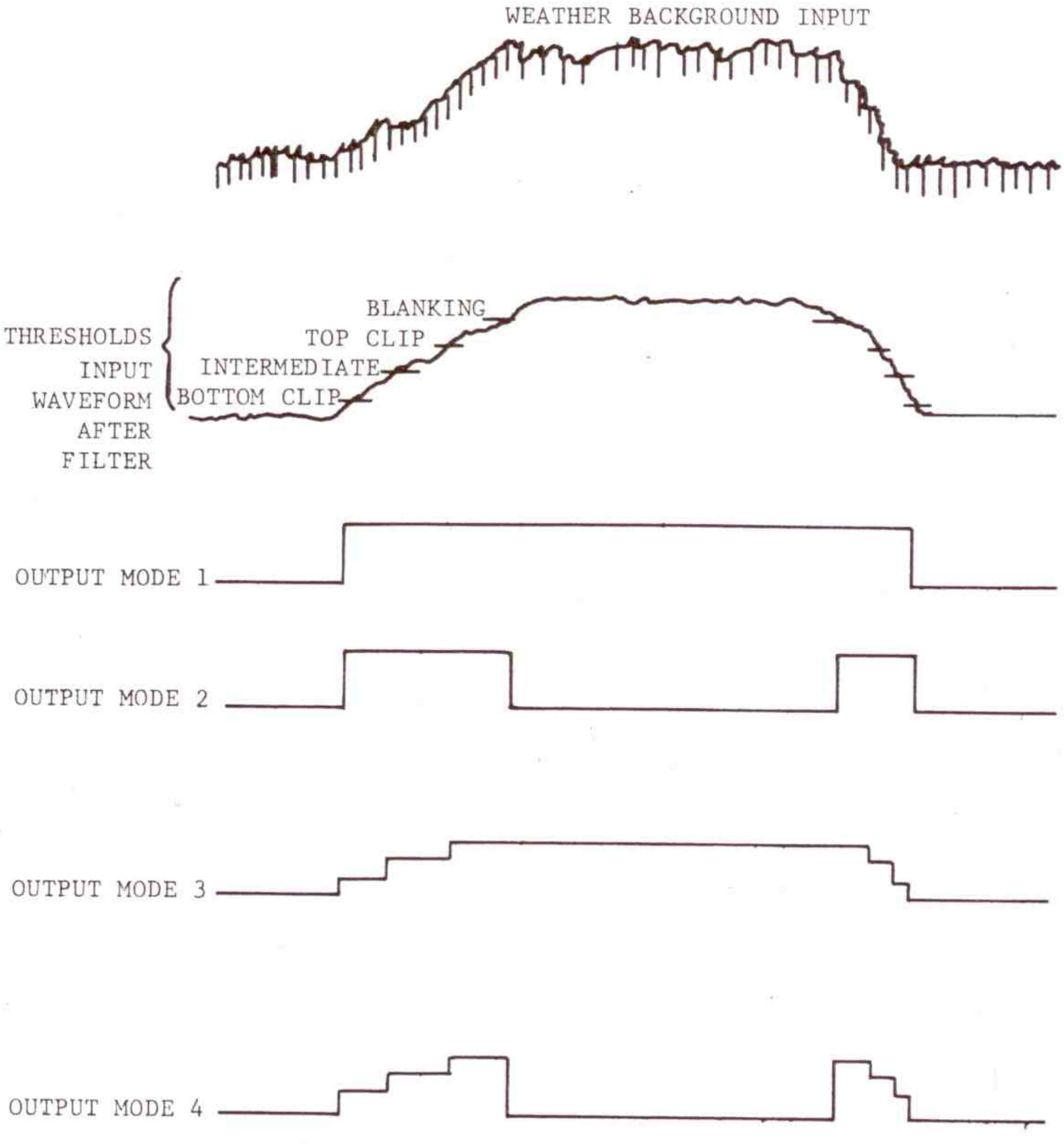

Figure 3-32. Weather Background Modes.

