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MOVING TARGET INDICATION BY NONCOHERENT DETECTION

Isaac Levin

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THESIS

MOVING TARGET INDICATION BY NONCOHERENT DETECTION

by

Isaac Levin

June 1975

Thesis Advisor: Prof. D. B. Hoisington

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An IF amplifier and detector were designed for a noncoherent MTI radar. The amplifier was designed to satisfy the following two requirements:

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B. When strong clutter is present, the amplifier must amplify the peak of the signal, since the effects due to small

moving targets are carried in the peak of the resultant signal.

The performance of the AN/UPS-1 air search radar, operated as a noncoherent MTI system with the modified IF amplifier, was checked. This modification provides increased sensitivity for the noncoherent MTI radar over a radar employing a logarithmic IF amplifier. The advantage of noncoherent MTI is its simplicity. It is therefore attractive for those applications where space and weight are limited. It is also attractive for airborne applications since no compensation is required for radar motion.

Moving Target Indication by Noncoherent Detection

by

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Major, Israeli Air Force
B.S., Israel Institute of Technology, 1966

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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June 1975

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An IF amplifier and detector were designed for a non-coherent MTI radar. The amplifier was designed to satisfy the following two requirements:

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The author wishes to thank Professor D. B. Hoisington for help, encouragement and generosity. He is also grateful to Mr. R. Seely and Mr. C. Sproule for their assistance, and to his wife for her untiring aid.

I. INTRODUCTION

The composite echo signal from a moving target and clutter at the same range fluctuates in both phase and amplitude. The coherent MTI and the pulse doppler radar make use of the phase variations in the echo signal to recognize the doppler component produced by a moving target. In this case amplitude fluctuations are normally removed by a phase detector and limiter, and the local oscillator producing the reference signal is coherent with the transmitter signal.

The doppler component generated by a moving target can also be detected by means of the pulse-to-pulse amplitude variations of the combined echo and clutter signal. In this case the transmitted signal does not have to be coherent, and no coherent local oscillator is required. An MTI radar which extracts information about moving targets in this fashion is said to be noncoherent or externally coherent. The noncoherent system does not require an internal coherent reference or a phase detector, the phase reference being supplied, in effect, by the clutter itself.

The noncoherent technique provides a relatively cheap form of MTI, and the whole systems is simple. Disadvantages will be mentioned later.

In general, if R is the distance from the radar to a target which has a radial velocity V_r with respect to the radar, then the number of wavelengths in one round trip is

$2R/\lambda$. The path from radar to target to radar has a phase length of ϕ

$$\phi = 2\pi \times \frac{2R}{\lambda} = \frac{4\pi R}{\lambda}$$

The change of this path length with time gives the doppler frequency, ω_d.

$$\frac{d\phi}{dt} = \frac{4\pi}{\lambda} \times \frac{dR}{dt} = \omega_d = 2\pi f_d$$

We know that for a closing target the received frequency is higher than the transmitted one, and R decreases, or $\frac{dR}{dt} < 0$ hence one can write:

$$\frac{4\pi}{\lambda} \times \frac{dR}{dt} = -\omega_d$$

$$\frac{4\pi}{\lambda} \times \frac{dR}{dt} = \frac{4\pi}{\lambda} V_r = -2\pi f_d$$

$\therefore$

$$f_d = \frac{-2V_r}{\lambda} = -\frac{2V_r}{c} f_o$$

Where f_o is the transmitted frequency.

In a coherent system a comparison is made between the reference signal, frequency f_o, and the target signal, frequency $f_o + f_d$. In a noncoherent system the extraction of a moving target information is explained as follows with the aid of Figure 1.

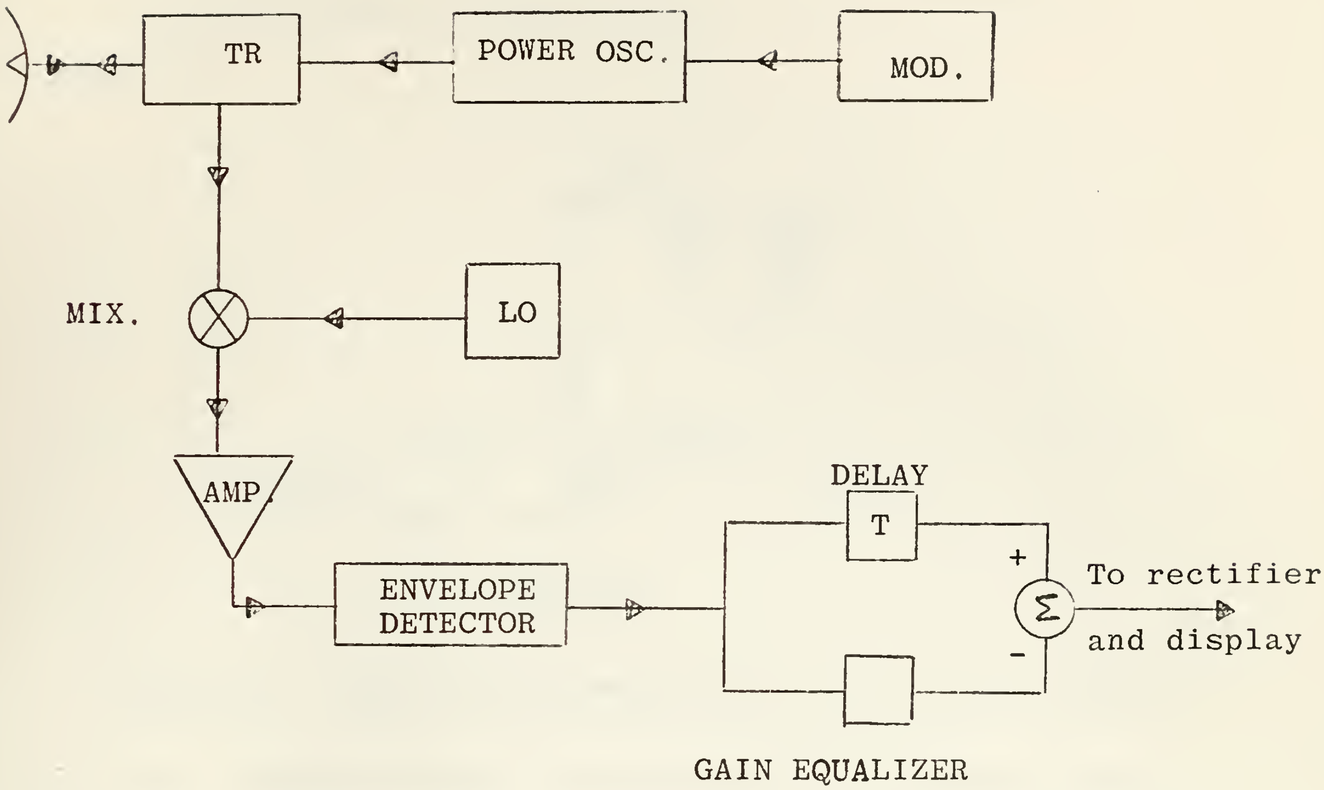

Figure 1. Noncoherent radar block diagram.

The modulator pulse modulates the RF signal and the energy is passed through the TR device to the antenna. The received signal is mixed with the local oscillator signal (LO) to produce the IF signal. One advantage of the system is that the local oscillator need not be as stable as in a coherent MTI. As will be shown later, if the envelope detector obeys a square-law output-input relation, then the canceller circuit will form the difference between the squares of the amplitudes of signals T seconds apart. For presentation on PPI scope, the output signal from the canceller (bipolar video) needs rectification.

A phasor diagram of the target signal is shown in Figure 2.

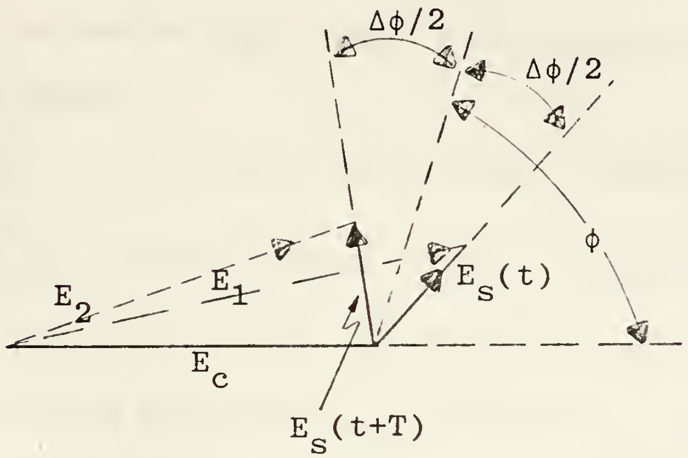

Figure 2. Relation between clutter and target signals.

E_c is the clutter voltage and serves as a reference vector. $E_s(t)$ is the target voltage at time t. $E_s(t+T)$ is the Target voltage at time T later. $(T=1/f_r)$; where f_r is the pulse repetition frequency. E_1 and E_2 are the resultant vectors of target plus clutter. ϕ is the average phase of the target signal relative to the clutter for these two phases and $\Delta\phi$ is the phase change of the target signal relative to the clutter during the interpulse period.

The resultant voltage amplitude may be expressed in terms of the signal and clutter amplitudes by using the law of cosines,

$$E_1^2=E_c^2+E_s^2-2E_cE_s\cos\ [180-(\phi-\frac{\Delta\phi}{2})] = E_c^2+E_s^2+2E_cE_s\cos(\phi-\frac{\Delta\phi}{2})$$

At a time T later the target echo is assumed to have changed phase by $\Delta\phi$, since the target is moving. For

simplicity there is assumed to be no scintillation.

$$E_2^2 = E_c^2 + E_s^2 + 2E_cE_s\cos(\phi+\Delta\phi/2)$$

If the detector prior to the canceller circuit is a square-law device, the output of the canceller network will have the form:

$$E_r^2 = E_1^2 - E_2^2 = 2E_cE_s\ |\cos(\phi-\Delta\phi/2) - \cos(\phi+\Delta\phi/2)|$$

$$E_r^2 = 2E_cE_s\ |2\sin(2\phi/2)\sin(-\Delta\phi/2)| = 4E_cE_s\ |\sin\phi\ \sin\Delta\phi/2|$$

In order to find an expression for $\Delta\phi$ assume that the echo signal is given by $V_{echo} = A\sin[2(f_t \pm f_d)t+4\pi f_tR/c]$ where f_t is the transmitted frequency, R is the target range and c is the speed of propagation.

