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A PRECISION RANGE DELAY UNIT

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A PRECISION RANGE DELAY UNIT

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March 4, 1948

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ACKNOWLEDGMENT

The double-coincidence synchronizing circuit, compensated coarse delay circuit, and various blocking oscillator techniques were adapted from the range circuits of the Radar Mark 35. These circuits are described in Radiation Laboratory Report M-240, November 30, 1945, Preliminary Instructions for Radar System Mark 35.

The fundamental principles used in the design of the subject unit were first investigated at the Naval Research Laboratory prior to World War II. At this time a precision range circuit was developed which employed a crystal-controlled oscillator as a time base and provided triggers at the PRF through the use of frequency division. Continuous ranging was accomplished by means of a 360^{0} phase shifter coupled to a linear coarse delay circuit which selected one cycle of the phase-shifted output. The subject unit is thus identical in basic principle to this original circuit.

CONTENTS

Abstract	vi
Problem Status	vi
Authorization	vi
INTRODUCTION	1
OUTLINE OF THE PRECISION RANGE DELAY CIRCUIT	2
CIRCUIT DETAILS	5
TUBE FUNCTIONS	5
Crystal Oscillator and Cathode-Follower	5
Pip Generator	6
Repetition Rate Divider	6
Pre-Pulse Delay Circuit	6
Trigger Coincidence Circuits	6
Transmitter Trigger Circuits	6
Coarse Delay Circuit	9
Quadrature Voltage Circuit	9
360-Degree Phase Shift Condenser	9
Amplifier Stages	10
Phase Shifted Pip Generator	10
Range Marker Coincidence Circuits	10
Power Requirements	10
PERFORMANCE DATA	10
EXPERIMENTAL DATA	11
Cyclic Error of Phase-Shift Condenser	11
Range Zero Shift with Tube Replacement	11
Range Zero Shift vs PRF	12
Pulse Time Modulation Characteristics of the PRF Oscillator Detection System	12
Frequency Response of the PTM System	12
Zero Shift with Filament and Plate Voltage Changes	14
Drift During Warm-Up	15
Crystal Oscillator Drift	15
Stability over Long Periods	15
Overall Range Accuracy	15
PREVIOUS NRL REPORTS	16

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ABSTRACT

In order to achieve satisfactory analyses of missile performance, it was necessary to obtain a range delay circuit with greater accuracy than was possible with the Meacham circuit employed in the Mark 12 and other fire control radars. This report describes a precision range unit which has an overall accuracy of ±10 yards in 100,000 and permits pulse-time modulation of the PRF by any time function. The principles of its operation are discussed and performance data are tabulated and analyzed.

PROBLEM STATUS

This is the final report on this phase of the problem. Work on other phases is continuing.

AUTHORIZATION

NRL Problem No. R05-16.

A PRECISION RANGE DELAY UNIT

INTRODUCTION

In the test program proposed for the Lark Guided Missile Project very accurate range data are needed to permit satisfactory analyses of missile performance. The Meacham range circuit employed in the Mark 12 and other fire control radars has a specified accuracy of ±15 yards, ±0.1 percent of the indicated range. Since missile tracking data are desired to ranges of 100,000 yards the overall accuracy of the Meacham unit may be as poor as ±115 yards, due to the large range percentage error present. Since overall accuracies of ±5 to ±10 yards at any range out to 100,000 yards are desired for Lark tracking, the Meacham circuit was consequently considered inadequate.

The percentage error of the Meacham unit is caused by frequency instability in the keyed LC oscillator. Since the tank circuit is enclosed in a temperature-controlled oven in the present unit there is slight chance of any substantial improvement in this characteristic. The ±15 yard error, however, is independent of range and represents a cyclic error in the 360 degree phase-shift condenser. This cyclic error is substantially a percentage of the range increment represented by one revolution of the phase-shift condenser, or one cycle of the driving voltage. In the Meacham unit the range increment is 2000 yards and the error is thus ±0.75 percent of this interval. It has been found that careful alignment of the condenser driving circuits will reduce the error to the order of ±0.5 percent. Thus by doubling the driving frequency, cyclic errors may be reduced to ±5 yards at any indicated range. The Meacham principle would then yield accuracy satisfactory for the Lark program if the time-base oscillator had an instability of ±0.005 percent instead of 0.1 percent. This order of precision can be achieved easily with a crystal-controlled oscillator. However, a satisfactory keyed crystal oscillator circuit was not available, and rather than attempt development of such a circuit, whicn presents many difficulties, it was decided to employ a free-running crystal oscillator as a time base and derive timing pulses locked in phase with the oscillator by means of a divider system. In this case the range unit serves also as the timing generator for the radar. The divider circuit proposed permitted pulse-time modulation of the PRF without any possibility of phase instability between the timing pulses and the time-base oscillator, making the unit equivalent, as a trigger source, to any separate timing generator available. This type of unit could not be used in a system employing a spark-gap or other non-servel modulator, but was condidered satisfactory for the Lark work. It should also find application in other systems where increased range accuracy is desired.

A range delay circuit based on the principles outlined was developed, and a laboratory unit built and tested. Absolute accuracy of better than ±5 yards, ±0.005 percent of the range was obtained. Zero shifts over ±10 percent variations in plate-supply voltage were less than ±2 yards. For ±10 percent filament voltage changes, ±6-yard zero shifts occurred. Changing tubes in the most critical locations resulted in zero errors of ±13 yards. The factor of ±.005 percent of range represents the grinding tolerance for the crystal employed and frequency stability of the order of ±.001 percent over long periods should be easily obtained, giving a calibrated accuracy of ±6 yards at 100,000 yards.

A discussion of the circuits employed, and a more detailed analysis of performance data are given below.

OUTLINE OF THE PRECISION RANGE DELAY CIRCUIT

The circuit outlined below derives its principle advantage over previous crystal timing circuits from the double-coincidence divider used to establish the trigger outputs in phase with the time-base oscillator. When a chain of conventional dividers is used to obtain a ratio of 100 to 1 or 200 to 1 as is required in dividing from the crystal oscillator frequency to a suitable PRF the phase of the trigger pulse with respect to the oscillator output is dependent on the exact operating point of four or five separate divider stages. Thus phase drift is likely to occur during any appreciable period of operation, and the PRF cannot be changed with any assurance that the phase relationship will remain the same. Under these circumstances pulse-time modulation of the repetition rate in a precision range circuit is not practicable.

