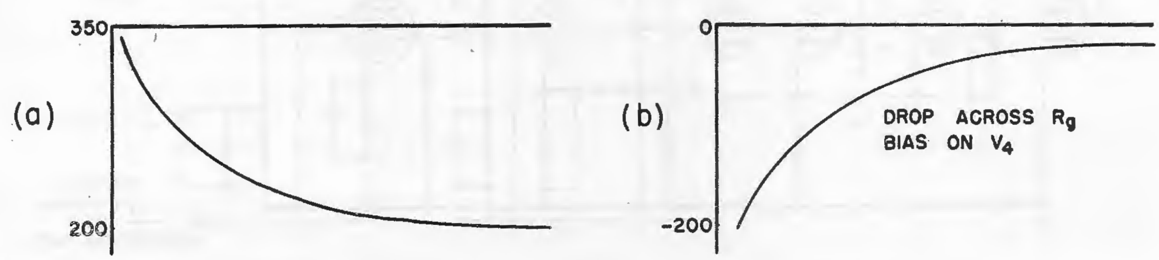

Fig. 5 - Curves of multivibrator characteristic

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The time constant does not control the duration of the unblanking pulse. Instead, the time constant ($C_1 R_g$) is made long enough so that V_4 will not begin conducting until a more accurately timed negative pulse reaches the grid of V_3, cutting that tube off. This, of course, drives the plate of V_3 and the grid of V_4 positive before terminating the unblanking pulse.

The Sweep Generator

Normally tubes V_6, V_7, V_8, and V_9, whose basic circuitry is shown in Figure 6, are conducting. V_6 will conduct whenever the plate becomes positive with respect to the cathode, and the diode V_7 will also conduct due to the B-plus rise. V_8 and V_9 are cathode followers, and these cathodes always tend to stay at the same potential as their grids.

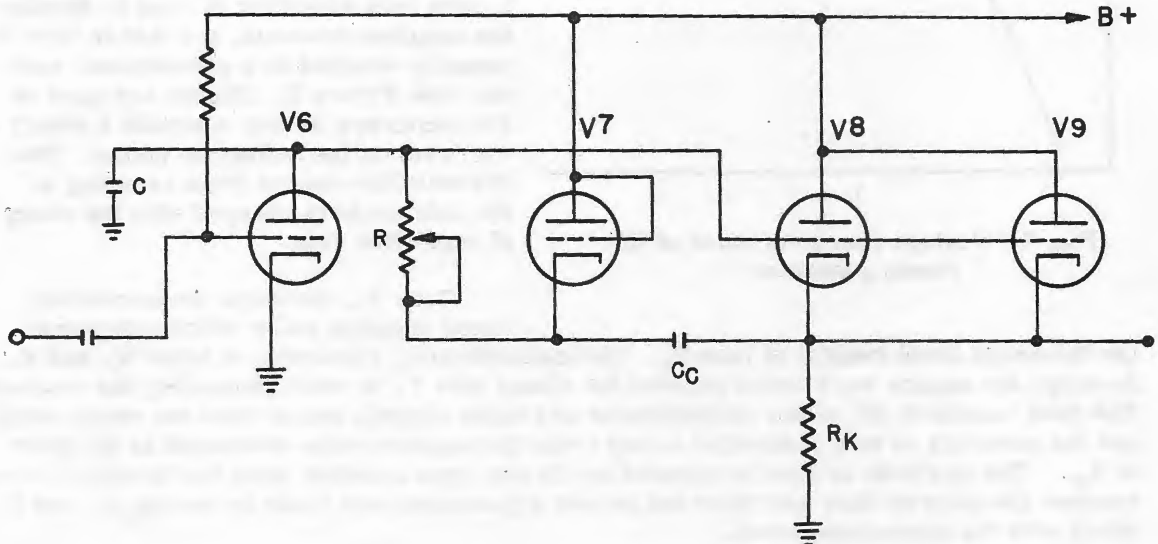

Fig. 6 - Sweep-generator circuit

When V_6 and V_7 conduct, almost all the voltage drop appears across the resistor R. Approximately 5 volts appears across tubes V_6 and V_7; hence the drop across the resistor R is about 345 volts. The plate of V_6 is at plus 5 volts; consequently the cathodes of V_8 and V_9 must be at plus 5 volts plus the grid bias. Thus the coupling condenser from the cathode of V_7 to the cathode of V_8 and V_9 is charged at 345 volts. Condenser C, which is connected from the plate of V_6 to ground, is the sawtooth generator condenser, and initially it has 5 volts at equilibrium.

Considering tubes V_6 and V_7 and disregarding the coupling condenser C_C, this voltage variation with time would be as shown in Figure 7. When the tube V_6 is cut off, the voltage across the condenser C would increase exponentially as shown in curve a.

Now C is made large enough so that the voltage developed across it remains constant as it is charged from the B-plus source through the diode V_7. Thus, linearization, as shown in curve b, is added,* making it possible to calibrate the sweeps more easily.

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* Bernard Newsom's method of linearization by feed-back means. British Patent 493,843.

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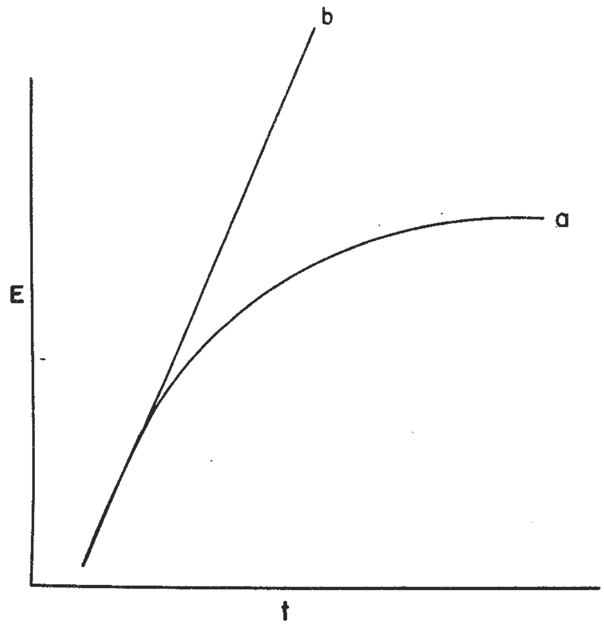

Fig. 7 - Voltage characteristics of the sweep generator

When the sweep generator tube V_6 again is made conductive, condenser C is discharged through tube V_6. During the flyback period, V_7 is conducting and holding the condenser at the B-plus level while the charge flows back into C_c through R_k. The flyback time is thus assisted by the value $R_k C_c$, which product should be kept at a minimum.

The positive sawtooth generated is then capacity-coupled to the plate of the cathode-ray tube deflection plate. To complete the balance deflection circuit, a unity gain amplifier is used to develop the negative sawtooth, and this in turn is capacity-coupled in a conventional manner (see Figure 3). Diodes are used as d-c restorers to help maintain a steady d-c level on the deflection plates. This prevents the sweeps from creeping as the duty cycle is changed with the changing of repetition rate.

Tube V_{10} develops the accurately timed negative pulse which overcomes the threshold-level control of tube V_3. The multivibrator, consisting of tubes V_3 and V_4, develops the square wave which enables the clamp tube V_6 to start generating the sawtooth. The time constants RC of the multivibrator are made slightly longer than the sweep used, and the accuracy is then controlled solely from the negative pulse developed at the plate of V_{10}. The sawtooth is then terminated by its own time constant when the threshold level reaches the desired time and when the proper adjustments are made by setting R_4 and R_t, which sets the operational level.

This circuitry was chosen both to prevent the multivibrator from being initiated until the sweep is over and to keep the components of the timing circuits and adjustments down to a minimum. Other means of timing can be used, however, as long as stable conditions and fast return times at high keying rates do not overcome circuit stability.

