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AN I. F. SIGNAL SIMULATOR FOR FM RANGING SYSTEMS.(U)

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AN I.F. SIGNAL SIMULATOR FOR FM RANGING SYSTEMS

HDL-CR-77-045-1, An I.F. Signal Simulator for FM Ranging Systems, by Marion C. Bartlett and Raymond C. Johnson

June 1977

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An intermediate frequency signal simulator (IFSS) which is useful for testing many FM ranging systems is described. The IFSS can be constructed using readily available laboratory test equipment. Target delay time (τ) and doppler frequency can be set manually for static circuit tests or varied automatically to simulate dynamic target approaches. The IFSS also provides the capability for generating dynamic signals for measuring the ambiguous range responses of a system.

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I. INTRODUCTION

In the development of FM ranging systems, there arises a need for an IF signal simulator. The IF signal to be simulated results from product mixing of the transmitted and received signals and filtering to remove the output at double the RF carrier frequency. This report describes a simulator which is useful for testing many FM ranging systems. The IF Signal Simulator (IFSS) described herein can be realized with readily available laboratory equipment and can be automated to the degree desired by using hybrid (digital/analog) hardware techniques.

Section II of this report briefly describes typical FM ranging systems which may be tested using the IFSS. Section III derives the IF signal as measured at the RF mixer output. Section IV describes the functional operation of the IFSS. Section V derives the IF signal simulated by the IFSS and discusses methods of operating the IFSS to minimize errors. Section VI illustrates the operation of the IFSS with measured data. Section VII briefly summarizes the contents of the report. A more detailed description of the IFSS hardware is presented in Appendix A.

II. FM RANGING SYSTEM DESCRIPTION

The FM transmitter (figure 1) is frequency modulated by a voltage $m(t)$ obtained from a modulation generator. The transmitted signal $x(t)$ and the attenuated return signal $kx(t-\tau)$ are product mixed and filtered to obtain the IF signal $s(t)$. In this illustration separate transmit and receive antennas are shown; however, systems which employ a common transmit/receive antenna and obtain the IF signal by envelope detecting the composite antenna voltage are mathematically equivalent to figure 1.

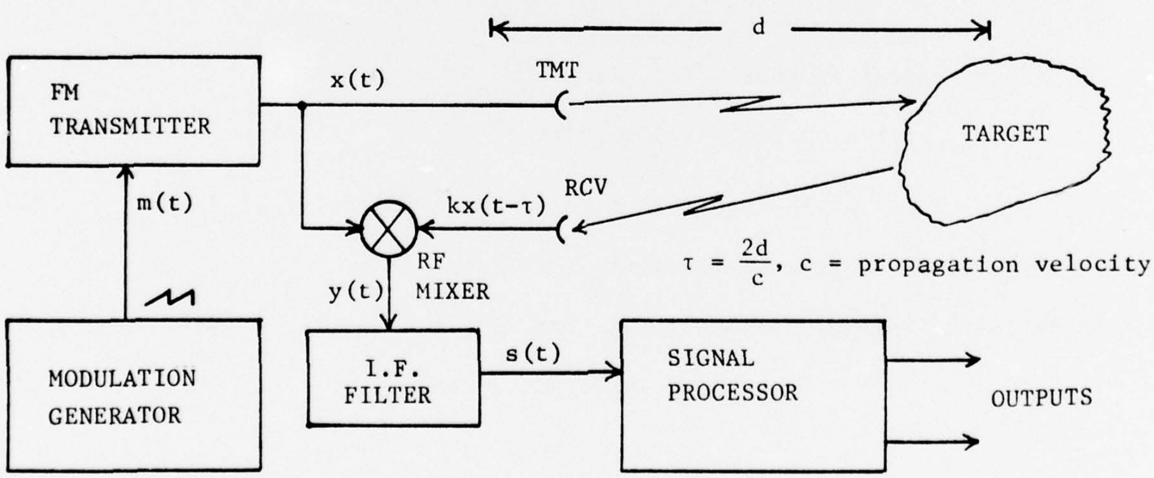


Figure 1. FM ranging system.

The IF signal s(t) is processed in various systems to measure range and range rate as indicated by target delay $\tau = 2d/c$ and doppler frequency $f_d = 2V/\lambda$ (V = velocity and λ = wavelength). Signal processors may employ frequency discriminators, IF correlators, etc., to measure the appropriate parameters (see selected bibliography for details of various FM ranging systems). The purpose of the IFSS is to generate an IF signal which can be used to test the ranging system signal processor.

III. I.F. SIGNAL DESCRIPTION

A frequency modulated signal can be described by

$$x(t) = \cos[\theta(t)] \ , \qquad (1)$$

where $\theta(t) = \int_0^t \omega(t')dt'$,

$\omega(t') = \omega_m(t')+\omega_0 = Dm(t')+\omega_0$,

D = deviation sensitivity in radians/volts,

$m(t')$ = modulation voltage,

and ω_0 = transmitter carrier frequency.

Correspondingly, the returned signal is described by

$$kx(t-\tau) = k\cdot\cos[\theta(t-\tau)] \qquad (2)$$

where $\theta(t-\tau) = \int_0^{t-\tau} \omega(t')dt'$.

The mixer product is then

$$y(t) = ck\cdot\cos[\theta(t)]\cos[\theta(t-\tau)]$$

$$= \frac{ck}{2}\{\cos[\theta(t)-\theta(t-\tau)] + \cos[\theta(t)+\theta(t-\tau)]\} \ . \qquad (3)$$

c is the RF mixer gain coefficient.