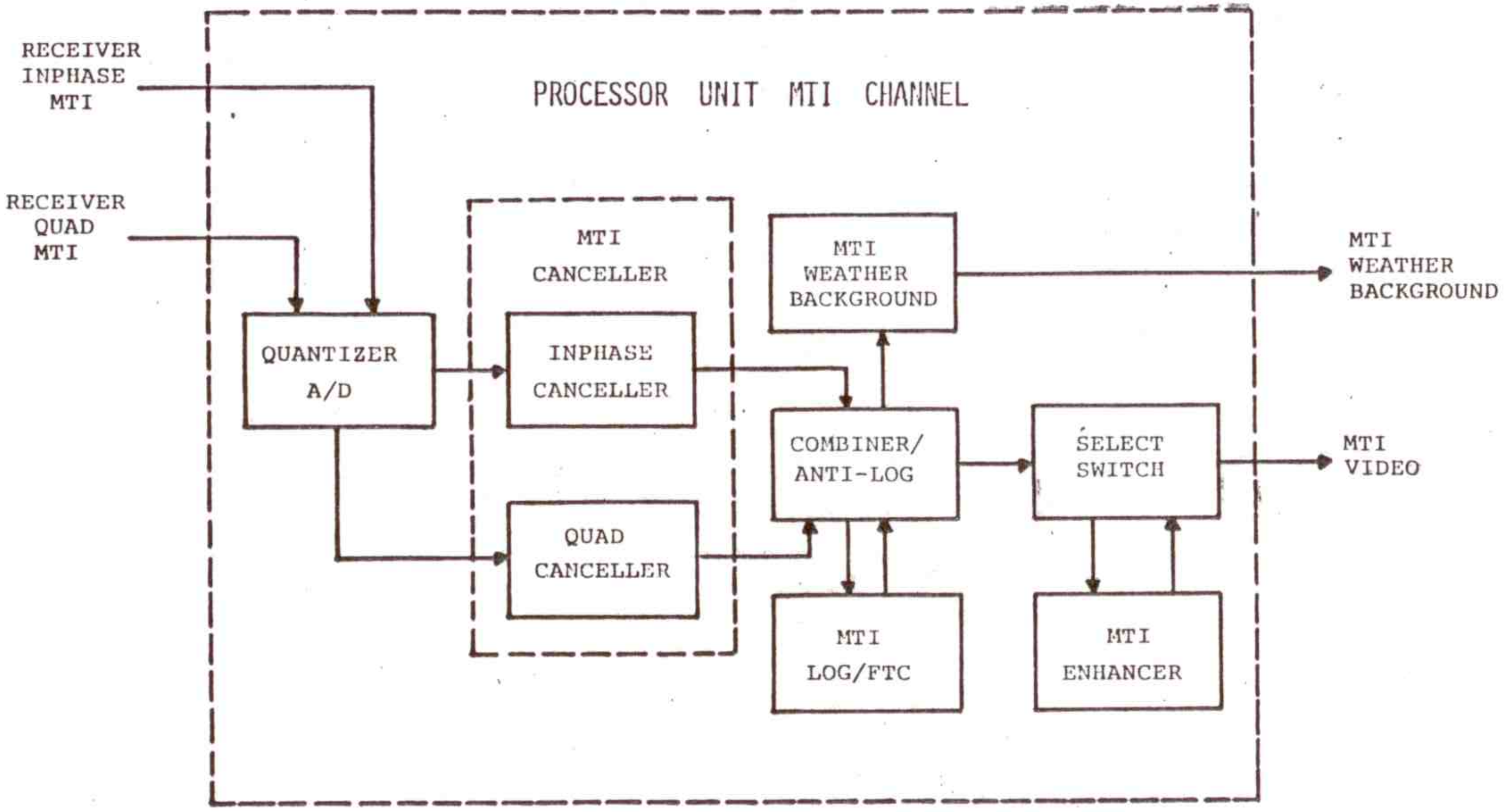

Figure 3-33. Processor Unit MTI Channel Block Diagram

clutter components will appear at zero frequency and at integral multiples of the radar Pulse Repetition Frequency (PRF), and will be suppressed.

Staggered PRF is generally employed by radars in the 2.7 to 2.9 GHz band to extend the blind speed of the radars. Analog radars typically have two or three staggers, while digital radars with their greater stability may have more than three staggers. The ASR-8 has a four-stagger system, and the ASR-7 has a six-stagger system. The analog MTI processors do not have Analog-to-Digital (A/D) converters and use delay line cancellers, while digital MTI processors have A/D converters and use shift register cancellers. The digital shift register cancellers have a much higher stability and do not decay in time. The transfer properties of analog and digital MTI cancellers can be treated identically with the exception of the quantization noise due to A/D conversion, roundoff, and truncation inherent in digital processing. In general, the error due to quantization, roundoff and truncation is very small, and can be neglected in most cases.

Both single channel and dual channel (inphase, I; and quadrature, Q) MTI processing is employed by radars in the 2.7 to 2.9 GHz band. The single channel MTI processors have either analog or digital cancellers, while the dual channel MTI processors are all digital. For dual MTI channel processing, it is only necessary to analyze one channel since both the I and Q channels are identical with the exception of the COHO signal being shifted 90 degrees and to take into account the transfer properties of the combiner.

Most radars in the 2.7 to 2.9 GHz band employ both single and double stage cancellers. Generally, the radars are operated in the double stage canceller mode which provides broader clutter-rejection nulls than the single cancellers. Some of the radars in the band also have the capability of introducing feedback in the double-canceller mode to improve the velocity response of the MTI filter, and thus have several Subclutter Visibility (SCV) modes of operation. The various operating modes of MTI cancellers are obtained by using the feed-forward coefficients (a_0, a_1, a_2) and feedback coefficients (b_1 and b_2) in the canceller hardware. For analytical purposes the single stage and double stage MTI cancellers with and without feedback can be represented in a canonical form as shown in Figure 3-34. TABLE 3-1 shows the equivalent canonical coefficients for the different modes of operation of the MTI cancellers in the ASR-7 and ASR-8 radars. The single stage MTI canceller mode is CANC1, and the double stage canceller mode without feedback is 1 & 2 CASC. The feedback modes are SCV-25, SCV-30, SCV-35, and SCV-40.

The following is a discussion of the MTI canceller transfer properties for the various modes for noise, desired signal, and asynchronous interference. A more detailed discussion of the MTI channel transfer properties and filter frequency response is given in Appendix C.

<u>Noise</u> - The noise amplitude at the MTI canceller input is Gaussian with zero mean. In all pulse radars, the inter pulse period (1/PRF) is much greater than 1/system bandwidth. Thus the sample of noise taken from the

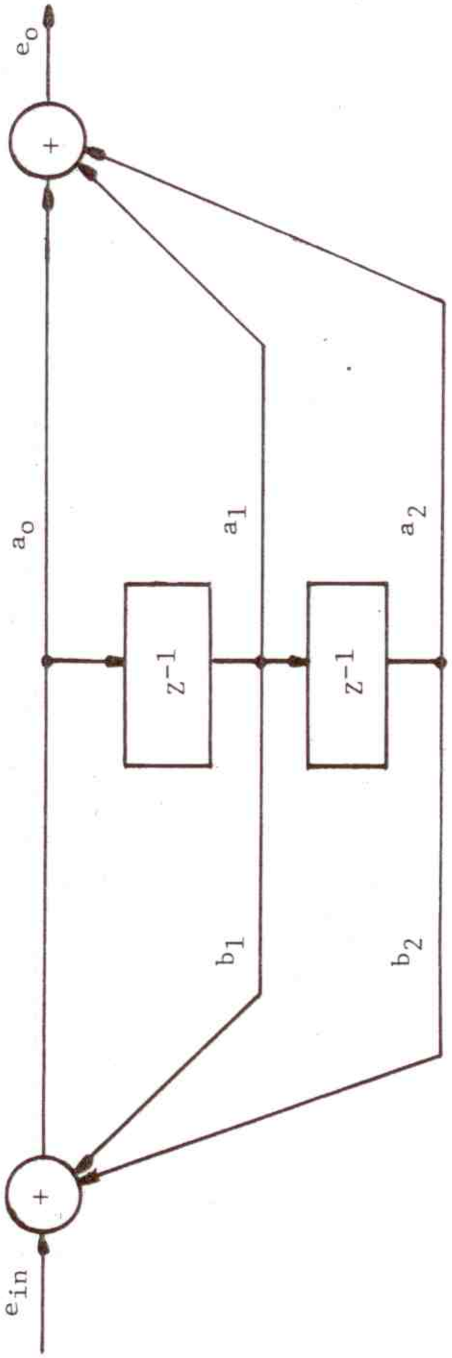

Figure 3-34. Canonical Form of Simulated ASR-7 MTI Canceller

TABLE 3-1

MTI CANCELLER TRANSFER PROPERTIES

MTI MODE	FEED-FORWARD COEFFICIENTS			FEEDBACK COEFFICIENTS		NOISE GAIN		PEAK INTER-FERENCE GAIN		PEAK INR (dB)
	a_o	a_1	a_2	b_1	b_2	VOLTS	dB	VOLTS	dB	
CANC 1	1	-1	0	0	0	$\sqrt{2}$	3	1.0	0	-3
1&2 CASC	1/2	-1	1/2	0	0	$\sqrt{1.5}$	1.76	1.0	0	-1.76
SCV-25	1/2	-1	1/2	1 1/4	-1/2	$\sqrt{0.454}$	-3.42	0.50	-6.0	-2.58
SCV-30	1/2	-1	1/2	1	-1/2	$\sqrt{0.6}$	-2.21	0.50	-6.0	-3.79
SCV-35	1/2	-1	1/2	3/4	-1/2	$\sqrt{0.777}$	-1.09	0.625	-4.08	-2.99
SCV-40	1/2	-1	1/2	1/2	-1/2	1.0	0	0.75	-2.49	-2.49

