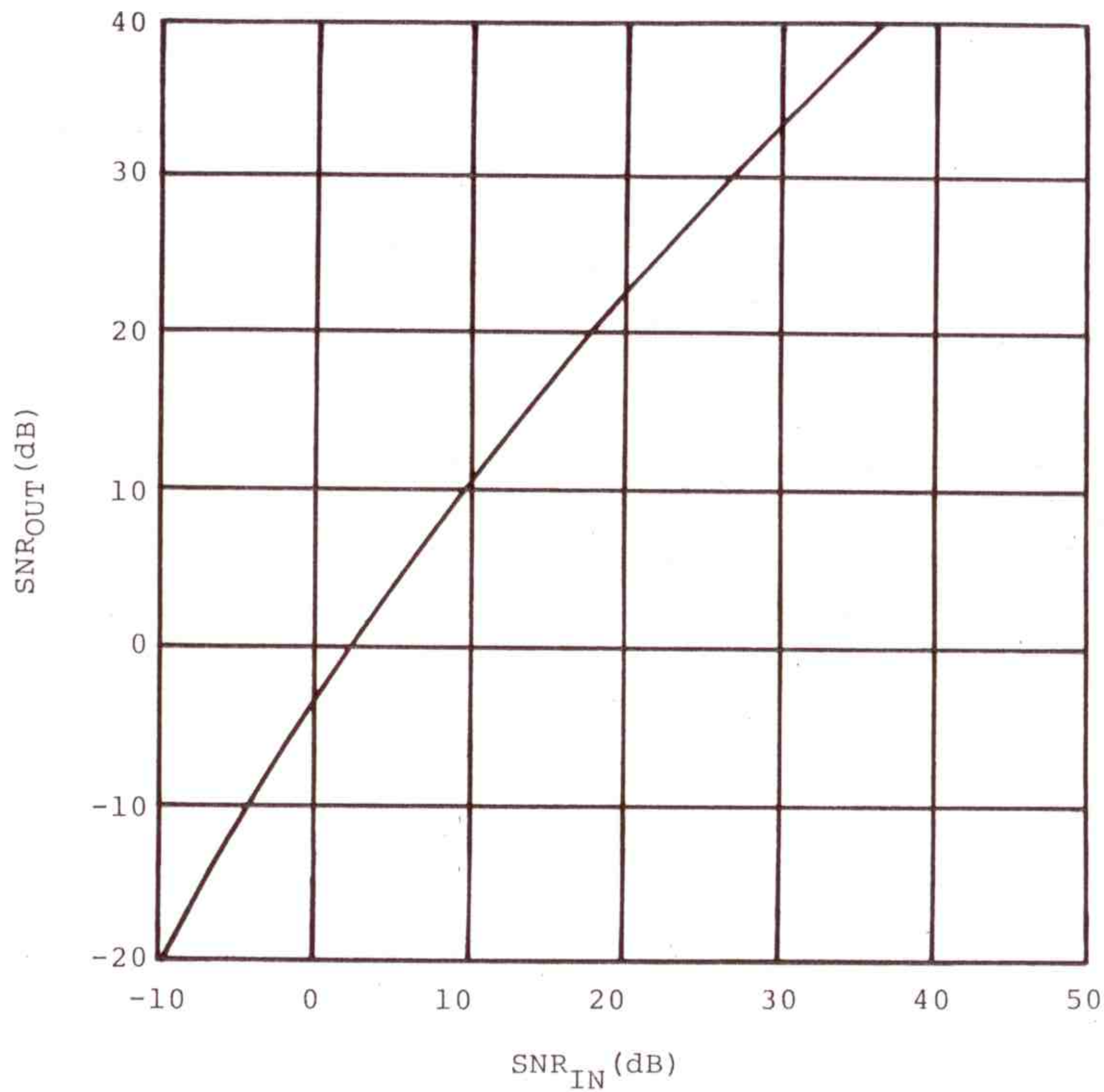

Figure 3-8. Signal-To-Noise Ratio Transfer Properties of a Linear Detector

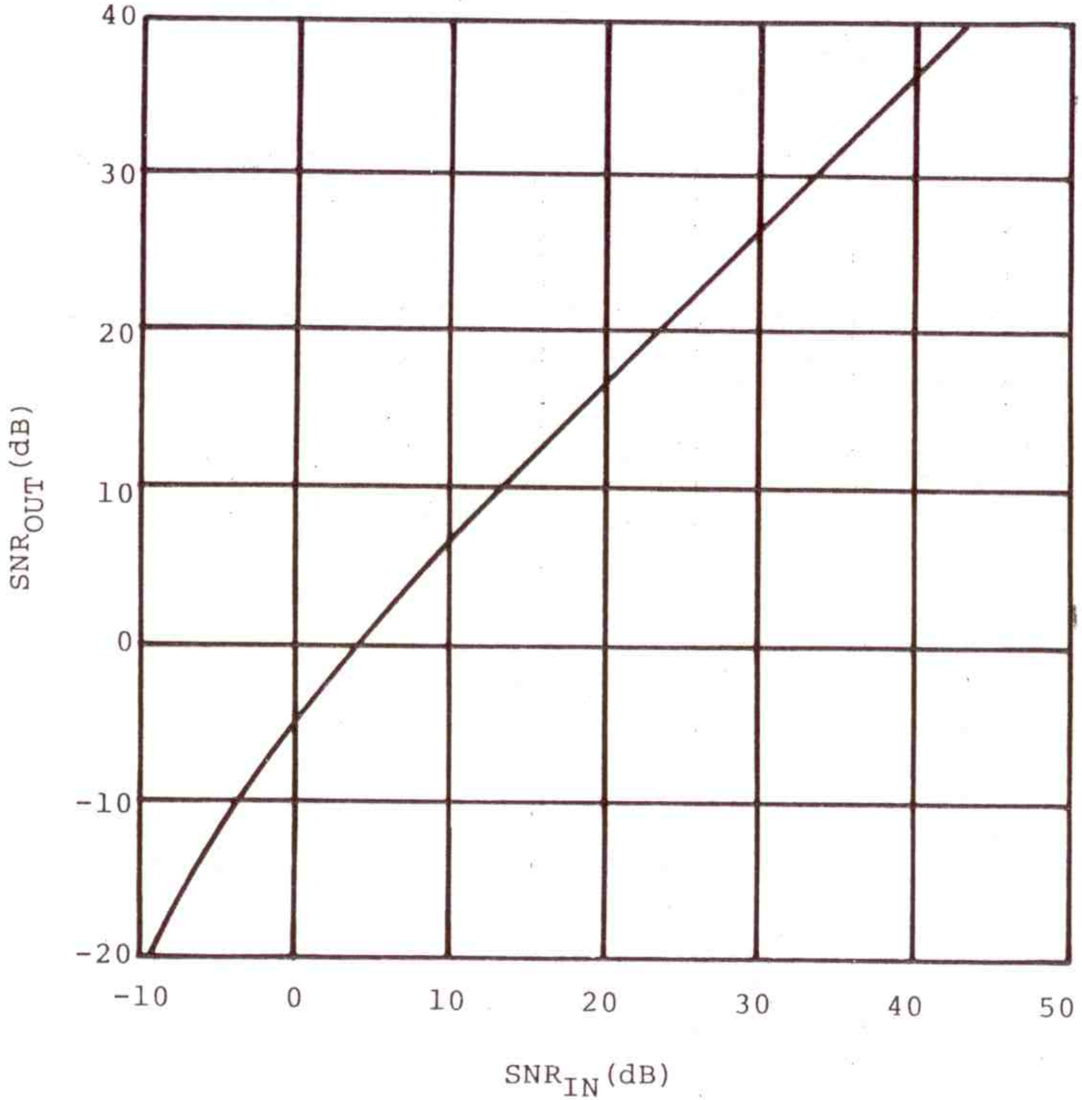

Figure 3-9. Signal-to-Noise Ratio Transfer Properties of a Square-Law Detector

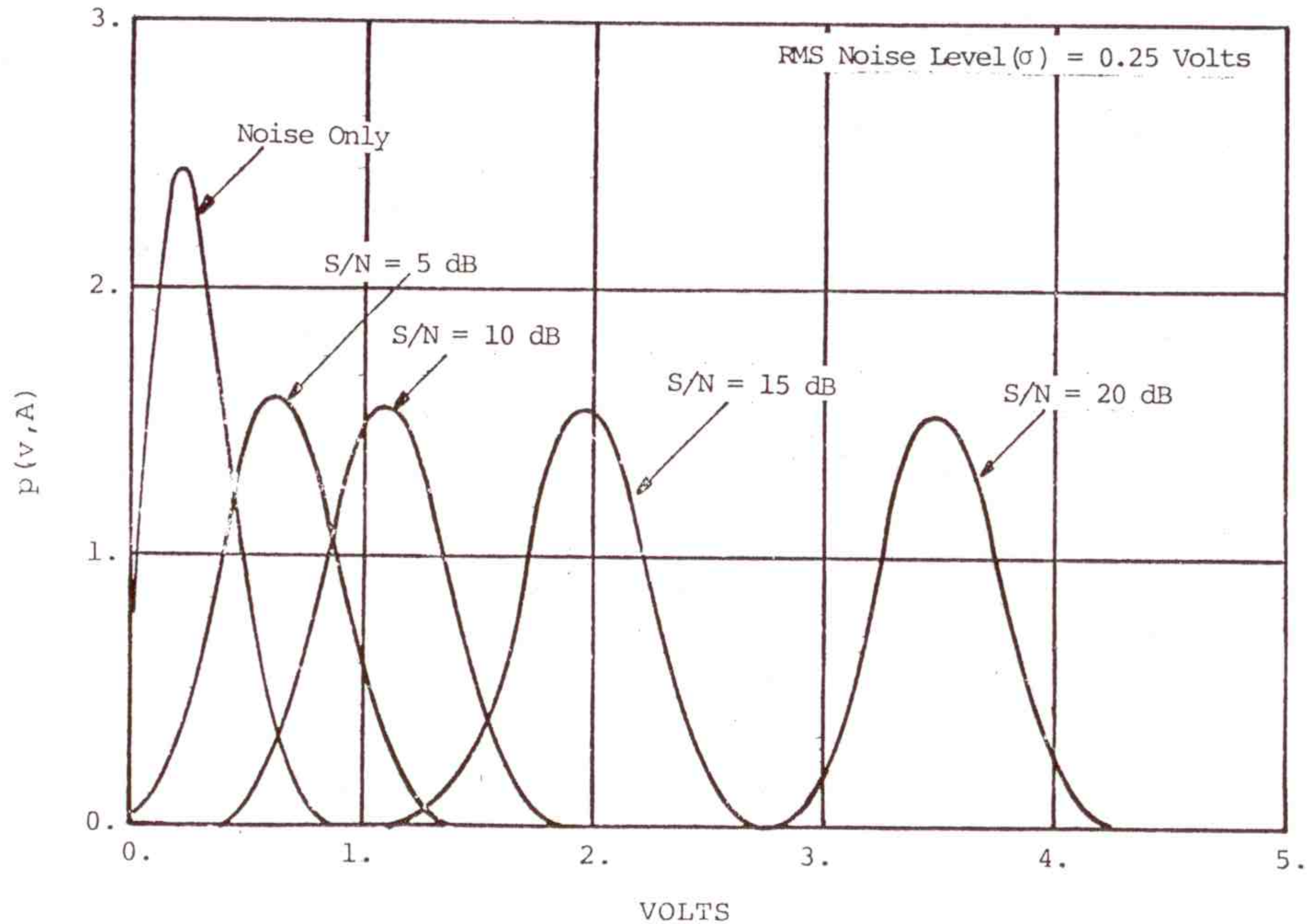

Figure 3-10. Probability-Density Function for Noise Only and for Signal-Plus-Noise at the Normal Channel Envelope Detector Output.

The envelope detector video output is low-pass filtered and amplified. For the normal channel the low-pass filter bandwidth is usually matched to the receiver normal channel IF bandwidth. Therefore, there is no improvement in the signal-to-noise ratio between the input and output of the normal channel low-pass filter. The low-pass filter output is amplified and sent to the video processor unit.

Log-Normal Channel

The log-normal channel IF subassembly accepts the 30 MHz IF signal from the preamplifier module and provides log IF amplification, video detection, and video amplification. The function of the log amplifier is to normalize the variances in precipitation clutter. The circuits operate on the principle that precipitation clutter, after being passed through a logarithmic response, has a noise variation about the average value that is independent of the average value. Filter circuits subtract out the average, leaving only the constant residue level. This level is adjusted to be equal to the receiver noise, thus totally eliminating precipitation clutter from the display. In the radar normal channel, the log function is performed by the log IF subassembly in the receiver unit. The filtering and subtraction is performed by the normal/LOG-FTC assembly in the processor unit. In general, the normal log IF channel amplifies IF signals logarithmically so that small target amplitudes are amplified more than large target amplitudes, and suppresses precipitation clutter; thus allowing for possible detection of small targets in precipitation clutter.

The log IF amplifier also permits a large radar receiver dynamic range in excess of 80 dB in some radars. Log IF amplifiers are also used in the WSR-57 and WSR-74S weather radars for the purpose of achieving a large dynamic range.