If $\Delta\phi$ is defined as the relative phase change during an interpulse period, T, then

$$\Delta\phi = 2\pi f_dT = 2\pi f_d/f_r$$

and the equation for the detector output is:

$$E_r^2 = 4E_cE_s\left|\frac{\sin 4\pi R}{\lambda} \times \frac{\sin\pi f_d}{f_r}\right|$$

This equation demonstrates that clutter must be presented for moving target detection, since if $E_c = 0$, $E_r = 0$, that blind speeds exist, (for $f_d = Nf_r$ where N is an integer), and that MTI canceller output varies with range.

As seen from the above explanation, the chief limitation of a noncoherent MTI is that if a moving target is to be detected, it must exist in the presence of clutter signals. The clutter serves the same function as does the reference signal in the coherent MTI.

Usually in noncoherent systems the IF portion of the receiver has a logarithmic gain characteristic which provides protection against saturation when the received clutter signal is strong. In addition, this kind of characteristic tends to make the IF output fluctuations smoother than the input. The disadvantage of a logarithmic response is that in a situation of heavy clutter, the output voltage is much less sensitive to changes in the input signal. Hence if a target appears in heavy clutter, its influence on the output voltage is minimized drastically.

II. OBJECTIVES

The objective of this work was to design and build an IF amplifier and envelope detector for noncoherent MTI detection to enable the detection of targets in low or high clutter power. It is essential that the amplifier not saturates at high signal levels.

An AN/UPS-1 air search radar was chosen as the basic MTI radar to which the modified IF strip was to be incorporated.

III. SYSTEM DESCRIPTION, DESIGN AND OPERATION

Referring to Figures 3, 4, the principle used for the modification is explained.

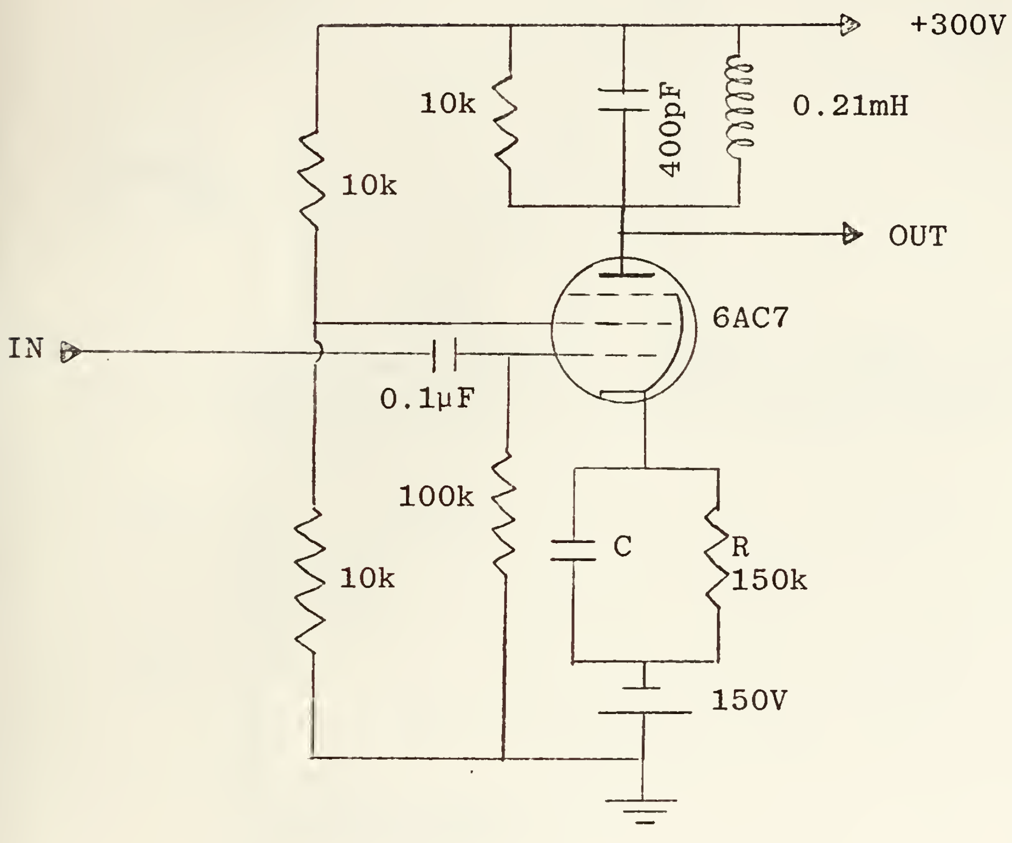

Figure 3. Vaccum tube amplifier with dc degeneration.

With large R in the cathode the current feedback is significant, and the average current through the tube is nearly constant and independent of input signal amplitude. This is shown in Figure 4.

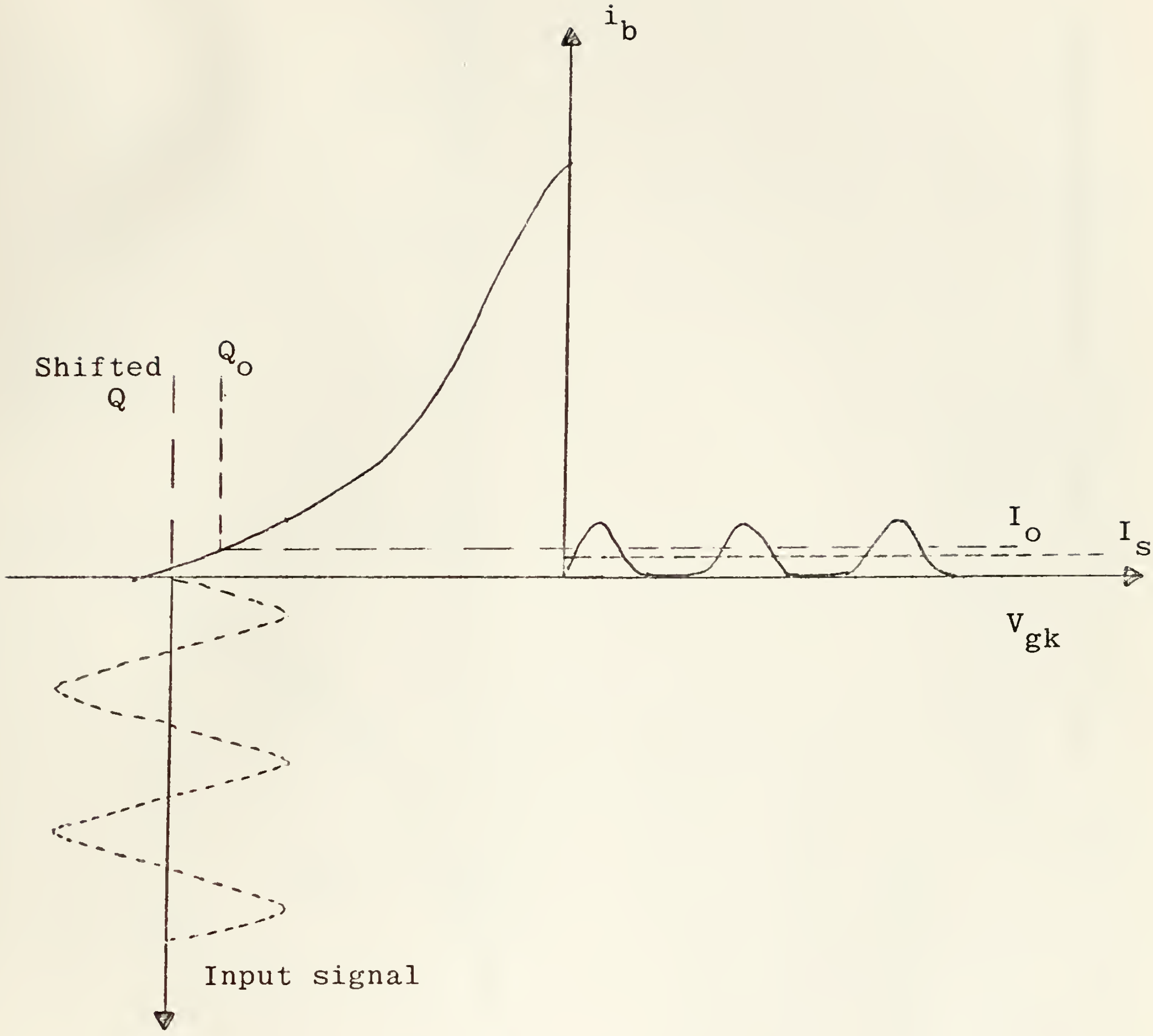

Figure 4(a). Quiescent point shifting.

Average anode current of signal plus the shifted quiescent current I_s equals approximately I_o