IF filtering removes the sum angle term to give

$$s(t) = a\cdot\cos[\theta(t)-\theta(t-\tau)] \ , \qquad (4)$$

Equation (4) can also be written as

$$s(t) = a\cdot\cos[\Delta\theta(t)] \ , \qquad (5)$$

where $\Delta\theta(t) = \int_{t-\tau}^{t} \omega(t')dt'$.

Expanding (5) gives

$$s(t) = a\cdot\cos\left[\int_{t-\tau}^{t}\omega_m(t')dt' + \int_{t-\tau}^{t}\omega_0 dt'\right]$$

$$= a\cdot\cos\left[\int_{t-\tau}^{t}\omega_m(t')dt' + \omega_0\tau\right] \qquad (6)$$

Equation (6) describes the IF signal or "beat pattern" as a function of τ.

The angular excursion of $\left[\int_{t-\tau}^{t}\omega_m(t')dt'\right]$ varies rather slowly with τ and determines the number of cycles of the beat pattern per modulation cycle. The angle $\omega_0\tau$ is the doppler angle and, when τ is varied, causes the IF beat pattern to be doppler shifted. It is useful to note that this doppler shift single sideband modulates the beat pattern.

IV. IFSS FUNCTIONAL DESCRIPTION

The functional diagram of the IFSS is shown in figure 2.

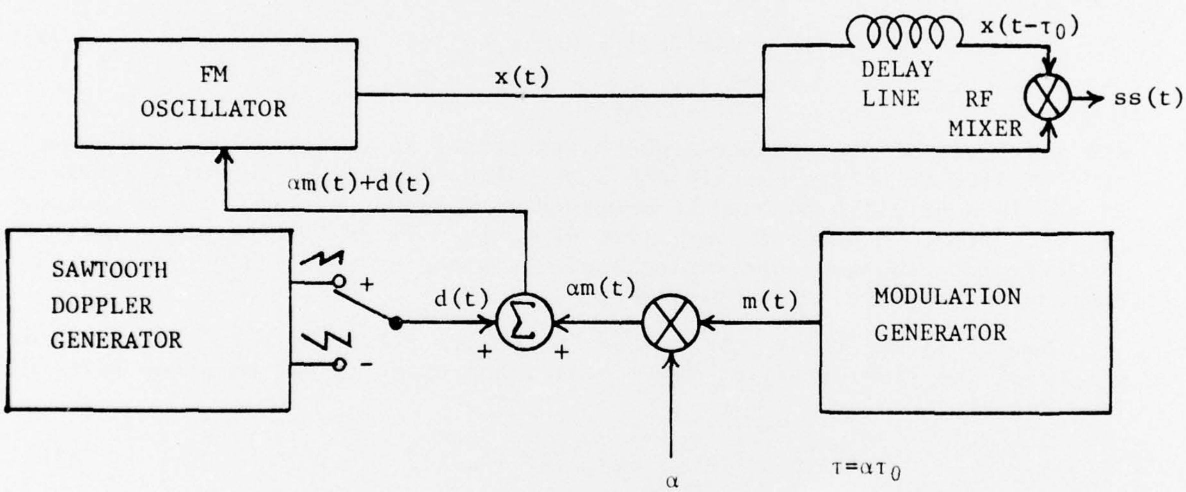


Figure 2. IFSS functional diagram.

The IF signal ss(t) is developed by frequency modulating the oscillator and using an RF delay-line/mixer to develop a beat pattern. τ variations about the point τ_0 are simulated by scaling the amplitude of the modulation voltage m(t). Target doppler is simulated by adding a positive or negative sawtooth (positive or negative doppler) modulation which is adjusted to produce exactly one beat cycle out of the RF delay-line/mixer. The modulation amplitude scale factor α is adjusted to simulate a target at delay-time $\tau = \alpha\tau_0$. α can be varied automatically to provide the correct dynamic target approach conditions for the system being evaluated. The amplitude of ss(t) can also be synchronously controlled, with α, to simulate space losses.

For typical operating conditions, a delay line τ_0 near the time delay of interest is chosen since the simulator IF signal is always correct at this point. The amplitude of d(t) is then adjusted to give exactly one beat cycle and the doppler frequency is set as desired. Adding the modulation voltage $\alpha m(t)$ then gives an IF signal for the delay $\tau = \alpha\tau_0$.

V. IFSS SIGNAL MODEL

By following the procedure outlined in Section II, the simulator signal ss(t) can be written as

$$ss(t) = \cos\left[\int_{t-\tau_0}^{t} D\alpha m(t')dt' + \int_{t-\tau_0}^{t} Dd(t')dt'\right]$$

$$= \cos\left[\int_{t-\tau_0}^{t} \alpha\omega_m(t')dt' + \int_{t-\tau_0}^{t} W(t')dt'\right] \quad . \tag{7}$$

When the period of the doppler sawtooth is much larger than τ_0, the second integral is approximately

$$\int_{t-\tau_0}^{t} W(t')dt' \cong W(t)\tau_0 = \theta_d(t) \quad . \tag{8}$$

The amplitude of the doppler angle $\theta_d(t)$ is set to 2π by adjusting the amplitude of d(t) to obtain exactly one beat cycle. The error in the approximation of (8) is negligible and can be observed on the beat pattern at the sawtooth fly-back time. A sawtooth variation of $\theta_d(t)$ over 2π is equivalent to a linearly increasing or decreasing angle as given by $\omega_0\tau$ of (6) provided the sawtooth fly-back time is very short.

