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PROGRESS REPORT NO. 6

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Prepared By: [redacted] 50X1
Project Engineer

Approved By: [redacted] 50X1
Chief Engineer

[redacted] 50X1

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INTRODUCTION

This is the sixth progress report on Research and Development Task IV. The report covers the design and test of one of the complete pulse time modulated systems developed under this task. The circuit was tested with a radio link. The unit was tested to evaluate the performance of the system with regard to communication effeciency. New circuits were designed to enable reception under weak signal conditions.

DISCUSSION

A pulse time modulation system operates on the basis of transmitting two narrow pulses in the course of a comparatively long cycle interval. The first pulse is the reference time. The second pulse is the signal. This is essentially pulse position modulation. It represents the intelligence by having its time of occurrence with respect to the reference pulse varied by the audio source.

It is desirable to have the pulse repetition frequency as low as possible within the limits of the Nyquist Theory for pulse communication. This theory sets the minimum sampling rate for proper reproduction of a signal, and states that the highest frequency to be transmitted, be sampled two times per cycle. This equipment was designed on a more conservative basis with a minimum sampling factor of 2.5. The highest frequency to be transmitted was chosen as 3200 cycles per second, since only voice communication is to be reproduced. This decision in turn placed the pulse repetition frequency at 8000 cycles per second.

The importance of a low pulse repetition frequency is explained by the ratio of signal pulse interval to pulse repetition interval, or duty cycle of the unit. The 8 kc. blocking oscillator designed as the basic pulse repetition source, required a three winding pulse transformer. It was noted that whereas any commercial transformer operated properly at 12 kc., they would introduce jitter at 8 kc. It was determined that the basic pulse source must be free of jitter or minute change of repetition frequency, since this jitter contributes noise to the intelligence. The choice of a high quality pulse transformer resulted in no detectable jitter at 8 kc.

Since R. F. output occurs only during the interval of the two pulses, the ratio of average power to peak power is determined in part by the ratio of pulse duration to cycle interval. As indicated by oscillogram 12, the pulse widths as measured at the half amplitude points are approximately one microsecond. However, in the course of passing through the succeeding stages, the pulse width is increased. At the transmitter output, oscillogram 15, the pulse widths are two microseconds. The pulse repetition interval, oscillogram 4, is 125 microseconds. This results in a duty cycle of 4/125 or 0.032.

Another basic advantage to pulse time modulation systems pertains to the constant amplitude of the pulses. As a result of this feature, it is possible to receive a signal with a relatively poor signal to noise ratio. The noise appears at the base and top of the pulse without affecting the rising and lagging edges. It then becomes a problem of clipping off the base and top and amplifying the clean middle section.

By a succession of clipping and amplifying, the pulse can be cleared of noise and built up to any required amplitude. Theoretically any signal to noise ratio greater than one can be accommodated by this method. In practise it becomes increasingly more difficult to design equipment of sufficient stability as the ratio of one is approached. At present the equipment can accommodate a ratio of two to one.

A pulse time modulated pulse is essentially a frequency modulated signal. It may also contain amplitude modulation components, but by proper design the A.M. can be eliminated. As indicated in oscillograms 15 and 16, there are no amplitude modulation components at the transmitter output or at the detector of the receiver.

DESIGN OF EQUIPMENT

The following is a description of the equipment designed during this period. Figure 1-A is a schematic diagram of the noise clipper and signal limiter. The first stage which is a pulse amplifier receives the output of the detector of the receiver. This output consists of the reference and signal pulses. Under weak signal conditions, it would have a poor signal to noise ratio. The second stage is an automatic noise clipper. The bottom diode section receives the positive pulses, which are riding a high noise level. Due to the long time constant of its circuit, the average current drawn by the tube is determined by the noise level rather than the pulse amplitude. This current creates a positive voltage which is then applied to the other diode as a bias voltage. As a result, the top diode section cannot conduct unless the applied signal exceeds a specified minimum, which is determined by the noise level. This prevents conduction of most of the noise, while permitting the pulses to pass. The third stage is a dual amplifier, which increases the pulse amplitude as well as providing the proper positive phase for further clipping. The next stage is a diode with a fixed bias, which removes the remaining noise level under the worst signal conditions to be received. The remaining stages are a pulse amplifier and a low impedance cathode follower output.

A modified pulse time demodulator was designed, Fig. 1, which differs from the unit described in the last report. The new design provides greater stability under weak signal conditions. The output of the noise clipper is the two pulses, reference and signal. They are both of negative polarity and are fed to the demodulator. The first stage is a pulse amplifier. The output of this stage is fed to two parallel channels. The top section is an ordinary sequence of amplifier and cathode follower, and handles both pulses. The cathode follower is necessary to provide a low impedance output for the mixer stage which follows.

The bottom channel carries both pulses through two amplifiers into a cathode follower. The output of the cathode follower triggers a one shot multivibrator. The output of this multivibrator is a square wave whose width is sufficient to cover the interval of both reference and signal pulses. This results in a single pulse whose leading edge corresponds to the leading edge of the reference pulse. This pulse is then coupled to an amplifier which acts as a limiter and eliminates irregularities along the top of the pulse.

This wide pulse is then differentiated in order to narrow it sufficiently to cover the original reference pulse with a slight overlapping of the signal pulse. The unwanted positive pulse resulting from the differentiator is eliminated by the germanium rectifiers. The negative pulse is coupled to another amplifier that shapes it and squares the top. This in turn is fed to a cathode follower.

This output is mixed with the top channel that carries both the reference and signal pulses. The reference pulse and the leading edge of the signal pulse are cancelled and replaced by a positive pulse. The signal pulse remains as a negative pulse with a new leading edge that is fixed by the original reference pulse. The lagging edge remains as the pulse time modulated signal.

The combined signal is then amplified and the unwanted cancellation pulse is removed by rectifiers. This leaves a signal that is pulse duration modulated which is coupled to the audio section through a cathode follower.

Minor changes were made in the other sections and they are detailed as follows:

Figure 29, modulator chassis, blocking oscillator transformer was changed to Freed Type MPT-11 to decrease jitter. A change in the differentiator circuit reshaped the reference pulse. An audio amplifier provided audio gain and isolation from modulator source.

Figure 30, the transmitter section, was revised to include a volume control for control of peak power output, and a damping circuit placed across the secondary winding to minimize ringing in the pulse transformer.

Figure 31, the audio amplifier, was revised to include two 8 kc. tuned circuits, to minimize the pulse repetition frequency appearing in the audio output.

TESTING

The following tests were made on the equipment during the period covered by this report. The maximum deviation permissible which corresponds to 100 percent modulation is 1.5 microseconds. The smallest deviation that was still detectable as a signal was 0.01 microseconds.

Oscillograms were made at various test points with results as follows:

Figures 2 and 3 are outlines of the transmitter and receiver. All the oscillogram test points are indicated by letter. The transmitter test points are:

Figure 4, The plate of the blocking oscillator indicates a pulse cycle interval of 125 microseconds. It corresponds to a pulse repetition rate of 8000 cycles per second. It also indicates no detectable jitter.

Figure 5, The input to the multivibrator, the positive leading edge acts as the trigger. The maximum deviation is determined by the amount that the negative pulse can be deviated by the modulating audio signal without making the multivibrator erratic.

Figure 6, The output of the multivibrator, which is a pulse duration modulated signal. The leading edge is fixed by the trigger pulse, and the lagging edge is variable to correspond with the modulating audio signal.

Figure 7, The output of the first differentiator, shows a positive pulse as the reference. The negative is the deviating pulse. This is the pulse time modulated signal, wherein the time of appearance of a signal pulse varies with respect to a fixed reference time.

Figure 8, This indicates the signal pulse after going through a rectifier to eliminate the reference pulse. The half amplitude pulse width is one microsecond.