The Video Amplifier and Synchronizing Circuit

The video amplifier (basic diagram, Figure 8) and its associated schematic circuit are shown in Figure 9. The video amplifier supplies the necessary deflection to the vertical plates of the cathode-ray tube. The indicator unit has only one panel control, which is in the input-level adjustment for the first video tube. This

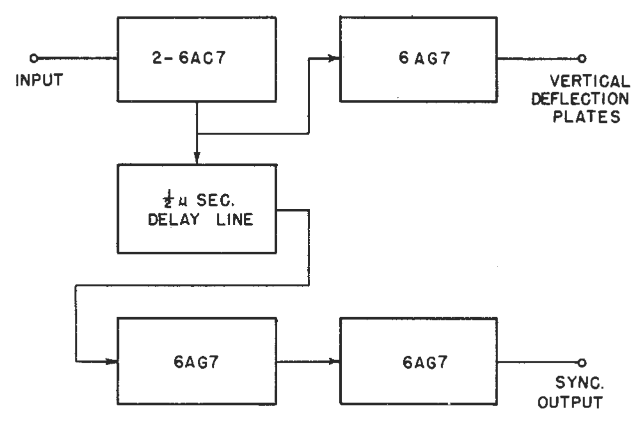

Fig. 8 - Basic diagram of video and synchronizing circuits

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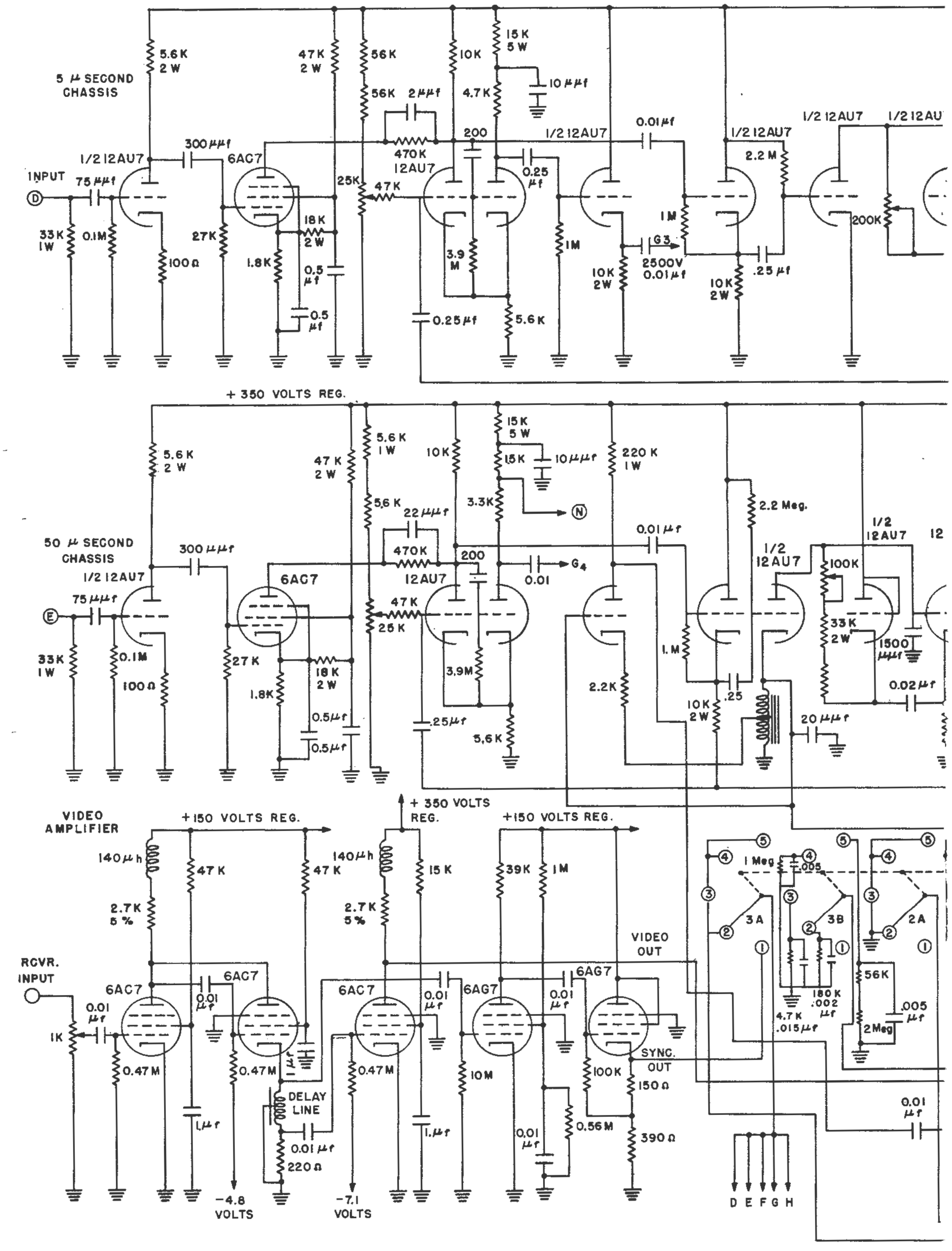

Fig. 9 - Pulse-analy

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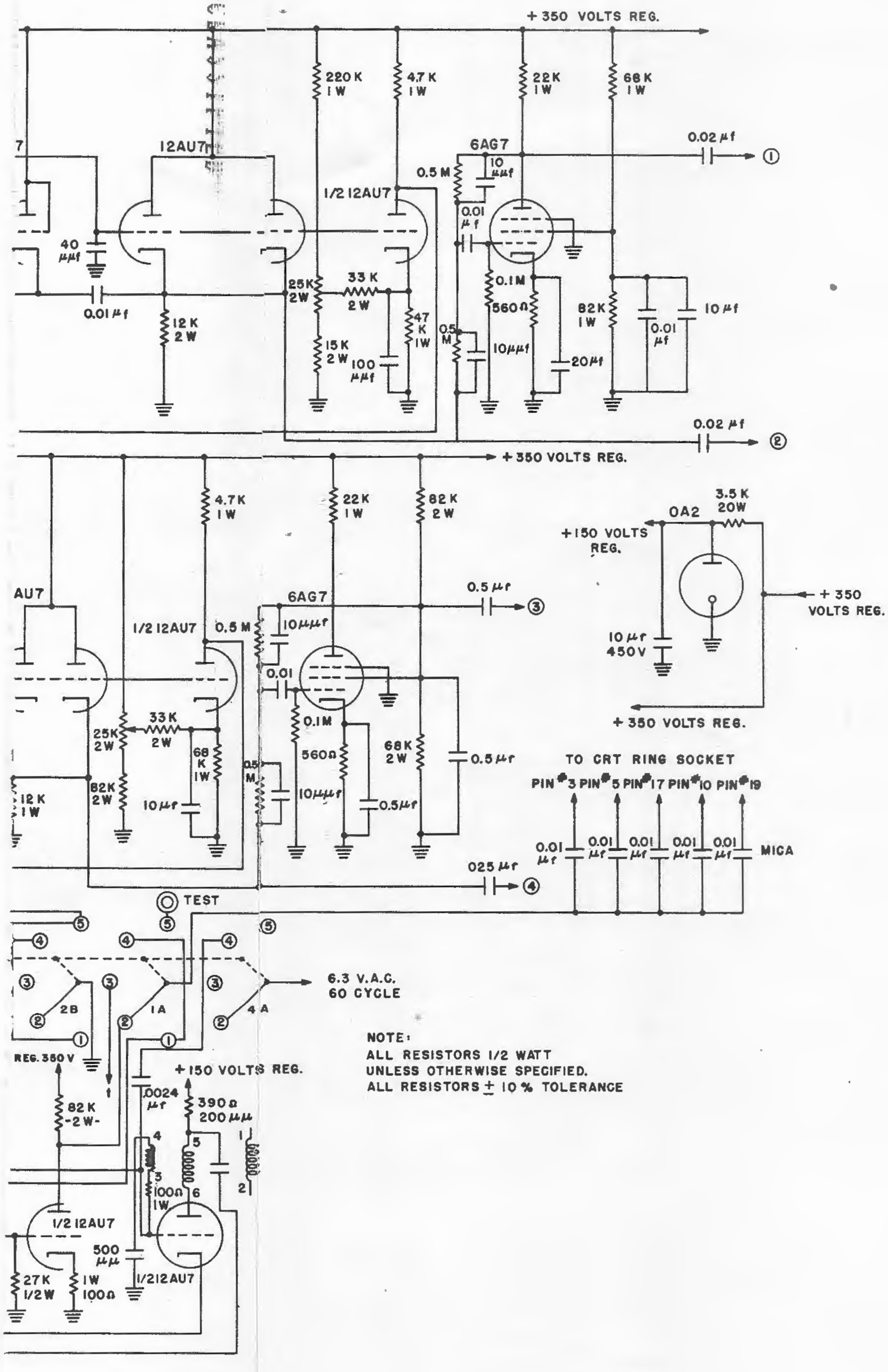
+350 VOLTS REG.
220 K 1 W
4.7 K 1 W
22 K 1 W
68 K 1 W
12AU7
1/2 12AU7
6AG7
0.5 M
10 μμf
0.01 μf
0.02 μf
40 μμf
0.01 μf
12 K 2 W
25 K 2 W
33 K 2 W
15 K 2 W
100 μμf
47 K 1 W
0.1 M
560 Ω
10 μμf
20 μf
82 K 1 W
10 μf
+350 VOLTS REG.
4.7 K 1 W
22 K 1 W
82 K 2 W
0A2
3.5 K 20W
+150 VOLTS REG.
+350 VOLTS REG.
10 μf 450V
AU7
1/2 12AU7
0.5 M
6AG7
0.5 μf
10 μμf
0.01
33 K 2 W
25 K 2 W
68 K 1 W
82 K 2 W
12 K 1 W
10 μf
0.1 M
560 Ω
10 μμf
68 K 2 W
0.5 μf
+350 VOLTS REG.
TO CRT RING SOCKET
PIN #3 PIN #5 PIN #17 PIN #10 PIN #19
0.01 μf
MICA
025 μf
TEST
6.3 V.A.C. 60 CYCLE
2B
1A
4A
REG. 350 V
82 K -2 W-
.0024 μf
+150 VOLTS REG.
390 Ω
200 μμ
100 Ω 1W
1/2 12AU7
500 μμ
1/2 12AU7
27 K 1/2 W
1W 100 Ω
NOTE:
ALL RESISTORS 1/2 WATT
UNLESS OTHERWISE SPECIFIED.
ALL RESISTORS ± 10 % TOLERANCE

