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TECHNICAL REPORT 2496

HIGH RANGE RESOLUTION COHERENT RADAR

by

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JUNE 1964

U. S. ARMY ELECTRONICS LABORATORIES
U. S. ARMY ELECTRONICS COMMAND

FORT MONMOUTH, N. J.

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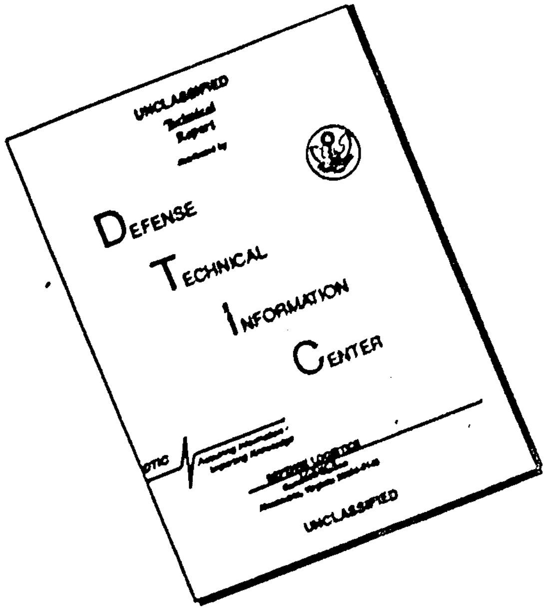

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ABSTRACT

An experimental coherent radar was assembled to investigate the value of high range resolution, without comparable azimuthal resolution, in differentiating between natural targets and man-made targets. A pulsed varactor diode in a microwave switch was used to modulate the output of a CW klystron. The peak power output was about 100 milliwatts. The best range resolution obtained was about three feet. Since the system used coherent detection, any target motion appeared quite clearly on the A-scope presentation. A distinct difference could be seen between the return from a steadily moving target such as a vehicle and the return from an irregularly moving target such as a tree branch or foliage swaying in the wind. A range resolution of 15 feet was found to be insufficient to show any clear differences between a walking man and a moving vehicle. With a six-foot range resolution, however, the return from a moving vehicle began to show more than one peak. With the three-foot resolution, a vehicle might show as many as four or five peaks. An intensity-modulated raster display was used for part of the tests. This type of display, which presented the relative phases of the separate returns from a target where the resolution was fine enough to produce more than one return, also indicated the possibility of showing whether a slowly-moving target was approaching or receding. The use of different types of vehicles at varying aspects is recommended for further evaluation of the high range resolution technique. Reduction in equipment size and weight to provide portability is also recommended.

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HIGH RANGE RESOLUTION COHERENT RADAR

INTRODUCTION

A primary objective in the design of a radar for combat surveillance is the ability to distinguish between targets of military interest such as vehicles, weapons, and personnel, and natural targets such as trees and foliage. Several techniques have been proposed to this end. Among them are frequency signature, polarization sensitivity, and high resolution. An experimental breadboard-type radar was assembled to investigate the value of high range resolution, without comparable azimuthal resolution, in differentiating between natural targets and man-made targets.

EXPERIMENTAL EQUIPMENT

In the tests conducted with the experimental high range resolution coherent radar, three system configurations were tried and several differing pulse-forming circuits were employed. Various stationary and moving targets were used in the investigation.

System Block Diagrams

1. *Original Setup*

A block diagram of the experimental radar system as it was originally assembled is shown in Figure 1. The source of RF energy is an X-band klystron with a power output of about 100 milliwatts. The klystron is not pulsed. Its output is routed to an RF switch via a four-port circulator. The switch is tuned to either absorb or reflect the RF power, thus it functions as the modulator when a pulse is applied to it. The RF pulse reflected by the switch is transmitted through the circulator and a tuner to the antenna. The tuner is adjusted for maximum cancellation of reflections from the antenna.

Received signals pass through the circulator to a crystal mixer. Enough leakage through the circulator from the klystron reaches the mixer to act as a reference, so that the mixer functions as a coherent detector. The system is essentially a superheterodyne with an intermediate frequency of zero, hence a second detector is not required. The video signal from the mixer is amplified by wideband distributed amplifiers. A wideband oscilloscope is used to provide an A display.

2. *Adjustment for Local Oscillator Injection*

A modified form of the system, which provides an adjustment for the amount of local-oscillator injection, is shown in Figure 2. In this modification, two three-port circulators are required. The tuner between the two circulators is adjusted to reflect back the desired amount of the klystron power to the crystal mixer. Unfortunately, the incoming received signal is reflected by the same amount on the other side of the tuner. However, the reflection factor is normally less than 10 percent, therefore the loss is insignificant.

For adjustment of the initial system setup, the antenna tuner is set for minimum reflection of the transmitted pulse from the antenna. With the system as shown in Figure 2, the antenna tuning is not independent of the adjustment for local-oscillator injection as far as minimization of the transmitted pulse in the receiver is concerned. This situation makes alignment of the system a rather tedious process, since four interdependent adjustments are involved. Presumably the problem is caused by internal reflections of the transmitted pulse between the two tuners.

3. *Balanced Mixer*

In order to eliminate one of the tuners while still allowing some control over the local-oscillator injection, a third configuration was tried (Figure 3). Here a balanced crystal mixer is used. The local-oscillator signal is obtained separately from a directional coupler that follows the klystron. This version of the system is easier to tune, but it has the disadvantage of requiring a somewhat larger waveguide assembly. Each of these waveguide configurations has both advantages and disadvantages over the others, so that no one configuration is superior to the others. Once initial alignment is accomplished, the performances of the three versions are about equal.

Varactor Switch

The varactor switch, which modulates the RF energy, is essentially the heart of the system. The switch consists of a short section of waveguide with the varactor mounted at the center, parallel to the E-vector. One end of the waveguide section is terminated in a matched load and the other end is connected to a tuner, which in turn is connected to the remainder of the equipment. The tuner is adjusted so that absorption of the RF energy takes place when the varactor is forward biased and reflection takes place when it is reverse biased. The switch assembly must be used with a circulator so that the reflected and incident components can be separated. The varactor used is Microwave Associates, Type SC-70. A change of only a few volts at low power is needed to switch between the *on* and *off* conditions. The switch does not impose any limit on the rise time of the RF pulse that can be generated in this way.

Pulse Generators

The means for generating the pulse applied to the varactor switch have evolved through several forms as efforts were made to shorten the transmitted pulse and thus improve the range resolution.

1. *Shorted Coaxial Cable*

The first method used to obtain a reasonably short pulse that could be applied to the varactor switch was to electrically differentiate the output of a Dumont Model 404 pulse generator with a length of coaxial cable, shorted at one end. The Dumont generator affords variable pulse length down to 0.1 microsecond and output of up to 50 volts at either polarity, across 50 ohms. In addition, it has the important advantage, for this application, of repetition rates in excess of 50 kilocycles. The output rise time is of the order of 10 nanoseconds.

The circuit is shown in Figure 4. An appropriate bias is included to keep the varactor switch in the *off* condition until the pulse occurs. The waveform applied to the varactor is two pulses of opposite polarity, separated by a time equal to the length of the output pulse from the generator. The polarity of this output pulse can be selected so that the second of the two resulting short pulses produces the transmitted pulse. Then the other pulse, which may cause some output from the receiver, will be completed before the A-scope sweep starts. The minimum pulse width that can be produced by this method is determined by the rise time of the generator output. Hence the length of the shorted delay line must be such as to give a round-trip delay approximately equal to the generator rise time. By using the circuit of Figure 4, a transmitted pulse width of about 30 nanoseconds at half amplitude is obtained, giving a range resolution of approximately 15 feet.