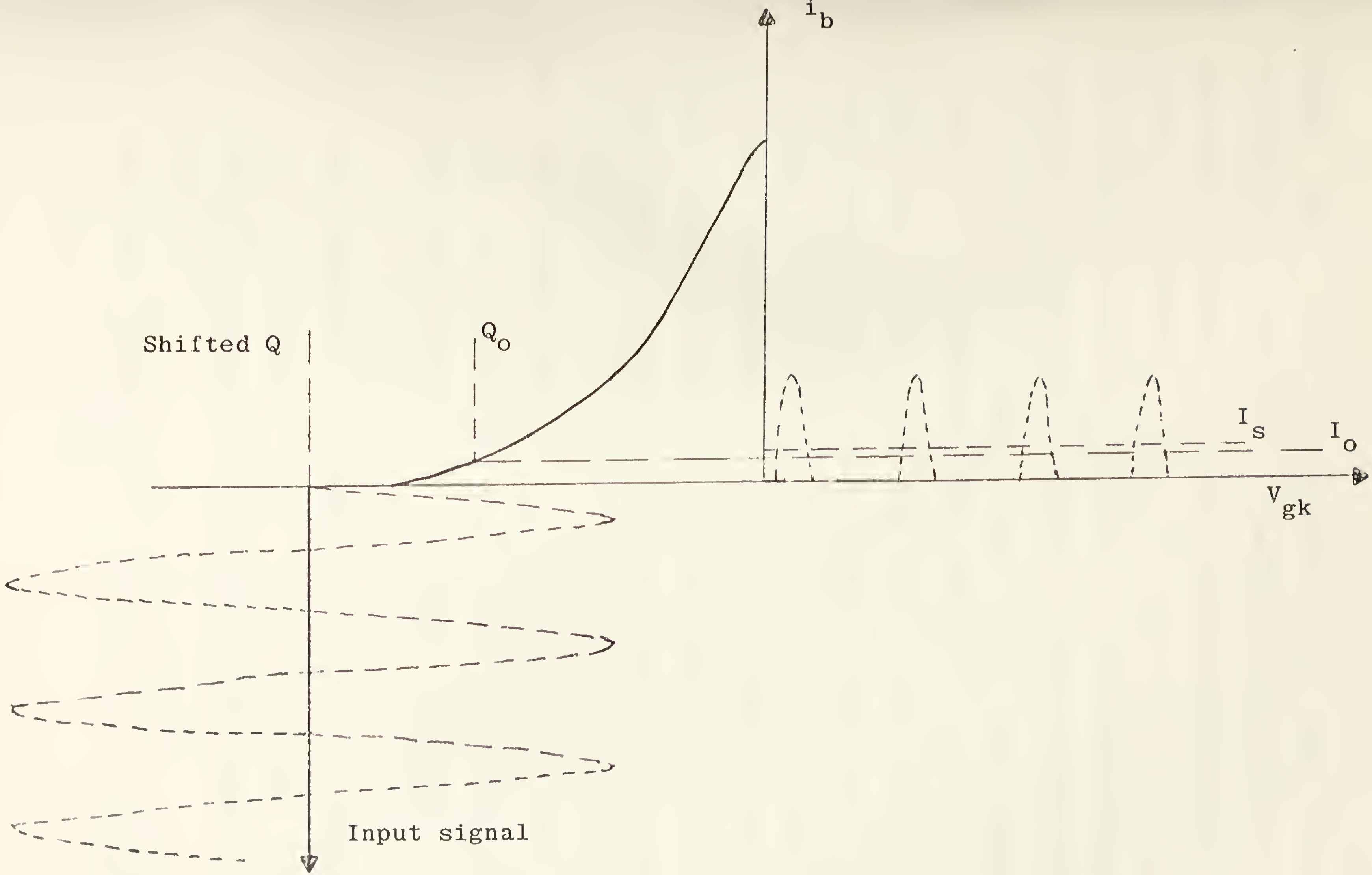

Figure 4(b). Quiescent point shifting

Average anode current of signal equals approximatley the quiescent current I_o

The Q point is chosen to be near the cut-off point of the 6AC7. When a signal is presented at the input terminal, a DC component of current will be added to the quiescent current as shown in Figure 4. If the signal becomes larger - the current increases and the Q point shifts to the left, since the voltage on the grid relative to the cathode becomes more negative. This type of automatic biasing enables the amplifier to amplify only the peak portion of the input voltage which might be the clutter with the moving echo atop it. With a large value for R a small increase in current gives a relatively large change in bias voltage. Note that the net bias voltage is given by $(150-I_cR)$ where I_c is the cathode current.

By selecting the proper value of the R-C time constant in the cathode we can achieve smoothing of the amplitude fluctuation of the clutter without reducing the target echo. A compromise must be made for the following demands:

A. The charging time of C, through the tube, should be greater than the radar pulse width so that the bias will not change appreciably during a pulse width. The charging time should be less than the average period of the clutter variations.

B. The discharging time constant RC should be much less than the average period of the clutter variations. The discharging time constant should be larger than the pulse width.

C. The time constant must be much larger than $1/f_o$ where f_o is the IF frequency.

Condition A ensures that in the echo pulse duration there will only be a small change in the operating point, and gain is maintained high during the whole of the pulse.

Condition B assures that the cathode bias voltage will follow variation of clutter envelope, causing smoothing of the clutter output.

Condition C is necessary to prevent degeneration at the intermediate frequency.

In the one stage experiment a 455KHz signal IF was amplitude modulated by a 400 Hz voltage, representing the amplitude changes of the clutter. Smoothing or compression of amplitude variation was checked by that circuit and the results are shown schematically in Figure 5.

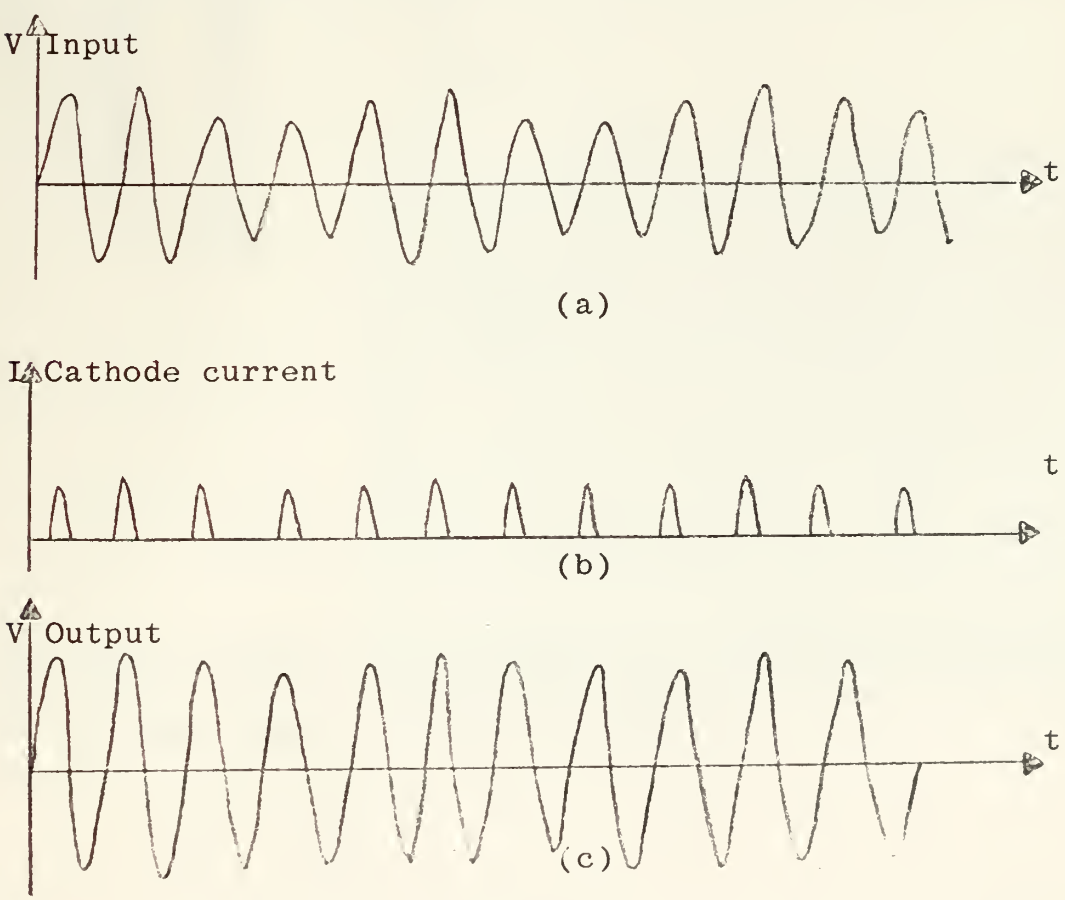

Figure 5. Amplitude compression by the amplifier stage

A similar experiment, in order to show the effect of amplitude compression, was done with one transistor stage, Figure 6. The results, Figure 7, indicate that an index of modulation of 50% was reduced to 17%.

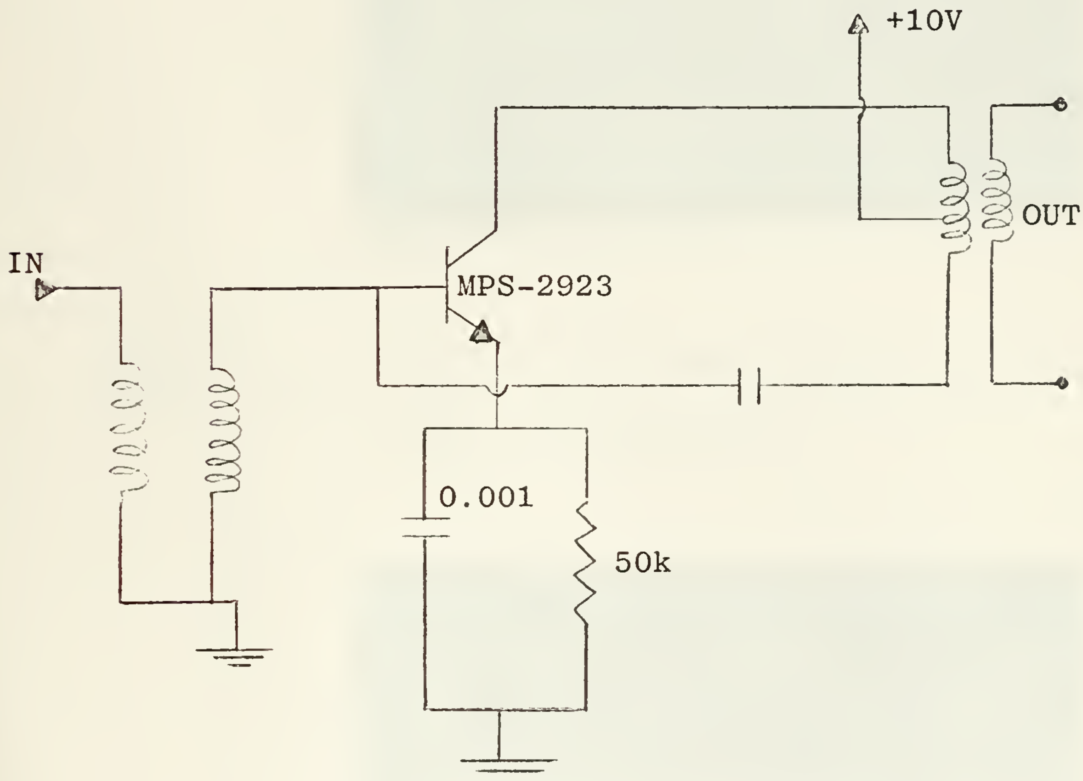

Figure 6. Transistor stage.

The input signal is a 455KHz carrier, amplitude modulated by a 400Hz signal, and 10μsec pulse.

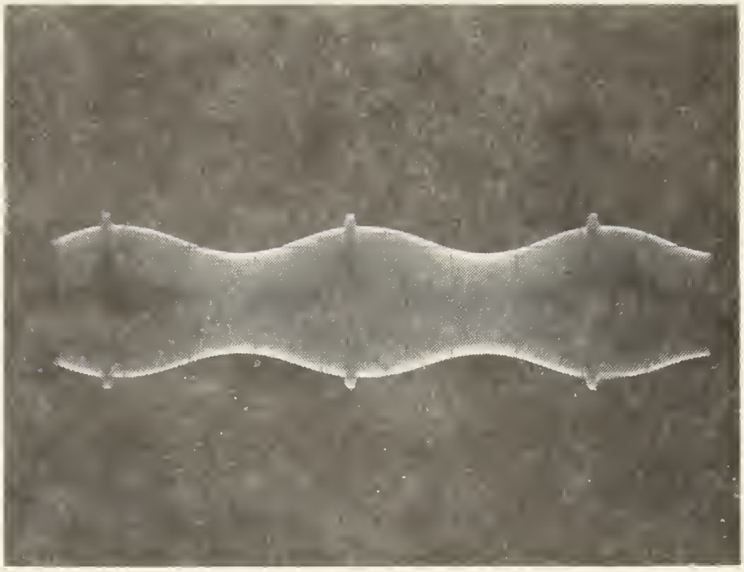

Figure 7 (a). Input signal 455KHz, 10μsec pulse and 400Hz amplitude modulation.

