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MEASUREMENT PROCEDURES FOR THE RADAR SPECTRUM ENGINEERING CRITERIA

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ACKNOWLEDGMENT

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ABSTRACT

NTIA and member agencies of the Interdepartment Radio Advisory Committee (IRAC) have long recognized the need for a set of measurement procedures to augment the Radar Spectrum Engineering Criteria (RSEC). In light of this, a Working Party was formed under the auspices of the Technical Subcommittee Standards Working Group of the Technical Subcommittee, TSC, a subcommittee of the IRAC, for the purpose of developing such a set of measurement procedures.

This report presents one or more test procedures(s) for each of the equipment parameters covered by the RSEC that will yield adequate measured data for checking against the RSEC. The included procedures and this report were approved by the IRAC.

KEY WORDS

Antenna
Measurement Procedures
Radar Spectrum Engineering Criteria
Receiver
RSEC
Transmitter

1. INTRODUCTION

1.1. BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the radio spectrum allocated to the U. S. Federal Government. Part of NTIA's responsibility is to: "...establish policies concerning spectrum assignment, allocation and use, and provide the various departments and agencies with guidance to assure that their conduct of telecommunications activities is consistent with these policies" (Department of Commerce, 1980). In support of these requirements, the guidance provided by NTIA with the assistance of the Interdepartment Radio Advisory Committee (IRAC) encompasses the areas of: utilizing spectrum, identifying existing and/or potential Electromagnetic Compatibility (EMC) problems between systems of various departments and agencies, providing recommendations for resolving any compatibility conflicts, and recommend changes that result in more efficient and effective use of the spectrum and to improve spectrum management procedures.

The Radar Spectrum Engineering Criteria, RSEC, published as Section 5.3 of the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management* specifies certain system parameters of Federal radar systems. The National System Review Process (described in Section 8.3 of the NTIA Manual) requires that agencies requesting certification of spectrum support for radar systems furnish the equipment characteristics of these systems by specification, calculation or measurement for comparison to the RSEC. Although the radar equipment parameters indicated in Section 8.3 are defined in the RSEC, heretofore there has been no published set of measurement procedures to serve as guidelines for obtaining the data if they are to be provided by means of measurements. Consequently a Working Party was formed under the auspices of the Standards Working Group of the Technical Subcommittee, a subcommittee of the IRAC. The Working Party was chaired by NTIA and its membership consisted of representatives from the Navy, Army, Air Force, Coast Guard, FAA and NSA. Its purpose was to develop a document that would contain at least a possible measurement technique for obtaining adequate data on each of the equipment parameters covered by the RSEC. It was realized from the outset that there are often many techniques for measuring a particular equipment parameter and therefore, a selection of techniques should be presented.

1.2. Purpose

This document furnishes measurement procedures which can be used to provide data necessary to facilitate the National level system review process for radars which come under the purview of the Radar Spectrum Engineering Criteria (RSEC), Reference Section 5.3 of the NTIA Manual. Specifically, this document:

1. provides at least one measurement procedure,. for each radar characteristic specified by the RSEC.

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*Available from the Government Printing Office

2. is intended to clarify, by explanation and example, the parameters submitted for systems review purposes.

3. suggests reasonable interpretation for several test parameters which are undefined in the RSEC, such as number of frequencies to test, conditions under which tests are to be performed, etc.

4. provides a set of test procedures for Government radars.

5. provides a set of test procedures for parameters which may not be covered by other agency test procedures.

1.3. Relationship to Other Documents

This document is subordinate to the RSEC. If apparent conflicts are discovered between this document and the RSEC, the RSEC must be followed. Although this document specifies procedures which are implied but not made specific in the RSEC, it must be understood that this document must not be interpreted in a way which diminishes or extends the authority of the RSEC. Accordingly, this document does not:

1. require that only the procedures recommended herein can be used to provide data needed for the Systems Review Process.

2. extend the number or scope of the measurements required for RSEC data.

3. limit flexibility on the choice of measurement conditions, reference points, etc., as required to meet the intent of the RSEC.

4. require that radar data be based on measurements instead of calculations, nor is it intended to discourage the use of calculated data.

5. prohibit agencies from -specifying more stringent performance requirements, as needed.

6. prohibit submission of measured data available from development or production tests.

1.4. Scope of Measurement Procedures

These measurement procedures are directly applicable to many radars but may have to be adapted to measure more complex radars, e.g., radars with multiple pulse types, variable PRR's or those using phased array antennas. For example, it may be sufficient to obtain data at a single frequency for a frequency agile radar and to extrapolate the data to other frequencies. The basic purpose for obtaining data is to provide a reasonable representation of an equipment's utilization of spectrum space and to this end a combination of measured and calculated data may be sufficient.

2. SUMMARY OF RSEC PERFORMANCE PARAMETERS

2.1. Radar Emission Spectrum Levels

Group A: No Requirement

For Groups B through D:

The limitation on the permissible levels of RF emissions at frequencies other than those required for proper operation of the radar is the fundamental concept on which the RSEC is based. The actual numerical limits on the emission spectrum of a radar are dependent on several radar characteristics and must be calculated from a knowledge of the radar frequency, output power, pulse repetition rate (PRR), pulsewidth, and pulse rise time. In addition, these limits are dependent on the age of the radar; older radar types are allowed to meet less stringent requirements. These radar categories are divided among 4 groups (Groups A through D) summarized in Table 2-1; details of the description of "old" vs. "new" radars are contained in the RSEC. Table 2-1 also contains a value of K applicable to each group of radars; K is needed in the calculation of the maximum allowable system bandwidth.

Figure 2-1 illustrates the limits given, in the RSEC for the 40 dB emission bandwidth, B(-40 dB), and emission bandwidth at the -X dB floor, B(-X dB). Note that the frequency scale in Figure 2-1 is plotted in terms of logarithmic frequency difference from the radar operating frequency, Fo, in MHz. The absolute frequencies associated with this figure will depend on the calculation of the emission bandwidths for B(-40 dB) and B(-X dB).

"The maximum allowable emission bandwidth at the -40 dB level, B(-40 dB), determined by the parameters listed in Tables 2-1 and 2-2, is that emission bandwidth outside of which all emissions must be suppressed such that the levels lie below the S dB per decade roll-off lines from the -40 dB level down to and including the -X dB level indicated in Figure 2-1." Table 2-2 gives formulas for computing the value of B(-40 dB), for the various types of radars covered by the RSEC. The roll-off slope, S, from the B(-40 dB) to B(-X dB) points is at 20 dB per decade for Groups B and C, and at 40 to 80 dB per decade for Group D. The maximum allowable emission spectral level between B(-40 dB) and B(-X dB) points is obtained by subtracting the suppression (dB) given by the following formula, from the maximum spectral level,

$$\text{Suppression (dB)} = -S \cdot \log|((F-F_o)/[B(-40\text{ dB})/2])| - 40$$

where:

$$[B(-40\text{ dB})/2] \leq |F - Fo| \leq [B(-X\text{ dB})/2]$$

The emission spectrum bandwidth at the -X dB point, B(-X dB), is given by:

$$B(-X\text{ dB}) = (10 \exp \alpha)\,[B(-40\text{ dB})]$$

where:

$\alpha = (X-40)/S$

S = roll-off slope from -40 dB to X dB points

TABLE 2-1

VALUE OF K FOR VARIOUS GROUPS OF RADARS

	Value of K
Group A Pulsed radars of 1 kW or less rated peak power; or radars with an operating frequency above 40 GHz; or man-portable radars; or man-transportable radars; or Radionavigation radars in the band 9300-9500 MHz; or expendable, non-recoverable radars and missiles; or non-pulsed radars of 40 W or less rated average power.	Not applicable, no restrictions
Group B Radars having a rated peak power of more than 1 kW but not more than 100 kW and operating between 2900 MHz and 40 GHz.	K = 10 for RSEC, Column A Criteria* K = 7.6 for RSEC, Column B Criteria*
Group C All radars not included in Groups A, B or D.	K = 7.6 for RSEC, Column A Criteria* K = 6.2 for RSEC, Column B Criteria*
Group D All fixed radars in the 2700-2900 MHz band.	K = 6.2

*See RSEC for applicability of Columns A and B Criteria.

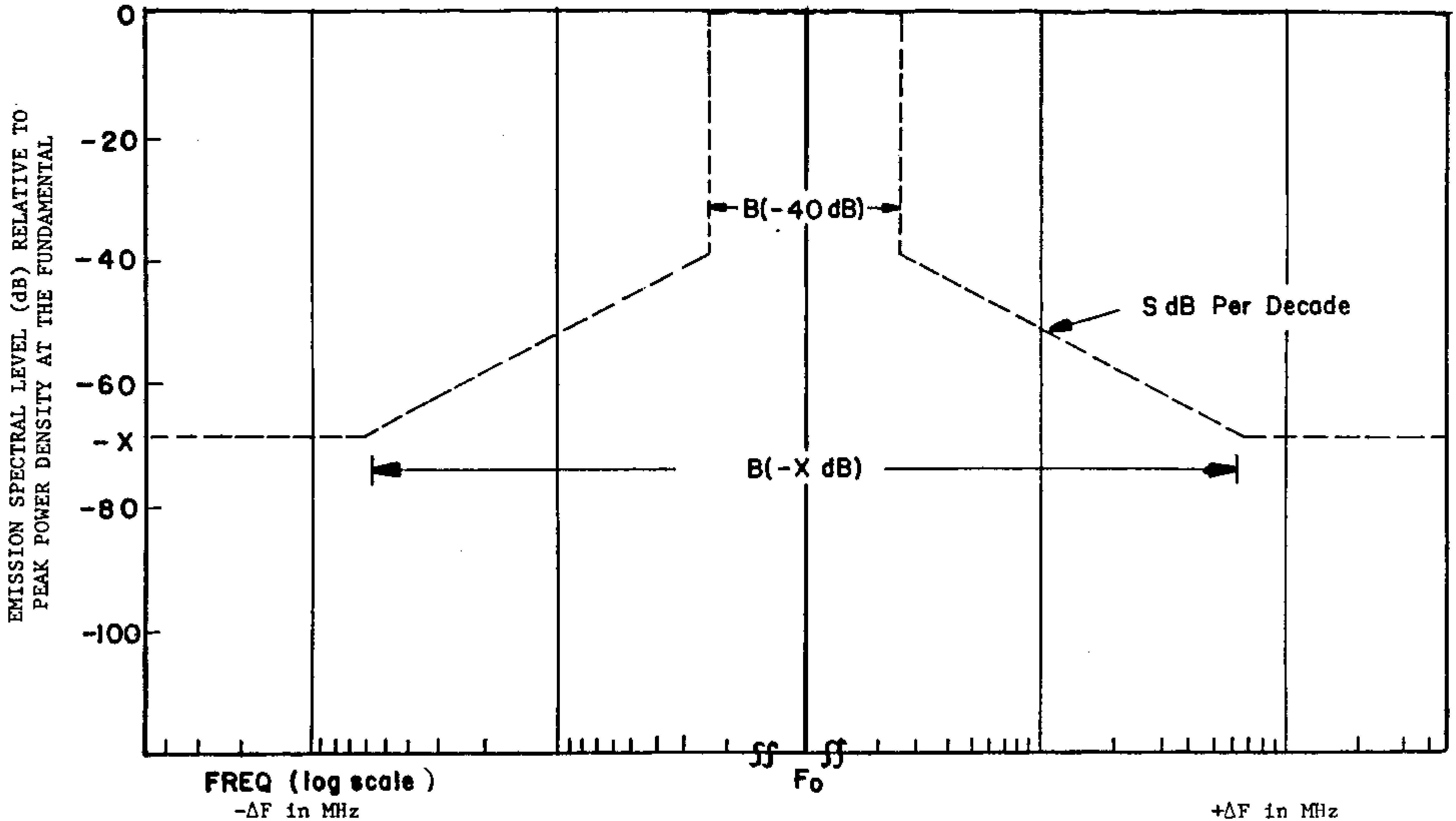


Figure 2-1. Radar Emission Bandwidth and Emission Levels.

TABLE 2-2

FORMULAS FOR CALCULATING B(-40 dB)

	Type of Radar Emission	B(-40 dB) MHz
(A)	Pulse, non-FM	$K/(t_r t)^{1/2}$, Notes 1, 2
(B)	Pulse, FM	$K/(t_r t)^{1/2} + 2B_C$, Note 3
(C)	Pulse, Frequency-Hopping	$K/(t_r t)^{1/2} + 2B_C + B_S$, Note 4
(D)	CW	$0.0003\ F_O$
(E)	FM/CW	$0.0003\ F_O + 2B_d$

NOTES:

1. Including spread spectrum or coded pulse radars.

2. Up to a maximum of 64/t.

3. For FM-pulse radars with pulse rise time of less than 0.1 microseconds, an operational justification for the short rise time shall be provided.

4. These formulas yield the total composite B(-40 dB) bandwidth of a frequency hopping radar as if all channels included within Bs were operating simultaneously. Individual channels will have a B(-40 dB) radar emission given by cases A and B above. For frequency hopping radars, the radar shall not intrude into adjacent spectrum regions on the high or low side of the band, defined by Bs, more than would occur if the radar were fixed-tuned at carrier frequencies equivalent to the end values of Bs and was complying with the constraints of radar emission types A and B above.

B_C = bandwidth of the frequency deviation (the total frequency shift during the pulse duration) in MHz.

B_d = bandwidth of the frequency deviation (peak difference between instantaneous frequency of the modulated wave and the carrier frequency) (FM/CW radar systems).

B_S = maximum range in MHz over which the carrier frequency will be shifted for a frequency hopping radar.

t_r = emitted pulse rise time in μsec. from the 10% to 90% amplitude points on the leading edge. For coded pulses, it is the rise time of a sub-pulse; if the sub-pulse rise time is not discernable, assume that it is 40% of the time to switch from one phase or sub-pulse to the next.

and:

$X(dB) = 60$ dB or
$X(dB) = P(t) + 30$
Whichever is the larger value for Groups B and C

$X(dB) = 80$ for Group D

$P(t) = P(p) + 20 \log(Nt) + 10 \log(PRR) - PG - 90$, where:

P(t) = maximum spectral power density, in dBm/kHz

P(p) = peak power, in dBm

N = total number of sub-pulses in pulse, N =1 for non-FM pulse and FM pulse radars

t = pulse width, in microseconds

PRR = pulse repetition rate, in pulses/sec*

PG = processing gain (dB), 0 for non-FM, non-encoded pulse radars
= 10 log (d), for FM pulse radars
= 10 log (N), for coded pulse radars

d = pulse compression ratio

Section 6.3 contains examples of numerical calculations and additional graphs.

It should be noted that there are no limits, per se, on peak power, pulse width, pulse rise time, or PRR. Sections 4 and 5 contain measurement procedures for these quantities, because they are needed as input parameters in calculations of the emission bandwidth limits and are, in addition, required data for frequency allocation procedures.

2.2. Antenna Pattern

Groups A and B: No requirement

For Group C and D:

Since electromagnetic compatibility considerations involve phenomena which may occur at any angle, the allowable antenna patterns for many radars may be usefully described by "median gain" relative to an isotropic antenna. Antennas operated by their rotation through 360 degrees of the horizontal plane shall have a "median gain" of -10 dB or less, as measured on an antenna test range, in the principal horizontal plane. For other antennas, suppression of lobes other than the main antenna beam shall be provided to the following levels, referred to the main beam:

first three sidelobes-17 dB;
all other lobes-26 dB.

*The PRR used in these calculations is the average PRR, as measured by a counter in a period of one second or longer.

2.3. Frequency Tolerance

Group A: Not covered by the RSEC, but Section 5.2.3 of the NTIA Manual may be applicable.

For Groups B through D:

Radar transmitters shall meet a frequency tolerance no larger than those noted below:

Frequency range (MHz)	Tolerance (Parts/Million)
below 960	400
960-4,000	800
4,000-10,500	1,250
10,500-30,000	2,500
30,000-40,000	5,000

2.4. Radar Tunability

Group A: No requirements

For Groups B and C:

Each radar shall be tunable in an essentially continuous manner either over the allocated bands for which it is designed to operate, or over a band which is 10 percent of the midband frequency. Crystal controlled radars conform to this requirement if operation at essentially any frequency across the band can be achieved with a crystal change.

For Group D:

Radar system shall be tunable over the entire 2700-2900 MHz band.