same source at intervals of 1/PRF apart are essentially uncorrelated. Zero mean uncorrelated sources add rms. The noise gain of the MTI canceller is a function of the feed-forward and feedback coefficients, and therefore is a function of the MTI canceller mode. Appendix C contains an analytical derivation of the MTI canceller noise gains. TABLE 3-1 shows the MTI canceller noise gain for each of the operating modes of the ASR-7 and ASR-8 radars.

Since the MTI canceller sums the noise at the input to the canceller which has a Gaussian amplitude distribution, the canceller output noise amplitude distribution is also Gaussian. Therefore, the noise amplitude distribution at the MTI canceller input and output are Gaussian distributed with zero mean.

<u>Desired Signal</u> - For the desired signal (synchronous signal), the signal power transfer gain of the MTI canceller without feedback or with feedback when averaged over all possible Doppler frequencies is the same as the noise power transfer gain (see noise gain in TABLE 3-1). Since the noise power density is uniform over the MTI filter, the filter treats both noise and signal (on the average) alike. Thus the signal-to-noise ratio (SNR) at the MTI canceller output is the same as at the input to the canceller when averaged over all doppler frequencies.

<u>Interfering Signal</u> - For an asynchronous interfering signal, the MTI canceller will produce several interfering pulses at the canceller output for each asynchronous interfering pulse at the MTI canceller input. These interfering pulses at the MTI canceller output are synchronous with the radar system (i.e., fall in the same range bin in successive azimuth change pulses). The amplitude and number of pulses produced by each interfering pulse are a function of the feed-forward coefficients (a_0, a_1, a_2) and the feedback coefficients (b_1 and b_2), and therefore are a function of the MTI canceller mode the radar is operating in.

For a single stage canceller (mode CANC 1), each interfering pulse produces two synchronous interfering pulses. For a double stage canceller without feedback (mode 1 & 2 CASC), each interfering pulse produces three synchronous interfering pulses. When operating in the feedback mode, there are more than three pulses out for each interfering pulse. However, by the third or fourth pulse, the interfering signal is down below the receiver noise level (1 volt) depending on the feedback constants and interfering signal level. Appendix C Figure C-11 and Figures C-15 through C-20 show measured and simulated responses of a MTI canceller to asynchronous interference for the various modes of MTI canceller operation.

The peak interfering signal transfer properties were obtained using a combination of analytical and simulation techniques, and are discussed in Appendix C. TABLE 3-1 summarizes the peak interfering signal and peak Interference-to-Noise Ratio (INR) transfer properties for each of the MTI canceller modes after rectification.

Rectifier

The output of single channel MTI canceller circuits are fed to a full-wave rectifier in analog radars or a magnitude and scale algorithm in digital radars to convert the bipolar video at the canceller output to unipolar. The signal-to-noise ratio (SNR) or interference-to-noise ratio (INR) at the rectifier or magnitude and scale output is the same as at the input. The noise amplitude distribution at the full-wave rectifier output will be one-sided Gaussian since the noise amplitude at the MTI canceller output was Gaussian. The noise amplitude PDF at the rectifier output is given by:

$$p(v) = \frac{2}{\sqrt{2\pi}\sigma} e^{-v^2/2\sigma^2} \quad ; \; o \leq v \leq \infty \qquad (3\text{-}25)$$

where:

σ = rms noise level, in volts

The desired signal-plus-noise amplitude distribution PDF at the single channel MTI rectifier output for a double stage MTI canceller is shown in Figure 3-35. It should be noted that the rectifier output signal-plus-noise amplitude distribution PDF shown in Figure 3-35 is for the radar operating in the staggered mode and the signal averaged over all possible doppler frequencies. The PDF shown in Figure 3-35 was obtained by simulation. Although the desired signal-plus-noise amplitude distribution PDF is not of the nature of a one-sided Gaussian distribution, it is shown in Appendix C that the desired signal-plus-noise amplitude distribution PDF at the single channel MTI rectifier output for a double stage MTI canceller can be approximated by a one-sided Gaussian distribution.

Combiner

The output of dual channel (inphase and quadrature) MTI canceller circuits are fed to a combiner. The signal transfer properties of the inphase and quadrature channels are identical to the single channel transfer properties previously discussed. The output of each channel is combined in the following manner:

$$R = \sqrt{(I)^2 + (Q)^2} \qquad (3\text{-}26)$$

Circuit implementation to achieve Equation 3-26 in the combiner is complex. Often a simplified approximation to Equation 3-26 is implemented by summing the larger vector amplitude with one-half the smaller vector amplitude as

