averages over several range bins. Therefore, long pulse interference acts somewhat like clutter, and the interfering signal level at the subtractor output is reduced. Measurements made on an ASR-8 radar showed that for interfering pulse widths greater than 2.0 μsecs the interference was suppressed. Thus, interference from height finding radars (AN/FPS-6, 90), and weather radars operating in the 4.0 μsec mode can be suppressed by operating in the Log-FTC mode. For CW type interference, the Log-FTC circuit reduces the interference down to the receiver noise level since the CW interference appears somewhat like clutter. However, the desired signal will not be detected unless the signal is above the CW interference. Therefore, for every dB the CW interference is above the receiver noise level the desired signal sensitivity will be reduced by that number of dB.

Normal Enhancer

The process of summing the echo pulses from a target is called integration. The following is a discussion of the transfer properties of integrators (enhancers) used by radars in the 2.7 to 2.9 GHz band. The discussion includes the integrator transfer properties of noise, desired signal, and asynchronous interfering signals. Also discussed are the trade-offs in the desired signal transfer properties of the enhancers in suppressing asynchronous interfering signals.

Integrators are generally used in the primary radars for two reasons:

1. To enhance weak desired targets for PPI display.

2. To suppress asynchronous pulsed interference.

The principle of the radar video integrator is that radar signal returns from a point target consist of a series of pulses generated as the radar antenna beam scans past the target, all the pulses from the target will occur in the same range bins in successive radar periods. It is this series of pulses from a target which permits integration of target returns to enhance the weak signals. The number of pulse returns (N) from a target depends upon the radar antenna beamwidth (BW), the rate of antenna rotation (RPM), the radar pulse repetition rate (PRF), and the target characteristics. The equation for the number of pulses from a point target is given by (Skolnik, 1962):

$$N = \frac{PRF \cdot BW}{6 \cdot RPM} \qquad (3\text{-}21)$$

where:

PRF = Radar pulse repetition frequency, in PPS

BW = Antenna 3 dB beamwidth, in degrees

RPM = Antenna scan rate, in rpm

A range value of N for radars in the 2.7 to 2.9 GHz band is 12 to 20. The integrator will suppress asynchronous interference since the interfering pulses will not be separated in time by the radar period, and thus will not occur in the same range bin in successive periods (asynchronous with the system). Therefore, the asynchronous interference will not add-up, and can be suppressed.

All radars in the 2.7 to 2.9 GHz band employ post detection or noncoherent integrators. The types of post detection integrator employed in radars in the 2.7 to 2.9 GHz band can be categorized either as a feedback integrator or a binary integrator. Radars employing feedback integrators may be of analog (delay line) or digital (shift register) type. Only digital binary integrators are used. Appendix D contains a detailed discussion of the feedback and binary integrator transfer properties and the trade-offs in suppressing asynchronous interference. The transfer properties were investigated analytically and by simulating the noise, desired signal, interfering signals, and the feedback and binary integrator hardware. Appendix E contains a detailed discussion of the methods used to simulate the noise, desired signal, interfering signal, and the actual radar hardware simulated.

Feedback Integrator Figure 3-17 shows a block diagram of a typical feedback integrator used by radars in the 2.7 to 2.9 GHz band. The feedback integrator consists of an input limiter, an adder, and a feedback loop with an output limiter and a delay equal to the time between transmitter pulses (1/PRF). The radar period delay for digital radars is achieved by clocking a shift register, and the actual integrator hardware is essentially represented in Figure 3-17. Analog radars in the 2.7 to 2.9 GHz band generally use quartz delay lines, thus accomplishing the delay accoustically to reduce the size of the delay line. However, the inherent loss of quartz delay lines requires use of additional hardware, such as, modulators, attenuators, amplifiers, detectors, and balancing circuits (AGC) to achieve integration. If the analog integrator balancing circuitry is aligned properly, the transfer properties of an analog integrator can, for analytical simplicity, be modeled by the operations shown in Figure 3-17. Digital integrators will also introduce some quantization, roundoff and truncation error. However, the error due to quantization, roundoff and truncation is generally very small and can be neglected in most cases.

Prior to the input of the feedback integrator, signal processing circuitry is used to reduce the mean noise level at the input to the feedback integrator. This circuitry generally consists of an attenuator, subtractor, and bottom clipper so that the noise at the input to the feedback integrator will be positive. The function of this circuitry is to reduce the mean level of the noise at the integrator input to reduce the noise gain of the feedback integrator. Since the noise is being continually added by the feedback integrator, the noise amplitude probability density function at the feedback integrator output by the central limit theorem is approximately Gaussian with

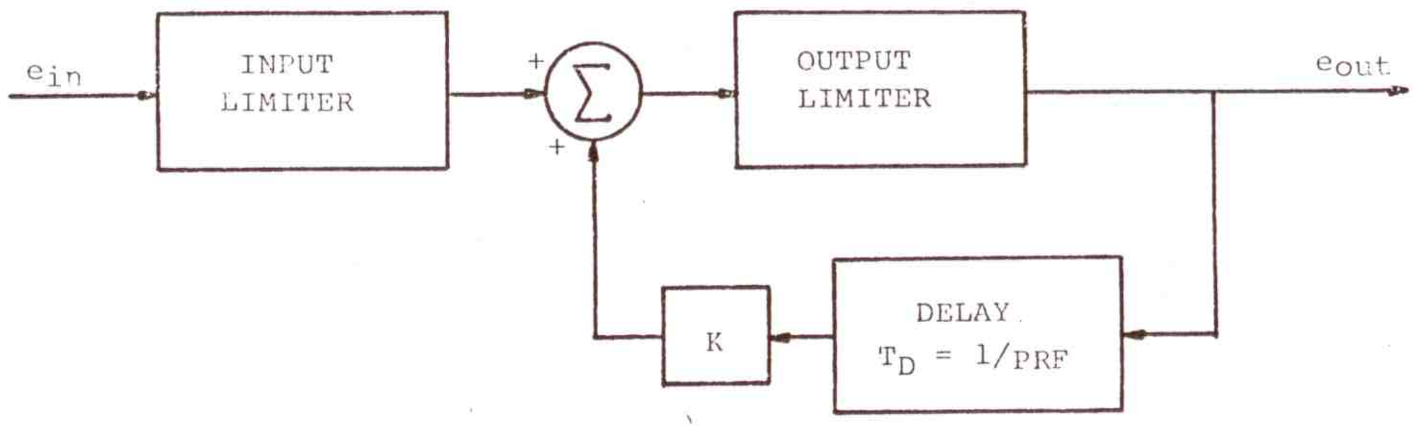

Figure 3-17. Feedback Integrator Block Diagram

non-zero mean.

It is shown in Appendix D (Equation D-10) that the signal-to-noise-ratio enhancement (SNR_E) of the desired signal is given by:

$$SNR_E = 20 \log_{10} \left[\left(\frac{1-K^N}{1-K} \right) (1-K^2)^{1/2} \right] \qquad (3-22)$$

where:

N = Number of target return pulses

K = Integrator feedback constant

Equation 3-22 is only a first order approximation of the signal-to-noise ratio enhancement of a feedback integrator since it assumes zero mean noise amplitude distribution and a constant desired signal level. The desired signal level actually varies from pulse-to-pulse due to fluctuations in target returns (scintillation and antenna pattern modulation). Studies (Trunk, 1970) have been made which take into account pulse amplitude variations due to the antenna pattern modulation. Trunk concluded that the SNR enhancement of a feedback integrator could be reduced by as much as 1.6 dB due to antenna beam shape pulse amplitude variations. The actual reduction in SNR enhancement due to the radar antenna pattern is between 0 and 1.6 dB, and is also a function of the integrator input limiter limit level setting. It is shown in Appendix D using Equation 3-22 and measurement results that the optimum value of the feedback constant (K) is between .92 and .94 for 20 pulses from a target (N = 20), and the signal-to-noise-ratio enhancement (SNR_E) due to integration is approximately 10 to 12 dB.

