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SPECIAL EMC AND DEGRADATION MEASUREMENTS ON THE AN/SPS-55 RADAR--ETC(U)

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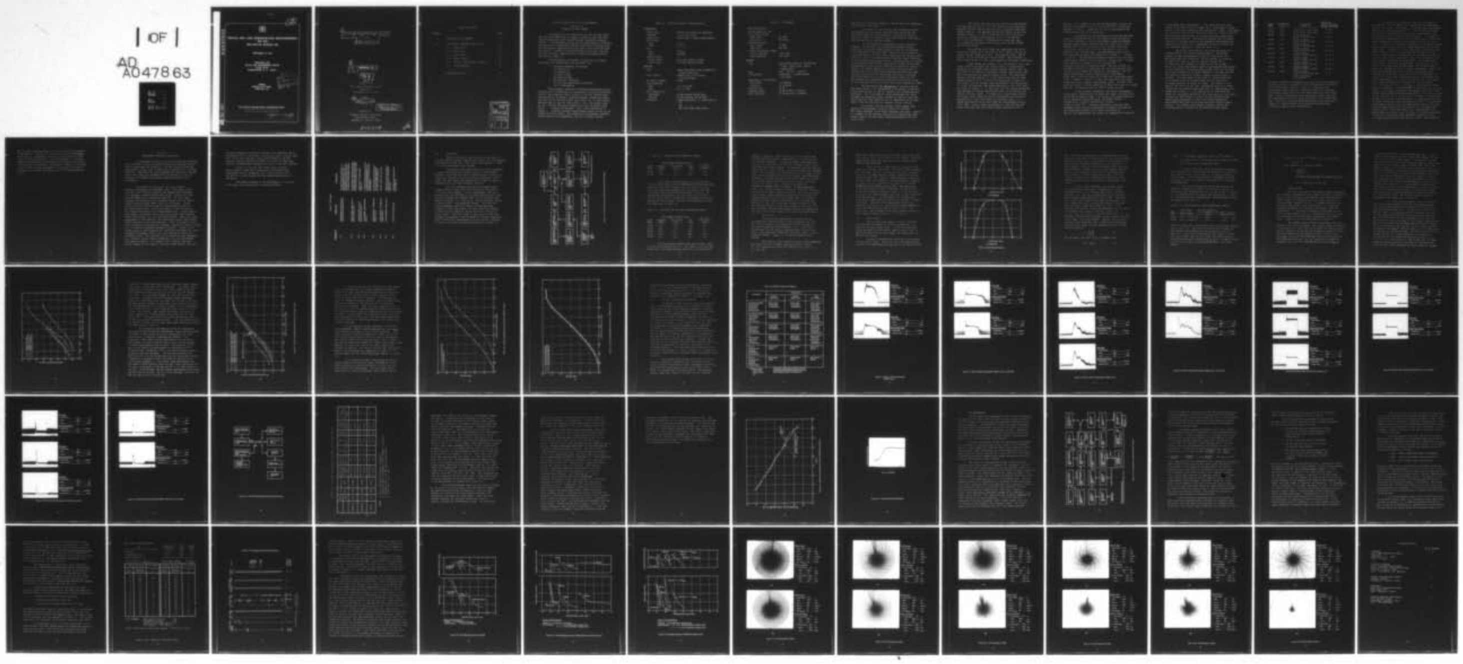

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SEPTEMBER 23, 1977

PREPARED FOR:
NAVAL SHIP ENGINEERING CENTER
CODE 6174D
WASHINGTON, D. C. 20362

UNDER:
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TASK NO. 22

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AN/SPS-55 RADAR SPECIAL EMC MEASUREMENTS

SECTION 1.0
INTRODUCTION AND SUMMARY

The purpose of this task was to provide measured equipment and performance data to support current and near-term ship topside design activities and performance degradation modeling efforts. The measurement results are also applicable to evaluation and solution of interference problems found aboard existing ships. The measurements reported herein were made on the AN/SPS-55 Radar Set, Serial 2, located in the ET"C" School at the Naval Station, Norfolk, Virginia. Nominal AN/SPS-55 Radar Set characteristics are listed in Table 1-1.

The measurements performed, divided into two general categories, are summarized in the following list.

1. Equipment Reference Performance
   (a) Sensitivity
   (b) Selectivity
   (c) Noise Figure
   (d) Dynamic Range
2. Interference Validation
   (a) Off-Tune Interference Validation
   (b) PPI Degradation

The equipment reference performance measurements provide information for correlating the interference validation measurement results, one to another and to compare to existing measured data. The sensitivity and dynamic range measurements include the characteristics at two receiver output test points; (1) IF output before detection and (2) the PPI video output. Also, the dynamic range was measured with the output taken at the first available video test point following the detector. Test signal modulations included representative shipboard interference signals as well as the nominal AN/SPS-55 values. The selectivity measurements, combined with CW sensitivity measurements with the IF output response

Table 1-1. AN/SPS-55 Nominal Characteristics.

Transmitter	
Power Output	130 kW peak minimum at magnetron
Frequency	9.05 to 10.00 GHz
Tuning Rate	Across band, 1 minute approximately
Pulse Width	
Long	1.0 μs
Short	0.12 μs
PRF	
Long	750 pps
Short	2250 pps
Sector Radiate	
Sector width	10 to 180 degrees azimuth
Sector start	0 to 360 degrees azimuth
Receiver	
Type	Image-suppression mixer preamplifier, single conversion
Noise Figure	Antenna port of circulator, 10.0 dB maximum
IF Center Frequency	60 MHz
Pulse Bandwidth	
Long	1.2 ± 0.25 MHz
Short	10 ± 1.0 MHz
Skirt Selectivity	
Narrowband	20 MHz maximum (80 dB down)
Wideband	200 MHz maximum (80 dB down)
Processors	Linear/Logarithmic IF, Logarithmic IF STC FTC MBS (Main-bang suppression)

Table 1-1 (Continued)

Receiver (Con't.)	
Minimum Range for One-Square Meter Target	
Short Pulse	50 yards
Long Pulse	200 yards
Resolution Range	
Short Pulse	75 feet
Long Pulse	550 feet
Minimum Discernible Signal	
Narrow bandwidth	-102.2 dBm
Wide bandwidth	-93.0 dBm
Antenna	
Type	Back-to-back end-fed, slotted wave-guide, linear array, squint compensated
Scan	Rate: 16 rpm ± 1 rpm CW
Polarization	Selectable: Circular/linear-horizontal
Beamwidth, At 3-dB points	
Horizontal	1.5 degrees
Vertical	20.0 degrees
Absolute Gain	31 dB
Sidelobe level	27 dB within ± 5 degrees
Below main lobe	30 dB outside ± 5 degrees

monitored on a true RMS voltmeter, provided data for evaluating the receiver noise figure.

The purpose of the off-tune interference validation measurements was to provide information for validating the existing NAVSEC Ship Electromagnetic Compatibility Analysis, Microwave, Number 1 (SEMCAM 1) data file currently being used in ship topside design computer programs.

The PPI degradation measurements have a threefold purpose. In each case, the measurements consider signals applied at the receiver input (desired, then desired combined with interference) and the effect produced on the information extraction device - in this case, a plan position indicator (PPI); AN/SPA-25. The first purpose employed problem inputs resulting from ship topside design activities. The test effort was limited to those interference sources predicted to produce the greatest interference-to-noise ratios (INR's) at the AN/SPS-55 receiver IF output. The second purpose was to gather additional data to validate the NAVSEC interference degradation prediction model developed during previous measurement and analysis programs. The third purpose was to provide additional samples of PPI observations for expanding the measured data base which serves as the foundation for the existing search radar degradation model.

The terminology PPI degradation is derived from the end-result effect, i.e., degradation in the ability to detect a given target display on the PPI caused by the interference presentation. This is an overall system operational test which includes any degrading effects between the receiver input terminals and PPI video output as well as degradation which might occur in the PPI unit and plus operator response effects.

The results from the minimum visible signal (MVS) sensitivity measurement, listed in Table 2-2, validate the values contained in the NAVSEC equipment data base. Table 2-3 is a summary of the receiver sensitivity to desired and interfering signals with the output response monitored on the PPI (range ring).

The results from the receiver selectivity measurements are summarized in Figure 2-2 for the receiver wide pulse/narrow bandwidth (WP/NB) mode (a) and the narrow pulse/wide bandwidth (NP/WB) mode (b). The measured selectivity values, at the 3-dB bandwidth points, 1.07 MHz in WP/NB and 10.4 MHz in NP/WB are within the equipment specifications of 1.2 ± 0.25 MHz and 10 ± 1 MHz, respectively. Effective noise bandwidths (B_N), calculated from the selectivity curves, were 1.08 MHz (WP/NB) and 12.3 MHz (NP/WB).

The receiver noise figure was calculated from the CW sensitivity values, for 3-dB S+N/N at the IF output, and the B_N values from the selectivity test. The resulting noise figures were 9.1 dB for WP/NB and 10.0 dB for NP/WB. The difference in noise figure values (0.9 dB) is attributed to measurement uncertainty.

Three output test points, TP-3, TP-4 and TP-5, test video output (J26) on the Radar Set Control Panel, IF output before detection (J2 on WB/NB Filter Assembly 2A3A18) and PPI video output (J19) on the Receiver-Transmitter Cabinet, respectively, were used for measuring the receiver dynamic range. The measurement results, with the receiver IF in the LIN/LOG mode and the video output monitored at TP-3 and TP-5 are summarized in Figure 2-3. The results from the dynamic range measurements with the receiver IF in the LOG mode and video output monitored at TP-5 (PPI video) are shown in Figure 2-4. In this case, the test signal modulations were expanded to include interfering signals in addition to the nominal received signals. For analysis of interference effects, the signal levels (both desired and interference) are generally expressed as a ratio with respect to the noise level, i.e., signal (desired) to noise ratio (SNR) and interference-to-noise ratio (INR). Dynamic range measurements to yield SNR and INR values were made with the receiver output monitored at TP-4.

Figure 2-5 is a summary of the SNR/INR measurement results with the receiver operated in the WP/NB mode and LOG IF processing selected. Figure 2-6 summarizes the SNR/INR measurements for NP/WB operation and LOG IF processing.

Oscilloscope display photographs showing the amplitude versus time characteristics of the detected pulse envelope at TP-3 were obtained as a part of the dynamic range measurements. Selected signal levels, starting from the lowest (mid) interference level and incremented up to the maximum (saturated) interference levels used in the PPI degradation tests, were applied to the receiver input. The measurement results with WP/NB receiver operation are summarized in Figure 2-7. Figures 2-8 and 2-9 show the detected pulse characteristics with interference pulse widths of 0.3 μs and 16 μs, respectively. In each case (Figures 2-7 through 2-9), the receiver was operated in the LOG IF processing mode. When the receiver is switched to LIN/LOG IF processing, the fast time constant (FTC) circuit is also placed into operation. Consequently, the FTC action discriminates against long-duration interference pulses and, in the end result (PPI video) the interference pulse width is reduced. Figure 2-10 shows the resulting video output signal from a 16-μs pulsed interference signal. The test conditions for Figure 2-10 were identical to those for Figure 2-9 except that the IF processing mode was LIN/LOG rather than LOG.

In the off-tune interference validation measurements, a test pulse, simulating an off-tune radar signal, was applied at the AN/SPS-55 receiver input. The level of the interference was set to selected values provided by the NAVSEC SEMCAM 1 procedure for a typical interference situation (shown in Table 2-5). Frequency separations (receiver tuned frequency versus off-tune interference frequency) required for the interference effects to be barely perceptible on the PPI were measured and the results are summarized in Table 2-6.

In performing these measurements, it was noted that the interference pulse width could be changed over a large range of values without a noticeable change in the interference display. This effect was expected, since the off-tune pulse energy is a function of the pulse risetime and falltime, at a given amplitude, rather than mid-pulse time duration. The emission spectrum roll-off characteristics of the test pulse for the validation measurements are summarized in Figure 2-12. A photograph of the test pulse risetime (detected envelope) is shown in Figure 2-13.

The primary test effort in this task assignment was concentrated on PPI degradation measurements. The central element in these measurements was the PPI trial where, for pre-established test conditions, the PPI operator is given up to twenty PPI scans to locate a simulated target return at fixed location, selected at random, on the PPI screen. Thirty PPI trials were made for each of the selected combinations of test conditions, this group being called a PPI run, to yield statistical information on target detection. The data from the PPI runs were analyzed to obtain a summary in three areas of interest: (1) mean number of PPI scans for target detection, (2) standard deviation of mean number and (3) probability of target detection in twenty PPI scans. The results of the analysis for forty-two PPI runs, considering cases of no interference and with selected types and levels of interference, are summarized in Table 2-7. The compilation of individual data sheets was considered unnecessary for presentation in this report. Instead, the data summary is given with the individual data sheets being maintained on file in the NAVSEC degradation measurements data base for on-going and future analysis applications. The selected interference situations covered the following areas of interest in the respective radar modes:

RADAR MODE	INTERFERENCE LEVEL	INTERFERENCE SOURCE	NUMBER OF MEAN SCANS FOR TARGET DETECTION
WP/NB	HIGH	LN-66 Radar, Long Pulse	H, M, L
WP/NB	MID	LN-66 Radar, Long Pulse	H, M, L
NP/WB	HIGH	AN/SPQ-9 Radar, (Long Pulse) Max PRF	H, M, L
NP/WB	HIGH	AN/SPQ-9 Radar, (Long Pulse) 1/3 PRF	H, M, L
NP/WB	MID	AN/SPQ-9 Radar, (Long Pulse) Max PRF	H, M, L
NP/WB	MID	AN/SPQ-9 Radar, (Long Pulse) 1/3 PRF	H, M, L
NP/WB	HIGH	AN/SPQ-9 Radar, (Short Pulse), Max PRF	H, M, L
NP/WB	HIGH	AN/SPQ-9 Radar, (Short Pulse), 1/3 PRF	H, M, L
NP/WB	MID	AN/SPQ-9 Radar, (Short Pulse), Max PRF	H, M, L
NP/WB	MID	AN/SPQ-9 Radar, (Short Pulse), 1/3 PRF	H, M, L
NP/WB	HIGH	AN/SPQ-9 Radar (Short Pulse) @ Max PRF Plus LN-66 Radar (Long Pulse)	H, L

The data in the PPI run summaries are, for most of the situations measured, plotted in graphical form to afford easier comparison of the interference effects. Figure 2-16 summarizes the measurement results for high (saturation point) and mid-range interfering signal levels with the radar operating in the SP/NB mode. Several interfering signal modulations (pulse width and PRF combinations) were used for measurements in the NP/WB radar mode. The results from the NP/WB measurements are summarized in Figures 2-17 and 2-18 for high (saturating) and mid-range interfering signal levels, respectively.

The effects of interference upon the PPI detection performance, i.e., PPI degradation, based upon the measurement summaries in Figures 2-16 through 2-18, ranged from considerable down to just noticeable degradation. These results show that the amount of PPI degradation is primarily a function of the duty cycle and level of the interfering siganl. In Figure 2-16, the amount of degradation from either signal level is relatively small because the interfering signal duty cycle is low, i.e., 0.0005. However, the saturating interfering signal level requires higher desired signal levels for target detection than the mid-range level. In Figure 2-17, the interfering signal having the highest duty cycle (16-μs pulse width at 2987-pps PRF; duty cycle = 0.048) produces considerable PPI degradation because the desired signal levels, compared to the no interference levels, for comparable detection are much higher. In the remaining three curves, the amount of degradation diminishes as the duty cycle of the interfering decrease until, at the lowest duty cycle, the degradation effect is barely noticeable. Figure 2-18 (mid-level interference) shows effects from changing the interfering signal duty cycle similar to those described for Figure 2-17 (saturating interference level). The highest duty cycle interference (16-μs pulse width at 2987 pps) was noticed to be range-dependent so two separate PPI runs were made; (1) $R < 1/3\ R_{MAX}$ and (2) $R \geq 1/3\ R_{MAX}$ to illustrate the effect upon PPI detection. The displacement of the curves ($R < 1/3\ R_{MAX}$ versus $R \geq 1/3\ R_{MAX}$) illustrates that highest duty cycle interference causes poorer detection performance at the close-in ranges. In the remaining curves (Figure 2-18), the amount of degradation decreases as the duty cycle decreases. A comparison of the curve for each interfering signal modulation in Figure 2-17 (saturated interference level) to the same modulation in Figure 2-18 shows that the degradation effect decreases at the mid-range interference levels. The highest duty cycle interference (16-μs pulse width at 2987 pps) curve in Figure 2-17 would be expected to show the same type of range dependency measured for the mid-range interference at the same duty cycle. The pattern of the "railing" lines generated on the PPI may affect the degree of degradation. Figures 2-19 through 2-24 are PPI photographs which show the interference display for the majority of interference situations measured. In each photograph, a simulated target was generated at approximately 60 percent of the display maximum range at a bearing of 280 degrees. Though it is obvious in most of the original photographs, the target may be hard to distinguish here since some detail is lost in the reproduction process.

SECTION 2.0

MEASUREMENT PROCEDURES AND RESULTS

A considerable portion of the existing measured data base for the AN/SPS-55 radar set includes parameters measured with MIL-STD-449 techniques and procedures. The data resulting from the measurements in this task, in many cases, supplements the existing data base. Therefore, the test procedures and parameters outlined herein were based upon comparable MIL-STD-449 tests, as far as practical, to produce test results compatible with existing information.

Consistent test procedures were used, whenever possible, throughout the measurement task. Test signal levels injected to the AN/SPS-55 receiver and antenna were referenced to a secondary standard thermal power meter. Power levels were read and tabulated to the nearest tenth-dB. The test signal frequency was measured with a frequency counter with the readout value listed to greater than 1 part on 10^6 accuracy. Output signals from the AN/SPS-55 radar set were measured directly or by signal substitution. The direct method is preferred because this lessens the possibility of measurement error. Direct measurements employ instruments such as the oscilloscope, RMS voltmeter, thermal power meter, etc., as calibrated devices. Where the direct measurement was not practical, the alternative signal substitution method represents a two-step operation. First, the output is monitored with the spectrum analyzer frequency selective voltmeter (FSVM), etc., to obtain a reference response indication. Second, a calibrated signal is substituted to the responding instrument and signal parameters (frequency, level, etc.) are adjusted to regain the referenced value. The insertion loss of peripheral test componentt, e.g., filters, coaxial cable, attenuators, etc., was calibrated-out whenever possible. For example, with a coaxial cable and filter inserted at the output of the test signal source, the point for power reference is selected such that both components can be considered a part of the source. Furthermore, when a coaxial cable and a filter (or attenuator) were inserted ahead of the test receiver (spectrum analyzer or FSVM), the point for signal substitution included these components as a part of the test receiver.

