TABLE 4-9

ARTS-IIIA/RDAS PROBABILITY OF TARGET HIT WHEN CONNECTED TO ASR-7 RADAR THAT IS RECEIVING INTERFERENCE FROM THREE RADARS OF THE SAME TYPE

VICTIM RADAR CHANNEL	INTERFERING RADAR	INTERFERING RATE ν PULSES/SEC	PROBABILITY OF TARGET HIT (RQT = 23)	PROBABILITY OF TARGET HIT (RQT = 24)
NORMAL	ASR-7	3006	0.6842	0.6686
NORMAL	ASR-8	3120	0.6944	0.6681
NORMAL	AN/CPN-4	3576	0.6989	0.6639
NORMAL	AN/FPS-90	1068	0.6895	0.6886
NORMAL	WSR-57	498	0.6948	0.6944
MTI	ASR-7	3006	0.6536	0.6097
MTI	ASR-8	3120	0.6832	0.6087
MTI	AN/CPN-4	3576	0.6968	0.5975
MTI	AN/FPS-90	1068	0.6692	0.6665
MTI	WSR-57	498	0.6847	0.6834

NOTE: RQT = RANK QUANTIZER THRESHOLD
PROBABILITY OF TARGET HIT WITHOUT INTERFERENCE = 0.7

TABLE 4-10

ARTS-IIIA/RDAS PROBABILITY OF TARGET HIT WHEN CONNECTED TO ASR-8 RADAR THAT IS RECEIVING INTERFERENCE FROM ONE RADAR

VICTIM RADAR CHANNEL	INTERFERING RADAR	INTERFERING RATE ν PULSES/SEC	PROBABILITY OF TARGET HIT (RQT = 23)	PROBABILITY OF TARGET HIT (RQT = 24)
NORMAL	ASR-7	1002	0.6921	0.6918
NORMAL	ASR-8	1040	0.6954	0.6916
NORMAL	AN/CPN-4	1192	0.6965	0.6906
NORMAL	AN/FPS-90	356	0.6972	0.6970
NORMAL	WSR-57	166	0.6987	0.6985
MTI	ASR-7	1002	0.6767	0.6758
MTI	ASR-8	1040	0.6864	0.6753
MTI	AN/CPN-4	1192	0.6898	0.6723
MTI	AN/FPS-90	356	0.6918	0.6911
MTI	WSR-57	166	0.6961	0.6958

NOTE: RQT = RANK QUANTIZER THRESHOLD
PROBABILITY OF TARGET HIT WITHOUT INTERFERENCE = 0.7

TABLE 4-11

ARTS-IIIA/RDAS PROBABILITY OF TARGET HIT WHEN CONNECTED TO ASR-8 RADAR THAT IS RECEIVING INTERFERENCE FROM THREE RADARS OF THE SAME TYPE

VICTIM RADAR CHANNEL	INTERFERING RADAR	INTERFERING RATE ν PULSES/SEC	PROBABILITY OF TARGET HIT (RQT = 23)	PROBABILITY OF TARGET HIT (RQT = 24)
NORMAL	ASR-7	3006	0.6767	0.6758
NORMAL	ASR-8	3120	0.6870	0.6753
NORMAL	AN/CPN-4	3576	0.6898	0.6722
NORMAL	AN/FPS-90	1068	0.6917	0.6910
NORMAL	WSR-57	498	0.6961	0.6958
MTI	ASR-7	3006	0.6323	0.6300
MTI	ASR-8	3120	0.6601	0.6287
MTI	AN/CPN-4	3576	0.6698	0.6200
MTI	AN/FPS-90	1068	0.6753	0.6733
MTI	WSR-57	498	0.6885	0.6875

NOTE: RQT = RANK QUANTIZER THRESHOLD
PROBABILITY OF TARGET HIT WITHOUT INTERFERENCE = 0.7

Monte-Carlo simulating a series of target hits and misses and comparing this binary sequence to the target detection criteria. The details of this program are given in Appendix F, and the results of the calculations plotted on probability paper in Figures 4-28 and 4-29. The probability of target detection versus probability of target hit curves in Figure 4-28 are for a rank quantizer threshold of 23 and those in Figure 4-29 for a rank quantizer threshold 24. The family of curves on each graph represent combinations of hit and miss count threshold detection parameters. From the graphs, it is evident that for a given hit and miss count threshold, a rank quantizer threshold setting of 23 results in a slightly higher probability of target detection than 24. This is because a rank quantizer threshold setting of 23 results in a greater probability of hit due to noise alone (probability of false target hit), which in effect increases the probability of the hit count satisfying the target detection criteria (hit count threshold). That is, the noise hits in azimuth for a given range bin can cause an initial non-zero hit count before radar return pulses from the target are received. The probability of this occurring is greater for a rank quantizer threshold setting of 23 than 24.

The curves in Figures 4-28 and 4-29 were used to relate the interference effect on probability of target hit to probability of target detection. This procedure was followed to relate the probability of target hits in TABLES 4-8 through 4-11 for various interfering conditions to the probability of target detection values shown in TABLE 4-12. The values are for the most likely ARTS-IIIA/RDAS detection parameters that will be used in the field (hit count threshold of 9, miss count threshold of 3, and rank quantizer threshold setting 23). The probability of detection without interference (0.8892) is shown at the bottom of TABLE 4-12. It is evident from TABLE 4-12 that interfacing the ARTS-IIIA/RDAS to the ASR-8 results in, except for the AN/FPS-90 and WSR-57 interfering radar types, a lower probability of target detection than when interfaced to an ASR-7. A lower probability of detection also results when the ARTS-IIIA is connected to a single MTI channel than to a normal or dual MTI channel. The lowest probability of detections occurred for the interferer and victim radar combinations involving the ASR-7 and ASR-8, because this combination resulted in the greatest decrease in probability of target hit due to interference. The impact of interference on the probability of target hit detection was defined for rank quantizer threshold 23 by Equations 4-3 and 4-19. For the case in which the interfering pulse width is less than the sum of the victim radar range bin width and hold time, radars with the largest duty cycles (τ_i x PRF) have the greatest interference effect on ARTS-IIIA/RDAS performance. For the case in which the interfering radar pulse width is greater than the sum of the victim radar range bin width and hold time, the impact of interference is independent of the interfering radar pulse width and increases only with interfering radar PRF.