2.5. Radar Receivers

Group A: No requirement

Group B:

The overall receiver selectivity characteristics shall be commensurate with or narrower than the transmitter bandwidth, as portrayed in Figure 2-1. Rejection of spurious responses, other than image responses, shall be 50 dB or better except where broadband front ends are required operationally. Receivers shall not exhibit any local oscillator radiation greater than -40 dBm at the receiver input terminals. The frequency stability shall be commensurate with, or better than, that of the associated transmitter.

Group C and D:

The overall receiver selectivity characteristics shall be commensurate with the transmitter bandwidth, as portrayed in Figure 2-1. Receivers shall be capable of switching bandwidth limits to appropriate values whenever the transmitter bandwidth is switched (pulse shape changed). Receiver image rejection shall be at least 50 dB, rejection of other spurious responses shall be at least 60 dB. Radar receivers shall not exhibit any local oscillator radiation greater than -40 dBm at the receiver input terminals. Frequency stability of receivers shall be commensurate with, or better than, that of the associated transmitters.

2.6. Measurement Capability

Group A: No requirement

For Groups B through D:

In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary, an accuracy of ± 100 parts in 10 exp6 is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy. Accordingly, each Government agency shall have access to the instrumentation necessary to make a frequency measurement to at least ±100 parts in l0exp6 and suitable oscilloscopes and spectrum analyzers to measure time and frequency parameters necessary to determine conformance with these criteria. For fast rise time devices, such as magnetrons, oscilloscopes with bandwidths of at least 50 MHz should be used.

3. GENERAL MEASUREMENT PARAMETERS AND TEST CONDITIONS

3.1. Introduction

The recommendations made in this section, if implemented, should provide with reasonable confidence, data that is representative of the radar. It is not practical to exhaustively test a radar under all anticipated operational configurations and operating conditions. The following sections contain guidance to agencies, recommending a practical subset of test conditions and configurations.

3.2. Radar-tuned Frequencies

The radar-tuned frequencies, F(0), to be used in the emission and susceptibility tests to verify compliance with the RSEC are summarized in Table 3-1.

3.3. Frequency Test Range for Spurious Emissions

At a given radar-tuned frequency, a radar should be tested for spurious emissions continuously over the entire frequency range between F(Min) and F(Max) as defined below. In radar systems using a coaxial transmission line between the transmitter and antenna, F(Min) is the minimum of 0.5 F(0), or F(base) [where F(base) is the lowest frequency used in a frequency multiplying or frequency synthesizing method of generating F(0)]. In a system using waveguide to connect the transmitter to the antenna F(Min) is 0.5 F(0) or 0.9 F(co), whichever is greater. F(co) is the waveguide cutoff frequency.

F(Max) is defined by the following list:

F(O) (GHz)	F(Max) (GHz)
0 to 2	10 F(0) or 10 GHz, whichever is less
2 to 5	5 F(0) or 18 GHz, whichever is less
5 to 12	4 F(0) or 26 GHz, whichever is less
12 to 40	3 F(0) or 40 GHz, whichever is less

Note that measurements in waveguide systems at frequencies which are above the normal operating range of the waveguide (e.g., harmonics of a signal) are extremely difficult and may be impractical to make if accuracy is needed. The same inaccuracies and uncertainties occur in the calibration factors of waveguide directional couplers, in waveguide antenna feeds, and in all other waveguide systems operating at frequencies above their normal operating range. Therefore, if the possibility exists, perform this testing at points where the signal flows through coaxial components.

3.4. Reference Point for Measurements

The values determined for the radar parameters associated with transmitted or received signal amplitudes shall be referenced to the input to the antenna. When tests are performed at some other point in the system, additional calibration data must be obtained to convert measured data to the (sometimes

TABLE 3-1
SUGGESTED RADAR-TUNED FREQUENCIES FOR TESTING

TEST PARAMETER	RADAR TUNED FREQUENCIES (F_0) (Note 1)
Transmitter	
Power Output	F_L, F_M, F_H
Pulse Width and Rise Time	F_L, F_M, F_H
Emission Bandwidth	F_L, F_M, F_H
Spurious Emission	F_L, F_M, F_H
Frequency Tolerance	F_M
Transmitter Tunability	F_L, F_M, F_H
Antenna	
Antenna Gain and Sidelobe Suppression	F_M
Receiver	
Overall Selectivity	F_M
Spurious Response	F_L, F_M, F_H
Tunability	F_L, F_M, F_H
Frequency Stability	F_M
Oscillator Radiation	F_L, F_M, F_H

NOTE 1: F_L = Lowest nominal radar operating frequency.

F_H = Highest nominal radar operating frequency.

F_M = Radar operating frequency approximately halfway between F_L and F_H.

hypothetical) reference point at the input to the antenna. Test points are ranked as follows (most desirable first):

1) Radar signal sampler incorporated at the antenna input. (closed system)

2) Sampler inserted at antenna input. (closed system)

3) Sampler located somewhere between transmitter and antenna, but including any bandpass filters or other frequency-restrictive devices. (closed system)

4) A calibrated test antenna remotely located from the radar. (open-field)

3.5. Reporting of Data

The result of testing under several operational modes and at several frequencies will produce a large quantity of data, which may prove valuable in the future, and which should prudently be retained by the agency. The information included in system reviews requested of the SPS, should as a minimum include typical values obtained at F(M), a frequency near the midpoint of the operating range. An exception to this general rule occurs whenever characteristics, not in compliance with the RSEC are observed. These should be reported in addition to typical values of measurements.

3.6. Measurement Capabilities

The only measurement equipment specifications given in the RSEC are a frequency measurement capability of ±100 parts in l0exp6 and an oscilloscope bandwidth of at least 50 MHz.

4. TRANSMITTER OUTPUT POWER

4.1. Introduction

4.1.1. Objectives

Transmitter output power, measured in terms of the peak power, P(p), is obtained by using this procedure. The peak power is used together with other radar characteristics to establish which set of RSEC specifications must be met by the radar under test. In particular, the peak power is one of the parameters used in determining in which group a radar belongs (Table 2-1) and in determining how much ultimate suppression, X(dB), is required in the emission spectrum of the radar.

Average power, P(a), is also a useful parameter which should be measured in a radar. For simple radars, the relationship P(a) = P(p)xPWxPRR may be used to calculate P(a) if P(p) is known, and vice versa. This section contains a procedure for direct measurement of Peak power incorporating the same equipment set-up used for pulse shape measurement (Section 5). An alternative procedure is also described which shows the measurement of average power.

4.1.2. Definitions

The peak power is defined as the power of the nominal "flat-top" level of the transmitter pulse, as measured at the radar antenna input port. Measurements made elsewhere in the system must be corrected to the antenna input port.

4.1.3. Specification Limits

There are no RSEC limits on transmitter peak power. Transmitter power will be determined by user operational requirements.

4.1.4. Test Conditions

Peak power should be measured for all possible normal modes of operation. Table 3-1 recommends that these tests be done for a low, middle, and high operating frequency.

Absolute antenna gain measurements are generally difficult to make accurately. Therefore, the selection of a closed-system measurement point for peak power will be strongly preferred over an open-field measurement. (See Section 3.4).

4.1.5. Relation to Other Measurements

This procedure and test set-up is identical to the first several steps of the radar pulse shape measurement procedures. Measurement of peak power can be obtained as part of the pulse shape measurement procedures, with the following additional considerations:

1. Less rigorous bandwidth requirements are needed to make peak power measurements; the measurement system only has to respond accurately to the pulse width so that the nominal flat-top amplitude can be determined.

2. Absolute amplitude calibration must be maintained in measurements of peak power. Therefore, care should be taken to obtain a calibration accuracy of 1 dB or better at the antenna terminal. Open field measurements will usually be much too inaccurate to provide a useful measurement of transmitter power, although good pulse shape data can often be obtained from open-field measurements.

3. Additional radar component calibration data may be needed in order to relate the peak power measured at the detector to the peak radar power at the antenna input terminal. This additional data will generally be limited to system losses between the signal sampling point and the antenna.

4.2. Measurements

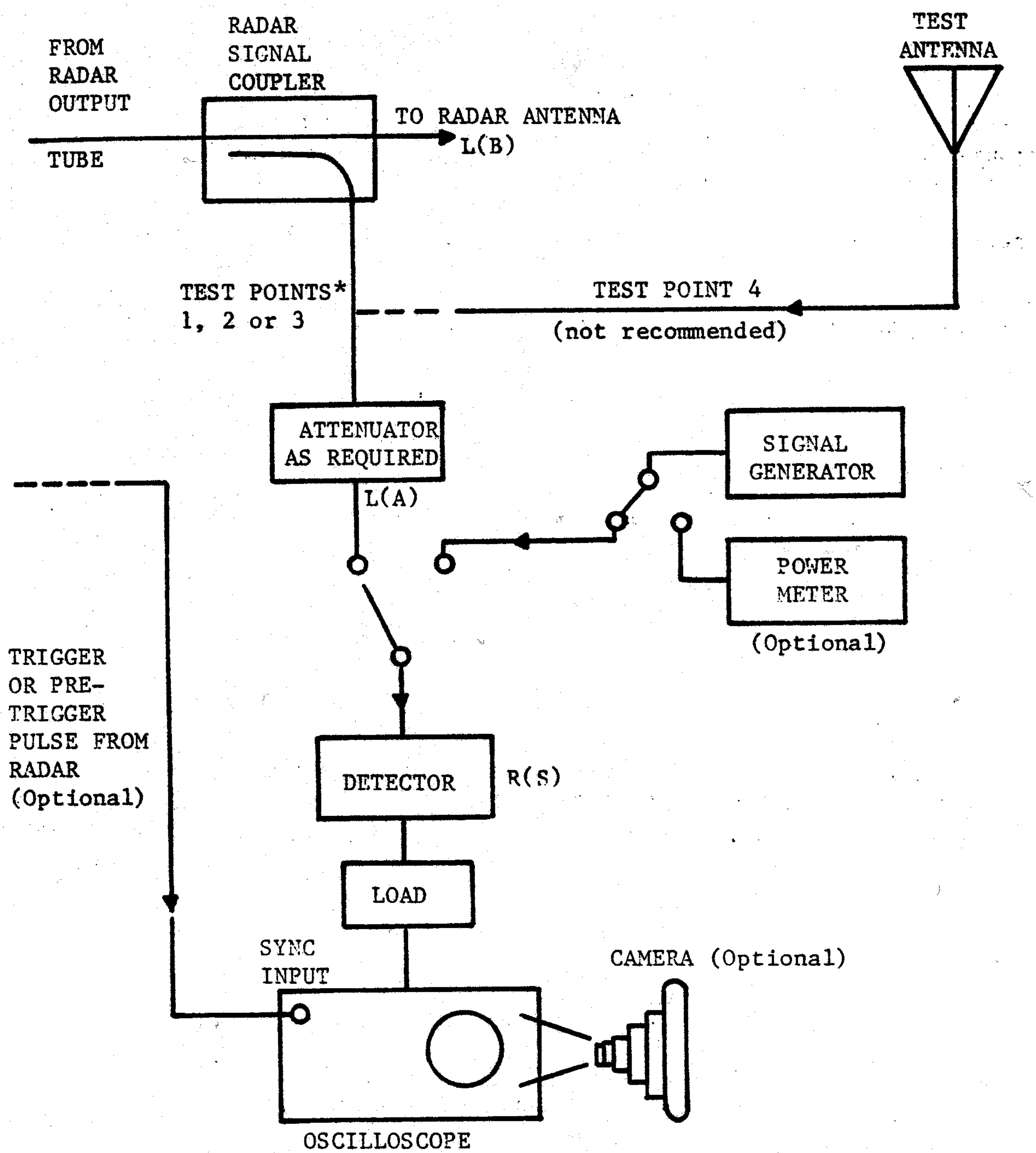
4.2.1. Instrumentation

The required test set-up is shown in Figure 4-1. Radar signals are typically obtained through a waveguide coupler with known coupler insertion loss. An attenuator may be needed to reduce the amplitude of a test signal to place it within the measurement range of the crystal detector. The wideband crystal detector is used to convert the radar RF pulse into a DC waveform corresponding to the envelope of the RF pulse; the DC waveform is displayed by the oscilloscope using a DC-coupled input mode. An oscilloscope camera may be used to record the pulse for further analysis, particularly if the pulse shape is sufficiently non-ideal so that some effort is required to establish the position of the nominal pulse flat-top. A signal generator, preferably with internal pulse modulation capabilities, tuned to the approximate radar frequency, is used to provide amplitude calibration of the detector and to verify that the system has adequate bandwidth for accurate pulse measurements. The power meter is to be included in the measurement equipment if the signal generator does not contain sufficiently accurate internal amplitude calibration capabilities.

Several precautions must be observed in order to avoid EQUIPMENT DAMAGE or INVALID MEASUREMENTS:

1. Peak and average power levels produced by the radar may burn out measurement equipment. Before any equipment is assembled for these measurements, calculate the peak and average power levels expected to be seen at the test point selected. If attenuators are needed to decrease peak or average power to usable levels, be sure that the rated power dissipation of the attenuator is at least as large as the expected average power of the radar signal at that point. Additional attenuation should also be inserted if peak power levels exceed the burnout level of the crystal detector. Assume a detector burnout level of +20 dBm if no other data is available on the detector being used.

2. Most detectors have a high output impedance, which will stretch out the pulse trailing edge considerably and may continuously charge the output to the voltage produced by the peak pulse power. These detectors require a low impedance load to operate properly. If no other data is available, assume that 50 ohms or 75 ohms is the required load. If the oscilloscope input or the



*See paragraph 3.4

Figure 4-1. Instrumentation for Peak Power Measurements.

detector output has a low impedance internal load, no external termination will be needed, but the cable connecting the oscilloscope to the detector must match the impedance of the internal load. All amplitude calibration must be performed with the selected termination in place. Some crystal detectors employ AC-coupled output circuits. CW signals cannot be used to calibrate these. Use a pulsed signal generator with duty cycle and pulse width characteristics similar to the radar under test.

3. The bandwidth of the detector/oscilloscope system must be tested to assure a rise time measuring capability of less than one-fifth the radar pulse width. A measurement system response time which is too slow will prevent the actual pulse peak amplitude from being seen. The time response of the system may be tested by using the internal pulse generation capability of the signal generator to generate a pulse with a duration substantially shorter than that of the radar under test. If this test shows a well-behaved trapezoidal pulse relatively free from overshoot or "glitches" on the leading or trailing edges, with rise and fall times less than 1/5th the pulse duration of the radar under test, one may assume adequate instrumentation bandwidths. If the above conditions are not met, it will be necessary to try another signal generator, termination arrangement, or oscilloscope.

4.2.2. Test Procedures

Before any equipment is connected to the radar, be sure that expected radar power levels in the measurement system have been calculated and that adequate attenuation has been inserted to protect measurement instrumentation. Set up the test instrumentation according to the procedures in 4.2.1. This may be described using a form similar to the Radar Peak Power Data Form (Figure 4-2).

a. Connect the signal generator to the detector and apply a gated +10 dBm signal with the same pulse width and PRR as the radar's, using the fastest rise time setting on the signal generator. Note the waveform and maximum pulse amplitude on the oscilloscope display. The oscilloscope display should show a nearly rectangular pulse (flat on top), with very fast rise and fall times, and with only a small amount of overshoot. Adjust the oscilloscope triggering and sweep rates to give a good picture of the entire pulse.

b. Connect the detector to the RF signal from the radar and adjust the attenuation to give about the same oscilloscope deflection as in step a. The peak signal level from the radar is now nearly +10 dBm.

c. The use of the oscilloscope external trigger input with a pretrigger pulse from the radar will often facilitate getting a stable trace on the oscilloscope. The oscilloscope trace will be considered suitable for peak power measurements if the radar pulse nominal flat-top can be determined.

d. From the oscilloscope trace of the radar pulse, determine the nominal flat-top amplitude, using the criterion described in Section 5.1.2. Mark this amplitude on the oscilloscope screen or record its position in some other suitable manner.

e. Remove the radar signal from the crystal detector and connect the signal generator to it. Adjust the signal generator to the same PRR and

DATE *Oct. 17, 1979*

Opr. *D. Jones*

Equipment under Test

Transmitter nomenclature *FPN-395A* Ser. No *3*

Freq 3000 *MHz* Mode *3us PW* PRR *395 pps*

Selected Sampling Point:

ITEM - NOTES	LOSS (dB)
Waveguide Coupler (Type N14/A) - (Measured)	*55.0*
20 ft. test cable (Measured at 3000 *MHz)*	7.2
10 dB Attenuator (Calibrated)	*10.1*
Total loss between sampling point and detector,= L(A)	*72.3 dB*

Signal loss between sampling point and antenna input

ITEM - NOTES	LOSS (dB)
Coupler (Mainpath) - (Measured)	0.3 *dB*
Waveguide, Switches, TR, Rotary Joint, etc. (Measured)	0.9 *dB*
Total loss from sampling point to *Antenna Input, L(B)*	1.2 *dB*

Figure 4-2. Radar Peak Power Data Form (Page 1 of 2).