'zer circuit

control in turn maintains the level at which the sweep circuits are energized and the amplitude of deflection on the cathode-ray tube display.

In the cathode of the second video tube there is incorporated a delay line which will delay the pulse a half-microsecond so that the rise time of the displayed pulse can be shown. The final tube is a 6AG7, and the bandwidth is 2 Mc.

The synchronization pulse is amplified and put through a cathode follower, and this in turn triggers the inputs of the various sweep channels.

The Pulse Stretcher

In order to see narrow pulses with low repetition rates, a means of expanding the pulse had to be devised. After careful consideration of pulse stretchers in the video, it was decided that the most economical and effective means was to take the gate from the 50-microsecond sweep since it was already synchronized with the other sweeps in the display. Through a simple switching scheme, the incoming pulse was expanded so as to display the summation of the incoming pulse and the artificial pulse developed from the 50-microsecond gate.

The Five-Gun Cathode-Ray Tube

The five-gun cathode-ray tube (Figure 10) is one of special design incorporating five separate, individual gun structures capable of writing on a fluorescent screen simultaneously. They are of the zero-anode-current variety which will maintain a fine spot size with high-intensity light output. The shielding between gun structures, as can be seen in Figure 11, is especially designed to prevent interaction and cross talk in the higher frequency limits.

Since the interpretation of analysis is dependent solely on a direct calibration scale, the entire tube was shielded with a mu-metal shield so that low-frequency extraneous fields would not shift the traces.

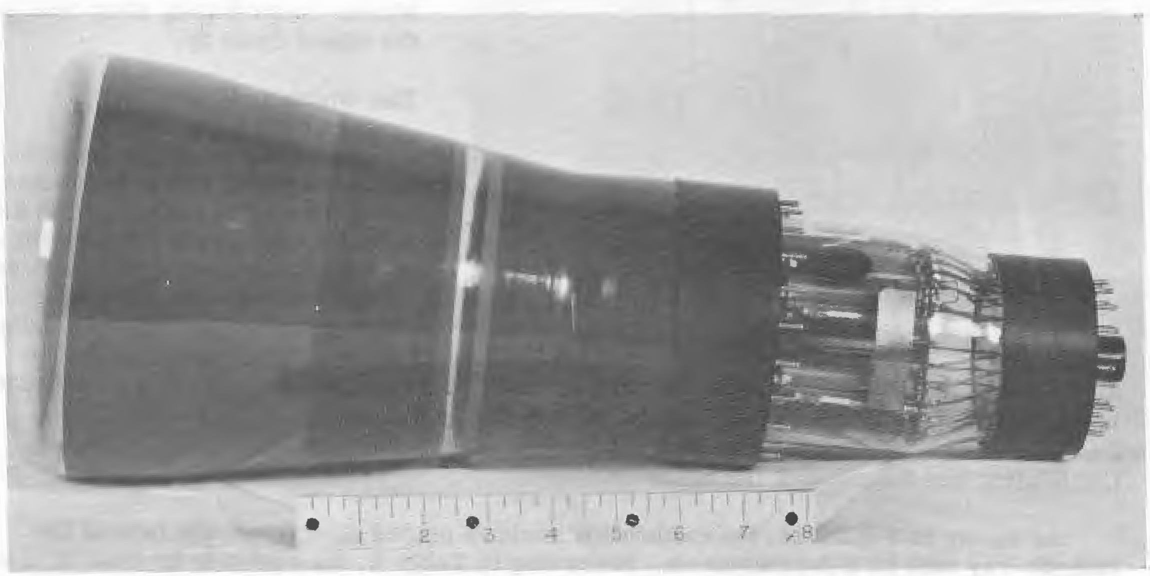

Fig. 10 - Five-gun cathode-ray tube

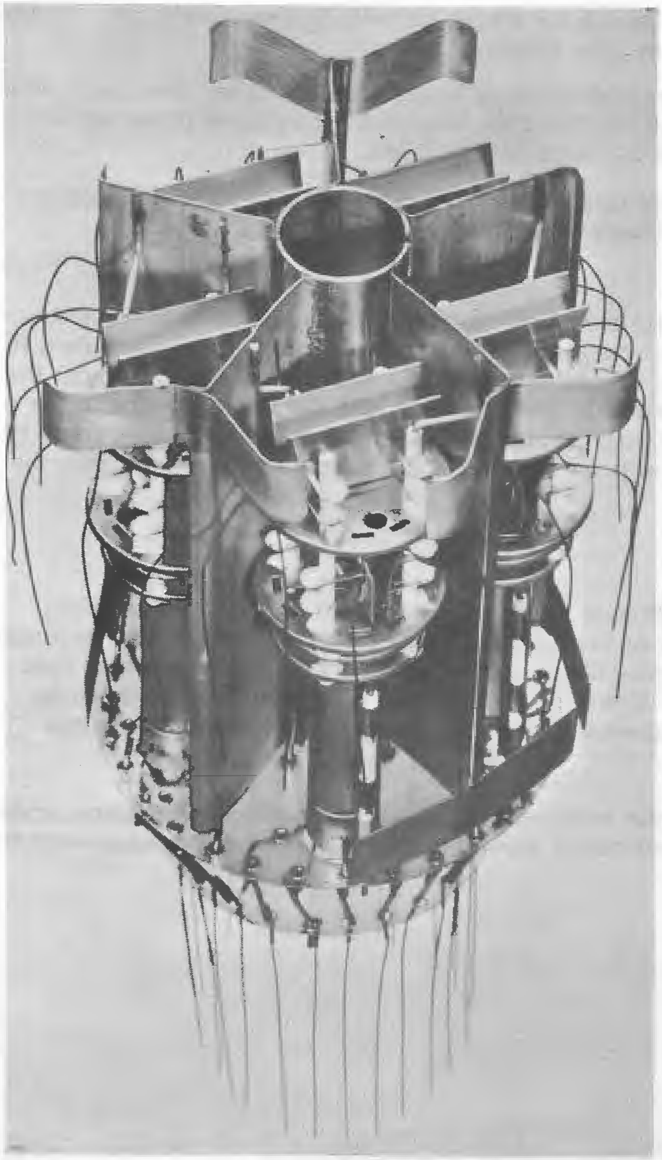

Fig. 11 - Internal structure of the five-gun cathode-ray tube

Power Supply

The power supply, whose circuit schematic appears in Figure 12, is a straightforward conventional unit consisting of high-and-low voltage assembly, the latter regulated electronically. The total power consumption is in the order of 600 watts.