Figure 9, The reference pulse following a rectifier which eliminates the signal pulse. The pulse width is two microseconds and requires further shaping before it can be re-combined with the signal pulse.

Figure 10, The reference pulse after further narrowing by means of additional differentiators. It is now comparable to the signal pulse in shape, but smaller in amplitude.

Figure 11, This shows the input to the pulse amplifier. The shaping of the reference pulse is completed and it is now ready to be amplified to make its amplitude comparable to the signal pulse.

Figure 12, Both pulses have the same polarity. This condition is required to modulate the transmitter efficiently. This is the output of the pulse time modulator and is coupled to the R. F. section through a low impedance cathode follower.

Figure 13, It was found necessary to use these relative amplitudes to have the transmitter output pulses of equal amplitude.

Figure 14, This indicates the pulses at the plate of the R. F. modulator stage. The equal amplitudes are well demonstrated.

Figure 15, This indicates the transmitter output. The pulses are very nearly equal. This is an important specification, as the ability of a receiver to detect the signal is determined by the signal to noise ratio of the weaker of the two pulses. Since the pulses are the only voltage applied to the plate of the R. F. modulated stage, there is output only during the pulse intervals and results in an output signal with a good peak to average power.

The following oscillograms were made at the receiver. The test points are indicated in Figure 3.

Figure 16, This is the output of the receiver's detector. The transmitted pulses have been reproduced with little distortion. This is attributed to the wide band characteristics of the video section of the receiver which is a nimimum of 4 megacycles. In practise a 2 megacycle bandwidth would have been adequate with a resulting decrease in receiver equivalent input noise. This in turn would decrease the minimum detectable signal.

Figure 17, The output of the one shot multivibrator is indicated as a square wave of 25 microsecond duration. Since the signal pulse occurs 7 microseconds after the reference, it cannot affect the operation of this stage. The result is a single long pulse whose leading edge corresponds to the leading edge of the reference pulse.

Figure 18,	The long square wave has been differentiated to secure a more narrow pulse. This corresponds in time with the reference pulse and will be used to cancel out part of the original signal.
Figure 19,	The differentiated pulse has been rectified to eliminate the positive portion, and is ready for shaping.
Figure 20,	The differentiated pulse has now been shaped and squared and is sufficiently wide to cancel out the reference pulse and the leading edge of the signal pulse.
Figure 21,	The cancellation pulse and the original two pulses have been combined. The result is a positive pulse that has replaced the original reference pulse, as well as the leading edge of the signal pulse. The remainder of the signal pulse appears as a negative pulse.
Figure 22,	The output of this cathode follower stage is a duration modulated pulse. The leading

edge is fixed with respect to the reference pulse. The lagging edge deviates with the signal pulse. This pulse is coupled to the audio amplifier section.

Figure 23, The output of the pulse amplifier is a triangular pulse due to the inductive loading effect of the low pass filter to which it is coupled. The lagging edge is the one that deviates.

Figure 24, For this test a 1000 cycle per second signal was used to modulate the system. The 8 kc. pulse has been minimized by the low pass filter and the first 8 kc. rejection filter. The 8 Kc. pulse remains as a ripple riding the 1 kc. signal.

Figure 25, This is the final test position, and demonstrates the fidelity of the overall system. The 1 Kc. signal is indicated as a smooth sine curve.

The following oscillograms were made at the noise clipper section under weak signal conditions to demonstrate the effectiveness of these stages.

Figure 26,	This is the input to the noise clipper and indicates a signal to noise ratio of 1.7:1
Figure 27,	The effectiveness of the self-biasing noise clipper is demonstrated. The signal to noise ratio is now 13:1
Figure 28,	The output of the noise clipper section indicates the final signal to noise ratio of 20:1

CONCLUSIONS AND FUTURE PLANS

A pulse time modulated unit was tested on a system basis using a radio link. It was found to perform in accordance with predicted design requirements.

A noise clipper was designed that enabled the unit to reproduce intelligence of a signal with a signal to noise ratio of 2 to 1.

The demodulator was redesigned to be more stable under weak signal conditions.

It is planned to design a pulse duration modulated unit. It will be tested on a system basis and evaluated with respect to the units previously designed, pulse time and pulse amplitude modulated systems.

Field tests will be made on all three systems and they will be evaluated under various noise conditions.

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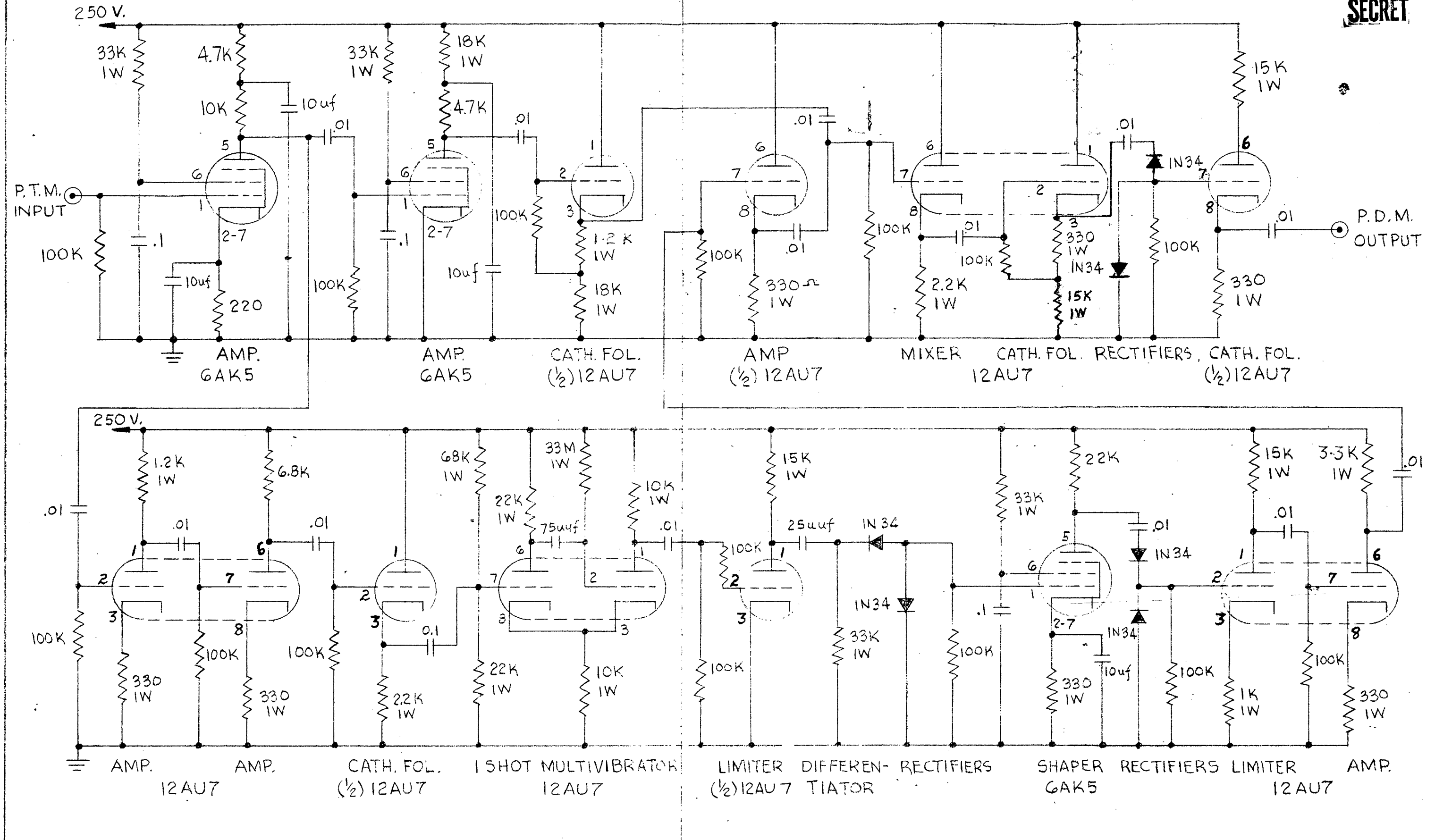