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Reference signal:

Signal generator level Rg *12.6 dBm*

Cable losses to det. *0*

Net signal at detector, R(S) *12.6 dBm*

Peak Power calculations

P(P) = R(S) + L(A) - L(B)

P(P) = 12.6 + 72.3 - 1.2 = 83.7 dBm

Average Power (Optional)

PRR *395 pps* 10 log PRR *25.9*

Pulse width *3 us* 10 log PW *4.8*

$P_a = P_P + 10 \log (PRR) + 10 \log (\text{pulse width}) - 60$

$P_a = 83.7 + 25.9 + 4.8 - 60 = 54.4$ *dBm*

Figure 4-2. Page 2 of 2.

pulse width as the radar. Adjust the signal generator amplitude until the detector output is equal to the nominal flat-top amplitude determined in step d. Note the signal generator output reading, R(g) in dBm. Record the loss of the cable connecting the signal generator to the detector. Calculate the signal level at the input to the detector R(S) as indicated in Figure 4-2.

f. Measure or otherwise determine the following losses: L(A) =loss (dB) from coupler input to crystal detector input, including coupler loss and any external attenuators. L(B)=loss (dB) from coupler input to antenna input

g. Calculate Peak power, P(p) (dBm) = R(S) + L(A) - L(B)

Repeat for other radar operating mode/frequency/pulse modulation combinations. If the measured values of peak power are the same for all combinations, it will not be necessary to submit multiple data on peak power. If different powers are measured, each peak power reading should be identified with the respective operating conditions.

4.3. Sample Data and Calculations

Figure 4-2 is a sample completed data form. There is no requirement to use this form, but it provides a means of recording the data needed for the peak power calculations.

The form contains an initial section identifying the radar under test (type and serial number), as well as the particular operating condition of the radar (frequency, PRR, mode).

The next section of the form contains several lines which may be used to itemize losses between the selected sampling point and the crystal detector. In the example shown in Figure 4.2, the only elements included are the coupling loss of a waveguide coupler (measured at 55.0 dB), a 20-ft cable between the coupler and the detector (measured at 7.2 dB at 3000 MHz), and a 10-dB attenuator (with a 10.1 dB calibration indicated). The total of these losses is 72.3 dB between the sampling point and the detector.

Note that the selected sampling point must be a point in common between the signal path to the antenna and the signal path to the detector; therefore, the input to the waveguide coupler was selected.

The next section of the form contains data on losses between the selected sampling point and the antenna input terminal. Since the peak power measurements must be referred to the antenna input terminals, measurements at the detector must be corrected to that point (not to the radar tube output).

The next section contains data on the signal generator source. A line is provided for cable losses between the generator and the detector. In the sample problem, cable loss is 0 dB since the detector is connected directly to the generator output. It would also be equal to 0 dB if a power meter were used to calibrate the signal at the detector end of the RF cable.

Using the data in the above sections, the peak power calculations result in +83.7 dBm. Finally, an optional section is included which allows conversion of peak power to average power. The calculation of average power is thereby facilitated.

4.4. Alternative Measurement Methods

The test procedure described in the previous two sections was selected because it is conveniently performed with commonly-available equipment and because it can conveniently be done in conjunction with the pulse shape measurements. In addition, it results in highly accurate measurements of peak power. Alternative techniques have also been identified which may have advantages in certain situations, but which are felt to have somewhat limited applicability. These will be mentioned in the remainder of this section, chiefly so that several potential problems in using them for RSEC measurements can be pointed out. With care, these alternative methods may be employed to give accurate measurements of radar peak power. The following alternative methods will be considered:

a. Average power meter conversion
b. Peak power meter

4.4.1. Average Power Meter Conversion

In this method an average power meter is used to measure the average power output of the radar. If the radar has a sufficiently simple modulation type that the relationship between average power and peak power can be accurately determined, this method gives accurate answers with simpler procedures than described in Sections 4.2 and 4.3. The average power can be converted to peak power by the following formula:

$$P(p) = P(a) - 10 \log (PRR) - 10 \log (PW) + 60$$

where

P(a) = average power, in dBm

P(p) = peak power in dBm

PRR = pulse repetition rate, in pulses per second

PW = pulse width in microseconds

In the test set-up for this measurement, the sampled radar signal is connected directly to an average reading power meter. Sufficient signal path attenuation should be provided to give a full-scale meter reading with one of the middle sensitivity ranges for the selected power meter and sensor head.

NOTE: ONLY THERMISTOR-TYPE OR THERMOCOUPLE-TYPE POWER METERS SHOULD BE USED FOR THIS MEASUREMENT. These power meters are inherently designed to withstand the peak pulse power of the radar, which may burn out other types of power meters. In particular, power meters utilizing diode detection of the RF signal or utilizing samplers may be burned out by the high peak power of the radar pulse. The thermal time constant of most thermistor and thermocouple type power meters is sufficient to average out the pulse power, thus protecting the meter. Check the power meter specifications for limitations on measuring short pulses before using the meter for this measurement.

The remainder of the measurement procedure is as follows. Use the power meter to measure the average power. Convert the average to peak power at the power meter using PRR and pulse width data. The calculated peak power is called "R(S)." Convert the peak power values at the power meter to peak power values at the antenna terminal, using the formula: $P(p) = R(S) + L(A) - L(B)$.

This technique provides relatively accurate average power measurements. The major limitation in converting average power measurements to peak power is due to inaccuracies in measuring the pulse width, particularly if the pulse is not an ideal rectangular pulse. For some pulse shapes, the standard definition of pulse width may not be suitable to provide values for this power measurement method.

4.4.2. Peak Power Meter

This measurement method utilizes a peak power meter to directly measure the peak power of the radar at a suitable sampling point. This method is accurate and practical only if the radar pulse peak coincides with the value of the nominal flat-top, i.e., if the radar pulse has negligible overshoot at the leading or trailing edges. Most peak power meters respond sufficiently fast so that they will measure the maximum amplitude of leading or trailing edge "glitches," resulting in measurements which are higher than the value which would have been selected from the nominal flat-top criterion (see figure 4-3).

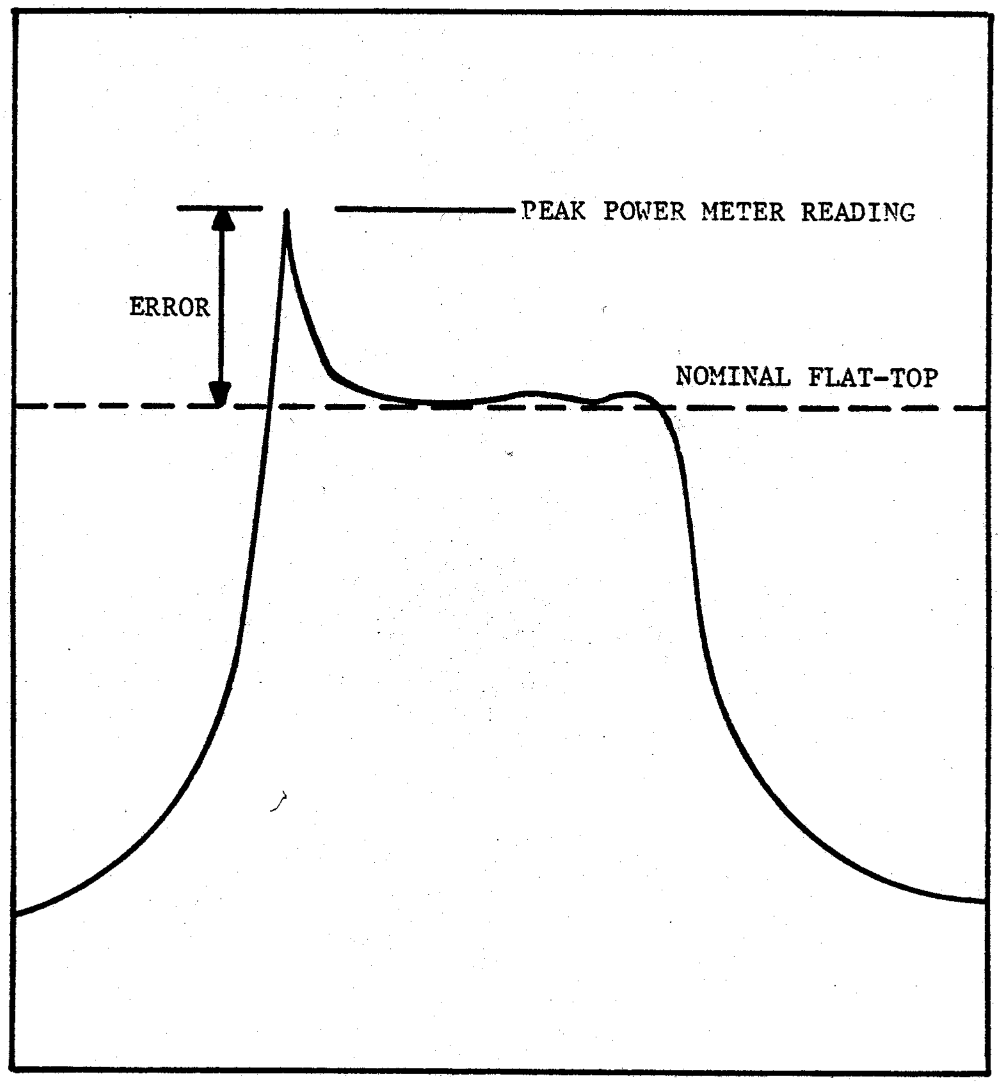


Figure 4-3. Source of Peak Power Meter Errors.

5. TRANSMITTER PULSE SHAPE

5.1. Introduction

5.1.1. Objectives

Pulse width, t, and pulse rise time, t(r), are the quantities which are to be measured by means of this test procedure. In addition, a picture of the entire pulse shape is often useful, especially if the pulse shape includes any significant departures from a trapezoidal pulse.

The RSEC uses the combination of pulse rise time and pulse width to establish the emission bandwidth limits at the -40 dB level. The same test set-up is used for the pulse width and the pulse rise time measurements, although less measurement system bandwidth is usually needed if only pulse width is measured. Note that the same test set-up can be used for the measurement of peak power and that it will often be desirable to perform all of these tests at the same time.

5.1.2. Definitions

The transmitter pulse width and risetime are defined by the RSEC as follows:

> "t = emitted pulse duration in microseconds at 50 percent amplitude (voltage) points. For coded pulses, the pulse duration is the interval between 50 percent amplitude points of one chip (sub-pulse). The 100 percent amplitude is the nominal flat top level of the pulse as shown in Figure 5-1."

> "t(r)= emitted pulse rise time in microseconds from the 10 percent to the 90 percent amplitude (voltage) points on the leading edge. See Fig. 5-1. For coded pulses it is the rise time of a sub-pulse; if the sub-pulse time is not discernable, assume that it is 40 percent of the time to switch from one phase or sub-phase to the next."

The criteria for defining the amplitude at which the nominal flat top level occurs is not given in the RSEC. The following guideline is suggested for establishing the "nominal" amplitude: the nominal flat top level will be that amplitude which is exceeded by the pulse for 50 percent of the time that the pulse is above one-half of the maximum pulse amplitude as illustrated by the dashed line in Figure 5-1.

5.1.3. Specification and Limits

Accuracies of ± 5 percent on measurements of t and t(r) are acceptable. There are no limits on the values of t and t(r), per se, but the RSEC does state that the use of t(r) smaller than 0.1 microsecond for FM pulse-radars or less than 0.01 microsecond for frequency-hopping radars must be justified on the basis of operational or technical necessity.

5.1.4. Preferred Test Point

The preferred test point is defined in paragraph 3.4 and the same one should be used for all measurements of pulse parameters and emission spectra.

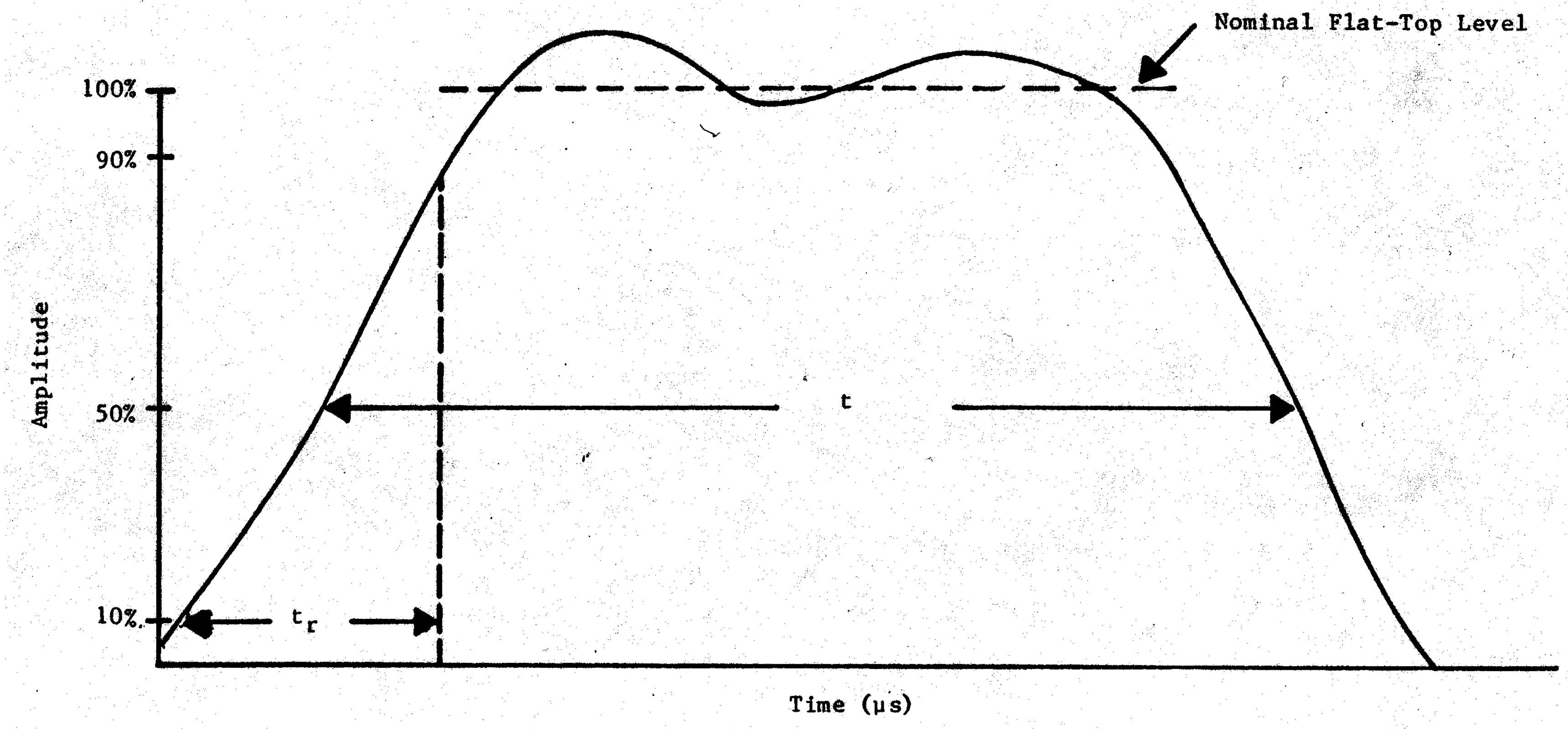


Figure 5-1. Determination of t and t_r.

Pulse shape measurements which are made "closed system" (measurement points 1, 2, or 3 in Figure 5-2) can generally be made on an absolute basis and will provide accurate data on peak pulse power, as well as pulse shape. Open-field tests of pulse shape are generally sufficient to provide accurate data on relative pulse shape, but include too much system gain uncertainty to provide accurate data on peak power.