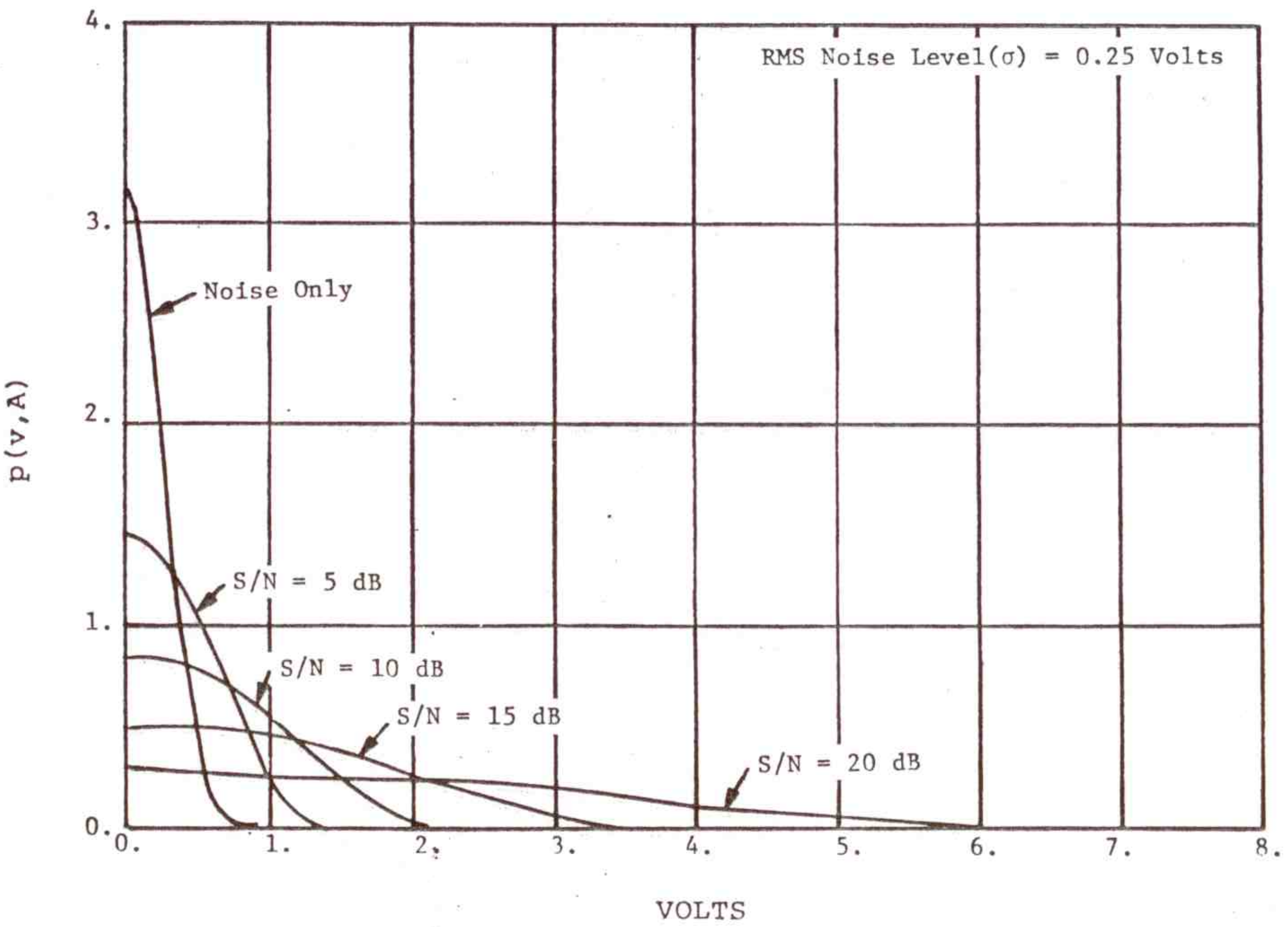

Figure 3-35. Probability Density Function for Noise Only and for Signal-Plus-Noise at the MTI Canceller Output for a Single Channel Double Stage Canceller (Simulated).

shown below:

$$R = |I| + |Q/2| \text{ if } |I| > |Q| \qquad (3\text{-}27)$$

$$R = |Q| + |I/2| \text{ if } |I| < |Q|$$

The noise amplitude distribution at the combiner output of a dual MTI canceller is Rayleigh since the transfer properties of the combiner (Equation 3-26) are similar to an envelope detector. The desired signal-plus-noise amplitude distribution PDF at the dual channel MTI combiner output for a double stage MTI canceller is shown in Figure 3-36. It should be noted that the combiner output signal-plus-noise amplitude ditribution PDF shown in Figure 3-36 is for the radar operating in the staggered mode and the signal averaged over all possible doppler frequencies. The PDF shown in Figure 3-36 was obtained by simulation. Although the desired signal-plus-noise amplitude distribution PDF is not of the nature of a Rayleigh distribution, it is shown in Appendix C that the desired signal-plus-noise amplitude distribution PDF at the dual channel MTI combiner output for a double stage MTI canceller can be approximated by a Rayleigh distribution.

The fact that dual MTI cancellers have the COHO reference signal of the inphase and quadrature channels phase shifted by 90 degrees, and the method in which the two channels are combined, a signal-to-noise ratio (SNR) improvement is achieved over a single MTI channel. The SNR improvement of dual MTI channels over a single MTI channel was investigated by Nathanson and Luke (1972). The SNR improvement of dual channel MTI over a single channel MTI for a single pulse is a function of the probability of detection and probability of false alarm. Nathanson and Luke show the SNR improvement to be between 3 and 13 dB for a single pulse. However, for a desired signal target return pulse train of 20 pulses the SNR improvement of a dual MTI channel is only about 1.5 dB. For asynchronous interfering signals, the INR enhancement of a dual MTI channel over a single MTI channel is approximately 1 to 2 dB at MDS.

MTI Log-FTC

Both the ASR-7 and ASR-8 have digital MTI log circuits. The log circuit converts the MTI digital video from a linear value to a base two logarithmic equivalent value, when Log-FTC is selected, the video is averaged over several range bins and subtraction takes place to eliminate weather clutter from the MTI video. In the ASR-8 the averaging, subtraction, and anti-log functions are done digitally, and in the ASR-7 the averaging, subtraction, and anti-log functions are done analog. The MTI Log-FTC circuit performs the same functions as the normal channel Log-FTC circuits, and therefore, the hardware can be represented by the same operations as the normal channel Log-FTC circuit (see Figure 3-16). The signal processing properties of the MTI Log-FTC circuit are also identical to the normal channel, and are discussed in the processor unit normal channel section.