FIG. 1 PULSE TIME DEMODULATOR

FIG. 1

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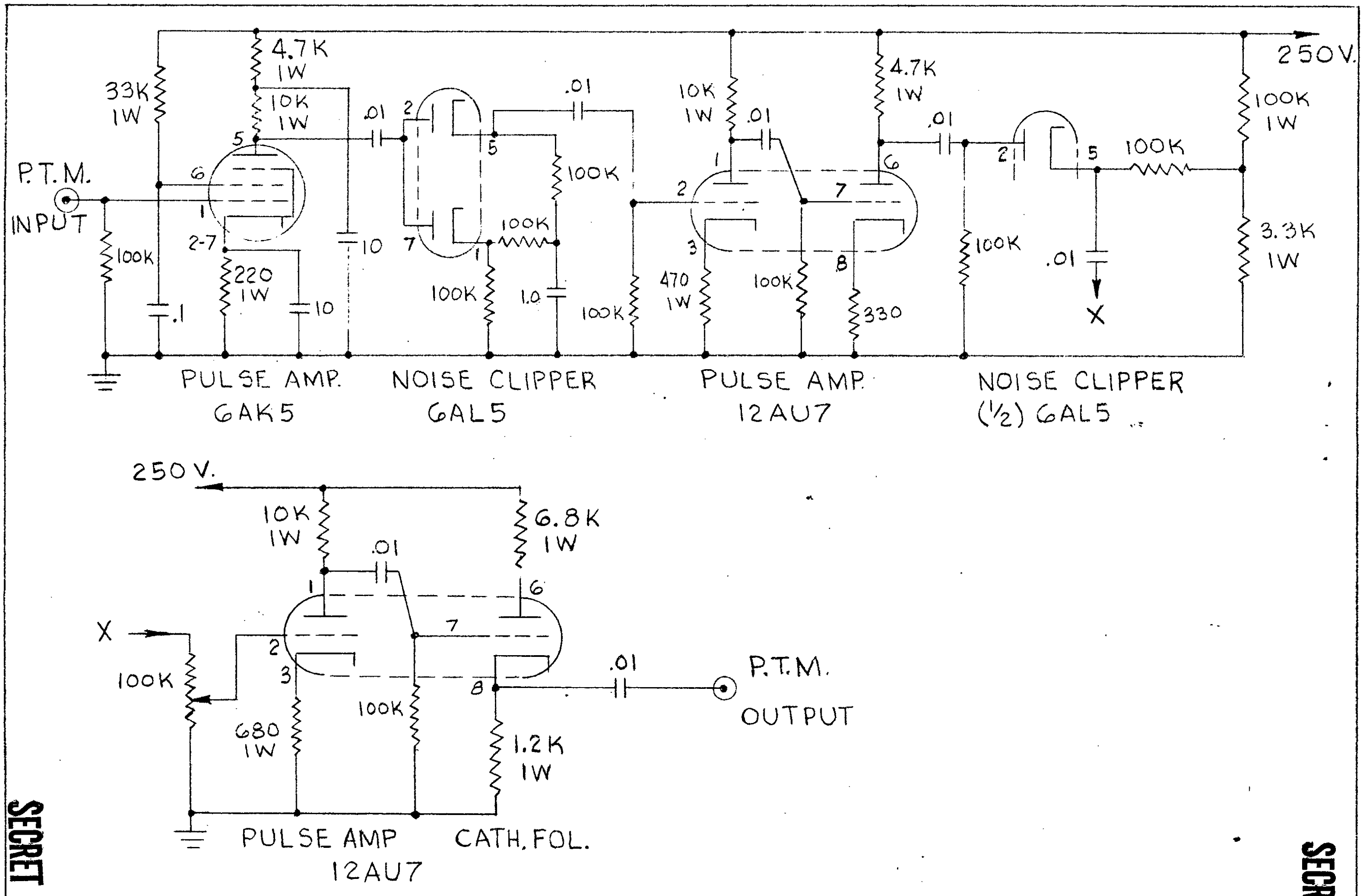

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FIG. 1A NOISE CLIPPER & SIGNAL LIMITER

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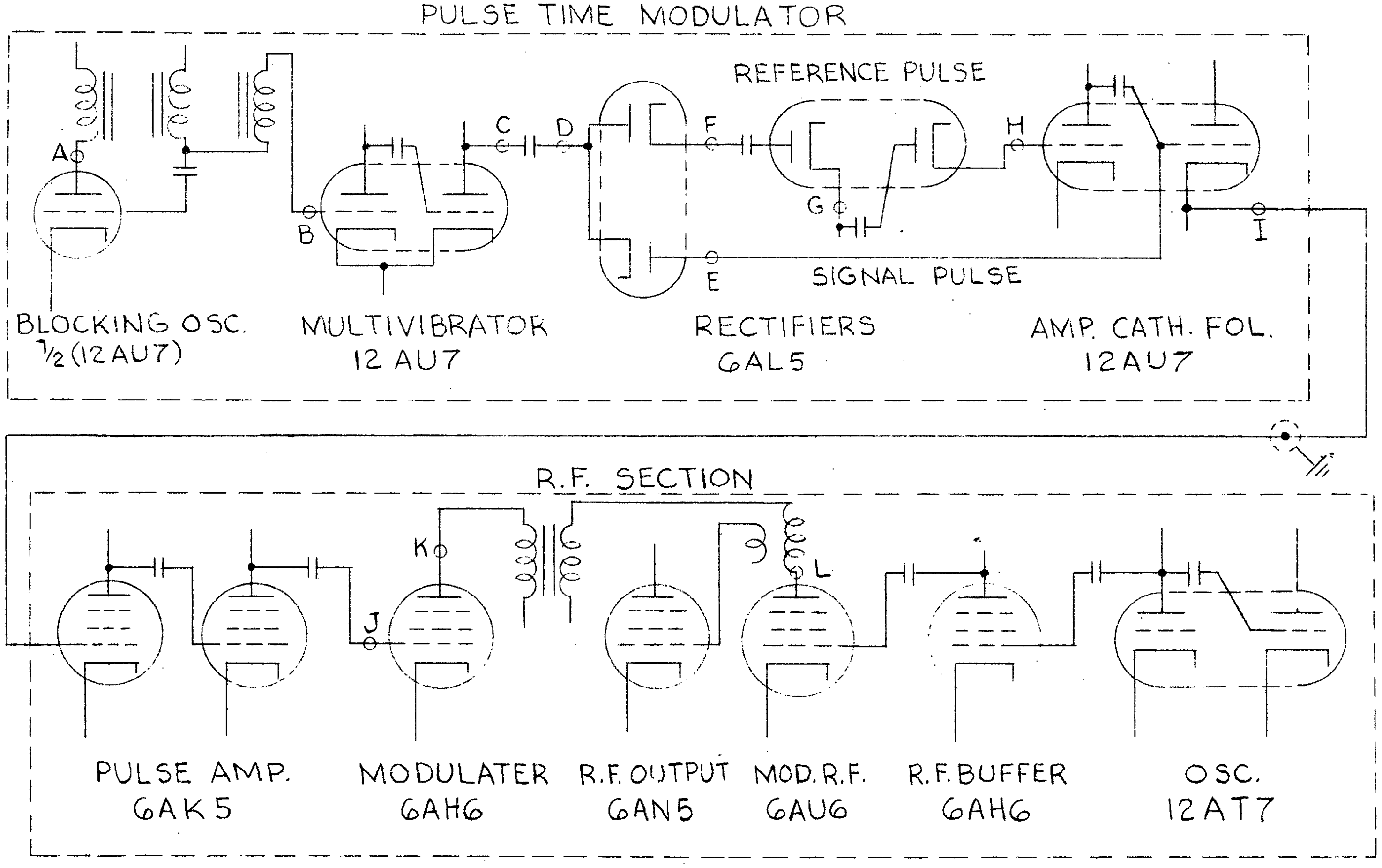