5.2. Measurements

5.2.1. Instrumentation

The required test set-up is shown in Figure 5-2. Radar signals are typically obtained through a waveguide coupler or from a calibrated test antenna, depending on the selection of the test point. Attenuators may be needed to reduce the amplitude of a test signal to place it within the measurement range of the crystal detector. A wideband crystal detector is used to convert the radar RF pulse into a DC waveform corresponding to the envelope of the RF pulse. The waveform is displayed by the oscilloscope which is in a DC-coupled input mode. An oscilloscope camera is used to record the displayed pulse shape for further analysis. A signal generator tuned to the approximate radar frequency, preferably with internal pulse modulation capabilities, is used to provide amplitude calibration of the detector and to verify that the measurement system response time is adequately fast for accurate measurements. The power meter is used solely to calibrate the signal generator output and may be omitted if the signal generator contains its own calibration capabilities.

The instrumentation described above has several limitations, which may result in EQUIPMENT DAMAGE or INVALID MEASUREMENTS if certain procedures are not followed:

1. Peak and average power levels produced by the radar may burn out measurement equipment. Before any equipment is assembled for these measurements, calculate the peak and average power levels expected to be seen at the test point selected. If attenuators are needed to decrease peak or average power to usable levels, be sure that the rated power dissipation of the attenuator is at least as large as the expected average power of the radar signal at that point. Additional attenuation should also be inserted if peak power levels exceed the burnout level of the crystal detector. Assume a detector burnout level of +20 dBm if no other data is available on the detector being used.

2. Most detectors have a high output impedance, which will stretch out the pulse trailing edge considerably and may even continuously charge the output to the voltage produced by the peak pulse power. These detectors need to be terminated properly. If the oscilloscope input or the detector output has a low impedance internal load, no external termination will be needed, but the cable connecting the oscilloscope to the detector must match the impedance of the internal load. All amplitude calibrations must be performed with the selected termination in place. Some crystal detectors employ AC-coupled output circuits. CW signals cannot be used to calibrate these. Use a pulsed signal generator with duty cycle and pulse width characteristics similar to those of the radar under test.

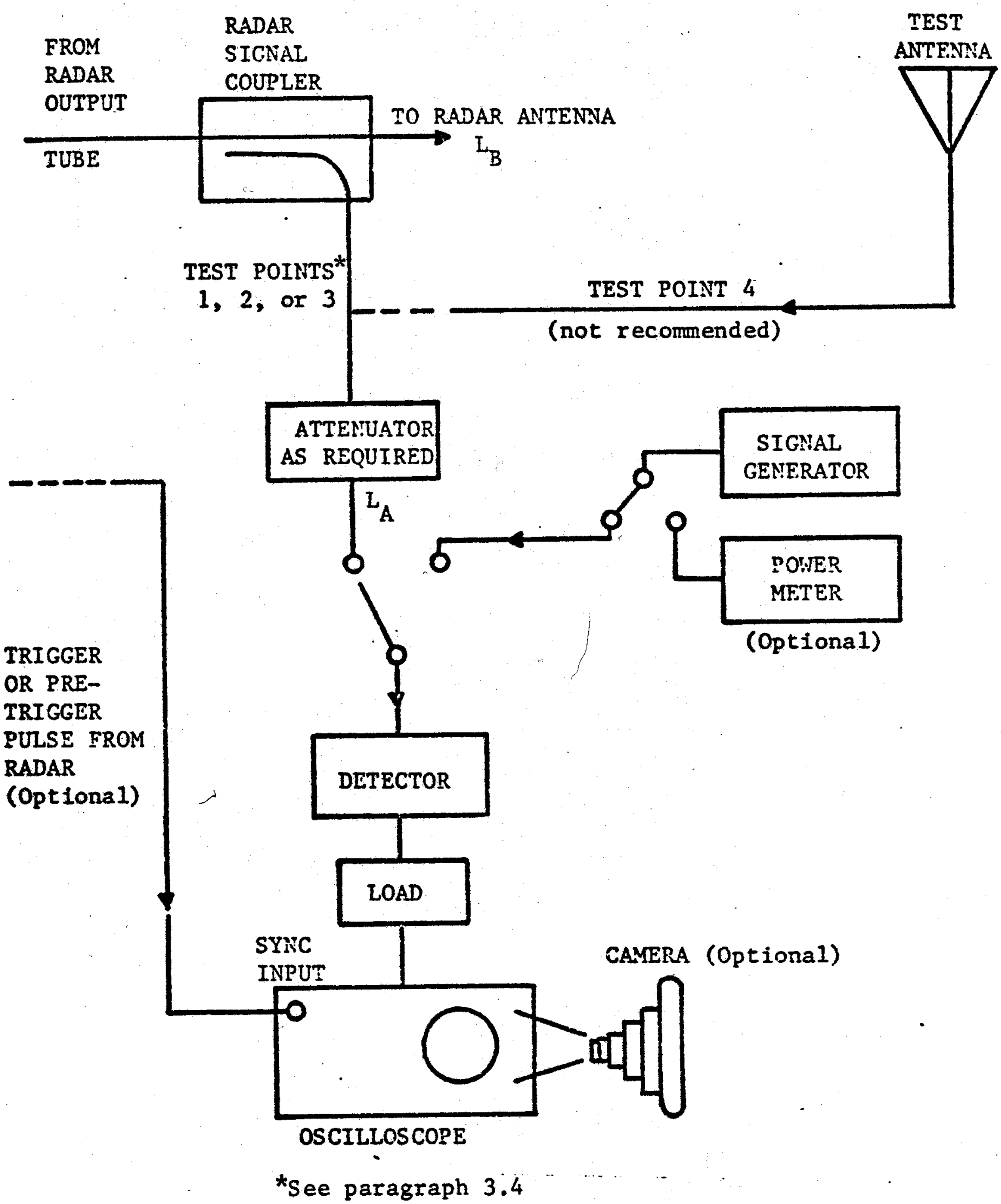


Figure 5-2. Instrumentation for Pulse Shape Measurements.

3. The bandwidth of the detector/ oscilloscope system must be measured to assure a response time of less than one-fifth the radar pulse rise time. A measurement system response time which is too slow will distort the pulse shape being measured. The time response of the system may be tested by using the internal pulse generation capability of the signal generator to generate a pulse with rise and fall times substantially shorter than that of the radar under test. If this test shows a well-behaved trapezoidal pulse relatively free from overshoot or "glitches" on the leading or trailing edges, with rise and fall times less than 1/5th the rise and fall times of the radar under test, one may assume adequate instrumentation bandwidths.

4. The crystal detector is not linear; therefore the 10 percent, 50 percent, and 90 percent voltage points for the RF signal may not appear to be 10 percent, 50 percent, and 90 percent voltage points at the DC output of the detector. A calibrated signal generator is needed to determine the exact DC output voltages for these input voltages. With a 100 percent reference level of 0 dB, the following relationships can be used to set the signal generator output:

90 percent . . . . -0.9 dB
50 percent . . . . -6.0 dB
10 percent . . . . -20.0 dB

Another problem with crystal detectors is that they do not produce much DC output until RF power levels are relatively high. This tends to lead to the use of detector power levels which are close to the burnout level.

5.2.2. Test Procedures

Before any equipment is connected to the radar, be sure that expected radar power levels have been calculated and that adequate attenuation has been inserted to protect measurement instrumentation. Set up and test instrumentation response according to procedures in 5.2.1. The test set-up may be described, using a form similar to Radar Pulse Shape Set-up Information Form (Figure 5-3). The measurement calibration and results may be recorded on a form similar to the Test Data Form for Radar Pulse Shape (Figure 5-4).

a. Connect the signal generator to the detector and apply a gated +10 dBm signal with nearly the same pulse width and PRR as the radar, using the shortest rise time setting. Note the waveform and maximum pulse amplitude on the oscilloscope display. The oscilloscope display should show a nearly rectangular pulse, flat on top with very short rise and fall times and little overshoot.

b. Connect the detector to the RF signal from the radar and adjust the attenuation to give nearly the same oscilloscope deflection as in step a. The peak signal level from the radar is now near +10 dBm.

c. Adjust the oscilloscope triggering and sweep rates to give a good picture of the entire pulse. (The use of the oscilloscope external trigger input with a pre-trigger pulse from the radar will often facilitate obtaining a stable trace on the oscilloscope.) This will occur

Date Oct. 17, 1979

Opr D. Jones

Equipment Under Test (Nominal Characteristics):

Transmitter Nomenclature FPN-395A   Serial No. 3

Tuning Range 2900 - 3100 MHz

Modulation PULSE ONLY

Nominal Pulse Width(s) 3   6 µs

Nominal PRR(s) 395   250 PPS

Nominal Peak Power +85   +85 dBm

Nominal Average Power +55.7   +56.8 dBm

Comments: FREQUENCIES: 2900, 3000, 3100

PULSE WIDTHS: TWO

TOTAL NUMBER OF TEST MODES = 6

Measurement Method:

Details and comments, if different from recommended procedure

STANDARD PROCEDURE

Test Equipment and Significant Control Settings:

TEKTRONIX 7623 OSCILLOSCOPE WITH 100MHz PLUG-INS

HP 8642 SIGNAL GENERATOR

AERODYNE 416 DETECTOR

Test Data:

Selected Test Point WAVEGUIDE COUPLER FOLLOWING SWITCH

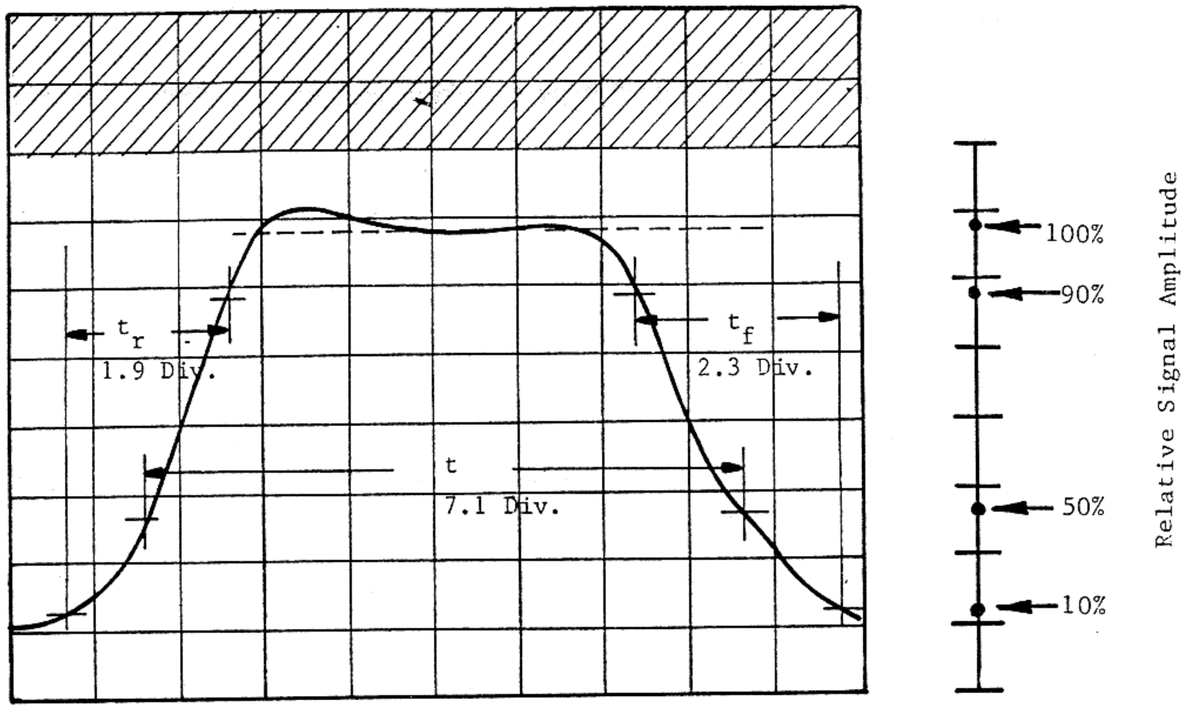
Signal Losses to Test Point 62.0 dB (MEASURED COUPLER LOSS)

Peak Power at Test Point 85-62 = +23 dBm

Average Power at Test Point ~56-62 = -6 dBm

Attenuation to Reduce Peak Power to +20 dBM 5 (USE 10dB PAD)

Figure 5-3. Radar Pulse Shape Test Set-Up Information Form



Pulse Width
Scale Factor 0.5 μs/div.

Rise Time
Scale Factor 0.5 μs/div.

Equipment Nomenclature FPN-395A

Photo No. 5 Measurement Method Standard Procedure

Test Equipment Bandwidth >10 MHz (Checked Okay)

Nominal Characteristics:

Frequency 3000 MHz PRR 395 pps

Pulse Width 3 μs Mode Short Pulse

Signal Generator Reference Level +14.3 dBm

Measured Values (from photograph):

*Pulsewidth (t = no. of div x s/div)

7.1 div X 0.5 μs/div = 3.55 μs

**Risetime (t_r = no. of Div x s/div

1.9 div x 0.5 μs/div = 0.95 μs

***Falltime (t_f = no. of div x s/div)

2.3 div x 0.5 μs/div = 1.15 μs

Comments: Same pulse shape measured for 2900 and 3100 MHz.

---

*50% Peak Voltage Point (6 dB below peak).
**10% to 90% of Peak Voltage (20 dB to .9 dB below peak).

Figure 5-4. Test Data Form for Radar Pulse Shape when the leading edge of the pulse is near the left edge of the display and the calibrated oscilloscope sweep rate is chosen to give the largest display that contains the pulse completely on-screen. Choose a vertical gain and offset (variable gain is satisfactory) that allows the pulse shape to fill the display. Photograph the pulse shape, making sure that the oscilloscope graticule can be seen distinctly.

d. If necessary, readjust the triggering and sweep to get a good display of the leading edge of the radar pulse. Do not change the vertical scale. The sweep should be adjusted so that the leading edge of the radar pulse extends over several major time divisions of the oscilloscope graticule. Take a photograph of the leading edge of the radar pulse, making sure that the oscilloscope graticule can be clearly seen.

e. Repeat "d" for the trailing edge of the pulse.

f. Record all pertinent data on the Test Data Form for Radar Pulse Shape (Figure 5-4). If the grid on the Test Data form is not identical to the oscilloscope graticule (for example, 8 x 10 divisions), cross out or add grid sections to make the Test Data graticule identical.

g. From the photograph of the pulse shape, determine the nominal flat top amplitude of the radar pulse. Project a line to the righthand Relative Signal Amplitude scale in Figure 5-4 and at the intersection label this as the 100 percent amplitude point.

h. Connect the signal generator to the crystal detector. Adjust the signal generator for approximately the same PRR and pulse width as that of the radar. Adjust the signal generator output amplitude until the amplitude of the pulse seen at the detector output is exactly equal to the radar nominal flat top pulse (called the 100 percent level). Decrease the generator output by 20 dB. This indicates the 10 percent (voltage) point on the oscilloscope. Mark this level on the amplitude scale as the 10 percent line. Note: If there is no distinct change in oscilloscope amplitude between the 10 percent pulse amplitude and zero signal, it will be necessary to go back to the first step of the measurement procedure and repeat it with 5 dB higher signal levels.

i. Increase the signal generator output to 6 dB below the 100 percent level. This indicates the 50 percent (voltage) amplitude. Mark the oscilloscope amplitude on the relative amplitude scale as the 50 percent point.

j. Increase the signal generator output to 0.9 dB below the 100 percent level. This indicates the 90 percent level. Mark the oscilloscope amplitude on relative amplitude scale as the 90 percent level. (If a 0.9 dB attenuator adjustment is not available, use a 1 dB step and interpolate to the 0.9 dB step).

k. Scale the levels determined in steps h. thru j. onto the photographs. Using sweep rate information for each photograph, determine the time between 50 percent points (equal to pulse width) and the time between the 10 percent and 90 percent points on the leading edge of the pulse (equal to pulse rise time). Repeat for other radar operating mode/frequency/pulse modulation combinations. If measured data for all the combinations give the same results, it will not be necessary to submit multiple data on t and t(r). It will be necessary, however, to state that measurements resulting in single values for t and t(r) were made on allowable combinations of radar operating modes.

5.3. Sample Data and Calculations

This section contains two completed forms, the Test Set-Up Information form (Figure 5-3) and the Test Data form (Figure 5-4). It will be assumed that both of these forms are used since the information contained on the forms illustrates the measurement techniques. There is no requirement to use this particular set of forms.

The test set-up information form contains nominal data on the radar which will be needed to select test modes, to calculate expected power levels at the detector, and to allow calculation of additional attenuation needed to protect the detector. The first section on the form describes the nominal characteristics of a hypothetical FPN-395A radar. If some of the radar characteristics have already been measured and are known more precisely, these values may be used instead of the nominal ones. Said radar incorporates two combinations of pulse width/PRR, each of which is to be tested at a low, middle, and high frequency, making a total of six tests required.