The ASR-7 and ASR-8 have a log IF bandpass filter followed by a chain of untuned amplifier-video detectors and a video amplifier (see Figure 3-11). The gain of the string of amplifier-video detectors is such that the last stage in the string becomes overdriven with inherent noise signals and limiting commences. As the 30 MHz signal amplitude increases, successive stages toward the first stage becomes overdriven and further limiting occurs. The net effect is that the video output increases as a function of the log of the input signal. The resultant video output is sent to both the weather channel and the subtractor antilog circuitry in the processor unit. The log-function begins at signal levels 20 dB below the rms noise level for the ASR-7 and ASR-8. Some radars (WSR-57 and WSR-74S) include the tuned bandpass filter circuits in the amplifier-video detector chain. Therefore, the log IF amplifier bandwidth becomes a function of the signal level.

Log IF Bandpass Filter

As with the normal channel IF bandpass filter, this log IF bandpass filter has a much narrower bandwidth and a sharper selectivity characteristic

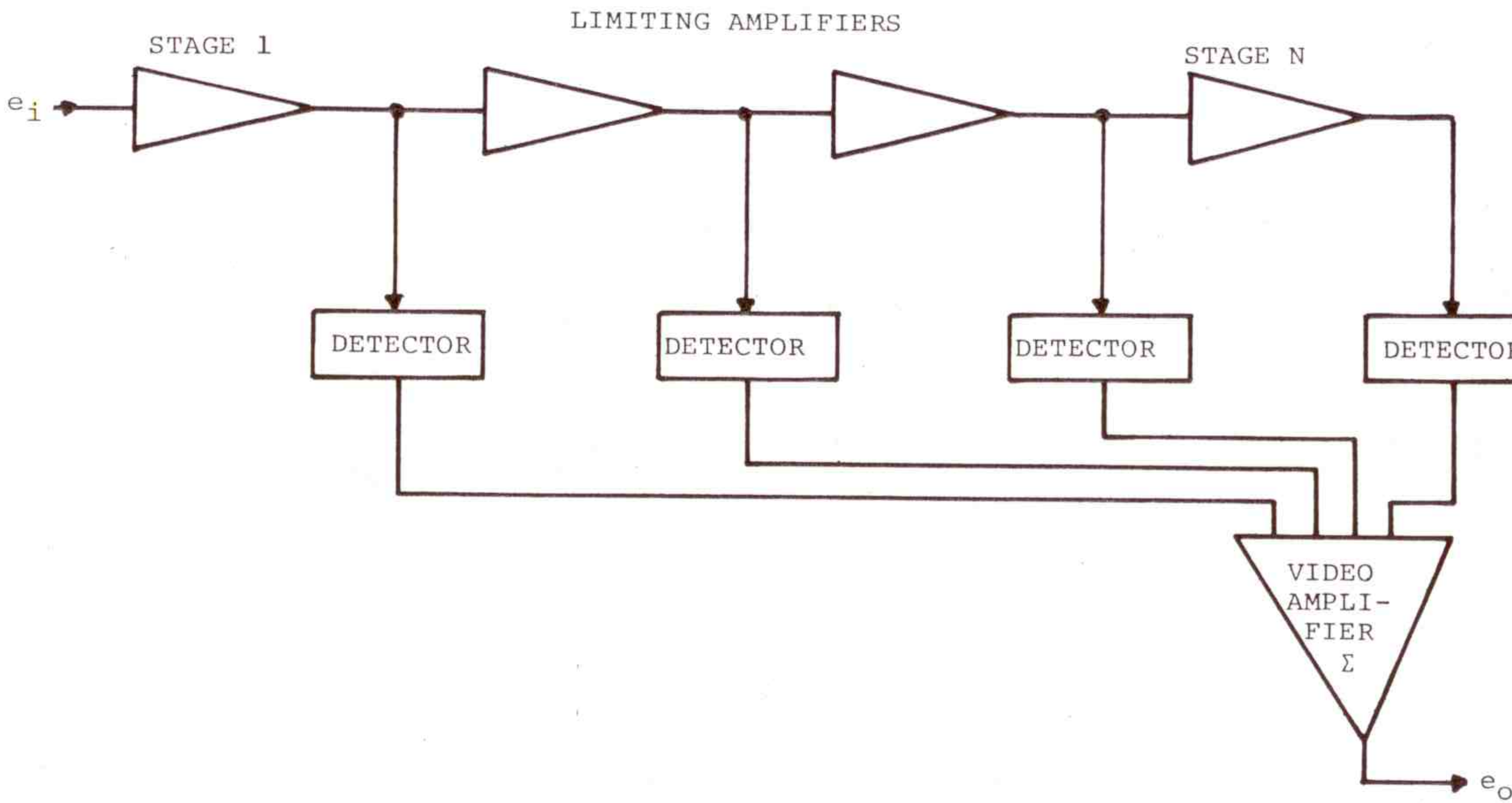

Figure 3-11. Logarithmic Amplifier-Detector Block Diagram.

than the preceding receiver unit stages. Therefore, the desired signal or interfering signal time response at the log IF bandpass filter output is essentially governed by the log IF bandpass filter characteristics.

The desired and interfering signal transfer properties of the log IF bandpass filter are identical to the normal channel IF bandpass filter, and are discussed in detail in Appendix B and previously discussed in the radar normal channel section (Equations 3-5 through 3-7 and Figure 3-7).

Log IF Amplifier-Video Detector

Figure 3-11 shows a typical block diagram of the log IF amplifier and video detector hardware of the ASR-7 and ASR-8 radars. The response of a log amplifier can be expressed as:

$$e_o = a \ln \left[1 + b e_i\right] \quad (3\text{-}10)$$

Where the break point between the linear region and logarithmic region occurs approximately where $be_i \approx 1$. The signal-to-noise ratio (SNR) transfer properties have been derived (Atlantic Research Corporation, 1974), and are given by:

$$(S/N)_o = (\eta_{S+N} - \eta_N)^2/\sigma_N^2 \quad (3\text{-}11)$$

where:

$$\eta_{S+N} = \ln(1 + 0.885\ kF) - 1/2 \left(\frac{0.215\ K^2 B}{(1 + 0.885\ kF)^2}\right)$$

$$\eta_N = \ln(1 + 0.885\ K) - 1/2 \left(\frac{0.215\ K^2}{(1 + 0.885K)^2}\right)$$

$$\sigma_{N2} = \frac{0.215\ K^2}{(1 + 0.885\ K)^2}$$

$$F(-1/2; 1; -z) = e^{-z/2}\left[(1 + z)\ I_o\ (z/2) + zI_1\ (z/2)\right]$$

$$B = \left(\frac{1 + 2.33\ (S/N)_i}{1 + (S/N)_i}\right)$$

$$z = (S/N)_i$$

Figure 3-12 shows the signal-to-noise transfer characteristics for various Break Points (BP) in a logarithmic amplifier relative to the RMS noise input level. As previously mentioned the ASR-7 and ASR-8 have a BP = -20 dB.