FIG. 2 74 MC. PULSE TIME TRANSMITTER OUTLINE

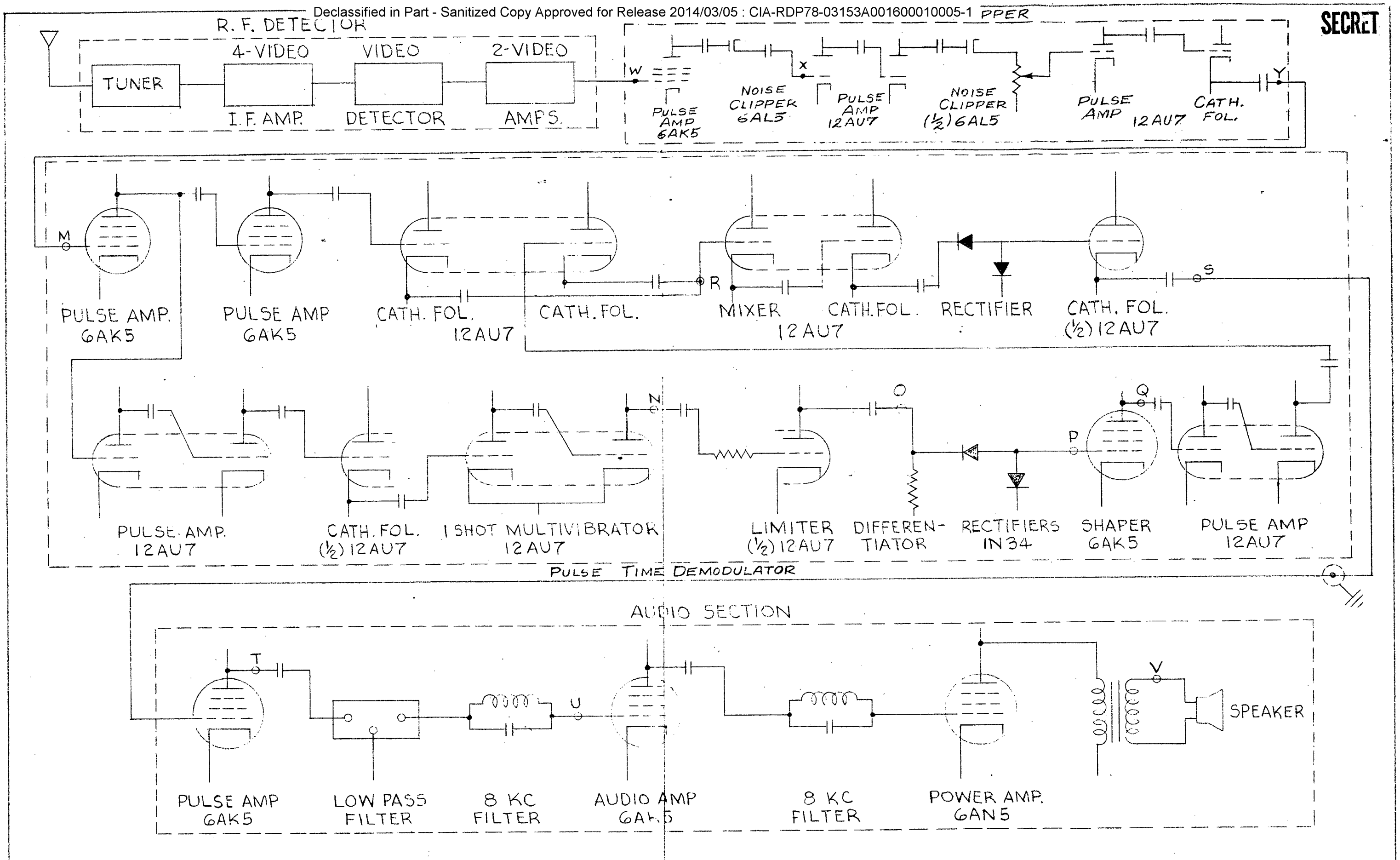

FIG. 3 PULSE TIME RECEIVER OUTLINE

FIG. 3

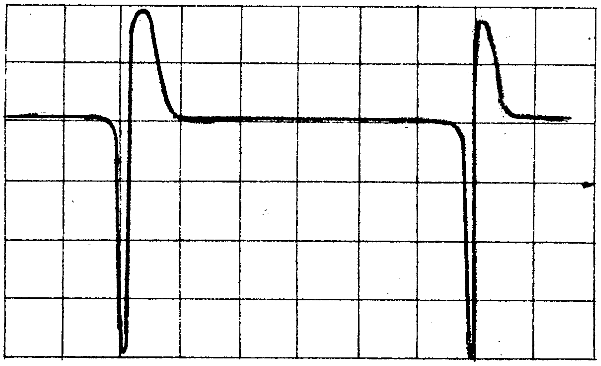

FIG. 4

SENSITIVITY - V/CM 47

SWEEP - μ SEC/CM 21

SIGNAL A

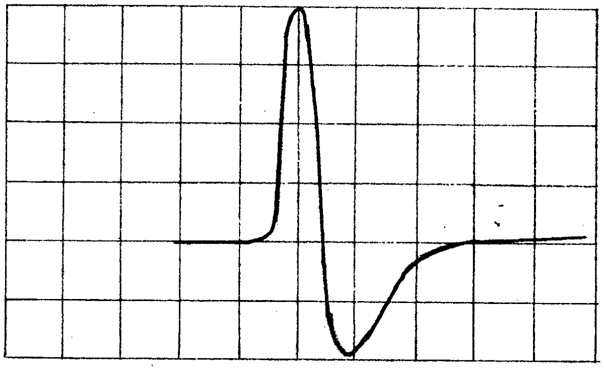

FIG. 5

SENSITIVITY - V/CM 4

SWEEP - μ SEC/CM 3

SIGNAL B

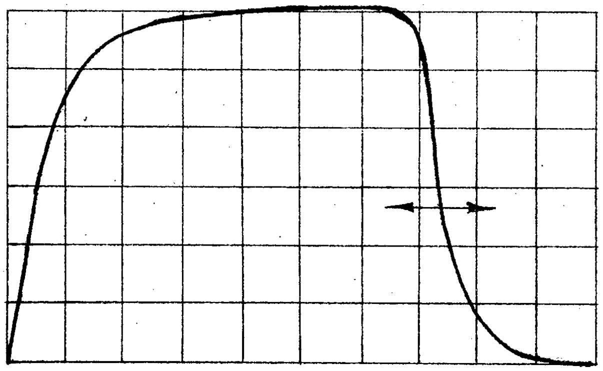

FIG. 6

SENSITIVITY - V/CM 12

SWEEP - μ SEC/CM 1

SIGNAL C

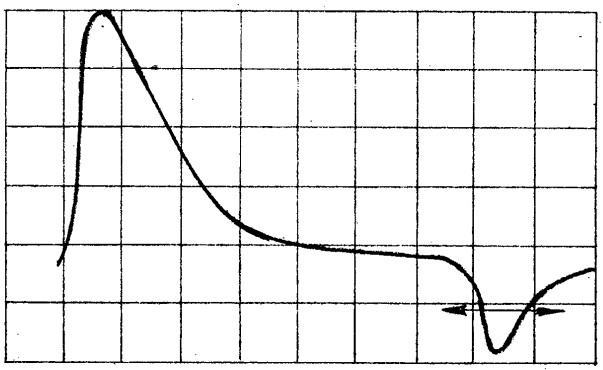

FIG. 7

SENSITIVITY - V/CM 2

SWEEP - μ SEC/CM 1

SIGNAL D

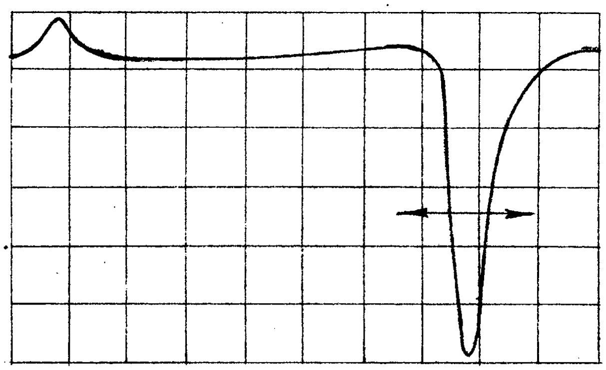

FIG. 8

SENSITIVITY- V/CM 0.7
SWEEP-μ SEC/CM 1
SIGNAL E

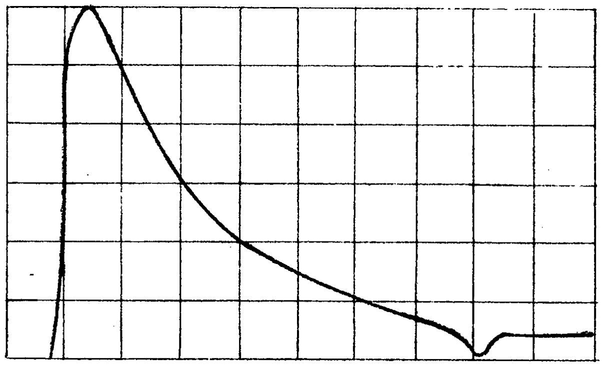

FIG. 9

SENSITIVITY - V/CM 1.3
SWEEP-μ SEC/CM 1
SIGNAL F