The last section of Figure 5-3 contains data on coupler loss and nominal peak and average power expected at the test point. The computed average power of -6 dBm presents no average power dissipation problem, so that any attenuator rated at 1/2 Watt or more can be used. The expected peak power of +23 dBm is higher than the desired +20 dBm, therefore a 10 dB attenuator is used in the signal path to reduce the peak signal to +13 dBm.

Figure 5-4 contains the values of data measured during the pulse shape test. For this illustration, the radar pulse has been drawn on the larger grid. Usually a photograph of the radar pulse would be attached at that position. Since the particular oscilloscope employed in the test uses an 8 x 10 grid, the upper two rows of the grid have been crossed out. The nominal characteristics show that the radar was tested using its nominal 3 microseconds pulse width (short pulse) mode at the middle of the operating frequency band (3000 MHz). A note at the bottom of the page states that tests were also made at 2900 MHz and 3100 MHz, giving identical results.

As soon as the pulse picture has been taken, a value is determined for the nominal flattop of the pulse. This amplitude is labeled "100 percent," a dot is drawn on the Relative Signal Amplitude Line at that amplitude. The amplitude of the pulse is measured by substituting the signal generator for the radar signal and for this sample case 100 percent amplitude corresponds to +14.3 dBm. Amplitude levels are also measured for the 90 percent, 50 percent, 10 percent, and 0 percent levels, with corresponding dots being located on the Relative Signal Amplitude line. Finally, lines are scaled on the photograph to identify these levels on the pulse. The appropriate distances on the photograph multiplied by the time per division gives the rise time, pulse width, and fall time.

5.4. Alternative Measurement Methods

The test procedure described in the previous two sections was selected because it has the highest degree of general applicability for a test method which utilizes commonly available radar test equipment and gives sufficiently accurate results. Several alternative methods are available which may offer advantages in particular situations. Although none of these alternative methods will be described in the detail with which the preceding method was described, the following descriptions will provide enough detail so that the knowledgeable engineer can fill in the remaining details. These alternative methods listed below, or any others that can be shown to produce data of acceptable quality may be used to make pulse shape measurements.

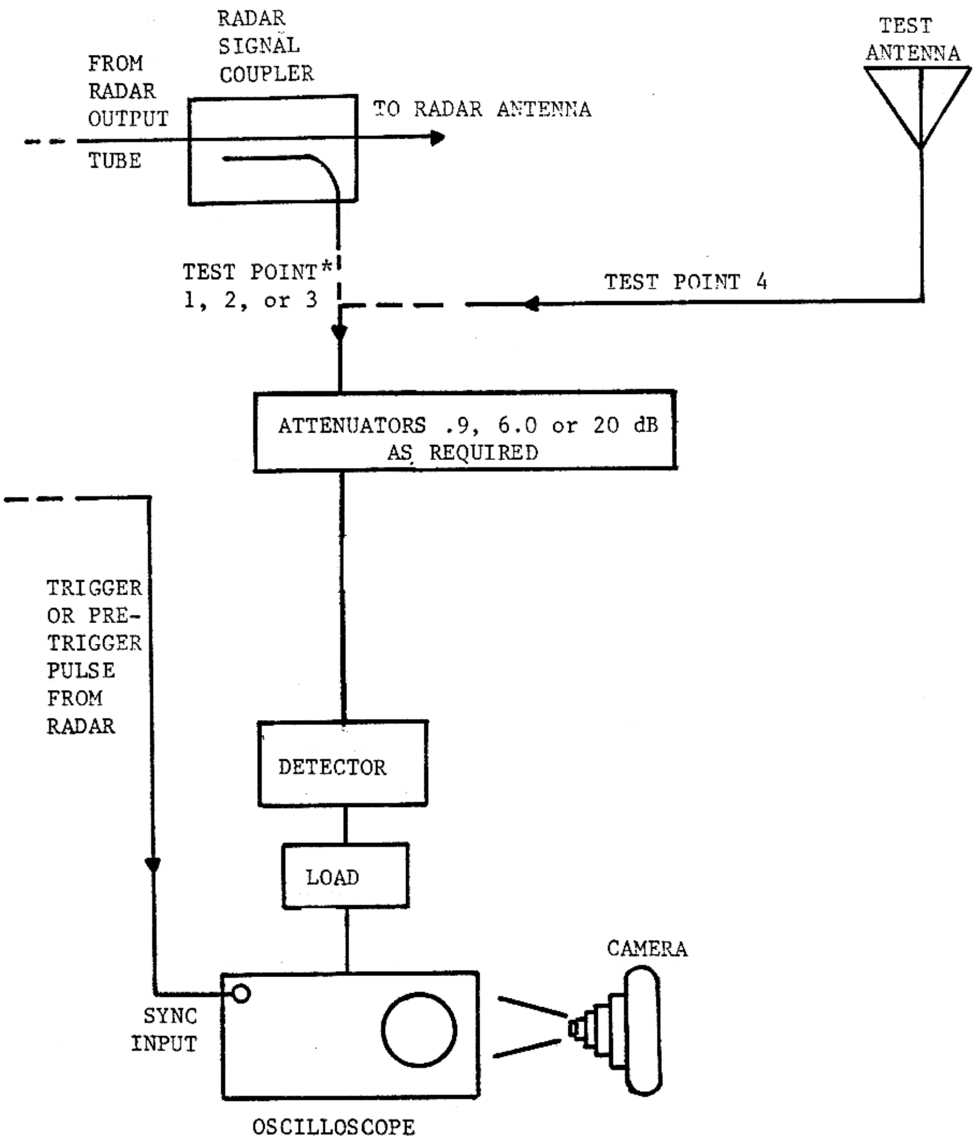
a. Crystal detector with 10 percent, 50 percent, and 90 percent attenuators.
b. Sampling or direct oscilloscope.
c. Detector Log Video Amplifier (DLVA).
d. Spectrum Analyzer.

5.4.1. Crystal Detector with 10 percent, 50 percent, and 90 percent Attenuators

This method is a variation of the method described in Section 5.2. Its major advantage is that a signal generator is not needed to make the tests provided that the measurement system has adequate bandwidth. Instead of using a signal generator to calibrate the output of the detector of the 10 percent, 50 percent, and 90 percent amplitudes, the radar signal itself is attenuated to 10 percent (20 dB), and 50 percent (6 dB), and 90 percent (0.9 dB). The method has two major disadvantages: it cannot be used to provide an absolute calibration of peak radar power, and it is often difficult to obtain a 0.9 dB attenuator.

A block diagram of said method is shown in Figure 5-5. Figure 5-6 shows the oscilloscope displays that are seen using this method. The measurements will be more convenient if oscilloscope sync is obtained directly from a pretrigger in the radar; using the oscilloscope with internal triggering will cause the position of the radar pulse to shift as the radar signal amplitude is changed.

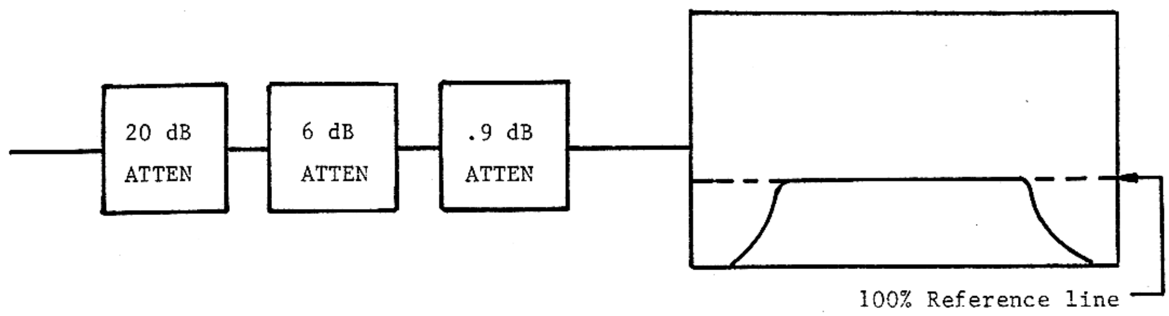
If the pulse shape is measured with a crystal detector and oscilloscope, the amplitude can be accurately marked by adjusting the vertical offset of the oscilloscope to make the 100 percent level fall exactly on one of the horizontal graticule lines (Step 1, Figure 5-6). If the RF pulse from the radar is increased exactly 10 percent, accomplished by removing 0.90 dB attenuation from the signal path, the portion of the radar pulse which is 90 percent of the reference level (Step 2, Figure 5-6) now falls exactly on the reference graticule line. If a total of 6 dB attenuation is removed from the signal path, the portion of the pulse which now crosses the reference line is 50 percent amplitude (Step 3, Figure 5-6). Finally, if a total of 20 dB attenuation is removed from the RF signal path, the portion of the pulse which was 10 percent of nominal peak amplitude will be indicated by the reference line (Step 4, Figure 5-6).



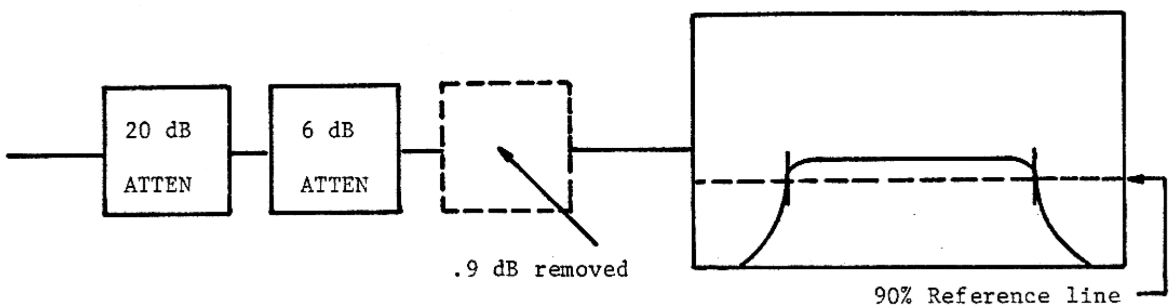
*See Paragraph 3.4.

Figure 5-5. Crystal Detector with 10%, 50% and 90% Attenuators.

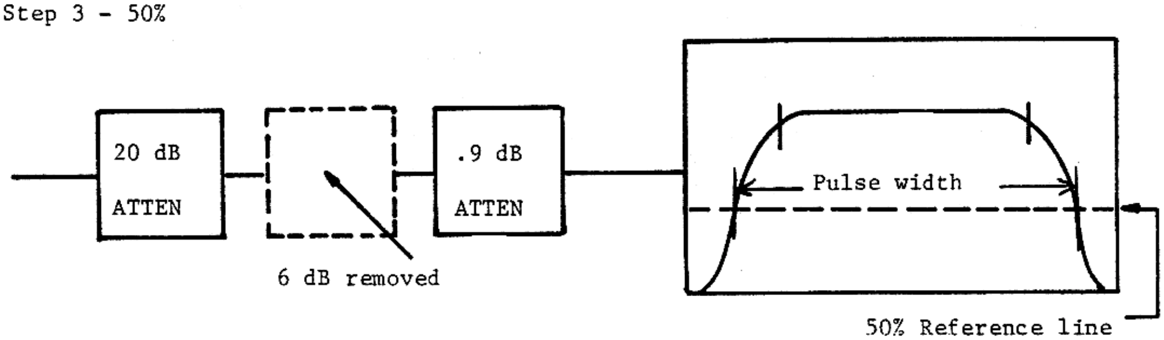
Step 1 - 100%



Step 2 - 90%



Step 3 - 50%



Step 4 - 10%

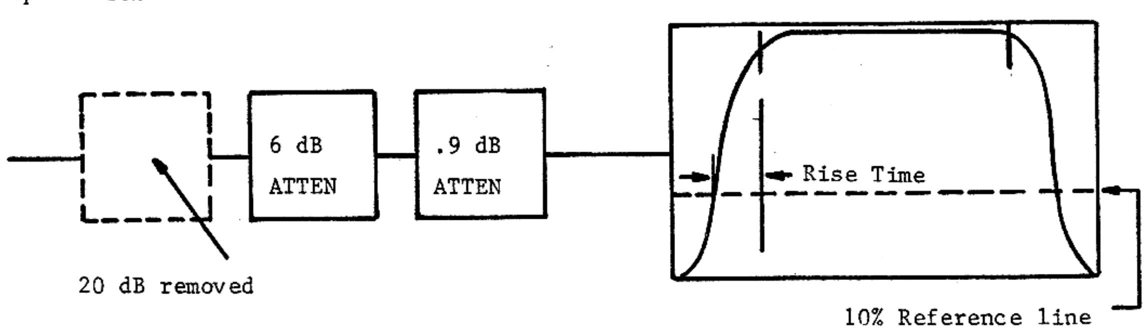


Figure 5-6. Crystal Detector Waveshapes with 10%, 50%, and 90% Attenuators.

By photographing the oscilloscope displays after each step, or by marking the points where each pulse trace crosses the reference line, the time interval between the 10 percent, 50 percent, and 90 percent points can be easily established, thereby establishing the desired pulse width and pulse rise time.

5.4.2. Sampling or Direct Oscilloscope

Conceptually, the easiest way to measure the shape of modulation on an RF pulse is to merely display the RF pulse itself on an oscilloscope. In this display, the 10 percent, 50 percent, and 90 percent levels of the RF amplitude will be linearly reproduced, and can be directly scaled from a photograph of the pulse. The major problem with the technique is that most of the oscilloscopes available do not have the frequency response necessary to display the RF frequency of the radar. A few oscilloscopes are available which will display frequencies up to 1 GHz. For frequencies above 1 GHz, it will be necessary to use a sampling oscilloscope. Figure 5-7 shows a block diagram of this measurement method. The major operational problem with the method is associated with properly triggering the oscilloscope. Read the oscilloscope instruction manual carefully for triggering instructions; also be aware of the peak voltages which may safely be placed on the oscilloscope input.

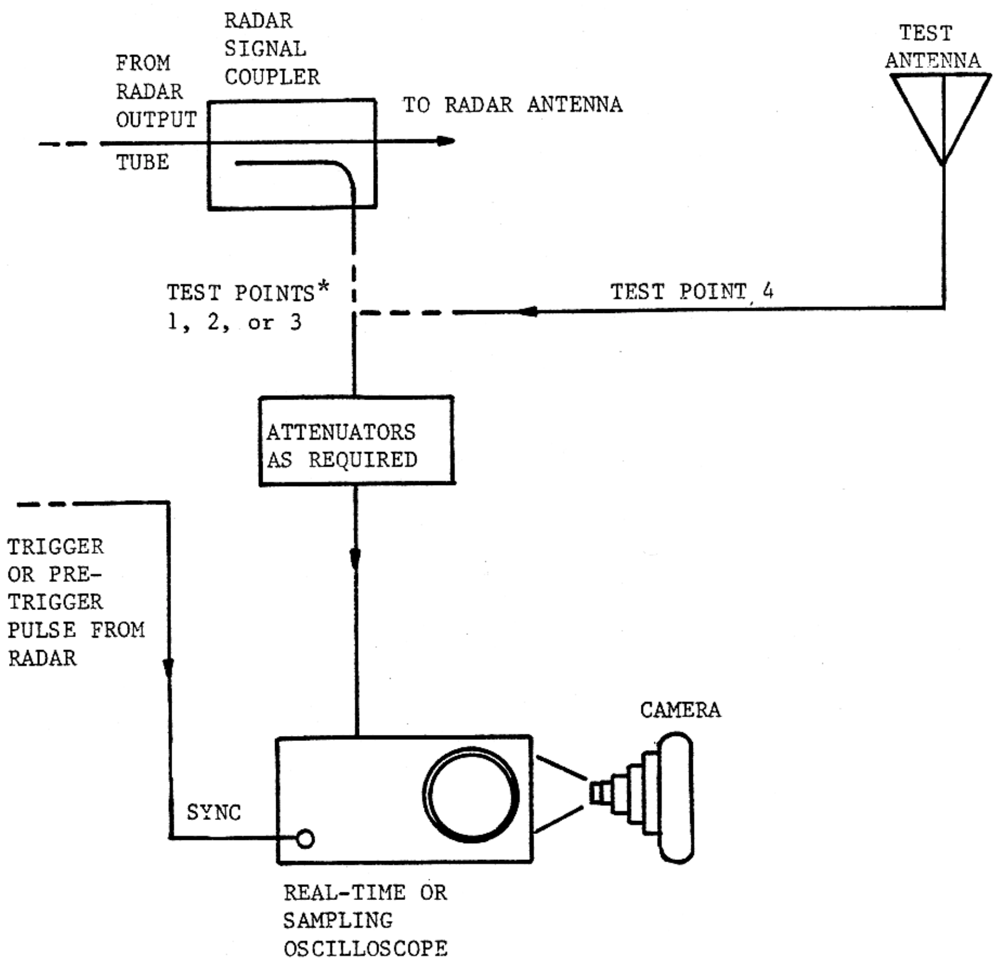
5.4.3. Detector Log Video Amplifier

This method is a variation of crystal detector methods, which utilizes a detector log video amplifier (DLVA) module in place of a crystal detector. The DLVA is a component available from several manufacturers which combines a crystal detector with some logarithmic shaping circuits to give a detector with a well-controlled logarithmic output characteristic over a 40 dB range. Thus, one or two 10 dB calibration points are all that are required to relate the logarithmic slope factor to the oscilloscope graticule. If the oscilloscope vertical gain is adjusted to make each graticule division exactly equal to 5 dB or 10 dB and the nominal top of the pulse is set exactly on a graticule line, the 90 percent, 50 percent, and 10 percent points can be directly read from the display (-0.9 dB, -6 dB, and -20 dB, respectively). Moreover, the amplitude of any point on the waveform can then be accurately determined. The measurement block diagram is identical to Figure 5-2, except that the detector and load are replaced with a DLVA.