Table 2-1 lists the test points used to measure sample outputs, inject test signals and for peripheral test requirements such as triggering, etc. The test point list includes the circuit location and measurement application for each point.

The general sequence of the measurements corresponded to the order in which each test is described herein.

TABLE 2-1. TEST POINTS.

DESIGNATOR	DESCRIPTION	APPLICATION
TP-1	ANTENNA PORT (WAVEGUIDE) OF CIRCULATOR DUPLEXER, 2A1HY1	RF INPUT PLANE OF REFERENCE FOR TEST SIGNALS INJECTION IN ALL MEASUREMENTS. COAXIAL INPUT WAS ACHIEVED THROUGH INSTALLATION OF COAXIAL TO WAVEGUIDE ADAPTER.
TP-2	TEST TRIGGER OUTPUT, J25, ON CONTROL PANEL, UNIT 2	SYSTEM TRIGGER FOR SYNCHRONIZING DESIRED SIGNAL GENERATOR TO RADAR PRF WHERE APPLICABLE DURING TESTS.
TP-3	TEST VIDEO OUTPUT, J26, ON CONTROL PANEL, UNIT 2	VIDEO OUTPUT FOR MEASURING SENSITIVITY.
TP-4	J2 ON ASSEMBLY 2A3A18, WB/NB FILTER	IF OUTPUT (60 MHz) BEFORE DETECTION FOR SNR, INR MEASUREMENTS AT IF, PLUS SELECTIVITY AND NOISE FIGURE MEASUREMENTS.
TP-5	J19 ON RECEIVER - TRANSMITTER CABINET, UNIT 2	PPI VIDEO OUTPUT FOR DRIVING PPI UNIT PLUS DYNAMIC RANGE, SNR, INR, AND MVS MEASUREMENTS.
TP-6	J15 ON RECEIVER - TRANSMITTER CABINET, UNIT 2	TRIGGER OUTPUT FED TO PPI UNIT.
TP-7	TP-4 ON ASSEMBLY 2A3A15, UNIT 2	SHM TRIGGER FOR SYNCHRONIZING SIMULATED TARGET TEST SIGNAL GENERATOR.
TP-8	DISPLAY CRT ON AN/SPA-25	PPI NOMINAL AND DEGRADATION MEASUREMENTS.

2.1 Sensitivity

Receiver sensitivity was measured at the start of the task and at intervals thereafter to verify that the receiver operation was normal while other tests were underway. Figure 2-1 is the measurement block diagram.

The receiver sensitivity serves as a basic parameter to which the results from several tests are interrelated. Therefore, more than one type of standard output response was needed for relating the variety of tests performed. In all cases, the test signal was injected at TP-1 and the radar was operated at the mid-band frequency; 9525 MHz.

The first standard response was minimum visible signal (MVS) as viewed on a test oscilloscope connected to TP-3 (test video output). In this measurement, the test signal source was modulated at the radar nominal pulse width and pulse repetition frequency (PRF) for the receiver mode being considered, i.e., wide pulse - narrow bandwidth (WP/NB) or narrow pulse - wide bandwidth (NP/WB). With the test signal frequency tuned to produce a maximum amplitude response at the video output, the test signal was adjusted to obtain an MVS output as seen on the test oscilloscope video display. The test signal RF input level in dBm, and frequency in megahertz, were measured for MVS data tabulation. The MVS sensitivity measurements with the receiver operated in the LOG IF processing mode are summarized in Table 2-2.

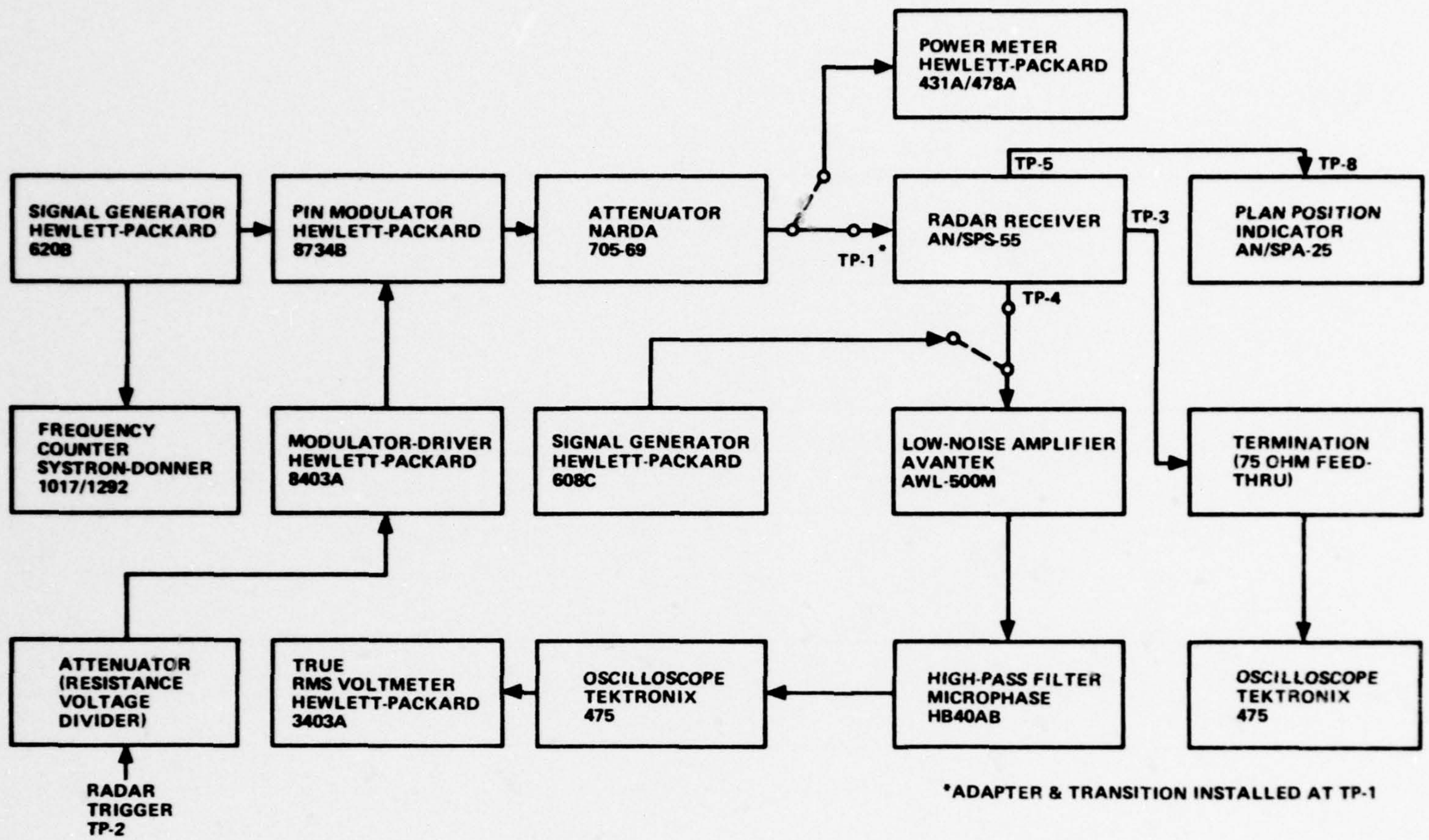


Figure 2-1. Nominal Receiver Parameters Measurement Block Diagram.

Table 2-2. RECEIVER MVS MEASUREMENT SUMMARY

	Test Signal Characteristics			
Radar Mode	Frequency (MHz)	Pulse Width (μs)	PRF (pps)	MVS Sensitivity (dBm)
WP/NB	9525	1.0	750	-107
NP/WB	9525	0.12	2250	-100

The second standard response was also minimum visible signal (MVS) except as measured at the plan position indicator video (PPIV) output from the radar set at TP-5. These sensitivity measurements are identified as PPIV MVS to prevent confusion with MVS measurements at TP-3. The measurement procedure was the same as described earlier for MVS except that the sensitivity to potential interference modulations was included. The PPIV MVS measurement results are summarized in Table 2-3.

Table 2-3. RECEIVER PPI VIDEO MVS MEASUREMENT SUMMARY

	Test Signal Charcteristics			
Radar Mode	Frequency (MHz)	Pulse Width (μS)	PRF (pps)	PPIV MVS Sensitivity (dBm)
WP/NB	9525	1.0	750	-107
WP/NB	9525	1.0	500	-107
NP/WB	9525	0.12	2250	-100
NP/WB	9525	0.3	2987	-104
NP/WB	9525	16.0	2987	-105

The third output response was the IF output signal-to noise ratio measured at TP-4. The output at TP-4 was measured with a true RMS voltmeter which has a 2 Hz-to-100 MHz frequency response. The noise level at TP-4 was below the minimum amplitude response (approximately 1.7 millivolts) of the true RMS voltmeter. A low-noise tunnel diode amplifier (LN TDA) was inserted at the true RMS voltmeter input to provide additional amplification. The bandwidth specification for the LN TDA is 0.001 to 500 MHz. An active probe (high impedance input - 50-ohm output) was inserted at the LN TDA input to minimize circuit loading at TP-4 from the output signal measuring equipment. With the addition of the active probe and LN TDA's the true RMS voltmeter reading was not a direct indication of the TP-4 signal level. A two-step procedure was employed to measure the TP-4 levels. At each measurement point, the true RMS voltmeter reading was noted for reference with the active probe connected to TP-4. Next, the calibrated output from a signal generator, terminated into 50 ohms, was signal-substituted to the active probe input. The signal generator output, tuned to the AN/SPS-55 IF of 60 MHz and adjusted in level for a true RMS voltmeter reading to match the reference value, was read and recorded as test data. The measured data using the third output response are reported in the selectivity, noise figure and dynamic range measurements.

2.2 Selectivity

The selectivity measurements provided data for evaluating the receiver effective noise bandwidth (B_N) and the receiver response at frequencies slightly removed from the radar fundamental tuned frequency (f_o). Selectivity was measured for two receiver operating modes; narrow pulse width - wide bandwidth (NP/WB) and wide pulse width - narrow bandwidth (WP/NB). Figure 2-1 is the measurement block diagram.

The receiver output standard response while measuring selectivity was an IF output signal plus noise-to-noise ($S_o + N_o$) equalling two times the reference (N_o) value, i.e., $S_o + N_o = 2N_o$.

Under this condition, the S_o power equals the N_o power and the signal-to-noise ratio (SNR) is unity (SNR=1). The test signal level (reference input level) and frequency were measured and tabulated.

Next, the test signal level was increased 3 dB above the reference input level. The test signal frequency was tuned away from f_o, first below then above, to points where the true RMS voltmeter reading equalled the on-tune value for unity SNR. The test signal frequency, measured at each point, was tabulated. This procedure was repeated, in steps, for test signal level increases of 6, 10 and 20 dB above the reference input level. The selectivity in the NP/WB mode was rather sharp and, because of local oscillator frequency variations (drift), it was necessary to measure the tuned frequency each time a given selectivity point was measured. This procedure, for the most part, successfully compensated for the local oscillator frequency variations. The selectivity measurement results are summarized in Figure 2-2. The WP/NB data were averaged to obtain the smooth curve shown in Figure 2-2(a). In both curves, the frequency points were computed relative to the on-tune frequency value, i.e., $\Delta f = f_x - f_o$.

2.3 Noise Figure

The receiver noise figure is a basic paramater indicative of the quality of receiver performance. In essence, the noise figure value describes the additional noise, generated in the receiver input circuits, that is amplified along with received signals for presentation at the receiver output.

Two basic techniques are available for measuring receiver noise figure. The first uses a calibrated source of excess wide bandwidth noise applied to the receiver front

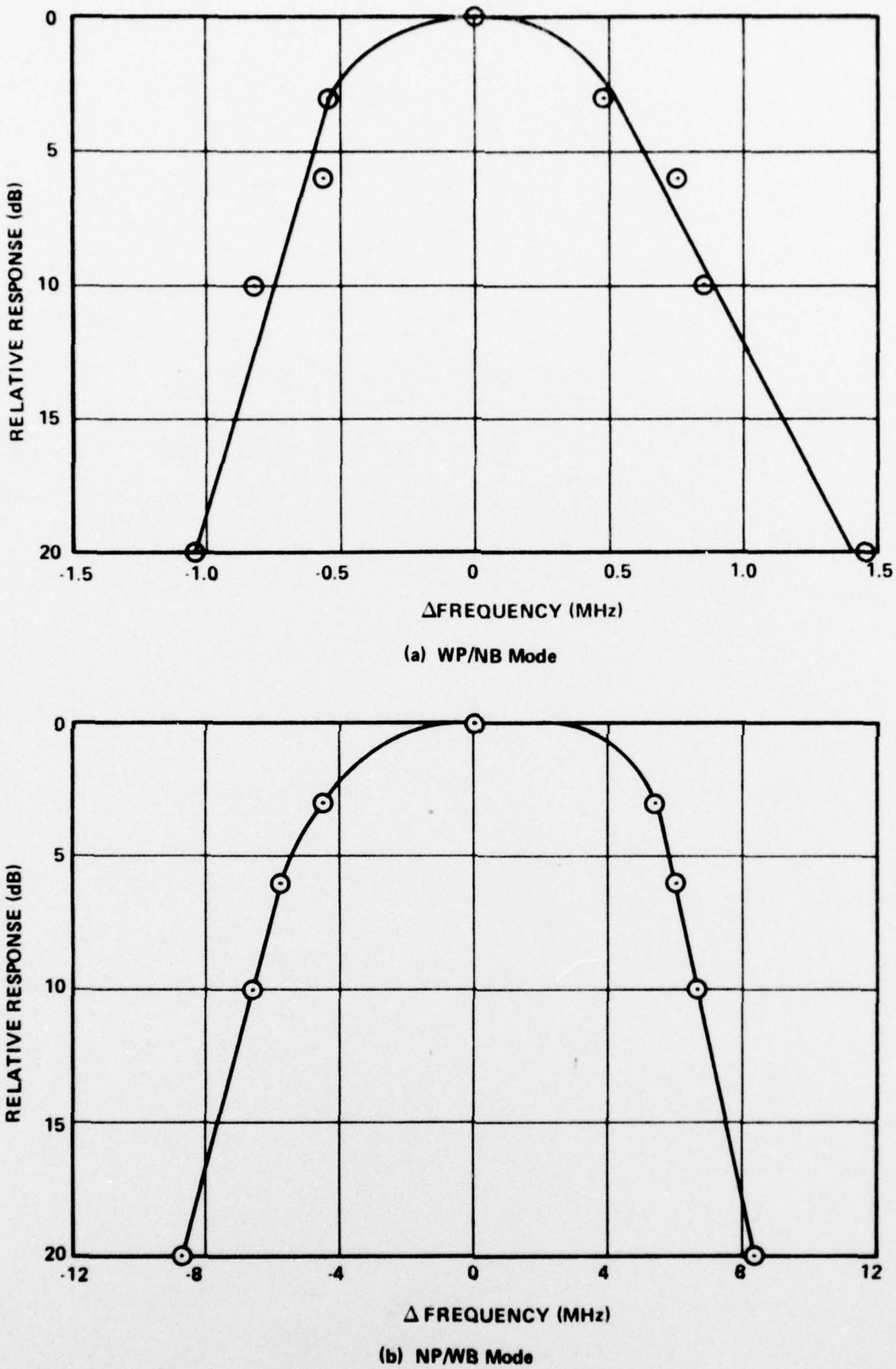


Figure 2-2. Receiver Selectivity Summary.

end. The receiver output noise is measured with the noise source off, then on, and a comparison of the results provide the noise figure value. This technique is advantageous in that receiver bandwidth information is not required. A disadvantage is that any receiver responses other than the tuned frequency response, e.g., receiver "image" response can add to the "signal" (in the form of wideband noise) being received. If the sensitivity to these "off-tune" response frequencies is comparable in magnitude to the tuned frequency response, an erroneous noise figure value results.

In the second technique, the receiver output (IF output before detection) is measured with a power responding device, e.g., thermal power meter, true RMS voltmeter, etc. The noise output power (N_o) is measured with no input signal applied to the receiver. Then the test signal (CW) is applied and tuned on-frequency. The test signal level (S_i) is adjusted to obtain a selected value of output signal-plus-noise ($S_o + N_o$). It is convenient to use an S_i value which obtains a $S_o + N_o$ value 3 dB greater (twice-power) than the N_o value, i.e., $S_o + N_o = 2N_o$, giving $S_o = N_o$ and the ratio $S_o/N_o = 1$. The advantage of the second technique is that off-tune responses to the input signal are excluded. However, the receiver effective noise bandwidth (B_N) is required for evaluating the noise input power (N_i) and computing the noise figure from the equation.

$$F = \frac{S_i/N_i}{S_o/N_o} \qquad (1)$$

With B_N known, the value of N_i is computed from

$$N_i = kT_oB_N \qquad (2)$$

where k = Boltzmann's constant, 1.38×10^{-23} Joules/°K

T_o = Temperature, ^oK (conventionally assumed as 293^oK)

B_N = Effective noise bandwidth, Hertz

In both of the noise figure measurement techniques just discussed, the receiver gain is assumed to be linear over the range of levels (excess noise or CW signal) required in the procedure. If the receiver gain is nonlinear, the measured noise figure is erroneous; in proportion to the amount of nonlinearity.

The second technique was chosen for measuring the AN/SPS-55 receiver noise figure. The receiver has two IF processing modes available for use; (1) LOG IF and (2) LIN/LOG IF. The measurements were made in the LIN/LOG mode. Figure 2-1 is the measurement block diagram. The measurement results are summarized in Table 2-4.

Table 2-4. RECEIVER NOISE FIGURE MEASUREMENT SUMMARY

Radar Mode	Test Signal Level, S_i (dBm)	Test Signal Level, S_i (Watts)	Receiver Effective Noise Bandwidth, B_N (MHz)	Noise Figure (Numerical)	Noise Figure (dB)
WP/NB	-104.5	3.55×10^{-14}	1.08	8.13	9.1
NP/WB	-93.0	5.00×10^{-13}	12.3	10.1	10.0

The test signal level listed in the table is the value required for $S_o + N_o = 2N_o$. The receiver effective noise bandwidth (B_N) values were obtained from the selectivity curves in Figure 2-2. Each curve was converted into a power relationship curve rather than dB (not shown) from which graphical integration procedures obtained the B_N value. A sample calculation for noise figure, using the NP/WB data in the table follows.