Comparing the first integral of (6) to (7) illustrates the basic approximation of the IFSS; that is, for $\tau = \alpha\tau_0$, the exact signal obtained from (6) is given by

$$s(t) = \cos\left[\int_{t-\alpha\tau_0}^{t} \omega_m(t')dt' + \theta_d(t)\right] \tag{9A}$$

whereas, the simulator signal from (7) is given by

$$ss(t) = \cos\left[\int_{t-\tau_0}^{t} \alpha\omega_m(t')dt' + \theta_d(t)\right] \quad . \tag{9B}$$

Equation (9) illustrates that when $\alpha = 1$, an exact IF signal will be generated corresponding to the delay $\tau = \tau_0$. As α is varied from unity to simulate $\tau = \alpha\tau_0$, some errors will develop depending on the modulation parameters. There are some useful guidelines which can be used to evaluate the seriousness of the simulator error in various situations. First, the simulator signal is always correct at $\tau = \tau_0$ and, by inserting a few different delay lines and varying τ about that point, any system can be tested with small errors. Second, the simulator error for an IF signal component at frequency Δf can be estimated by computing the phase error $\theta_e = 2\pi\Delta f\tau_0(\alpha-1)$, where $\alpha\tau_0$ is the delay being simulated and τ_0 is the fixed delay line. In many cases, the ranging system response due to this phase error will vary according to $\cos\theta_e$. For many low height ranging systems the errors will be negligible and the systems can be tested from a large τ to $\tau = 0$ by varying α.

VI. EXPERIMENTAL WAVEFORMS AND SPECTRA

The time waveforms available from the IF Signal Simulator are illustrated on figure 3. For these measurements α was held constant so that the beat waveform could be recorded. The top two waveforms show the IF signal without doppler, while the lower two have the doppler shift included on the beat.

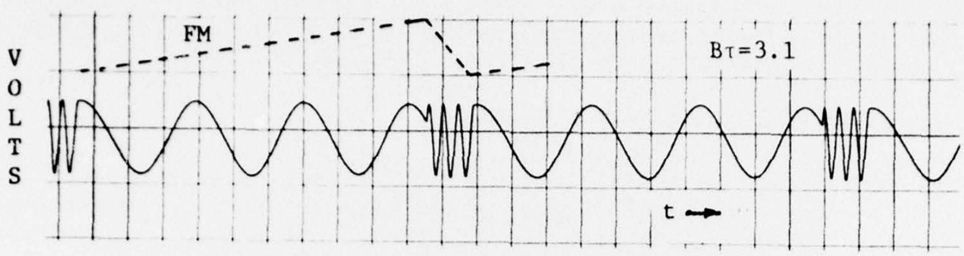
The voltage spectra of the simulated IF signals are shown on figures 4 and 5. Here, the signal spectrum as shifted by the doppler is shown for various delay times as τ is shifted from $B\tau = 4$ to $B\tau = \frac{1}{2}$, where B is the modulated bandwidth of the RF signal. In a dynamic simulation of a target signal, τ would be linearly reduced at a rate corresponding to the target velocity.

The doppler band response of a zero-order FM ranging system to simulated signals from the IFSS is shown on figure 6. For these recordings, τ is programmed to repetitively decrease linearly from maximum τ to zero and then continue to decrease to maximum negative τ. Negative τ is accomplished by inverting the doppler sawtooth to provide a negative doppler shift.

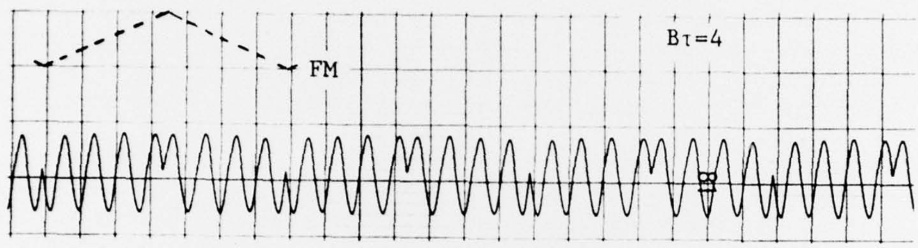
When the doppler shift, f_d, is made large enough to fall near the harmonics of the FM modulating frequency ($f_d = 1/T$, $2/T$, etc.), the simulated signal will cause the system being tested to produce its ambiguous range responses. These ambiguities for a zero-order FM ranging system are shown on figures 7 and 8 for triangular and sawtooth frequency modulation respectively.

VII. CONCLUSIONS

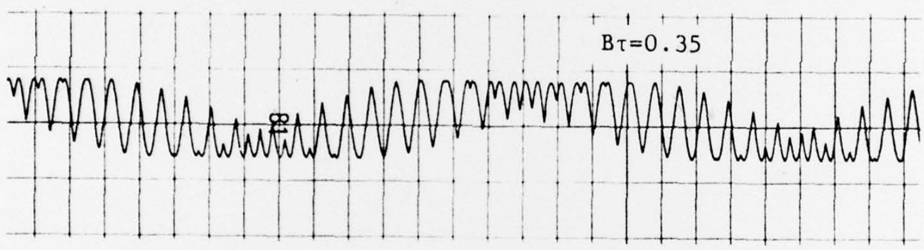
An IF signal simulator (IFSS) has been described which is applicable for testing many FM ranging systems. The IFSS is most useful for testing IF correlator-type FM ranging systems which use an IF reference which is developed in or synchronized by the modulation circuitry. For system tests where the phase error ($\theta_e = 2\pi\Delta f$, where Δf = IF frequency and τ = delay time of interest) is small, testing can be done over a wide range of time delays by scaling the modulation voltage. For system tests where the phase error is large, tests can be conducted in steps by substituting different delay lines of time delay τ_0. For this case, the simulator phase error will be $2\pi\Delta f(\tau-\tau_0)$. Directional doppler shift is simulated by adding a positive or negative sawtooth to the modulation voltage. Tests of IF correlators and doppler processing circuitry can be conducted statically by manually adjusting to a fixed τ and simulating any desired doppler frequency or by varying τ automatically to simulate dynamic target approaches. For large doppler shifts, the simulated signal will cause the FM ranging system being tested to produce its ambiguous range responses.