When a double coincidence system is used, one synchronized PRF oscillator stage accomplishes the division from the time-base oscillator to the PRF and the ratio of this division may be pulse-time modulated without affecting the stability of the final trigger. No attempt is made to secure a high degree of phase stability in the synchronized oscillator output, and the period between pulses may vary by an amount corresponding to several cycles at the high frequency. The dividing oscillator will, however, have almost the same percentage frequency stability as an ordinary repetition-rate oscillator. The output at the PRF is used to form a gating pulse, and this pulse is fed to a mixer or coincidence tube where it is mixed with a train of pips exactly synchronized with each cycle of the time-base oscillator. The mixer produces an output when one of the pips coincides in time with the gate, and this output is used to form a second gating pulse. To insure that coincidence will always occur the gate pulses are made longer than the interval between two pips. Since the circuits following the mixer can be made insensitive for a relatively long period after once triggering, the first pip picked up by the gate is effective and any additional pips will produce a mixer output but will not disturb the associated circuits.

The second gating pulse will be fairly phase stable with respect to the pip train, but may have a jitter corresponding to the rise time of the pips since coincidence may occur at any point on the front edge or top of the first gate. Thus the mixer output pulse may start any time during the front edge of the pip. However, when the second gate is mixed again with the pip train in a second coincidence tube the mixer output will have a very small phase jitter, since coincidence will always occur at nearly the same point on the flat top of the second gate. When a timing trigger is formed from the output of the second mixer the phase jitter is found to be negligible for range unit applications. In this system the phase lock between the timing pulse and the time-base oscillator does not depend upon divider operation or even upon the division ratio. Thus the PRF is easily changed by adjusting the PRF-oscillator time constant and may be time-modulated by introducing a modulating voltage into the oscillator circuit. The period between pulses at the PRF, of course, must be an integral multiple of the period of the time-base oscillator. However, for a PRF as high as 2500 cps the oscillator period at the frequency employed is only 1.5 percent of the period at the PRF and for a variation of 10 percent or more the PTM produced will be a continuous function so far as operation of any practical detector is concerned.

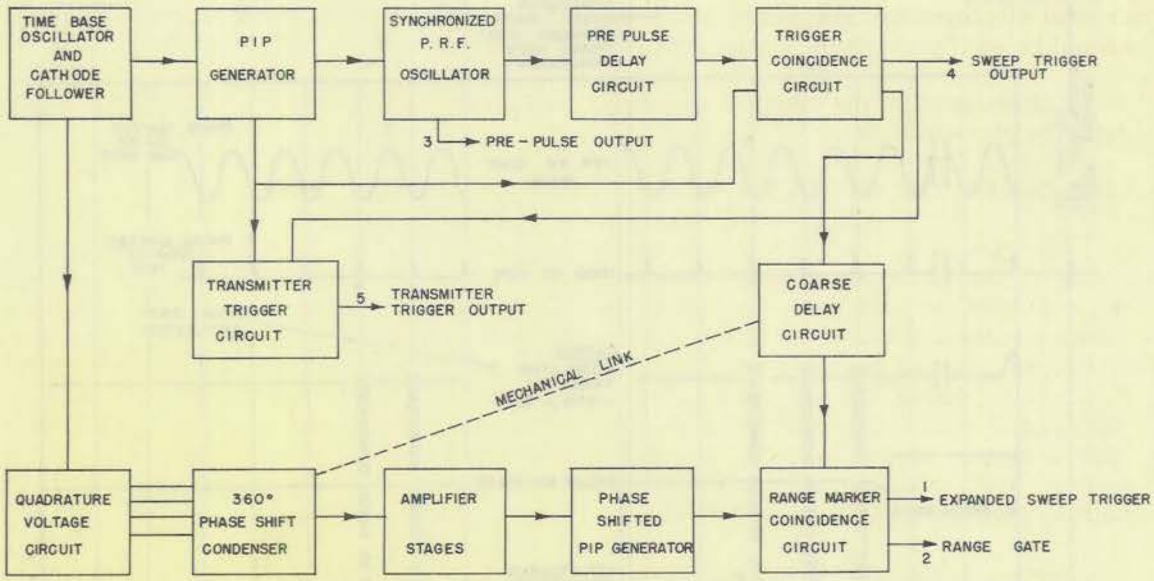


Fig. 1 - Block Diagram

The block diagram given in Figure 1 illustrates the principle components of the circuit. The free-running crystal oscillator operates at 163.91 kc or a period corresponding to 1000 yards of range delay. The oscillator output drives a pip generator which forms a train of half-microsecond triangular pips, locked in phase with the oscillator sine-wave. The oscillator also drives phase-splitting circuits which develop the quadrature voltage inputs to the 360 degree phase-shift condenser. The condenser output is amplified and fed to a second pip generator which forms another train of half-microsecond pips which are shifted continuously with respect to the first train as the phase-shift condenser is rotated. The time relationships between these and other signals are shown in Figure 2. The fixed pip train synchronizes the PRF oscillator which produces a trigger at the desired PRF. The PRF oscillator output pulse has considerable jitter (approximately 2 microseconds) with respect to the pip train but is satisfactory for use as a modulator charging trigger. To obtain a pre-charging interval for the modulator the divider output is used to key the pre-pulse delay circuit which is a multivibrator having a plate pulse approximately 250 microseconds long. The back edge of this pulse then keys the trigger coincidence circuits which produce the sweep triggers. These circuits consist of two coincidence tubes, two gate generators, and a trigger generator which forms the output pulse. The multivibrator pulse keys the first gate generator which forms a gating pulse several thousand yards long. This gate and the 1000-yard pip train are fed to the first coincidence tube which produces a keying pulse when it receives the first pip following the front edge of the gate. This keying pulse is then used to drive the second gate generator which forms a second gating pulse, similar in form to the first but having much less phase jitter with respect to the pip train. This stable gate is mixed with the pip train in the second coincidence tube which forms a keying pulse when the next pip is picked up by the gate. This output keys the sweep trigger generator, producing a trigger output which has negligible phase jitter with respect to the original oscillator sine wave.