Camera Recording

To obtain records of any radar analysis, a Leica camera is furnished mounted on two rigid arms as shown in Figure 13. When not in use, it folds back out of the way of the operator. The camera is prefocussed at about 14 inches and set with a shutter speed of 1/10 second, the lens opening, or "f stop," being the only mechanism requiring adjustment. The latter depends solely on the speed of the film and amounts to f/3.2 with XX film.

In practice the camera is used only when signals of short duration and a high antenna-rotation speed are encountered. The procedure is to set the shutter on "time" with the lens open and then to close the shutter immediately after hearing the signal flash by.

The Watch and Data Card

As illustrated by Figure 14, the unit is equipped with a watch and a data card, both of which are mounted on the front panel within view of the camera. The date, intercepted frequency, antenna-rotation speed, and the case number on the counter of the particular signal being recorded, will show up in the picture, which is then correlated with the other intercepted information received at the time of the operation.

Calibration and Function of the Scale

As shown in Figure 14, the calibration scale is placed directly on the face of the cathode-ray tube as a decalcomania. Referring to Table A, the sweep to be read is always the one with the least number of pips, and the calibration of the scale under the pip gives the repetition frequency directly.

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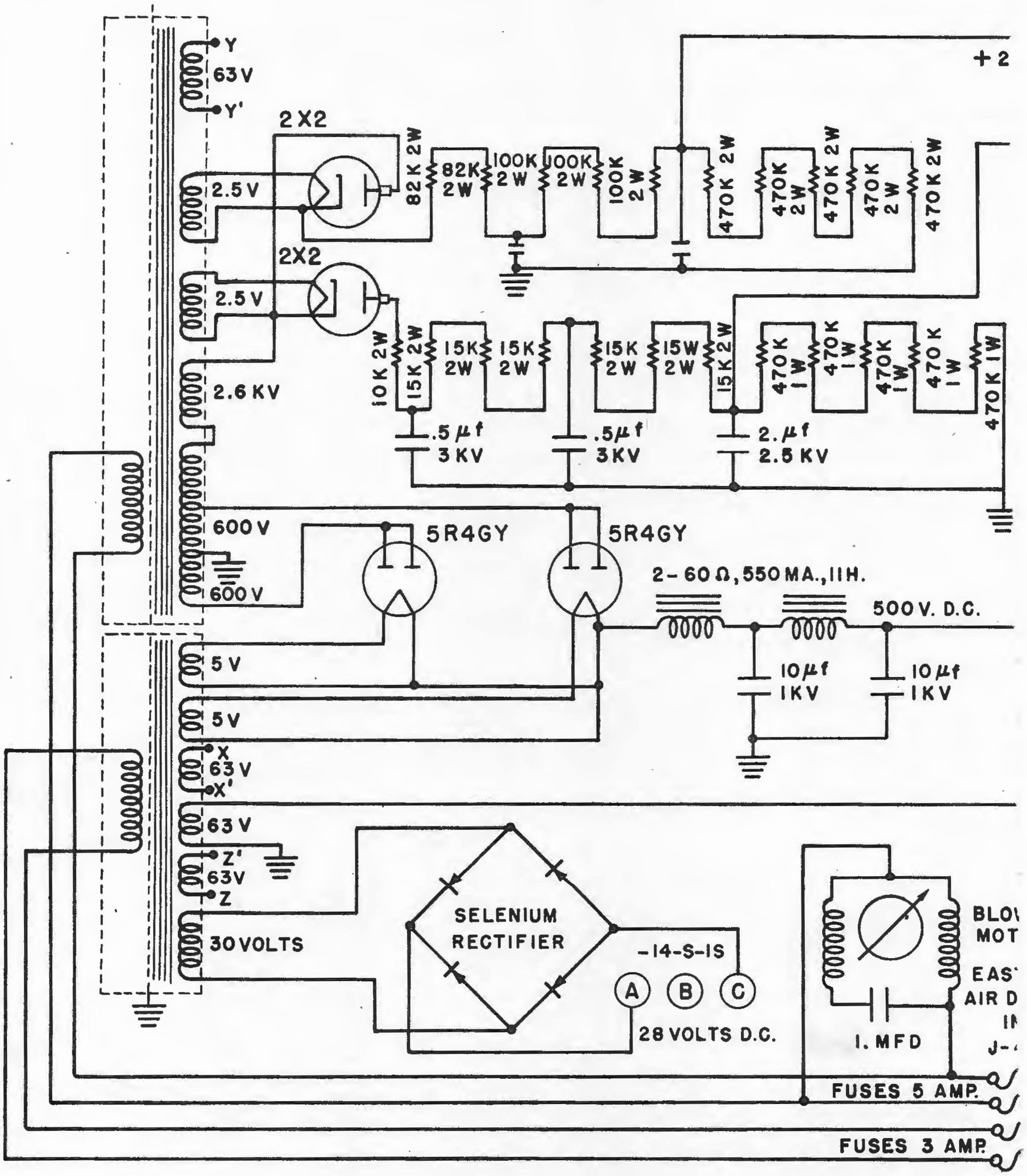

Fig. 12 - Power-s

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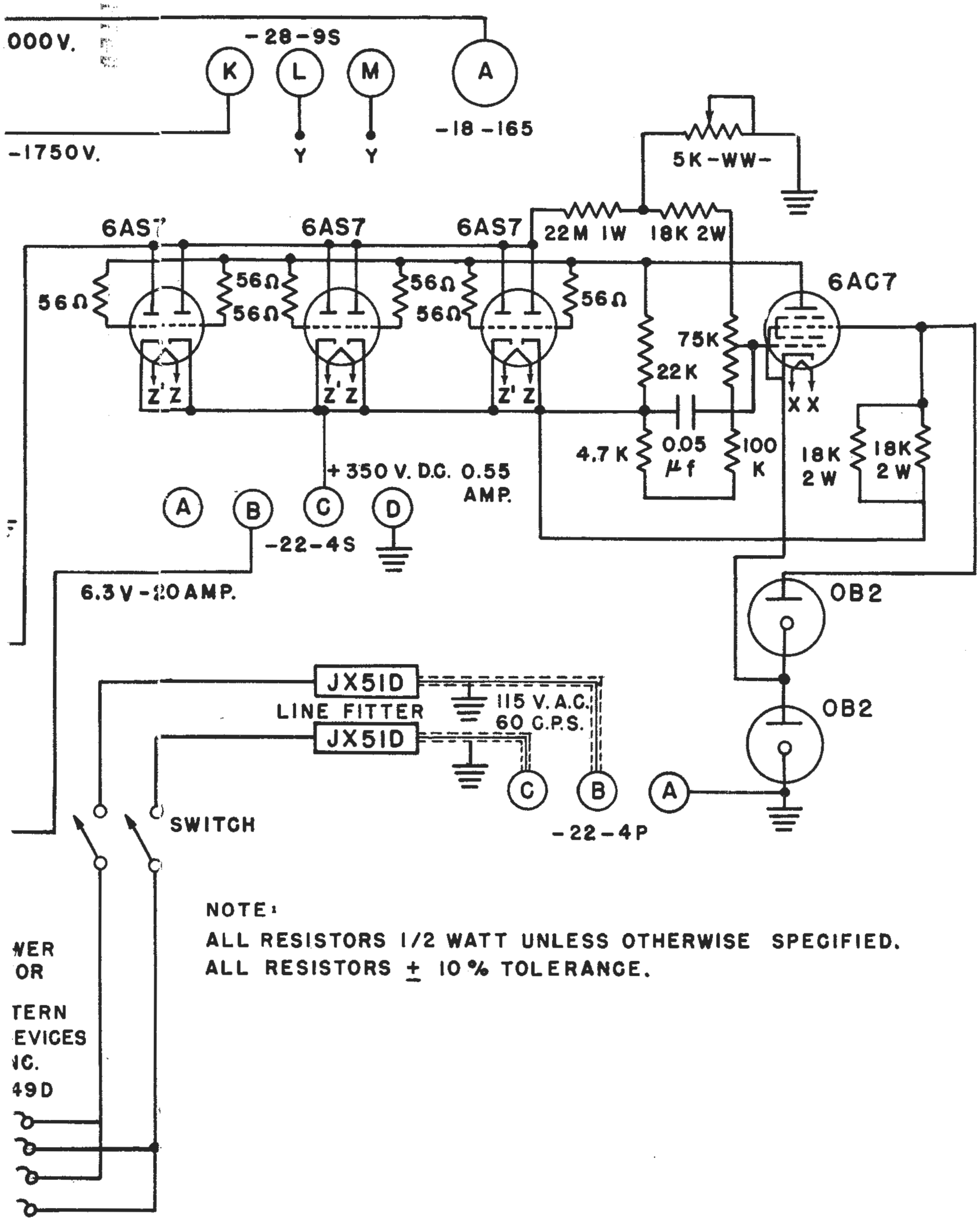