Interpretation of Interference Effects on Target Detection

It is evident from TABLE 4-12 that the difference between the lowest probability of target detection (0.7581) and that for no interference

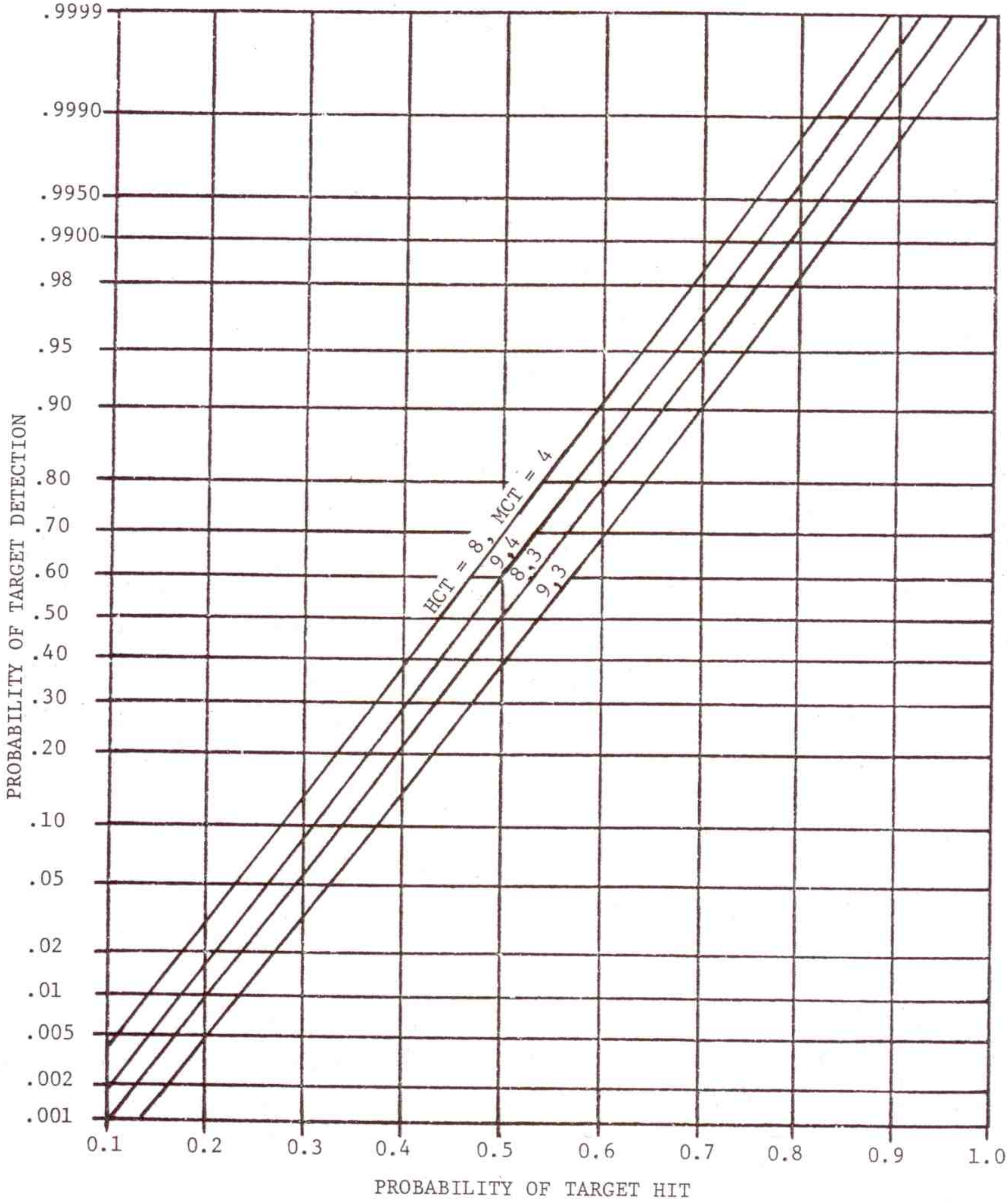

Figure 4-28. ARTS-IIIA/RDAS Probability of Target Detection Versus Probability of Target Hit for Rank Quantizer Threshold 23 and Various Hit/Miss Count Threshold Parameters Combinations (Probability Scale)

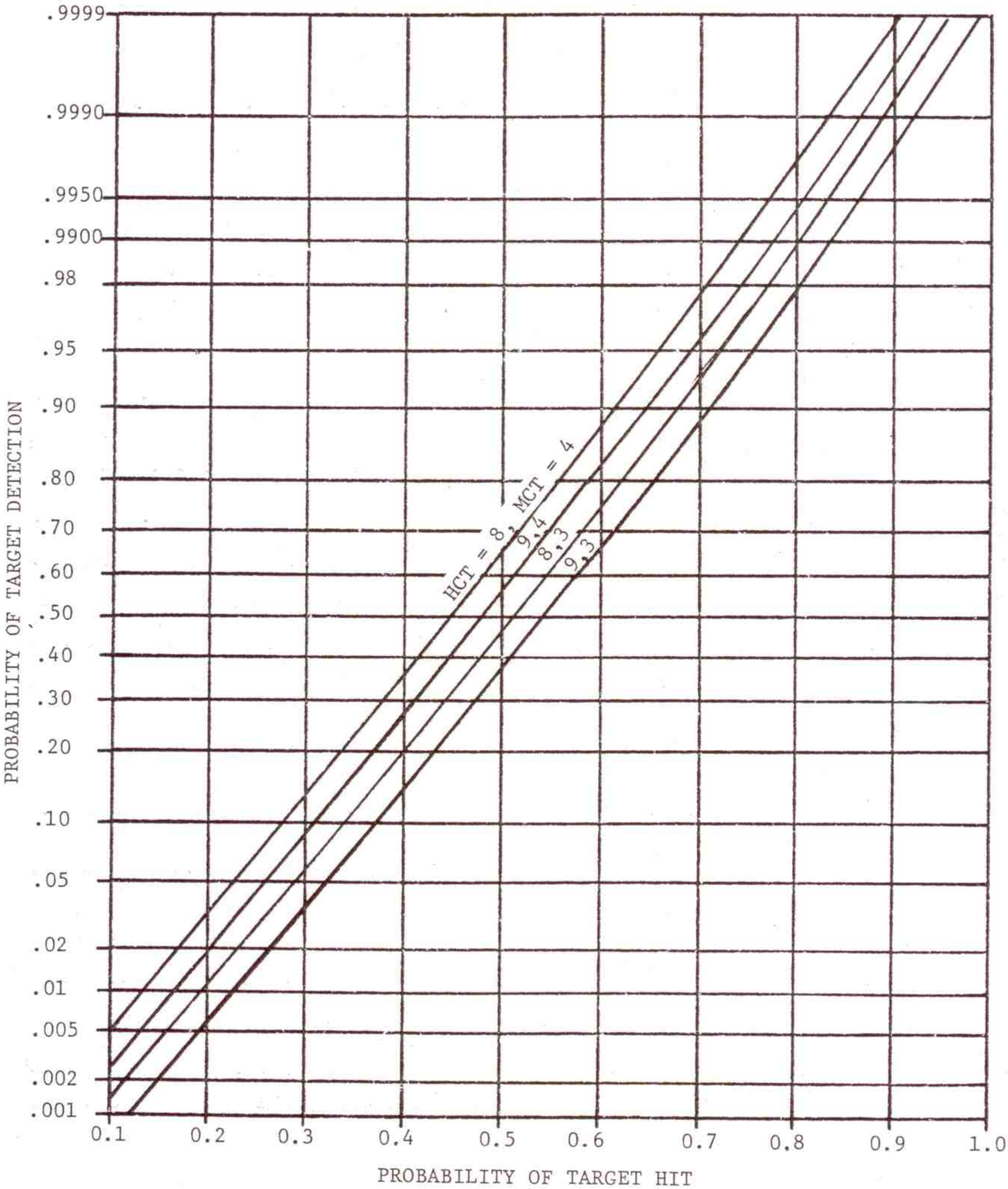

Figure 4-29. ARTS-IIIA/RDAS Probability of Target Detection Versus Probability of Target Hit for Rank Quantizer Threshold 24 and Various Hit/Miss Count Threshold Parameter Combinations (Probability Scale)