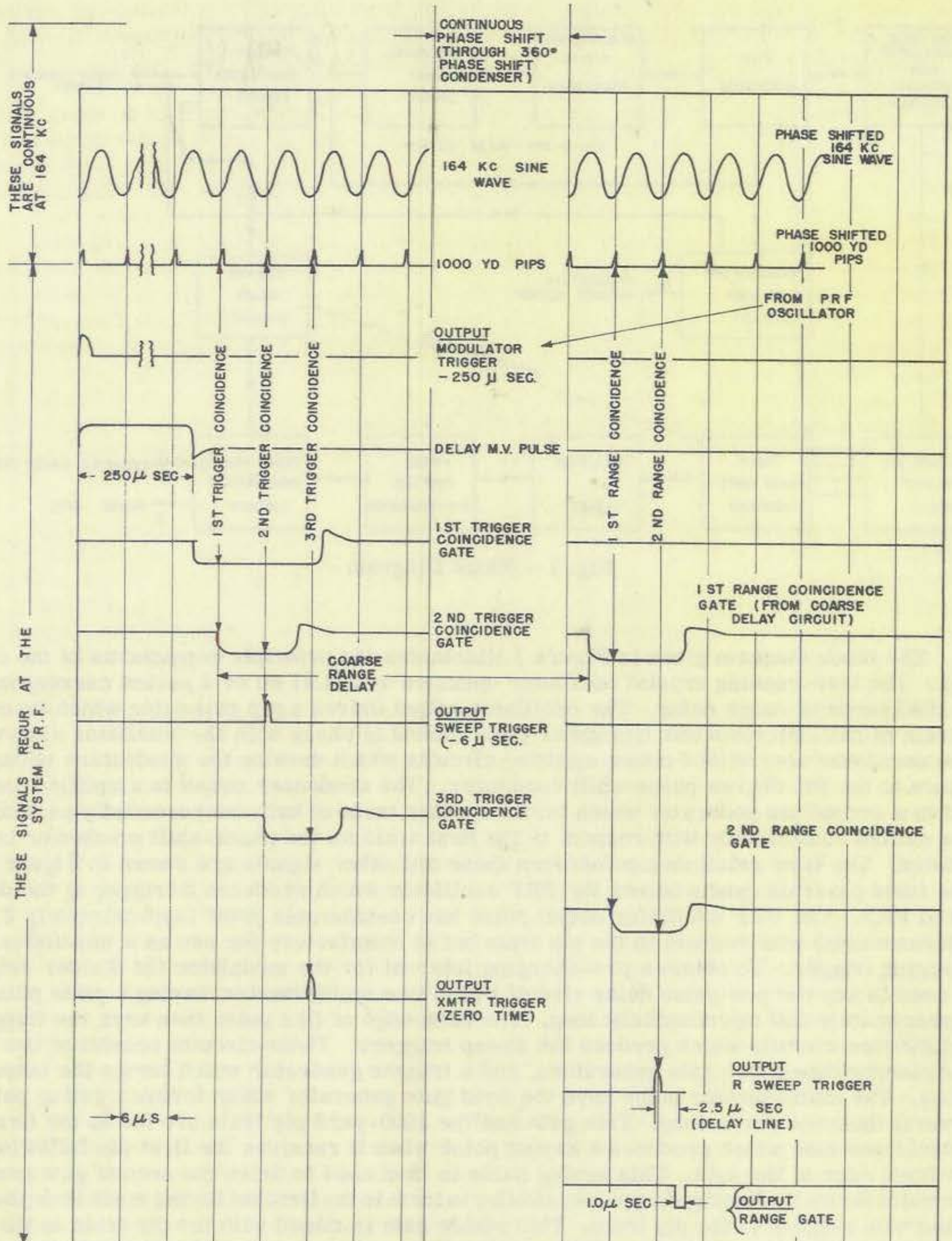


Fig. 2 - Time Relationships of Pulse Outputs

The sweep trigger also keys the transmitter trigger circuit, consisting of a third gate generator, a third coincidence tube and a trigger generator, which forms the transmitter trigger output. Since each successive coincidence picks up the next adjacent pip in the train, a 1000-yard delay is introduced between the front edge of the gate and the keying pulse formed by the coincidence tube. A stable transmitter trigger, automatically delayed from the sweep trigger by a 1000-yard interval, is thus produced.

The range marker coincidence circuits establish the R sweep trigger in exact phase with the shifted pip train by means of two coincidence tubes operating in the same way as those in the trigger coincidence circuits. Proper pip selection, or tracking, is provided by the coarse delay circuit which forms the gate supplied to the first coincidence tube. The coarse delay circuit employs a compensated RC charging circuit in which the delay is a linear function of the position of a ten-turn precision potentiometer. This linear relationship holds true to within ±0.1 percent of the set delay. Thus by linking the potentiometer to the phase-shift condenser with a suitable gear train the gate may be made to track a pip of the phase shifted train to a range of 100,000 yards with a maximum error of ±100 yards. This error is well within the allowable maximum of approximately ±400 yards.

The range gate output is obtained by feeding the R sweep trigger into a 2.5-microsecond delay line and keying a gate generator with the output from the line, thus delaying the gate from the start of the expanded sweep.

CIRCUIT DETAILS

The complete circuit diagram of the unit is given in Figure 3. The circuit sections represented by the blocks of the diagram in Figure 1 are identified, and all components are labeled. All tubes used perform conventional functions as multivibrators, blocking oscillators, amplifiers, and grid-cathode mixers. The blocking oscillator transformers used are especially designed for this service, providing inherent damping which limits the reverse overshoot to a small percentage of the desired pulse. To form the trigger outputs the X-143T-3 transformer is connected in a conventional servel circuit. This transformer has a resonant frequency of approximately 1 megacycle and produces a half-microsecond trigger having a rise of better than 0.1 microsecond. A peak amplitude of 30 volts is developed across a 50-ohm external load. The gating pulses used in the coincidence circuits are developed by blocking oscillators using the X-154T-1 transformer, which has a resonant frequency of approximately 200 kc. By using cathode feedback, gates 12 to 18 microseconds long are obtained. All gates and 1000-yard pips are developed at a low impedance level of 200 to 300 ohms. This minimizes the effect of inductive and capacitative coupling between circuit sections. The peak pulse amplitudes are all approximately 40 volts. The fact that there are no pulse signals differing widely in amplitude, combined with the low impedance level, means that pulse circuit wiring is not critical. The only low-level high-impedance point in the circuit is the 164-kc sine-wave output from the phase-shift condenser. If the first amplifier stage is mounted on a bracket with its grid pin near the condenser output terminal no shielding or other precautions are required.