Figure 3-18 shows a simulated unintegrated target return pulse train for target azimuth shift and angular resolution reference. Figures 3-19 through 3-21 show a simulated feedback integrator output of a target return pulse train for 20 pulses for an input limiter limit level setting of 1.0, 0.5, and 0.34 volts. A detailed discussion of the radar simulation model is given in Appendix E. When a feedback integrator is used there are trade-offs in target azimuth shift and angular resolution. A comparison of Figure 3-18 with Figures 3-19 through 3-21 shows that the center of the target return pulse train has shifted in time. This shift in time is related to a target azimuth shift on the Plan Position Indicator (PPI) display. Also a comparison of Figure 3-18 with Figures 3-19 through 3-21 shows that the number of pulses above 1.0 volts (peak noise level) increases when the feedback integrator is used. This increase in number of pulses results in a decrease in angular resolution. (The property of the radar to distinguish between two targets.) Appendix D contains a detailed investigation of the trade-offs in target azimuth shift and angular resolution when an integrator is used. In summary, it was shown that a feedback integrator causes a target azimuth shift of approximately 0.90 degrees, and an angular resolution loss

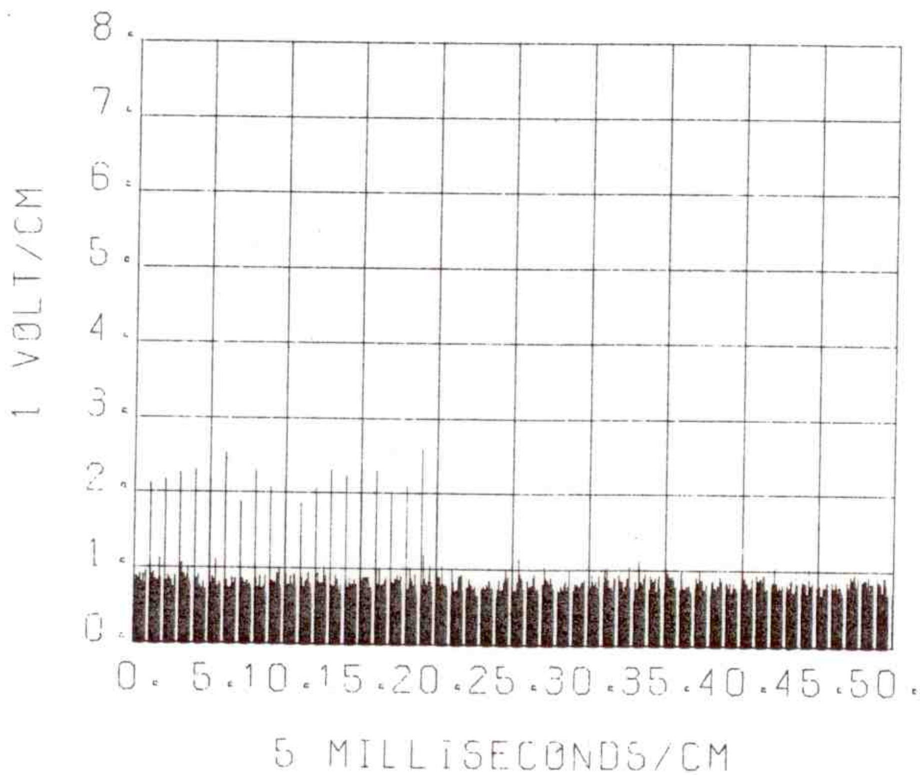

Figure 3-18. Simulated Normal Channel Unintegrated Target Return Pulse Train for a SNR = 15 dB

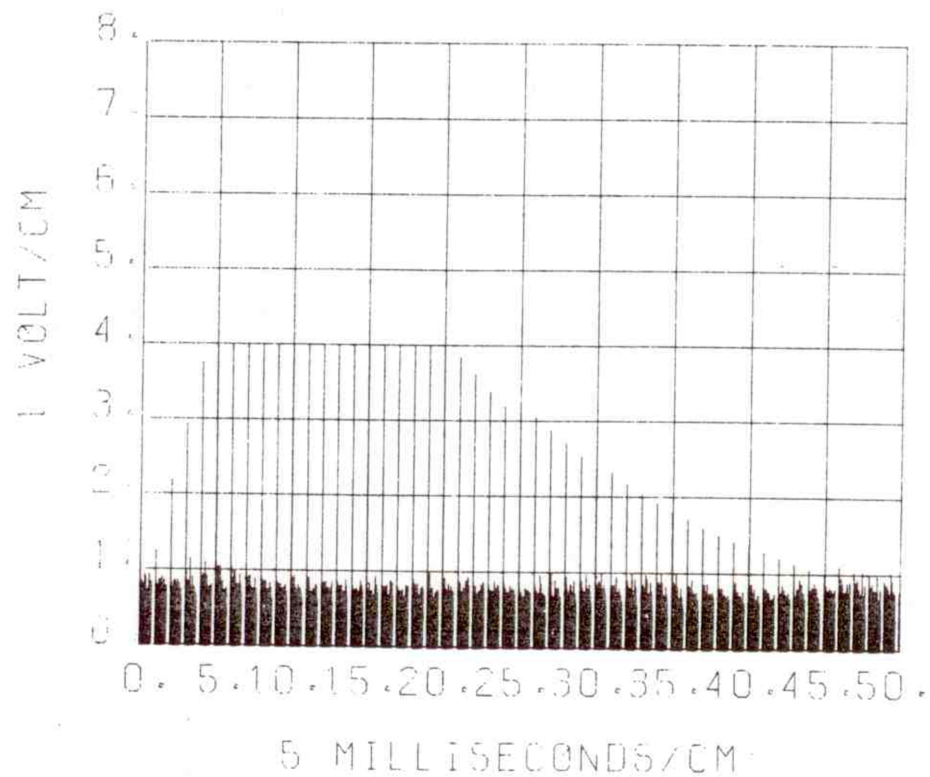

Figure 3-19. Simulated Normal Channel Integrated Target Return Pulse Train for the Input Limiter Set at 1.0 Volts and a SNR = 15 dB