2. *Reverse-Bias Series Diode*

Since the varactor is forward biased in the *off* condition, a change of only a few tenths of a volt is required to take it out of conduction and into the *on* condition. As a consequence, the width of the transmitted pulse is determined by the width of the base of the voltage pulse applied to the varactor. The circuit shown in Figure 5 was used in order to allow the peak of the applied voltage pulse, which is, of course, much narrower than its base, to determine the transmitted pulse width. In this circuit, a reverse-bias series diode is employed so that only that part of the delay-line pulse which is near the peak value is used. A change of only a few volts at the varactor is needed; both the amplitude of the pulse before clipping and the diode bias can be selected so as to make use of only a tenth or so of the total pulse excursion. However, because the shape of the pulse from the delay line is not truly triangular, a proportionate decrease in transmitted pulse width is not realized. Also, the switching time of the series diode may impose some limitation. A range resolution of about 6 feet was obtained with this arrangement.

3. *Avalanche Breakdown*

With another method of pulse generation, a range resolution of about three feet was achieved. The circuit used was that of Figure 6. This circuit makes use of the avalanche mode of breakdown[1] in a silicon transistor, with the differentiated pulse from the Dumont generator serving only as a trigger. A very high rate of rise of current can result from the avalanche breakdown. When the breakdown occurs, most of the voltage across C_2 appears across R_3 as a fast-rising voltage pulse. This voltage then decays exponentially as C_2 discharges. A clipping diode is used in the avalanche-breakdown mode, to gain a further reduction in pulse width. The diode bias can be **adjusted by changing** R_4.

4. *Transistorized Trigger Generator*

The Dumont pulse generator has the disadvantage that it causes some ringing in the receiver which shows up in the display. This ringing is apparently due to stray pickup, since it is present even when the avalanche breakdown circuit is not energized. The generator can be eliminated by using the transistorized trigger generator circuit shown in Figure 7 to furnish the trigger for the circuit of Figure 6. The transistorized trigger generator circuit consists of a free-running multivibrator followed by a shaping stage, a differentiator, a blocking oscillator, and another shaping stage. The output is a 12-volt rectangular pulse about .05 microsecond long, repetitive at about 120 kilocycles. Very desirable reductions in size, weight, and power consumption are obtained.

5. *Astable Multivibrator*

Still another circuit that can accomplish the entire pulse-generating function is shown in Figure 8. The circuit consists of an astable multivibrator followed by a differentiator, two shaping stages, a second differentiator which is adjustable, and two more shaping stages. A clipping diode is used at the output, as with the circuits shown in Figures 5, 6, and 7. An additional output is taken off in front of the second differentiator for use as a sweep trigger for the oscilloscope. This circuit provides a three-foot range resolution and requires less power than the other circuits.

The circuit given in Figure 8 was developed only recently by the author. Preliminary work has shown a slight drift in pulse amplitude which may have to be controlled before this circuit can be used conveniently with the coherent radar system.

Video Amplifiers

The experimental radar system made use of three Spencer-Kennedy Laboratories, Inc. Model 202 C/D wideband distributed amplifiers in cascade. Each of these amplifiers has a nominal gain of 20 db and a rise time of 2.6 nanoseconds.

A-Type Display

Originally, a Tektronix oscilloscope, Model 517, which has a rise time of about 7 nanoseconds, was used for the display. A range resolution of six feet was about the best that could be obtained. Acquisition of a Model 581, which has a rise time of approximately 3.5 nanoseconds, allowed attainment of the three-foot resolution.

Intensity-Modulated Raster Display

Intensity modulation of a raster on the oscilloscope was used in a few of the tests. The raster was produced by applying a low-frequency triangular-wave voltage, instead of the video signal, to the vertical input of the scope. This triangular wave was also applied to the klystron repeller to provide a frequency sweep approximately linear with time. The video was passed through two additional distributed amplifiers and used to modulate the intensity of the raster. With this arrangement, some rather interesting pictures were obtained.

Antenna

In all of the work discussed in this report, a dish antenna 18 inches in diameter was used. An 18-inch diameter affords an antenna beamwidth of about 4-1/2 degrees at X-band. No attempt was made to make changes in the azimuthal resolution comparable with those made in the range resolution.

Initial System Adjustment

When the arrangement of Figure 1 or that of Figure 2 is used, initial tuning of the system consists of only two steps:

1. The tuner adjacent to the varactor switch is set for the best transmitted pulse shape. This pulse shape is quite sensitive to the amplitude of the pulse applied to the varactor, therefore the two pulses must be adjusted at the same time. Some experimentation to find the optimum varactor bias may be worthwhile.

   The shape of the transmitted pulse can be examined by substituting a crystal detector for the antenna and observing its output directly on the oscilloscope. The crystal should be loaded with a low resistance (50 ohms or so) to insure an accurate presentation of the pulse shape. The antenna tuner, if not removed with the antenna, should be set for minimum reflection.

2. The antenna must be pointed away from any close targets. When the antenna is in place, the antenna tuner should be adjusted for minimum reflection of the transmitted pulse. The transmitted pulse is very short, so that the reflected pulse is received from the tuner before it is received from the antenna; hence, a complete cancellation cannot be effected. The tuner must, therefore, be set for minimum ringing on the base line of the A-scope presentation. In order to minimize the ringing, particular attention should be paid to the grounding of the individual units of the system. Trial-and-error seems to be the best method for finding the optimum grounding scheme.

DATA

The target returns displayed on the oscilloscope were photographed and the resulting oscillograms analyzed. Typical examples are presented in Figures 9 through 15.

Range Resolution, Fifteen Feet

One of the early A-scope pictures, taken with a range resolution of about 15 feet, is shown in Figure 9. The horizontal (range) scale is 100 feet per centimeter. A stationary wire fence at a distance of about 460 feet was used as a target. The fence was not perpendicular to the beam of radiation, so that echoes were produced from more than one range. A tree swaying in the wind, situated about 315 feet from the radar, was selected as a second target. As the tree moved, the phase of the received signal changed with respect to the local-oscillator reference, and the amplitude of the video pulse was proportional to the cosine of this phase difference.

The photograph, a 2-second time exposure, shows the motion of the tree quite clearly in contrast to the stationary fence. Note that a tree movement of only 5/16 of an inch is required to change the video pulse from its positive to its negative limit. In addition, movement of the tree in the wind changes the relative phases of the returns from the many individual points of reflection. This change in relative phases results in a change in amplitude of the composite return.

Range Resolution, Six Feet

Figure 10 shows an oscillogram taken after the range resolution was improved to about 6 feet. Here the range scale is 50 feet per centimeter. The first 50 feet are not shown in the picture. The target, at a range of 210 feet, is a walking man. The returned video pulse is seen as a continuous blur over the exposure time of one second, since the phase of the returned pulse is constantly changing with respect to the reference. Figure 10 also shows the return from a fixed target located at a range of about 280 feet. Some ringing due to the transmitted pulse is evident for the first 150 feet of range. The ringing could not be completely eliminated.

A similar situation is shown in Figure 11, but in this case the moving target is a vehicle. Here the range of the target changed sufficiently during the one-second exposure time to cause a stretching of the video pulse as recorded on the photograph.

The oscillogram in Figure 12 represents the returns from three stationary targets: at a range of about 165 feet, a sedan was parked; at 230 feet, a 2-1/2-ton truck was positioned; a trailer was located behind the truck. Note that the return from the sedan produced two peaks on the display and that two peaks were also returned from the truck. The second peak from the truck, smaller than the first, was of the opposite polarity. Only one peak was returned from the trailer.