TUBE FUNCTIONS

Crystal Oscillator and Cathode-Follower

Tube V14 functions as a crystal-controlled transitron oscillator. This type was found to give more stable operation at the relatively low 164-kc frequency than a tuned-grid-tuned-plate or similar circuit.

Tube V15A is a conventional cathode follower providing a low impedance output to other sections of the circuit.

Pip Generator

Tube V15B is a conventional amplifier at 164 kc. Tube V16A acts as a keying tube supplying a synchronizing signal to V16B. The 200-ohm cathode degeneration resistor reduces the change of synchronizing phase with plate supply and filament voltage changes.

Tube V16B is a blocking oscillator synchronized at a 1 to 1 frequency ratio with the 164-kc sine wave to produce half-microsecond pips spaced 1000 yards and locked in constant phase with the sine-wave input.

Repetition Rate Divider

Tube V17A is a grid synchronized blocking oscillator dividing from the 164-kc pips to the PRF. PRF adjustment is made by changing the resistance in the grid RC or introducing a voltage between the grid return and ground.

The latter method may be used to produce PTM following a voltage of any injected wave form. The modulator trigger output is taken from the cathode of this tube.

Pre-Pulse Delay Circuit

V18A and V18B comprise a standard servel multivibrator which introduces a 250-microsecond delay between the modulator trigger and keying of the trigger coincidence circuits.

Trigger Coincidence Circuits

V17B is a blocking oscillator functioning as the first gate generator and producing a 12-microsecond gate.

V19A is a grid-cathode mixer, the first coincidence tube.

V19B is the second gate generator producing a 10-microsecond gate.

V20A is the second coincidence tube, having a circuit identical to V19A.

A longer gate is used in the first gate generator to prevent the back edge of the gate from coinciding with the final mixing in the second coincidence tube and causing possible phase jitter. The small cathode bypass condensers in the coincidence tubes slow down the front edges of the gates to prevent part of the 164-kc pip which triggered the gate generator from being passed by the tube instead of the next following pip, as is desired for stable mixing.

V20B is the trigger generator forming the half-microsecond sweep trigger at a low impedance level. When the output is loaded by a 50-ohm cable a peak amplitude of 30 volts is developed. The unloaded output is approximately 60 volts.

Transmitter Trigger Circuits

V21A and V21B comprise a keying section and third gate generator. The gate generator is identical to V19B.

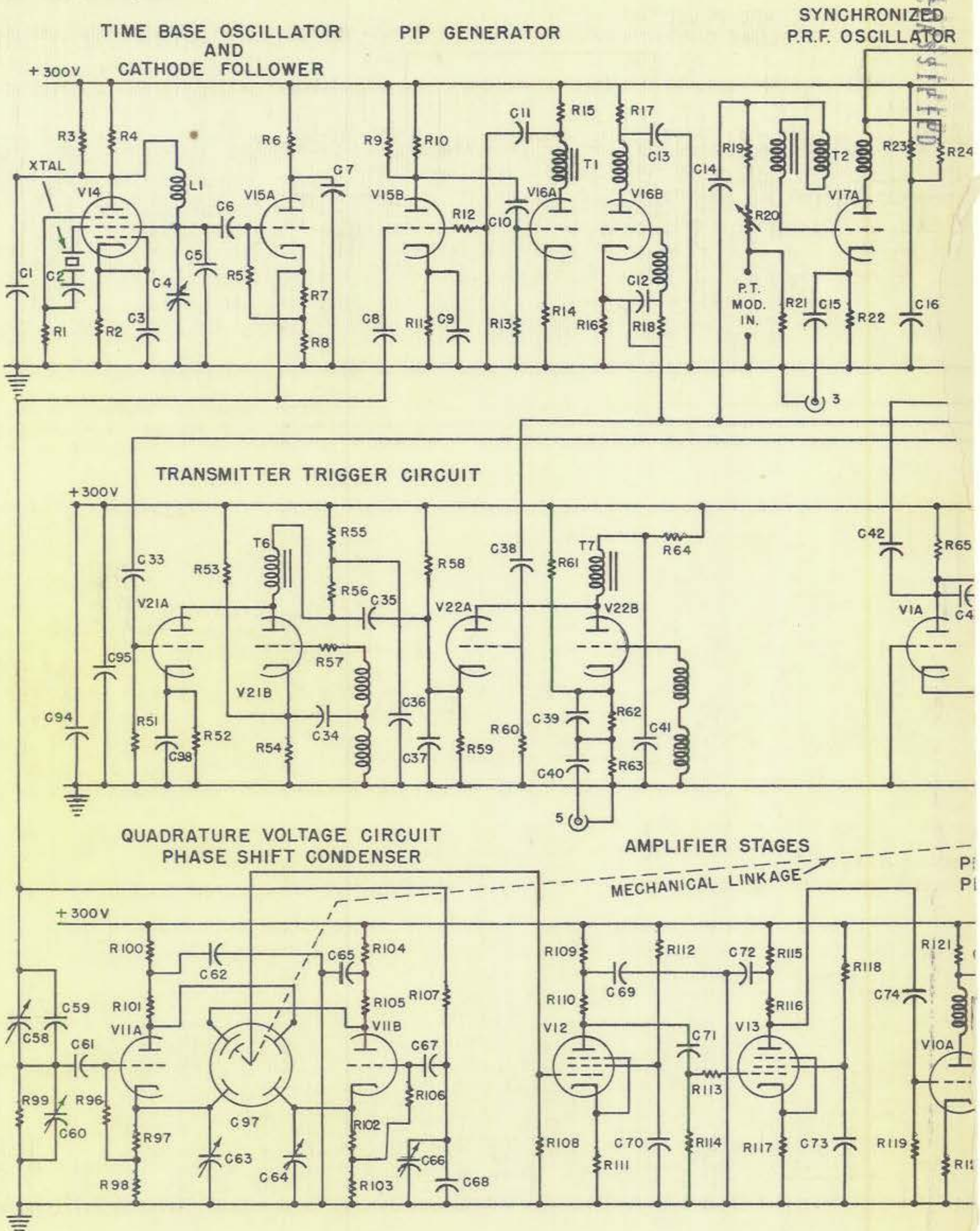
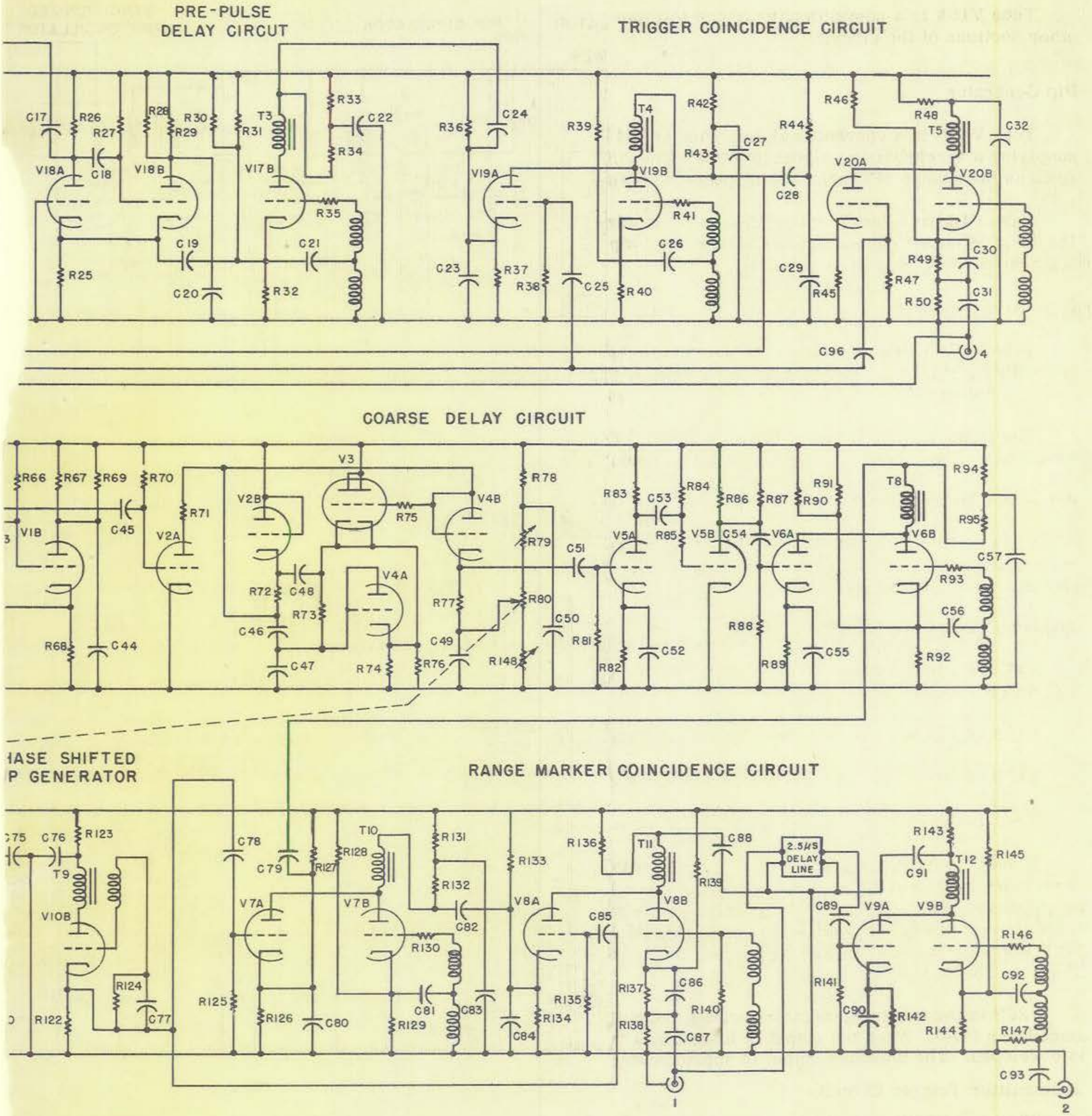