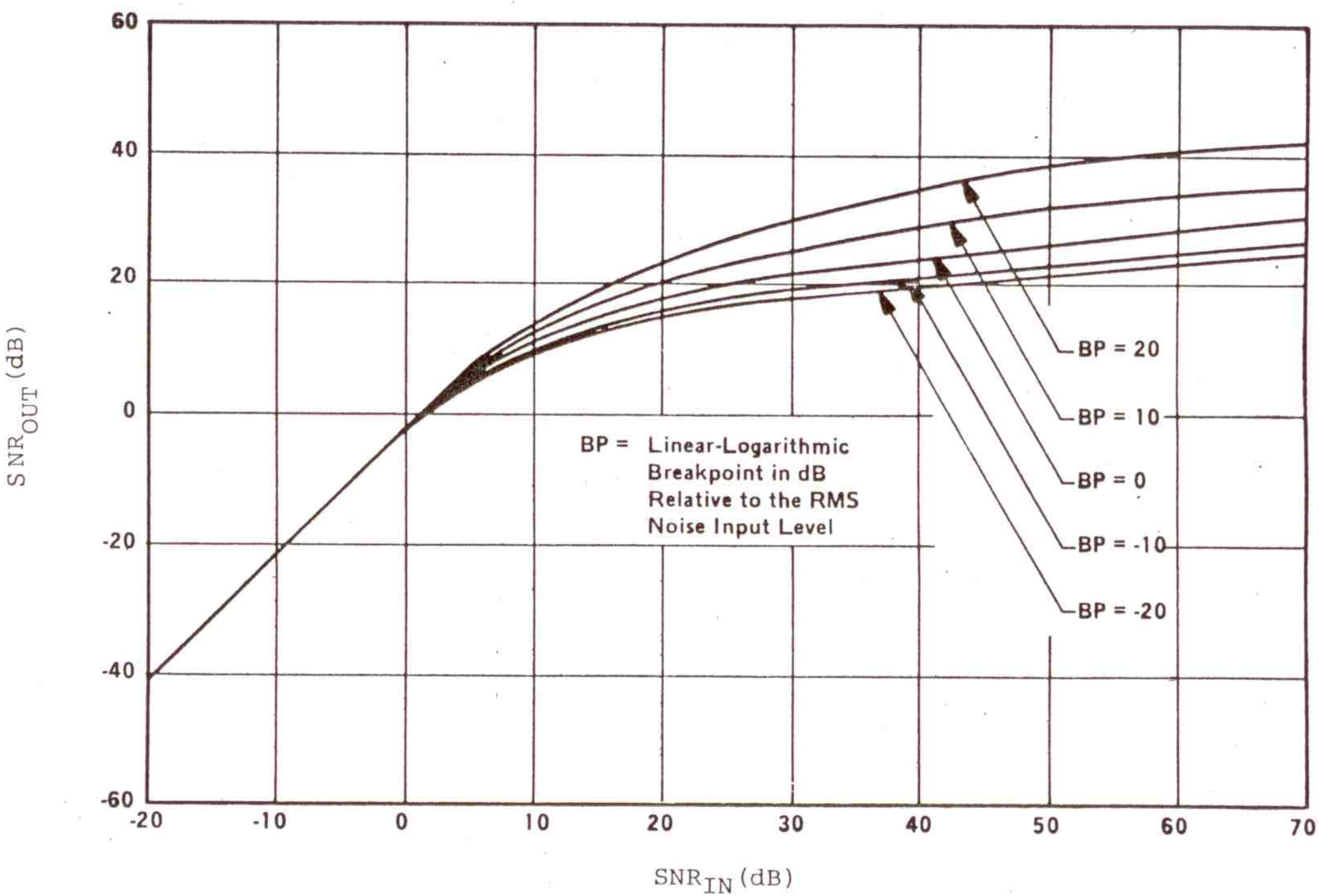

Figure 3-12. Log Amplifier Transfer Characteristics

The signal-to-noise ratio (SNR) transfer characteristics shown in Figure 3-12 are also applicable to interfering signal transfer characteristics.

The detectors in the log-normal channel are linear envelope detectors. Therefore, the signal-to-noise ratio (SNR) transfer curve shown in Figure 3-8 can be used.

Moving Target Indicator (MTI) Channel

The ASR-8 MTI receiver unit channel consists of IF filter, linear limiting amplifier, quadrature phase detector, and low pass filter amplifier circuits (Figure 3-13). The receiver unit MTI channel output feeds the digital cancelling circuits and other processing circuits in the processor unit. The function of the MTI receiver unit channel and processor unit is to reduce ground clutter return and stationary target echoes to system noise level and to enhance moving target echoes on the PPI display. This is accomplished by using the phase difference between the transmitted pulse and reflected pulse. The COHO provides the basic timing and phase reference. One output from the COHO is mixed with an output from the STALO to produce the RF signal used to drive the transmitter amplifier. Another output from the COHO is applied to the phase detector in the MTI circuit. This output retains the phase of the transmitted signal. After down conversion to IF, the returned signal is amplified and applied to the phase detector. The phase detector output voltage is proportional to the phase difference between the transmitted (reference) signal and the returned signal. For stationary targets, the phase difference from pulse to pulse is always the same, causing the output voltage from the phase detector to be constant. For moving targets, the changing range from pulse to pulse causes a pulse-to-pulse change in phase. The output voltage from the phase detector varies from pulse-to-pulse rather than remaining constant as it does for stationary targets. The output from the phase detector, consisting of the return from both stationary and moving targets, is sent to the processor unit where the constant voltage is removed leaving only the fluctuating voltage caused by moving target echoes. The fluctuating voltage is applied to the PPI to provide the visual presentation of moving targets. In a MTI system employing a single phase detector and canceller the voltage fluctuations cause fading of parts of the visual display as the antenna scans past the moving target. To overcome this undesirable fading, the ASR-8 employs an "inphase" (I) and "quadrature" (Q) phase detector and digital canceller for each of these MTI channels. Because the phase detector output varies from a plus voltage through zero to a minus voltage as the relative phase between transmitted and received signals varies through 180 degrees, there are times when the return from a target produces a zero or near-zero output from the phase detector. If a second phase detector is used and supplied with a reference voltage delayed in phase 90 degrees from the reference voltage supplied to the first detector and the reflected voltage is divided and applied in phase to the signal inputs of each of the phase detectors, there is always a non-zero output from one of the detectors. If after cancellation, the two phase detector outputs are combined with the appropriate format, very little fluctuation will be present in the moving target voltage applied to the PPI.

A block diagram of the ASR-8 receiver unit MTI I and MTI Q channel is shown in Figure 3-13.