The same target arrangement was used with the intensity-modulated display to produce the oscillogram of Figure 13. The horizontal scale still corresponds to range, as in the preceding photographs. The vertical scale, however, is now proportional to the change in the transmitted frequency, since the klystron frequency is being linearly swept in proportion to the vertical deflection of the oscilloscope trace. The range scale is 50 feet per centimeter. In this case, the first 50 feet are not omitted. The spots repeat in the vertical direction when the change in frequency is sufficient to change the phase relationship between the transmitted and received signals by 360 degrees. In other words, the change in frequency from one spot to the next (along the vertical scale) indicates a change of one wavelength in the round-trip distance. The spots are closer together for targets at greater ranges since the number of wavelengths in the round-trip distance is greater and a smaller change in frequency is required to change this number by one.

Although the inferior dynamic range of the intensity-modulated display causes some loss of range resolution, the two peaks for the sedan and the two for the truck are plainly visible. This type of display shows the relative phases of the returns from a single target, with a 360-degree ambiguity. If the target moves, these phases will change together and the spots will move vertically. If the spots move up, an approaching target is indicated. A down motion means that the target is receding, provided that the motion of the target is sufficiently slow to preclude ambiguities from the raster frequency. The vertical scale gives very fine but highly ambiguous range information, in comparison with the horizontal scale.

Range Resolution, Three Feet

The results obtained with a range resolution of about three feet are shown in the oscillograms of Figures 14 and 15. In each case the target was a 2-1/2-ton truck and the range scale was 25 feet per centimeter. In Figure 14, the radar was looking almost head-on at the truck from a range of about 150 feet. Five separate peaks are apparent. The aspect was changed by 90 degrees for Figure 15. Here, only two or possibly three peaks result from a side view of the vehicle. Severe ringing due to the transmitted pulse obscures the first 50 feet of range in these pictures.

RESULTS

The A-scope oscillograms given in Figures 9 through 15 demonstrate how a coherent radar can differentiate between fixed and moving targets. Motion of as little as a fraction of a wavelength is immediately evident. In addition, irregular motion, as exhibited by tree branches or bushes swaying in the wind, can be readily distinguished from the steady motion of a target such as a vehicle or a walking man.

When the target is a vehicle and the radar has a range resolution of 15 feet, only one peak appears on the A-scope. Hence, except for the difference in amplitude, the returns from a vehicle and from a man are similar. With the 6-foot resolution, however, vehicles begin to show more than one peak, and as many as four or five peaks can be seen with the 3-foot resolution. A comparison of Figures 14 and 15 shows that with a 3-foot resolution the number of peaks produced by a vehicle is sensitive to aspect.

The intensity-modulated raster display shows the relative phases of the separate returns from a target, where the resolution is fine enough to produce more than one return. In addition, this type of display has the possibility of showing whether a slowly moving target is approaching or receding.

RECOMMENDATIONS

Most of the effort in this investigation has been directed toward improvement of the range resolution and performance of the coherent radar system. Little further improvement in resolution can be expected from use of the equipment at hand. Hence any further experimentation should be directed toward obtaining data on the radar returns from different types of vehicles at varying aspects.

Further evaluation of the high range resolution technique in the field would be facilitated by reducing the size and weight of the equipment to provide portability. To this end the possibility of developing a small A-scope display with the necessary bandwidth should be investigated. Some work has already been done on a small transistorized video amplifier to replace the large distributed amplifiers now in use. A transistorized pulse generator and klystron power supply are presently available.

REFERENCE

1. Millman, J. and Taub, H., "Pulse Digital Circuits," p. 555, McGraw-Hill Book Company, Inc., New York (1956)

Selected Reference

Military Standardization Handbook, "Selected Semiconductor Circuits," MIL-HDBK-215 (15 June 1960)