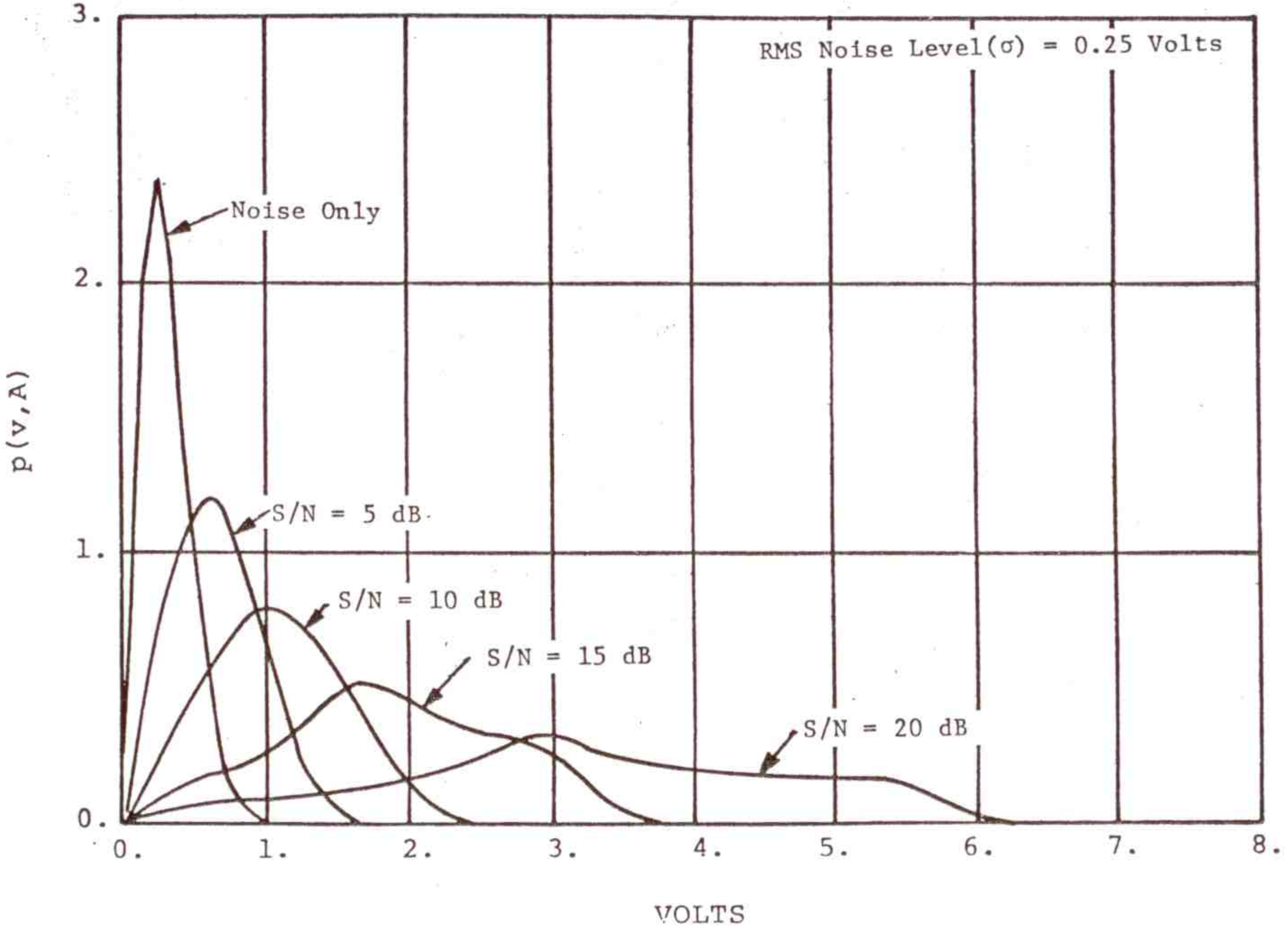

Figure 3-36. Probability Density Function for Noise Only and for Signal-Plus-Noise at the MTI Canceller Output for a Dual Channel Double Stage Canceller (Simulated).

In the ASR-8 the log-anti-log circuits are also used to introduce a bias for each of the various MTI operating modes so that the MTI channel output video noise level remains constant and independent of the operating mode. Noise normalization is achieved by scaling the video data by some factor. In the MTI channel this is implemented by adding the bias to the video data. The video data at this point in the processing is logarithmic; therefore, multiplication is accomplished by adding the logarithm of the two numbers. Since the scaling involves both adding to and subtracting from the video data, the bias values are positive or negative, respectively.

In the ASR-7 a rms noise compensation network is used to normalize the noise. The rms-noise compensation network consists of a resister divider network. Both methods of normalizing the noise will not change the signal-to-noise ratio (SNR) or interference-to-noise ratio (INR) at the output of the noise normalization networks.

MTI Enhancer

The MTI channel integrator (enhancer) circuits are separate but electronically identical to the normal channel enhancer circuitry. Therefore, the MTI channel enhancer hardware and functions are identical to the normal channel enhancer which has been previously described in the processor unit normal channel. (See Figures 3-17 and 3-24 for feedback and binary integrator block diagrams, respectively.) The major difference in the signal processing properties of the MTI channel enhancer and the normal channel enhancer are due to the difference in the statistical characteristics of the noise, desired signal, and interference signal at the input of the normal and MTI enhancer. The following is a summary of the MTI channel enhancer transfer properties for both the feedback and binary integrators which are discussed in detail in Appendix D.

Noise - The noise at the output of a single channel MTI canceller has a one-sided Gaussian amplitude distribution, while the noise at the output of a dual channel MTI canceller has a Rayleigh amplitude distribution like the normal channel. For the feedback integrator, the signal processing of the noise (attenuation, subtraction, and bottom-clipping) will result in a slightly different noise gain of the feedback integrator for a radar with a single channel MTI canceller than for a dual channel MTI canceller. However, this difference can be made small by adjusting the attenuation, subtraction, and bottom clipping circuits prior to the enhancer input. For the binary integrator the noise level at the integrator output for a single or dual channel MTI canceller can be made equal by adjusting the threshold comparator level at the input to the binary integrator. The adjustment of the threshold comparator as a function of the noise amplitude statistical characteristics is discussed in detail in Appendix D.

Another factor which affects the noise gain of the MTI channel enhancers is that the noise is correlated from range/azimuth cell to range/azimuth cell due to the MTI cancellers. This correlation of the noise is discussed in detail in Appendix D. The MTI channel noise correlation affect for a feedback integrator was simulated by Trunk (1977), and found to be approximately 1 dB for a single stage MTI canceller and 1.8 dB for a double stage MTI canceller. Therefore, the feedback integrator signal-to-noise ratio enhancement (SNR_E, see Equation 3-22) would be reduced by 1 dB for a single stage MTI canceller and 1.8 dB for a double stage MTI canceller over the normal channel SNR_E due to MTI noise correlation.

Desired Signal - The desired signal-plus-noise amplitude distribution when averaged over all possible Doppler frequencies is shown in Figure 3-35 for a single channel MTI canceller, and Figure 3-36 for a dual channel MTI canceller. The desired signal enhancement of a feedback or binary integrator for a single MTI channel will be significantly less than a dual MTI channel. This should be expected when comparing the signal-plus-noise amplitude distribution at the MTI canceller output as a function of the signal-to-noise ratio (SNR) for the single and dual MTI channels. Compare Figure 3-35 (single MTI channel signal-plus-noise amplitude distribution) with Figure 3-36 (dual MTI channel signal-plus-noise distribution).