TABLE 4-12

ARTS-IIIA/RDAS PROBABILITY OF TARGET DETECTION FOR TYPICAL DETECTION PARAMETERS AND VARIOUS COMBINATIONS OF INTERFERING AND VICTIM RADARS

VICTIM RADAR	VICTIM RADAR CHANNEL	NUMBER INTERFERING RADARS OF SAME TYPE	INTERFERING RADAR TYPE				
			ASR-7 τ_i = 0.83 μs PRF = 1002	ASR-8 τ_i = 0.60 μs PRF = 1040	AN/CPN-4 τ_i = 0.5 μs PRF = 1192	AN/FPS-90 τ_i = 2.0 μs PRF = 356	WSR-57 τ_i = 4.0 μs PRF = 166
ASR-7	NORMAL	1	0.8789	0.8855	0.8884	0.8824	0.8859
ASR-7	NORMAL	3	0.8586	0.8784	0.8871	0.8689	0.8791
ASR-7	MTI	1	0.8586	0.8784	0.8871	0.8693	0.8793
ASR-7	MTI	3	0.7994	0.8567	0.8830	0.8296	0.8596
ASR-8	NORMAL	1	0.8739	0.8803	0.8824	0.8838	0.8867
ASR-8	NORMAL	3	0.8441	0.8640	0.8695	0.8731	0.8816
ASR-8	MTI	1	0.8441	0.8628	0.8695	0.8733	0.8816
ASR-8	MTI	3	0.7581	0.8119	0.8307	0.8414	0.8669

NOTE: 1. ARTS IIIA/RDAS TYPICAL TARGET DECTECTION PARAMETERS
RANK QUANTIZER THRESHOLD = 23
HIT COUNT THRESHOLD = 9
MISS COUNT THRESHOLD = 3

2. PROBABILITY OF TARGET DETECTION WITHOUT INTERFERENCE = 0.8892

(0.8892) is 0.13. This reduction in probability of target detection is for the MTI channel of the victim radar receiving continual and simultaneous interference from three radars. A 0.13 reduction in target detection probability implies that if 350 targets per antenna rotations are detected without interference, only about 305 would be detected with interference. This degree of target detection degradation due to interference would be unacceptable. However, it should be pointed out that this number represents extremely worst-case interference conditions which do not currently exist in congested U.S. terminal areas. Recent measurements by NTIA (Hinkle, 1976) in the Los Angeles and San Francisco area indicated that for those FAA radars which received interference, interference was usually received from one radar at a time over only small sectors of the PPI. The lowest probability of target detection listed in TABLE 4-12 for one interfering radar is 0.8441, and represents a 0.045 decrease due to interference. This implies that if 350 targets are detected without interference, only 334 targets would be detected with interference. If it is assumed that interference is received over only 50 percent of the antenna rotation and that aircraft targets are uniformly distributed in azimuth, the number of targets detected per antenna rotation would be decreased by interference from 350 to 342. This is equivalent to a 0.02 decrease in the probability of a target being detected in one antenna rotation. The decrease corresponds to one radar interfering over 50 percent of the antenna rotation, or multiple interfering radars which do not interfere simultaneously but in combination, interfere over 50 percent of the antenna rotation.

The above estimated reduction in detection probability (0.02) due to present interference levels in congested terminal areas, and in general those detection probabilities listed in TABLE 4-12, are pessimistic. In addition to worst-case interference signal level assumptions, the 0.7 target hit probability chosen for a zero interference reference base results in a worst-case interference impact on target detection probability. This can be seen from the linear plot of target detection probability versus target hit probability shown in Figure 4-30. The slope of the (9/3) curve (used in the analysis) in the 0.7 target hit probability region is very steep. Consequently, a decrease in probability of target hit from 0.7 due to interference results in a significant decrease in probability of target detection. For interference reference target hit probabilities greater than 0.7 the slope of the curve approaches zero. Therefore, interference has considerably less impact on target detection probability for these target hit probability ranges.

It is evident from Figures 4-17, 4-18, and 4-19 that a 0.7 probability of target hit and rank quantizer threshold of 23 chosen for the analysis corresponds to a signal-to-noise ratio of approximately 6 dB, 12 dB, and 7 dB for the ARTS-IIIA/RDAS connected to the ASR-7 or ASR-8 normal channel, ASR-7 MTI channel, and ASR-8 MTI channel, respectively. The 12 dB signal-to-noise ratio for the single MTI channel is fairly typical; however, the 6 dB and 7 dB signal-to-noise ratio for the normal and dual MTI channel is considerably less than typical. For this reason, the interference effects on target detection indicated in TABLE 4-12 are more pessimistic for the normal and