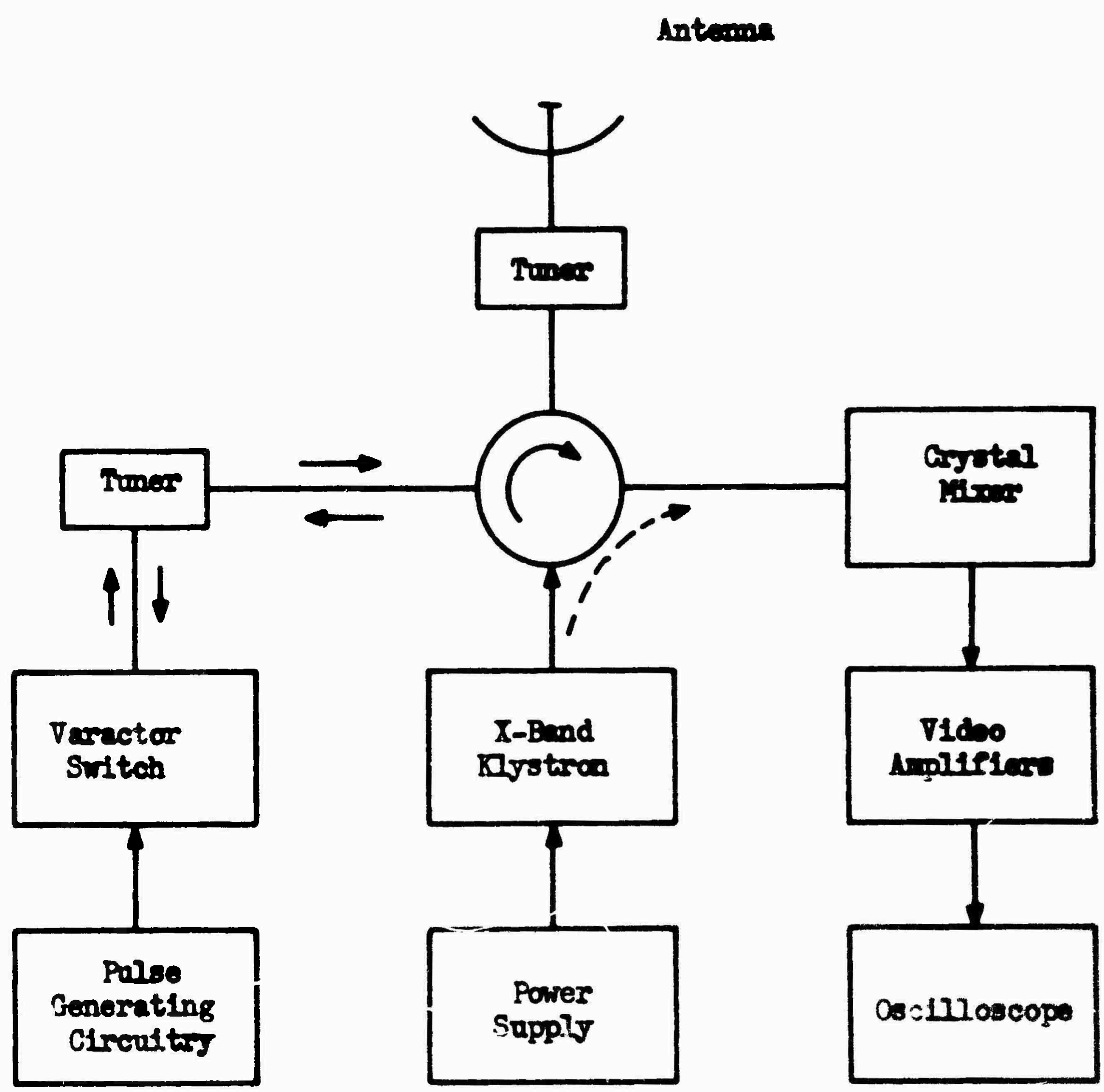


FIGURE 1

ORIGINAL SYSTEM SETUP

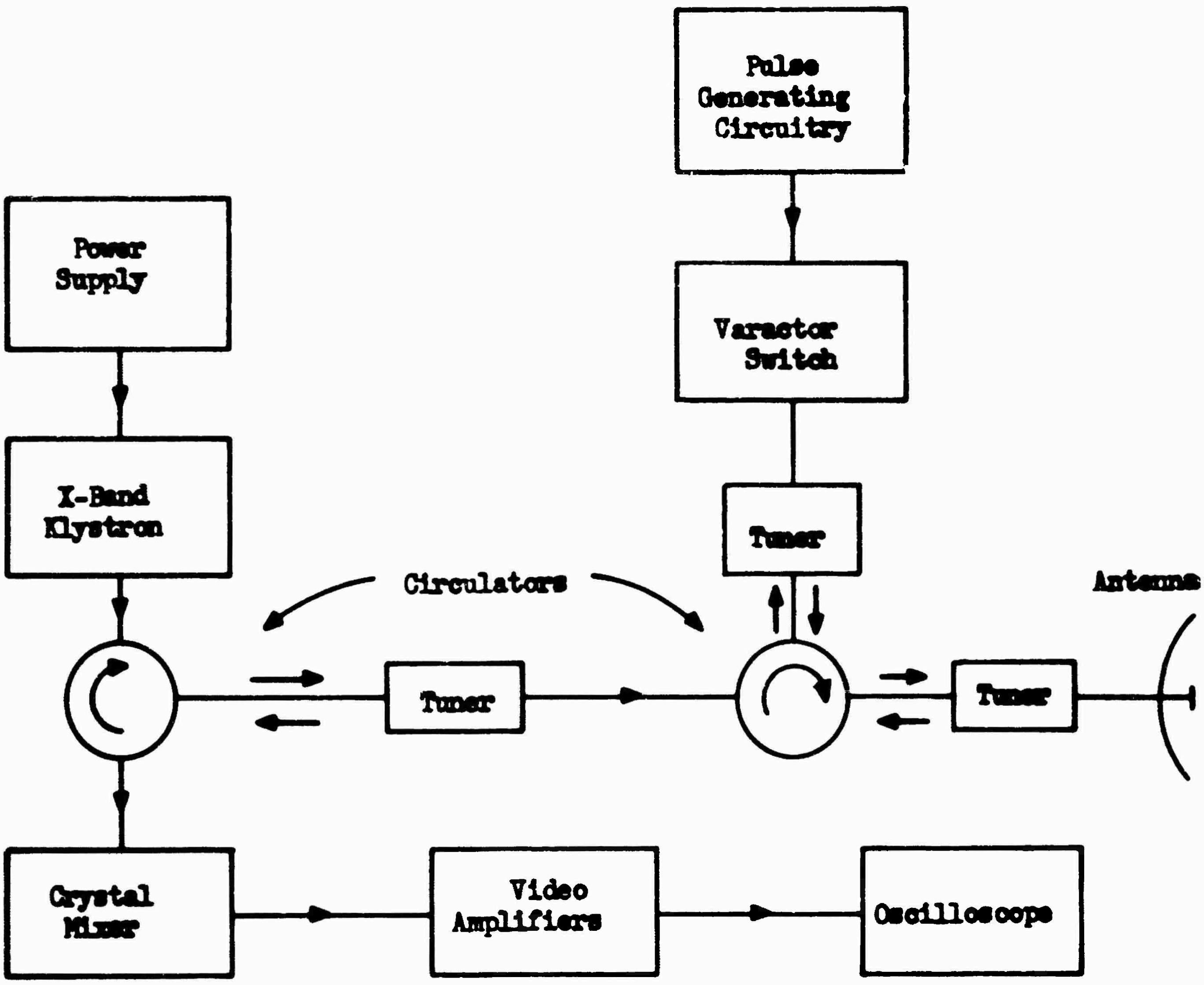


FIGURE 2

MODIFIED SYSTEM WITH ADJUSTABLE LOCAL-OSCILLATOR INJECTOR

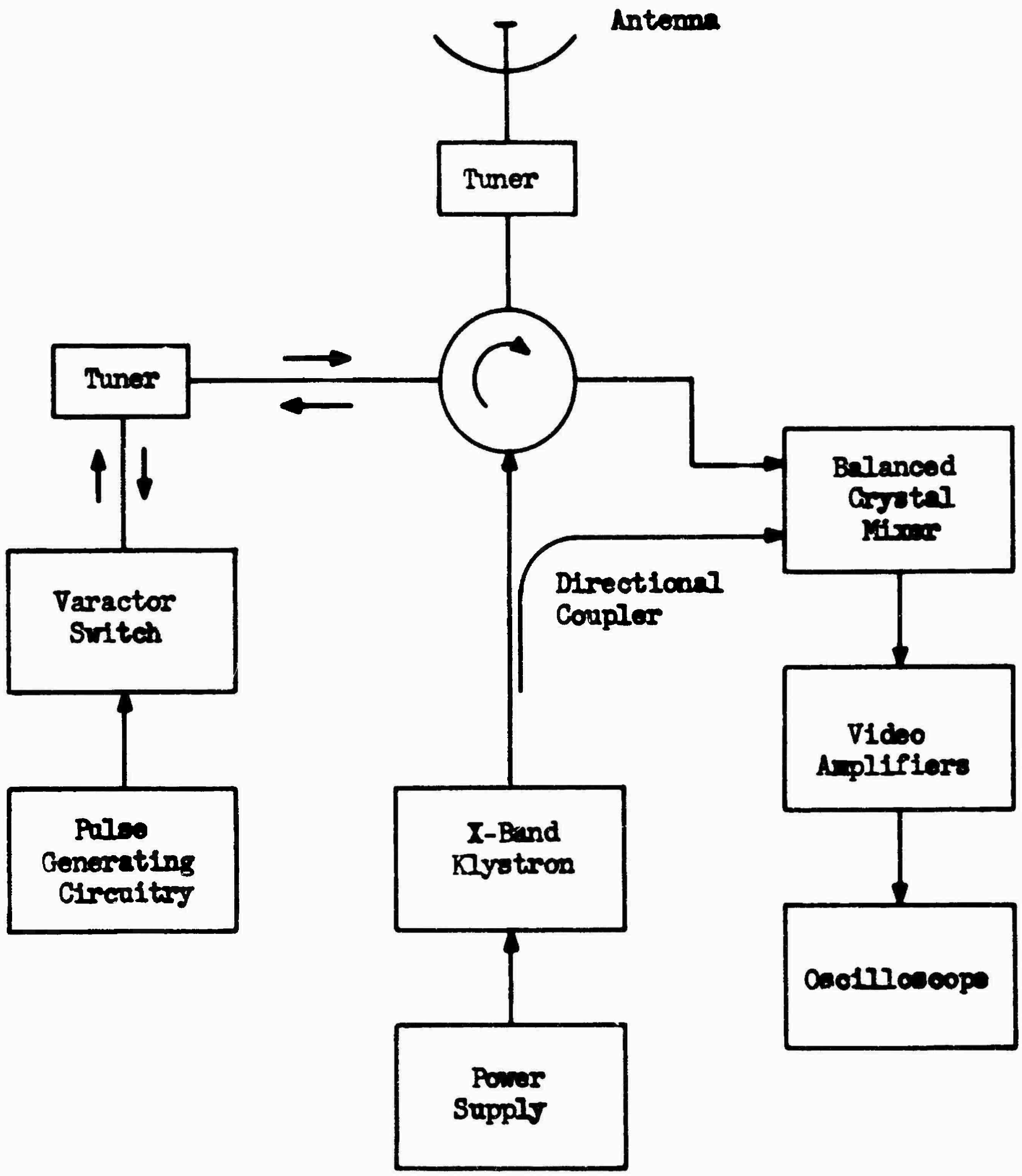


FIGURE 3