Given: $S_i = 5.00 \times 10^{-13}$ watts, $B_N = 12.3 \times 10^6$ Hz,

$S_o/N_o = 1$

With Equations (1) and (2) combined

$$F = \frac{S_i/KT_oB_N}{S_o/N_o}$$

$$= \frac{5.00\ (10^{-13})/1.38\ (10^{-23})\ (293)(12.3)(10^{-6})}{1}$$

$$= 10.1 \text{ (numerical) or } 10.0 \text{ dB}$$

2.4 Dynamic Range

The basic objective in the dynamic range measurements was to obtain information on the signal (desired or interfering) to noise ratio produced at the plan position indicator video (PPIV) output as a function of the RF signal level at the receiver input terminals (TP-1). A secondary objective was to measure the dynamic range characteristic as a reference equipment parameter for comparison to previous AN/SPS-55 measurements. As accessory information, photographs of the detected video output signal, as displayed on an oscilloscope, were obtained for selected input signal levels and modulations. Figure 2-1 is the measurement block diagram.

The dynamic range reference measurements were performed as the first test group. The receiver output was measured at two points TP-3 (test video on the Radar Set Control Panel) and TP-5 (PPIV at J19 on Receiver Transmitter Cabinet) with the receiver operating in the LIN/LOG IF mode. Two test runs were made, first with the WP/NB mode selected and second with the NP/WB mode selected. The test signal pulse modulation parameters were 1.0 μs at 750 pps and 0.12 μs at 2250 pps, respectively, for the first and second test runs. A dual-trace oscilloscope was used for simultaneous display of the TP-3 and TP-5 video output signals. The procedure in each mode consisted of first establishing the input RF signal level required for an on-tune minimum visible signal (MVS) video output response. At this point, the video signal level is just barely discernable in relation to the peak video noise level. The test signal level was listed as the reference level along with the measured amplitudes of the TP-3 and TP-5 signals. Next, the input RF signal level was increased by 3 dB over the reference value and the corresponding TP-3 and TP-5 peak voltages were tabulated. This procedure was repeated for additional increases in test signal level, first by 3 dB and then in 6-dB increments thereafter, up to the point where additional level increases produced no significant change in the video output level. The results from this group of measurements are summarized in Figure 2-3.

In the second group of dynamic range measurements, the receiver was operated in the LOG IF processing mode. This was the mode employed for essentially all of the PPI degradation measurement runs. The basis for selecting this mode was that, in the opinion of site personnel, the radar is most usually operated with LOG IF processing selected. The radar PPI video (PPIV) was monitored at TP-5 for each of the four test runs performed. Three dynamic range measurement runs were made with the WP/WB operating mode selected. The first measurement was run with the test signal modulated to duplicate the nominal received signal, 0.12 μs pulse width at 2250 pps, for NP/WB operation. The next two runs were performed with the test signal modulated to simulate the characteristics of a potential interference source, i.e., 0.3 μs or 16 μs pulse width at a PRF of 2987 pps. A single dynamic range measurement run was made for the WP/NB mode using the test signal modulated for one-μs width at 750 pps.

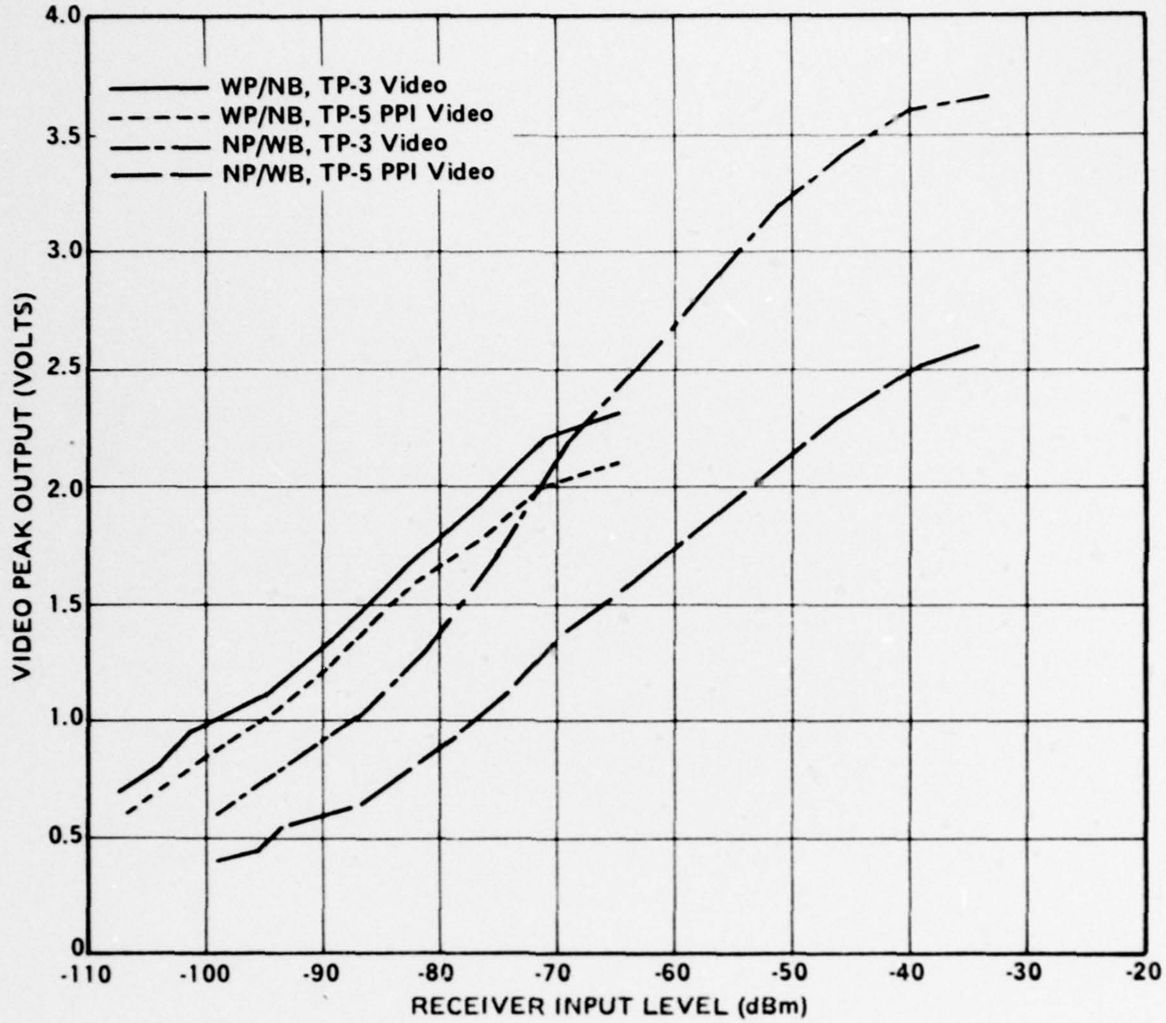


Figure 2-3. Dynamic Range Measurement Summary, LIN/LOG IF.

A potential interference source (LN-66 Pathfinder Radar) operates with a one-μs pulse width and a 500-pps PRF. The dynamic range characteristics measured with a one-μs pulse width at 750 pps were compared at several points to those with the PRF reduced to 500 pps. No significant changes in video peak output level were noted. Therefore, the WP/NB dynamic range measurement results are considered valid for either PRF; 750 pps or 500 pps. The measurement procedure was the same as that described earlier for the measurements in the LIN/LOG IF mode. In two measurement runs (WP/NB with one-μs pulse width and NP/WB with 16-μs pulse width), the mid-pulse video output level began limiting at an input signal level of approximately 33 dB above the MVS sensitivity level. The region where this effect started was noted in the data as "mid-pulse saturation level". The measurement results for the LOG IF mode, with PPI peak video output voltage monitored, are summarized in Figure 2-4.

In the analysis and modeling of the PPI degradation, the levels of the desired and interference signals are normalized, in a ratio, to the output noise level measured at the output from the last IF amplifier preceding the detector. For simplicity, these output signal relationships will be termed SNR (meaning IF output signal-to-noise ratio) and INR (meaning IF output interference-to-noise ratio). The receiver IF output for the SNR and INR measurements was monitored at TP-4. An active probe, connected at TP-4, was used to prevent circuit-loading by the test equipment. The active probe output was amplified with a low-noise amplifier and the oscilloscope Channel 2 amplifier to provide a level sufficient for dispaly on the oscilloscope (Channel 1). Two dynamic range measurements runs were made in WP/NB receiver mode with test signal modulations of; (1) one-μs pulse width at 500 pps and (2) 0.1-μs pulse width at 1000 pps. In NP/WB mode, the test signal modulations (pulse width and PRF) were as follows: (1) 0.12 μs at 2250 pps, (2) 0.3 μs at 2987 pps and (3) 16 μs at 2987 pps.

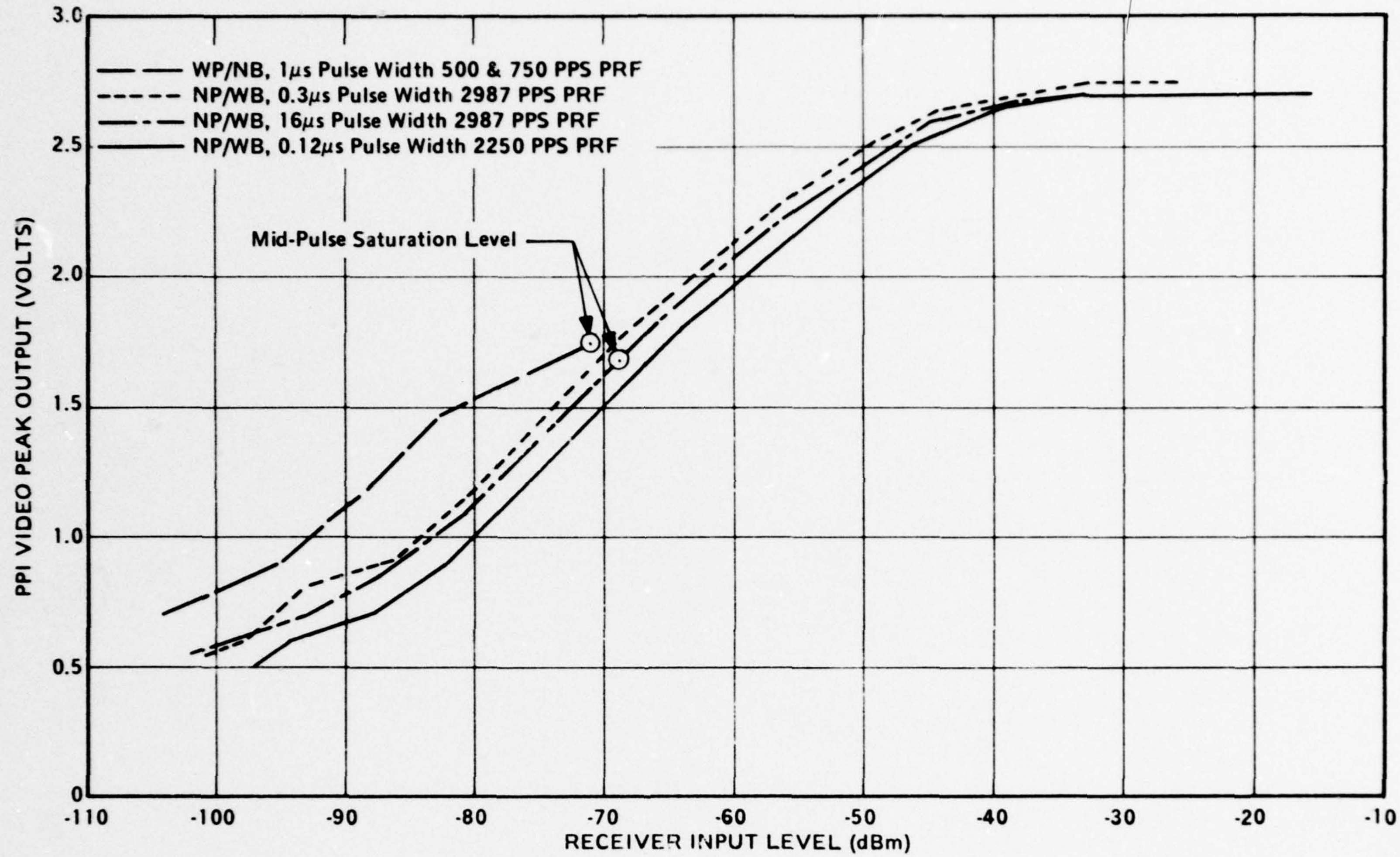


Figure 2-4. Dynamic Range Measurement Summary, PPI Video, Log IF.

A two-part procedure was employed for each combination of radar mode and test signal modulation parameters. In the first part, the peak-to-peak output noise level was noted on the oscilloscope with no signal applied. Next, the test signal (pulse) was turned on. The frequency was tuned for maximum IF output response. The test signal level providing a minimum visible pulse in the IF output was measured for reference. Then, the test signal level was increased by a selected amount above the reference value and the resulting peak-to-peak pulse amplitude on the oscilloscope was noted. This procedure was repeated with the test signal level increased, in steps, up to the point where additional increases produced no significant change in the peak-to-peak IF pulse amplitude.

In the next part of the procedure, a calibrated signal generator, tuned to 60 MHz (receiver IF), was signal-substituted at the input to the low noise amplifier. The signal generator output was adjusted to obtain each of the peak-to-peak levels noted in the first part of the measurement and the output level value was noted. The IF output SNR and INR values were computed by comparing all output levels measured in a given test run to the lowest output level obtained in that run. The results from the SNR, INR measurements in the WP/NB mode are summarized in Figure 2-5. A similar summary for the NP/WB measurements appears in Figure 2-6.

To illustrate the radar video output obtained at several levels of interfering signal, covering all of the pulsed interference sources considered, the test oscilloscope display was photographed. The test signal levels ranged from the lowest interference level used in the PPI

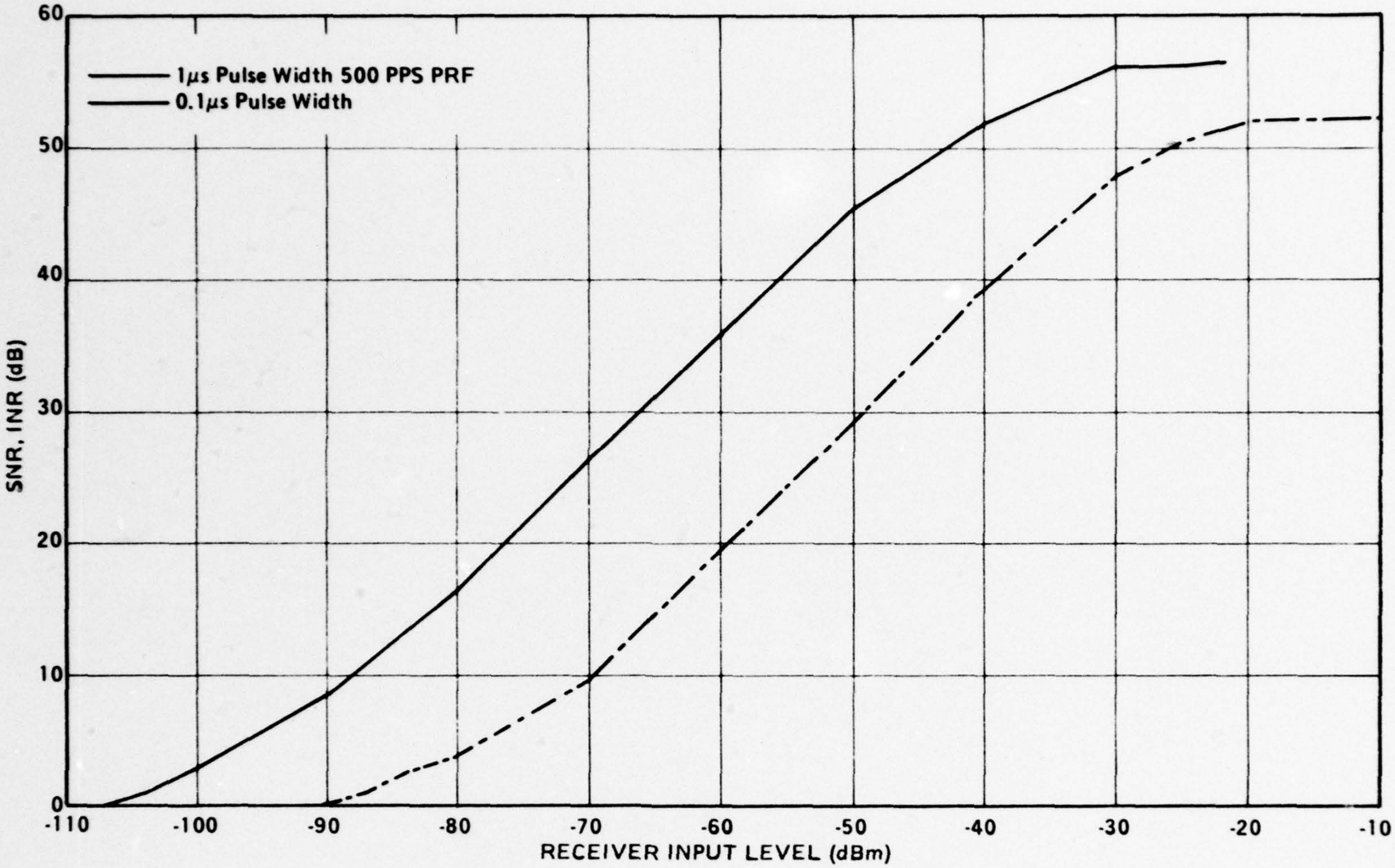


Figure 2-5. Dynamic Range Measurement Summary, WP/NB, IF Output.