TIME BASE OSCILLATOR
AND
CATHODE FOLLOWER
PIP GENERATOR
SYNCHRONIZED
P.R.F. OSCILLATOR
+300V
XTAL
V14
V15A
V15B
V16A
V16B
V17A
T1
T2
P.T.
MOD.
IN.
3
TRANSMITTER TRIGGER CIRCUIT
+300V
V21A
V21B
V22A
V22B
T6
T7
V1A
5
QUADRATURE VOLTAGE CIRCUIT
PHASE SHIFT CONDENSER
AMPLIFIER STAGES
MECHANICAL LINKAGE
+300V
V11A
V11B
C97
V12
V13
V10A

Fig. 3



Precision Range Delay Unit

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V22A is the third coincidence tube; V22B is a trigger generator, identical to V20B, which forms the transmitter trigger, delayed 5 microseconds from the sweep trigger by the use of the third coincidence circuit.

Coarse Delay Circuit

Tubes V1 to V6 comprise the coarse delay circuit, including the first gate generator of the range marker series.

Tubes V1A and V1B form a gating multivibrator triggered by the differentiated front edge of the pulse from the second gate generator of the trigger series, V19B.

Tubes V2A and V2B are a switching amplifier and diode combination which restores and clamps the RC discharge network between delay cycles and unclamps it to start the linear sawtooth when gated by the negative pulse from V1.

Tube V3AB is a cathode follower which provides primary compensation of the sawtooth by maintaining the charging current in the RC combination nearly constant over the charging cycle.

Tube V4A is a restoring diode for the integrating network used to effect final compensation of the linear sawtooth.

Tube V4B is a pick-off diode which conducts when the sawtooth carries its plate to the cathode level set by the ten-turn precision "helipot". A pulse delayed from the sawtooth start by an interval which is a linear function of potentiometer position is thus obtained. The potentiometer is linked mechanically to the phase-shift condenser.

Tubes V5A and V5B amplify the signal appearing at the diode cathode. The output of V5B then drives the keying section of the first gate generator in the range marker series.

Tubes V6A and V6B are the keying tube and blocking oscillator of the first gate generator. V6B is identical to V17B, the first gate generator of the trigger series.

A delay accuracy of ± 0.1 percent of the set delay is obtained with this circuit.

Quadrature Voltage Circuit

Tubes V11A and V11B are two 180-degree phase splitters which drive the 360-degree phase-shift condenser. Tube driving voltages differing 90 degrees in phase obtained by two RC networks giving leading and lagging phase angles of 45 degrees with respect to the oscillator voltage. Correct adjustment of the two trimmers in the ground legs of the two "L" sections provides inputs of the correct phases which are also matched exactly in amplitude.