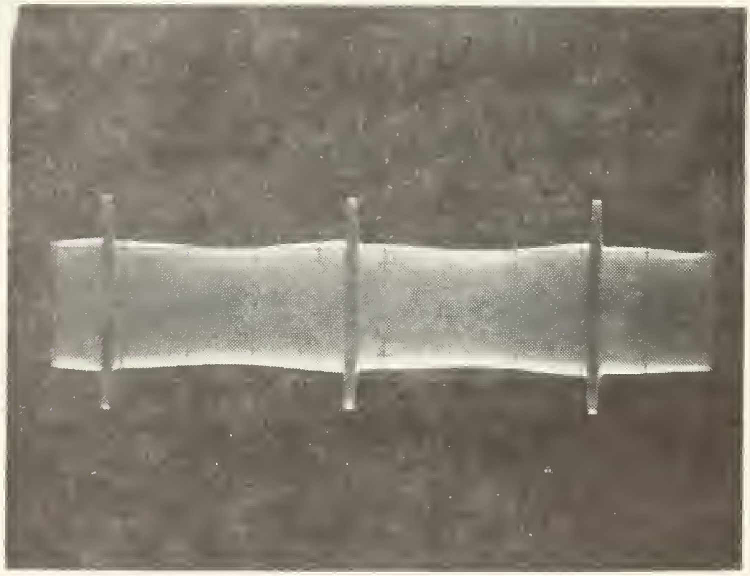

Figure 7 (b). Output signal

Figure 7 shows that by properly choosing the RC time constant i.e. long compared to pulse width and short compared to modulation period, then the slow variations (400Hz) are diminished in amplitude, but the 10μsec pulse is amplified as shown in that Figure. It should be recalled that with a large input signal the shift in the Q point results in amplification of the peak of the input wave only. In this way the relative amplitude of the pulse is increased.

The set-up for the experiment with transistor stage is shown below.

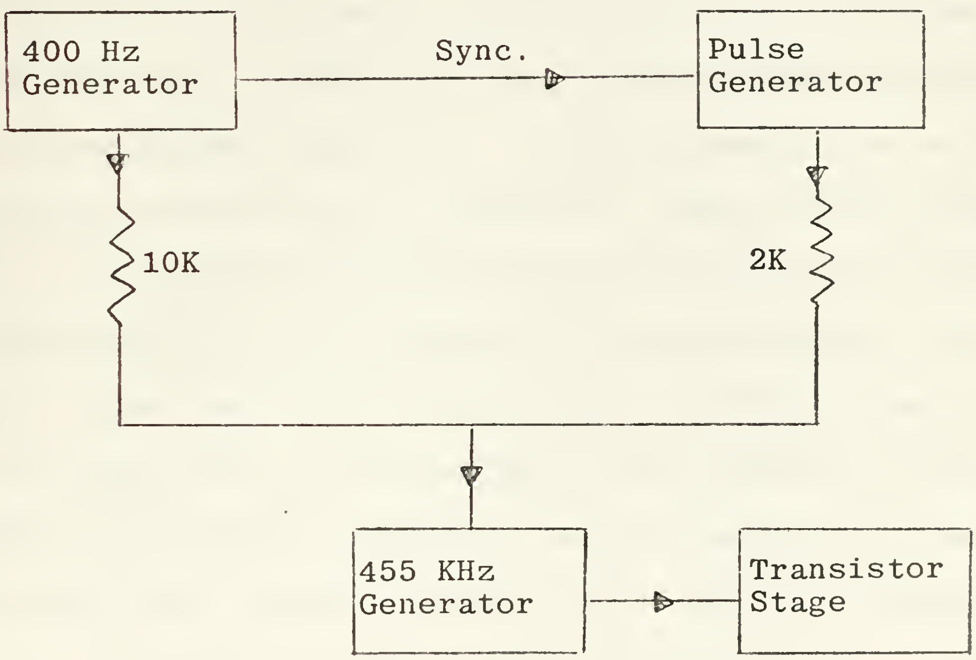

Figure 8. Set-up for checking modulation index of clutter and target.

The 400Hz generator synchronizes the 10μsec pulse generator and the sum is used to modulate the 455KHz signal generator. The same principle of shifting the quiescent point according to the signal strength as for the vacuum-tube amplifier is applied here, and hence the Q point without signal is placed near cutoff (collector current 0.16 ma). The next step was to take an IF amplifier and modify it in such a way that it was compatible with the UPS-1 radar and perform a noncoherent moving target detection. The schematics of the amplifier before and after the modification are shown in Figures 9 and 10 respectively.

Referring to Figure 10 a brief explanation is given about the new amplifier. The input stage 6BC4 and 6CB6 constitutes a low noise cascode amplifier. A 3db attenuator in the 6BZ7 stage may be switched in, if desired. The last three 6CB6 tubes are the stages modified for variable Q point to provide for amplification of the envelope of large signals. Only the peaks of large amplitude clutter with the target echo atop of it are amplified. The discharge time constant of the capacitor and resistor in the cathode of each of the last three tubes, were chosen to give the optimal performance, i.e.

$$7.5 \times 10^{3} \times 500 \times 10^{-12} = 3.75\mu sec$$

The charging time constant of the capacitor through the tube can also be calculated. As shown in Figure 11 and as was verified by measurement the transconductance near cut-off at cathode current of 1 mA is 200μmho. Thus the time