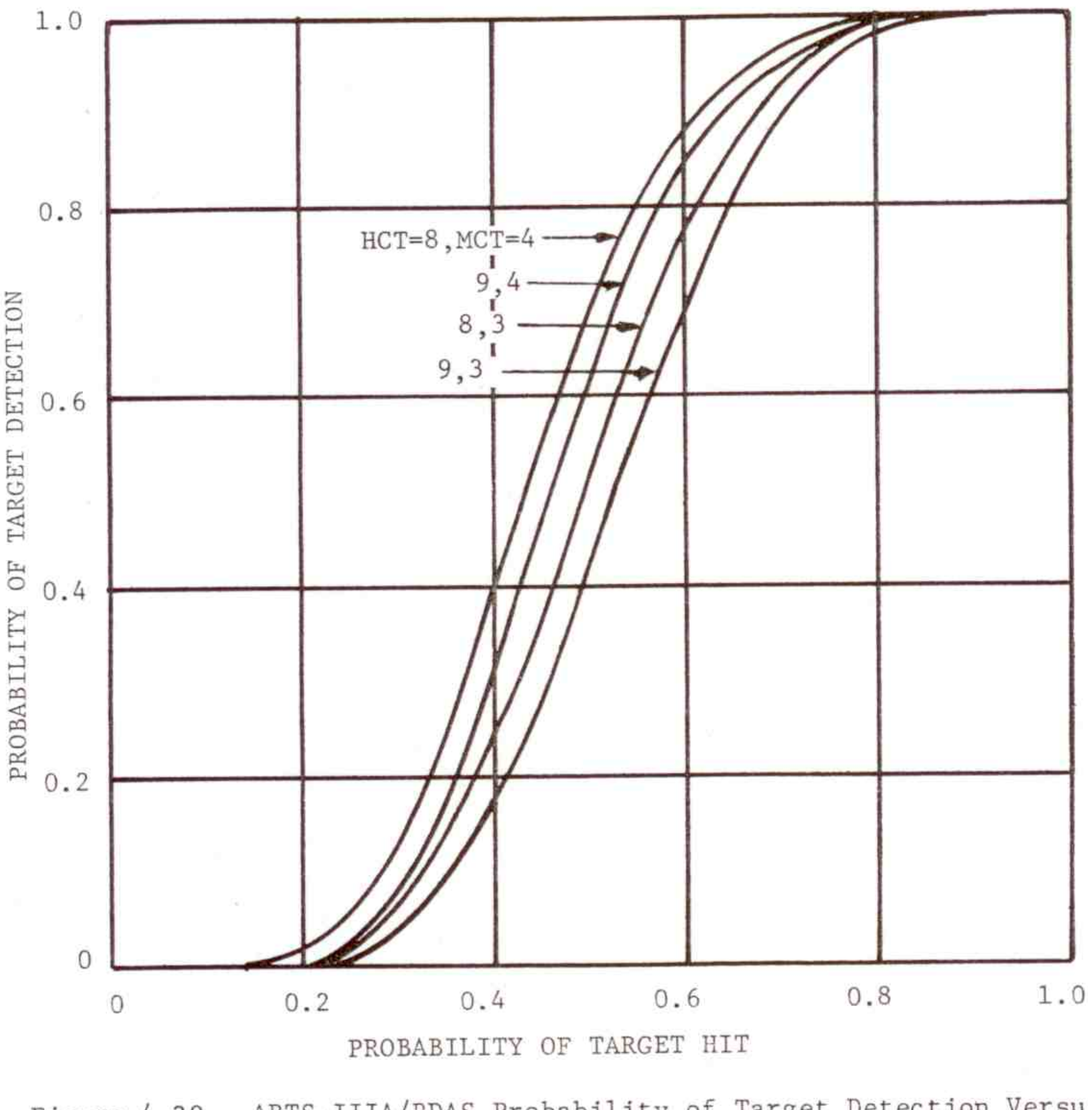

Figure 4-30. ARTS-IIIA/RDAS Probability of Target Detection Versus Probability of Target Hit for Rank Quantizer Threshold 23 and Various Hit/Miss Count Threshold Parameter Combinations (Linear Scale)

dual MTI channel than the single MTI channel.

The hit count threshold of 9 used in the target detection analysis corresponds to only the lowest hit count threshold value that the MTI channel can have at any given time. As discussed in a previous section and described in Figure 4-7, the MTI channel hit count threshold is automatically increased from 9 to a maximum of 20 depending on the degree of clutter correlation. From comparison of the target detection probability curves in Figure 4-30, it is evident that the slope of the curves for hit count thresholds greater than 9, in the 0.7 target hit probability region, would be approximately the same as for the (9, 3) hit/miss count threshold curve. Since the (9, 3) curve and a 0.7 target hit probability (zero interference reference base) was used to determine the interference impact on detection probability, the analysis results should at least typify ASR-7 MTI channel performance for a 12 dB signal-to-noise ratio, and 7 dB signal-to-noise ratio for the ASR-8 MTI channel, in the lower portion of the automatically varied hit count threshold range of 9 to 20.

Trade-Off Between Interference Suppression and ARTS-IIIA/RDAS Performance

This subsection addresses the trade-offs between interference suppression and radar performance for various ARTS-IIIA/RDAS detection parameter settings. The interference case chosen for the trade-off analysis included three continually interfering radars and the ARTS-IIIA/RDAS connected to the victim radar MTI channel. This combination was chosen for the trade-off analysis because it results in the greatest impact of interference on target detection probability.

TABLES 4-13 through 4-16 indicates the effect of interference on the probability of detection and false alarm for various interfering radar types and ARTS-IIIA/RDAS detection parameter combinations. In particular, TABLES 4-13 and 4-14 indicate the affect of interference on false alarm and TABLES 4-15 and 4-16 the interference effect on target detection. The first column of the table gives the ARTS-IIIA/RDAS rank quantizer, hit count, and miss count threshold combinations. The probability of false alarm or target detection for no interference and a particular combination of detection parameters is given in the last column of the tables. From the tables and detection theory, it is evident that increasing probability of target detection also increases probability of false alarm. An optimum set of detection parameters involve maximizing the probability of detection while maintaining an acceptable false alarm rate (probability of false alarm). FAA considers probability of false alarms that exceed approximately 10^{-6} to be unacceptable. Therefore, the false alarm probability (1.164×10^{-5}) listed in TABLES 4-13 and 4-14 for no interference and the (23, 8, 4) rank/hit/miss detection threshold parameter combination would likely be unacceptable.

Rank Quantizer Threshold Trade-Off

It is evident from TABLES 4-13 and 4-14 that, with the exception of the

TABLE 4-13

ARTS-IIIA/RDAS PROBABILITY OF FALSE ALARM WHEN CONNECTED TO ASR-7 RADAR (MTI CHANNEL) THAT IS RECEIVING INTERFERENCE FROM THREE RADARS OF THE SAME TYPE

ARTS-IIIA PARAMETERS			INTERFERING RADAR TYPE					PROBABILITY OF FALSE ALARM WITHOUT INTERFERENCE
RQT	HCT	MCT	ASR-7 PW = 0.83 μs PRF = 1002	ASR-8 PW = 0.60 μs PRF = 1040	AN/CPN-4 PW = 0.5 μs PRF = 1192	AN/FPS-90 PW = 2.0 μs PRF = 356	WSR-57 PW = 4.0 μs PRF = 166	
23	8	3	3.176×10^{-6}	3.893×10^{-6}	4.440×10^{-6}	3.263×10^{-6}	2.195×10^{-6}	2.500×10^{-6}
23	8	4	1.505×10^{-5}	1.869×10^{-5}	2.145×10^{-5}	1.550×10^{-5}	2.408×10^{-5}	1.164×10^{-5}
23	9	3	7.075×10^{-7}	9.699×10^{-7}	11.702×10^{-7}	7.392×10^{-7}	4.051×10^{-7}	4.596×10^{-7}
23	9	4	4.085×10^{-6}	4.956×10^{-6}	5.622×10^{-6}	4.190×10^{-6}	2.881×10^{-6}	3.262×10^{-6}
24	8	3	2.129×10^{-8}	1.352×10^{-8}	1.038×10^{-8}	3.168×10^{-8}	0.909×10^{-8}	1.081×10^{-8}
24	8	4	10.839×10^{-8}	7.997×10^{-8}	6.766×10^{-8}	14.633×10^{-8}	6.050×10^{-8}	7.008×10^{-8}
24	9	3	2.688×10^{-9}	1.621×10^{-9}	1.238×10^{-9}	4.112×10^{-9}	1.203×10^{-9}	1.250×10^{-9}
24	9	4	2.323×10^{-8}	1.384×10^{-8}	1.043×10^{-8}	3.577×10^{-8}	1.003×10^{-8}	1.057×10^{-8}

NOTE: RQT = RANK QUANTIZER THRESHOLD
HCT = HIT COUNT THRESHOLD
MCT = MISS COUNT THRESHOLD

TABLE 4-14

ARTS-IIIA/RDAS PROBABILITY OF FALSE ALARM WHEN CONNECTED TO ASR-8 RADAR (MTI CHANNEL) THAT IS RECEIVING INTERFERENCE FROM THREE RADARS OF THE SAME TYPE