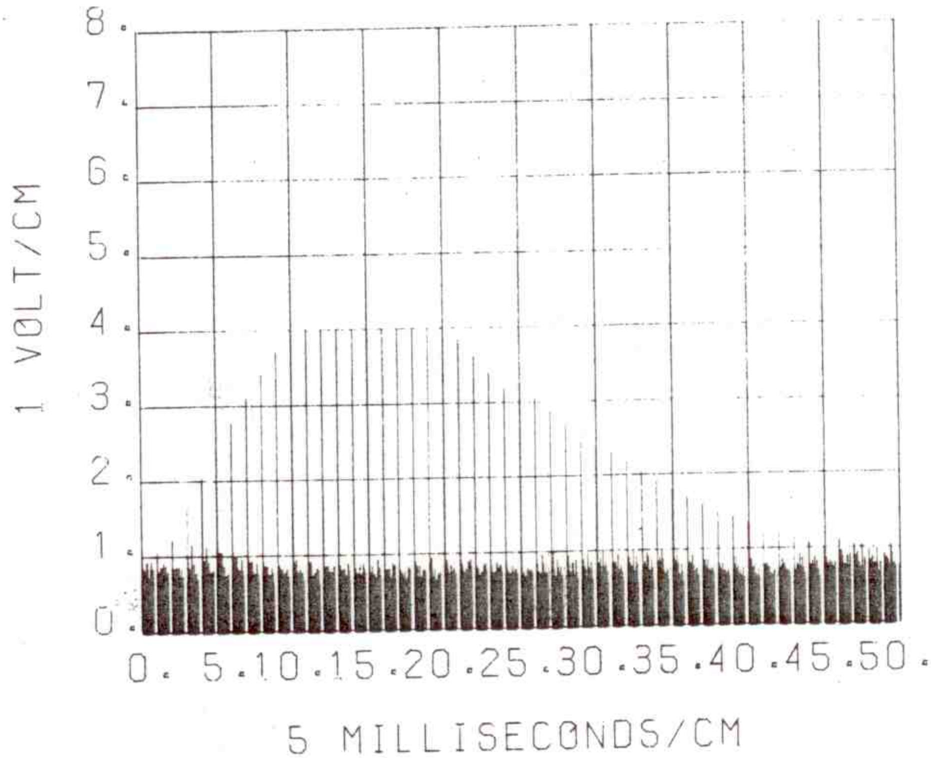

Figure 3-20. Simulated Normal Channel Integrated Target Return Pulse Train for the Input Limiter Set at 0.5 Volts and a SNR = 15 dB

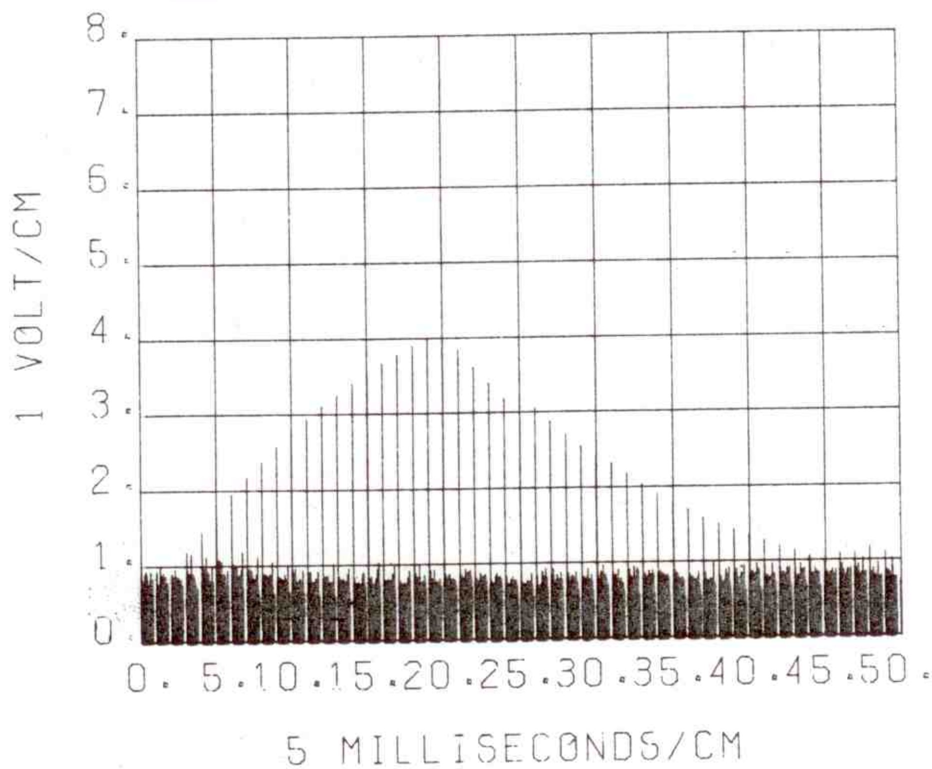

Figure 3-21. Simulated Normal Channel Integrated Target Return Pulse Train for the Input Limiter Set at 0.34 Volts and a SNR = 15 dB

of approximately 1.2 to 1.5 degrees relative to an unintegrated target return pulse train.

In congested areas when there is potential for asynchronous interference from other radars in the 2.7 to 2.9 GHz band, adjustments to the feedback integrator input limiter are required to suppress the asynchronous interference. By adjusting the integrator input limiter limit level the peak interference level can be suppressed to the one volt noise level at the integrator output. Suppression of asynchronous interference in the radar normal channel and the trade-offs to the desired signal are discussed in detail in Appendix D. The analysis showed that the suppression of asynchronous interference does not significantly increase the target azimuth shift or decrease the target angular resolution given the integrator is going to be used. Figure 3-22 shows a simulated normal channel radar unintegrated output for three interference sources (ASR-5, INR = 10 dB; ASR-8, INR = 15 dB; and AN/FPS-90, INR = 20 dB), and a desired target signal-to-noise ratio of 15 dB. Figure 3-23 shows for the same interference condition the radar output after feedback integration for an input limit level setting of 0.34 volts. The asynchronous interference has been suppressed (compare Figure 3-21 with 3-23) by the feedback integrator. Measurements made on the Stapelton Airport ASR-8 radar in Denver, Colorado, showed that on-tune pulsed interference levels of 50 dB above the receiver noise level (approximately -60 dBm) could be suppressed by the feedback integrator so that they did not appear on the PPI display. The measured change in target detection sensitivity in suppressing the asynchronous interference was 1 dB or less. In summary, feedback integrators can suppress asynchronous interference, in the normal channel, by adjusting the feedback integrator input limiter limit level, and the trade-offs in target azimuth shift, angular resolution, and target detection sensitivity appear to be minimal.

Binary Integrator The ASR-7 and AN/GPN-12 radars are made by the same manufacturer, and the enhancer used in the two radars are electronically identical. The integrator (enhancer) used in the two radars can be represented by the block diagram shown in Figure 3-24. The binary integrator consists of a threshold detector or comparator, binary counter (adder/subcontractor circuit), a five bit shift register memory, and a digital-to-analog (D/A) converter. Each PRF period is divided into range bins of .625 μsec. If a pulse of a target return pulse train exceeds the comparator threshold level, the enhancer stores a one level digital signal in the shift register memory for that range bin. If the successive pulses of the target return pulse train continue above the comparator threshold in the given range bin, the binary counter will add one level to the stored digital signal in the shift register memory in each PRF period until a maximum integrator level of 31 is reached. If in any PRF period the signal fails to exceed the comparator threshold, the binary counter subtracts one from the stored integrator state in the given range bin until a digital signal level of zero is reached. The subtraction provides the target return pulse train signal decay required after the antenna beam has passed the target, and also enables the suppression of asynchronous interfering signals. The voltage amplitude at the enhancer D/A converter output is determined by the binary