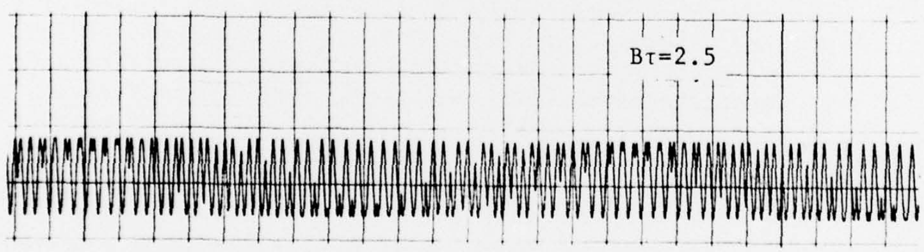
I.F. SIGNAL FOR SAWTOOTH FM



I.F. SIGNAL FOR TRIANGULAR FM



I.F. SIGNAL WITH DOPPLER SHIFT
FOR TRIANGULAR FM



I.F. SIGNAL WITH DOPPLER SHIFT
FOR TRIANGULAR FM

Figure 3. Simulated IF signals.

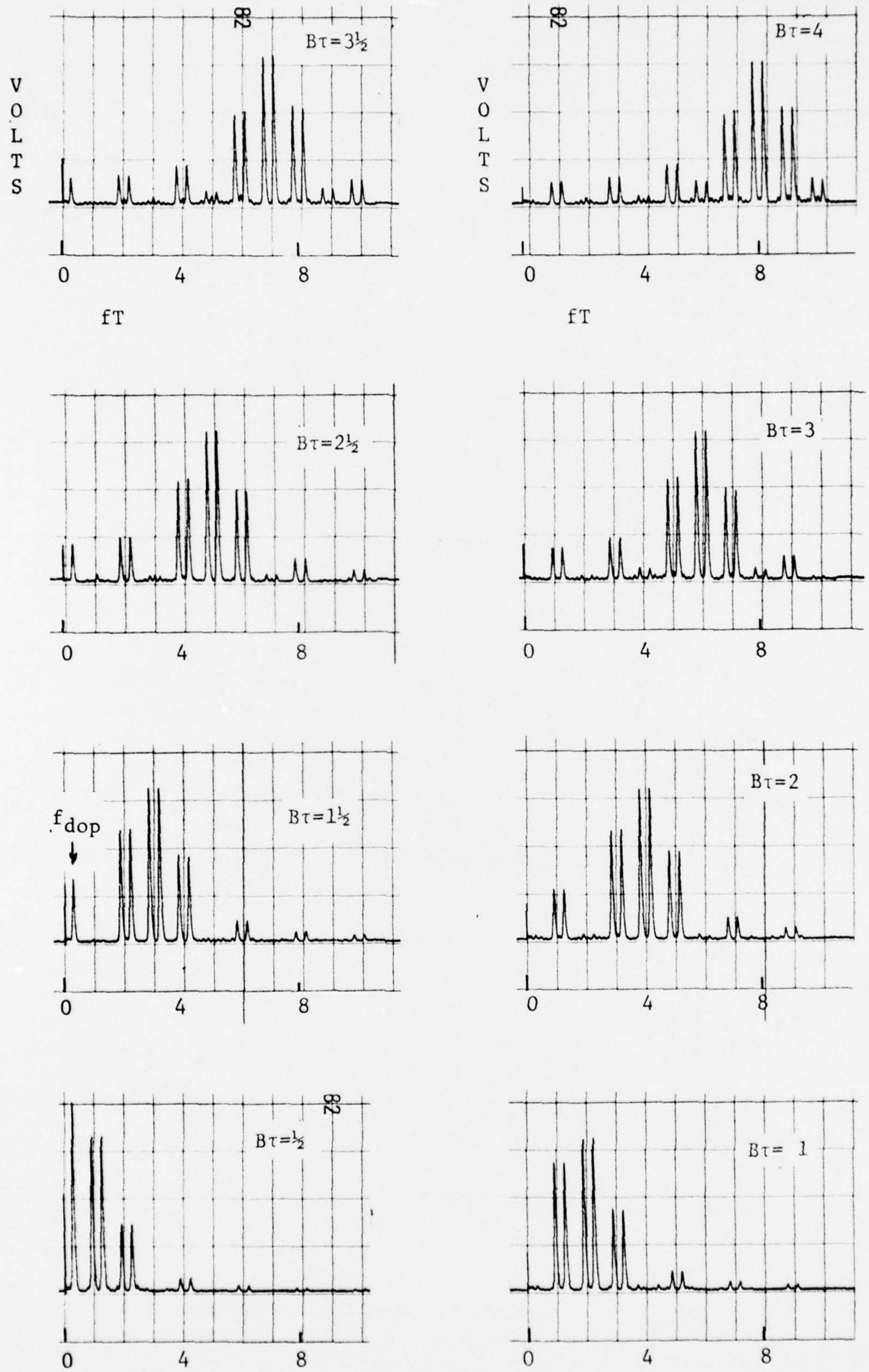


Figure 4. Spectrum of simulated IF signal with doppler shift for triangular FM.