360-Degree Phase-Shift Condenser

The phase-shift condenser is the Western Electric D150734, having four-phase input connections and providing the coupling variation needed for continuous phase shift by means of a dielectric rotor. This rotor changes the relative capacitance between the output and the four inputs by changing the relative dielectric constant in the four coupling paths.

Amplifier Stages

V12 and V13 are amplifier stages which raise the level of the phase-shift condenser output to that required for stable synchronization of the phase-shifted pip generator. Operation of these stages with unbypassed cathodes gave increased phase stability with plate supply and filament voltage changes.

Phase Shifted Pip Generator

V10A and V10B are the keying tube and blocking oscillator of the pip generator, which is identical to the circuit of V16A and V16B.

Range Marker Coincidence Circuits

V7A is the first coincidence tube of the range marker series, fed by the first gate from the coarse delay circuit and the phase shifted pips.

V7B is the second gate generator, identical to V19.

V8A is the second coincidence tube and V8B the R sweep trigger generator. These circuits are identical to those of V20A and V20B.

V9A and V9B are a keying tube and blocking oscillator combination which generates the range gate output. An X-143T-3 transformer is used in a cathode feedback circuit to produce a substantially square 1-microsecond gate. With a 50-ohm external load connected to the output the gate amplitude is 8 volts. The keying tube is triggered by the output of a 2.5-microsecond delay line driven by the R sweep trigger. Thus the range gate is delayed from the sweep trigger by 2.5 microseconds, placing it in the center of a 5.0-microsecond expanded sweep.

The use of identical circuits in many parts of the trigger and range marker coincidence series reduces the possibility of serious differential phase shift between the two chains as components age or operating voltages change. This is an important consideration, since such a phase shift would appear directly as an error in the range delay.

Power Requirements

The power requirements are as follows:

Plate supply 185 milliamperes, 300 volts dc.

Heater supply, 6.9 amperes, 6.3 volts ac.

PERFORMANCE DATA

The performance data tabulated below are the results of tests made on a laboratory unit employing the exact circuit given in the attached diagram (Figure 3). This unit was constructed on a standard rack-panel chassis, and aside from locating the first amplifier stage following the phase shifter on a bracket close to the output terminal and using a logical arrangement of the other tubes on the chassis no special precautions were taken. Small components were wired on terminal rings mounted around each socket, no special placement of parts or leads being used. A GT-cut crystal was used in the oscillator to provide maximum stability, but no temperature control was provided. A dial and counter system enabled the range delay to be read to the nearest yard, and a PRF control permitting a range of 400 to 700 cps was provided.

EXPERIMENTAL DATA

Cyclic Error of Phase-Shift Condenser

The driving circuits of the phase-shift condenser were aligned during test by comparing the time delay of the range gate with a series of pips obtained by multiplying the crystal oscillator output to the 12th harmonic. These pips were also used as reference points in measuring the cyclic error. When the alignment procedure was carried out with reasonable care, cyclic errors as low as ±2.5 yards were obtained. For this condition the amplitudes of the condenser driving voltages were matched within 1.5 percent. The output variation with condenser rotation was ±3 percent. The residual cyclic error may be due to the limitations of the alignment procedure, harmonic content of the driving voltages, and mechanical inaccuracies in the phase-shift condenser.

Replacing the original phase-inverter tube (VII) with five stock tubes changed the overall cyclic error by ±0.5 yard or less and individual range readings by ±1 yard or less. Tubes having abnormally low or high transconductance in one or both sections will cause much larger errors, however.

Range Zero Shift with Tube Replacement

For these tests five new tubes were selected at random from stock and placed successively in each location while changes in range zero were observed. The results of these tests are tabulated below. The error figures indicate the total spread of the readings for the five tubes (Maximum to Minimum).

V1 -V7 -	less than 1 yard
V8 -	3 yards
V9 -	less than 1 yard
V10 -	2 yards
V11 -	2 yards
V12 -	4 yards
V13 -	13 yards
V14 -	4 yards
V15 -	5 yards
V16 -	3 yards
V17 - V22 -	less than 1 yard

These errors are all range zero errors and contain no measurable component which is a percentage of range. Thus a check of the zero set following tube replacement is the only recalibration required.

The delay of the tracking pedestal of the coarse delay unit is sensitive to replacement of tubes V2 and V3. A total dispersion of readings of 300 yards at 100,000 yards range setting occurred. This would not ordinarily cause the pedestal to pick up the wrong 164-kc pip, but a tracking check is probably desirable if these tubes are changed.

Range Zero Shift vs PRF

No measurable (less than 1 yard) range zero shift occurred over the 400 to 700 cycle PRF range of the subject unit. Tracking pedestal shifts of ± 100 yards in 100,000 yards were observed.

In its present form the upper PRF of the circuit is limited to approximately 800 cps for a 100,000 yard maximum by the performance of the coarse delay circuit. This circuit shortens its delay excessively at duty cycles much higher than 50 percent. The remaining circuit components, however, will operate at 3,000 cps or higher without modification. Thus higher PRF's may be used if a decrease in the maximum range can be tolerated.

Pulse-Time Modulation Characteristics of the PRF Oscillator Detection System

To obtain the data given below a sawtooth generator was synchronized at a 1 to 1 ratio by the sweep trigger pulse from the subject unit so that the amplitude of each sawtooth pulse was proportional to the time interval between successive triggers. The PTM of the PRF was thus reproduced as an amplitude modulation of the sawtooth output. A sawtooth time constant of 1.5/PRF was used; approximately the same as the grid time constant of the PRF oscillator. The sawtooth output was connected to a harmonic analyzer through a parallel T and RC filter combination adjusted for maximum rejection at the 1000 cycle PRF. The frequency response of the filter and harmonic analyzer combination was plotted and these data used to correct all the readings obtained from the analyzer to the same reference level. The harmonic analyzer was set for a half-bandwidth (40 db down) of 30 cycles during the tests. The modulating signal used was a sinusoidal voltage of low harmonic content.

Frequency Response of the PTM System

Figure 4 presents curves showing the variation of detector output amplitude with frequency for two modulating signal levels, and the variation of noise output with frequency. Curves are plotted for normal pip-synchronized operation of the PRF oscillator and the free-running condition where the PRF is not limited to sub-multiples of the 164-kc pip frequency. The modulating signal levels for the two cases were the same. The slightly higher output in the unsynchronized case is obtained because, in the absence of the synchronizing pips, it was found necessary to increase the slope of the oscillator grid exponential to maintain the same mean PRF.