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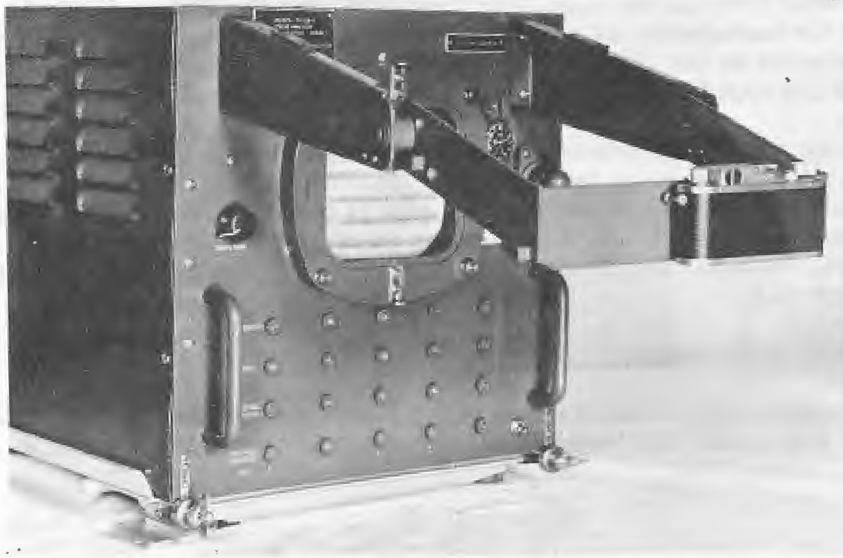

Fig. 13 - Complete unit showing camera attachment

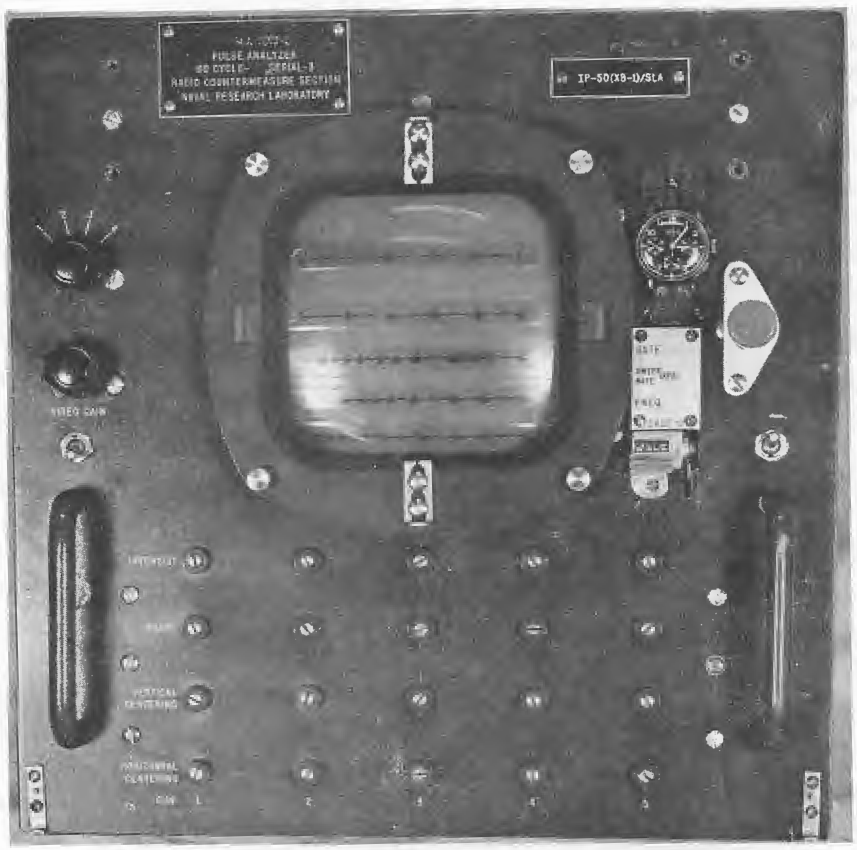

Fig. 14 - Front view of unit

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As a double check on the repetition frequency, one can always count the pips and multiply by the fundamental rate of the sweep frequency. As a typical example, if four pips were counted on the 200-cycle sweep, one would have 4 x 200 = 800 cycles. In this way a check can rapidly be made from one scale to the other.

The calibration of the scales can be accomplished by using a shocked oscillator and impressing the sine waves on individual sweeps. The circuit consists of a tuned circuit in the cathode of a triode, and the negative gate is used to interrupt the current flow, thereby generating a series of damped shock waves. These frequencies are as accurate as the high-Q resonant circuit and are usable for setting the sweep circuits within the required accuracy.

Basic Diagram and Circuits

The complete basic block diagram of the instantaneous pluse analyzer is shown in Figure 15. The circuit schematics there outlined are covered in Figures 9, 12, 16, and 17.

SUMMARY

The indicator herein described represents a new technique in pulse-analysis systems. It is suitable for the instantaneous analysis of all types of pulse signals such as those in radar, IFF, beacons, pulse altimeters, pulse navigation systems, television, pulse control systems, and in many other pulse systems. It will display simultaneously all the important characteristics of the signal such as pulse length, pulse-repetition rate, number of pulses present, and number of groups of pulses, and will in addition differentiate between the various types of modulation such as pulse amplitude, pulse spacing, or pulse count.