MODIFIED SYSTEM WITH BALANCED MIXER

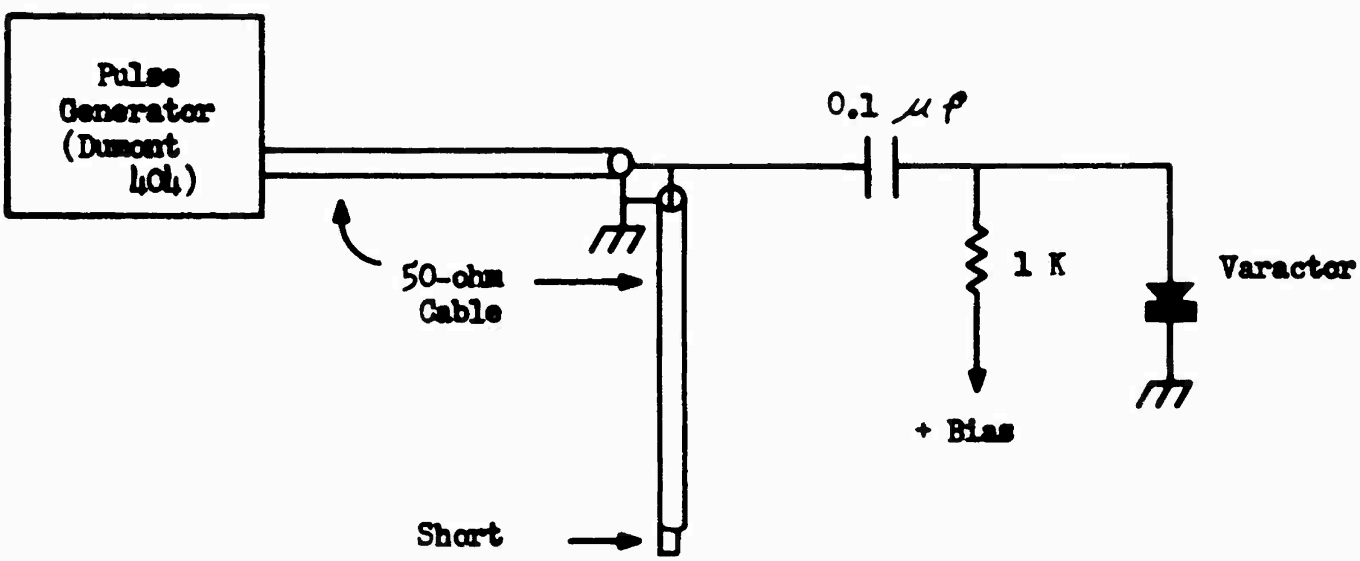


FIGURE 4

PULSE-GENERATING CIRCUITRY AFFORDING
FIFTEEN-FOOT RANGE RESOLUTION

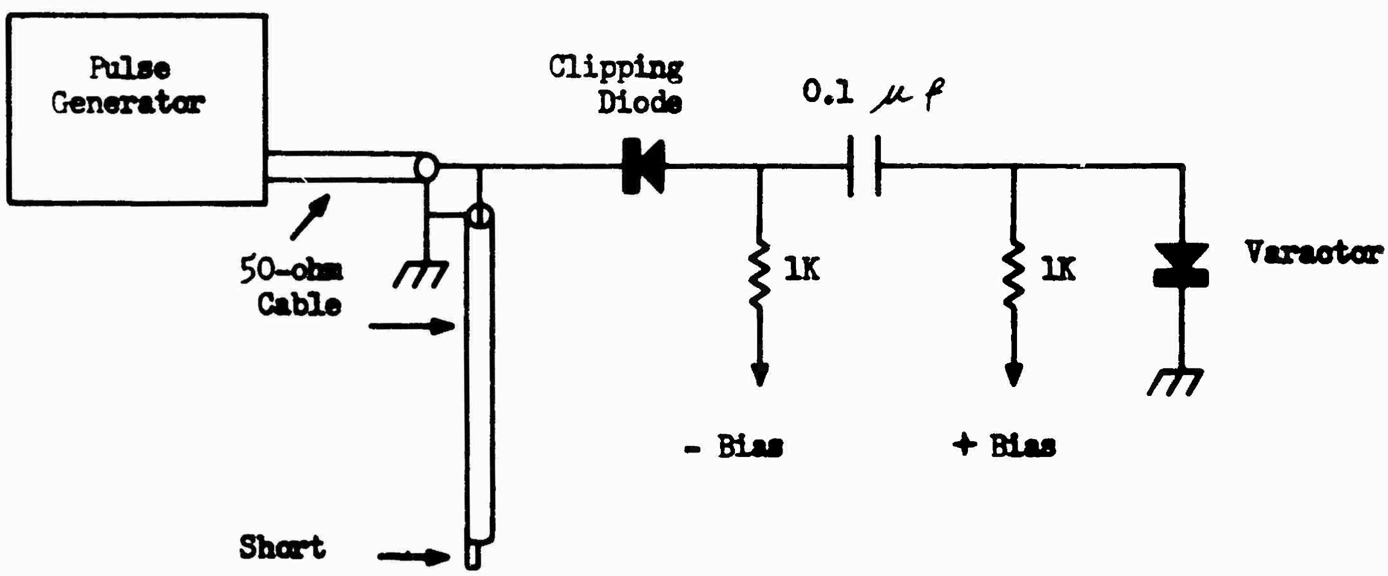


FIGURE 5

PULSE-GENERATING CIRCUIT WITH CLIPPING DIODE