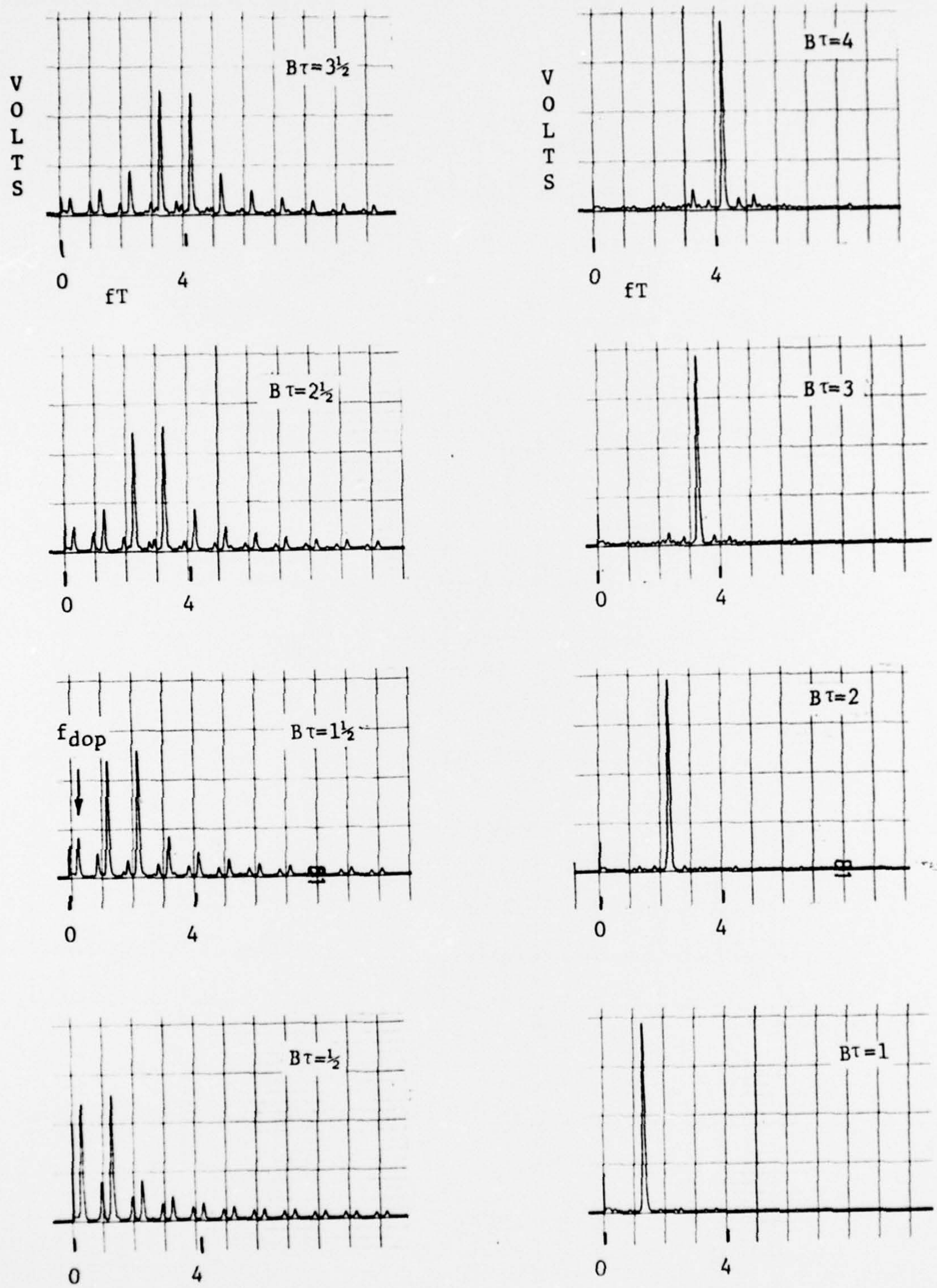
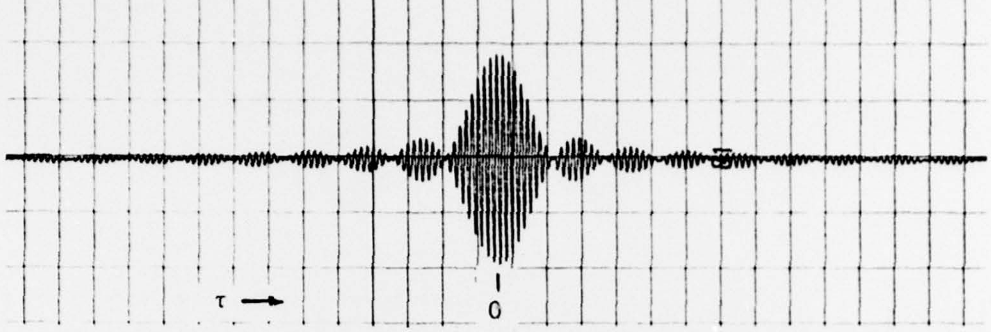
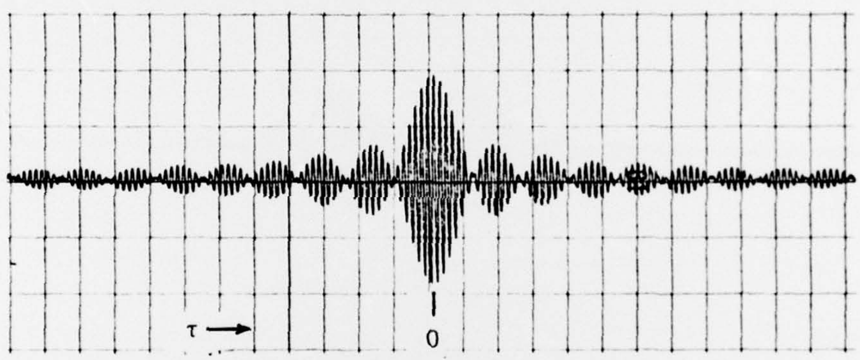