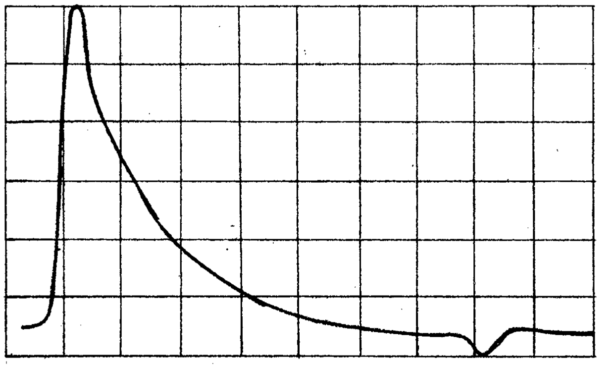

FIG. 10

SENSITIVITY- V/CM 0.3
SWEEP-μ SEC/CM 1
SIGNAL G

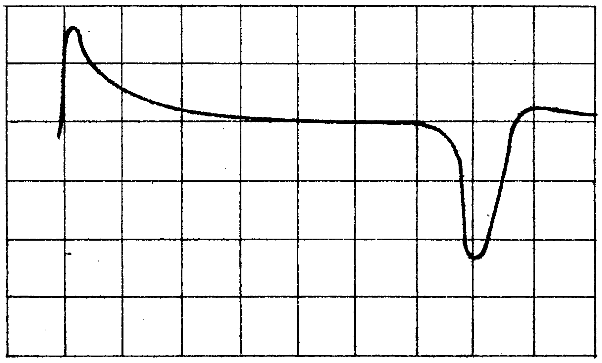

FIG. 11

SENSITIVITY-V/CM 0.2
SWEEP-μ SEC/CM 1
SIGNAL H

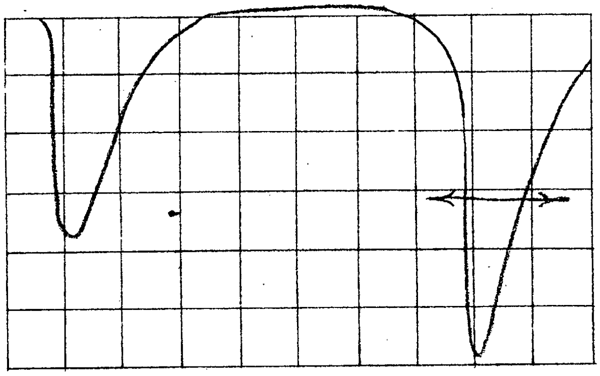

FIG 12

SENSITIVITY - V/CM 0·23

SWEEP - μ SEC/CM 1

SIGNAL I

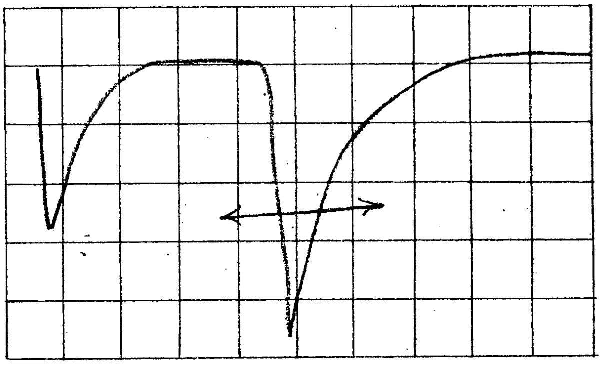

FIG 13

SENSITIVITY - V/CM 0·3

SWEEP - μ SEC/CM 2

SIGNAL J

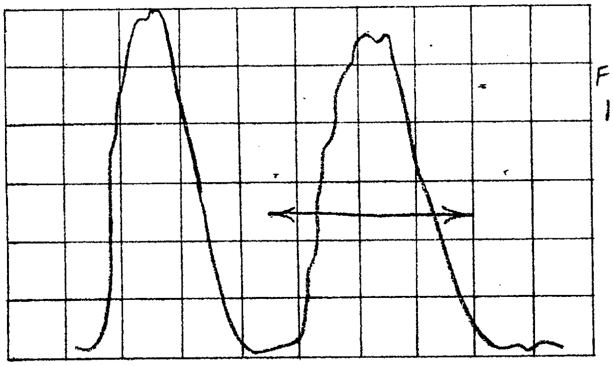

FIG. 14

SENSITIVITY - V/CM 10

SWEEP - μ SEC/CM 2

SIGNAL K

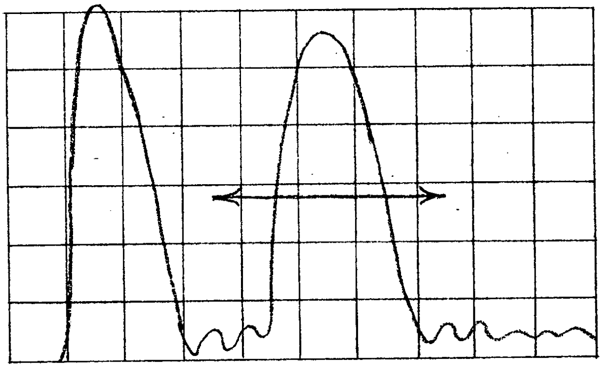

FIG. 15

SENSITIVITY - V/CM 4

SWEEP - μ SEC/CM 2

SIGNAL L

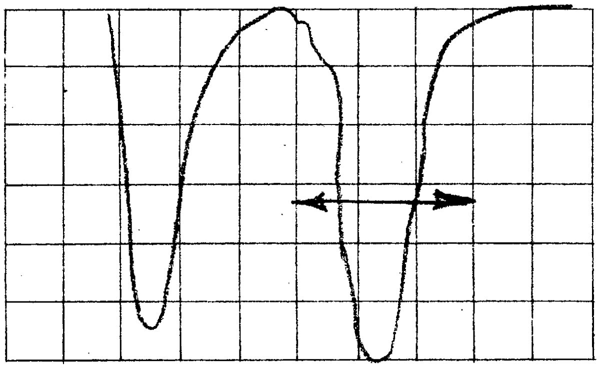

FIG. 16

SENSITIVITY - V/CM 0.3
SWEEP - μ SEC/CM 2
SIGNAL M