There are two major disadvantages to this method. First, DLVA modules are not widely available. Second, the frequency response of typical DLVA modules is around 10 MHz, which will limit measurements to pulses with rise times of 0.2 microseconds or more.

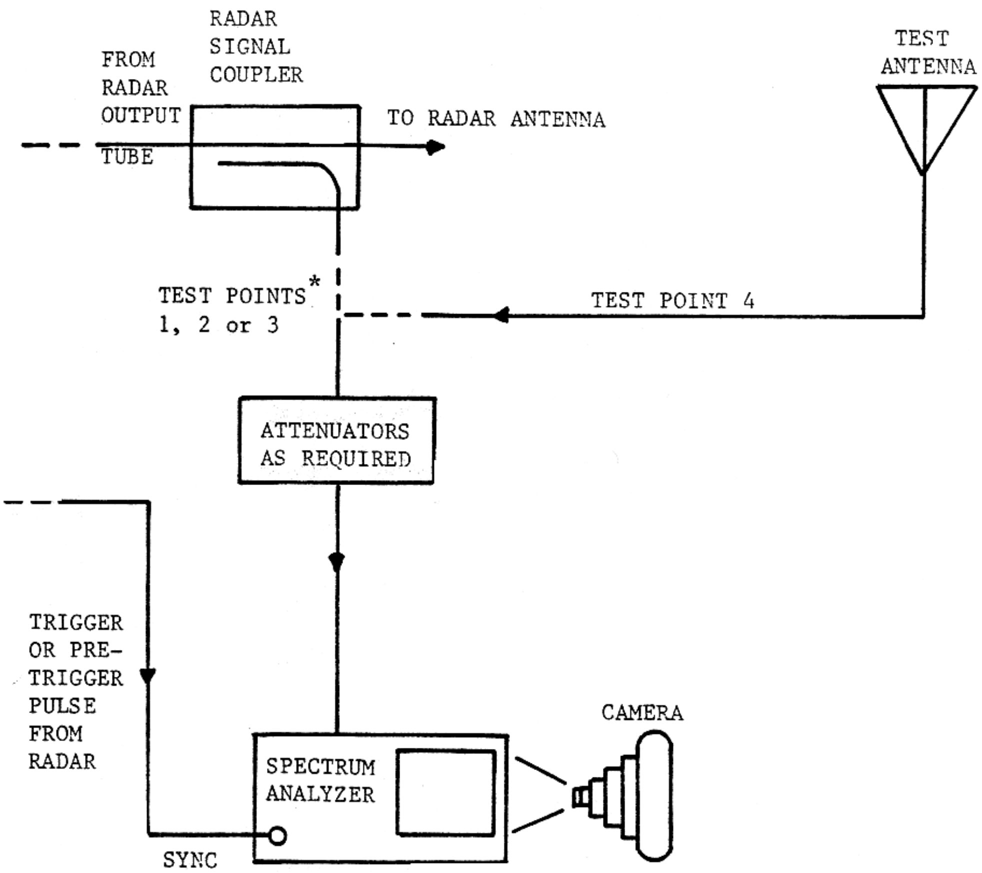
5.4.4. Spectrum Analyzer

A spectrum analyzer can be used in a zero-scan width mode to get a display of pulse shape which is well calibrated in amplitude and time. The chief problem with the use of a spectrum analyzer is that most spectrum analyzers have a maximum IF bandwidth of 300 KHz or 3 MHz. Thus, use of a spectrum analyzer is limited to measurements of radars with pulse rise times of more than 16 microseconds or 1.6 microseconds. It is a very convenient instrument to use, however, and later models of spectrum analyzers may have wider bandwidths available. A feasible configuration for measurements utilizing a spectrum analyzer is shown in Figure 5-8.



*See Paragraph 3.4.

Figure 5-7. Real-Time or Sampling Oscilloscope.



*See Paragraph 3.4

Figure 5-8. Spectrum Analyzer.

6. EMISSION SPECTRA

6.1. Introduction

6.1.1. Objectives

The measurements described herein are fundamental to spectrum conservation in radar bands. In general, most radars produce spurious emission sidebands, which are not needed for proper radar operation. These can cause interference to radars operating on adjacent frequencies. These spurious emission sidebands are caused by certain non-ideal characteristics of the radar transmitter.

Since various radar functions require different signal bandwidths to perform properly, it is not reasonable to set a single allowable emission bandwidth for all radars. Therefore, the RSEC provides formulas to calculate the allowable radar emission bandwidth and maximum spectral level, based on specified radar operating characteristics. These radar characteristics include the pulse width and the rise time of the pulse, and the radiated power of the radar. In addition the age of the radar is considered in these calculations. Newer radars are required to meet more stringent specifications. The details of these calculations are available in the RSEC and in Tables 2-1 and 2-2.

6.1.2. Definitions

The measurement parameters of emission spectra of radars is spectral power density, P(t), in dBm/kHz. This parameter is the average power per unit bandwidth, averaged over a complete radar pulse repetition cycle. In practice, spectral power density of a radar signal is difficult to measure directly. Therefore the RSEC gives a formula for calculating spectral power density from parameters that can be measured.

$$P(t) = P(p) + 20 \log(Nt) + 10 \log(PRR) - PG - 90,$$ where:

P(p) = peak power, in dBm

N = total number of subpulses in pulse (N=1 for non-FM pulse and FM pulse radars)

t = pulse width, in microseconds

PRR = pulse repetition, rate in pulses/sec

PG = processing gain (dB), 0 for non-FM, non-encoded pulse radars
= 10 log (d) for FM pulse radars
= 10 log (N) for coded pulse radars

d = pulse compression ratio

<u>Radar emission bandwidth,</u> B, is the frequency range (in MHz) between the lowest frequency where the spectral density is higher in amplitude than -40 dB (with respect to the highest spectral amplitude at the radar operating frequency) and the highest frequency where the spectral density is higher in amplitude than -40 dB points. B is to be measured at the input to the antenna.

Maximum allowable radar emission bandwidth, B(-40 dB), is the maximum allowable value of B for a given type of radar. B(-40 dB) is calculated according to the formulas given in section 6.1.3.

The Maximum Emission Spectral Level, X(dB), is the amount of suppression (in terms of dB below the peak spectral density at the radar operating frequency) required for frequencies substantially removed from the radar operating frequency. A transition region between the 40 dB suppression required at the edge of B(-40 dB) and the frequency range specified by the maximum emission spectral level is also defined. Figure 2-1 shows the details of this transition.

6.1.3. Specifications and Limits

The RSEC specifies maximum allowable limits for B (specified at the 40 dB down points and measured at the antenna input, called B(-40 dB). This is determined by calculating an allowable value, based on the radar operating characteristics and other considerations.

For Non-FM pulse radars:

$B(-40\ dB) = K/(t_r t)^{1/2}$ or $64/t$, whichever is less.

K = 10, 7.6 or 6.2, according to details in Table 2-1 in Section 2.

For FM-pulse radars:

$B(-40\ dB) = K/(t_r t)^{1/2} + 2B_C$.

However, any t_r less than 0.1 microseconds must be justified on operational requirement grounds.

For frequency-hopping radars:

$B(-40\ dB) = K/(t_r t)^{1/2} + 2B_C + B_S$.

However, radars utilizing pulse compression shall require justification for t_r, less than 0.1 microseconds. Radars without pulse compression shall require justification for t_r less than 0.01 microseconds.

For CW radars:

$B(-40\ dB) = 0.0003\ F(o)$

For FM/CW radars:

$B(-40\ dB) = 0.0003\ F(o) + 2\ B(d)$

At all frequencies outside of a specified frequency range near the radar operating frequency, all emissions from the radar shall be suppressed at least X(dB) below the emission at the operating frequency.

X(dB) = 60 dB or P(t) + 30, whichever is the larger number, where P(t) is the maximum spectral density at the radar operating frequency.

X(dB) = 80 dB for radars operating in the 2700-2900 MHz band.

These requirements are summarized in Figure 2-1. The radar emission spectra must be below the dashed lines shown in the figure. The frequency scale is in f removed from the fundamental F(o).

6.2. Measurements

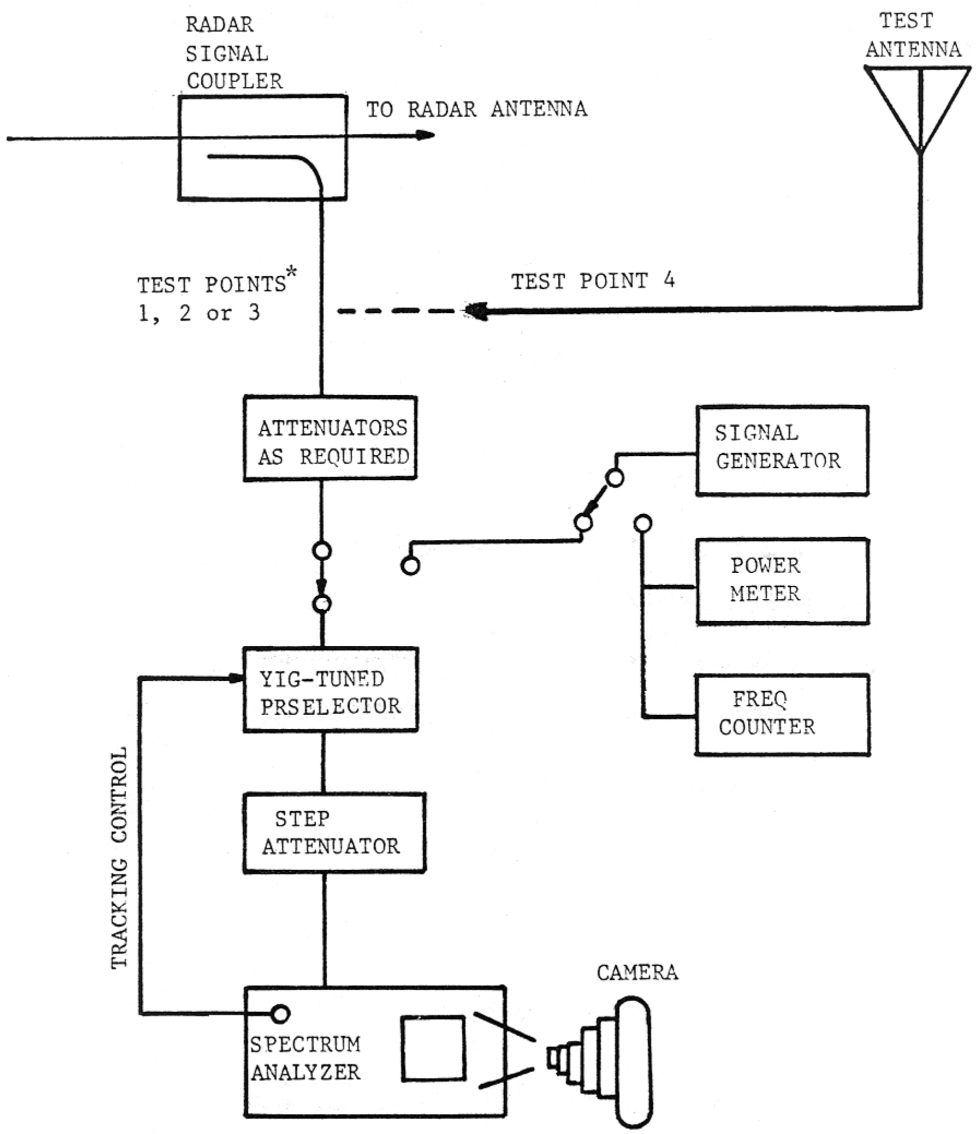
6.2.1. Instrumentation

Measurements of the emission spectra of a radar are prone to substantial errors. In addition expensive test instrumentation may be subjected to damaging levels of input signal. Therefore, it is recommended that the procedure be read completely and that the levels of power at the spectrum analyzer input be calculated before any instrumentation is connected to the radar.

Figure 6-1 shows a block diagram of the measurement system. The YIG-tuned preselector may be built into the spectrum analyzer, or it may be a separate companion unit designed to automatically frequency-track with the particular model of spectrum analyzer selected to be used in these measurements. Similarly, the step attenuator may be built into the spectrum analyzer, or may be a separate unit with 10 dB attenuation steps. It is often possible to make good measurements without tracking YIG preselection. The advantages gained for use thereof include better dynamic range for measurement of sideband levels more than 60 dB below the fundamental, considerable protection against accidentally burning out the first mixer in the spectrum analyzer, and freedom from spectrum analyzer spurious responses. The latter may make the radar appear worse than it is. Alternative measurement methods will be shown for the case in which a YIG preselector is not available, for example, in some of the radar bands below 2 GHz.

The spectrum analyzer should have a logarithmic display with 70 dB or more dynamic range displayed at one time, together with enough RF and IF dynamic range to make accurate measurement within the selected display range. The latter condition will often not be met, and it will be necessary to measure the actual dynamic range of the measurement system with a radar-like signal.

The proper selection of spectrum analyzer measurement bandwidth (IF resolution) is critical, 0.5-0.2 times 1/t is an ideal choice. (t is the radar pulse duration, or the minimum duration of the subpulse in a coded pulse radar). The use of a bandwidth greater than this value will result in readings which will indicate that the radar sidebands are greater than they actually are. The correction factor for the use of excessive measurement bandwidth is a function of 20 log B(IF), though calculation of the actual number requires a knowledge of the details of the impulse bandwidth of the spectrum analyzer and is considered to be beyond the scope of this measurement procedure.



*See Paragraph 3.4

Figure 6-1. Block Diagram of Emission Spectra Measurement System.

With respect to the lower limit of measurement bandwidth, any measurement bandwidth between 0.5 times 1/t and 2/PRR will give a numerically correct answer if the spectrum analyzer has sufficient dynamic range. However, the use of the largest possible bandwidth in this range will result in the smallest dynamic range requirements on the spectrum analyzer.

It is important that the spectrum analyzer selected for these measurements is capable of being adjusted so that the peak of the radar spectra can be displayed on the screen. This may require some adjustment of display brightness and display persistence in a variable-persistence mode in order to get proper photographic characteristics. The use of an average responding instrument will not be acceptable in these measurements.

The signal generator is used in these measurements solely to assist in setting up and testing the spectrum analyzer display characteristics, and to measure the radar frequencies more precisely than can be measured using the spectrum analyzer frequency display.

The selection of the radar test point follows the criteria given in Section 3.4, with a point at the antenna input being preferred. If any other reference point is selected, it will be necessary to establish the relationship between the spectrum at the antenna input and at the selected reference point. This is particularly important with radars which may employ bandpass or other filters between the radar transmitter output device and the antenna input. Note that devices that act as bandpass filters are not necessarily labeled as bandpass filters in the radar block diagram; diplexers and other devices are often designed to have frequency selective characteristics. If there is no accessible reference point following a frequency-selective component in the signal path to the antenna, it will be necessary to make the spectrum measurement in the far-field of the radiated signal. The measurement procedure will be much simpler under these conditions if the radar antenna can be held in a position pointed at the test antenna. Be extremely careful under these conditions to take adequate precautions against RF radiation hazards to personnel and equipment.