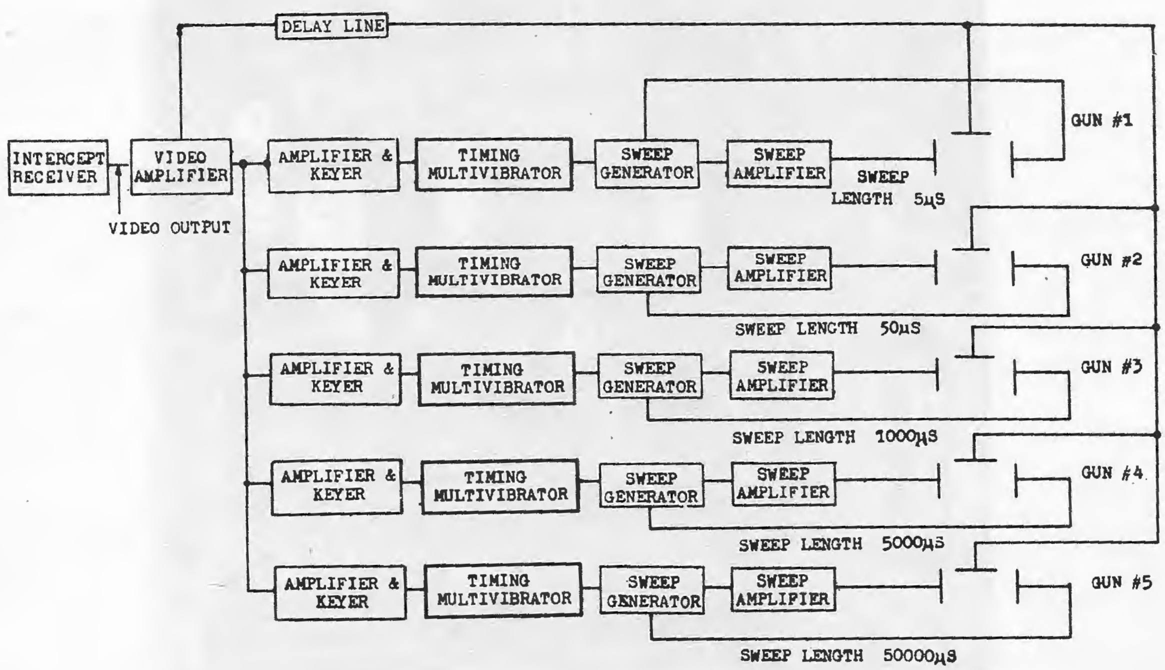

Fig. 15 - Complete block diagram of the instantaneous pulse analyzer

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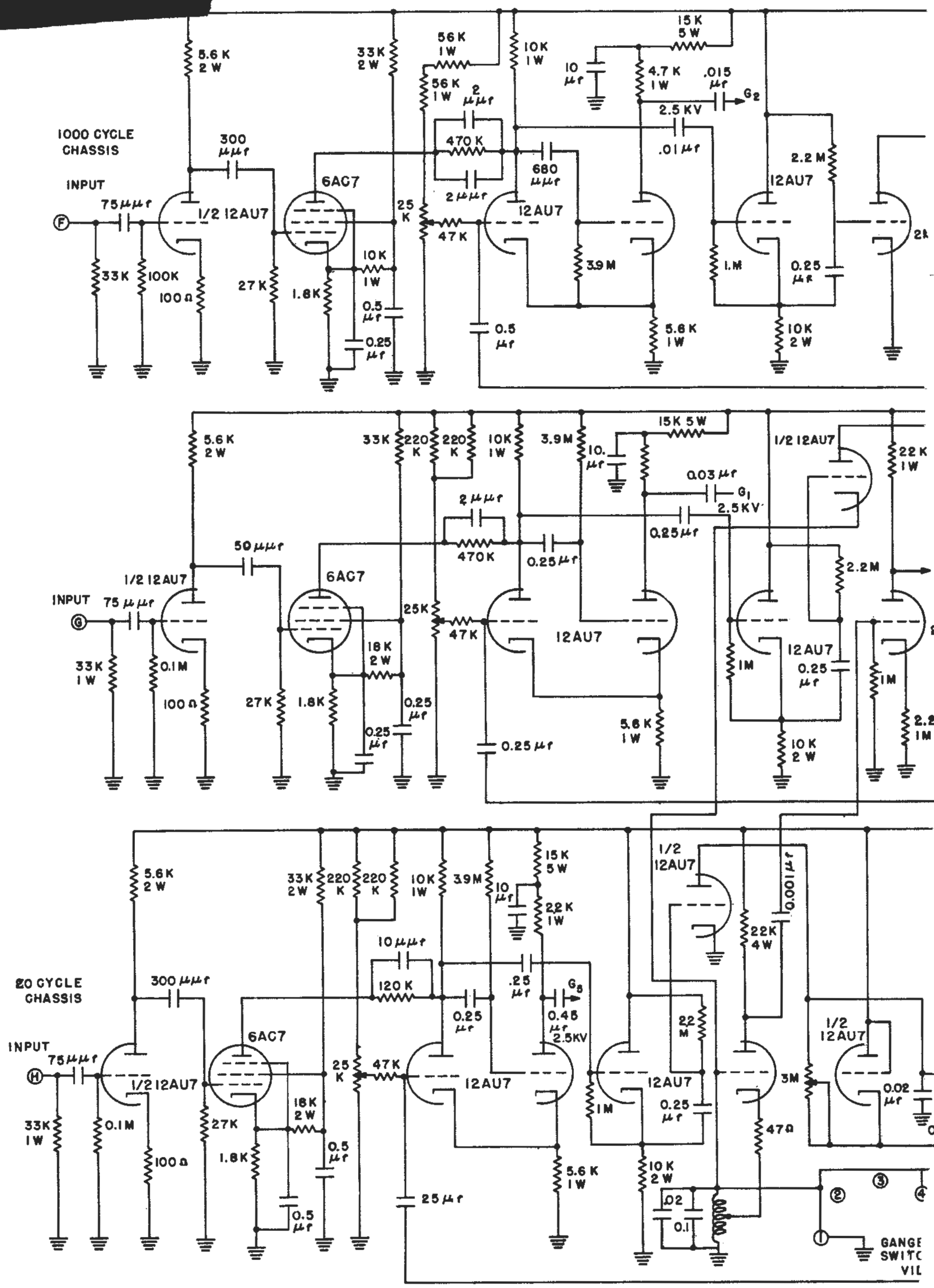