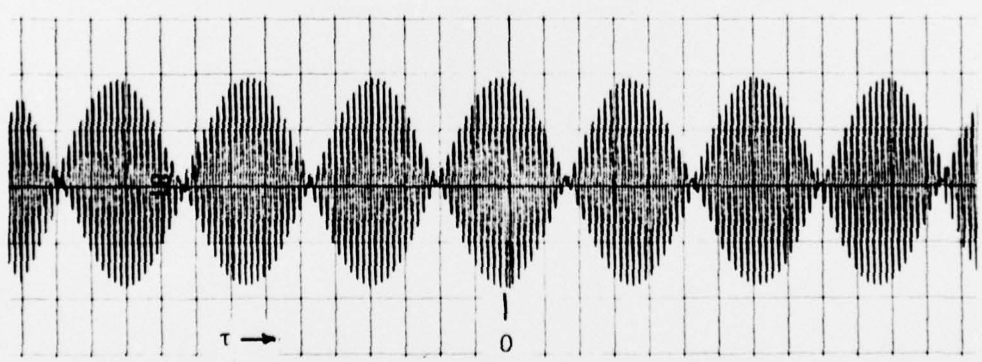
Figure 5. Spectrum of simulated IF signal with doppler shift for sawtooth FM.



A. TRIANGULAR FREQUENCY MODULATION



B. SINE-WAVE FREQUENCY MODULATION



C. SQUARE-WAVE FREQUENCY MODULATION

Figure 6. Doppler band response of zero-order FM ranging system to simulated IF signals from the IFSS.

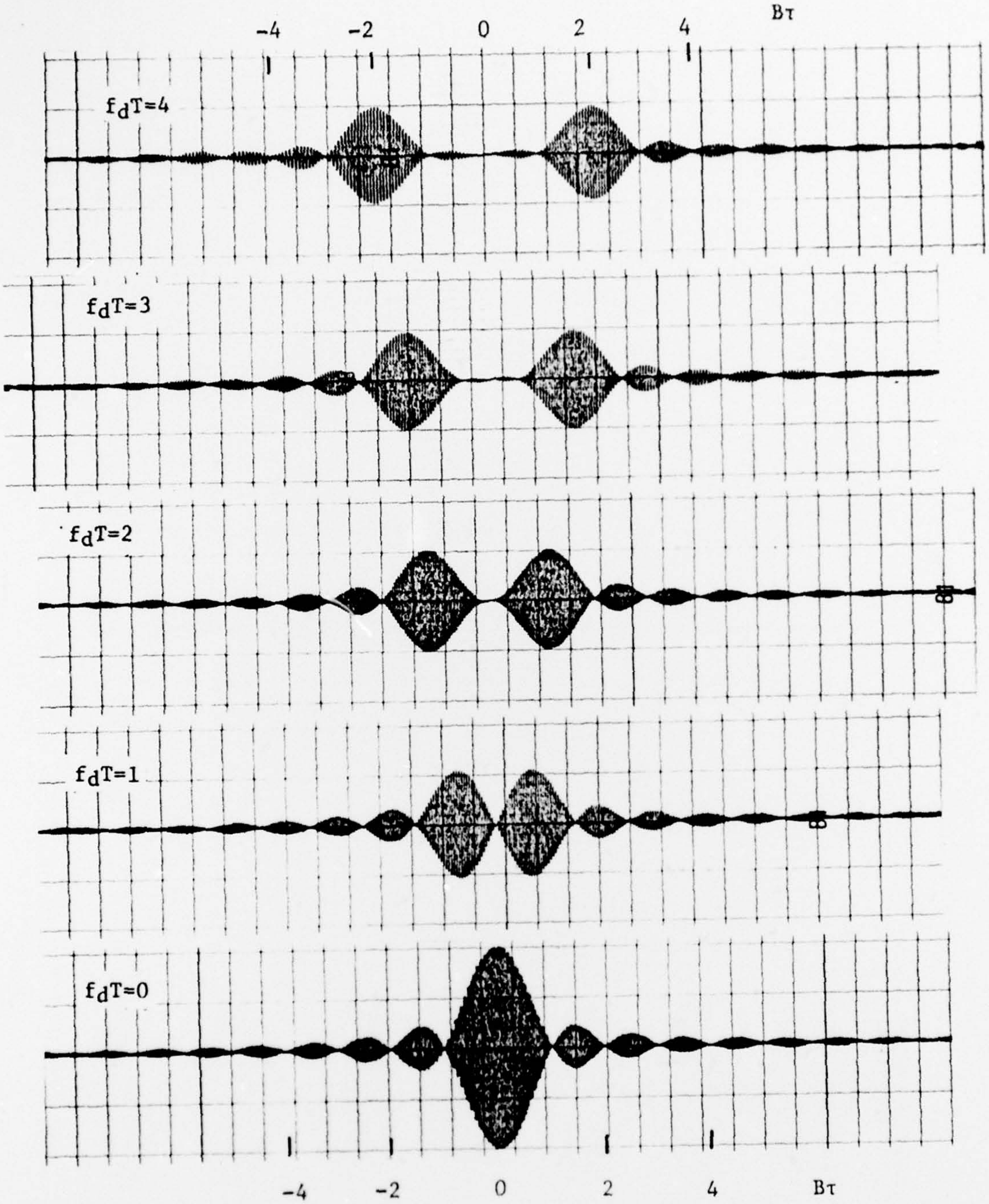


Figure 7. Response of zero-order FM system to simulated signals for triangular modulation and large doppler shifts (f_dT=0 to 4).