ARTS-IIIA PARAMETERS			INTERFERING RADAR TYPE					PROBABILITY OF FALSE ALARM WITHOUT INTERFERENCE
RQT	HCT	MCT	ASR-7 PW = 0.83 μs PRF = 1002	ASR-8 PW = 0.60 μs PRF = 1040	AN/CPN-4 PW = 0.5 μs PRF = 1192	AN/FPS-90 PW = 2.0 μs PRF = 356	WSR-57 PW = 4.0 μs PRF = 166	
23	8	3	2.400×10^{-6}	2.966×10^{-6}	3.313×10^{-6}	2.011×10^{-6}	2.271×10^{-6}	2.500×10^{-6}
23	8	4	1.116×10^{-5}	1.400×10^{-5}	1.575×10^{-5}	0.931×10^{-5}	1.055×10^{-5}	1.164×10^{-5}
23	9	3	4.417×10^{-7}	6.305×10^{-7}	7.575×10^{-7}	3.723×10^{-7}	4.187×10^{-7}	4.596×10^{-7}
23	9	4	3.136×10^{-6}	4.364×10^{-6}	5.183×10^{-6}	2.652×10^{-6}	2.976×10^{-6}	3.262×10^{-6}
24	8	3	2.848×10^{-8}	2.065×10^{-8}	1.175×10^{-8}	0.872×10^{-8}	0.887×10^{-8}	1.081×10^{-8}
24	8	4	13.464×10^{-8}	10.606×10^{-8}	9.454×10^{-8}	5.997×10^{-8}	6.292×10^{-8}	7.008×10^{-8}
24	9	3	3.673×10^{-9}	2.600×10^{-9}	2.168×10^{-9}	1.174×10^{-9}	1.215×10^{-9}	1.250×10^{-9}
24	9	4	3.190×10^{-8}	2.245×10^{-8}	1.865×10^{-8}	0.938×10^{-8}	1.001×10^{-8}	1.057×10^{-8}

NOTE: RQT = RANK QUANTIZER THRESHOLD
HCT = HIT COUNT THRESHOLD
MCT = MISS COUNT THRESHOLD

TABLE 4-15

ARTS-IIIA/RDAS PROBABILITY OF TARGET DETECTION WHEN CONNECTED TO ASR-7 RADAR (MTI CHANNEL) THAT IS RECEIVING INTERFERENCE FROM THREE RADARS

ARTS-IIIA PARAMETERS			INTERFERING RADAR TYPE					PROBABILITY OF DETECTION WITHOUT INTERFERENCE
RQT	HCT	MCT	ASR-7 PW = 0.83 μs PRF = 1002	ASR-8 PW = 0.60 μs PRF = 1040	AN/CPN-4 PW = 0.5 μs PRF = 1192	AN/FPS-90 PW = 2.0 μs PRF = 356	WSR-57 PW = 4.0 μs PRF = 166	
23	8	3	0.8559	0.9028	0.9242	0.8806	0.9051	0.9293
23	8	4	0.9352	0.9619	0.9741	0.9492	0.9632	0.9770
23	9	3	0.7994	0.8567	0.8830	0.8296	0.8596	0.8892
23	9	4	0.9068	0.9418	0.9579	0.9253	0.9436	0.9617
24	8	3	0.7786	0.7770	0.7568	0.8688	0.8956	0.9219
24	8	4	0.8924	0.8915	0.8788	0.9426	0.9576	0.9723
24	9	3	0.7026	0.7006	0.6752	0.8160	0.8497	0.8829
24	9	4	0.8513	0.8506	0.8338	0.9176	0.9373	0.9567

NOTE: RQT = RANK QUANTIZER THRESHOLD
HCT = HIT COUNT THRESHOLD
MCT = MISS COUNT THRESHOLD

TABLE 4-16

ARTS-IIIA/RDAS PROBABILITY OF TARGET DETECTION WHEN CONNECTED TO ASR-8 RADAR (MTI CHANNEL) THAT IS RECEIVING INTERFERENCE FROM THREE RADARS OF THE SAME TYPE

ARTS-IIIA PARAMETERS			INTERFERING RADAR TYPE					PROBABILITY OF DETECTION WITHOUT INTERFERENCE
RQT	HCT	MCT	ASR-7 PW = 0.83 μs PRF = 1002	ASR-8 PW = 0.60 μs PRF = 1040	AN/CPN-4 PW = 0.5 μs PRF = 1192	AN/FPS-90 PW = 2.0 μs PRF = 356	WSR-57 PW = 4.0 μs PRF = 166	
23	8	3	0.8223	0.8663	0.8816	0.8903	0.9111	0.9293
23	8	4	0.9160	0.9411	0.9498	0.9547	0.9666	0.9770
23	9	3	0.7581	0.8120	0.8307	0.8414	0.8669	0.8892
23	9	4	0.8816	0.9145	0.9620	0.9325	0.9481	0.9617
24	8	3	0.8109	0.8088	0.7950	0.8796	0.9021	0.9219
24	8	4	0.9104	0.9092	0.9015	0.9487	0.9612	0.9723
24	9	3	0.7431	0.7405	0.7232	0.8296	0.8579	0.8829
24	9	4	0.8750	0.8735	0.8633	0.9255	0.9421	0.9567

NOTE: RQT = RANK QUANTIZER THRESHOLD
HCT = HIT COUNT THRESHOLD
MCT = MISS COUNT THRESHOLD

(23, 8, 4) detection parameters combination, either a rank quantizer threshold setting of 23 or 24 would yield an acceptable false alarm probability. Even for heavy interfering conditions, the probability of false alarm is not increased up to an unacceptable level for these two parameter settings.

The probability of target detection values listed in the right column of TABLES 4-15 and 4-16 for no interference indicates that for a given hit and miss count threshold, and target hit probability, that detection performance is slightly greater for a rank quantizer threshold 23 than 24. However, the probability of detecting a target without interference is actually larger for a rank quantizer threshold setting of 23 than indicated. It is evident from Figures 4-17, 4-18, and 4-19 that approximately 1 to 2 dB greater signal-to-noise ratio is required for a rank quantizer threshold of 24 than 23 to achieve a given probability of target hit. This implies that for a given signal-to-noise ratio, a rank quantizer threshold setting of 23 results in a higher probability of target detection. Therefore, a rank quantizer threshold setting of 23 is optimum for radar detection performance without interference.

It is evident from TABLES 4-15 and 4-16 that a rank quantizer threshold setting of 23 is also more desirable than 24 for interference suppression. For a given interfering radar and hit/miss threshold combination, the decrease in probability of detection caused by interference is significantly less for a rank quantizer threshold setting of 23 than 24. This is because there is a lower probability of interfering pulses falling in two rank quantizer comparison range bins than one. As discussed previously, a rank quantizer threshold setting of 24 implies that the signal level in the target range bin of interest has to exceed all 24 comparison range bin signal levels before a target hit (logical 1) is generated. However, the signal level in the target range bin of interest for rank quantizer threshold setting 23 only has to exceed 23 of the 24 comparison range bins for a target hit to be generated.

It is evident from this logic and the results of the analysis that rank quantizer thresholds lower than 23 would further reduce the impact of interference on target detection probability. However, lowering the rank quantizer threshold below 23 would begin to adversely affect the rank order detection processor's capability to maintain a constant false alarm rate (probability of false alarm) in varying levels of clutter.

Hit and Miss Count Threshold Trade-Off

It was shown in the previous section that a rank quantizer threshold setting of 23 is superior to 24 for ARTS-IIIA performance, with or without interference. This section considers the hit and miss count threshold detection parameter combinations associated with this rank quantizer threshold which yields optimum ARTS-IIIA performance. As previously discussed, the (23, 8, 4) rank/hit/miss detection threshold parameter combination yields an unacceptably high false alarm probability. Therefore, only the (23, 8, 3), (23, 9, 3), and (23, 9, 4) parameter combinations will be considered.

It is evident from TABLES 4-13 and 4-14 that for a rank quantizer threshold of 23, the probability of false alarm increased the most for the (9, 3) hit/miss count threshold combination and the least for the (8, 3) combination. The probability of false alarm increase for the (9, 4) combination was between that for the (8, 3) and (9, 3) combination. However, the increase in false alarm probability is not significant enough to warrant recommendation of a particular hit/miss count threshold combination.