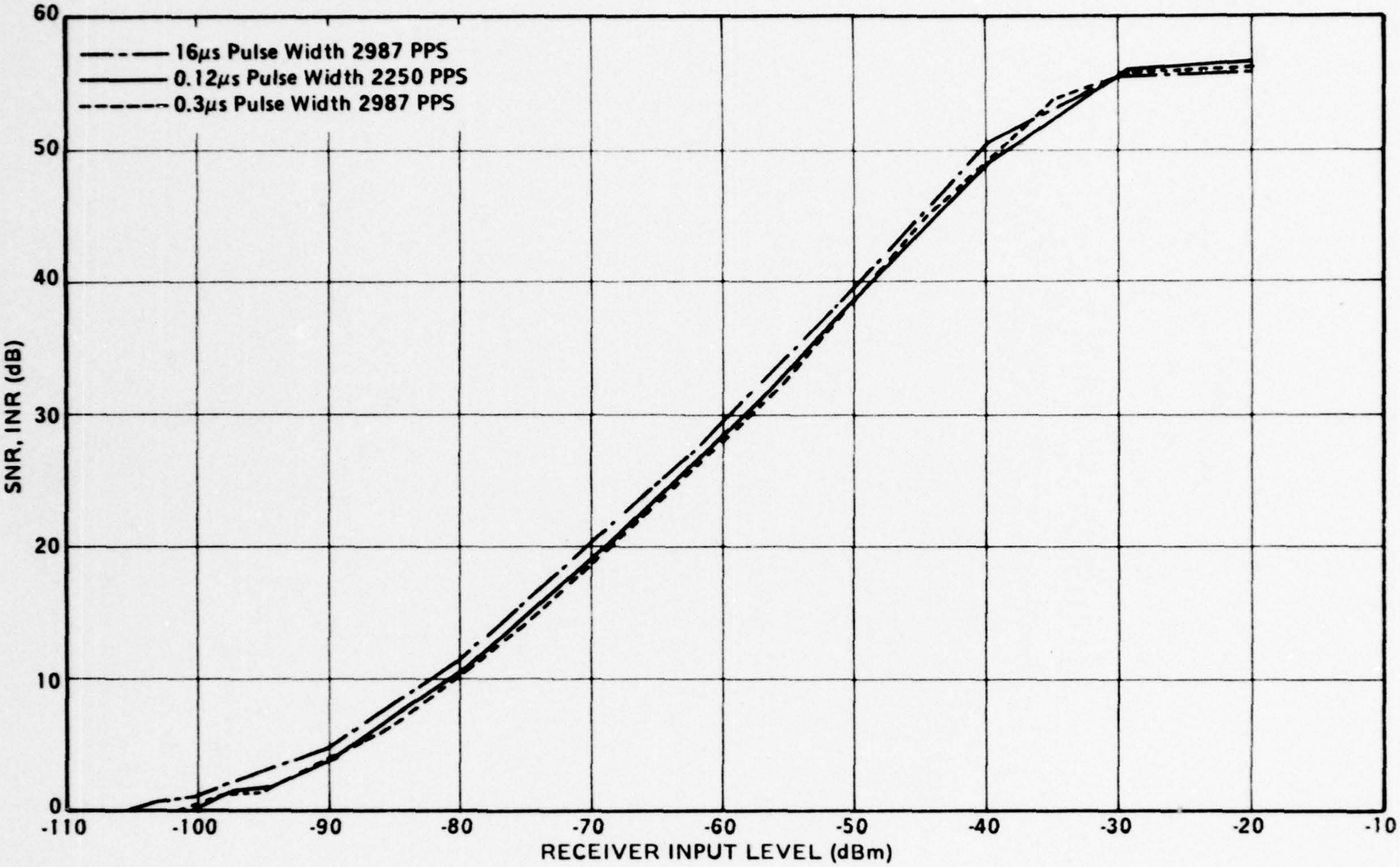


Figure 2-6. Dynamic Range Measurement Summary, NP/WB, IF Output.

degradation measurements up to the maximum or saturation level. All of these measurements were obtained with the test oscilloscope connected to TP-3. The video output response photographs and the pertinent test details and parameters are summarized in Figures 2-7 through 2-10.

2.5 Off-Tune Interference Validation

The purpose of this test was to provide measured data for validating the results from interference predictions made with the NAVSEC SEMCAM 1 procedure. Selected interference sources in the AN/SPS-55 radar receiver tuning band and a typical shipboard problem input were used to generate the SEMCAM 1 results summarized in Table 2-5. The interference from the sources in Table 2-5 was simulated, as closely as possible, at the AN/SPS-55 receiver input. The subsequent validation measurements were performed in two parts. First, simulated interference fundamental emission duplicating the predicted values were established and the amount of frequency separation (Δf, in Megahertz) between the receiver f_o and the simulated emission f_o was measured for each interference situation. Second, the amplitude versus frequency rolloff of the simulated emission spectrum was measured for reference information in the validation analysis. The test setup block diagram for the first-part measurements is shown in Figure 2-1. Figure 2-11 is the test pulse emission spectrum rolloff measurement block diagram.

The measured SNR, INR data in Figures 2-5 and 2-6 served as reference information for setting-up the level of the simulated interference signal (fundamental emission). The predicted interference-to-noise ratio (INR) values, Table 2-5, ranged from 63 dB up to 103 dB. The measured dynamic range data (Figures 2-5 and 2-6) show a maximum

TABLE 2-5. SEMCAM 1 PREDICTION SUMMARY.

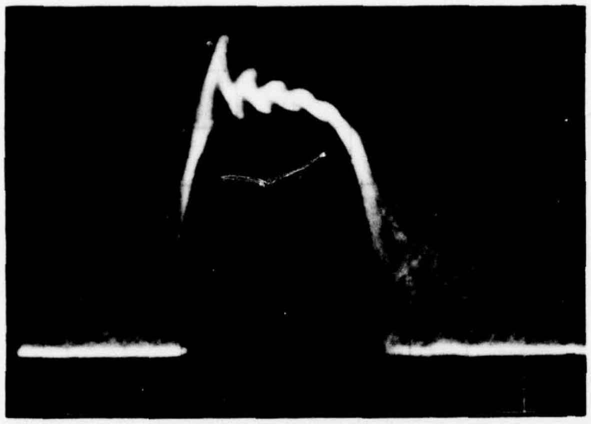
RECEIVERS	TRANSMITTERS		
	AN/SPQ-9 LONG PULSE	AN/SPQ-9 SHORT PULSE	LN-66 HIGH-POWER FF
RF BURN-OUT POWER FOR AN/SPS-55, LONG PULSE, HORIZONTAL POLARIZATION	SIDE-TO-SIDE * -31 dBm CASE, FUNDAMENTAL	SIDE-TO-SIDE * -31 dBm CASE, FUNDAMENTAL	MAIN-TO-MAIN * +1 dBm AND SIDE-TO-SIDE * -21 dBm CASE, FUNDAMENTAL
RF BURN-OUT POWER FOR AN/SPS-55, LONG PULSE, CIRCULAR POLARIZATION	SIDE-TO-SIDE * -35 dBm CASE, FUNDAMENTAL	SIDE-TO-SIDE * -35 dBm CASE, FUNDAMENTAL	MAIN-TO-MAIN * -3 dBm AND SIDE-TO-SIDE * -25 dBm CASE, FUNDAMENTAL
INR FOR AN/SPS-55, LONG PULSE, HORIZONTAL POLARIZATION	SIDE-TO-SIDE * +73 dB CASE, FUNDAMENTAL	SIDE-TO-SIDE * +67 dB CASE, FUNDAMENTAL	MAIN-TO-MAIN * +103 dB AND SIDE-TO-SIDE * +81 dB CASE, FUNDAMENTAL
INR FOR AN/SPS-55, LONG PULSE, CIRCULAR POLARIZATION	SIDE-TO-SIDE * +69 dB CASE, FUNDAMENTAL	SIDE-TO-SIDE * +63 dB CASE, FUNDAMENTAL	MAIN-TO-MAIN * +99 dB AND SIDE-TO-SIDE * +77 dB CASE, FUNDAMENTAL
DELTA P FOR ZERO INR * AN/SPS-55 HORIZONTAL POLARIZATION	SIDE-TO-SIDE * 115 MHz	SIDE-TO-SIDE * 44 MHz	SIDE-TO-SIDE * 362 MHz
DELTA F FOR ZERO INR * AN/SPS-55 CIRCULAR POLARIZATION	SIDE-TO-SIDE * 92 MHz	SIDE-TO-SIDE * 38 MHz	SIDE-TO-SIDE * 288 MHz

*ABBREVIATIONS:

SIDE-TO-SIDE — SIDELOBE-TO-SIDELOBE ANTENNA COUPLING

MAIN-TO-MAIN — MAINLOBE-TO-MAINLOBE ANTENNA COUPLING

INR — INTERFERENCE SIGNAL-TO-NOISE RATIO



Test Signal

Pulse Width: 1.0 μs

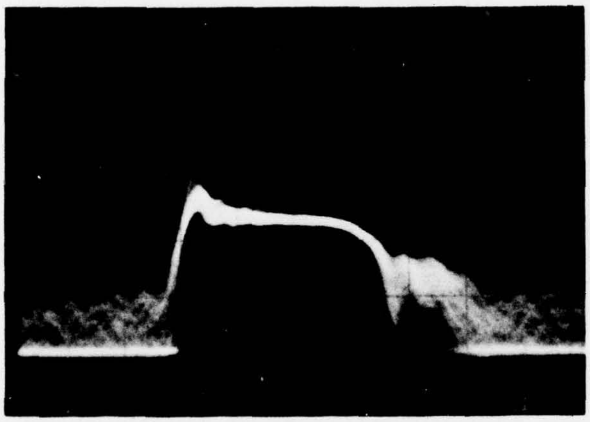
PRF: 1000 pps

Level: -80 dBm

Oscilloscope Display

Amplitude: 0.5 volts/div.

Sweep Time: 0.5 μs/div.



Test Signal

Pulse Width: 1.0 μs

PRF: 1000 pps

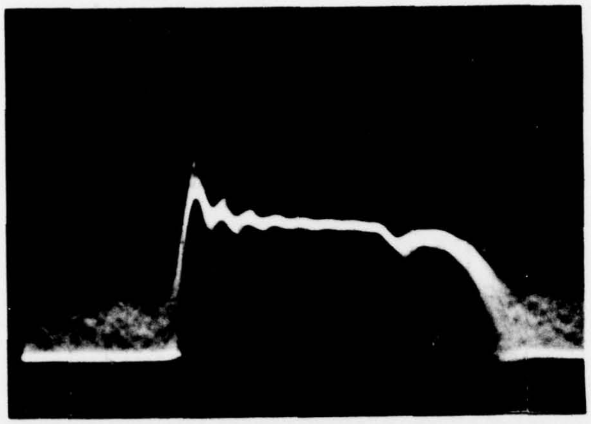
Level: -70 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 0.5 μs/div.

Figure 2-7. Receiver Video Output Signal, WP/NB, Log IF.



Test Signal

Pulse Width: 1.0 μs

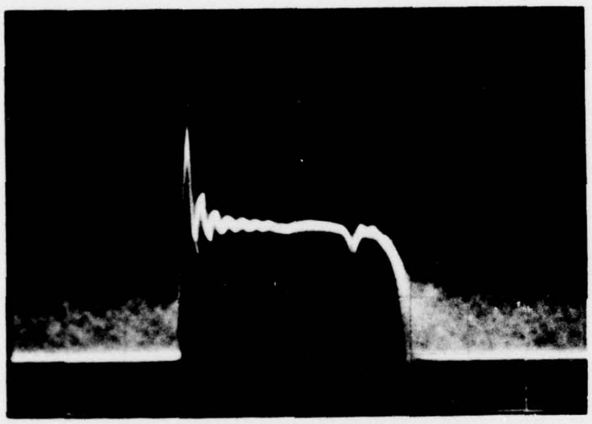
PRF: 1000 pps

Level: -60 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 0.5 μs/div.



Test Signal

Pulse Width: 1.0 μs

PRF: 1000 pps

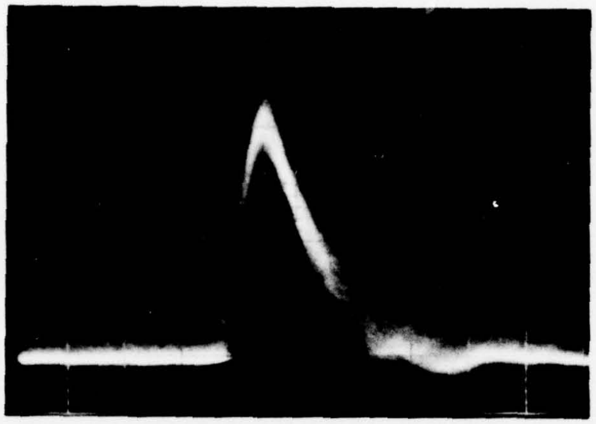
Level: -35 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 1.0 μs/div.

Figure 2-7. Receiver Video Output Signal, WP/NB, Log IF. (Continued)



Test Signal

Pulse Width: 0.3 μs

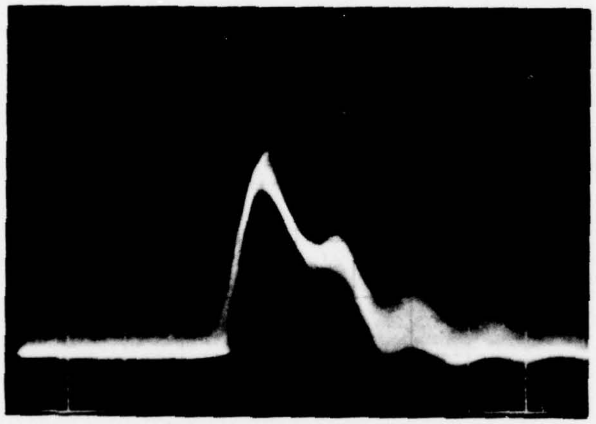
PRF: 2987 pps

Level: -80 dBm

Oscilloscope Display

Amplitude: 0.5 volts/div.

Sweep Time: 0.2 μs/div.



Test Signal

Pulse Width: 0.3 μs

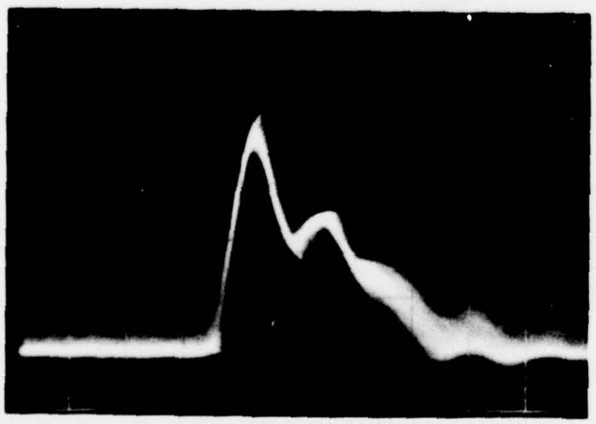
PRF: 2987 pps

Level: -70 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 0.2 μs/div.



Test Signal

Pulse Width: 0.3 μs

PRF: 2987 pps

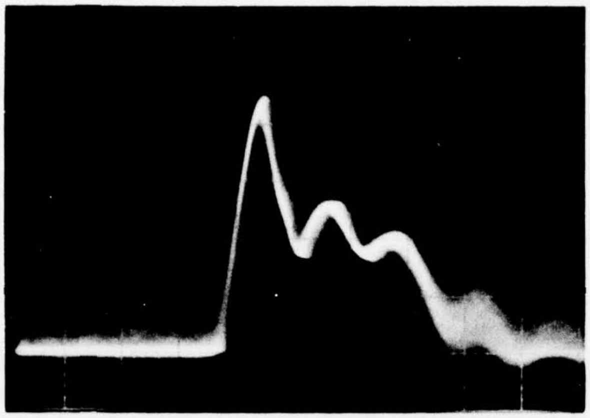
Level: -60 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 0.2 μs/div.

Figure 2-8. Receiver Video Output Signal, NP/WB, Log IF.



Test Signal

Pulse Width: 0.3 μs

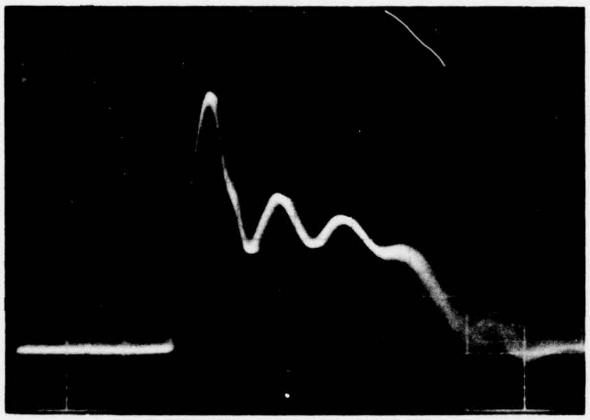
PRF: 2987 pps

Level: -50 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 0.2 μs/div.



Test Signal

Pulse Width: 0.3 μs

PRF: 2987 pps

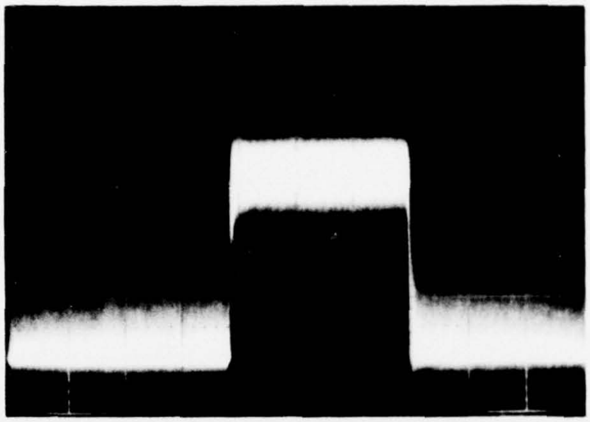
Level: -35 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 0.2 μs/div.

Figure 2-8. Receiver Video Output Signal, NP/WB, Log IF. (Continued)



Test Signal

Pulse Width: 16 μs

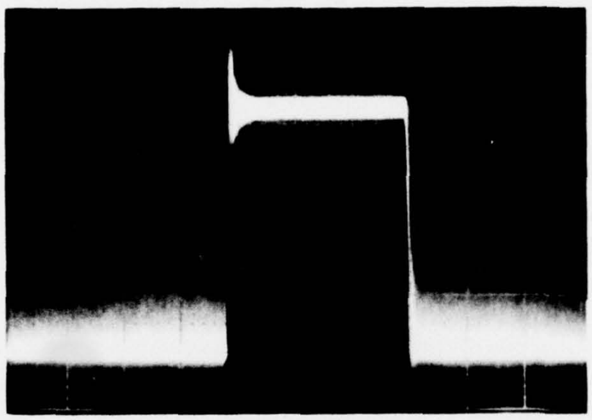
PRF: 2987 pps

Level: -85 dBm

Oscilloscope Display

Amplitude: 0.5 volts/div.