Interference - As discussed previously in the MTI canceller signal processing properties of interference, and in Appendix C, each interfering pulse at the MTI canceller input produces several synchronous interfering pulses (i.e., fall in the same range bin in successive azimuth change pulses) at the MTI canceller output. The number of interfering synchronous pulses at the MTI canceller output is a function of the MTI canceller operating mode. Because the interference at the MTI canceller output consists of several synchronous pulses which occur in the same range bin in successive azimuth change pulses, there is potential for the interference to be integrated like the desired signal. That is, the peak interference-to-noise ratio (INR) at the MTI channel enhancer output will be greater than the peak (INR) at the MTI channel enhancer input. However, since the synchronous interference at the MTI canceller output only consists of two or three pulses that are above the receiver system noise level (one volt), the interference can be suppressed by both the feedback and binary integrators if adjusted properly.

The capability of the feedback and binary integrators to suppress MTI channel asynchronous interference was investigated using a 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 3-37 shows a simulated single channel MTI canceller radar unintegrated output for three interfering sources (ASR-5, INR = 10dB; ASR-8, INR = 15 dB; and AN/FPS-90, INR = 20 dB), and a desired target signal-to-noise ratio (SNR) of 20 dB. Figure 3-38 shows a simulated output of a feedback integrator for the feedback integrator input limit level adjusted improperly (2.0 volts) for the same interference condition shown in Figure 3-37. As discussed previously the asynchronous MTI channel interference can be enhanced if the feedback enhancer is not adjusted properly. Figure 3-39 shows a simulated output of a feedback integrator for the feedback integrator input limit level adjusted at .34 volts for the same

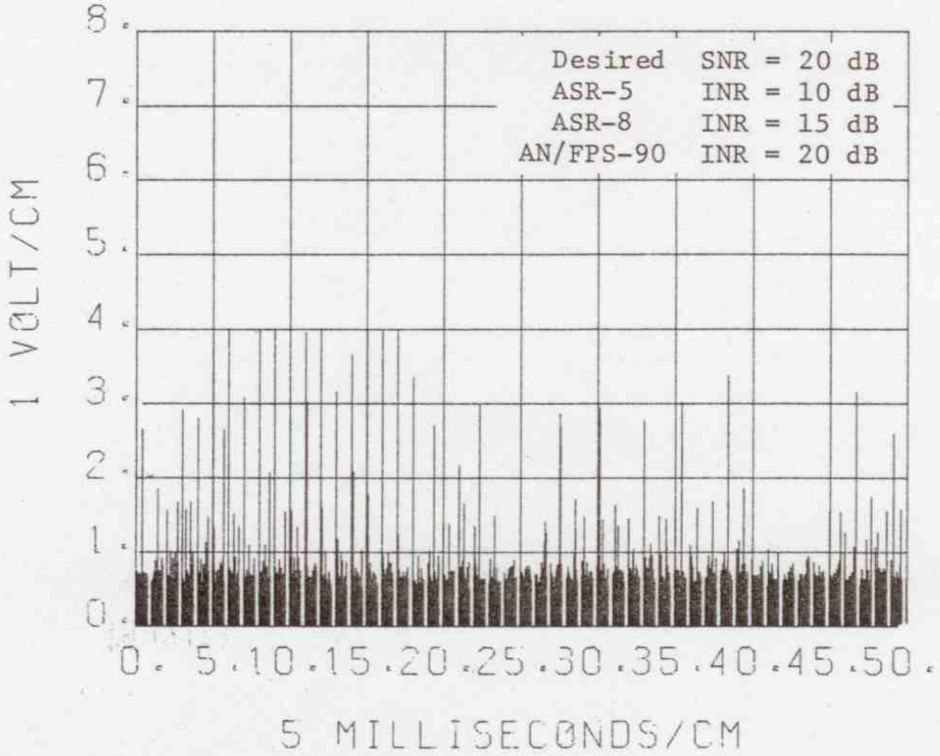

Figure 3-37. Simulated MTI Channel (Mode 1 & 2 CASC) Unintegrated Radar Output with Interference

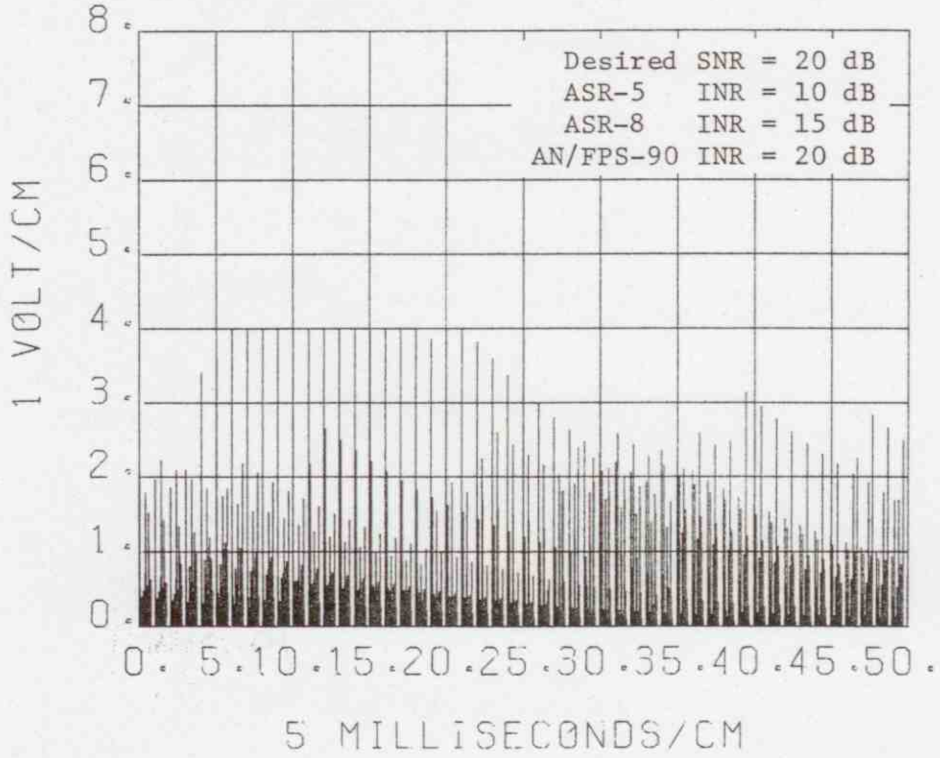

Figure 3-38. Simulated MTI Channel (Mode 1 & 2 CASC) Radar Feedback Integrator Output with Interference for the Input Limiter Set at 2.0 Volts