From TABLES 4-15 and 4-16, it is evident that the probability of target detection decreased the most for the (9, 3) hit/miss count threshold parameter combination and the least for the (9, 4) combination. For example, the probability of detection for an ASR-7 radar interfering with an ASR-8 and (9, 3) hit/miss count threshold combination decreased from 0.8892 to 0.7581 (14.7 percent decrease). On the other hand, for a (9, 4) hit/miss count threshold parameter combination, the probability of detection decreased from 0.9617 to 0.8816 (8.3 percent decrease). The target detection probability decreased for the (8, 3) hit/miss count threshold parameter combination from 0.9293 to 0.8223 represents a 11.5 percent decrease.

The reason that the (23, 9, 4) rank/hit/miss detection threshold parameter combination results in the probability of detection being less affected by interference than other parameter combinations can be seen from Figure 4-30. The graph indicates a linear scale plot of target detection probability versus target hit probability for various hit/miss count threshold parameter combinations. The tangential slope of the (9, 4) curve for a 0.7 target hit probability (value used as zero interference reference) is less than that for the (8, 3) and (9, 3) hit/miss parameter curves. This implies that a smaller reduction in probability of detection occurs on the (9, 4) curves, for a given reduction in probability of target hit due to interference, than for the (8, 3) and (9, 3) curves. In general the tangential slope of the (9, 4) curve is less than the (8, 3) and (9, 3) curve for target hit probabilities greater than 0.5. From Figures 4-17, 4-18, and 4-19, a 0.5 probability of target hit corresponds to a 4 dB signal-to-noise ratio for the ARTS-IIIA/RDAS connected to the normal (ASR-7 or ASR-8) and ASR-8 MTI channel, and 7.5 dB when connected to the ASR-7 MTI channel. Since typical signal-to-noise ratios are greater than these values, the (9,4) hit/miss count parameter combination will result in suppression of interference most of the time.

The previous analysis indicated that the (9, 4) hit/miss count threshold parameter combination yields a maximum probability of target detection with and without interference while yielding an acceptable probability of false alarm. It should be pointed out that the analysis was based on the MTI channel with uncorrelated noise and clutter. As discussed previously, the MTI hit count threshold is automatically varied from 9 to 20 depending on the degree of pulse-to-pulse clutter correlation. However, comparison of the curves in Figure 4-30 for a given miss count threshold indicate that the interference suppression benefits of the (9, 4) hit/miss count threshold parameter combination should at least be realized over the lower hit count threshold values in the 9 to 20 range. If the tangential slope of the curve that represents the initial hit count threshold is low, the tangential slope of the curves which represent higher hit count thresholds will also be low.

FAA's NAFEC (National Aviation Facility Experimental Center) completed an evaluation of the ARTS-IIIA/RDAS performance at the end of 1978. Based on their measurements, they are recommending (23, 9, 3) rank/hit/miss detection threshold RDAS parameter settings for operational ARTS-IIIA's in the field.

Second Order Interference Effects

This section addresses the possible interference effects on the ARTS-IIIA/RDAS channel (normal or MTI) video select and MTI channel target hit count threshold controls. As discussed previously, the ARTS-IIIA/RDAS automatically selects normal radar channel video in zero or light clutter conditions, and MTI radar video in heavy clutter conditions. In addition, the MTI hit count threshold is adjusted to maintain a constant false alarm rate in pulse-to-pulse correlated clutter. The RDAS estimates the level of clutter by counting the normal channel isolated hits and the clutter correlation by counting the MTI channel isolated hits. An isolated clutter hit is defined as a clutter hit (logical 1) preceded and followed by a miss (logical 0) on adjacent ACP's.

Interference Effect on Clutter Hit Probability

A rank quantizer threshold of 17 is employed in the RDAS hit processing logic (see Figure 4-4) for generation of a clutter hit. This implies that the clutter level in the rank quantizer cell of interest must equal or exceed 17 or more of the 24 comparison range bins before a clutter hit is generated. Substituting 17 for RQT in Equation 4-5 gives a clutter hit probability of 0.32. Equation 4-6 can be used to determine the effect of interference on clutter hit probability by substituting 17 for RQT:

$$P_{i1}(17) = \left\{0.68\left[N\left(1-e^{-X_1\nu}\right)-1\right]+1\right\} e^{-NX_{17}\nu} \qquad (4\text{-}20)$$

The variable X_{23} in Equation 4-6 was changed to X_{17} in Equation 4-20 to indicate that the equation is for a rank quantizer threshold of 17. The variable X_{17} in Equation 4-20 is given by:

$$X_{17} = \begin{cases} 0 & \text{for } \tau_i < 6\ RB_w \\ 2(\tau_i - RB_H) & \text{for } \tau_i > 6\ RB_w \end{cases} \qquad (4\text{-}21)$$

where

τ_i = Interfering radar pulse width, in μs

RB_H = Victim radar range bin hold time (0.468 μs for ASR-7 and 0.300 μs for ASR-8)

RB_W = Victim radar range bin width (0.625 μs for ASR-7 and 0.467 μs for the ASR-8)

It is evident from Equation 4-21 that X_{17} is zero for an ASR-7 victim radar if the interfering radar pulse width is less than 3.75 μs. Similarly, X_{17} is zero for the ASR-8 as a victim radar if the interfering radar pulse width is less than 2.8 μs. The only radar considered in the analysis that has a pulse width greater than these two values is the WSR-57 (4.0 μs pulse width mode). Therefore, all interfering radars considered in the analysis have a zero X_{17} value except the WSR-57. From Equation 4-21, the value of X_{17} for the WSR-57 interfering with the ASR-7 is 7.064×10^{-6} and for the ASR-8, 7.40×10^{-6}. The variable X_1 in Equation 4-20 is independent of rank quantizer threshold and is given by Equation 4-2. The value of X_1 for various interfering and victim radar combinations is shown in TABLE 4-1. Equation 4-20 with appropriate values of X_1 and X_{17} substituted was used to compute the effect of interference on clutter hit probability for various interfering and victim radar combinations. The results of these calculations are shown in TABLE 4-17. The probability of clutter hit for normal and MTI channel are shown for three continually interfering radars of the same type. Therefore, a ν value equal to three times the interfering radar PRF was used in Equation 4-20 for the calculations. A value of 3 for N was used in Equation 4-20 to compute MTI channel clutter hit probability and a value of 1 for normal channel clutter hit probability.

Interference Effect on Video Selection Control

The RDAS radar micro controller maintains a count of the normal channel isolated clutter hits in each 32 Range Bins (RB) by 32 Azimuth Change Pulse (ACP) zone, and compares this sum with a clutter map threshold (typically 166). If the Isolated Hit Sum (IHS) for the zone exceeds the map threshold, the clutter count parameter is incremented by 1. If the IHS for the zone is less than the clutter map threshold, the clutter count parameter is decremented by 1. Normal channel is selected if the clutter count parameter is less than or equal to 7; otherwise the MTI channel is selected.