Sweep Time: 5.0 μs/div.



Test Signal

Pulse Width: 16 μs

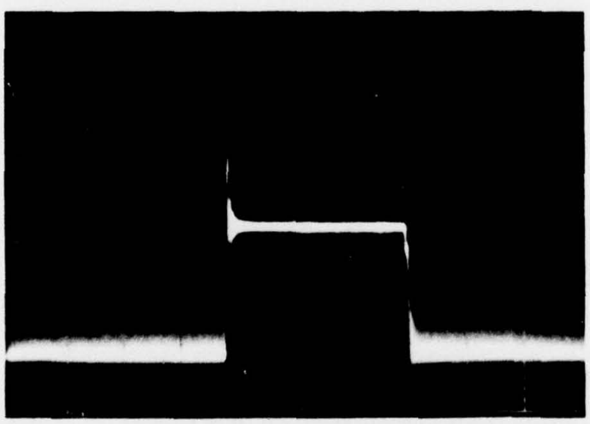
PRF: 2987 pps

Level: -75 dBm

Oscilloscope Display

Amplitude: 0.5 volts/div.

Sweep Time: 5.0 μs/div.



Test Signal

Pulse Width: 16 μs

PRF: 2987 pps

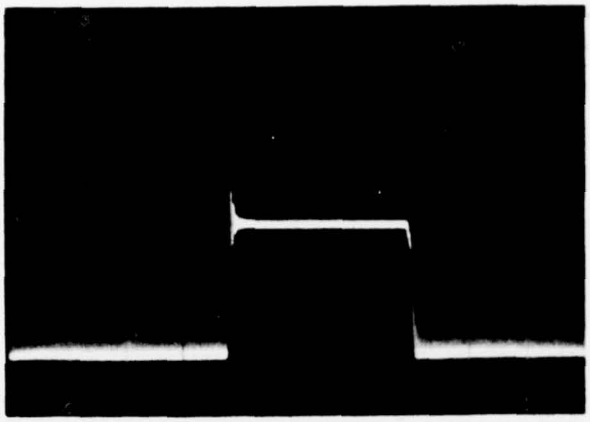
Level: -65 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 5.0 μs/div.

Figure 2-9. Receiver Video Output Signal, NP/WB, Log IF.



Test Signal

Pulse Width: 16 μs

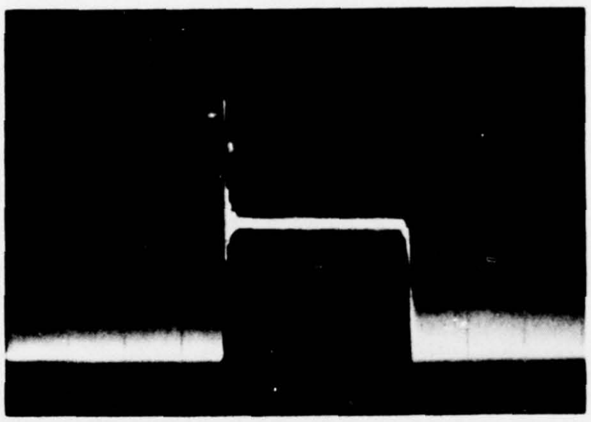
PRF: 2987 pps

Level: -55 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 5.0 μs/div.



Test Signal

Pulse Width: 16 μs

PRF: 2987 pps

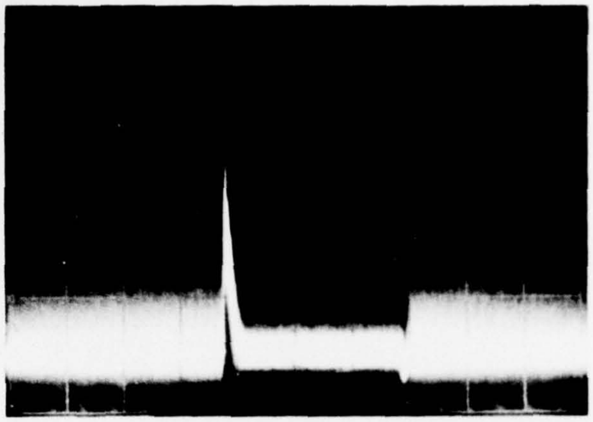
Level: -35 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 5.0 μs/div.

Figure 2-9. Receiver Video Output Signal, NP/WB, Log IF. (Continued)



Test Signal

Pulse Width: 16 μs

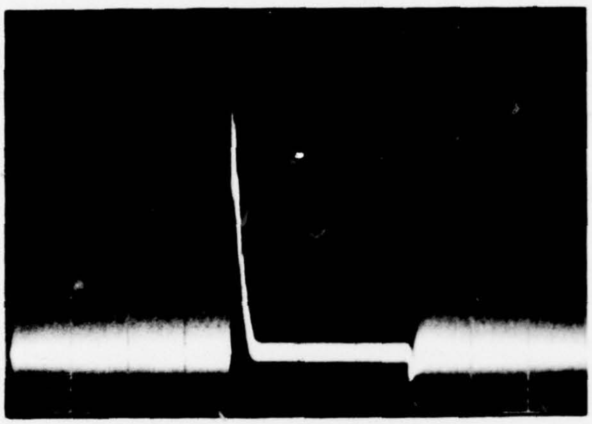
PRF: 2987 pps

Level: -85 dBm

Oscilloscope Display

Amplitude: 0.5 volts/div.

Sweep Time: 5.0 μs/div.



Test Signal

Pulse Width: 16 μs

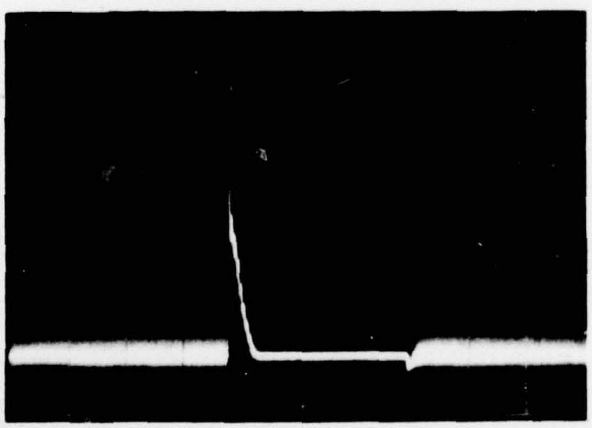
PRF: 2987 pps

Level: -75 dBm

Oscilloscope Display

Amplitude: 0.5 volts/div.

Sweep Time: 5.0 μs/div.



Test Signal

Pulse Width: 16 μs

PRF: 2987 pps

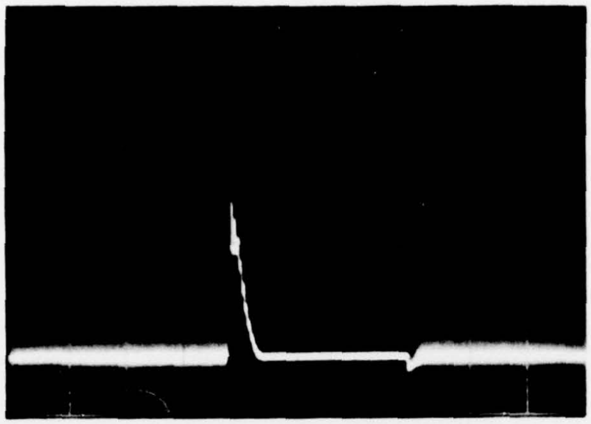
Level: -65 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 5.0 μs/div.

Figure 2-10. Receiver Video Output Signal, NP/WB, LIN/LOG IF.



Test Signal

Pulse Width: 16 μs

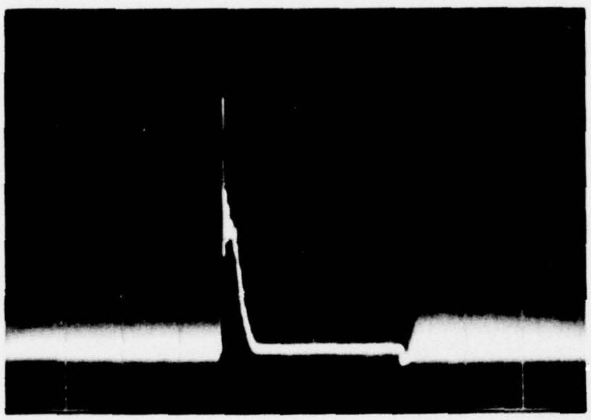
PRF: 2987 pps

Level: -55 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 5.0 μs/div.



Test Signal

Pulse Width: 16 μs

PRF: 2987 pps

Level: -35 dBm

Oscilloscope Display

Amplitude: 1.0 volts/div.

Sweep Time: 5.0 μs/div.

Figure 2-10. Receiver Video Output Signal, NP/WB, LIN/LOG IF. (Continued)

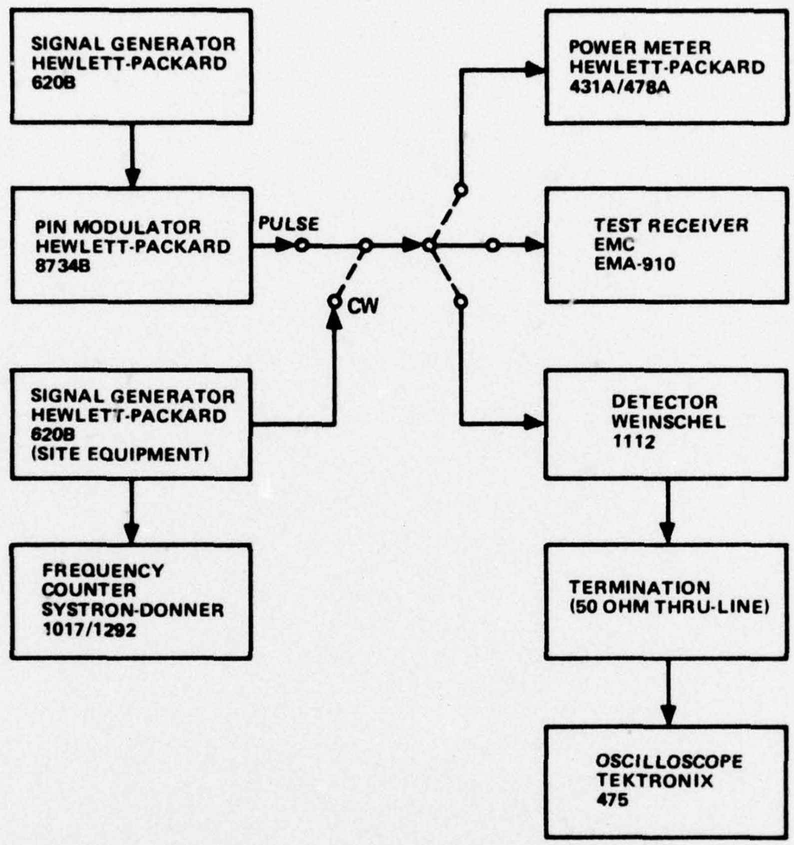


Figure 2-11. Test Pulse Emission Spectrum Measurement Block Diagram.

Table 2-6. Off-Tune Interference Validation Measurement Summary.

Interferer	Pulse Width (μs)	PRF (pps)	AN/SPS-55 Mode	AN/SPS-55 Polarization used in Prediction	Antenna Coupling (Note 1)	INR' (dB) (Note 2)	INR' (dB) (Note 3)	INR– INR' (dB)	Test Signal Level (dBm) (Note 4)	Δf (Desired f_o – Interference f_o) (MHz)
AN/SPQ-9	16.0	2987	NP/WB	Horizontal	S-S	73	29.5	43.5	-16.5	189
				Circular	S-S	69	29.5	39.5	-20.5	174
AN/SPQ-9	0.3	2987	NP/WB	Horizontal	S-S	67	28.0	39.0	-21.0	145
				Circular	S-S	63	28.0	35.0	-25.0	128
LN-66	1.0	500	WP/NB	Horizontal	S-S	81	36.0	45.0	-15.0	130
				Circular	S-S	77	36.0	41.0	-19.0	117

NOTES:
1. S-S = Sidelobe-to-Sidelobe condition.
2. Predicted INR at Fundamental (From SEMCAM 1 Procedure).
3. Measured INR at -60 dBm Input Signal Level.
4. -60.0 dBm + (INR – INR').

attainable INR value of 56.5 dB for the interference sources considered. To establish the interference signal level to be used, the linear INR region on the dynamic range curves was assumed to extend on a straight-line basis to higher INR values since the interference frequency is detuned from the AN/SPS-55 receiver f_o. The method for arriving at the interference level used will be explained for one interference situation in Table 2-5. The predicted INR for the AN/SPQ-9 short-pulse mode (16-μs) pulse width at 2987 pps) to the AN/SPS-55 in the WP/NB mode, with horizontal antenna polarization selected, was 73 dB. In the dynamic range measurements (Figure 2-6) an input signal modulated with the AN/SPQ-9 short-pulse parameters, i.e., 0.3-μs pulse width at a PRF of 2987 pps and a signal level of -60 dBm produced a measured INR (termed INR') at the AN/SPS-55 IF output of 29.5 dB. This value is 43.5 dB lower than the predicted INR value, i.e., INR (73.0 dB)-INR' (29.5 dB) = 43.5 dB. The equivalent receiver input siganl level, with straight-line extrapolation of the dynamic range linear region, should be 43.5 dB greater than the -60.0 dBm level that produced INR = 29.5 dB. Therefore, the interfering signal level to simulate the predicted 73.0 dB INR was computed as -60.0 dBm + 43.5 dB = -16.5 dBm. This procedure was used for computing the test signal level in each interference situation simulated for the measurements. The values used in the calculations are summarized in Table 2-6.

With the interference modulation and level simulated at the AN/SPS-55 receiver input, the interference frequency was tuned below the AN/SPS-55 receiver f_o until no interference was visible on the plan position indicator (PPI) connected to the radar set video output. Then, the interference frequency was increased slowly until the PPI observer declared the interference visible. At this point, both the interference frequency and the receiver tuned frequency were measured. The separation (Δf) between the two frequencies was computed for each measurement condition and the results are summarized in the last column of Table 2-6.

In the second part of the measurements (test pulse spectrum roll off), the test receiver was initially tuned to 9530 MHz. The No. 1 test signal generator output (CW) was modulated (PIN modulator and associated driver) to provide a test RF pulse width of 16 μs at 2987 pulses per second. The No. 1 test signal generator output level was set to maximum; thereby producing a peak level of -4.0 dBm measured at the PIN modulator output terminals. The test receiver 5 MHz bandwidth was selected to facilitate tuning adjustments. For the first measurement point, the test receiver was tuned for maximum response at the No. 2 generator f_o. After noting the test receiver meter reading for reference, the calibrated output (CW) from the No. 2 generator was signal-substituted to the coax going to the test receiver. After peaking the No. 2 generator frequency for maximum test receiver response, the output level was adjusted to regain the reference meter reading. The resulting No. 2 signal generator level noted in the data is called the reference on-frequency level. The measured No. 2 generator frequency was noted. In the next step, the coax was reconnected to the No. 1 generator. The test receiver was tuned above the No. 1 generator f_o until the test receiver meter response decreased about 40 dB. After noting the meter reading, the No. 2 generator was used to calibrate the response in the manner described for the reference on-frequency point. Both the frequency and level of the No. 2 generator were listed in the data. This procedure was repeated, with the test receiver response decreasing in steps, at successively higher frequencies above the No. 1 generator f_o. In the data reduction, each off-frequency level was subtracted from the reference on-frequency level at each measurement point. The frequency separation, Δf, was obtained by comparing each off-tune frequency to the reference on-tune frequency. The results from the test pulse spectrum roll-off measurements are summarized in Figure 2-12. The measured spectrum roll-off values are plotted as a point-to-point curve (solid line). The trend of the point-to-point curve indicated a straight-line relationship for roll-off, in dB, as a function of the frequency, in megahertz. The dashed line on the graph is the least mean squares curve fit to the measured data points.

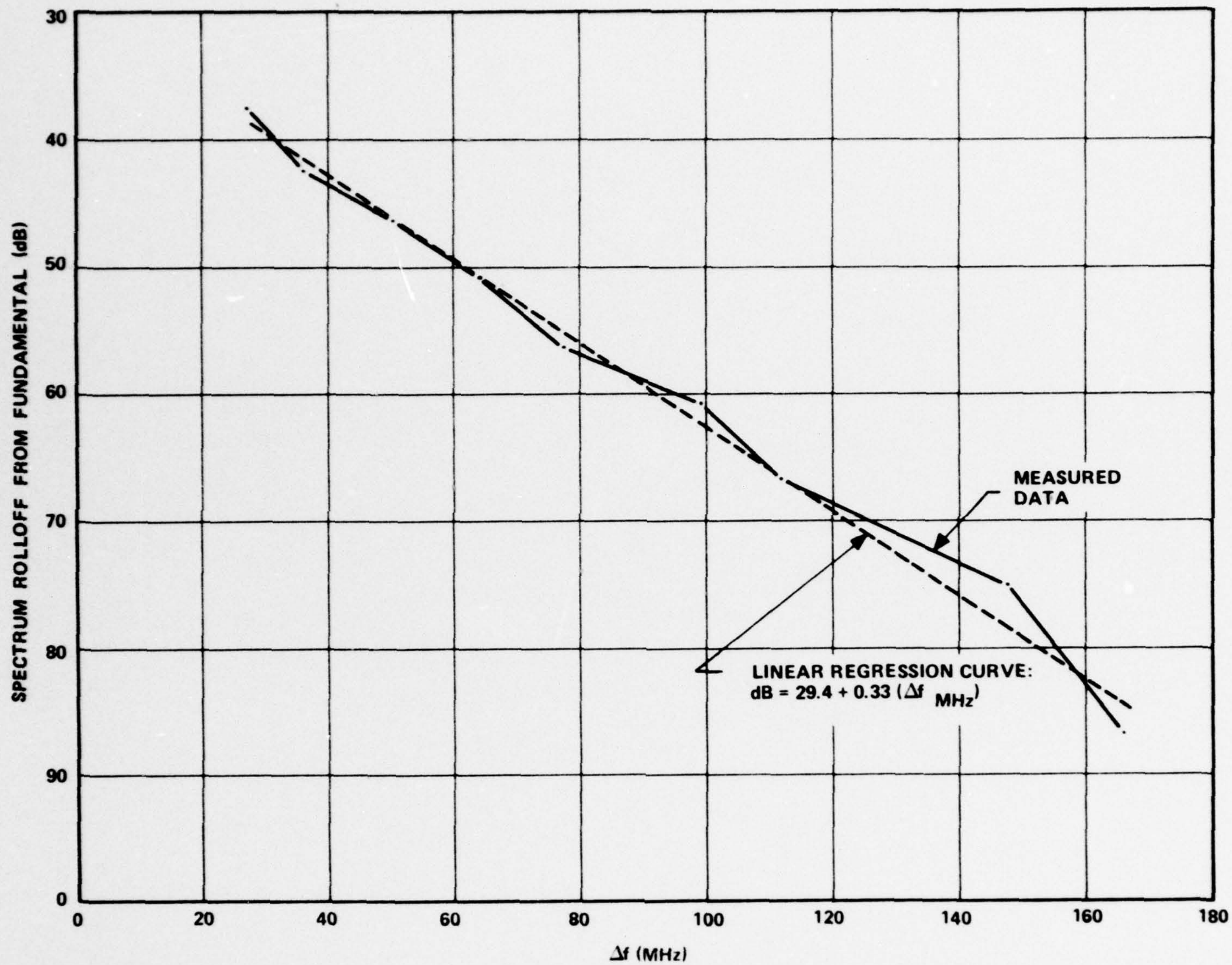


Figure 2-12. Test Pulse Emission Spectrum Rolloff Measurement Summary.