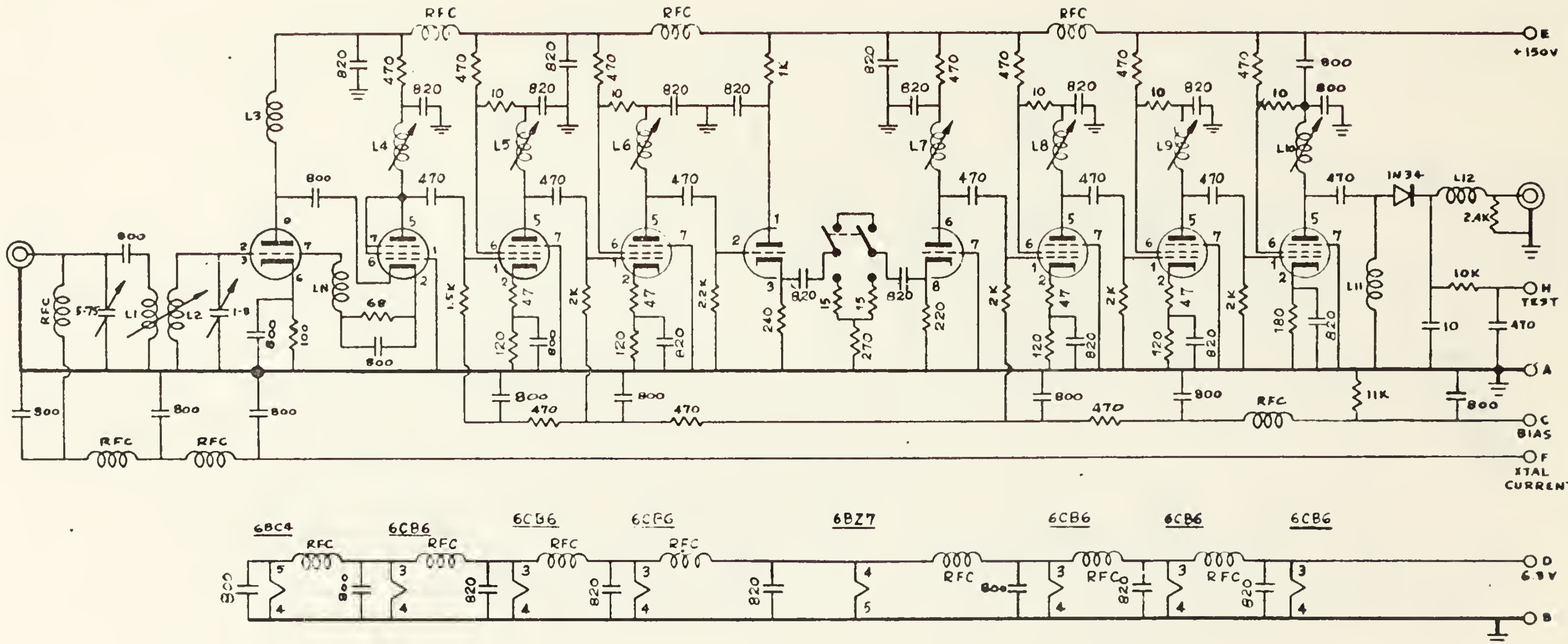

Figure 9. IF amplifier before the change

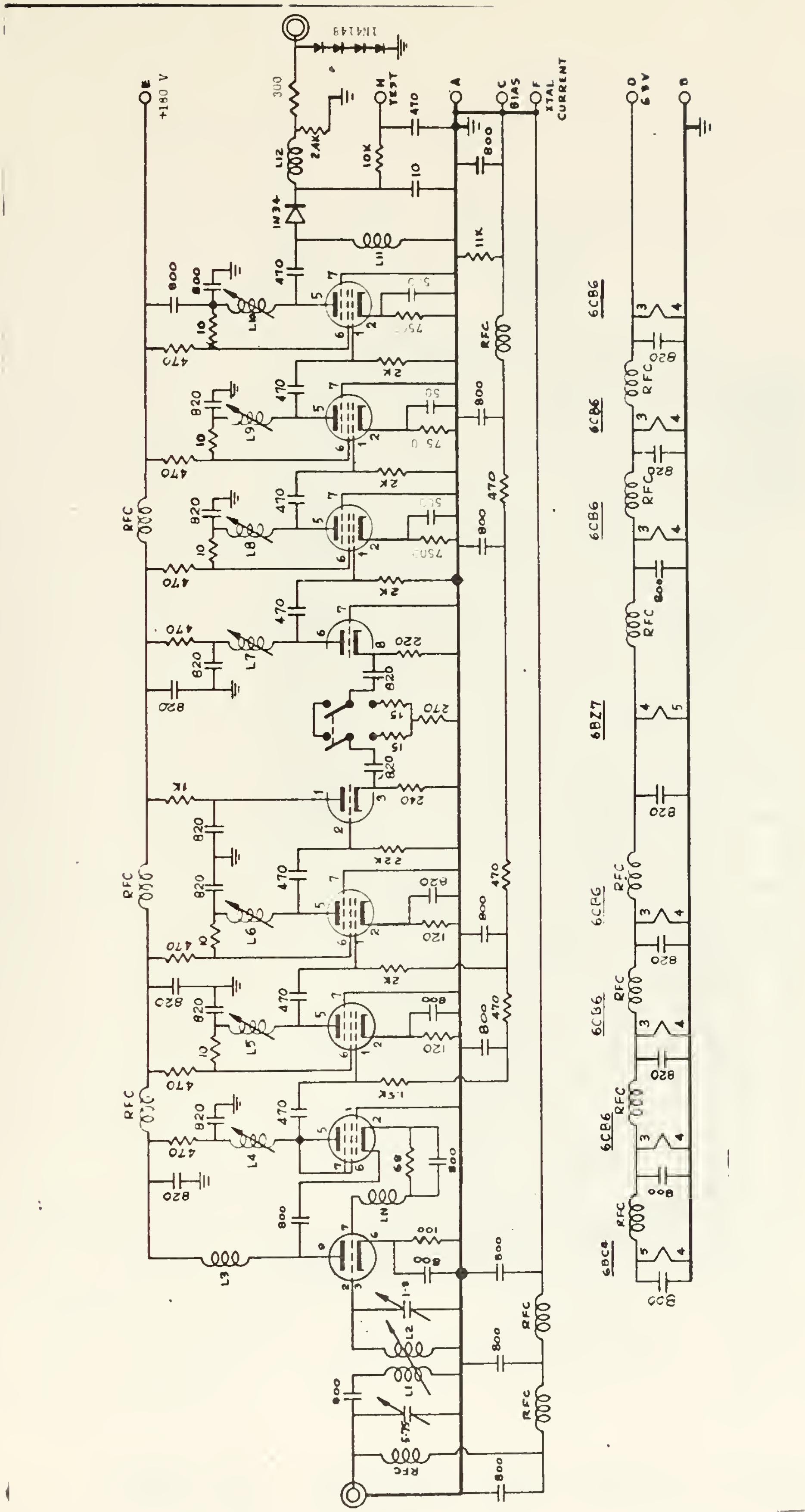

Figure 10. IF amplifier after the change

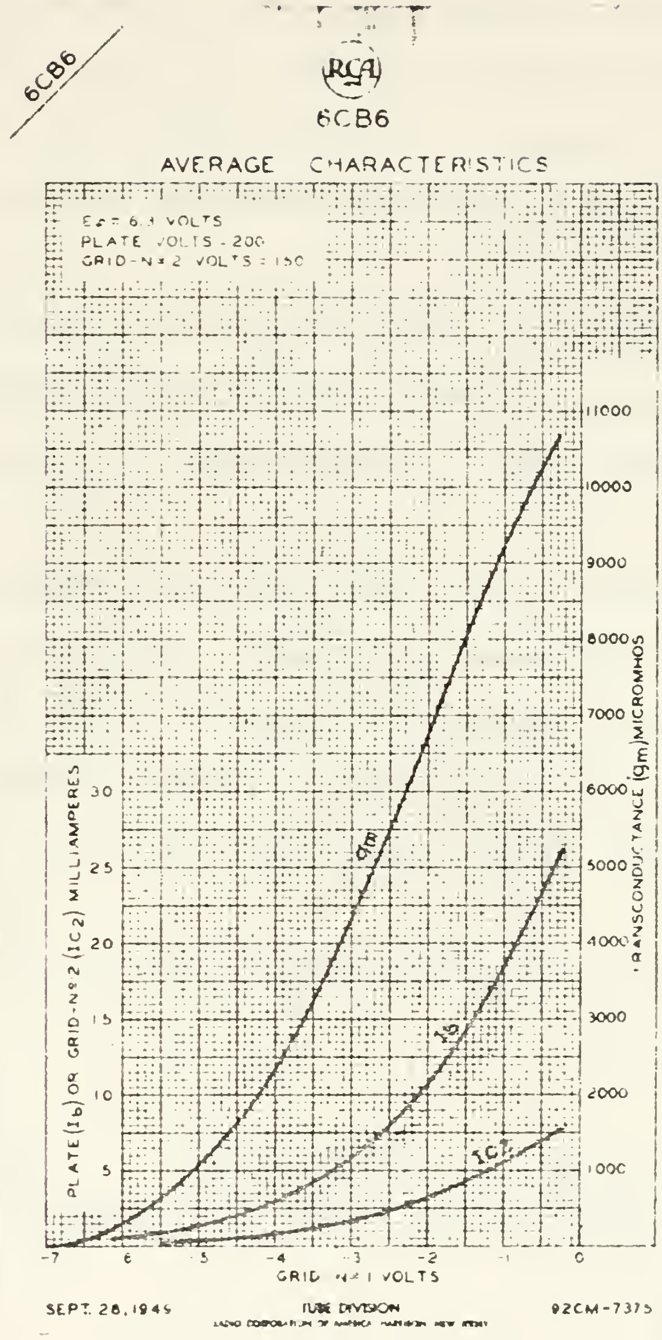

Figure 11. Average characteristics, 6CB6

constant is $\frac{1}{200 \times 10^{-6}} \times 500 \times 10^{-12} = 2.5\mu sec.$

$2.5\mu sec >$ radar pulse width, and hence negative feedback which is developed across C is not large enough to diminish the pulse, however some differentiation is seen.

$3.75\mu sec \gg 1/30MHz$ and hence the bias is not controlled by the IF frequency.

$3.75\mu sec <$ average period of clutter, and hence the cathode will follow the grid voltage, causing compression of the output amplitude variation compared to the input fluctuations.

Additional changes have been made in the IF amplifier as seen in Figure 10. These changes are necessary for increasing the gain of the amplifier and for preventing parasitic oscillations. A diode limiter was provided in the video output in order to limit the peak signal to the cancellation circuits to 2 volts.

The incorporation of the modified IF strip in the radar is shown below:

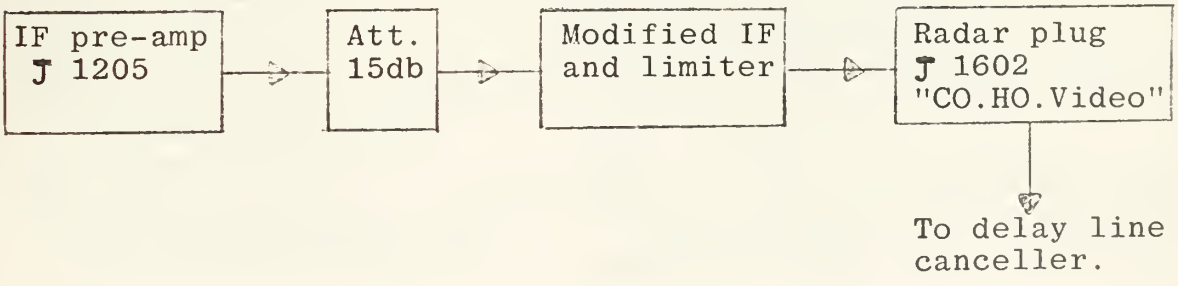

Figure 12. Incorporation of the IF in the AN/UPS-1

The radar set AN/UPS-1 [Ref. 2] is a general purpose, air search radar. It presents targets on an azimuth-range indicator PPI scope and on a monitor A scope. A coherent MTI system is incorporated as an aid to the enhancement of moving targets detection. The MTI system reduces the radar response to the clutter of fixed objects, thereby effectively increasing the ability to detect moving targets.

AN/UPS-1 Air Search Radar

Frequency Range	1250 to 1350 MHz
Average Power	1.6 Kw
Peak Power	1.4Mw
Pulse Width	1.4μsec.
PRF	800 Hz
Beam Width	3.8° Horizontal 10° Vertical
IF Frequency	30 MHz
IF Bandwidth	1.5 MHz
MTI Gate	0 to 80 miles
Minimum Detectable Signal	- 105 dbm
Subclutter visibility	20 to 30 db

Table I. Some rated performance characteristics of AN/UPS-1

IV. INITIAL TESTS WITH SIMULATED TARGET

During initial testing the set-up shown below was employed.

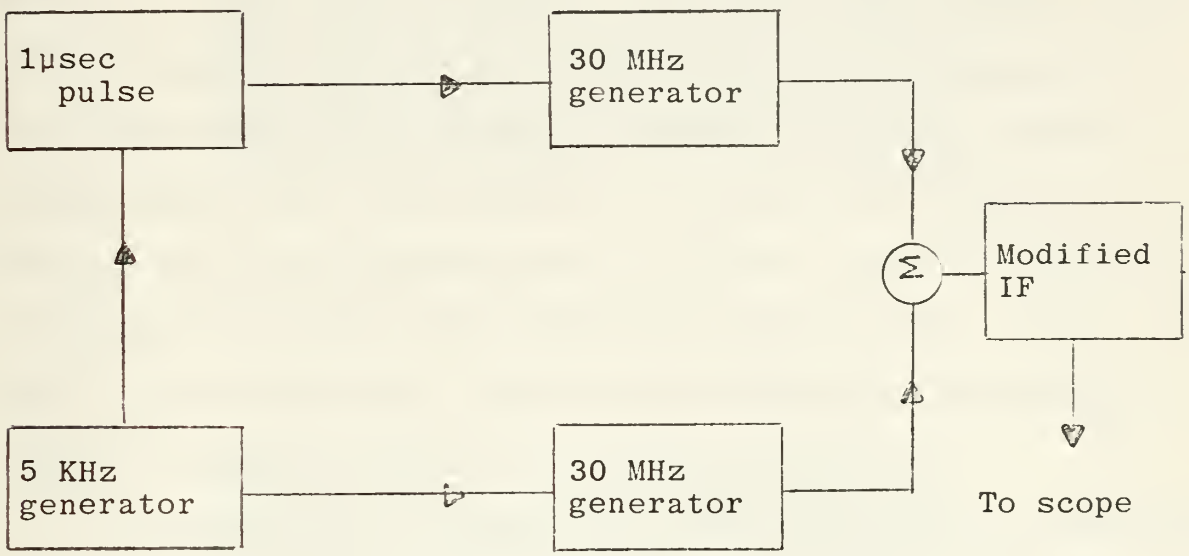

Figure 13. Test set-up for simulating a moving target.