The curves show that, so far as the output of a tuned amplifier is concerned, there is no significant difference in frequency response in the two cases. The only change caused by pip-synchronization is an increase of from 5 to 10 db in the noise output. This increased noise level still represents only 1.3 percent PTM at a maximum, however, and should not be objectionable for any ordinary transmission of PTM intelligence.

The decrease in output with increasing frequency which occurs in all cases would be expected from the method used to introduce the modulating voltage, in which the grid RC of the PRF oscillator acts as a low-pass filter. At frequencies close to the PRF the output would also fall off due to a decrease in the modulation-frequency component in the PTM spectrum.

Detector Noise - For any frequency other than 60 cps or 120 cps the noise output of the unsynchronized sawtooth generator was at least 30 db below the level obtained with the pip-synchronized PRF oscillator controlling the sawtooth. At 60 cps and 120 cps, hum

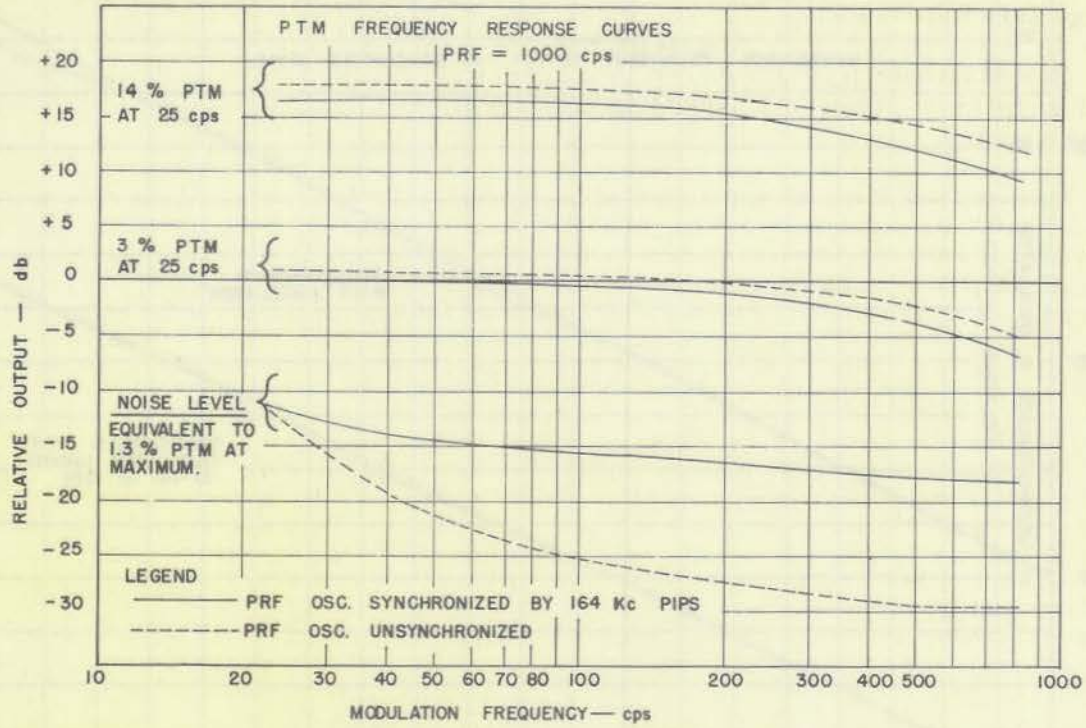

Fig. 4 - PTM Frequency Response Curves

components respectively 12 db and 14 db below the synchronized noise level were present. Thus the noise figures measured for the system represent closely the noise level of the PRF oscillator.

Output vs Modulating Signal Level - Figure 5 shows variation of output with modulating signal level at constant frequency for the synchronized and unsynchronized cases. Although in the pip-synchronized case the PRF oscillator can operate at only some 26 definite frequencies over a 16 percent modulation cycle, the output level from the tuned amplifier of the harmonic analyzer increases smoothly with increasing input level, and there is no significant difference in performance for the two cases.

Harmonic Distortion of Output - Data taken at 100 cps and 150 cps indicated that the second harmonic distortion present in the modulation frequency component of the detector output was less than 1.5 percent for 15 percent PTM. The third harmonic distortion was neglibible. Since only 0.1 percent second harmonic was present in the waveform of the modulating oscillator the figure of 1.5 percent represents closely the distortion introduced by the system.

Sum and Difference Frequency Components of Detector Output - Measurements of the outputs at the sum and difference frequencies between the PRF and the modulation frequency showed that the sum and difference outputs were approximately equal in amplitude. At a 25 cps modulation frequency the outputs at (PRF ±frequency of modulation) were 18 db above the modulation frequency output for 14 percent PTM. The relative level decreased as the modulation frequency increased, reaching approximately 0 db at 500 cps and maintaining nearly this level from 500 to 900 cps.