Fig. 16 - Circuits for 20,

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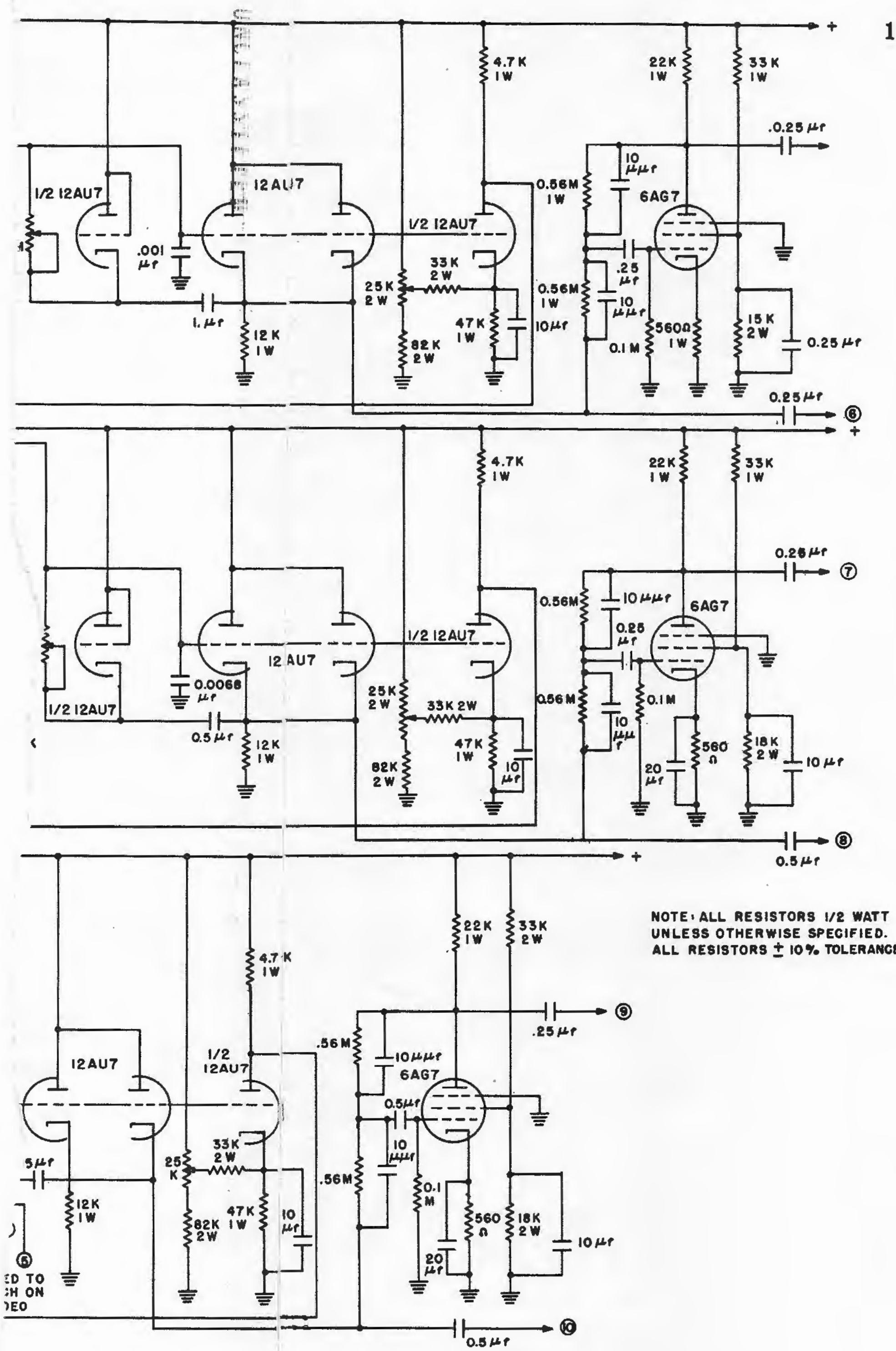
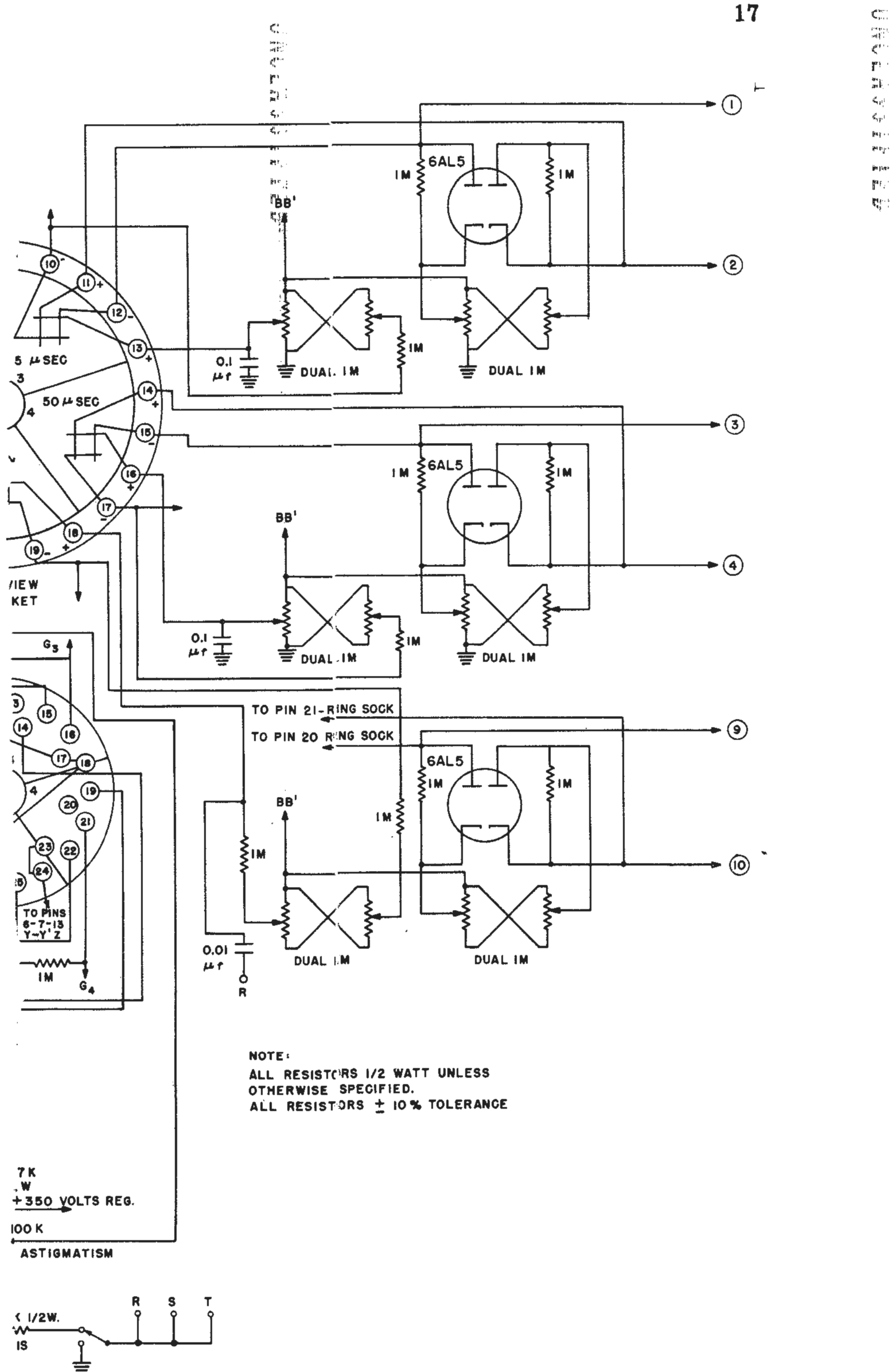


200 and 1000 cycles



NOTE:
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ALL RESISTORS ± 10% TOLERANCE

eder and d-c restorer circuit

The unit is also ideally suited for displaying such features as random pulsing, changes in pulse length, jitter in the repetition rate, and other pulse characteristics. In brief, within the limits given in Table A, this instrument is capable of analyzing any type of pulse signal for its basic system characteristics.

Typical samples of data presentation are the photographs of Figure 18 taken for radar signals of various repetition rates and pulse widths, with and without the pulse stretcher added to improve readability. Deserving particular attention is the fact that complete analysis and compilation of data is given by a single picture. In the right upper corner of each photograph the time of intercept is shown, and the split-second feature can be used to time antenna rotation and the duration of a continuous signal. Below the watch is the data card which presents to the camera the date, antenna-rotation speed, and the intercept frequency. The counter is used as a reference to the log sheets where additional information may have to be tabulated.

RECOMMENDATIONS

The indicator has been used with considerable success in the analysis of unknown signals received by ships in various parts of the world. A typical shipboard installation of a radar intercept system arranged around the indicator is shown in Figure 19. The rear view, Figure 20, shows the inner connections necessary for an installation whereby an operator can analyze and record an intercepted signal efficiently. Based on the findings and new techniques described in this report, it is strongly recommended that the indicator and intercept system be developed and adapted for future installations of countermeasures in the Fleet.

It is contemplated that work will continue on this general problem of instantaneous signal analysis and that still further improvements will be instituted with regard to automatic analysis and recording of radio-signal information. Further research should include an investigation of the relative advantages of linear vs exponential scales. Provided stability can be maintained in the circuits, an exponential scale might be developed. It would, of course, be less crowded. Accordingly, direct-coupled circuits might be investigated as a means of providing additional stability.

Finally, the same principle might be applied to the analysis of one- and two-tone pure sine waves. It is suggested that this might be accomplished by (1) proper distorting circuits so that the incoming signal sysnchronizes with the sweep, and (2) use of proper amplifiers so that a sine-wave presentation can be displayed.

ACKNOWLEDGMENT

A note of appreciation is extended to E. N. Munzer, J. D. Young, C. P. Laughton, J. S. Tomczak and F. B. Harper — all of the Radio Countermeasures Branch, Radio Division II of NRL — and to C. C. Mezger — formerly of the same Branch — for their cooperation in work on circuits and units. Thanks are also due H. S. Bamford of the Electronic Tube Corporation for his untiring efforts and for the cooperation of his personnel.