The 5KHz signal generator has a square wave output, 100μsec positive and 100μsec negative. This waveform amplitude modulates the 30 MHz generator and also triggers the 1μsec pulse generator. This 1μsec pulse amplitude modulates the second 30 MHz genrator and both outputs of the 30 MHz generators reach the summation point and are fed into the IF strip input. Since both RF genrators are not mutually coherent, then the 100μsec RF pulse represents a clutter return and the 1μsec pulse simulated the noncoherent echo of

a moving target. The output of the "clutter" generator is shown in Figure 14. And the output of the IF is shown in Figures 15 and 16.

Figures 15 and 16 indicate the different amplifier gains for the clutter and the 1μsec pulse. When the clutter is high the gain is higher for the pulse atop the clutter, Figure 15, and when the clutter is low the gain for the 1μsec pulse decreases, Figure 16. The spikes at the leading and trailing edges of the 100μsec "clutter" are due to the few cycles needed for the capacitor to charge and discharge. For the first few microseconds of clutter, before the bias voltage is developed, the amplifier gain is high. At the end of the 100μsec the capacitor will discharge increasing the gain again.

In Figure 17 it is shown that the target has a "butterfly" shape due to the fact that the two RF generators are not mutually coherent. Maximum amplitude is only attend for those pulses where signal and clutter are in phase. Only the positive portion is seen because of the positive envelope detection. The target echo without clutter is seen in Figure 18, note that the "butterfly" has disappeared and the waveform is clear.

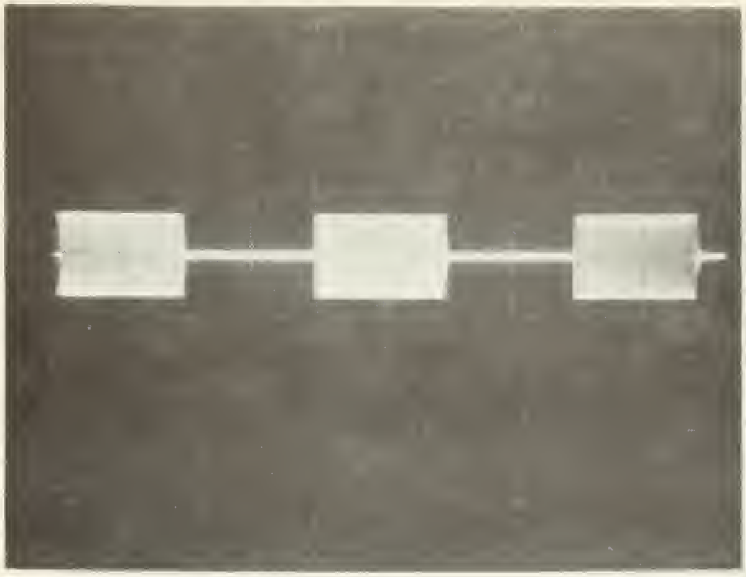

Figure 14. Simulated clutter, 50μsec/div.

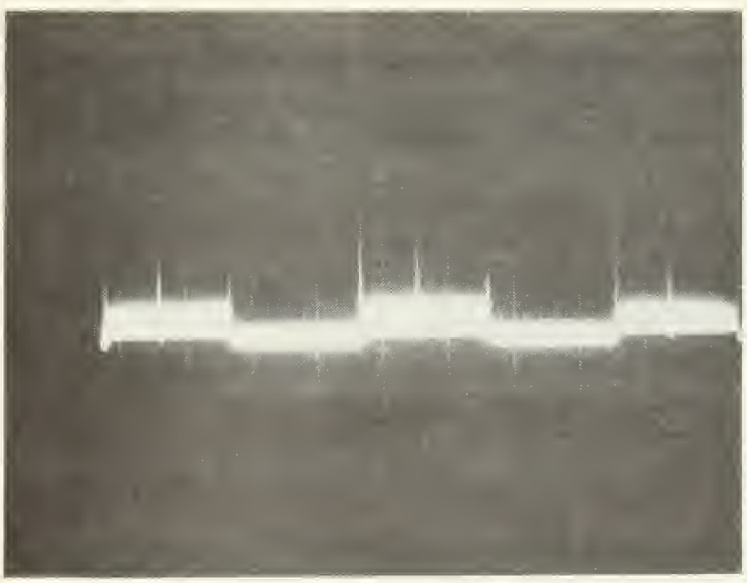

Figure 15. Detector output, echo is shown in the middle of 100μsec clutter.

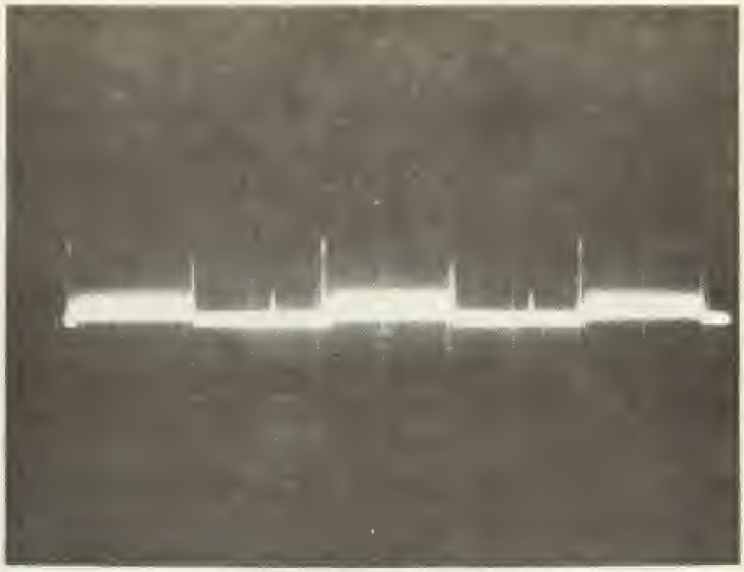

Figure 16. Detector output, 50μsec/div. 1μsec echo is shown as the smallest spike in noise.

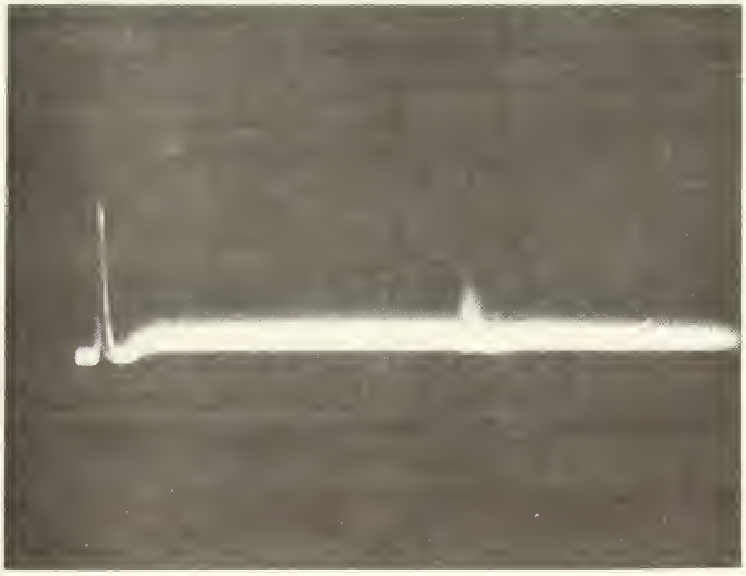

Figure 17. Detector output, 5μsec/div; target at 25μsec from the clutter start. Smearing of echo is due to "Butterfly" effect.

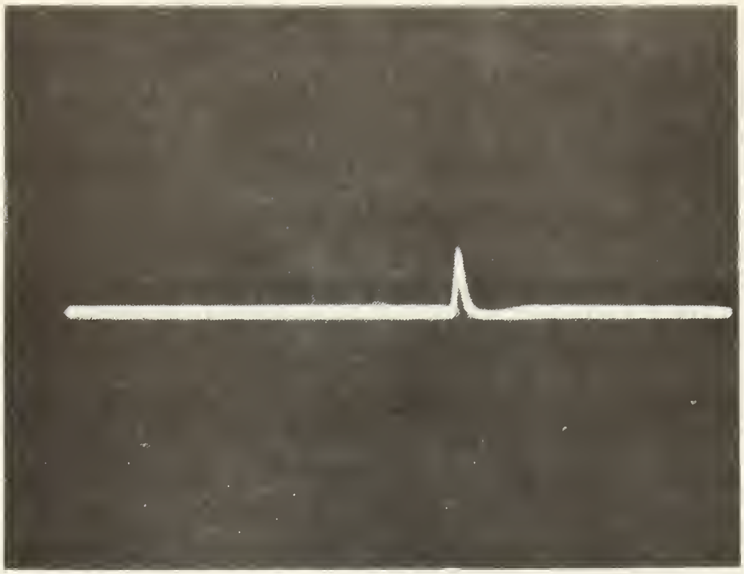

Figure 18. Detector output; clear target without clutter reference. 5μsec/div.

V. SUMMARY AND CONCLUSIONS

The results that were achieved proved that the method of shifting the Q point is effective and efficient. The performance with a target moving in heavy clutter is improved compared to the situation when a logarithmic amplifier is employed. Figures 19 a, b, c, are pictures of the PPI screen showing a simulated target as well as real targets. Only when clutter is present at the same range and azimuth as the moving target is the echo shown. Clutter is largely canceled by the delay-line canceller. Figure 20 shows the clutter before cancellation.

The receiver in this case employs an amplitude detector. When a signal from a moving target is present at the same time as the clutter echo, the resultant amplitude, from pulse to pulse, is different because of the changed relative phase, as shown on page 11.

The noncoherent receiver does not require the use of a coherent oscillator in the receiver but the following requirements must be satisfied:

1. Saturation must be avoided. This is necessary, otherwise the amplitude detector will not be sensitive to the changing amplitude from pulse to pulse, when a relatively small target signal exists in the clutter. This condition is not necessary in coherent MTI where a phase detector is employed and amplitude limiting is often employed.