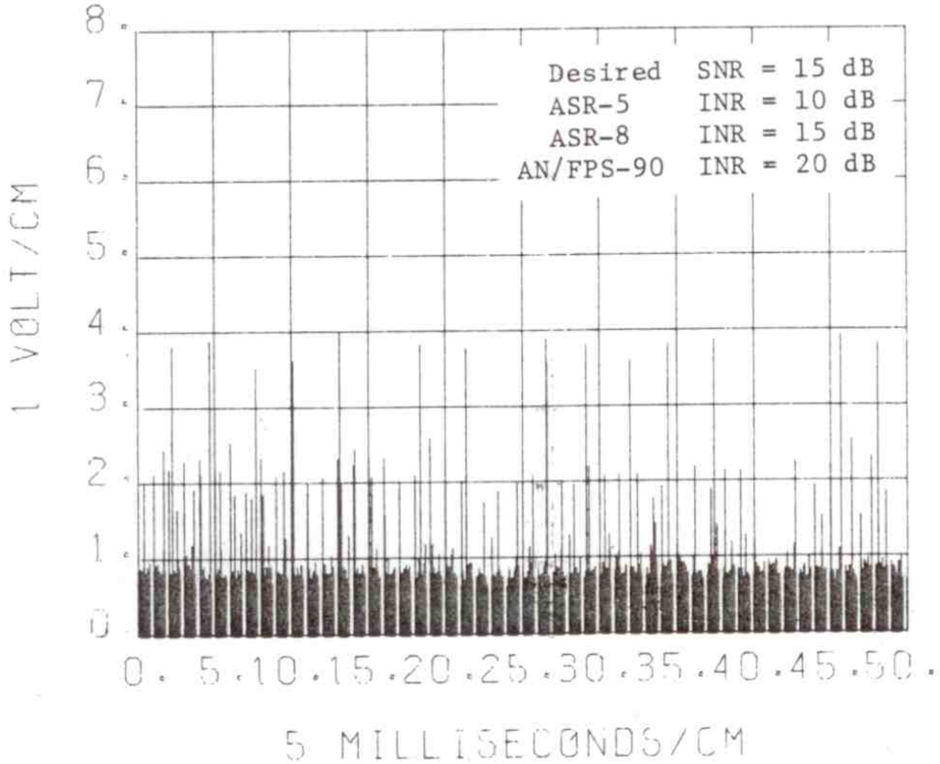

Figure 3-22. Simulated Normal Channel Unintegrated Radar Output with Interference

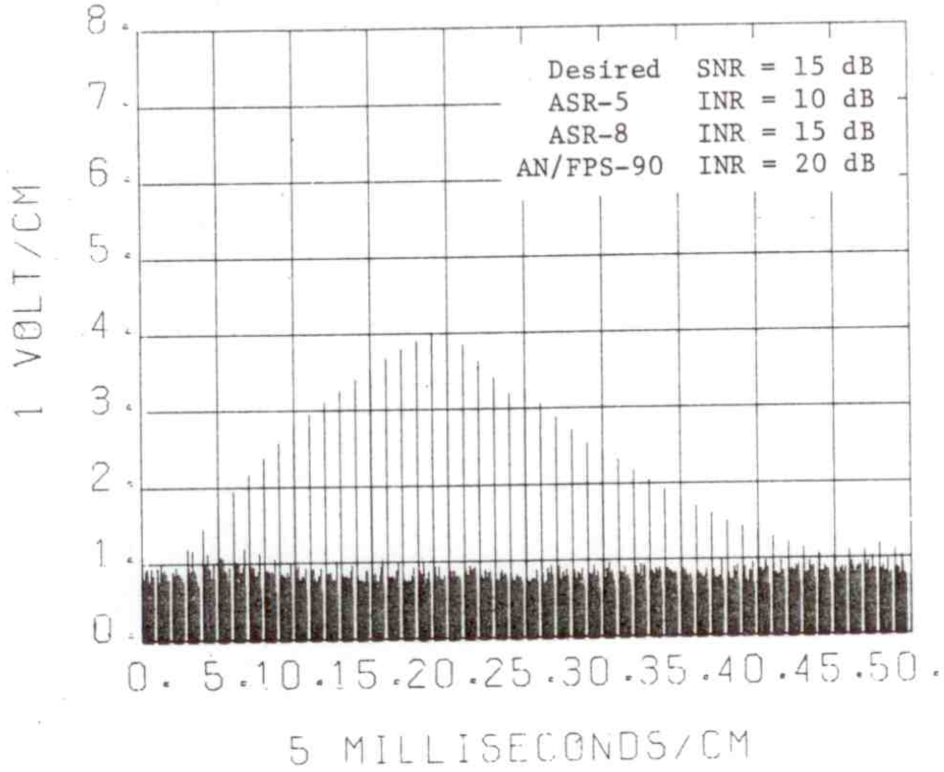

Figure 3-23. Simulated Normal Channel Integrated Radar Output with Interference

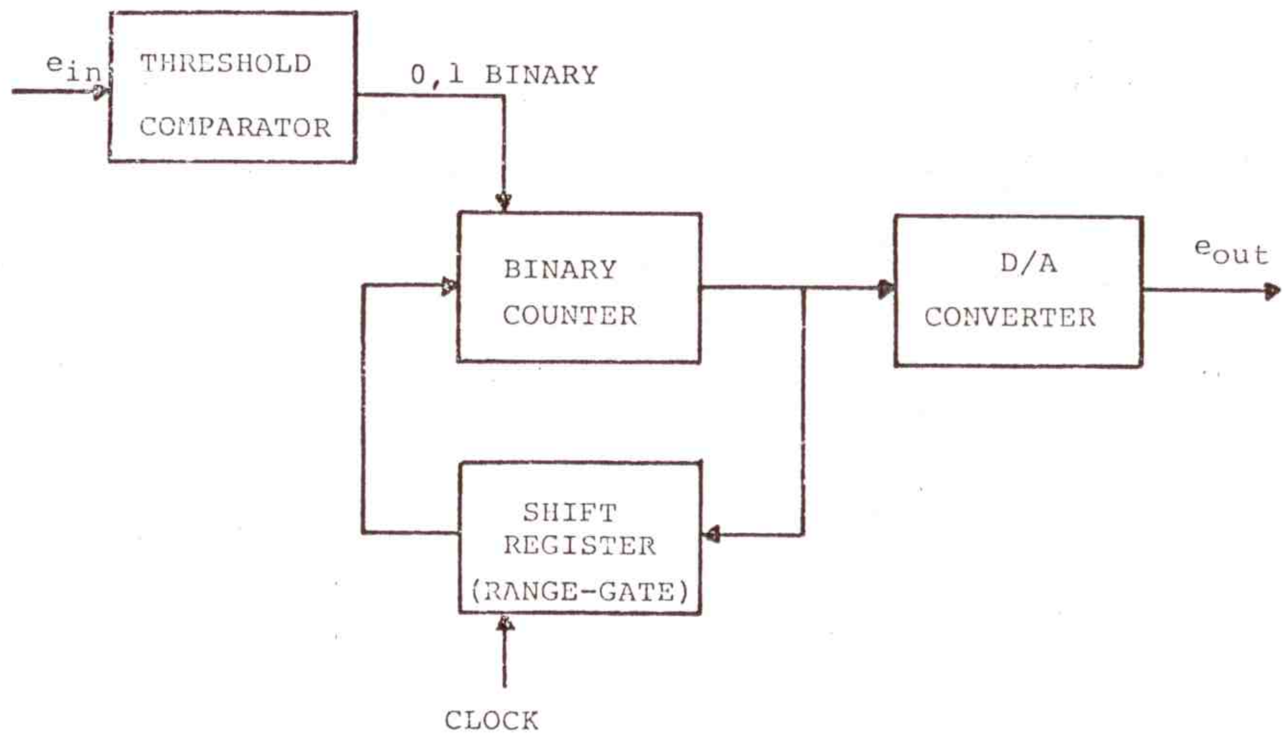

Figure 3-24. ASR-7 (AN/GPN-12) Binary Integrator Block Diagram

counter level (0 to 31) for the particular range bin times .125 volts. Therefore, for a binary counter level of 31, the maximum enhancer output voltage would be 3.875 volts (31 x .125).