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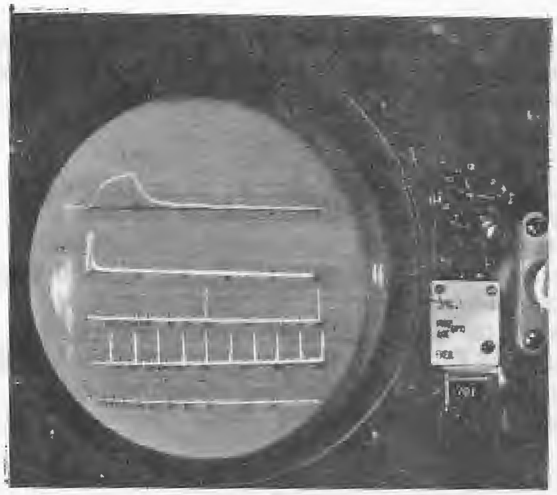
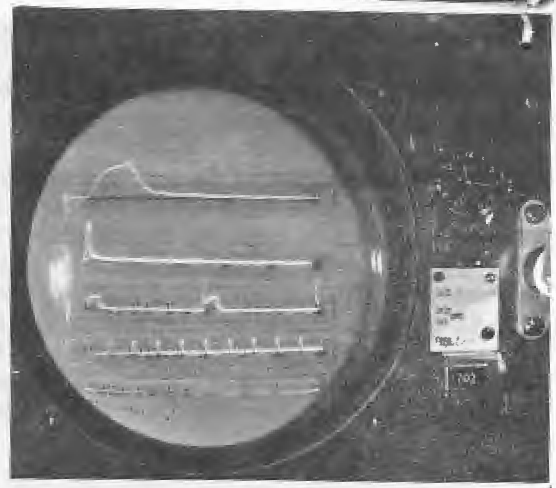
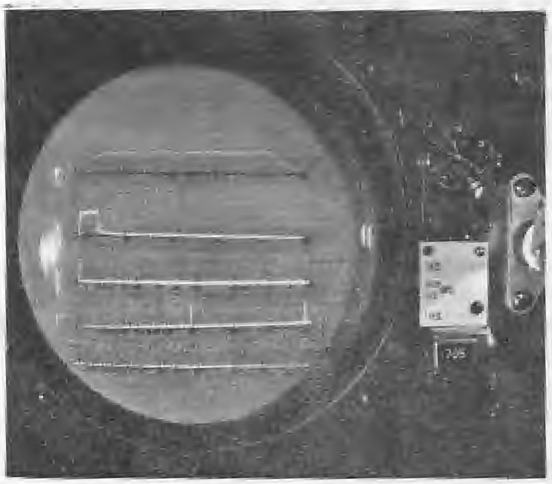


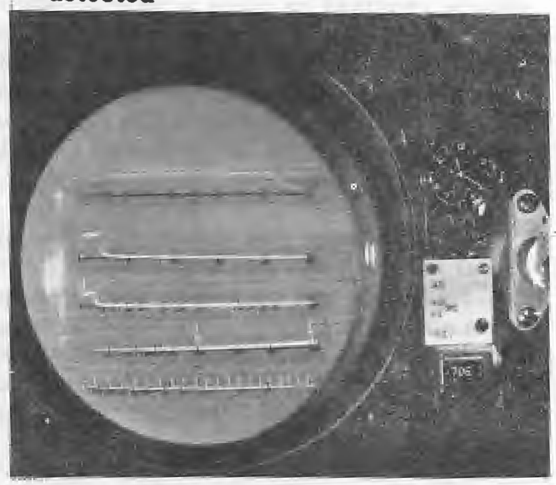
A. Top scale: pulse width, 1 μsec.
Third scale: repetition rate, 2000 cycles



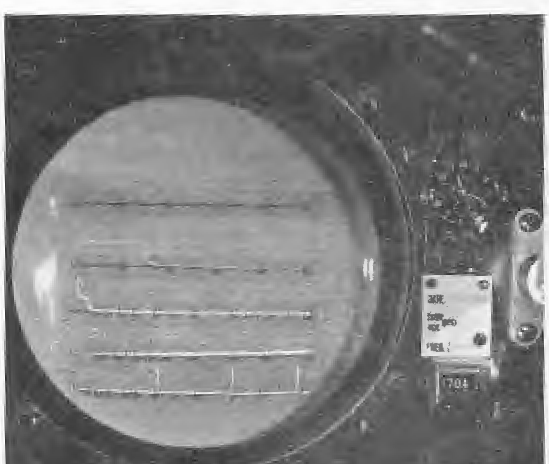
B. Same as A but with pulse stretcher added so that a rotating signal is more easily detected



C. Top scale: pulse width, 4 μsecs.
Fourth scale: repetition rate, 400 cycles



D. Same as C but with pulse stretcher added



E. Second scale: pulse width, 15 μ secs.
Bottom scale: repetition rate, 60 cycles, with pulse stretcher added

Fig. 18 - Typical presentations of pulse-signal characteristics

[redacted]

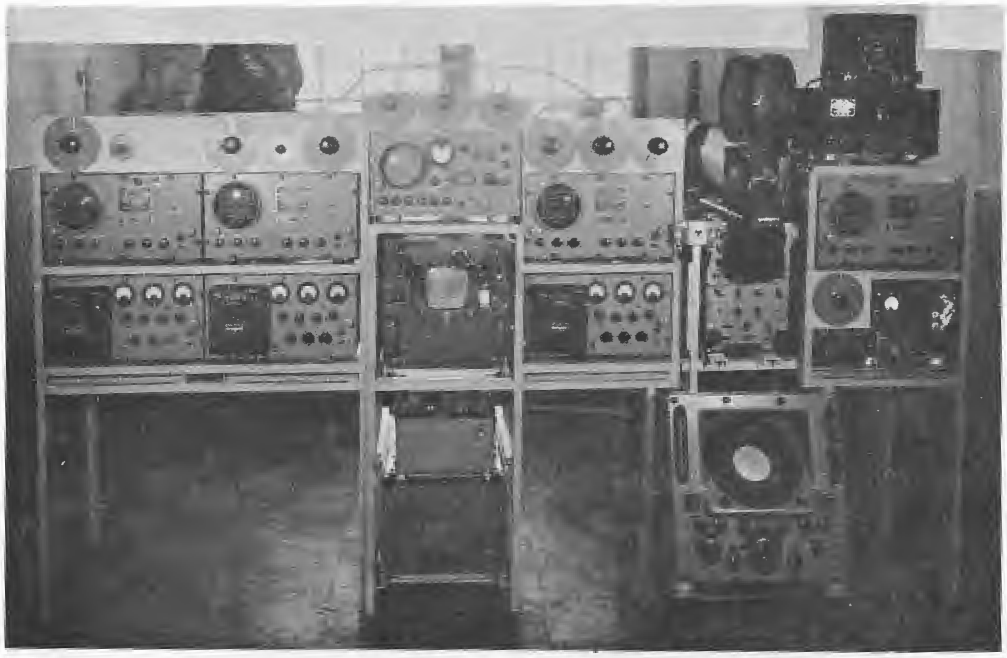


Fig. 19 - Typical intercept installation

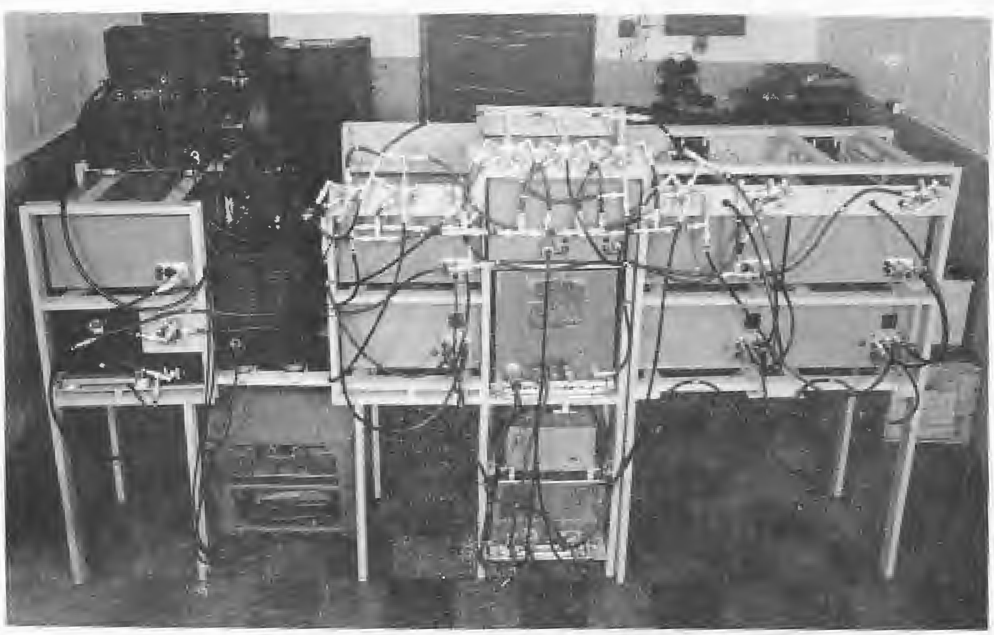


Fig. 20 - Typical intercept installation, rear view