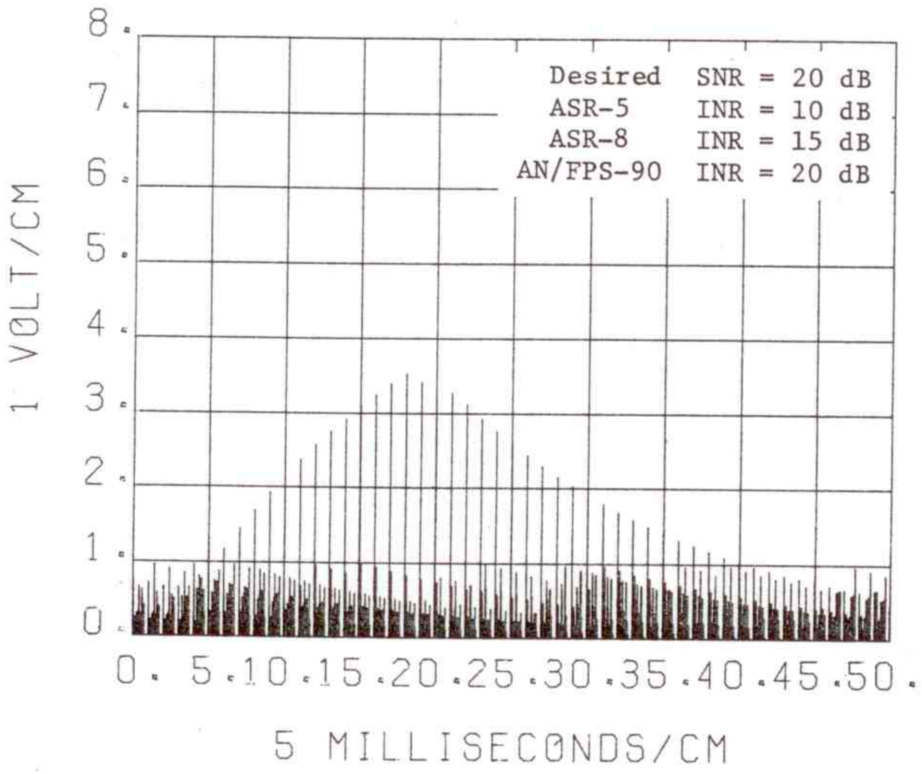

Figure 3-39. Simulated MTI Channel (Mode 1 & 2 CASC) Radar Feedback Integrator Output with Interference for the Input Limiter Set at 0.34 Volts

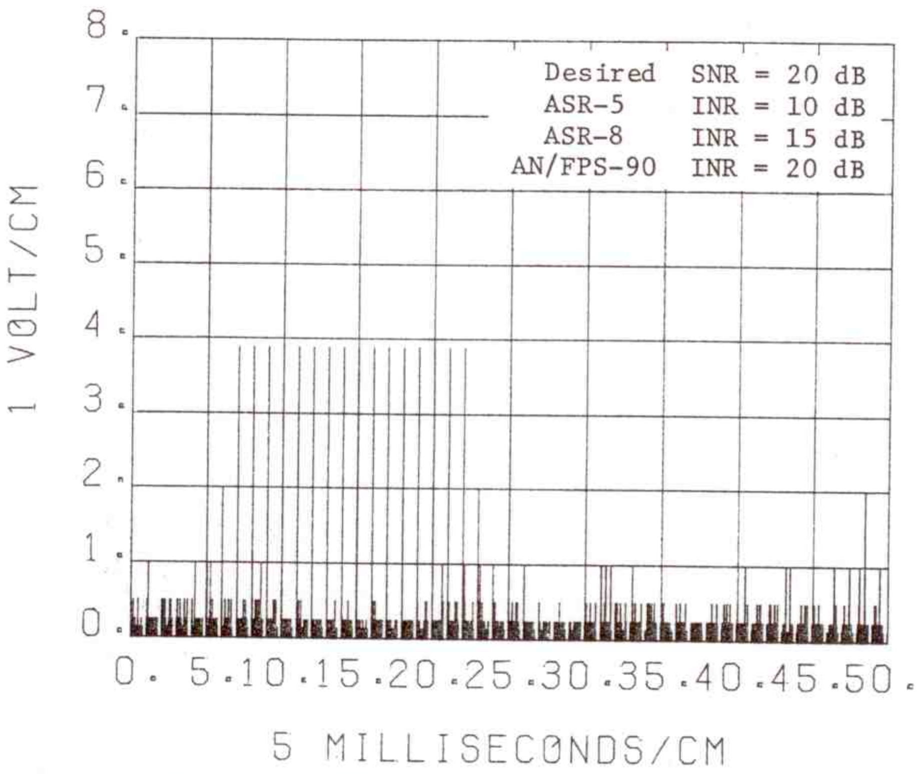

Figure 3-40. Simulated MTI Channel (Mode 1 & 2 CASC) Radar Binary Integrator Output with Interference

interference condition shown in Figure 3-37. The asynchronous interference has been suppressed by the feedback integrator. Measurements made on the Stapelton Airport ASR-8 radar in Denver, Colorado, showed that on-tune interference levels of 50 dB above the receiver noise level (approximately -60 dBm) could be suppressed in the MTI channel so that they did not appear on the PPI display. The ASR-8 radar has a feedback integrator (enhancer) and dual channel (Inphase and Quadrature) MTI channel processing. Figure 3-40 shows a simulated output of a binary integrator for the same interference condition shown in Figure 3-37. The asynchronous interference has also been suppressed by the binary integrator.

In summary, both the feedback and binary integrators will suppress asynchronous interference in the MTI channel. However, if the integrators are not adjusted properly, the integrators will enhance the interfering signals due to the synchronous interfering pulse transfer properties of the MTI cancellers. Therefore, if the integrators are not adjusted properly, the interference level will be greater with the integrators on than with the integrators off.

Processor Unit Alignment/Diversity Combiner

Figure 3-41 shows a block diagram of the processor unit Alignment/Diversity Combiner hardware in the ASR-8. Similar operations are performed in the ASR-7. The FAA is modifying the ASR-7 radars for frequency diversity. Therefore, the operations shown in Figure 3-41 should also be representative of the ASR-7 when modified for frequency diversity. The output of the Alignment/Diversity Combiner is sent to the Normal/MTI gating circuits then to the line drivers for distribution to the PPI displays.

MTI/Normal Alignment

The MTI and Normal Alignment circuits provide the delay required during STAGGER PRF operation to insure that a specific range bin in each PRF period occurs at the average PRF. During Non-STAGGER PRF operation, the alignment circuits are bypassed and the video has zero delay through the circuits. The circuit provides for the alignment of the MTI and Normal video as well as the weather background video associated with the MTI and normal channels.