FAA Integrator Modification

The FAA made modifications to the manufacturer's integrator (enhancer) printed circuit board due to deficiencies that were observed on the ASR-7 video enhancer at operational field sites. Deficiencies that were observed were: (1) loss of weak targets due to design of the enhancer integrators, and (2) excessive azimuth shift of the target (NAFEC Letter Report, FAA-MA-76-39-LR, 1976). The major modification made by the FAA was the replacement of the binary counter (IC's) with a programmable read-only-memory (PROM) logic. The PROMs permit the bypassing of some of the intermediate levels (0 to 31), depending on the PROM programming. Figure 3-25 shows the FAA standard hit/miss characteristic curve which is programmed into the PROMs. The figure shows that the enhancer state is a nonlinear function of the target hits above the comparator threshold level. It only takes four hits to get to level 8 (one volt noise level), and six hits to get to level 31 (3.875 volts). This results in a strong target enhancement with only a few hits. The primary advantage of the PROM enhancer is that, due to its programmable feature, it permits a radar site flexibility in selecting a hit-count sequence based on the radar site environment (interference and clutter). Similarly, the miss-count sequence can be precisely controlled to minimize the target azimuth shift and loss in angular resolution. In this way, the video enhancer performance can be optimized to give improved performance in a variety of environmental conditions.

The following discussion will center on the particular signal processing characteristics of the conventional integrator deployed in the ASR-7 and AN/GPN-12 and the modified ASR-7 integrator to noise, desired target return pulse train, and asynchronous interference. Also discussed are the trade-offs in the desired signal transfer properties of the enhancer in suppressing asynchronous interfering signals. Appendix D contains a detailed discussion of the binary integrator transfer properties and the trade-offs in suppressing asynchronous interference.

The normal channel noise amplitude distribution at the binary integrator input is Raleigh distributed. It is shown in Appendix D (Equation D-20b) that the probability of the binary counter being in state E_j due to noise (P_{nj}) can be modeled by a one-dimentional random walk with reflecting barriers where levels 0 and 31 are the reflecting barriers. Since the noise is continually summed in the binary integrator the number of steps (k) in the random walk is infinite. It can be shown that a one-dimentional random walk with reflecting barriers model for an infinite number of steps is identical to a truncated single channel queue model where the probability of being in state E_j due to noise (P_{nj}) can be expressed as (Saaty, 1968):

$$P_{nj} = \frac{(P_{N1}/P_{NO})^{j-1}}{\sum_{j=1}^{\rho} (P_{N1}/P_{NO})^{j-1}} \qquad (3\text{-}23)$$

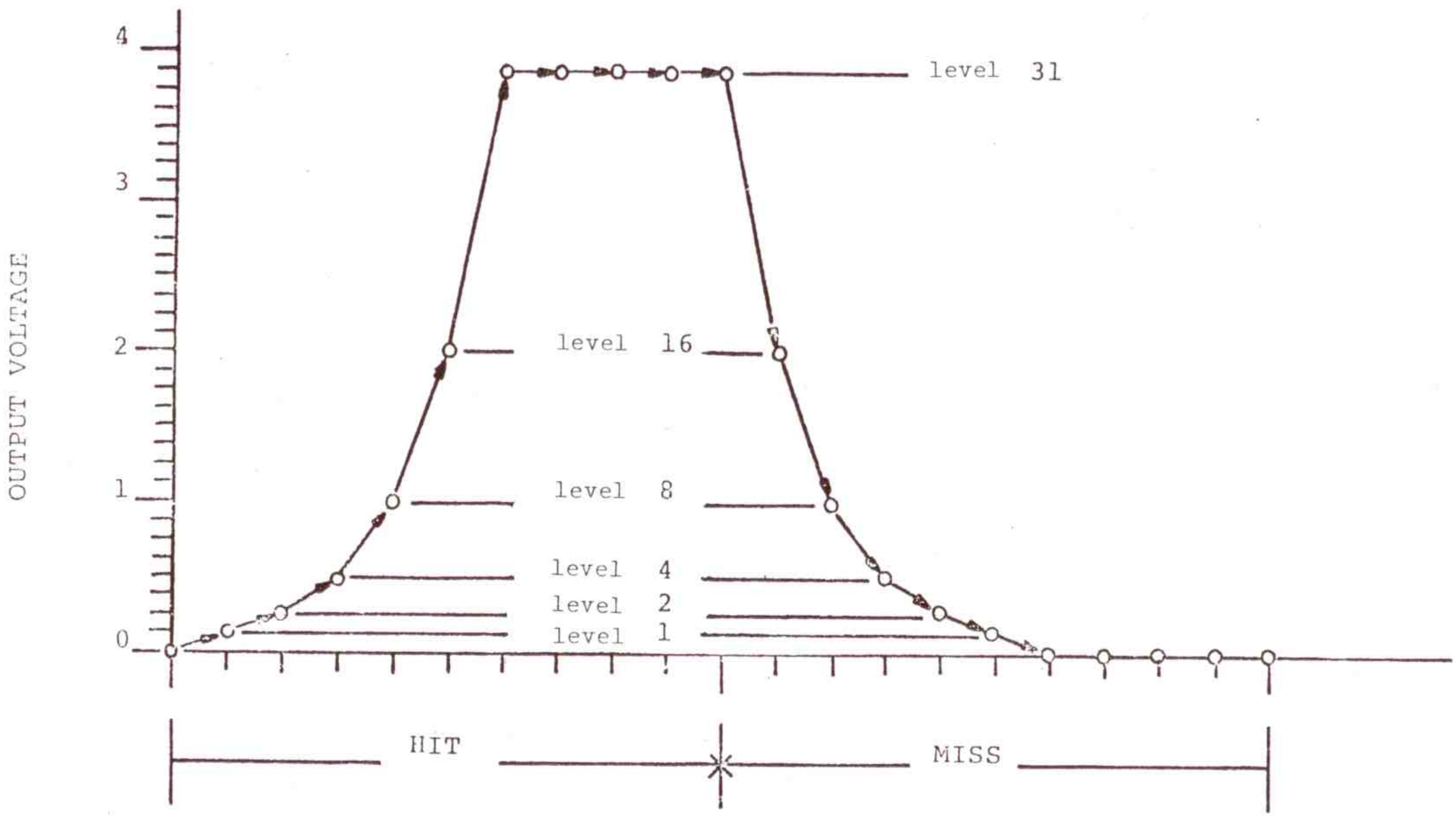

Figure 3-25. Hit/Miss Characteristic Curve for FAA Modified ASR-7 Enhancer

where:

$P_{N\emptyset}$ = Probability of the noise causing a 0 at the threshold comparator output

P_{N1} = Probability of the noise causing a 1 at the threshold comparator output

ρ = Number of states (function of counter level sequence)

The probability distribution given by Equation 3-23 is a geometric distribution, and is independent of the noise amplitude distribution at the enhancer input. The threshold comparator threshold level is normally adjusted to give a peak noise level of one volt (enhancer level 8, 8 x .125) with a certain probability of false alarm (probability of exceeding level 8). A detailed discussion of the setting of the threshold comparator threshold level for noise is given in Appendix D.