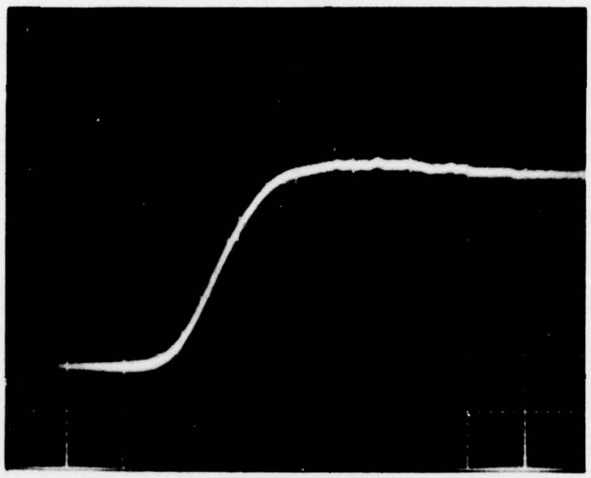


Figure 2-13. Test Pulse Risetime Photograph.

2.6 PPI Degradation

The PPI degradation measurements consisted of determining the number of PPI scans, statistically averaged, needed for detection of a target with known signal strength under controlled interference conditions. The nominal PPI target detection performance was established in measurements with a desired signal (S_D) as the simulated target return and no interference present. Subsequent PPI detection performance measurements were made with both the S_D and either one of two interfering signals applied simultaneously. Figure 2-14 is the measurement block diagram.

The first requirement in the PPI degradation measurements was to develop a simulated target return signal. It was desired to have a fixed target such that the target "blip" appeared at the same location (range and bearing) on each antenna/PPI scan cycle. Though fixed at a given location for a given PPI trial, the target position was placed at random points (range and bearing on the PPI display) from one PPI trial to another.

The setup for simulating the target return signal was assembled with several units of standard test equipment. The test signal source was a signal generator with the frequency tuned for maximum response near the mid-point of the AN/SPS-55 radar's operating range; 9525 MHz. The CW RF output from the signal generator was pulse-modulated, using a PIN modulator, to produce an RF pulse width (0.12 μs in the NP/WB mode and 1.0 μs in the WP/NB mode). The PIN modulator driver was synchronized to the AN/SPS-55 main PRF trigger via a pulse generator used as an adjustable delay generator with pro-
pulse generator used as an adjustable delay generator with pro-
vision for gating the trigger off/on. The target simulator source, up to this point, provided a target at all bearings, i.e., range ring on the PPI. The range value was varied by changing the delay setting on the pulse generator. A test oscilloscope, triggered by the pulse generator input trigger signal, was used for displaying the modulator driver output signal. The oscilloscope sweep rate was adjusted such that zero range coincided

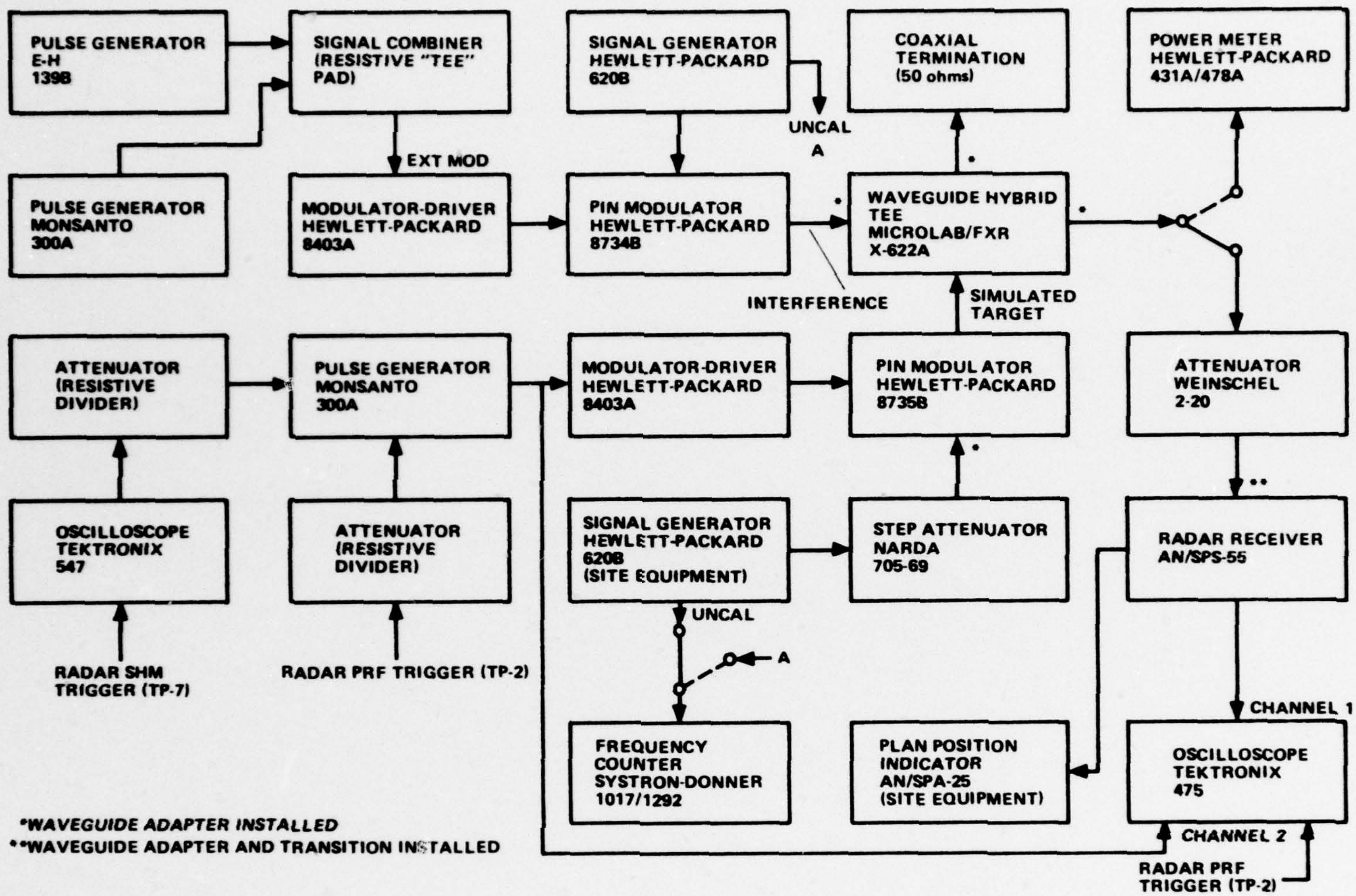


Figure 2-14. PPI Degradation Measurement Block Diagram.

with the extreme left graticule line and the maximum range used in the measurements (20 miles for NP/WB or 50 miles for WP/NB) coincided with the extreme right graticule line. With 10 display divisions between the two end points on the display, selected range values were easily set-up; each division corresponding to 10% of the maximum range.

The target bearing was produced with a test oscilloscope (Tektronix Model 547) operated as a pulse generator having variable delay. In this procedure, it was assumed that target information is present only during the time interval required for the radar antenna beamwidth, measured at the half-power (3-dB) points, to scan past a given bearing point. The radar antenna scan rate and beamwidth are 16 RPM and 1.5 degrees, respectively. Therefore, the 3-dB beamwidth scans past a given bearing line in 15.6 milliseconds $\left(\frac{1}{16}\frac{\text{Minutes}}{\text{Scan}} \times \frac{1}{360}\ \frac{\text{Scan}}{\text{Degree}} \times 60\ \frac{\text{Seconds}}{\text{Minute}} \times 1.5\ \frac{\text{Degrees}}{\text{Target}} = 0.0156\ \frac{\text{Seconds}}{\text{Target}}\right)$. The test oscilloscope (Tektronix 547) was operated in the A delayed by B mode with the duration of the A-sweep (and A-gate signal) adjusted to 15.6 milliseconds. The B-sweep was synchronized to the azimuth reference pulse (ARP) which is generated in the radar antenna drive assembly at the same bearing in each complete antenna scan. The B-sweep time for one complete sweep wa[illegible]t slightly less than the time required for one complete antenna scan, (approximately 60/16 seconds). With this setup, the A-gate signal can be adjusted, with the oscilloscope delay setting, to occur at almost any point during the radar antenna rotation. The point at which the A gate occurs is seen as an intensified dot on the oscilloscope screen. This permitted setting the simulated target bearing to selected values.

With the bearing simulation gate fed to the gate input of the pulse generator which provides the simulated range, the result was an RF pulse train covering a 1.5-degree sector on the PPI. The width of the bearing gate was checked by counting the number of RF pulses occurring during the gate time; about 12 pulses in WP/NB and 35 pulses in NP/WB.

The PPI degradation measurements begin with the desired signal (S_D) only injected into the AN/SPS-55 receiver. The PPI controls were adjusted as follows:

1. The maximum range was adjusted for either 20 miles or 50 miles corresponding to the radar mode selected; NP/WB on WP/NB, respectively.
2. The PPI video gain was set to minimum.
3. The PPI intensity was set for a barely perceptible sweep display.
4. The PPI video gain was increased until the sweep line was clearly evident, providing a visible noise display without blooming.

The basic element in the PPI detection runs is called the "trial". The procedure for one trial is as follows. First, with an operator stationed at the PPI, the simulated target signal, at a predetermined level, is applied at the radar receiver input. At the same time, the PPI operator is advised to find the target. The operator is given 20 complete PPI scans in which to find the target; however, if the target is not found in this number of PPI scans, the trial result is listed as "no detection". If the operator declares detection in ≤ 20 scans, the number of scans for detection is listed in the data. To verify that actual detection occurred, the test signal level is increased about 10 dB, producing an easily distinguished target. With detection verified, the coordinates of the target on the PPI are measured and listed. This procedure is also used in cases of no detection. If the identification result is negative, i.e., false alarm, the false alarm condition is annotated along with true target coordinates.

Thirty PPI trials were made at each test signal level for a given combination of modulation parameters (desired and interference) and the receiver operating mode selected. This number of trials represents a compromise between having a large number of data points for a reliable statistical analysis and the practical consideration for the test time budget. For convenience in future references, each set of thirty PPI trials is termed a "PPI run".

The basic purpose in the PPI runs was to determine detection as a function of the simulated target return level. The measure of detection performance was considered as the mean number of scans to detect the target on the PPI. It was desired for the measurement results to show three general levels of detection performance as follows:

1. High - one to three mean scans to detection.
2. Mid - four to nine mean scans to detection.
3. Low - 10 to 18 mean scans to detection.

The test signal level to obtain these performance levels was estimated through preliminary PPI trials at each set of test parameters. The high, mid and low mean scans to detection PPI runs were performed as a group with the selected simulated target levels intermixed (90 PPI trials total). The purpose of this was to prevent the operator from anticipating the degree of difficulty for finding the target. Consequently, the results from three runs could not be evaluated until the entire group of measurements was completed. In a few cases, the detection performance values were borderline or slightly outside the general region desired.

In the measurements with a single interfering signal in the WP/NB receiver mode, two interfering signal levels were selected as follows: (1) -35 dBm which produced saturation and -80 dBm which corresponds to approximately mid-way between MVS and top of the linear region on the dynamic range curve.

In the measurements with a single interfering signal in the NP/WB receiver mode, with the same selection process, -35 dBm (saturation) and -80 dBm (mid-level) were used when the interfering pulse width was 0.3 μs. With the interfering pulse width widened to 16 μs, the MVS value decreased so the interfering levels selected were -35 dBm (saturation) and -85 dBm (mid-level). For the multiple (2) interfering signals measurements, only the saturation level (-35 dBm) was used.

The combinations of interfering signal modulation, receiver pulse width/bandwidth mode and receiver IF processing were limited to those anticipated to have the greatest degradation in the PPI detection runs. The PPI runs with both the 16 μs and 0.3 μs interfering signals, at 2987 pps PRF, showed considerable degradation. Therefore, these measurements were repeated with the same values of pulse width and the PRF reduced to one-third of the original value (2987 pps ÷ 3).

The data from individual PPI detection runs were recorded on data sheets similar to the one shown in Figure 2-15. Each data sheet was analyzed to obtain the following information.

1. Mean scans to obtain target detection.
2. Standard deviation of mean scans.
3. Probability of target detection in 20 scans.

In computing the mean scans for target detection, it was assumed that target detection occurred on the twenty-first scan if no detection resulted through the twentieth scan. The results from the PPI detection runs are summarized in Table 2-7. The original data sheets are maintained in the NAVSEC Degradation Data Base.

The measurements with the single interference, 16-μs pulse width at 2987 pps, showed range as a significant factor in detecting the target. This effect was investigated through doubling the number of PPI runs and using higher levels for

Test Signal Characteristics:

TYPE	Pulse Width (μsec)	PRF (pps)	Level (dBm)
Desired:	0.12	2250	-68
Interference No. 1:	16.0	2987	-35
Interference No. 2:		OFF	

PPI Session No.: 16 Radar Mode: NP/WB IF: LOG

TARGET LOCATION		PPI SCANS TO DETECT	TARGET LOCATION		PPI SCANS TO DETECT
Range (nmi)	Bearing (Degrees)	(#)	Range (nmi)	Bearing (Degrees)	(#)
14	282	1	17	257	2
8	152	21*	11	298	7
16	061	1	17	126	1
8	320	2	16	168	1
9	222	6	10	094	7
11	079	2	9	036	8
10	289	2	15	096	2
8	270	21*	12	296	2
11	101	4	17	219	4
14	238	1	14	246	3
10	314	1	12	092	9
10	002	12	17	118	1
8	211	1	14	306	8
15	180	1	8	275	16
14	295	1	10	165	12

DATA SUMMARY: Mean scans to detect: 5.30
Standard Deviation: 5.80
Probability of detection: 0.93
SNR: 20.5 dB INR: 53.0 dB

NOTE: * Detection on 21st scan assumed, ** Within 20 scans.

Figure 2-15. Sample PPI-Run Data Sheet.

Table 2-7. PPI Degradation Measurements Summary.

RECEIVER MODE		DESIRED SIGNAL		INTERFERING SIGNAL			PPI SESSION SUMMARY			
PULSE WIDTH/ BANDWIDTH	IF	TYPE NOTE 1	LEVEL (dBm)	PULSE (μs)	PRF (pps)	LEVEL (dBm)	MEAN SCANS TO DETECT TARGET (#)	STANDARD DEVIATION	PROBABILITY OF DETECTION	REMARKS
WP/NB	LIN/LOG	1	-104		NONE		19.2	5.0	0.13	
			-103				17.8	5.2	0.34	
			-102				12.5	7.5	0.67	
	LIN/LOG		-101		NONE		5.9	2.9	1.00	
	LOG		-98		NONE		1.6	0.9	1.00	
			-101	1	500	-80	9.0	6.3	0.83	
			-100			-80	4.0	2.7	1.00	
			-98			-71	3.1	1.6	1.00	
			-100			-35	12.2	7.4	0.67	
			-98			-35	5.2	3.6	0.97	
WP/NB	LOG	1	-96		500	-35	2.9	2.0	1.00	
NP/WB		2	-91		NONE		17.0	5.0	0.50	
			-88		NONE		1.8	1.1	1.00	
			-82	16	2987	-86	13.0	7.9	0.57	$R \leq 1/3\, R_{MAX}$
			-78				4.6	4.4	1.00	$R \leq 1/3\, R_{MAX}$
			-74				1.3	0.5	1.00	$R \leq 1/3\, R_{MAX}$
			-86				19.3	4.5	0.23	$R > 1/3\, R_{MAX}$
			-84				7.7	8.0	0.83	$R > 1/3\, R_{MAX}$
			-82			-85	1.6	1.3	1.00	$R > 1/3\, R_{MAX}$
			-74			-35	10.4	5.6	0.81	
			-68				5.3	5.8	0.93	
			-55				4.1	4.4	0.97	
			-77				14.7	7.8	0.43	$R > 1/3\, R_{MAX}$
			-68			-35	9.7	7.2	0.77	$R \leq 1/3\, R_{MAX}$
			-86		2987/3	-85	8.7	7.3	0.87	
			-84			-85	3.8	4.4	0.97	
			-82			-85	1.7	1.0	1.00	
			-83			-35	7.8	6.1	0.93	
			-80			-35	3.4	3.5	1.00	
			-74	16	2987/3	-35	1.8	2.1	1.00	
			-90	0.3	2987	-80	14.9	7.3	0.50	
			-88			-80	8.9	5.4	0.90	
			-86			-80	1.8	1.0	1.00	
			-86			-35	15.4	7.9	0.48	
			-84			-35	7.0	5.8	0.93	
			-81		2987	-35	2.0	1.4	1.00	
			-90		2987/3	-80	14.9	6.7	0.53	
			-88			-80	3.6	2.4	1.00	
			-86			-80	1.9	0.7	1.00	
			-90			-35	16.5	5.5	0.50	
			-88			-35	4.2	2.8	1.00	
NP/WB	LOG	2	-84	0.3	2987/3	-35	1.8	1.0	1.00	
				MULTIPLE INTERFERERS						
NP/WB	LOG	2	-84	1 0.3	499 2987	-35 -35	13.1	7.4	0.70	1 INTERFERER 2 INTERFERER
NP/WB NP/WB	LOG	2	-81	1 0.3	499 2987	-35 -35	1.7	0.9	1.00	1 INTERFERER 2 INTERFERER