AFFORDING SIX-FOOT RANGE RESOLUTION

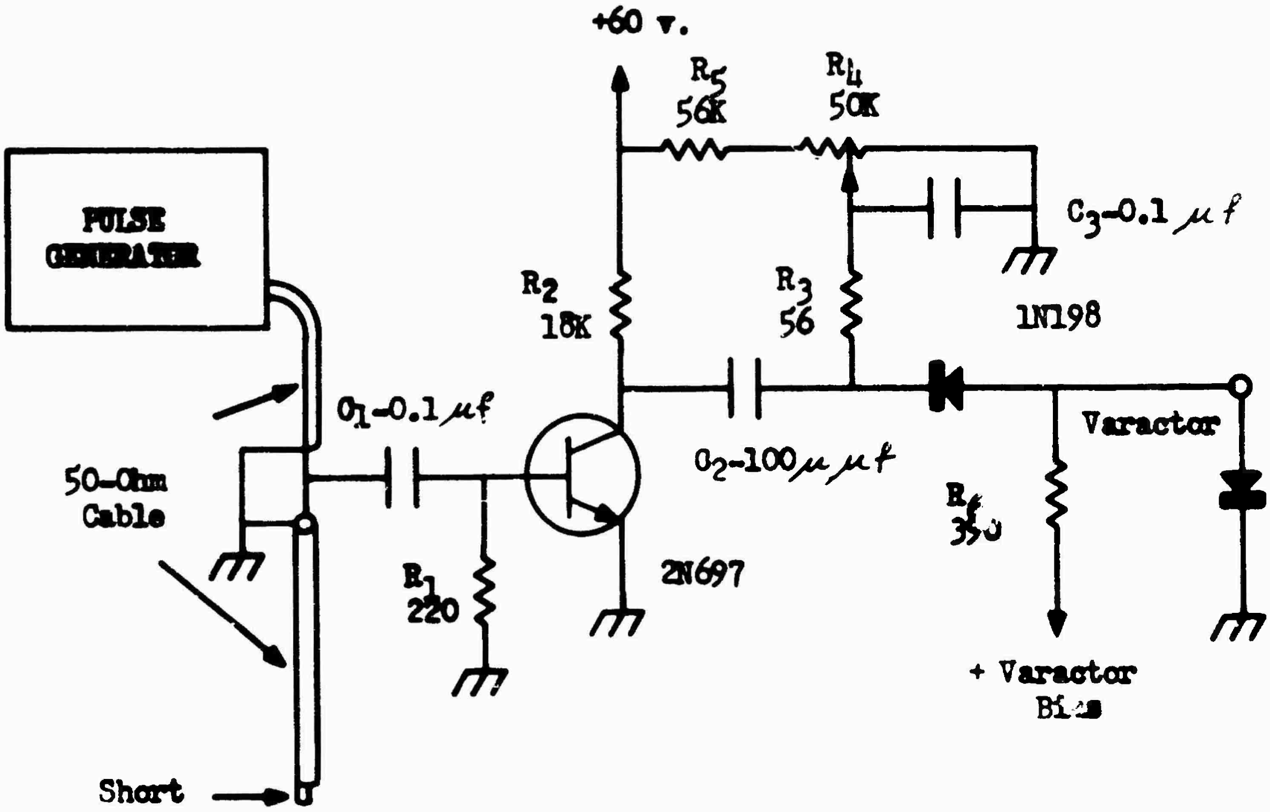


FIGURE 6

PULSE-GENERATING CIRCUIT USING TRANSISTOR IN AVALANCHE BREAKDOWN MODE

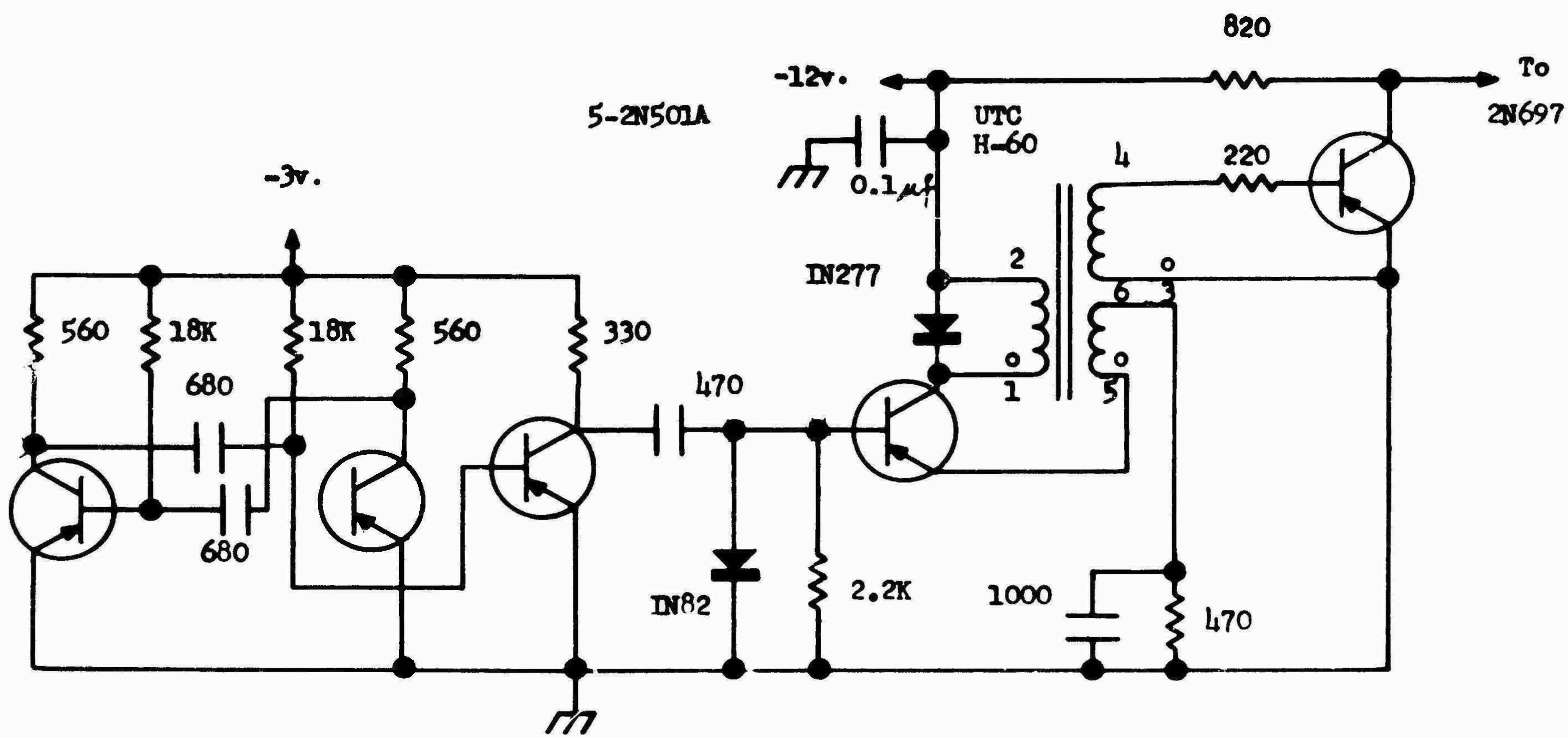
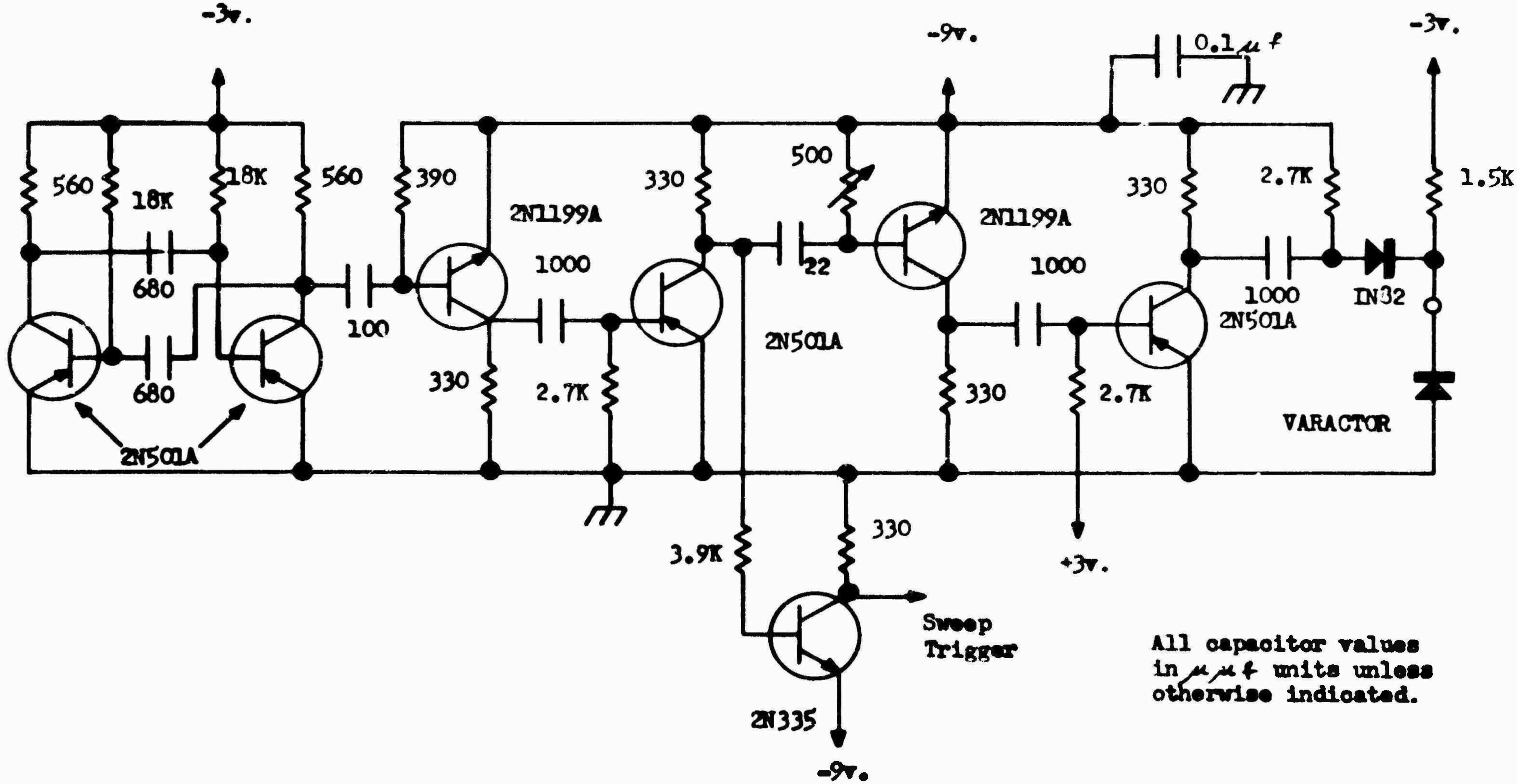