The normal channel signal-plus-noise amplitude distribtuion at the binary integrator input is Rice distributed (see Equation 3-9, and Figure 3-10). It is shown in Appendix D (Equation D-25a) that the probability of a desired target return pulse train of 20 pulses causing the binary integrator to be in state E_j can be determined by using a one-dimensional random walk with reflecting barriers model where levels 0 and 31 are the reflecting barriers. The probability of the desired target return pulse train causing the binary integrator to be in state E_j for a given signal-to-noise ratio is given by:

$$P_{sj} = \frac{\sum_{k=1}^{N} P_{ij}^{(k)}}{\sum_{j=1}^{\rho} \sum_{k=1}^{N} P_{ij}^{(k)}} \tag{3-24}$$

where:

$$P_{ij}^{(k)} = \frac{(p/q)-1}{(p/q)^{\rho}-1} \left(\frac{p}{q}\right)^{j-1} + \frac{2p}{\rho} \sum_{r=1}^{\rho-1} \frac{x_i^{(r)} y_j^{(r)} [2\sqrt{pq} \cos \pi r/\rho]^k}{1 - 2\sqrt{pq} \cos \pi r/\rho} \tag{3-24a}$$

and:

$$x_i^{(r)} = \left(\frac{q}{p}\right)^{i/2} \sin \frac{\pi r i}{\rho} - \left(\frac{q}{p}\right)^{(i+1)/2} \sin \frac{\pi r(i-1)}{\rho} \tag{3-24b}$$

$$y_j^{(r)} = \left(\frac{p}{q}\right)^{j/2} \sin \frac{\pi r j}{\rho} - \left(\frac{p}{q}\right)^{(j-1)/2} \sin \frac{\pi r(j-1)}{\rho} \qquad (3\text{-}24c)$$

ρ = Number of states (function of counter level sequence)

$q = P_{S\emptyset}$ = Probability of 0 at threshold comparator output

$p = P_{S1}$ = Probability of 1 at threshold comparator output

N = Number of desired signal pulses in target return pulse train

The values of P_{Sj} as a function of the signal-to-noise ratio are discussed in detail in Appendix D. Also the probability of the desired signal being in state E_j as a function of the signal-to-noise ratio is also discussed in detail in Appendix D (see TABLE D-6).

The signal processing of the ASR-7 binary integrator was simulated to investigate the trade-offs to the desired signal in suppressing asynchronous interference. A simulated ASR-7 enhancer output for a desired target return pulse train of 20 pulses without noise present is shown in Figures 3-26 and 3-27 for the conventional ASR-7 enhancer, and the FAA modified ASR-7 enhancer, respectively. A comparison of Figures 3-26 and 3-27 shows that the FAA Modified ASR-7 enhancer provides a significant improvement in signal enhancement, target azimuth shift, and angular resolution. Figure 3-28 shows the simulated radar output of the normal channel for a Signal-to-Noise-Ratio (SNR) of 15 dB with the binary integrator off (unintegrated). Figure 3-29 shows the radar output with the enhancer on (integrated) for the same SNR. Appendix D contains a detailed discussion of the desired signal transfer properties of the binary integrator as a function of the signal-to-noise-ratio.

It is shown in Appendix D that the FAA modified binary integrator causes a target azimuth shift of approximately .179 degrees. However, the feedback integrator causes a target azimuth shift of approximately 0.90 degrees. Therefore, the FAA modified binary integrator results in a significant improvement in target azimuth shift over the feedback integrator. Also the FAA modified integrator does not cause any loss in target angular resolution while the feedback integrator results in a loss in angular resolution of 1.2 to 1.5 degeees.

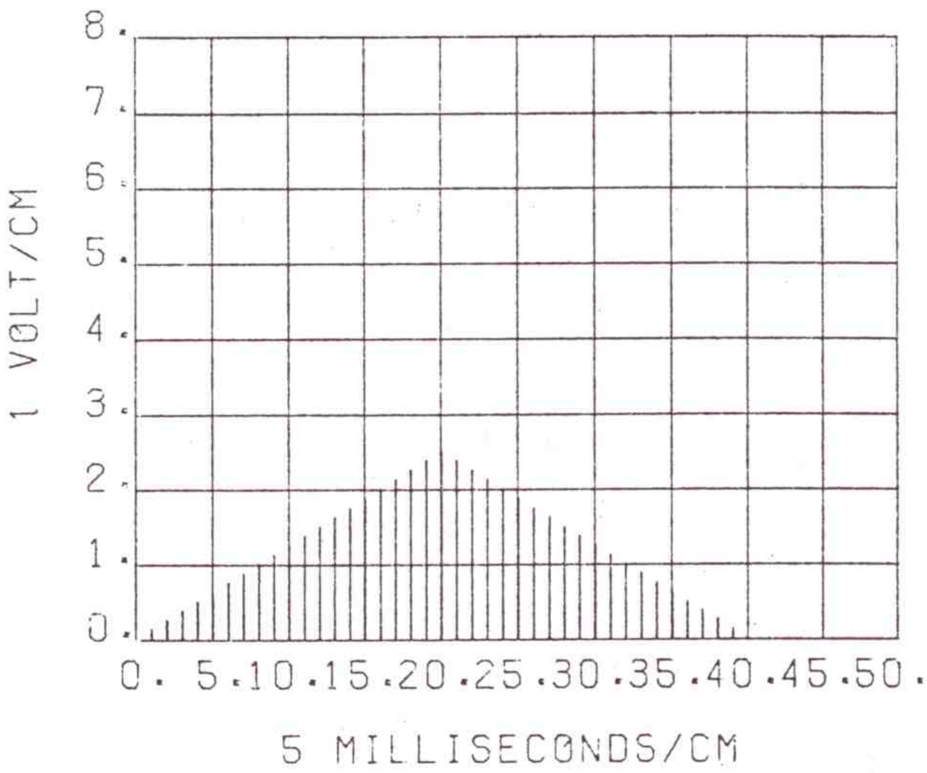

Figure 3-26. Simulated Binary Integrator Output for Target Return Pulse Train (ASR-7, AN/GPN-12)

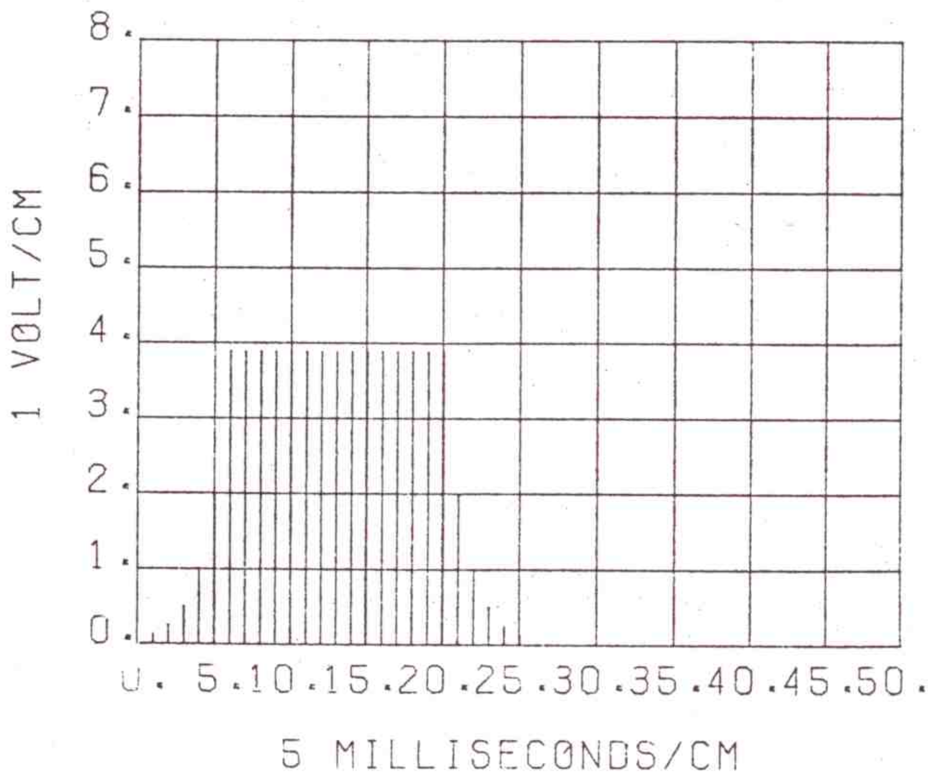

Figure 3-27. Simulated FAA Modified Binary Integrator Output for Target Return Pulse Train (ASR-7)