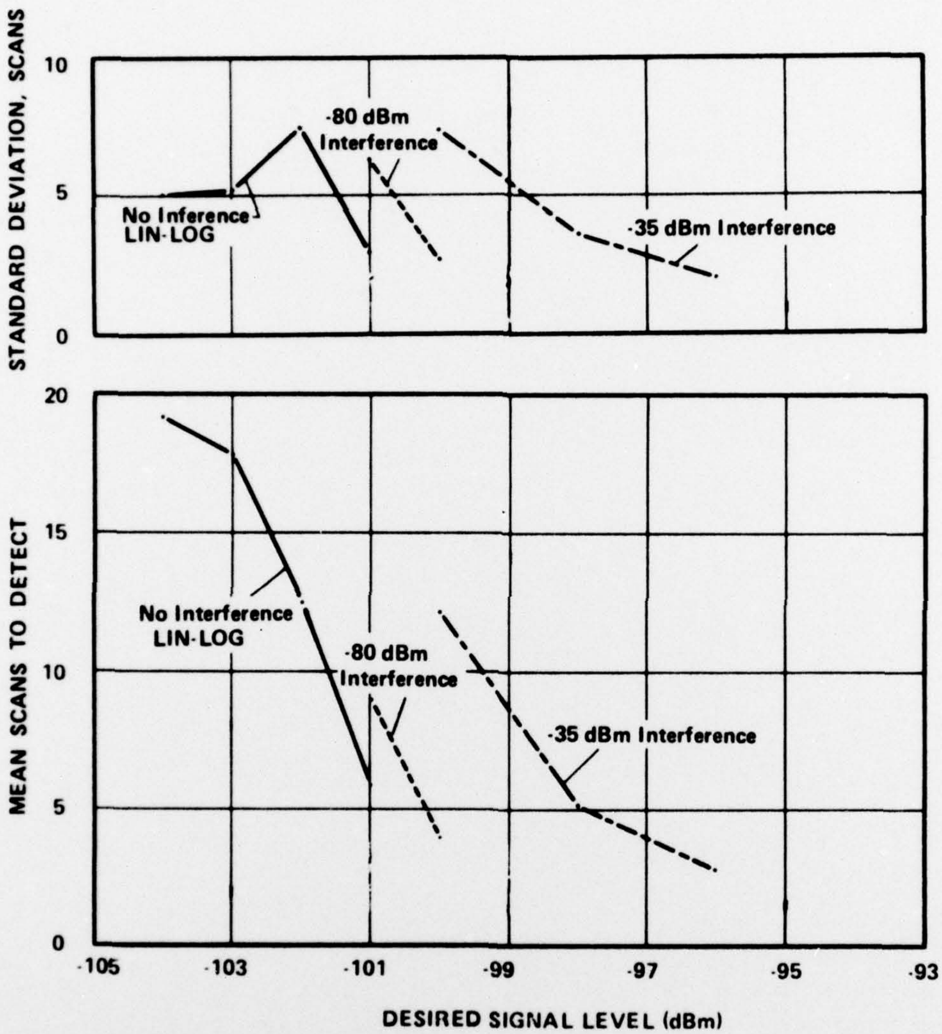
NOTE 1: DESIRED SIGNALS: TYPE 1 1 μs PULSE WIDTH AT 750 pps

TYPE 2 0.12 μs PULSE WIDTH AT 2250 pps

close-in ranges. One PPI run was obtained with target ranges set to greater than one-third the maximum PPI range (R_{max}). The second PPI run was made with target ranges restricted to less than or equal to one-third times R_{max}. Three runs were made for each range region to obtain high, mid, and low mean scans to detection.

The results in the PPI data summary are plotted in Figures 2-16 through 2-18 to show how degradation is influenced by the type of interference in each receiver mode. The WP/NB PPI data are shown in Figure 2-16 for the saturation (-35 dBm) and mid (-80 dBm) interference levels. The NP/WB PPI data for the saturation (-35 dBm) level are shown in Figure 2-17. Figure 2-18 shows the effects of the mid-level interference.

Photographs of the PPI display were made to show the "raster" type lines generated by the types and levels of the interfering signals that were used for measuring PPI degradation. These PPI photographs are shown in Figures 2-19 through 2-24. Figure 2-19 illustrates the display that produced the greatest degradation (16-μs PW at 2987 pps). The photograph shows that the inner-third of the display is almost "filled up" by the interference signal. This was the reason for "doubling-up" on the PPI runs for this interfering signal. The severity of the interference shown in Figure 2-20 is reduced considerably when the 16-μs pulse occurs at one-third of the 2987-pps rate. Some range dependence still existed but was not measured for this interfering signal. The effect of reducing the interfering pulse width to 0.3 μs at 2987 pps and 2987 ÷ 3 pps is shown in Figures 2-21 and 2-22, respectively. Figure 2-24 shows the appearance of the interfering signal (one-μs pulse width at 500 pps) with the radar operated in the WP/NB mode. Both the and the measured data show the degradation effects are low under the conditions measured. The effects of multiple interfering signals (two) on the PPI display are illustrated in Figure 2-24. The simulated target, though not visible in all cases, was located at 280 degrees bearing with range equalling about 60% of the maximum display range (30 miles in WP/NB, and 12 miles in NP/WB). Each target position is circled to aid in finding the location. The intensified sector is caused by the overlap of consecutive PPI sweeps during the photograph exposure time.

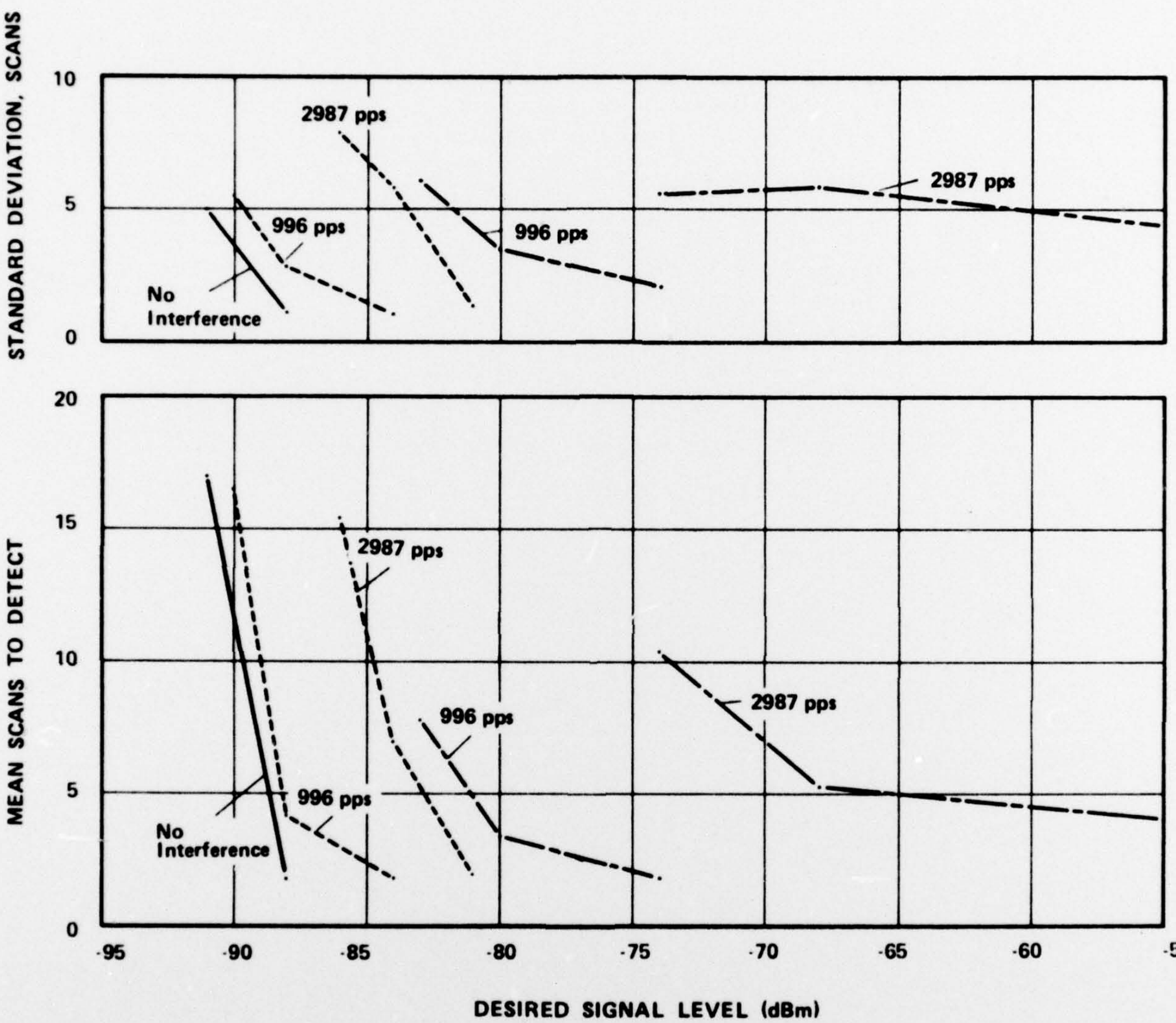


SIGNAL CHARACTERISTICS

DESIRED: 1 μs PULSE WIDTH AT 750 pps

INTERFERENCE: 1 μs PULSE WIDTH 500 pps

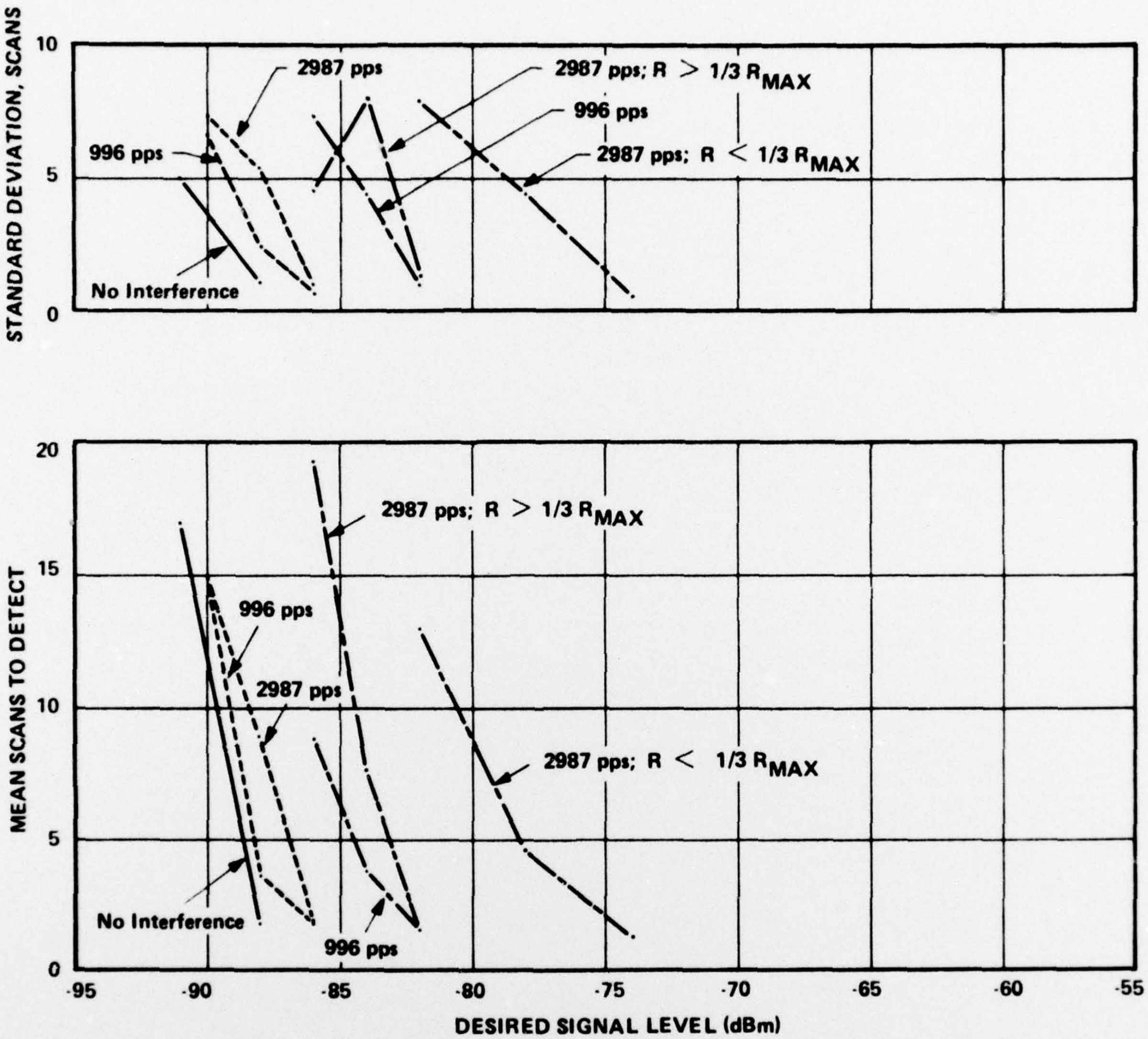
Figure 2-16. PPI Degradation Summary, WP/NB.



SIGNAL CHARACTERISTICS

DESIRED: 0.1 μs PULSE WIDTH AT 2250 pps
INTERFERENCE: — - — 16 μs PULSE WIDTH, -35 dBm LEVEL
------- 0.3 μs PULSE WIDTH, -35 dBm LEVEL

Figure 2-17. PPI Degradation Summary, NP/WB, Saturating Interference Level.



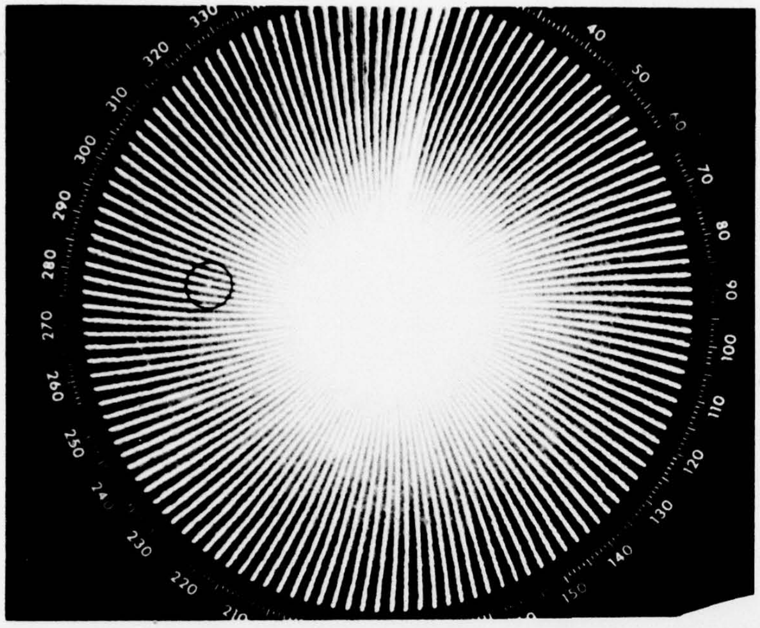
SIGNAL CHARACTERISTICS

DESIRED: 0.1 μs PULSE WIDTH, -85 dBm LEVEL

INTERFERENCE: —— - —— 16 μs PULSE WIDTH, -85 dBm LEVEL

— — — — — 0.3 μs PULSE WIDTH, -85 dBm LEVEL

Figure 2-18. PPI Degradation Summary, NP/WB, Mid Interference Level.



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -78 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signal

1. Pulse Width: 16 μs

   PRF: 2897 pps

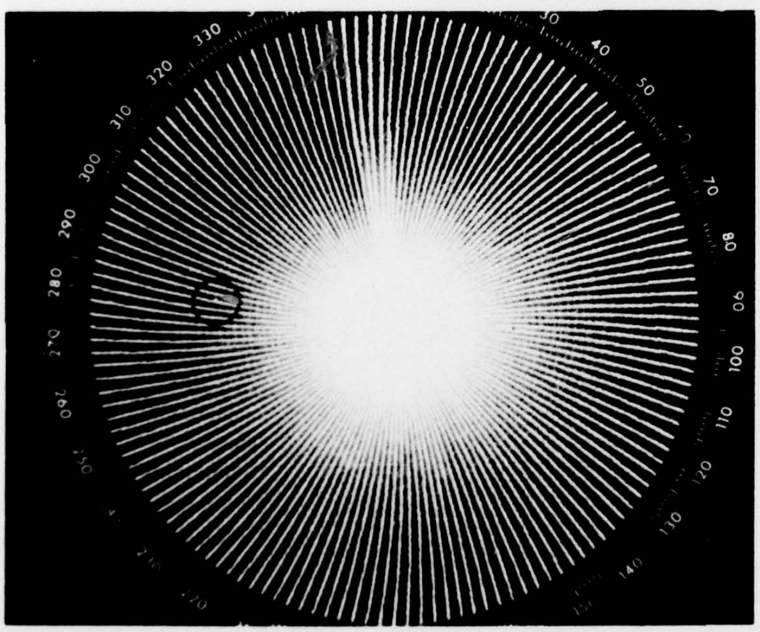
   Level: -35 dBm

2. Pulse Width N/A μs

   PRF: N/A pps

   Level: N/A dBm

(A)



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -84 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signals

1. Pulse Width: 16 μs

   PRF: 2987 pps

   Level: -85 dBm

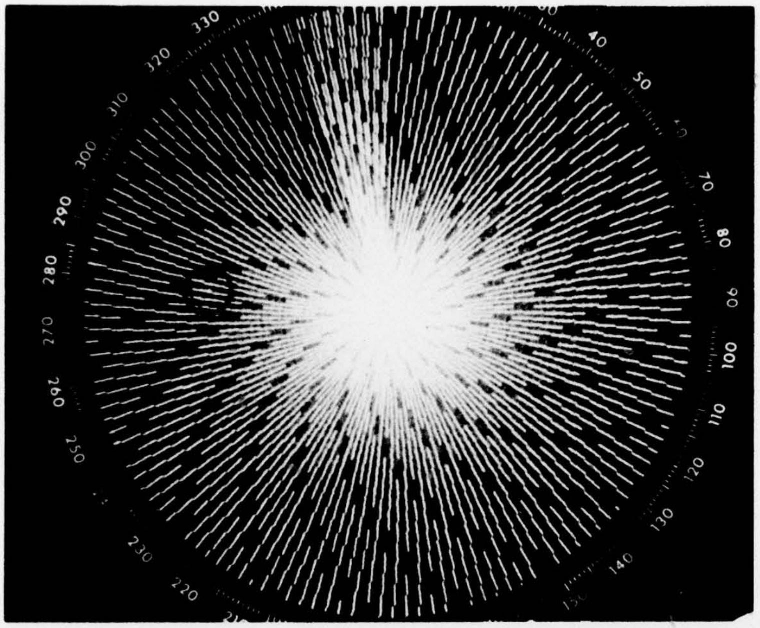
2. Pulse Width N/A μs

   PRF: N/A pps

   Level N/A dBm

(B)

Figure 2-19. PPI Photographs, NP/WB.