IF Filter

The ASR-8 MTI channel IF filter consists of eight cascaded synchronous single tuned stages with a 3 dB bandwidth of 5.0 MHz. The relative IF filter amplitude response $A_{dB}(F)$ is derived in Appendix B, and can be expressed as (Equation B-19):

$$A_{dB}(F) = -20 \log (1 + X^2)^{8/2} \tag{3-12}$$

where:

$$X = \frac{2\Delta F}{B_s}$$

and:

ΔF = Frequency relative to the receiver IF tuned frequency , in Hz

B_s = IF amplifier stage 3 dB bandwidth, in Hz

Since the MTI IF filter has the narrowest bandwidth and sharpest selectivity characteristics, the interfering signal peak power loss as a funtion of off-tuning (Frequency-Dependent-Rejection, FDR) is essentially governed by the receiver IF selectivity characteristics, interfering signal emission spectrum and the frequency separation between the interfering signal and victim radar tuned frequency. Appendix B discusses in detail the signal transfer properties of an IF filter. In summary, the MTI channel IF filter transfer properties can be treated the same as the normal channel. That is the interference-to-noise ratio (INR) at the MTI channel IF input is given by Equation 3-5, and the transfer properties of the MTI IF filter are given by Equation 3-6. Also the MTI channel IF output time waveform is given by Equation 3.7.

Since the MTI channel uses a phase detector which is amplitude and phase sensitive, both amplitude and phase modulation of the interfering signal IF output time waveform are important. Appendix B discusses in detail both the amplitude and phase response of an IF filter to an interfering signal as a function of off-tuning. It is shown in Appendix B that when the interfering signal is off-tuned, the IF filter causes a beat tone phase modulation during the steady state portion of the pulse equal to the off-tuning (Figure B-15). The affect of this beat tone phase modulation in relation to the MTI channel interfering signal processing properties will be discussed later. The

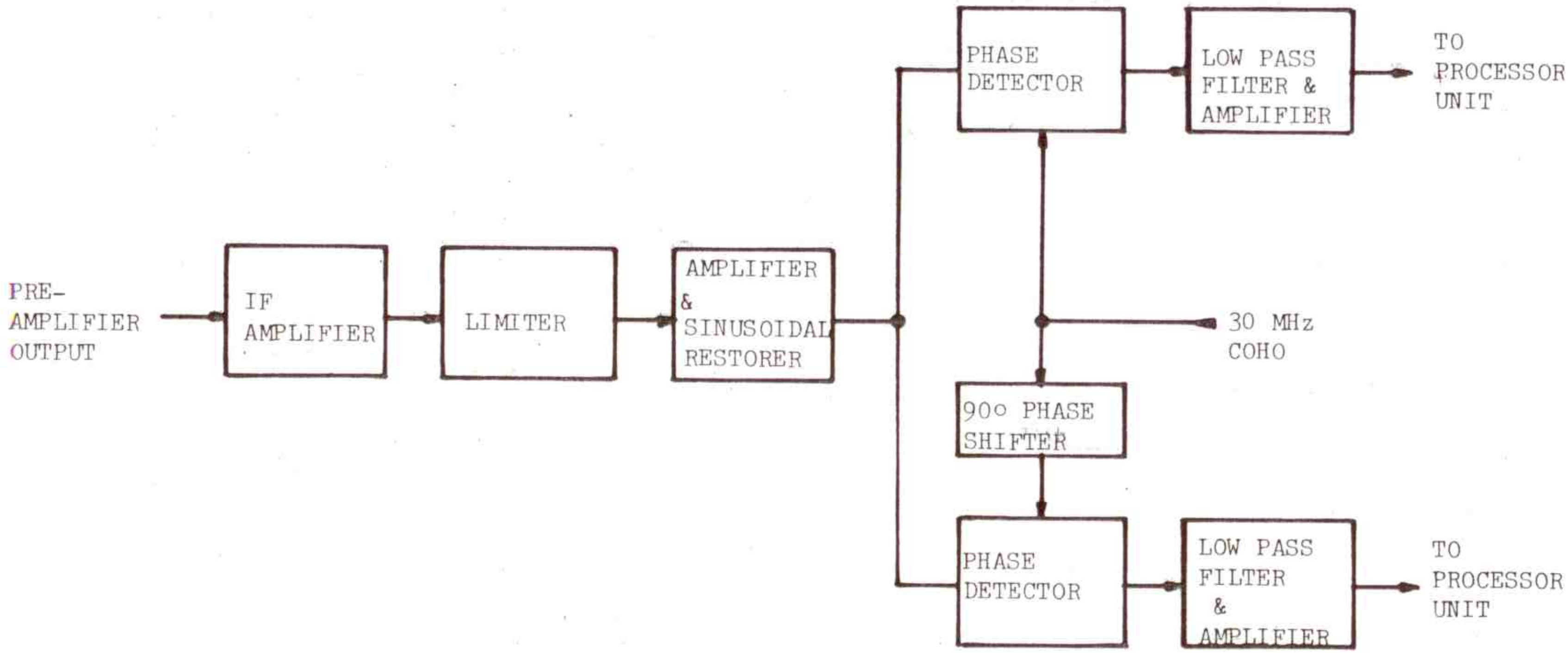

Figure 3-13. Receiver Unit MTI I and MTI Q Channel

narrowband white noise at the IF filter output has a Gaussian amplitude distribution and a uniform phase angle distribution.

Linear-Limiting Amplifier

The output of the IF amplifier is amplified and limited by series-diode limiters. The setting of the limit level is adjustable (L = 35 to 42 dB SNR) by setting the bias voltage level on the diodes. When the signal at the limiter input exceeds the bias level the signal is limited. The MTI linear-limiting amplifier signal processing properties can be expressed as:

$$SNR_o = \begin{cases} SNR_i & \text{for } SNR_i < LNR \\ LNR & \text{for } SNR_i > LNR \end{cases} \qquad (3\text{-}13)$$

Equation 3-13 also applies to the interference-to-noise (INR) transfer properties of the linear-limiting amplifer.

MTI Quadrature Phase Detector

The ASR-8 has a quadrature phase detector. Most of the radars in the 2.7-2.9 GHz band only have a single channel MTI phase detector. The quadrature MTI channel uses two phase detectors with the COHO signal into the two phase detectors being shifted by 90 degrees (see Figure 3-13). Both the single channel and quadrature channel MTI signal processing properties are discussed in detail in Appendix C. Since the inphase (I) and quadrature (Q) channel are identical except for the COHO being shifted by 90 degrees, it is sufficient to analyze the signal processing properties of only one phase detector.

The phase detector output is a function of the phase difference between the amplified and limited received signal and the reference COHO signal. The output is a video pulse of polarity and amplitude which is a function of the received signal amplitude and the phase difference between the applied input signals. Appendix C contains a derivation of the signal-to-noise ratio (SNR) and the interference-to-noise ratio (INR) transfer properties of the MTI phase detector. The transfer properties of the phase detector can be expressed as (Equation C-15):

$$SNR_{pdo} = SNR_{pdi} \qquad (3\text{-}14)$$

Equation 3-14 also applies to the interference-to-noise ratio transfer properties. That is the SNR or INR at the phase detector output is equal to the SNR or INR at the phase detector input.