FIGURE 7

CIRCUIT OF TRANSISTORIZED TRIGGER GENERATOR



All capacitor values in $\mu\mu f$ units unless otherwise indicated.

FIGURE 8

CIRCUIT FOR ASTABLE MULTIVIBRATOR AND SIX-NANOSECOND PULSE GENERATOR

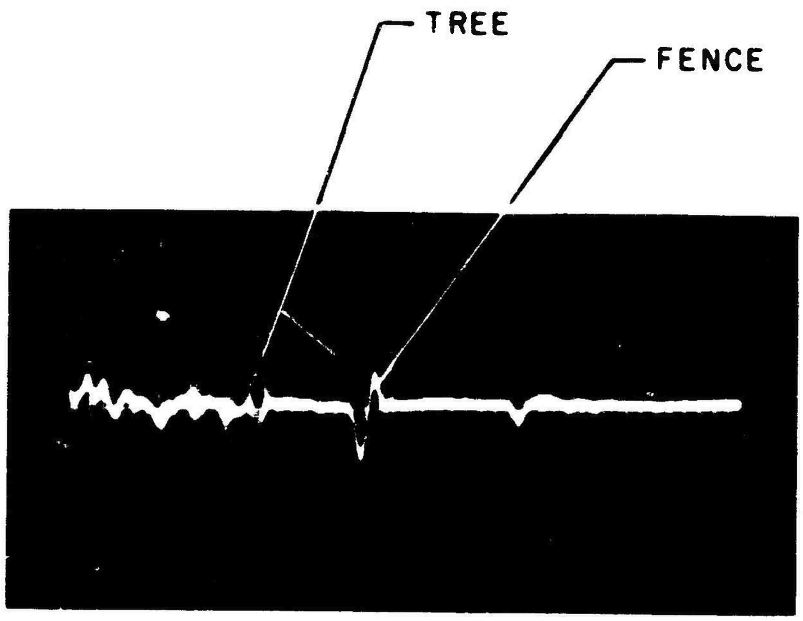


FIGURE 9

A-SCOPE OSCILLOGRAM SHOWING ECHOES FROM FENCE
AND TREE SWAYING IN WIND
RANGE SCALE, 100 FEET PER CENTIMETER
RANGE RESOLUTION, 15 FEET