The probability of a normal channel isolated clutter hit (010 hit/miss sequence) occurring is given by:

$$P_N(ICH) = P_{i1}(1-P_{i1})^2 \qquad (4-22)$$

TABLE 4-17

ARTS-IIIA/RDAS PROBABILITY OF CLUTTER HIT WHEN CONNECTED TO VICTIM RADAR THAT IS RECEIVING INTERFERENCE FROM THREE RADARS OF THE SAME TYPE

VICTIM RADAR	INTERFERING RADAR	INTERFERING PULSE ARRIVAL RATE (PULSES/SEC)	PROBABILITY OF CLUTTER HIT P_{c1} (NORMAL CHANNEL)	PROBABILITY OF CLUTTER HIT P_{c1} (MTI CHANNEL)
ASR-7	ASR-7	3006	0.32192	0.32575
ASR-7	ASR-8	3120	0.32160	0.32481
ASR-7	AN/CPN-4	3576	0.32159	0.32478
ASR-7	AN/FPS-90	1068	0.32156	0.32469
ASR-7	WSR-57	498	0.31888	0.31664
ASR-8	ASR-7	3006	0.32204	0.32612
ASR-8	ASR-8	3120	0.32162	0.32487
ASR-8	AN/CPN-4	3576	0.32162	0.32485
ASR-8	AN/FPS-90	1068	0.32000	0.32000
ASR-8	WSR-57	498	0.31882	0.31648

NOTE: PROBABILITY OF CLUTTER HIT WITHOUT INTERFERENCE = 0.32000 where P_{i1} is the probability of a clutter hit caused by interference and defined by Equation 4-20. Each of the 1024 range-azimuth bins in the 32 RB by 32 ACP clutter zone has an isolated clutter hit probability given by Equation 4-22. The isolated hit sum for the zone is the sum of 1024 (32^2) binary random variables and therefore has a binomial distribution given by:

$$P_N(IHS=K) = \binom{1024}{K} [P_N(ICH)]^K [1-P_N(ICH)]^{1024-K} \qquad (4\text{-}23)$$

where K is the sum of isolated hits in the clutter zone. Substituting Equation 4-22 for $P_N(ICH)$ in Equation 4-23 gives:

$$P_N(IHS=K) = \binom{1024}{K} [P_{i1}(1-P_{i1})][1-P_{i1}(1-P_{i1})]^{1024-K} \qquad (4\text{-}24)$$

The probability of the zone IHS equaling or exceeding the clutter map threshold (166) and causing the clutter count parameter to be incremented by 1 is therefore given by:

$$P_{UP} = \sum_{K=166}^{1024} \binom{1024}{K} [P_{i1}(1-P_{i1})]^K [1-P_{i1}(1-P_{i1})]^{1024-K} \qquad (4\text{-}25)$$

The probability of the zone IHS being less than the clutter map threshold, and causing the clutter count parameter to be decremented by 1 is:

$$P_{DOWN} = \sum_{K=0}^{165} \binom{1024}{K} [P_{i1}(1-P_{i1})]^K [1-P_{i1}(1-P_{i1})]^{1024-K} \qquad (4\text{-}26)$$

Since the number of samples (1024) is large, $1024 \times [1-P_{i1}(1-P_{i1})] >> 5$, the binomial distribution can be closely approximated by a normal distribution with a standardized variable given by:

$$Z = \frac{IHS-\overline{IHS}_N}{\sigma_N} \qquad (4\text{-}27)$$

The symbol IHS is the mean isolated clutter hit sum for the binomial distribution and is given by:

$$\overline{IHS}_N = 1024[P_{i1}(1-P_{i1})^2] \quad (4\text{-}28)$$

The σ_N in Equation 4-27 is the standard deviation of the normal distribution and given by:

$$\sigma_N = 1024[P_{i1}(1-P_{i1})^2][1-P_{i1}(1-P_{i1})^2] \quad (4\text{-}29)$$

The approximation of Equations 4-25 and 4-26 by the normal distribution with standardized variable Z is:

$$P_{UP} = \frac{1}{\sqrt{2\pi}} \int_{Z_1}^{Z_2} e^{-Z^2/2} = ERF(Z_2)-ERF(Z_1) \quad (4\text{-}30)$$

$$P_{DOWN} = \frac{1}{\sqrt{2\pi}} \int_{0}^{Z_3} e^{-Z^2/2} dZ = ERF(Z_3) \quad (4\text{-}31)$$

where $Z_1 = (166-\overline{IHS}_N)/\sigma_N$, $Z_2 = (1024-\overline{IHS}_N)/\sigma_N$, and $Z_3 = (165-\overline{IHS}_N)/\sigma_N$. The ERF symbol in Equations 4-30 and 4-31 represents the mathematical error function associated with the normal distribution and can readily be evaluated from probability tables (Ng, 1977).

The maximum (0.32204) and minimum (0.31882) clutter hit probability for interference and clutter hit probability for no interference (0.3200) listed in TABLE 4-17 were related to the probability of clutter parameter change by Equations 4-30 through 4-31. The results of these calculations are shown in TABLE 4-18. The first two columns of the table describes the probability of clutter hits extracted from TABLE 4-17. The last four columns, from left to right, indicate the results of evaluating Equations 4-28, 4-29, 4-30, and 4-31. From the last two columns, it is evident that the difference in the

TABLE 4-18

ARTS-IIIA/RDAS PROBABILITY OF CLUTTER PARAMETER DECREMENT AND INCREMENT DUE TO INTERFERENCE EFFECT ON NORMAL CHANNEL CLUTTER HITS

TABLE 4-13 CLUTTER HIT CHARACTERISTICS	PROBABILITY OF NORMAL CHANNEL CLUTTER HIT (P_{i1})	MEAN ISOLATED CLUTTER HIT SUM ($\overline{IHS}_M$)	STD. DEV. OF ISOLATED CLUTTER HIT SUM (σ_N)	PROBABILITY OF CLUTTER PARAMETER DECREMENT (P_{DOWN})	PROBABILITY OF CLUTTER PARAMETER INCREMENT (P_{UP})
NO INTERFERENCE	0.32000	151.51923	11.36218	0.3830	0.6170
MAXIMUM DUE TO INTERFERENCE	0.32204	151.56879	11.36372	0.3810	0.6190
MINIMUM DUE TO INTERFERENCE	0.31882	151.48488	11.36112	0.3815	0.6185

TABLE 4-19

ARTS-IIIA/RDAS PROBABILITY OF MTI HIT COUNT THRESHOLD AND SLIDING WINDOW ISOLATED HIT SUM CHANGE DUE TO INTERFERENCE

TABLE 4-3 CLUTTER HIT CHARACTERISTICS	PROBABILITY OF MTI CHANNEL CLUTTER HIT (P_{i1})	MEAN ISOLATED CLUTTER HIT SUM ($\overline{IHS}_M$)	STD. DEV. OF ISOLATED CLUTTER HIT SUM (σ_M)	PROBATILITY OF HIT COUNT THRESH. CHANGE BY 1 OR MORE	PROBABILITY OF ISOLATED HIT SUM CHANGE BY 1 OR MORE
NO INTERFERENCE	0.32000	96.97231	9.36958	————	————
MAXIMUM DUE TO INTERFERENCE	0.32617	97.05650	9.37322	$< 10^{-18}$	0.01351
MINIMUM DUE TO INTERFERENCE	0.31648	96.90109	9.36650	$< 10^{-18}$	0.01243

probability of a clutter parameter being changed (incremented or decremented) due to interference is no greater than 0.002. This implies that 500 antenna rotations would occur before a clutter parameter is changed in a particular clutter zone due to interference. It is therefore concluded that continuous interference from three radars would not have a significant degradation effect on automatic video selection control.