The MTI/Normal Alignment circuitry does not have any affect on the desired signal-to-noise ratio or interference-to-noise ratio transfer properties since the circuitry only realigns the video information in time.

Output D/A Converter

The Digital-to-Analog (D/A) converter circuit follows the MTI/Normal Alignment processed to convert the realigned MTI and Normal video words to an analog voltage.

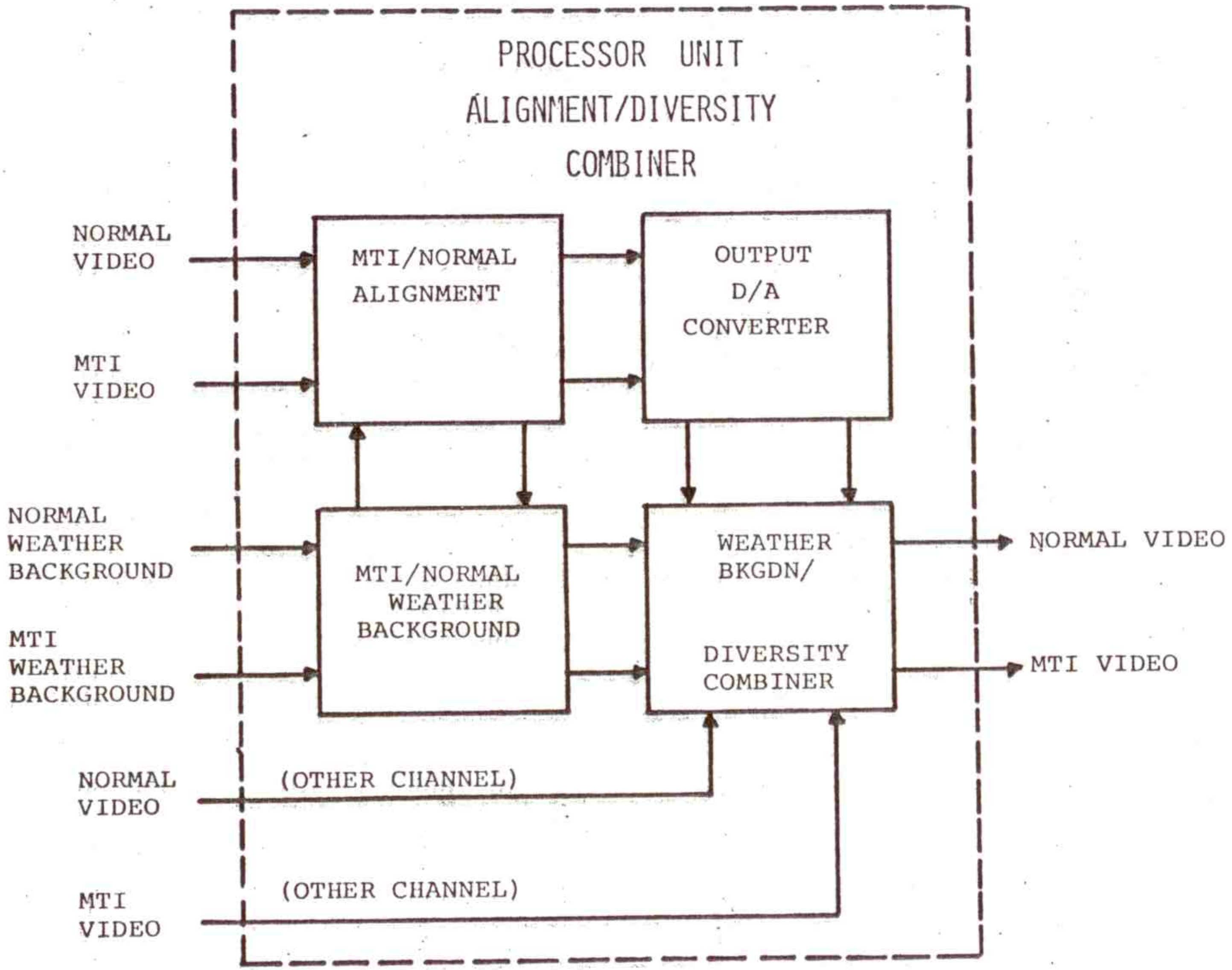

Figure 3-41. Processor Unit Alignment/Diversity Combiner Block Diagram

Weather Background/Diversity Combiner

The weather background/diversity combiner includes both MTI and normal combining circuits. After the MTI and Normal video is converted to an analog form in the output D/A converter it is routed to both the master and slave channel diversity combiners. Diversity operation involves the simultaneous operation of both radar channels to increase the effective transmittal power and improve the probability of detection. To prevent waveguide breakdown problems, the two transmitted outputs are separated in time by 1.4 μsec. To sum the signals from the two channels corresponding to the same target, this offset is realigned. A compensating delay line is, therefore, placed in the channel pulsed first, which is the master channel, thus making the two channels coincident. When two noise signals are summed, the output rms noise voltage increases by the square root of two. To maintain a constant output noise level from the radar, whether operating in diversity or single channel mode, a compensating attenuator is also included in the combiner circuit. When operating single channel, this attenuator is bypassed. After the combined or single channel video signal leaves the attenuator, it is applied to the output amplifier. The video output amplifier sums the weather background video and combined (single channel) video from the master channel when the weather background is enabled. Only the master channel weather background video is used, and it is mixed in after diversity combining since only one channel is needed to provide weather contour information. The output amplifier gain can be adjusted, however, the nominal gain is 1.4 for the combined video and 0.5 for the weather background video. A balance adjustment is also included in the summing amplifier and output amplifier.

The desired signal-to-noise ratio (SNR) improvement when operating in the frequency diversity mode is between 3 and 5 dB (Offi, 1969). The interference-to-noise ratio (INR) transfer properties of the diversity combiner when operating in the frequency diversity mode are a function of the operating frequency of the interfering radar relative to the victim radar, and the interfering signal pulse width. For the case where the interfering signal pulse width is less than 1.4 μsec, the interfering signal will not fall in the same range bin of both channels due to the 1.4 μsec separation of the transmitted pulses of the two channels, and there will be approximately a 3 dB loss in the INR. For the case where the interfering pulse is longer than 1.4 μsec (AN/FPS-6, 90; 2 μsec; WSR-57, 74S; 4.0 μsec), the interfering signal will fall in the same range bin of both channels, and there will be an increase in the INR. The maximum increase in the INR for this case is 3 dB which would only occur if the interference level was equal in both channels. When operating in the frequency diversity mode if there is interference above the noise level in either channel, the interference will appear on the PPI display.