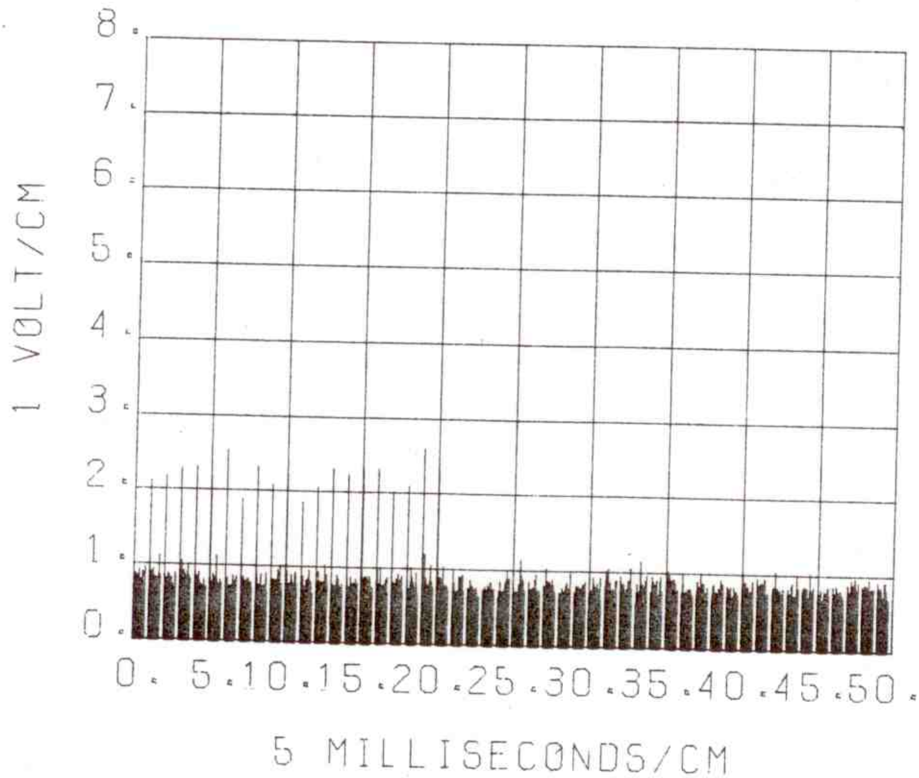

Figure 3-28. Simulated Normal Channel Unintegrated Target Return Pulse Train for a SNR = 15dB

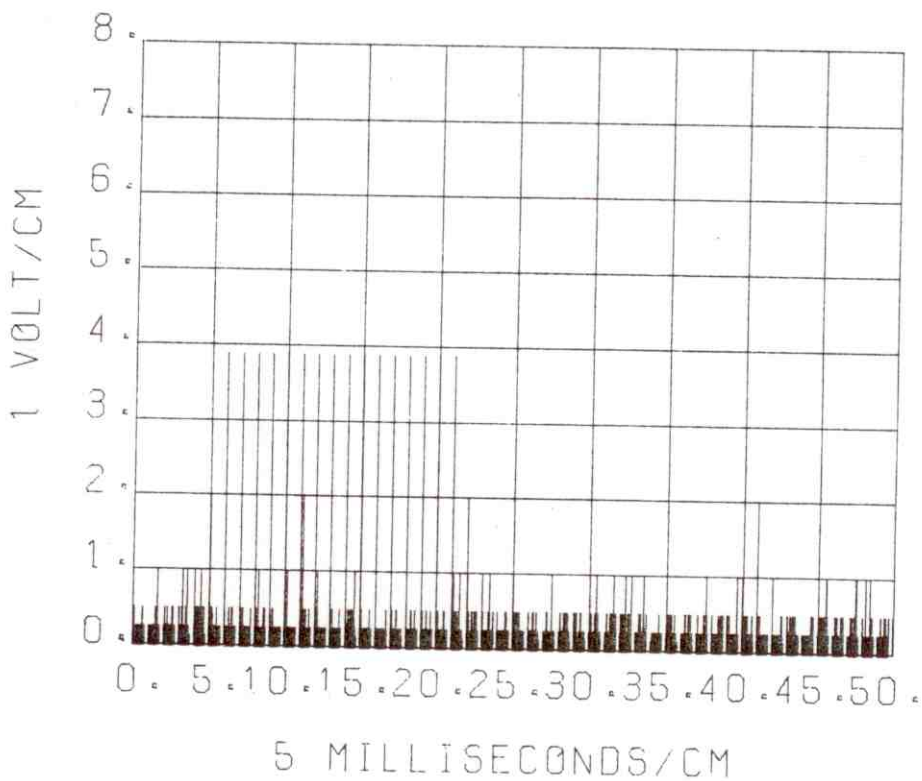

Figure 3-29. Simulated Normal Channel Integrated Target Return Pulse Train for a SNR = 15dB

The capability of the binary integrator in the ASR-7 to suppress normal channel asynchronous interference was also investigated using the radar simulation model (see Appendix E). Three interfering radar sources were simulated: ASR-5, ASR-8, and the AN/FPS-90. Figures E-3 through E-5 in Appendix E show the respective time waveforms simulated for each of the radar interfering sources. Figure 3-30 shows a simulated normal channel radar unintegrated output for three interference sources (ASR-5, INR = 10 dB; ASR-8, INR = 15dB; and AN/FPS-90, INR = 20 dB), and a desired target signal-to-noise ratio of 15 dB. Figure 3-31 shows for the same interference condition the radar output after binary integration. The asynchronous interference has been suppressed (compare Figure 3-29 with 3-31) by the binary integrator.

In summary, the FAA modified binary enhancer has the capability of suppressing normal channel asynchronous interference with very little trade-offs in target azimuth shift, target angular resolution, and desired target probability of detection. Asynchronous interference can be suppressed by the FAA modified enhancer by either adjusting the threshold comparator level setting, or by programming a hit/miss state sequence that will suppress the interference. Thus the FAA modified ASR-7 enhancer can be adjusted to optimize the radar desired signal performance in a variety of environmental conditions.

Normal Channel Weather Background

Both the ASR-7 and ASR-8 have weather background circuits which can be selected to add a weather outline to the processor output video when the normal Log-FTC video is selected. The weather background video is adjustable in amplitude relative to the Log-FTC video to provide the operator with the proper contrast between operating video and background video. The ASR-8 has two display modes for the weather background. The first is merely a limited and adjustable display of the entire detected weather area. In this mode, the operator views the complete weather video pattern at a reduced brightness. The second mode is an adjustable brightness contour or outline of the storm or weather video area. In this mode the operator views the outline of the weather video pattern but is not distracted by the complete weather video pattern which can compete with aircraft returns.