Interference Effect on MTI Channel Hit Count Threshold Control

The RDAS radar micro controller maintains a count of radar MTI channel isolated clutter hits in a sliding 32 RB by 32 ACP window. The MTI channel target hit count threshold is adjusted every ACP based on the current isolated hit count sum of the sliding window. The adjusted value of the MTI hit count threshold as a function of the sliding window isolated clutter hit sum is shown in Figure 4-7. Basically, the MTI hit count threshold is increased for high pulse-to-pulse correlation which is characterized by low isolated clutter hit sums.

The probability of a MTI channel isolated clutter hit (010 hit/miss sequence) occurring for correlated clutter can be derived using Discrete Time Markov Chain probability theory (Barnes, 1975). The resulting equation is given by:

$$P_M(ICH) = P_{il}(1-P_{il})^2(1-r)^2 \qquad (4-32)$$

where P_{il} is the probability of a single clutter hit caused by interference, and defined by Equation 4-20. The symbol r in Equation 4-32 depicts the pulse-to-pulse correlation of the clutter. There is a probability of an isolated clutter hit occurring in each of the 1024 range-azimuth bins in the 32 RB by 32 ACP sliding window. Therefore, the isolated clutter hit sum for the sliding window is the sum of 1024 binary random variables, and is defined by the binomial distribution:

$$P_M(IHS=K) = \binom{1024}{K} [P_M(ICH)]^K[1-P_M(ICH)]^{1024-K} \qquad (4-33)$$

where K is the sum of the isolated hits in the sliding window. Substituting Equation 4-32 for $P_M(ICH)$ in Equation 4-33 gives

$$P_M(IHS=K) = \binom{1024}{K} [P_{il}(1-P_{il})^2(1-r)^2]^K[1-P_{il}(1-P_{il})^2(1-r)^2]^{1024-K} \qquad (4-34)$$

The mean isolated hit sum for the binomial distribution is:

$$\overline{IHS}_M = 1024[P_{i1}(1-P_{i1})^2(1-r)^2] \tag{4-35}$$

and standard deviation:

$$\sigma_M = 1024[P_{i1}(1-P_{i1})^2(1-r)^2][1-P_{i1}(1-P_{i1})^2(1-r)^2] \tag{4-36}$$

Since the number of trials (1024) is large, $1024 \times P_{i1}(1-P_{i1})^2(1-r)^2 \gg 5$, and $1024 \times [1-P_{i1}(1-P_{i1})^2 (1-r)^2] \gg 5$, the binomial distribution can be approximated by a normal distribution.

The normal distribution approximation to the binomial distribution can be employed to determine the probability of interference increasing the IHS by a sufficient amount to result in a MTI hit count threshold change. If IHS_i and IHS_o represent sample sliding window isolated hit sums with and without interference, respectively, the distribution of their difference can be closely approximated by a normal distribution. This is possible because the IHS_i and IHS_o samples are normally distributed and their population standard deviations are known exactly (computed from Equation 4-36). The standard variable for the normal distribution which describes the IHS sample difference is given by (Natrella, 1963):

$$Z = \frac{(IHS_i - IHS_o) - (\overline{IHS}_{Mi} - \overline{IHS}_{Mo})}{\frac{1}{N}(\sigma^2_{Mi} + \sigma^2_{Mo})^{1/2}} \tag{4-37}$$

where

IHS_i = the sample isolated hit sum with interference

IHS_o = the sample isolated hit sum mean without interference

IHS_{Mi} = the actual isolated hit sum mean with interference computed from Equation 4-35

IHS_{Mo} = the actual isolated hit sum mean without interference computed by Equation 4-35

σ_{Mi} = the actual isolated hit sum standard deviation with interference computed by Equation 4-36

σ_{Mo} = the actual isolated hit sum standard deviation without interference computed by Equation 4-36

N = the number of samples (1024 in this analysis)

The probability of the difference, between the isolated hit sum with and without interference, exceeding a particular value Z is given by the integral:

$$P(\Delta IHS>Z_1) = \frac{1}{\sqrt{2\pi}} \int_{Z_1}^{\infty} e^{-Z^2/2}\, dZ = 0.5-ERF(Z_1) \qquad (4-38)$$

where

Δ IHS = difference between isolated hit sums in sliding window (IHS_i - IHS_o) with and without interference

ERF(Z) = mathematical error function that can be readily evaluated from probability tables

Z_1 = value of standard normal variable (Z) from evaluation of Equation 4-37

Similarly, the probability of the difference (ΔIHS) being less than a particular value Z_2 is given by:

$$P(\Delta IHS<Z_2) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z_2} e^{-Z^2/2}\, dZ = 0.5+ERF(Z_2) \qquad (4-39)$$

The maximum (0.32617) and minimum (0.31648) clutter hit probability for interference and clutter hit probability for no interference (listed in TABLE 4-17 for the MTI channel) were related to the mean and standard deviation of the isolated clutter hit sum by Equations 4-35 and 4-36. The results of these calculations are indicated in the third and fourth columns of TABLE 4-19. A clutter correlation coefficient (r) of 0.2 was assumed for the calculation because this value gives a typical isolated hit sum of 96.97 (see Figure 4-7). The probability of worst-case interference increasing the isolated hit sum enough to cause a hit count threshold decrease was computed from Equations 4-37 and 4-38, and the result is indicated in TABLE 4-19 (second row, fifth column). The isolated hit sum mean and standard deviation listed in the third and fourth columns of TABLE 4-19 were used in this calculation. In particular, the mean and standard deviation associated with no interference and maximum clutter hit probabilities due to interference, were used to calculate Z_1 in Equation 4-37. This combination resulted in the greatest (worst-case) probability of interference decreasing the MTI hit count threshold.

The probability of worst-case interference decreasing the isolated hit sum enough to cause a hit count threshold increase was computed from Equations 4-37 and 4-39, and the result is indicated in the bottom of the fifth column of TABLE 4-19. The isolated hit sum statistical parameters (mean and standard deviation listed in columns three and four of TABLE 4-19) that correspond to no interference, and minimum clutter hit probabilities due to interference, were used to calculate Z in Equation 4-37. This combination of values resulted in the greatest (worst-case) probability of interference increasing the MTI hit count thereshold.

An isolated hit sum difference (IHS_i-IHS_o) value of 5.333 was used in the above calculations (Equation 4-37) to represent a MTI channel hit count threshold change of 1. It is evident from Figure 4-7 that the MTI hit count threshold changes by 1 for each sliding window isolated hit sum change of 10.66. However, it is likely that the hit sum sample value without interference is closer to the point required for a hit count threshold change than 10.66. For this reason, a median value of 5.333 was chosen for the analysis.

The probability of interference causing the sliding window isolated hit sum to change by 1 was also computed from Equations 4-35, 4-36, 4-37, 4-38, and 4-39 by setting (IHS_i-IHS_o) in Equation 4-37 to 1. The results of these calculations are indicated in the last column of TABLE 4-19. It is evident from the above probability calculations and TABLE 4-19 that continual interference from three radars will not have a significant degradation effect on RDAS automatic MTI hit count threshold control. The probability of interference causing the MTI hit count threshold to change by 1 or more is less then 10^{-18}. In addition, the probability of interference causing the sliding window isolated hit sum count to change by only 1 or more is less than 0.01243.