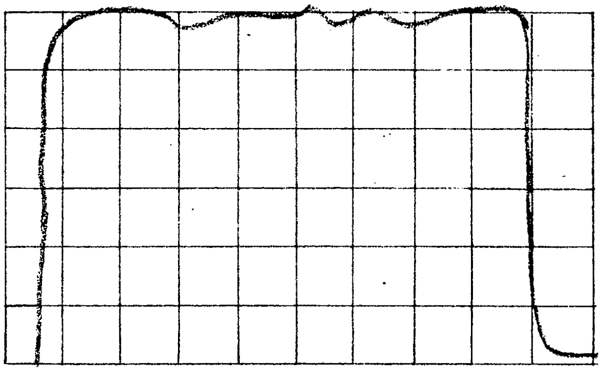

FIG 17

SENSITIVITY - V/CM 13
SWEEP - μ SEC/CM 3
SIGNAL N

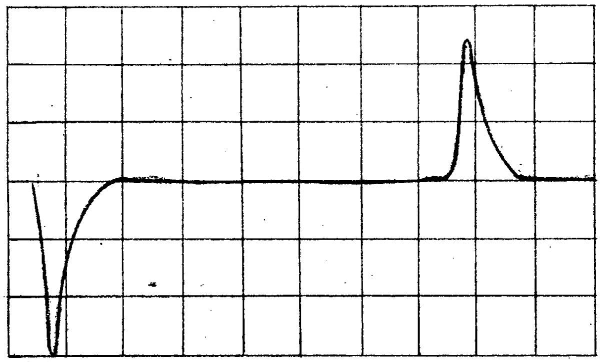

FIG. 18

SENSITIVITY - V/CM 20
SWEEP - μ SEC/CM 5
SIGNAL O

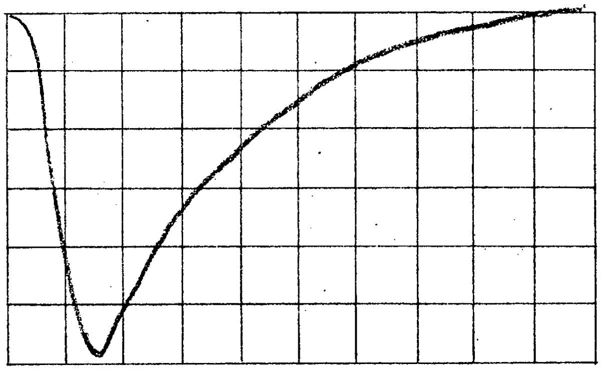

FIG 19

SENSITIVITY - V/CM 12
SWEEP - μ SEC/CM 0.7
SIGNAL P

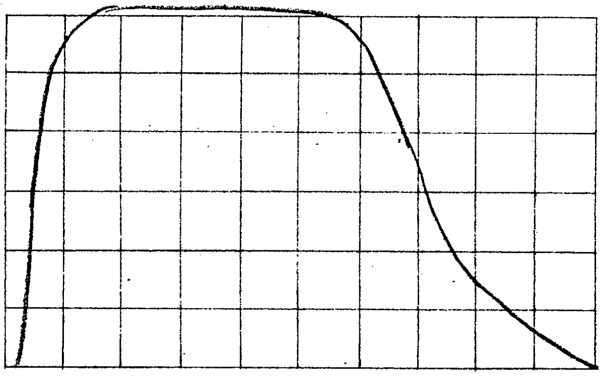

FIG 20

SENSITIVITY- V/CM 20
SWEEP -u SEC/CM 1·0
SIGNAL Q

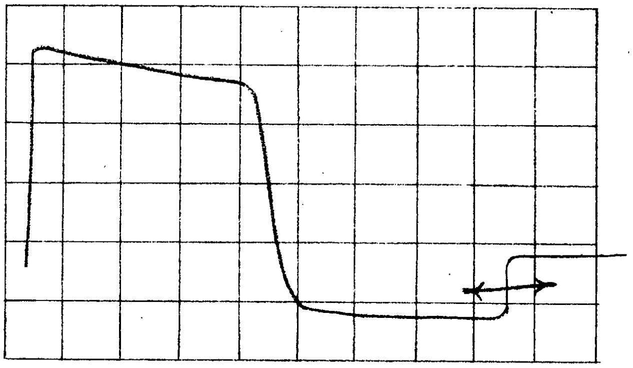

FIG 21

SENSITIVITY - V/CM 1·0
SWEEP-u SEC/CM 2
SIGNAL R

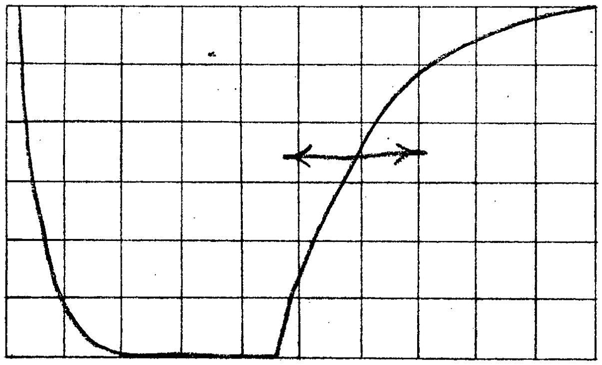

FIG 22

SENSITIVITY- V/CM 0·4
SWEEP-u SEC/CM 0·8
SIGNAL S

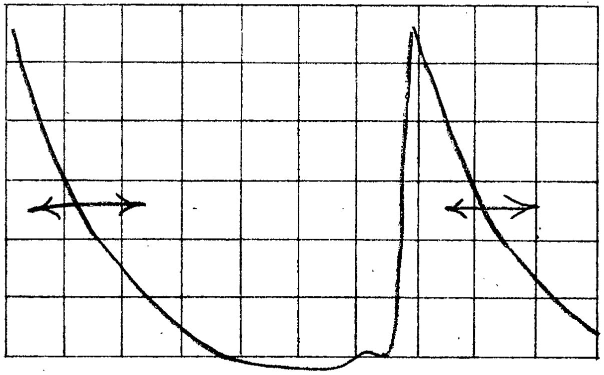

FIG 23

SENSITIVITY-V/CM 0·1
SWEEP-u SEC/CM 20
SIGNAL T

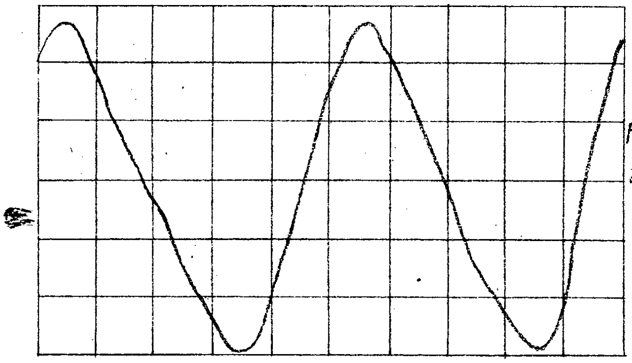