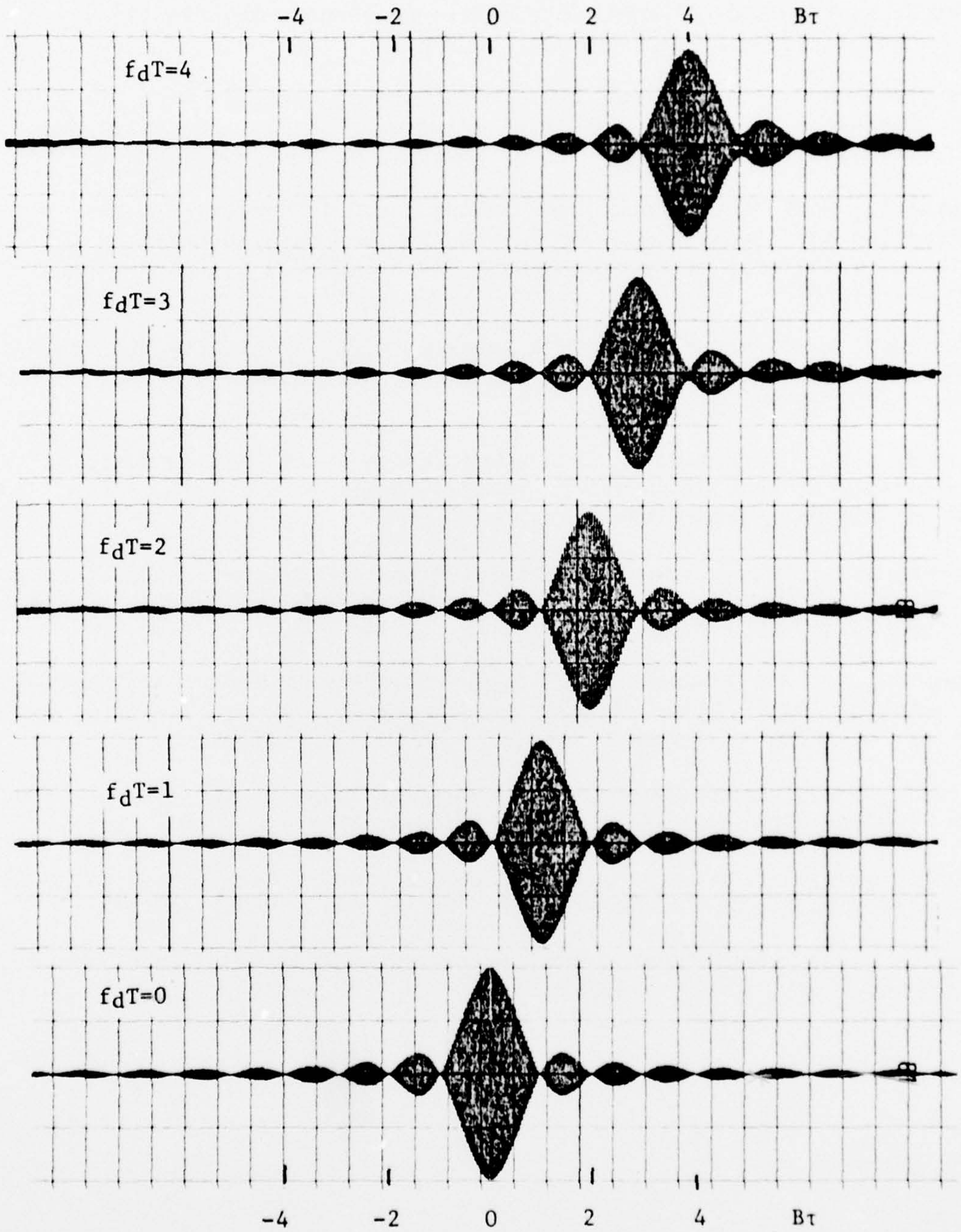


Figure 8. Response of zero-order FM system to simulated signals for sawtooth modulation and large doppler shifts ($f_dT=0$ to 4).

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APPENDIX A

IFSS HARDWARE DESCRIPTION

In the following paragraphs, the major hardware components necessary for implementing the IFSS are listed and their critical performance requirements are discussed.

1. WIDE-BAND FM OSCILLATOR

A wide-band FM oscillator which has a reasonably linear modulation characteristic and which exhibits low incidental AM with FM is required for the IFSS. For system tests requiring only a few beat cycles in the IF signal, fairly large errors in FM linearity can be tolerated; however, for tests requiring a large number of beat cycles ($n>10$), a high degree of linearity is required to produce IF signal components with the proper phase and amplitude.

In order to test systems beyond their operating height with the greatest accuracy, it is convenient to be able to deviate the transmitter frequency greater than the normal operating bandwidth ($\alpha>1$). Also, some additional linear range is required to accommodate the doppler modulation. For system development, the FM transmitter to be used in the system will normally have adequate range to serve in the IFSS. Since an IF signal is being simulated and the doppler added, oscillator carrier frequency has no effect and any FM oscillator with adequate linear FM bandwidth and low incidental AM can be used for test purposes.

The effects of incidental AM can be minimized by saturating one input to the RF mixer. The other input can also be overdriven to some extent to further minimize AM at the expense of generating a slightly triangular beat pattern waveform.

2. RF DELAY-LINE/MIXER

Any low-loss RF transmission line is suitable for the IFSS. It is helpful to use an RF amplifier if the FM oscillator signal is low so that maximum signal can be obtained from the RF mixer. This is particularly important if the oscillator has incidental AM and the RF mixer is unbalanced. This combination will cause undesirable components to be generated at the modulation and doppler frequencies and various sum and difference frequencies. By using a well balanced RF mixer and adjusting the drive levels correctly, a nearly ideal IF signal can be generated.

3. DOPPLER SAWTOOTH GENERATOR

Any function generator which produces a positive and negative sawtooth with very low fly-back time is suitable for the IFSS. A short fly-back time is necessary for correctly simulating the doppler shift of the IF signal. It should be noted that the FM oscillator modulation circuitry must also have a high frequency response in order to properly respond to the fly-back.