Note that waveguide components act unpredictably at frequencies above their normal operating frequencies because of "multimoding." Whenever possible, avoid depending on accurate calibration of waveguide components at frequencies at or above the second harmonic of the fundamental.

6.2.2. Test Procedure

Assemble the test equipment as indicated in Figure 6-1. Before connecting the spectrum analyzer system to the radar signal, determine (from manufacturer's literature) the maximum safe peak signal at the spectrum analyzer input and insert sufficient attenuation in the signal path so that a safe level is not exceeded.

a. Calculate B(-40 dB), X(dB), and determine the spectrum analyzer resolution measurement bandwidth to be used, using the Radar Emission Spectrum Worksheet (Figure 6-2) if desired.

Date Oct. 18, 1979

Operator D. Jones

1. Equipment under test:

Transmitter nomenclature FPN-395A Serial No. 3

Frequency (MHz) 2905 PRR (p/s) 395 t (us) 3.5 tr (us) 1

Peak power (dBm) +85 Correction to antenna 0

2. Calculation for B(-40dB): Use this section for non-FM pulse radars only.

K = 7.6 (10, 7.6 or 6.2, from Table 2-1 in Section 2)

2a. $B(-40dB) = K/(t \times t_r)^{\frac{1}{2}}$ = 4.1 MHz

2b. $B(-40dB) = 64/t$ = 18.3 MHz

B(-40dB) = 4.1 MHz (smaller of (a) or (b))

3. Calculation for X(dB):

3a. $X(dB) = P_p + 20 \log t + 10 \log PRR - PG - 90 + 30$

= 85 + 10.9 + 26 - 0 - 90 + 30 = 61.9 (a)

3b. or: X(dB) = 60

3c. X(dB) = larger of 3a or 3b = 61.9

4. Frequency limits for emission spectrum:

Center frequency = F_o = 2905 MHz b = 0.5 B(-40dB) = 2.05 MHz

$$F(-) = F_o - 10^{\frac{X-40}{20}} \times b \qquad F(+) = F_o + 10^{\frac{X-40}{20}} \times b$$

Suppression (dB)	F(-) MHz	F(+) MHz
40	2903	2907
42	2902.4	2907.6
44	2901.8	2908.2
46	2900.9	2909.1
48	2899.9	2910.1
50	2898.5	2911.4
52	2896.8	2913.2
54	2894.7	2915.3
56	2892.1	2917.9
58	2888.7	2921.3
60	2884.5	2925.5
62 *	2879.2	2930.8

*X(db) for this case = 62dB

Figure 6-2. Radar Emission Spectrum Worksheet.

b. Align the YIG preselector tracking to the spectrum analyzer, according to the manufacturer's instructions. Set the step attenuator to maximum. Connect the radar signal to the spectrum analyzer system and adjust the spectrum analyzer to display the signal on the CRT. Check the approximate maximum level of the signal as measured by the spectrum analyzer before removing additional attenuation.

c. Adjust the spectrum analyzer controls so that the maximum response at the radar center frequency is level with the top graticule on the display and centered on the screen. Adjust the scan width to give the narrowest scan width which will include the B(-40 dB) calculated frequency limits. Adjust the scanning rate, brightness, persistence, or other controls as necessary to obtain a clear and complete display. Take a picture of the display with the oscilloscope camera.

d. Check to see if the spectrum analyzer is in saturation at the top part of the display range by adding an additional 10 dB RF attenuation. If the top of the trace decreases by 10 dB, the top of the display range is correct. Similarly, the lower part of the trace should decrease by 10 dB if the lower part of the dynamic range is not being affected by system noise. If both portions of the display range change by 10 dB, the spectrum analyzer is linear over the entire displayed signal range. If the top portion of the dynamic range is in saturation, increase the RF attenuation or decrease the IF gain (try both to see which gives the best results). If the bottom of the range is affected by noise, increase IF gain or decrease RF attenuation.

e. After suitable settings have been determined in order to obtain a good photograph in which all portions of the signal are in the linear part of the dynamic range, connect the signal generator to the spectrum analyzer input (without changing the spectrum analyzer settings) and adjust the signal frequency until the signal coincides with the center of the display. The signal generator frequency is now identical to the radar frequency and can be measured accurately with the frequency counter. (This step will not be necessary if the spectrum analyzer contains sufficiently accurate internal frequency calibration.)

f. Increase the spectrum analyzer frequency span by a factor of 10. Reconnect the radar signal to the spectrum analyzer, making sure that the radar signal is centered on the display. Adjust scan rate and other necessary controls in order to obtain a good photograph. The photograph will be that of a spectrum over a frequency range, including 10 x B(-40 dB), outside of which the radar sidebands must be suppressed at least 60 dB or 80 dB for a radar covered by Criteria D. Repeat d, to measure the dynamic range of the measurement system to assure that the displayed measurement is valid. Take a photograph of the display; it will be used to determine if the radar meets the RSEC emission spectrum standards in the range between 40 dB and 60 dB or 80 dB down from the peak of the spectrum. Unfortunately, the result is not yet necessarily obvious from inspection because the limit plots as a curved line on the spectrum analyzer display due to its linear frequency scale.

g. If the value of X(dB) calculated in step a is 60 dB, a single combination of settings of RF attenuation and IF gain can probably be found which will cause the displayed frequency range over which the spectral level has fallen off by 60 dB to be linear. If the calculated or specified value of X(dB) is appreciably greater than 60 dB, as would be the case for a 2700-2900 MHz radar, or if the particular spectrum analyzer being used does not have sufficient dynamic range to measure the required range, some means will have to be found to effectively extend the dynamic range of the spectrum analyzer before the required measurement can be completed. The methods for doing so are discussed in the section on alternative measurement methods. The measurement procedure delineated herein will assume that the spectrum analyzer has sufficient dynamic range at a single appropriate combination of settings of RF attenuation and IF gain. Straightforward modifications to the rest of the procedure will have to be made if alternate methods are used to increase system dynamic range.

h. If the value of X(dB) is more than 60 dB, it will be necessary to extend the range of frequency measurement to F(o)+/-B(-X dB). This can be done by measuring the radar spectrum using progressively greater scan widths until the required frequency range is covered. An alternative approach is to measure a number of adjacent frequency spans of the same size, which can be pieced together to cover the required range. The latter approach is particularly useful to measure more detail in the spectrum, but either approach is adequate. As discussed in alternative methods to increase dynamic range, it may be useful to change RF attenuation where making measurements at several points in the frequency range to assure a set of measurements which are linear where they need to be.

i. The test procedure up to this point is for making tests at all frequencies at which responses higher or equal to X(dB) below the amplitude at the fundamental frequency exist. These include a relatively narrow band of frequencies centered on the operating frequency of the radar. The RSEC specifies that all emissions of frequencies outside this range be suppressed by at least X(dB); section 3.3 suggests a subset of frequencies at which tests should be made. Refer to section 3.3. to obtain the recommended frequency range.

This test can be made rigorously in coaxial systems; it is difficult to understand how such a very wide frequency range test could be made accurately in a waveguide system which is characterized in only a small frequency range. Nevertheless, it is important to identify frequencies at which a spurious emission occurs. Therefore, assume that the coupling coefficient of the waveguide coupler is essentially flat across the entire frequency test range. Extend the frequency span of the spectrum analyzer (but don't change bandwidth) to cover the required frequency range in one or several scans, noting any signals which are higher than the X(dB) limit. At any frequency where a spurious signal is observed, calibrate the spectrum analyzer with the signal generator and check the YIG preselector tracking, so that the level of X(dB) can be determined for these frequencies. It is not necessary to take photographs of the frequency scans; a list of frequencies and amplitudes for those emissions which exceed the RSEC will be adequate. Measure as many harmonics as is feasible, within the frequency limit suggested in Section 3.3.

j. The final task delineated by this measurement is the plotting of the RSEC limits on the photographs in order to determine if the radar meets the RSEC specifications. The frequency vs. suppression limit points calculated in step a must be plotted onto the photographs of the radar spectrum and joined with straight line segments. For frequencies further from the radar operating frequency, draw a horizontal line at the X(dB) suppression limit. It will then be obvious whether the radar emission exceeds the RSEC; any signal extending above the limits drawn will be in violation of the RSEC criteria.

This graphical work is discussed in detail in Section 6.3, where a typical example is worked out.

k. The process is repeated at other frequencies and for other radar operating modes, until spectral measurements at all operational combinations of modes, etc., have been made. Note that for most types of radar modulation, operating frequency is not one of the factors involved in calculation of B(-40 dB). Therefore, the same limit curves can be used to test spectra measured at the low, middle, and high test frequencies, shifted by the change in operating frequencies.

6.3. Sample Data and Calculations

6.3.1. Calculation of Allowable Limits

This section gives an example of calculation of the allowable RSEC emission limits. Refer to the Radar Emission Spectrum Worksheet (Figure 6-2) as an example of the procedure to follow.

The first part of the worksheet contains blanks for the various radar parameters which are used in the calculations. These blanks can be filled with either nominal data, or preferably measured data.

The next section of the worksheet is for calculating the value of the maximum allowable radar emission bandwidth, B (-40 dB). The worksheet incorporates only the case of the non-FM, pulsed radars. Formulas for calculating B(-40 dB) for other types of radars can be obtained from the RSEC or section 2.1. The value of K is to be determined from the RSEC or from Table 2-1 in section 2.0. The value of K determines how stringent the limits on the radar emission spectra will be. More modern radars have more stringent specifications (smaller K). The value of B(-40 dB) is calculated by putting values into formulas 2a and 2b of Figure 6-2. The value of B(-40 dB) which is actually used is the smaller of the two calculated values.

The maximum allowable emission spectral level, X(dB), the minimum required suppression below the amplitude at the operating frequency, is calculated in the next section. The calculation is based on equation 3a of Figure 6-2, which involves a calculation of transmitter spectral density from known transmitter characteristics. The actual suppression required is calculated from equation 3a, or 60 dB, whichever is larger. In the example, the calculated value is 61.9 dB, which is larger than the default value of 60 dB. In the case of a radar operating in the 2700-2900 MHz band, X(dB) = 80 dB.

Once the values of B(-40 dB) and X(dB) have been determined, it will be possible to determine the absolute numerical values for suppression vs. frequency. The formulas in part 4 of the worksheet were extracted from the plot of the required suppression curve in Figure 2-1. The formulas are in terms of F(o) and b, where b = 0.5[B(-40 dB)]. It will be necessary to calculate values of absolute frequency for the high frequency and low frequency limits for 2 dB increments of suppression from values of 40 dB to 60 dB (or as far beyond 60 as the calculated value of X(dB)). These frequencies and suppressions should be plotted on the measured spectral emission photographs. Note that one cannot merely draw a straight line between the -40 and -X(dB) points since the suppression limit line in this region is a straight line only if the frequency scale is logarithmic.

6.3.2. Measurements

This section shows steps in the measurement of the emission spectrum of a hypothetical FPN-395A radar. Pertinent data on this radar is shown in the Radar Emission Spectrum Worksheet (Figure 6-2).

The spectrum analyzer and YIG preselector used in these measurements will withstand +20 dBm peak power at the input with 10 dB RF attenuation. However, the output of the waveguide coupler will be as much as +23 dBm peak. Therefore, an external 6 dB pad was placed at the input to the spectrum analyzer. The radar's pulse has a duration of 3.5 microseconds, which necessitates a spectrum analyzer measurement bandwidth of 140 kHz or less. The next lower bandwidth available on the spectrum analyzer is 100 kHz, which was selected. The computed value of B(-40 dB) is 4.1 MHz. Therefore, the first picture of the display is taken with the spectrum analyzer span set to 5 MHz. Other spectrum analyzer settings include:

Video filter	- off
IF gain	- 10 dB
Sweep rate	- 1 mS/div.
RF atten	- 30 dB
Variable pers.	- on
Scan width	- 0.5 MHz/div.

The response of the spectrum analyzer to the radar signal at F(o) was set at the middle of the frequency scale and at the top of the reference scale. The picture which was taken is shown in Figure 6-3.

F_o = 2905 MHz
PW = 3.5 USEC
PK PWR = 85 DBM
B(-40 dB)= 4.06237 MHz
Roll Off = 20 DB/DEC

PRR = 395 Hz
PRT = 1000 USEC
X = -61.8471 DB
B(-X dB) = 50.2501 MHz
K = 7.6

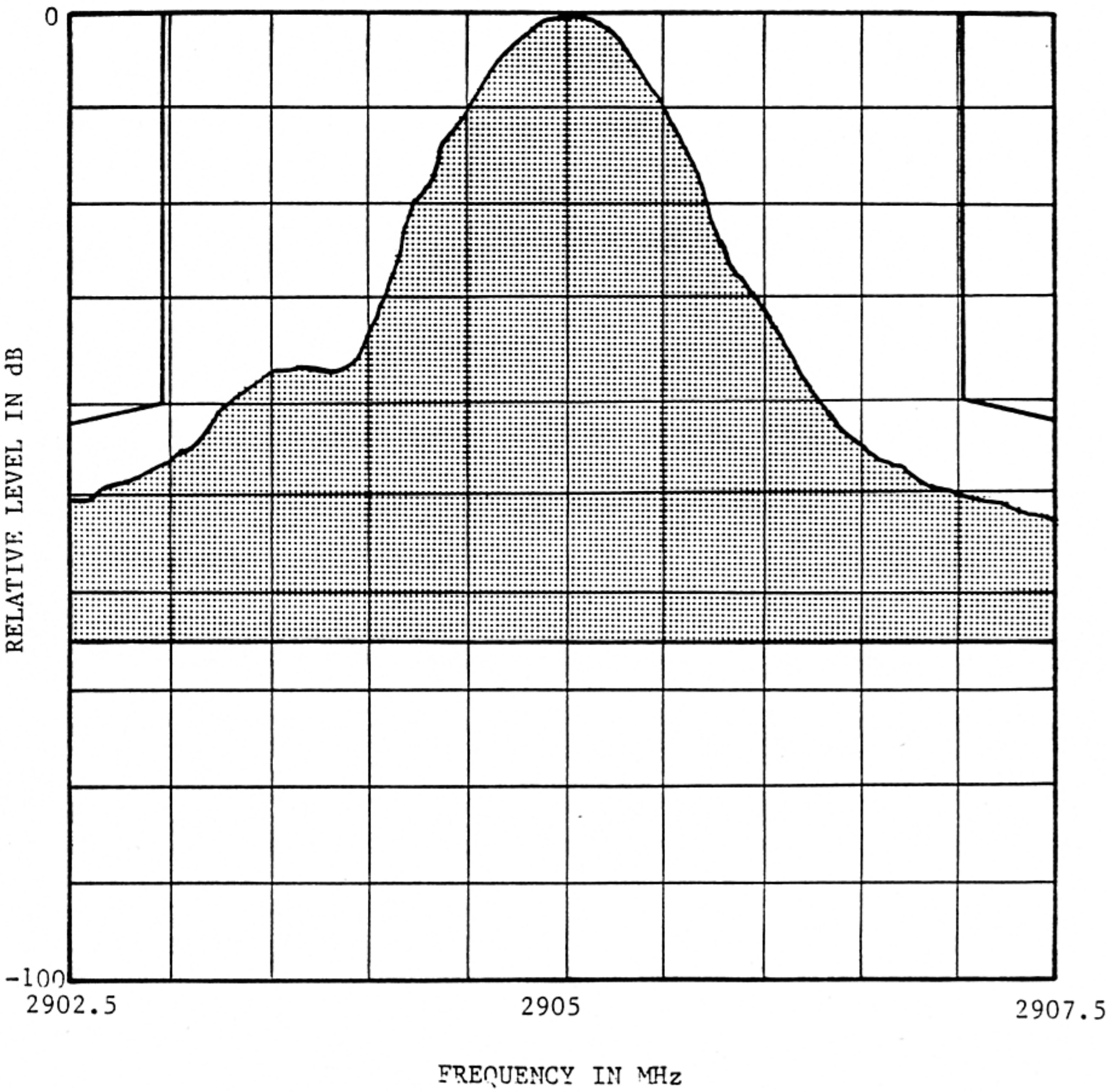


Figure 6-3. Close-In Radar Spectra.

To assure that the radar meets the RSEC over a larger frequency range, the frequency span of the spectrum analyzer was increased to 10 MHz/div., giving a total span of 100 MHz. All other controls were left at the same settings, and another photograph was taken (Figure 6-4). The plotted suppression limit shows that the radar passed the RSEC for all frequencies within the displayed range.