FIG 24

SENSITIVITY-V/CM 0·078
SWEEP-u SEC/CM 200
SIGNAL U

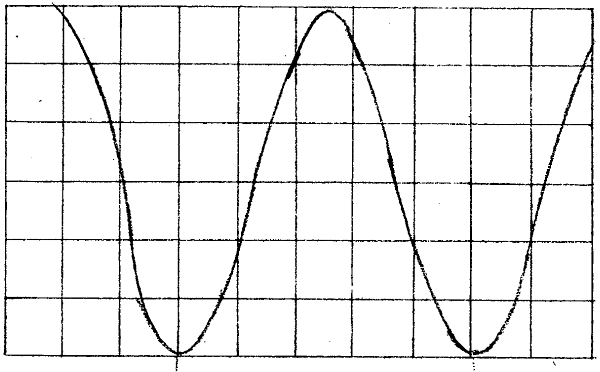

FIG 25

SENSITIVITY-V/CM 1·0
SWEEP-u SEC/CM 200
SIGNAL V

SENSITIVITY-V/CM
SWEEP-u SEC/CM
SIGNAL

SENSITIVITY-V/CM
SWEEP-u SEC/CM
SIGNAL

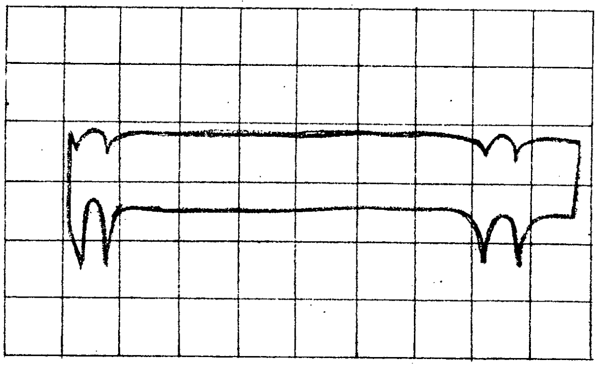

FIG 26

SENSITIVITY-V/CM 0·03
SWEEP-u SEC/CM 20
SIGNAL W
S/N = 1·7:1

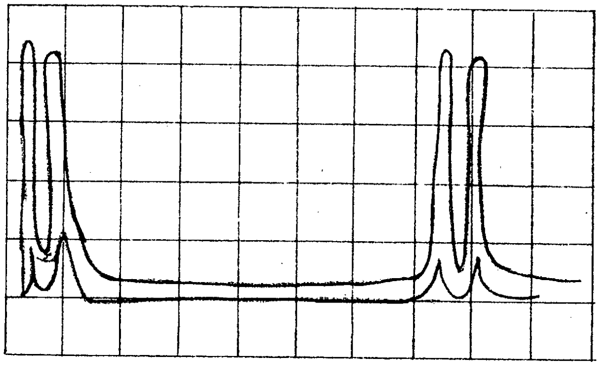

FIG 27

SENSITIVITY - V/CM 0·1
SWEEP-u SEC/CM 20
SIGNAL X
S/N = 13:1

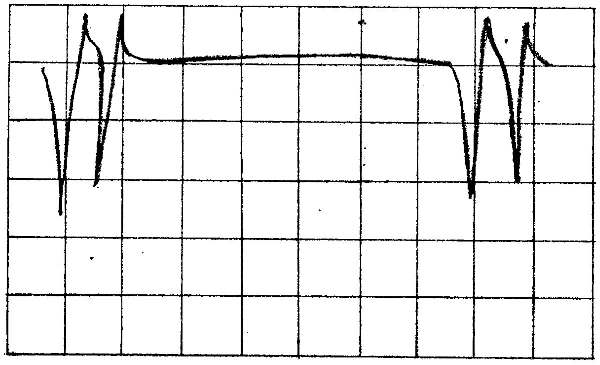

FIG 28

SENSITIVITY-V/CM 0·1
SWEEP-u SEC/CM 20
SIGNAL Y
S/N = 20:1

SENSITIVITY-V/CM
SWEEP-u SEC/CM
SIGNAL

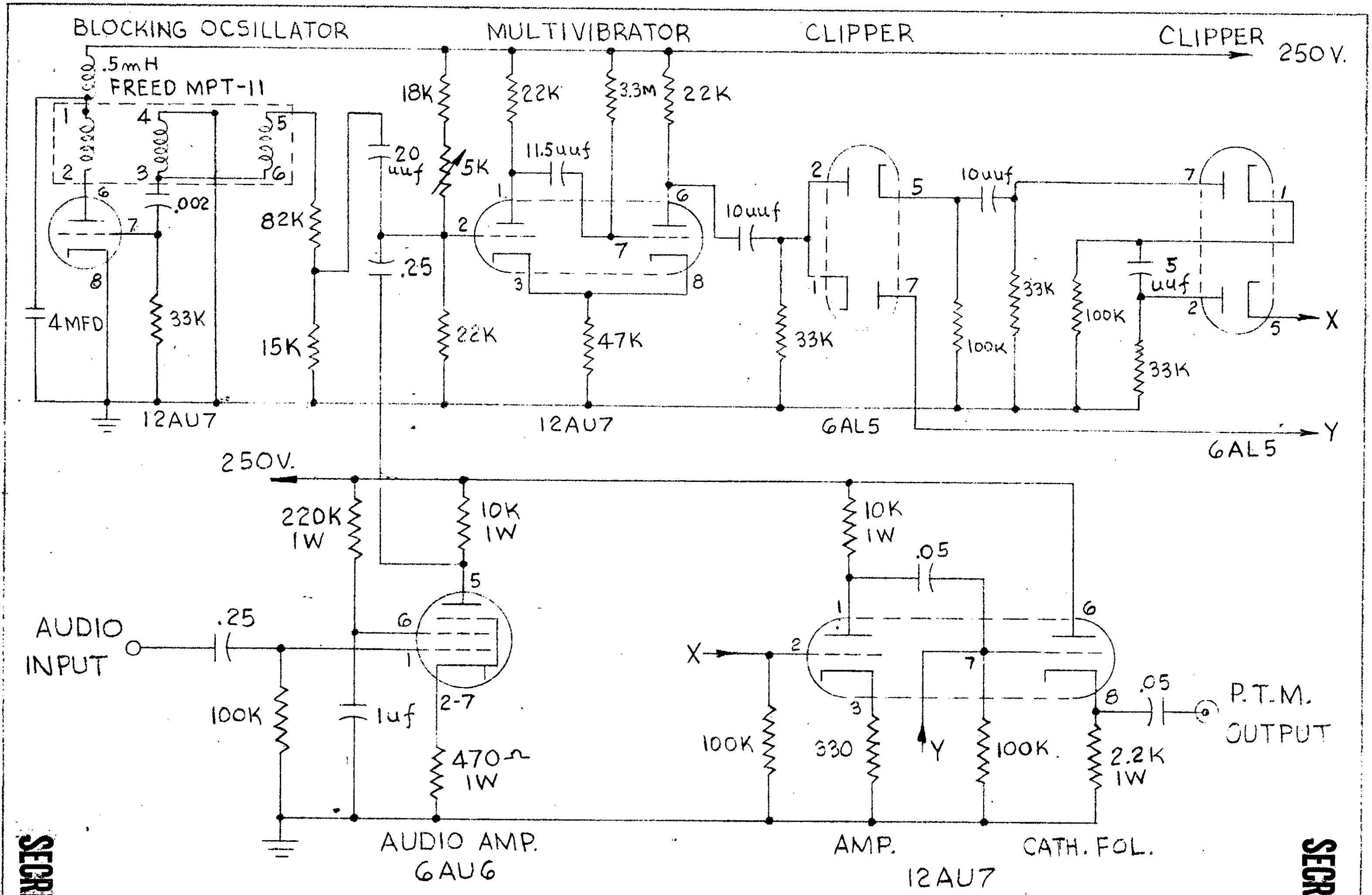

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FIG. 29 - PULSE TIME MODULATOR