The noise probability density function at the phase detector output is Gaussian. This is due to the fact that the phase detector is amplitude as well as phase sensitive. The noise amplitude PDF at the input to the phase detector is Gaussian distributed, and the noise phase PDF is uniform distributed. Therefore, the noise amplitude PDF at the phase detector output is Gaussian. If one considers a fixed amplitude (non-fluctuating) desired or interfering signal at the phase detector input, the signal-plus-noise at the phase detector output is given by:

$$v_{pdo}(t) = N(t) + A \cos \phi \qquad (3\text{-}15)$$

where:

- $N(t)$ = Noise amplitude which is Gaussian distributed, in volts
- A = Desired or interfering signal amplitude, in volts
- ϕ = Phase difference between received signal and COHO which is uniformly distributed

Popoulis (1965) derives the probability density function for Equation 3-15 which can be expressed as:

$$p(v,A) = \frac{1}{\pi\sigma\sqrt{2\pi}} \int_{0}^{\pi} e^{\frac{-(v-A\cos\phi)^2}{2\sigma^2}} d\phi \qquad (3\text{-}16)$$

where:

- σ = rms noise level, in volts

Equation 3-16 can not be written in closed form. The MTI channel phase detector output was simulated to investigate trade-offs in suppressing asychronous interfering signals. The simulation of the radar MTI channel is discussed in Appendix E. Figure 3-14 shows the PDF given by Equation 3-16 as a function of the signal-to-noise ratio. The PDF was obtained by simulation.

Low Pass Filter

The low pass filter in the MTI channel is used to reduce the MTI channel video noise level. The low pass filter bandwidth (B_{lpf}) is approximately equal to $1/\tau$ where τ is the desired signal pulse width. The MTI channel IF bandwidth is always much greater than $1/\tau$ (generally 5.0 MHz) to produce a constant phase characteristic across the desired pulse. Therefore, a narrower low pass filter bandwidth will improve the video signal-to-noise ratio. The MTI channel low pass filters are usually several stages. The low pass filter frequency response can be expressed as:

$$A_{LP}(F) = \frac{1}{\left[1 + j\left(\frac{F}{F_L}\right)\gamma\right]^n} \qquad (3\text{-}17)$$

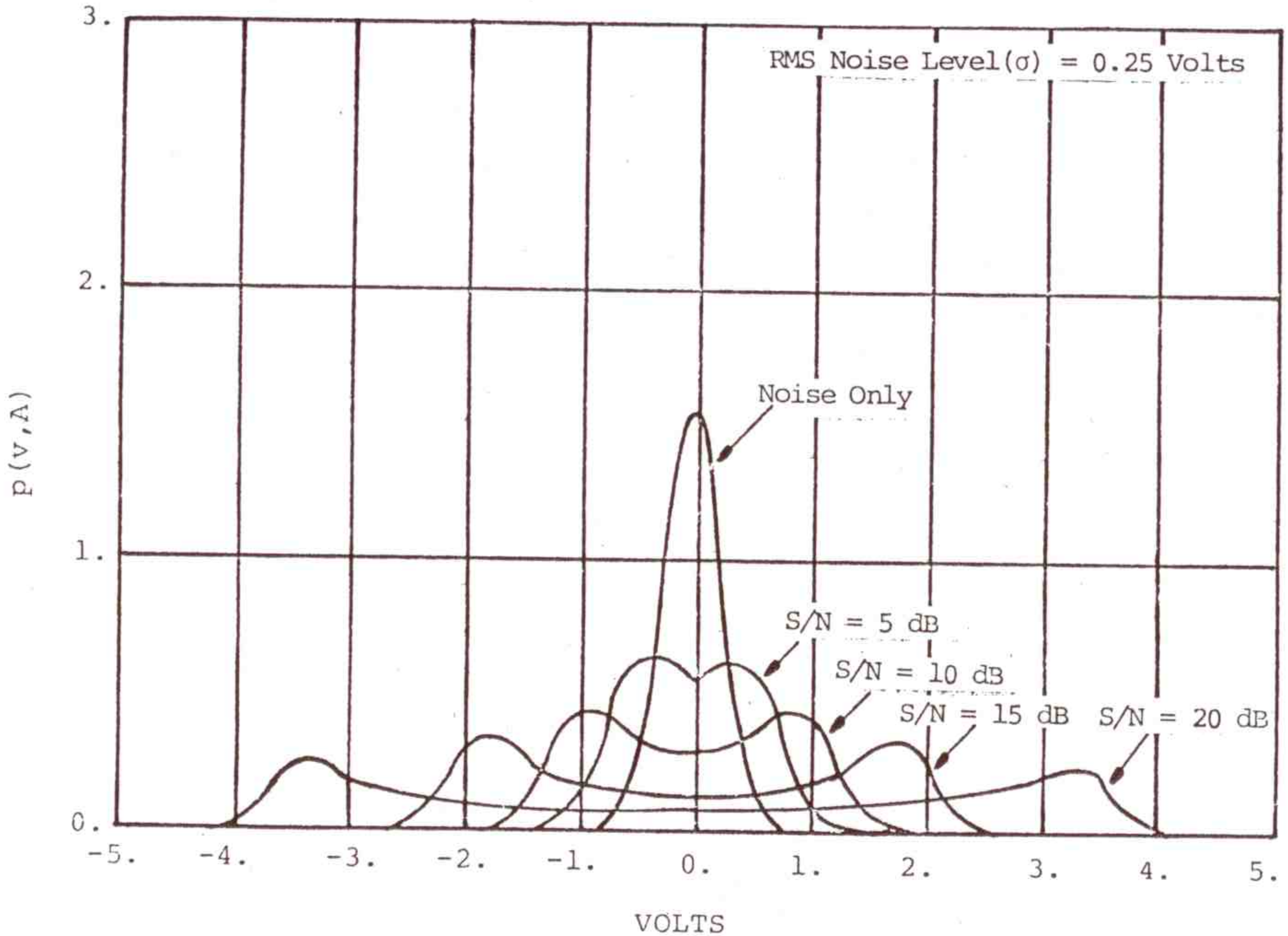

Figure 3-14. Probability Density Function for Noise Only and for Signal-Plus-Noise at the MTI Phase Detector Output.

where:

F_L = Low pass filter 3 dB cutoff frequency, in Hz

n = Number of low pass filter stages

$\gamma = \sqrt{2^{1/n}-1}$

The interfering signal low pass filter output time response, $V_{lpo}(t)$, can be obtained by multiplying in the frequency domain the low pass filter frequency response with the phase detector output interfering signal frequency spectrum, $V_{pdo}(F)$, and taking the Fourier transform. That is:

$$V_{lpo}(t) = \mathcal{F}^{-1} [V_{pdo}(F) \cdot A_{LP}(F)] \tag{3-18}$$

Measurements made on an ASR-8 showed that as the interfering signal is off-tuned (ΔF), the signal level followed the low pass filter selectivity due to the sinusoidal modulation during the steady state portion of the pulse. However, for ΔF greater than 3 MHz, the off-tuned interfering signal response started to follow the interfering signal RF frequency spectrum, and the low pass filter interfering signal output response was caused by the phase modulation that occurs during the transient part (rabbit ear response occurring at the leading and trailing edge of the IF filter output response, see Figures B-10, B-11, B-13, and B-14) of the interfering signal time waveform. Figure C-5 shows a photograph of the phase detector output time waveform of a 60 μs pulse signal off-tuned 200 kHz. The measurement was made on an ASR-8 radar. The pulse width was set at 60 μs to demonstrate the 200 kHz sinusoidal modulation during the steady state portion of the pulse which is caused by the phase modulation produced by the IF filter transfer properties, and is equal to the off-tuned frequency (ΔF). Figure C-6 shows a photograph of an ASR-8 low pass filter output of a .83 μs pulse off-tuned 5.0 MHz. Since the low pass filter interfering signal output response for off-tuned interference is due to the phase modulation which occurs during the transient portion of the IF filter response, the low pass filter output interfering signal time response changes from pulse-to-pulse. However, the average pulse amplitude appears to follow the interfering signal RF spectrum envelope as the interfering signal is off-tuned. Figure C-7 shows a photograph of the low pass filter output for the same interfering signal parameters as in Figure C-6. However, the phase modulation during the transient portion of the interfering signal did not cause a low pass filter output response.

The signal-to-noise (SNR) transfer properties of the MTI low pass filter can be expressed as:

$$SNR_{lpo} = SNR_{lpi} + 10 \log \frac{B_{IF}}{B_{lpf}} \quad (3\text{-}19)$$

For a radar with a 5.0 MHz IF bandwidth and a 1.2 MHz low pass filter bandwidth, the noise power at the low pass filter output is given by:

$$SNR_{lpo} = SNR_{lpi} + 6.2 \text{ dB} \quad (3\text{-}20)$$

Therefore, the low pass filter increases the MTI channel signal-to-noise ratio by 6.2 dB. Equations 3-19 and 3-20 also apply to the interference-to-noise transfer properties of the MTI channel low pass filter. The affect of the MTI channel low pass filter on off-tuned interference is discussed in detail in Appendix C.

PROCESSOR UNIT

The following is a discussion of the signal processing properties of the processor units of the ASR-7 and ASR-8 radars. The function of the processor unit is to accept raw video from the receiver unit, condition the video depending on the operating mode desired, and present the video to a Plan Position Indicator (PPI) display for Air Traffic Control (ATC) purposes. The processor unit accepts as inputs normal, log-normal, and bipolar MTI video. Both the ASR-7 and ASR-8 have digital processor units. Some of the radars in the 2.7 to 2.9 GHz band have analog processing units. In general, the signal processing properties of the analog radars can in most cases, and for analytical simplicity, be modeled by the same operations as the digital signal processing units. The digital processing units will 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. The following is a discussion of the signal processing properties of the processor unit normal, log-normal, and MTI channels to noise, desired signal, and asynchronous interference.

Processor Unit Normal Channel

A simplified block diagram of the processor unit normal channel is shown in Figure 3-15. The following types of normal video can be provided at the processor unit output for display on the PPI:

Normal Video
Enhanced Normal Video

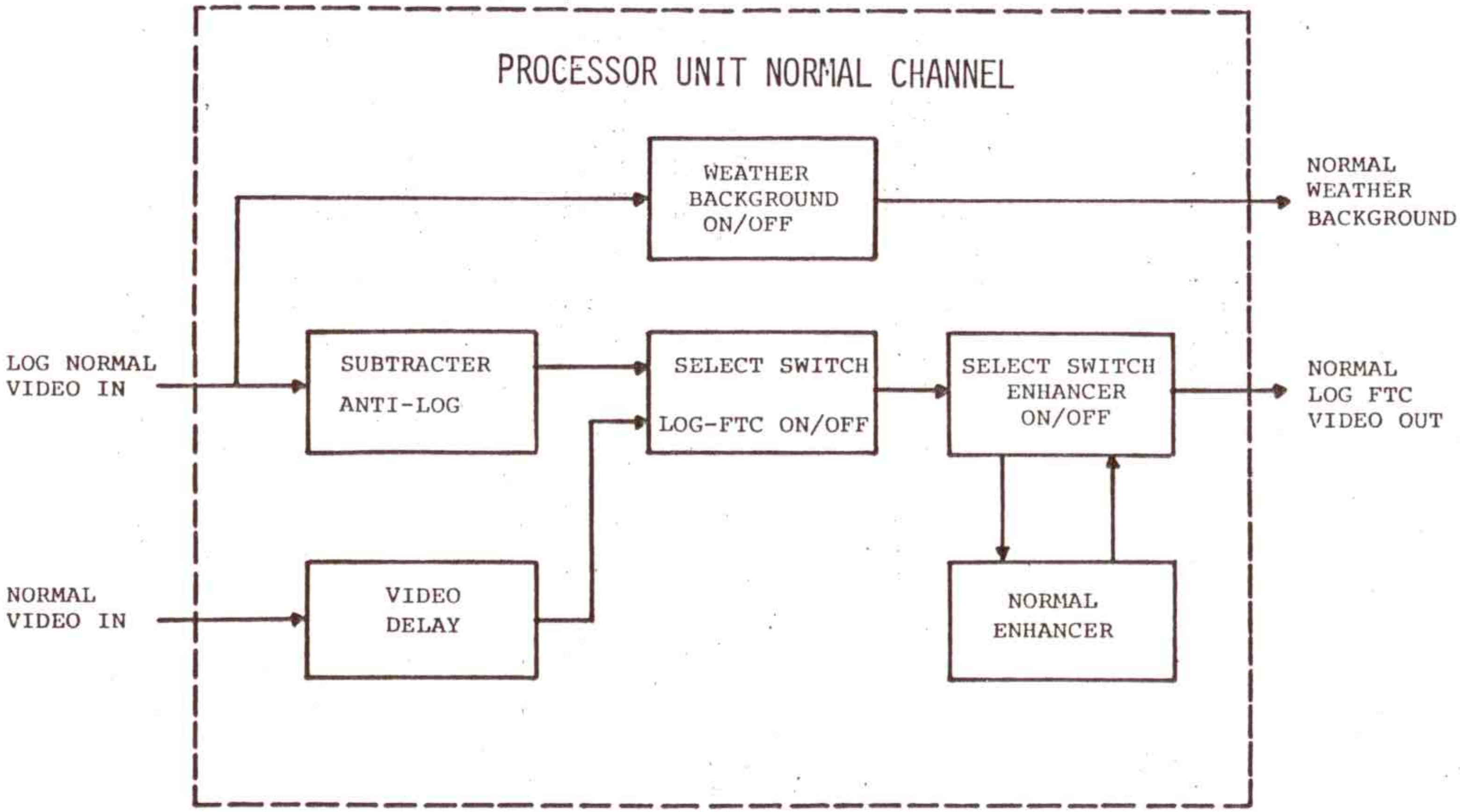

Figure 3-15. Processor Unit Normal Channel Block Diagram

Normal Log-FTC Video
Enhanced Normal Log-FTC Video
Normal LOG-FTC with Weather Background Video
Enhanced Normal LOG-FTC with Weather Background Video