For testing at this laboratory, a sawtooth generator using a binary counter and a 8-bit digital-to-analog converter (D/A) was constructed (figure A-1).

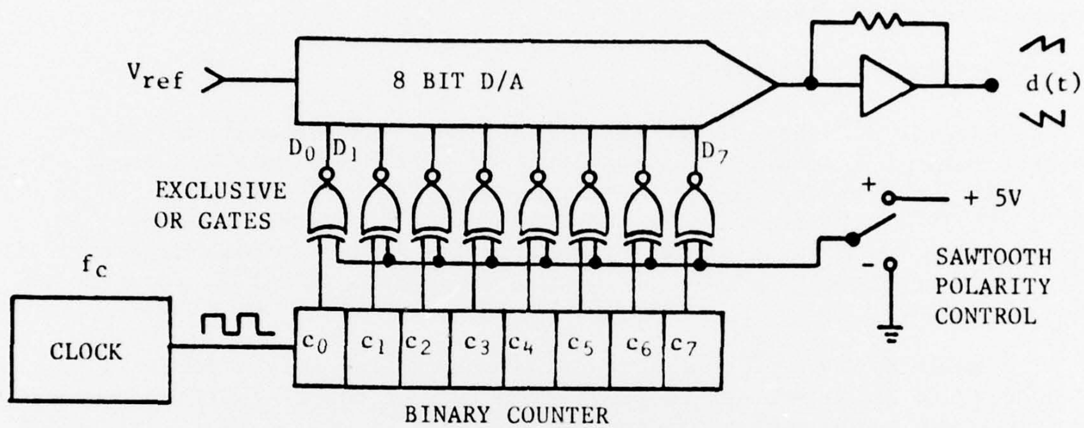

Figure A-1. Sawtooth generator.

An 8-bit binary counter normally counts from 0 to 255 and returns to zero. This digital input causes the output voltage to swing from minimum to maximum voltage. The exclusive OR gates logically invert the counter output when the control input is at logic zero so that the count now goes from maximum to minimum. There are many instances in which digital inversion is preferred over the equivalent analog inversion.

4. MODULATION AMPLITUDE CONTROL α

To simulate delay $\tau = \alpha\tau_0$, the modulation voltage must be scaled by α. For convenience in simulating dynamic target approaches, a multiplying 10-bit D/A converter controlled by a binary counter is used (figure A-2).

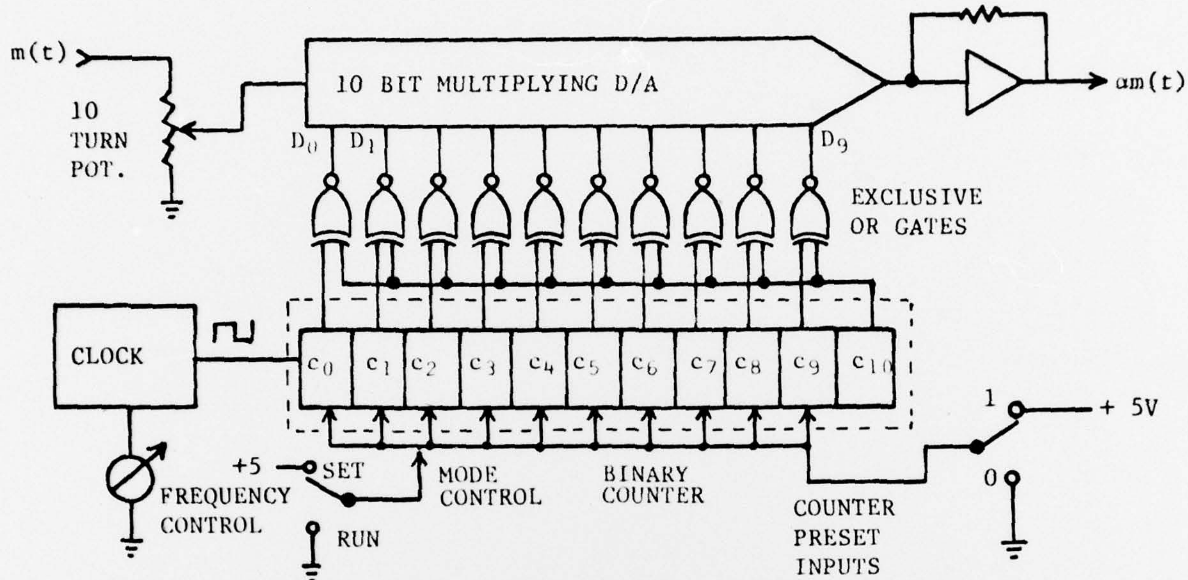

Figure A-2. Modulation control.

The digital count varies from 0 to 1023 which is equivalent to varying α from 0 to its maximum value. The exclusive OR gates are controlled by the last stage of the binary counter to produce a triangular variation rather than sawtooth. For simulating $\alpha>1$, the gain of the output amplifier is set to the maximum value of α or the amplitude of the modulation input can be increased by this factor. The clock frequency is adjusted to control the approach velocity. For testing directional doppler systems, the direction of the doppler shift can be made to agree with the approach direction by using the c_{10} output to control the polarity of the doppler sawtooth. One binary counter stage can be eliminated in figures A-1 and A-2 by using the clock output as the least significant bit provided the clock output is symmetrical.

To manually control α, the set/run switch is put in the set position and the 0/1 switch put to 1, forcing all counter outputs to 1. α is then set to the desired value using the 10-turn potentiometer. Manual control of α using a calibrated potentiometer is very useful for testing and adjusting signal-processor circuitry. The modulation output can be set to zero with the switch in order to facilitate adjustment of the doppler sawtooth amplitude. For dynamic target approaches, the set/run switch is put in the run position and the clock frequency adjusted to give the desired approach velocity.

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