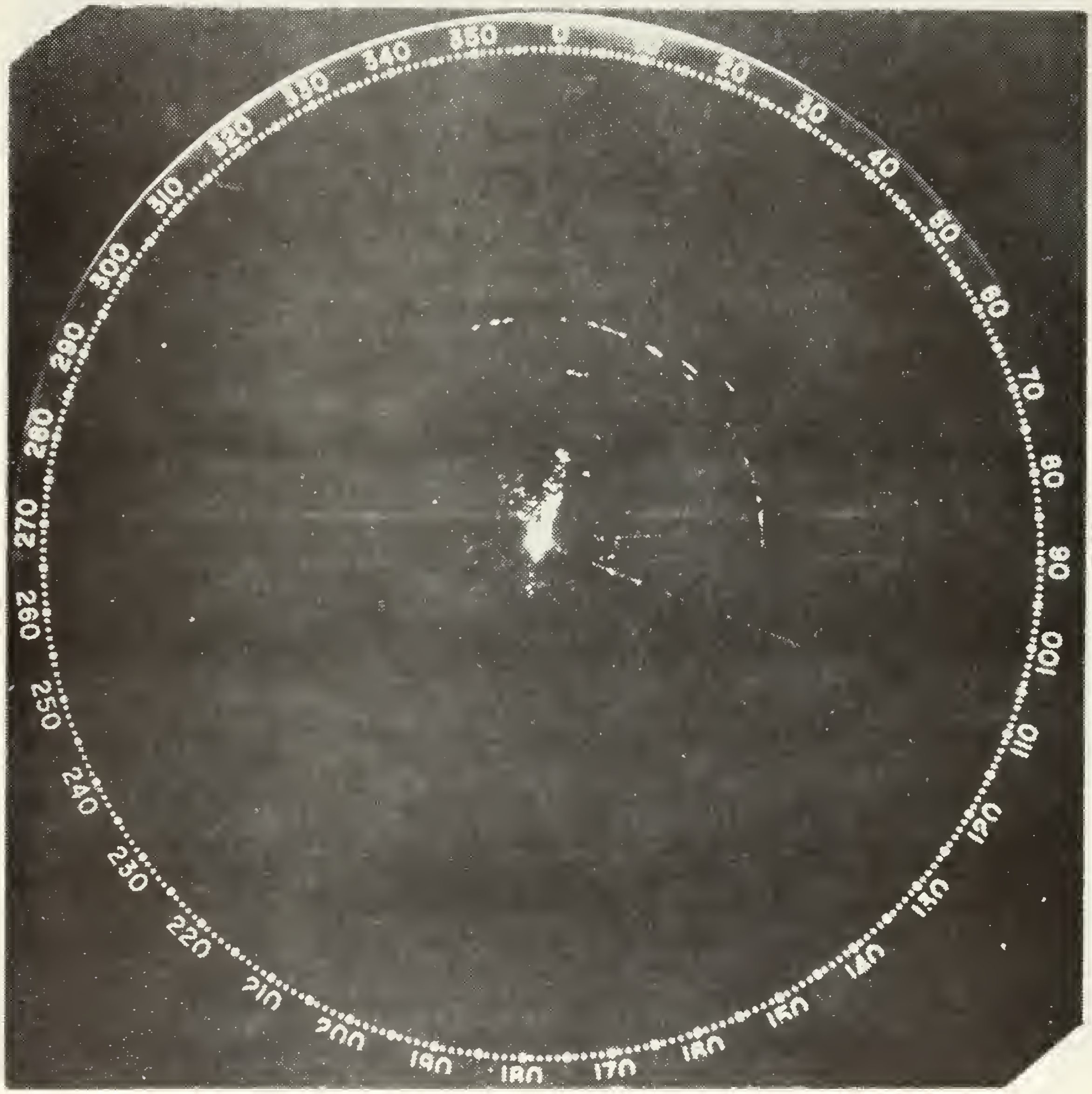

Figure 19 a. Simulated target and real targets on the PPI. Maximum range 50 miles.

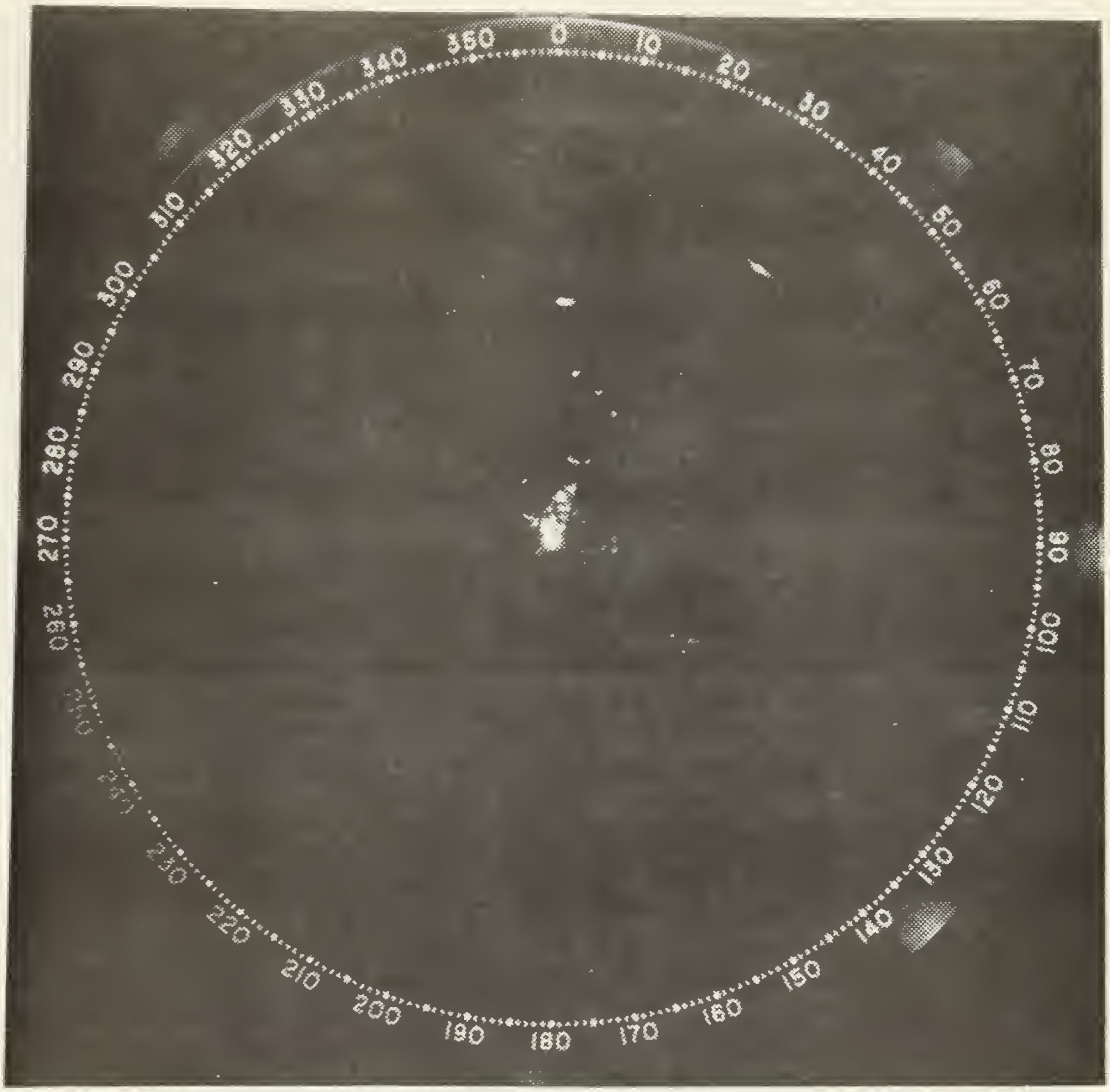

Figure 19 b. Real moving targets. Maximum range, 50 miles.

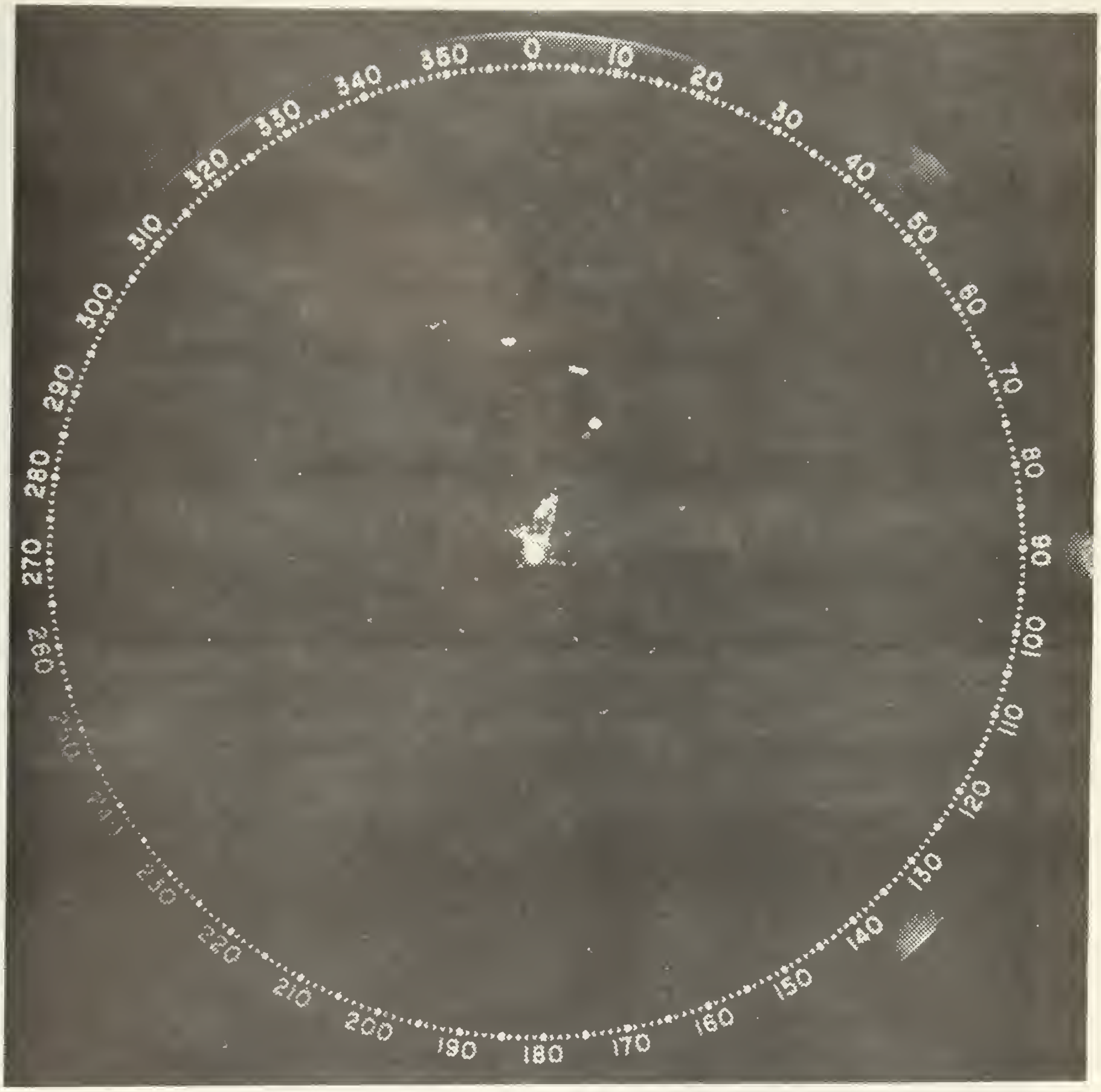

Figure 19 c. Real moving targets, maximum range 50 miles.