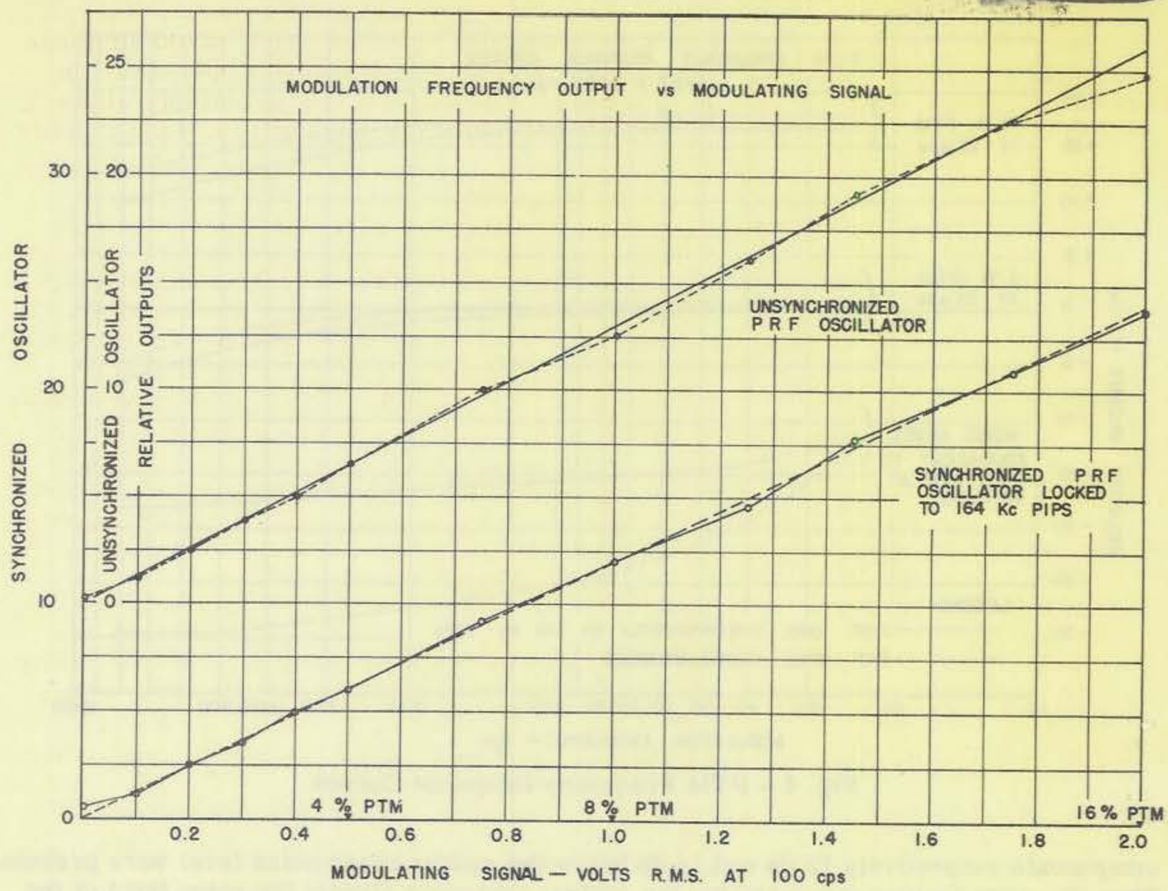

Fig. 5 - Curves of Modulation Frequency Output vs Modulating Signal Level

Outputs at the second side band frequencies of (PRF ± 2 x frequency of modulation) could be detected but were from 8 to 20 db below the first side bands for 14 percent PTM.

Conclusions - It may be concluded that in any practical PTM detection system the fact that the PRF of the subject unit is limited to sub-multiples of the 164-kc oscillator has no effect other than an increase in the effective noise level. At a PRF of 1,000 cps the noise increase is from 5 to 10 db depending on the frequency to which the detection system is tuned. (See Figure 4.)

Zero Shift with Filament and Plate Voltage Changes

The errors caused by changes in filament and plate voltages were found to be zero errors, unaffected by the range setting. The data obtained are tabulated below.

Plate Supply	Error	Heater Supply	Error
Normal (300 v)	0	Normal (6.3 v)	0
+10 %	+1 yard	+ 5%	0
+20 %	+2 yards	+10%	+3 yards
-10 %	-1 yard	+20%	+5 yards
-20 %	-2 yards	- 5%	+2 yards
		-10%	+6 yards
		-20%	+25 yards

These data indicate that any type of electronically regulated supply would eliminate plate voltage changes as a significant source of error. The filament supply should be regulated within at least ±10 percent of the rated tube voltages, and preferably within ±5 percent. Operation at 5 percent above normal filament voltage will increase stability if regulation is difficult.

Drift During Warm-Up

Drift during warm-up was found to be a range zero shift with no appreciable range percentage component. During warm-up from a room temperature of approximately 23°C a shift of ± 10 yards in range reading occurred before stable operation was reached. Approximately 8 yards of this shift occurred during the first 3 minutes of operation, and 9 yards during the first 5 minutes. At the end of 10 minutes, stable operation was reached and no further shift of the range setting occurred.

The final operating temperature of the chassis was 53 to 55°C, but was not reached until after about 2 hours of operation at an ambient temperature of 23°C. After 1 hour of operation temperatures of 48 to 50°C were reached.

Crystal Oscillator Drift

Variation of range calibration due to oscillator frequency changes was measured by comparing the range delay of the subject unit with that established by a Western Electric CW60ABZ radar range calibrator, which was operated from a regulated plate supply. This comparison was made at 40,000 yards range delay, the maximum for the calibrator.

The crystals used were GT-cut plates ground for a frequency of 163.91 kc at 30°C and mounted in standard holders. The specified tolerance was ±.005 percent. The units were manufactured by the Naval Gun Factory, Washington, D. C.

When four different crystals were checked a dispersion of readings of only ± 1 yard in 40,000 or ± 2.5 yards in 100,000 was found.

When a crystal was cooled to 6°C, then plugged into the circuit, a total range shift of less than 1 yard in 40,000 from cold operation to a chassis temperature of 46°C was observed. Thus frequency stability of ± 1 yard in 100,000 may be expected for room temperature operation.

Stability over Long Periods

During operation for 8 hour periods slow drifts in range reading were less than ± 1 yard. Readings were duplicated on successive days within a ± 1 yard margin. Over weeks or months of operation, ageing of tubes and components may be expected to cause larger changes, but periodic calibration should make this source of error a minor one.

Overall Range Accuracv

Assuming the use of an electronically regulated plate supply and regulation of the heater supply within ± 5 percent, the overall error may be computed as follows for a 100,000 range:

	Cause	Error
(1)	Cyclic Error	± 3 yards
(2)	Estimated Oscillator Frequency Drift	± 1 yard (Crystal operated at room temperatures of approximately 10° to $35^{\circ}C$.)
(3)	Plate Supply Variation	Negligible
(4)	± 5% Heater Supply Variation	± 2 yards

Total error - ± 6 yards in 100,000 or ± 5 yards ±.001 percent range, plus any reset error inherent in the system.

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PREVIOUS NRL REPORTS ON PROBLEM R05-16

Dodge, C. H., NRL Report No. R-3103, KAQ-1 Lark Beam-Rider Trajectory Analysis.

Locke, A. S., NRL Report No. R-3070, Lark-Wasp Guided Missile Seminar, January 1947.
NRL Report No. R-3075, Lark-Wash Guided Missile Seminar, February 1947.
NRL Report No. R-3094, Lark-Wasp Guided Missile Seminar, March 1947.
NRL Report No. R-3108, Lark-Wasp Guided Missile Seminar, April 1947.
NRL Report No. R-3135, Lark-Wasp Guided Missile Seminar, May 1947.
NRL Report No. R-3144, Lark-Wasp Guided Missile Seminar, June 1947.
NRL Report No. R-3188, Lark-Wasp Guided Missile Seminar, July 1947.

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