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -83 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signal

1. Pulse Width: 16 μs

   PRF: 2987 ÷ 3 pps

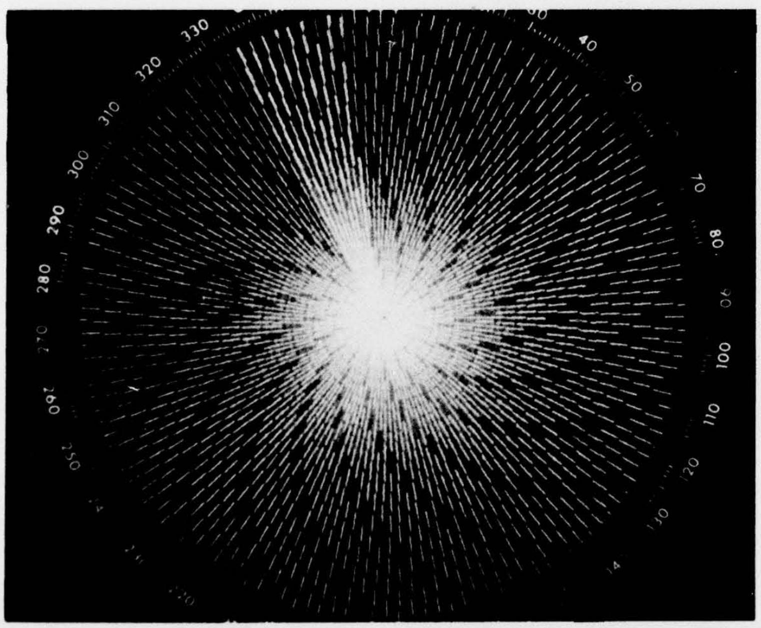
   Level: -35 dBm

2. Pulse Width N/A μs

   PRF: N/A pps

   Level: N/A dBm

(A)



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -84 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signals

1. Pulse Width: 16 μs

   PRF: 2987 ÷ 3 pps

   Level: -85 dBm

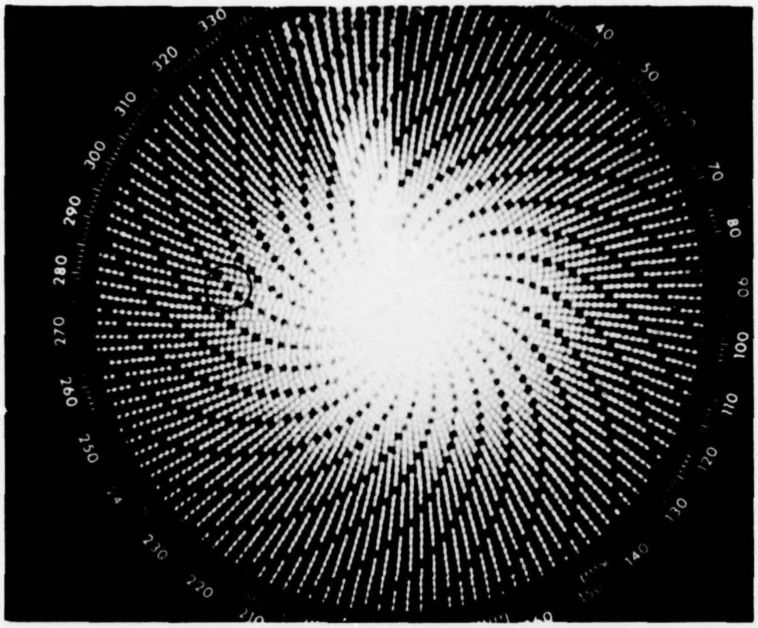
2. Pulse Width N/A μs

   PRF: N/A pps

   Level N/A dBm

(B)

Figure 2-20. PPI Photographs, NP/WB.



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -88 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signal

1. Pulse Width: 0.3 μs

   PRF: 2987 pps

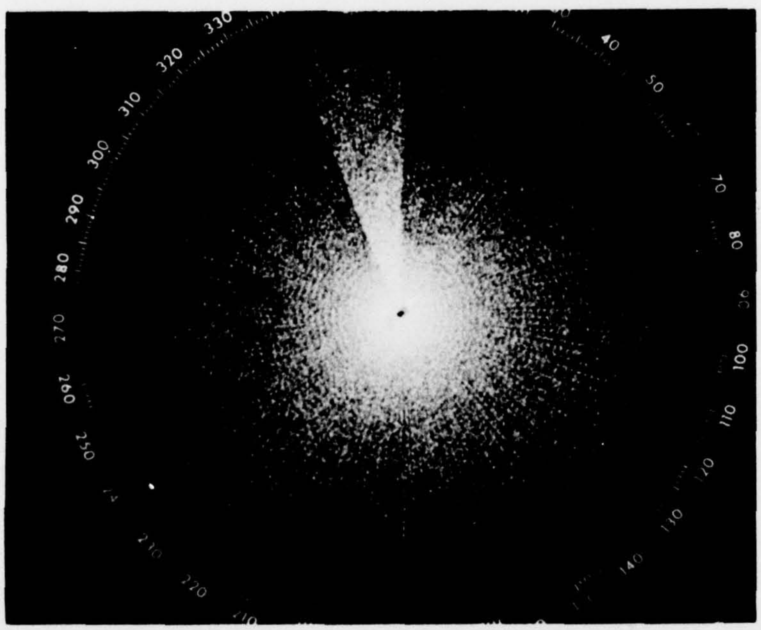
   Level: -35 dBm

2. Pulse Width N/A μs

   PRF: N/A pps

   Level: N/A dBm

(A)



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -88 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signals

1. Pulse Width: 0.3 μs

   PRF: 2987 pps

   Level: -80 dBm

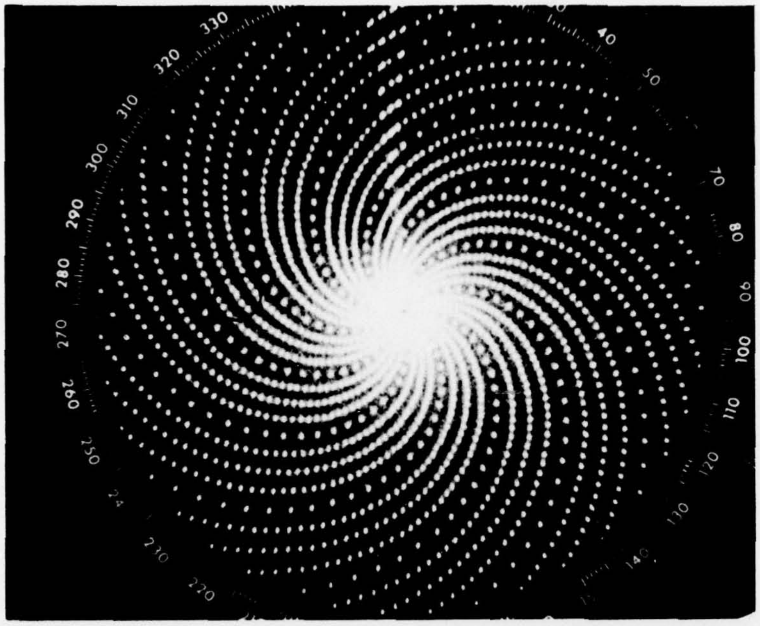
2. Pulse Width N/A μs

   PRF: N/A pps

   Level N/A dBm

(B)

Figure 2-21. PPI Photographs, NP/WB.



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -88 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signal

1. Pulse Width: 0.3 μs

   PRF: 2987 ÷ 3 pps

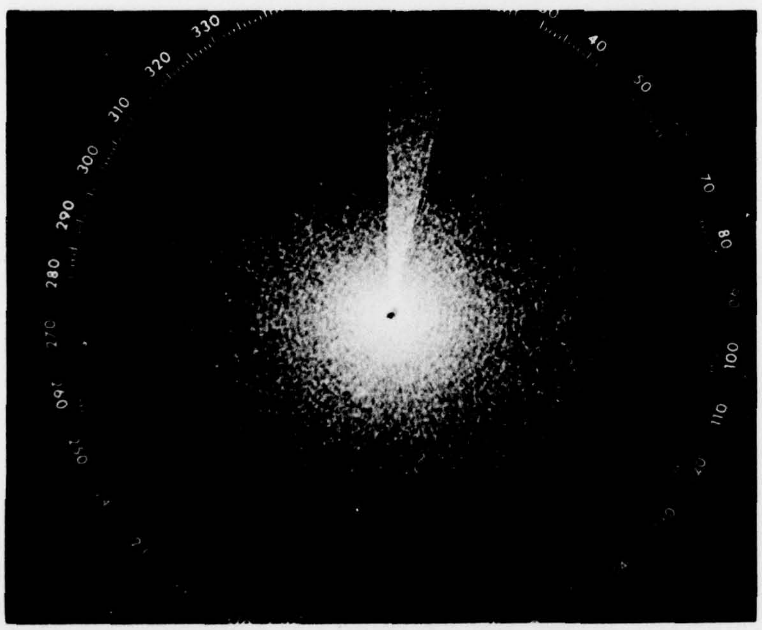
   Level: -35 dBm

2. Pulse Width N/A μs

   PRF: N/A pps

   Level: N/A dBm

(A)



Desired Signal

Pulse Width: 0.12 μs

PRF: 2250 pps

Level: -88 dBm

Bearing: 280 Degrees

Range: 12 Miles

PPI R_{MAX}: 20 Miles

Interfering Signals

1. Pulse Width: 0.3 μs

   PRF: 2987 ÷ 3 pps

   Level: -80 dBm

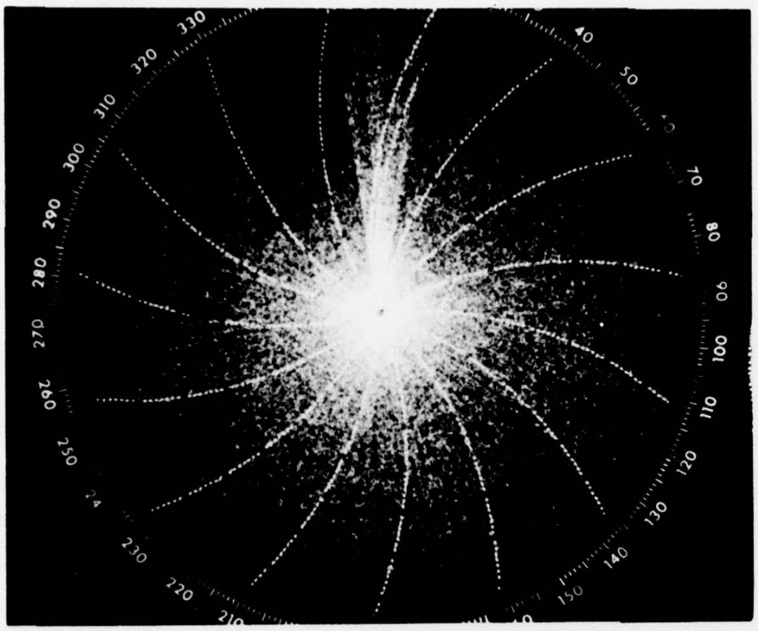
2. Pulse Width N/A μs

   PRF: N/A pps

   Level N/A dBm

(B)

Figure 2-22. PPI Photographs, NP/WB.



Desired Signal

Pulse Width: 1 μs

PRF: 750 pps

Level: -98 dBm

Bearing: 280 Degrees

Range: 30 Miles

PPI R_{MAX}: 50 Miles

Interfering Signal

1. Pulse Width: 1 μs

   PRF: 500 pps

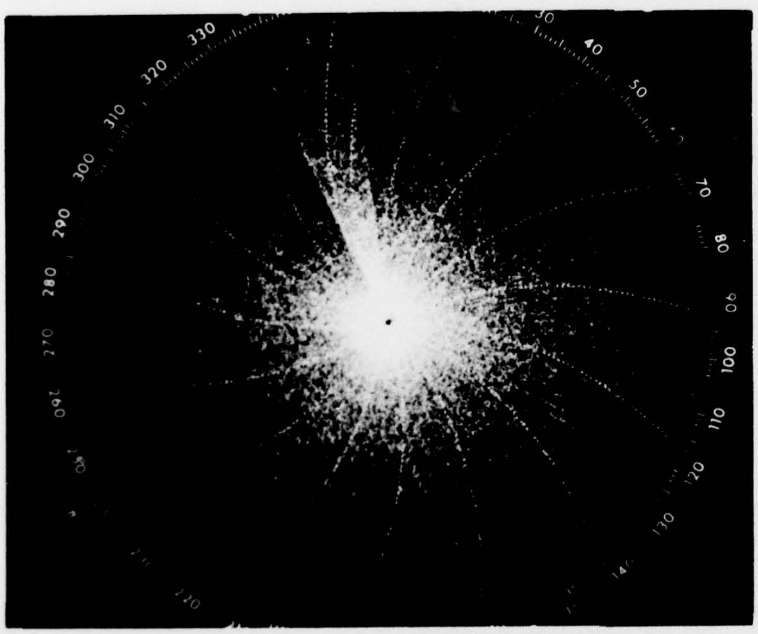
   Level: -35 dBm

2. Pulse Width N/A μs

   PRF: N/A pps

   Level: N/A dBm

(A)



Desired Signal

Pulse Width: 1 μs

PRF: 750 pps

Level: -98 dBm

Bearing: 280 Degrees

Range: 30 Miles

PPI R_{MAX}: 50 Miles

Interfering Signals

1. Pulse Width: 1 μs

   PRF: 500 pps

   Level: -80 dBm

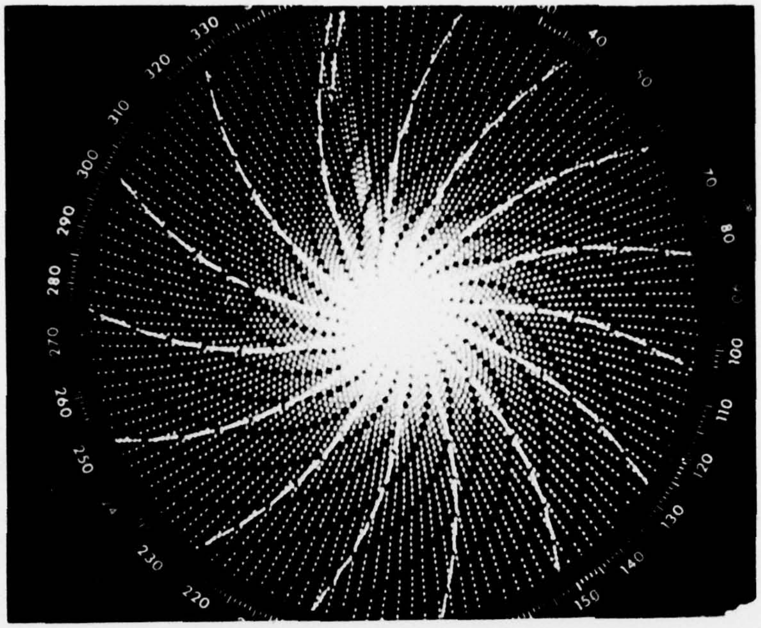
2. Pulse Width N/A μs

   PRF: N/A pps

   Level N/A dBm

(B)

Figure 2-23. PPI Photographs, WP/NB.



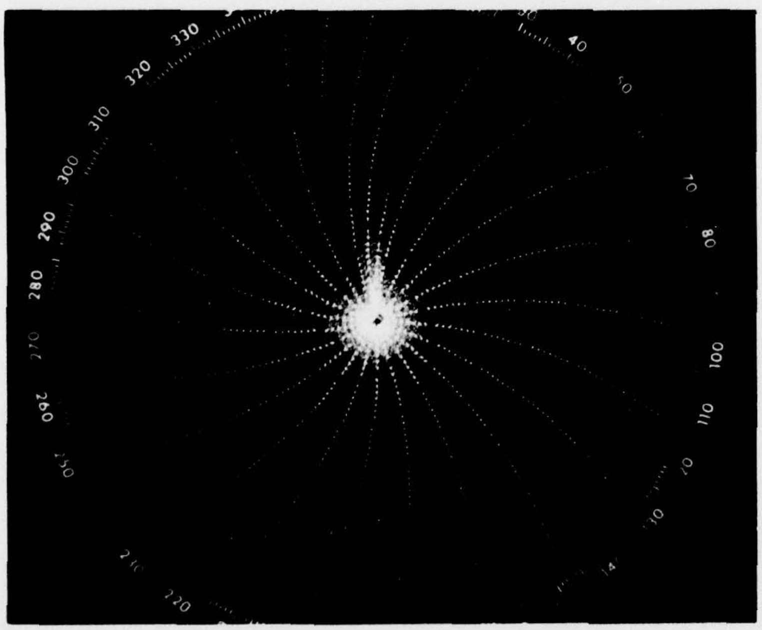
Desired Signal

Pulse Width: 0.12 μs
PRF: 2250 pps
Level: -79 dBm
Bearing: 280 Degrees
Range: 12 Miles
PPI R_{MAX}: 20 Miles

Interfering Signal

1. Pulse Width: 0.3 μs
   PRF: 2987 pps
   Level: -35 dBm
2. Pulse Width 1 μs
   PRF: 500 pps
   Level: -35 dBm

(A)



Desired Signal

Pulse Width: 0.12 μs
PRF: 2250 pps
Level: -79 dBm
Bearing: 280 Degrees
Range: 12 Miles
PPI R_{MAX}: 20 Miles

Interfering Signals

1. Pulse Width: 0.3 μs
   PRF: 2987 pps
   Level: -80 dBm
2. Pulse Width 1 μs
   PRF: 500 pps
   Level -80 dBm

(B)

Figure 2-24. PPI Photographs, NP/WB.

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