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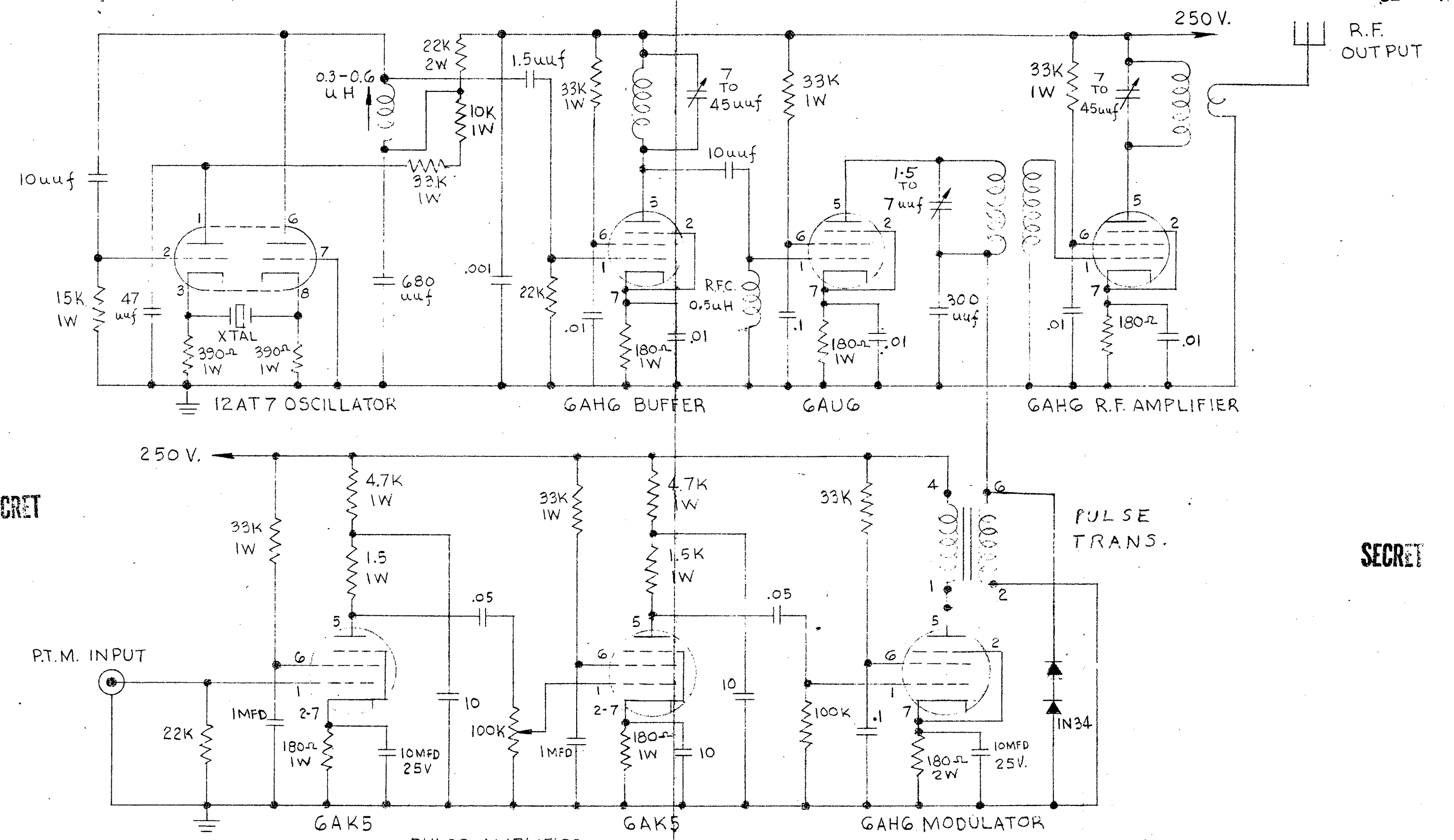

FIG.30 - 74MC. PULSE TIME TRANSMITTER

FIG. 30

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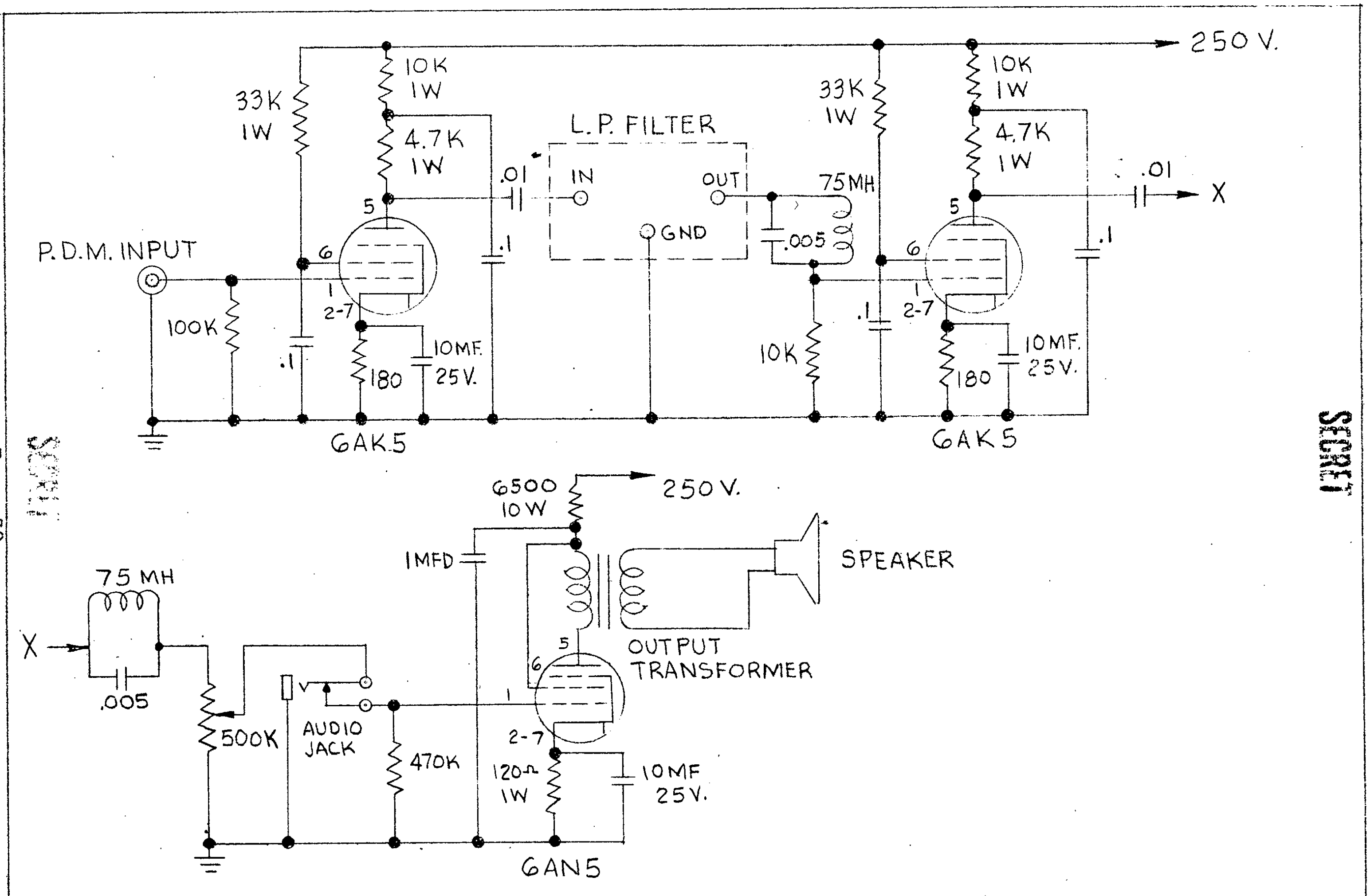

FIG. 31 - AUDIO AMPLIFIER