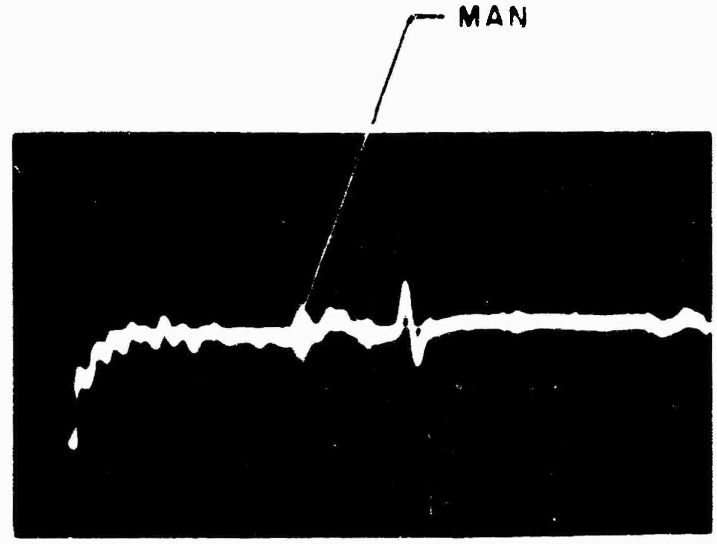


FIGURE 10

A-SCOPE OSCILLOGRAM SHOWING ECHO FROM WALKING MAN
RANGE SCALE, 50 FEET PER CENTIMETER.
RANGE RESOLUTION, 6 FEET

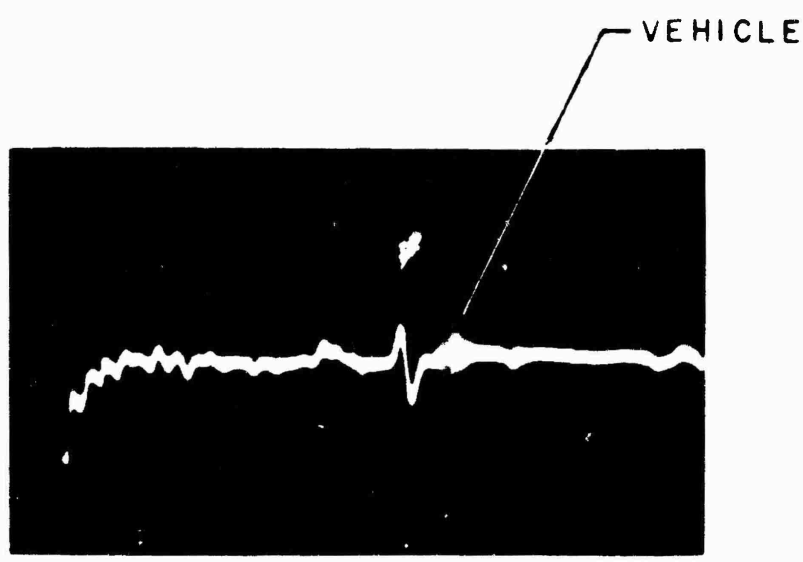


FIGURE 11

A-SCOPE OSCILLOGRAM SHOWING ECHO FROM MOVING VEHICLE
RANGE SCALE, 50 FEET PER CENTIMETER
RANGE RESOLUTION, 6 FEET

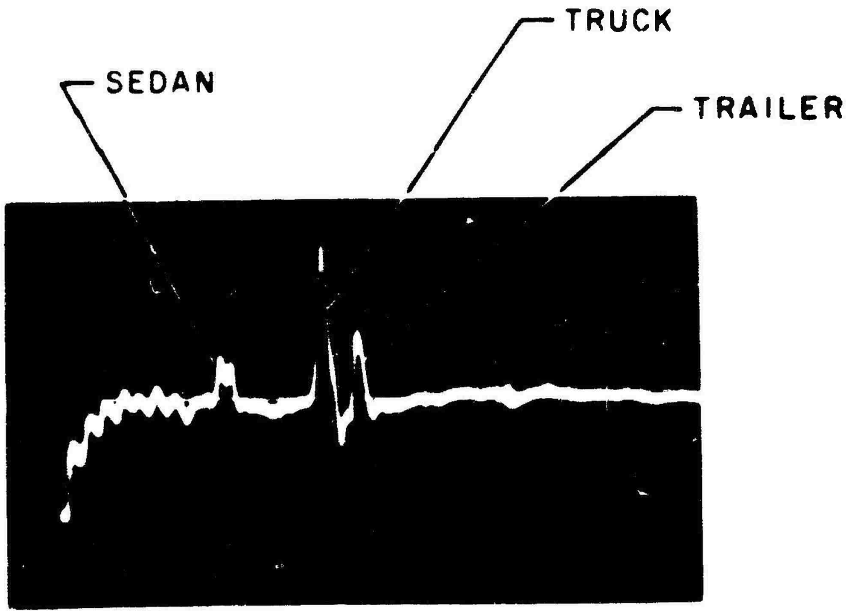


FIGURE 12

A-SCOPE OSCILLOGRAM SHOWING ECHOES FROM SEDAN,
2-1/2-TON TRUCK, AND TRAILER
RANGE SCALE, 50 FEET PER CENTIMETER
RANGE RESOLUTION, 6 FEET

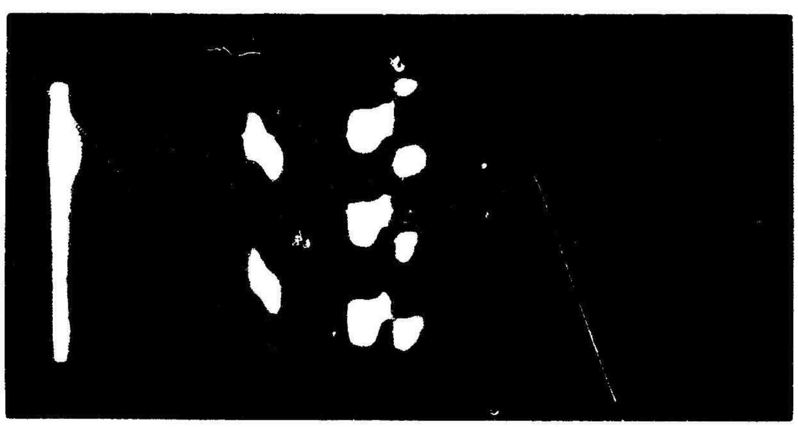


FIGURE 13

PHOTOGRAPH OF INTENSITY-MODULATED DISPLAY
WITH SAME TARGETS AS IN FIGURE 12
RANGE (HORIZONTAL) SCALE, 50 FEET PER CENTIMETER

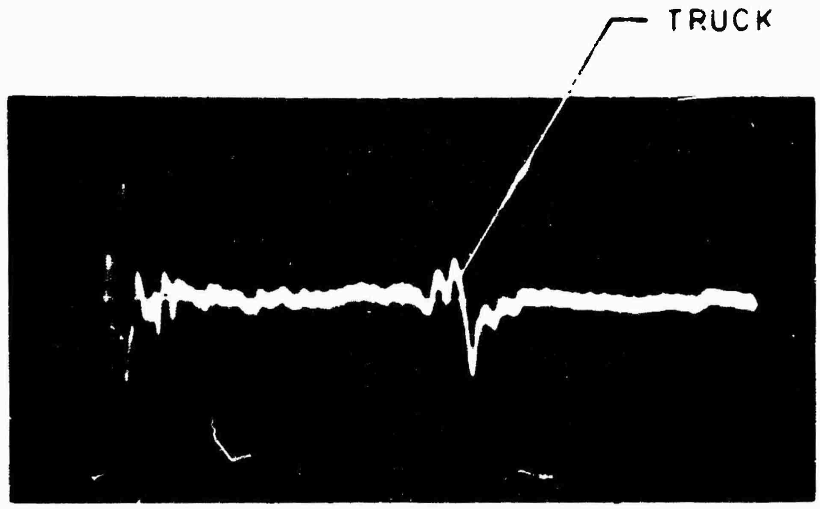


FIGURE 14

A-SCOPE OSCILLOGRAM SHOWING ECHOES FROM 2-1/2-TON **TRUCK**
FRONT ASPECT
RANGE SCALE, 25 FEET PER CENTIMETER
RANGE RESOLUTION, 3 FEET

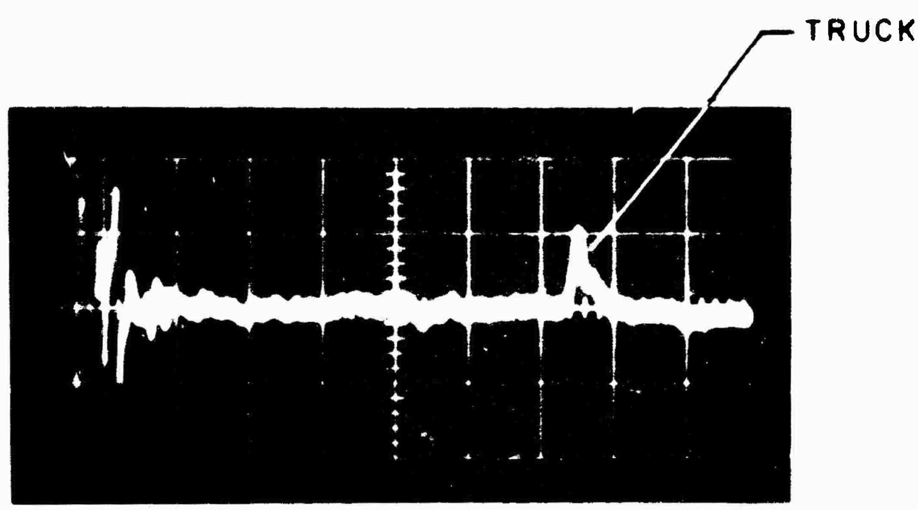


FIGURE 15

A-SCOPE OSCILLOGRAM SHOWING ECHOES FROM 2-1/2-TON TRUCK
SIDE ASPECT
RANGE SCALE, 25 FEET PER CENTIMETER
RANGE RESOLUTION. 3 FEET

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Army Electronics Laboratories, ECOM, Fort Monmouth, N. J.
HIGH RANGE RESOLUTION COHERENT RADAR by Samuel E. Craig. June 1964, 18 p. incl. illus., refs. (AEL Technical Report 2490)
(DA Task 1G6-20901-D-041-01)
Unclassified report

An experimental coherent radar was assembled to investigate the value of high range resolution in differentiating between natural targets and man-made targets. A pulsed varactor diode in a micro-wave switch was used to modulate the output of a CW klystron. Peak power output was about 100 milliwatts, best range resolution about three feet. A distinct difference could be seen on the A-scope presentation between returns from a steadily moving target such as a vehicle and from an irregularly moving target such as foliage swaying in the wind. An intensity-modulated raster display, used for part of the tests, presented the relative phases of separate returns from a target and also indicated the possibility of showing whether a slowly-moving target was approaching or receding. Use of different types of vehicles at varying aspects is recommended for further evaluation of the high range resolution technique. Reduction in equipment size and weight to provide portability is also recommended.

1. Short Pulse Radar
2. Combat Surveillance
3. Coherent Radar

I. Craig, Samuel E.
II. Army Electronics Laboratories, ECOM, Fort Monmouth, N. J.
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