In the normal video channel, the background is generated from the receiver logarithmic video, which is low pass filtered to reduce the noise variation amplitudes. The filtering reduces the possibility of weather background false-alarm signals which would clutter the display, yet does not degrade the detection of the extended weather blocks themselves. The filter is designed with a time constant which matches the Log-FTC delay in the normal channel. The filtered weather background video is presented to variable threshold circuits and the threshold output signals are converted to a binary-coded signal. The threshold circuits are voltage comparators with adjustable reference voltages. The upper threshold, which is adjustable from 10 dB above rms noise to the maximum input amplitude, is used for blanking.

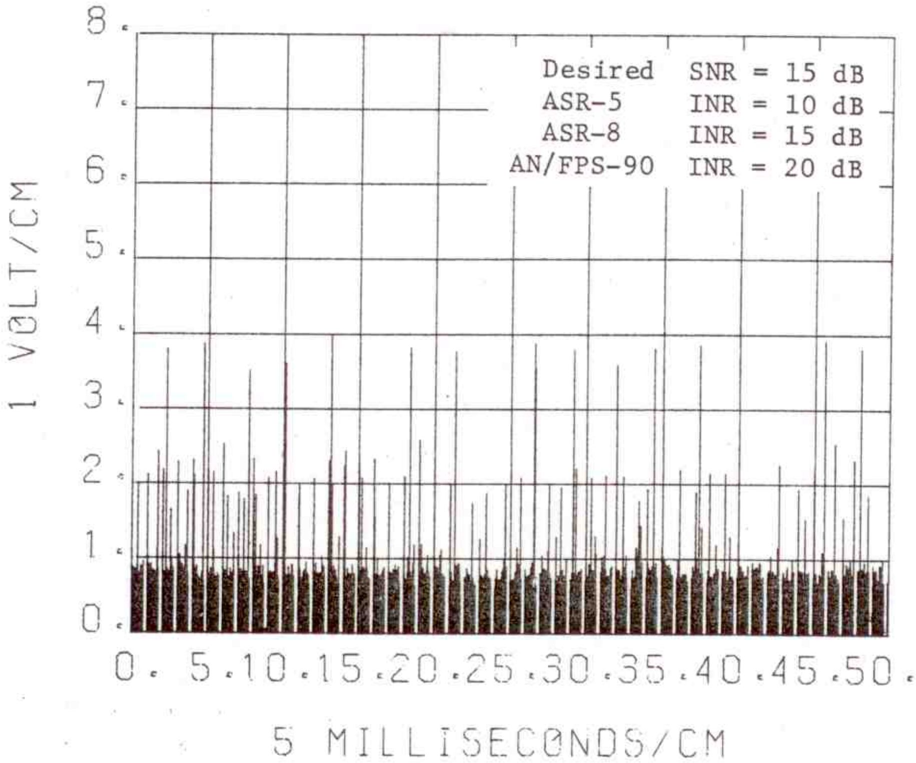

Figure 3-30. Simulated Normal Channel Unintegrated Radar Output with Interference

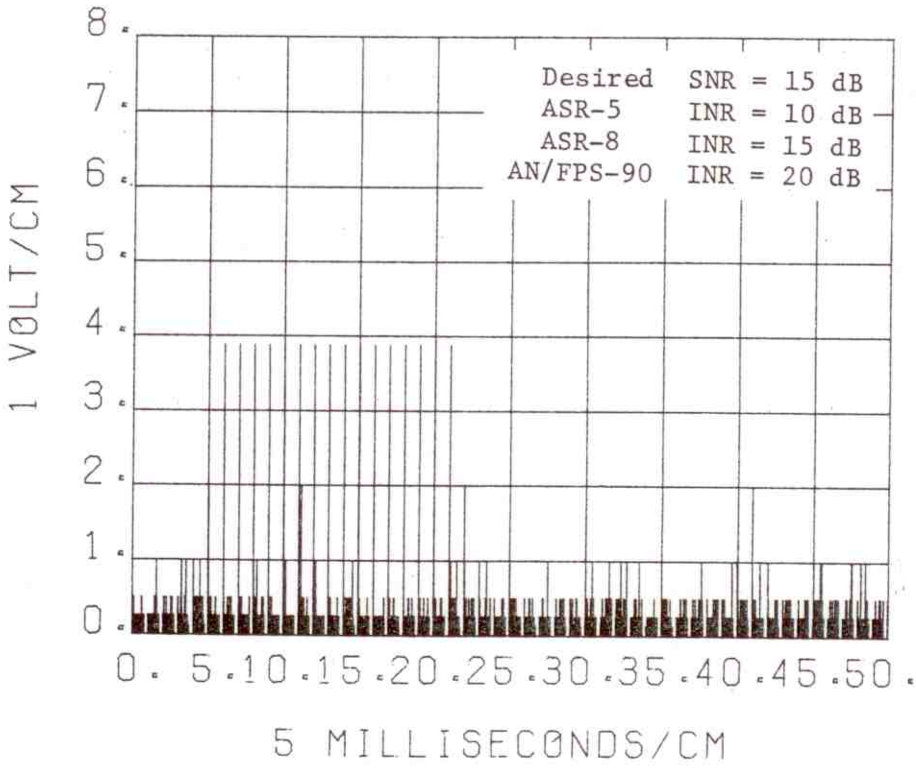

Figure 3-31. Simulated Normal Channel Integrated Radar Output with Interference

The other two independently adjustable thresholds are for top clipping and bottom clipping. They are adjustable over the range from 0 to 15 dB above rms noise. The fourth threshold is an intermediate threshold between the top-clip and bottom-clip thresholds and is used when the weather video output is reconstructed in a multiple level form. The four possible modes of weather background are:

Mode 1 - No blanking, quantize with bottom clipping
Mode 2 - Blanking, quantize with bottom clipping
Mode 3 - No blanking, top and bottom clipping
Mode 4 - Blanking, top and bottom clipping

One of the four operating modes can be selected. Input videc, before and after filtering, as well as representative output waveforms for these four modes, are shown in Figure 3-32. The normal weather background video is routed to the weather background/diversity combiner where it is added to the combined or single channel video.

The weather background channel does not have an integrator (enhancer). (See Figure 3-15.) However, asynchronous pulsed interference in the weather background channel will be reduced by the low pass filter since the filter essentially averages over six to eight range bins. Also if the interference appears above the blanking threshold level (approximately 10 dB INR), it will be suppressed by the blanking circuit. Since the master channel weather background video is used for display on the PPI, the channel that minimizes interference can be chosen as the master channel.

<u>Processor Unit MTI Channel</u>

A simplified block diagram of the processor unit Moving Target Indicator (MTI) channel is shown in Figure 3-33. The following types of MTI video can be provided at the processor unit output for display on the PPI:

MTI Video
Enhanced MTI Video
MTI Log-FTC Video
Enhanced MTI Log-FTC Video
MTI Log-FTC with Weather Background Video
Enhanced MTI Log-FTC with Weather Background Video

The various MTI channel modes are obtained by switching the Log-FTC and enhancer selection switches on or off.

<u>MTI Cancellers</u>

The target return signals, after phase detection are processed in the MTI cancellers. The MTI canceller circuits provide for cancelling fixed target signals (clutter), such as buildings, hills, and trees and allowing only moving targets, such as aircraft to be displayed on the PPI. The action of the MTI cancellers is that of a linear filter. In the ideal case, the