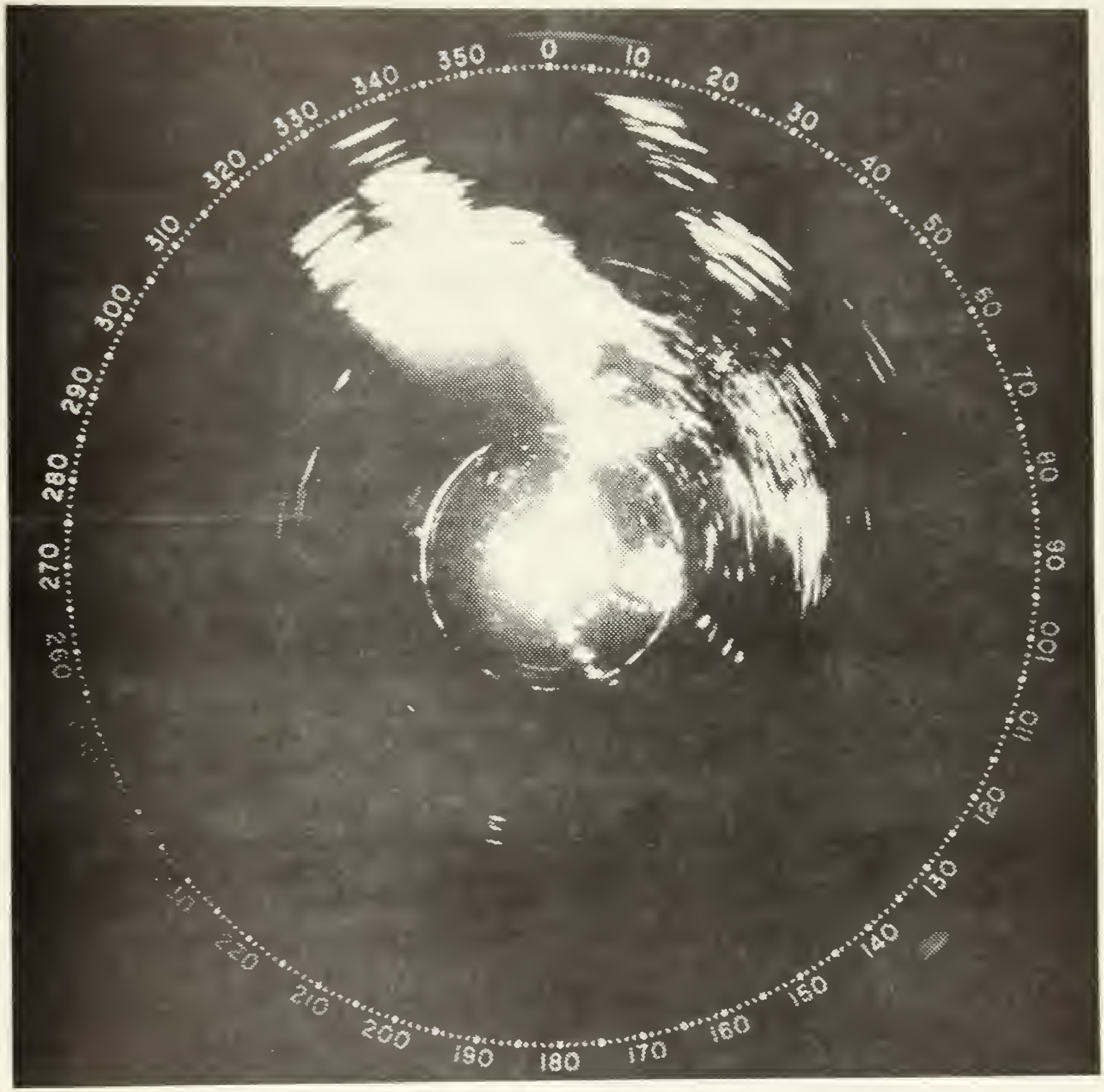

Figure 20. Clutter as received by the radar, without cancellation. Maximum range 50 miles.

2. Only targets in presence of clutter are detected. In fact the clutter signal takes the place of the coherent oscillator in the coherent MTI. The use of clutter as this reference gives the great advantage that the reference signal is automatically phase locked to the transmitted signal. For this reason this MTI is sometimes called "externally coherent."

In the noncoherent MTI a single or double canceller may be used just as with coherent MTI. The double canceller can be shown to give improved clutter suppression. [Ref, 1]

In a coherent MTI any frequency instability in the transmitter oscillator or receiver oscillator will cause a phase modulation which will result in reduced clutter cancellation. These stability problems are to a very large extent alleviated.

As already mentioned moving targets are cancelled with noncoherent MTI unless clutter is present. A further improvement can be made by introducing an MTI switch which will sense the presence of clutter and control the operation of the receiver. With MTI operation moving targets can be detected only when they coincide with clutter. Without MTI these targets are detected only when they are not in heavy clutter. As Figure 21 shows the MTI switch contains three blocks: Delay, Sensor, Electronic switch. The delay which is typically in the order of 5μsec, equals the reaction time of the sensor. The sensor operates only on extended clutter, not on isolated targets. Only when the clutter lasts for more than the delay time, does the switch operate, passing the

signal through the MTI canceller. When no clutter is present the receiver operates as a regular search radar.

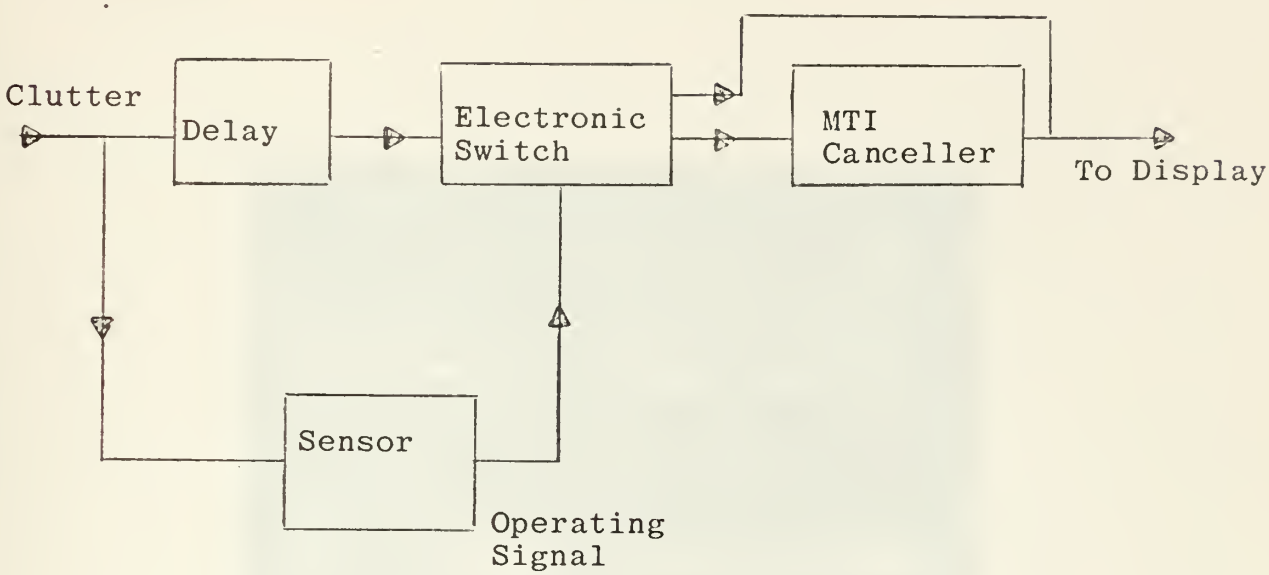

Figure 21. MTI Switch

The cathode circuit time constants in the last three IF stages are a compromise between the factors listed on page 18. When the clutter amplitude undergoes large variation in a time comparable to the radar pulse width, the gain cannot adjust rapidly enough. The result is a positive spike at the leading edge of the sudden strong clutter, and a loss of signal immediately following a sudden sharp drop in clutter amplitude.

The clutter signal as seen at the preamplifier output is shown in the lower trace of Figure 22. The same signal at the output of the IF strip is shown in the upper trace.

A moving target might well be lost when moving through the spikes, but would be seen both before and after. Further development to eliminate this small dead interval would be desirable.

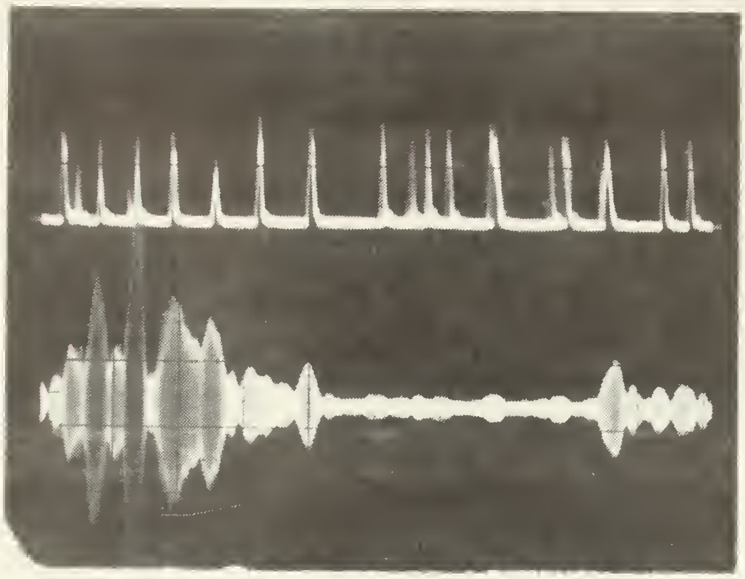

Figure 22. Lower trace: Clutter signal at the preamplifier output.
Upper trace: Clutter signal at the modified IF output.
Horizontal scale: 5μsec per division.

As a final comment it has to be mentioned that the type of adaptive IF amplifier used here, could not be found by the author in the literature that was available to him during the project period.

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4. Hughes Aircraft Company, Technical Memorandum 415, Predicting Non-Coherent AMTI Performance by Worthie Doyle, 15 December 1955.

5. University of Illinois, Urbana, Illinois, Report R-79, The Feasibility of An Airborne Pulsed Doppler, Noncoherent Radar For Army Reconnaissance, by Andrew Longacre, January 1956.

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7. Department of the Navy, Technical Manual, NAVSHIPS 94122, Radar Set AN/UPS-1, V. 2, June 1961.

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