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

Subtractor Anti-Log

Radars in the 2.7 to 2.9 GHz band use Logarithmic Fast Time Constant (Log-FTC) or Logarithmic Constant False-Alarm Rate (Log-CFAR) circuits to remove precipitation clutter or residue. The circuits operate on the principle that precipitation clutter, after being passed through a logarithmic response, has a noise variation about the average value that is independent of the average value. Filter circuits subtract out the average, leaving only the constant residue level. This level is adjusted to be equal to the receiver noise, thus totally eliminating precipitation clutter from the display.

Figure 3-16 shows a block diagram of the normal Log-FTC channel. In the radar normal channel, the log function is performed by the log IF module in the receiver unit. The filtering subtraction and anti-log functions are performed by the normal/Log-FTC assembly in the processor unit. The filter averages the log video over a certain time interval (8 to 12 range bins) to form an average value. The delay line delays the video signal of interest (one range-bin) so as to maintain coincidence with the averaging filter. The average video signal is then subtracted from the delayed video signal. A DC bias is then added to produce a positive mean and eliminate negative signals. The signal is then applied to an anti-log amplifier to return the signal to a linear function and eliminate the loss in detectability caused by logarithmic compression.

Noise - The DC bias in the Log-FTC circuitry is adjusted so that the noise amplitude distribution after the logarithmic detection, subtraction and anti-log function are performed is approximately Raleigh at the Log-FTC circuitry output.

Desired Signal - For the desired signal in the presence of noise only (no clutter), the detectability of the desired signal is only slightly degraded (1 or 2 dB) due to a small amount of the target energy falling in the adjacent range bins. In the presence of clutter, the desired signal level must be greater than the clutter in order for the signal to be detected. This is due to the fact that the signal must be greater than the average clutter signal in order to appear at the subtractor output.

Interference - The Log-FTC circuitry acts as a pulse width discriminator for interfering signals with a pulse width greater than the system designed pulse width. Long pulse interference which covers several range bins increases the average energy in the filter since the filter

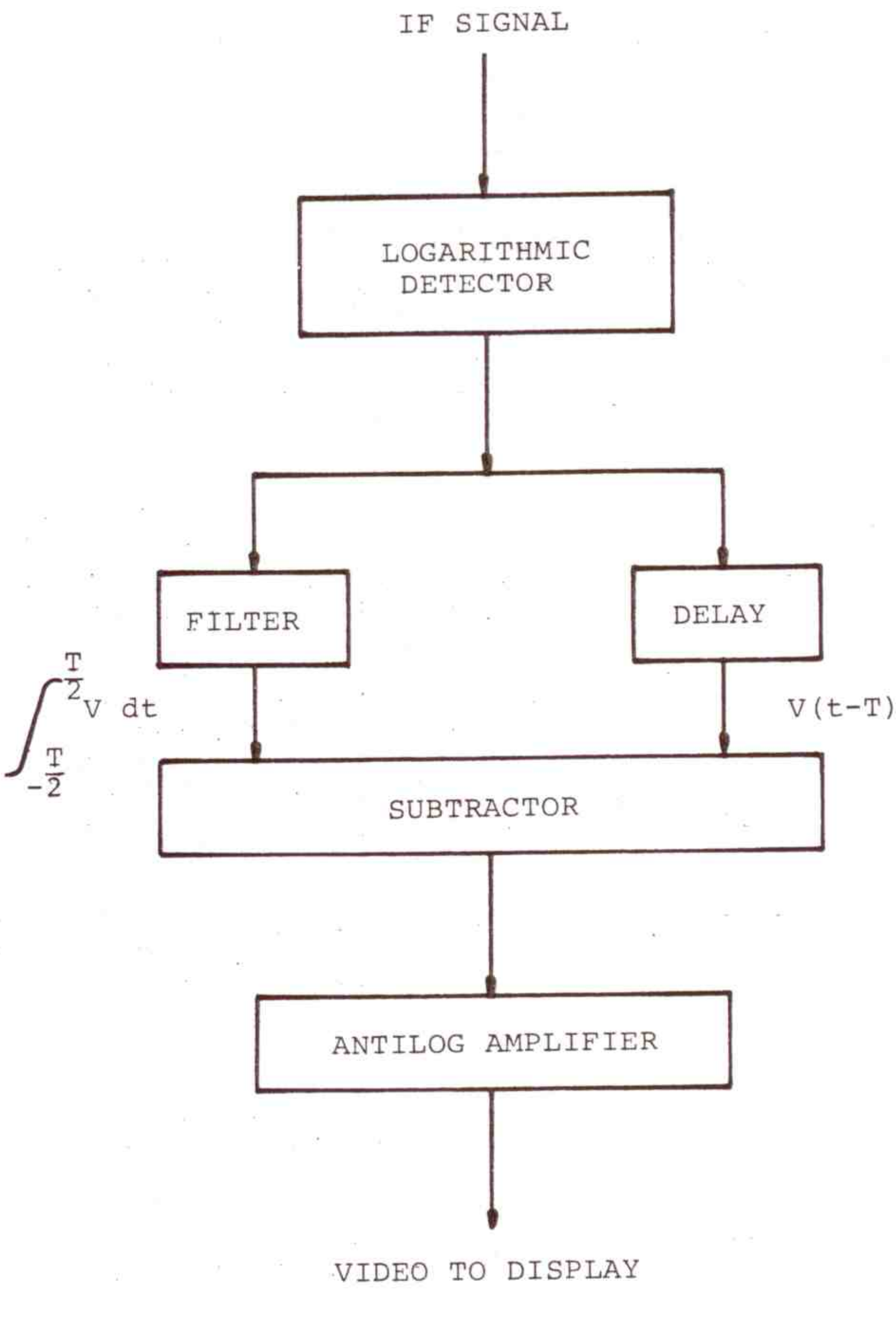

Figure 3-16. Log-FTC Block Diagram