Although it was not necessary to do here because only 61.9 dB of suppression was required, a greater dynamic range could have been observed by removing some RF attenuation and by further increasing the frequency scan. So long as damage levels are not reached at the spectrum analyzer input or on other components, a 20 dB decrease in RF attenuation will cause a 20 dB increase in the radar sideband levels which can be seen. The YIG preselector is indispensable here because it keeps the fundamental from saturating the spectrum analyzer front end components while making it possible to measure low level sidebands. Of course, this benefit is negated when the separation between the tuned frequency and the operating frequency of the radar is less than half the bandwidth of the YIG preselector (typically 20-40 MHz). In the case in which the fundamental is within the YIG bandpass, the spectrum analyzer is protected by the YIG filter's saturation characteristics, though measurements are not accurate if the YIG filter is in saturation.

Finally, in order to test for spurious emissions the spectrum analyzer is tuned across large frequency ranges, as specified in Section 3.3. For an operating frequency of 2900 MHz, the range searched is between about 1.5 GHz and 15 GHz. Leaving the spectrum analyzer in a more sensitive mode, in which the X(dB) amplitude will show up 10-20 dB above spectrum analyzer noise, the spectrum is swept or tuned across the entire frequency range. Although there is complete freedom in adjusting most spectrum analyzer controls for a convenient display, do not adjust the bandwidth or the RF attenuation. The YIG tracking control should be checked to ensure adequate sensitivity. In this case, no signals were seen. If signals had been seen, it would have been necessary to use a signal generator to calibrate the spectrum analyzer response at the signal frequency to measure its amplitude to see whether it exceeded the level of X(dB).

6.4. Alternative Measurement Procedures

6.4.1. Use of a Notch Filter Instead of a Preselector

In the instance that a YIG-tuned preselector is not available and more measurement dynamic range is required than could be safely obtainable by the use of simple spectrum analyzer, a notch filter may be used. The technique is also useful in combination with a YIG preselector in obtaining very large dynamic range measurements. Figure 6-5 shows a block diagram of a measurement system using a notch filter with the notch filter removed from the signal path. To measure emission sidebands with high sensitivity, the notch filter is inserted in the signal path and tuned to reject the high level signal at F(o). Note that it is not necessary to calibrate the depth of the notch at F(o) or other nearby frequencies, since the spectrum near F(o) is not measured with the notch filter in place. The important measurement is the insertion loss of the notch filter at frequencies widely separated from F(o), since that is where the notch filter is used. It is especially important to test the filter insertion loss at very

F_o = 2905 MHz
PW = 3.5 USEC
PK PWR = 85 DBM
B(-40 dB) = 4.06237 MHz
Roll Off = 20 DB/DEC

PRR = 395 Hz
PRT = 1000 NSEC
X = -61.8471 DB
B(-X dB) = 50.2501 MHz
K = 7.6

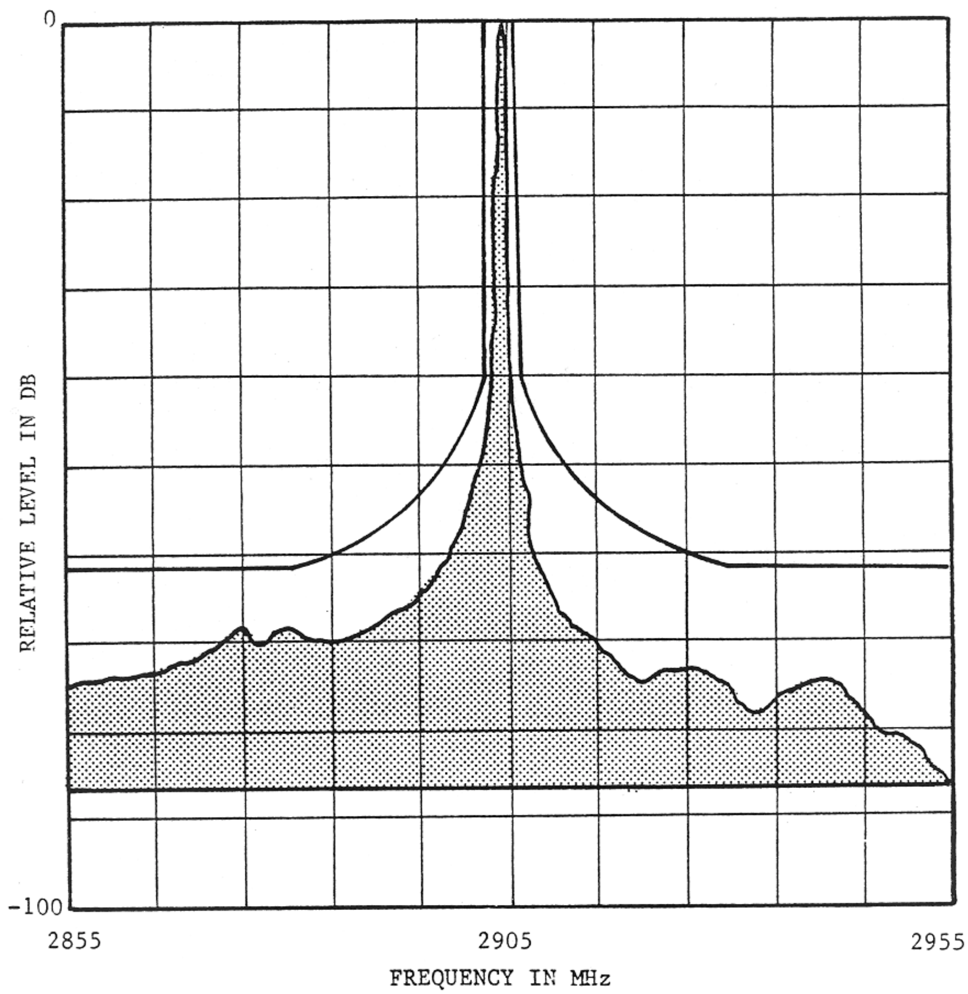


Figure 6-4. Extended Radar Spectra.

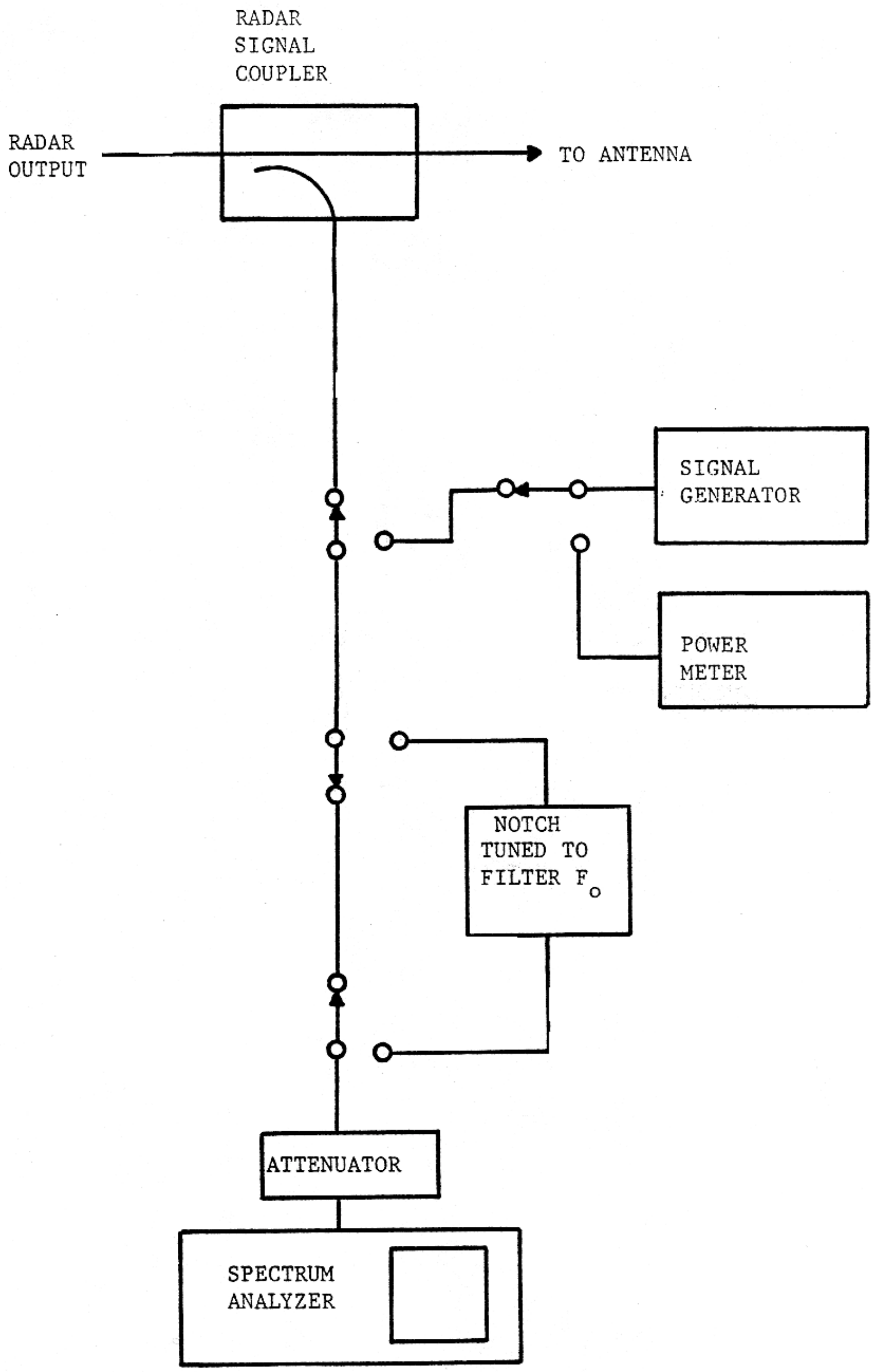


Figure 6-5. Notch Filter Test Set-Up For Emission Spectrum Measurement.

distant frequencies, for example, at 5 xF(o) when testing for harmonics. If the filter insertion loss is high at these frequencies, it may be necessary to remove the notch filter and replace it with a bandpass filter whose bandpass does not include F(o).

6.4.2. Automatic Systems

This section includes a discussion of some improved measurement techniques which are available with automatic systems. In some cases, these techniques may be useful with manual systems, also.

Peak detection may be available with some systems. The use of peak detection allows a single data point to be recorded for each frequency; due to the low-duty cycle of typical radar signals, if digital measurements of pulsed signals were to be made with a digitizer, it would not indicate the pulse peak as the digitizer would see no signal during the relatively long pulse off period. Therefore, to insure accurate measurements of the peak pulse amplitude most automatic systems use peak detectors to hold the instantaneous peak pulse amplitude until it is digitized.

Documentation can be greatly improved with digitally-controlled systems. Not only can the frequency and amplitude scales be plotted along with the spectrum, providing a much more self-documenting display, but the RSEC limits can be calculated and plotted along with the spectrum.

Calibration can be improved, by means of calibration factors derived on a point-to-point basis which are included in the emission spectrum measurement. Changes in RF attenuation or other parameters can be compensated for when the data is plotted. Notch filters can be used at F(o) to reduce the dynamic range of the emission spectrum seen by the measurement system, with the insertion loss of the notch filter being measured and used to correct the data on a frequency-by-frequency basis. These techniques can all be used, as needed to give a spectrum measurement range in excess of that provided directly by manual instruments.

Figure 6-6 shows a block diagram of a computer-aided spectrum measurement system. Although such a system might include many variations from what is shown here, there will be several fundamental components required in all systems. The system shows a desktop computer is used to control the measurements and to process the measured data. The details of the control and processing are determined by the computer program used in the system. The major components in the system are a digitally-controlled spectrum analyzer and a YIG-tuned preselector. The system is calibrated automatically at every frequency of interest using a digitally-controlled frequency synthesizer as a calibration source. If the noise figure of the spectrum analyzer is 20 dB or less, the frequency synthesizer can be replaced with a solid-state noise source. The noise source is much simpler and cheaper than the synthesizer, but produces only a low-level signal which might not be measurable if the noise figure of the spectrum analyzer is not low enough. For high dynamic range measurements, a notch filter tuned to F(o) can be inserted in the signal path. The system can be calibrated, with the notch filter in place, at all frequencies including F(o). This system will effectively increase the dynamic range of the spectrum analyzer

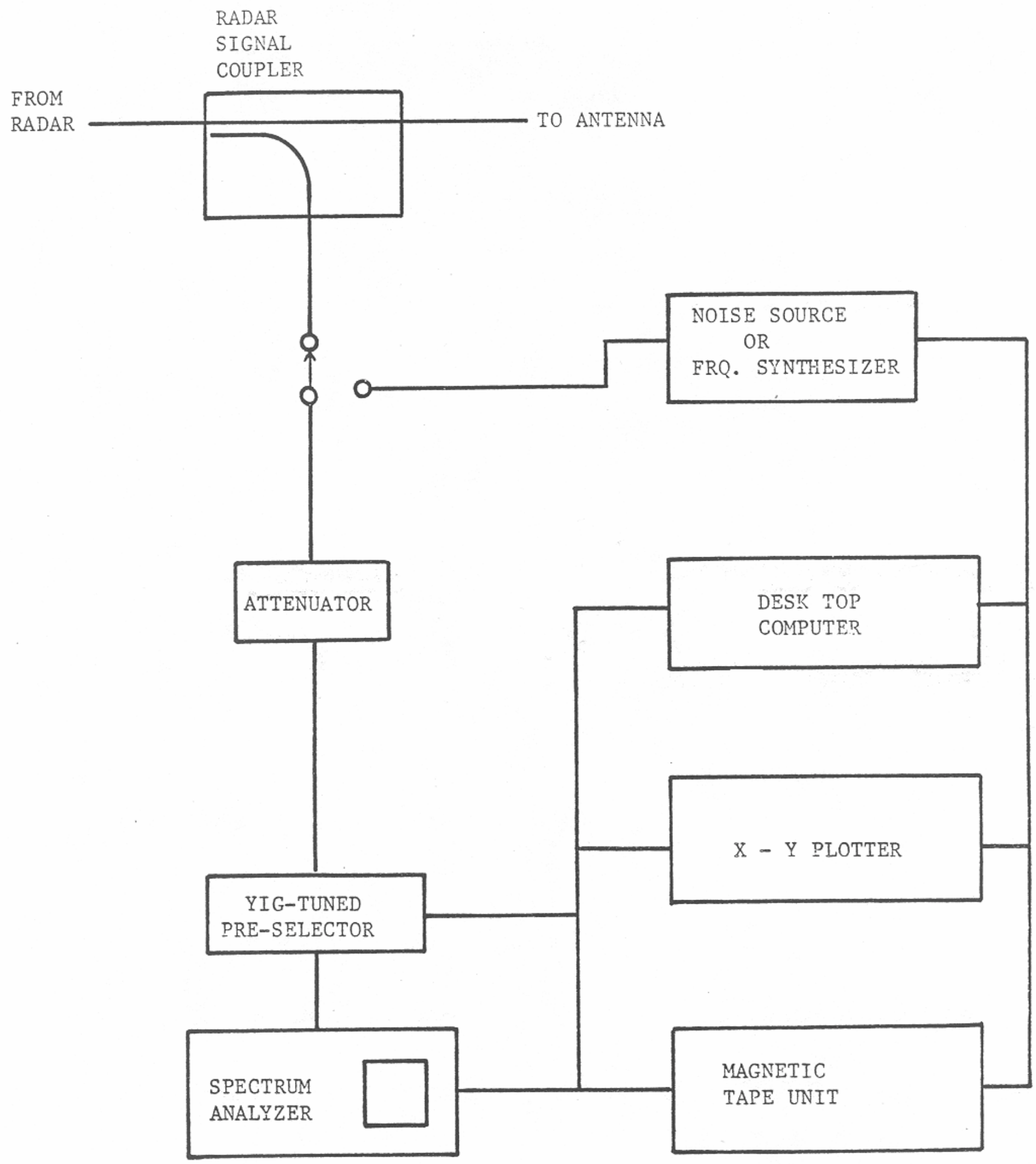


Figure 6-6. Computer-Aided Spectrum Measurement System.

by the depth of the notch at F(o), and calibration factors added to the measurements will produce numerically-accurate data.

Figure 6-7 shows an example of an emission spectrum measurement, which includes the use of peak hold detectors, YIG preselection, a notch filter producing a 30-dB notch at F(o), and a noise source for calibration. The Maximum Spectral Level curve was plotted with the system. The 130-dB dynamic range shown here is greatly in excess of that which could easily be obtained with a manual system (and in excess of what is required for the RSEC).

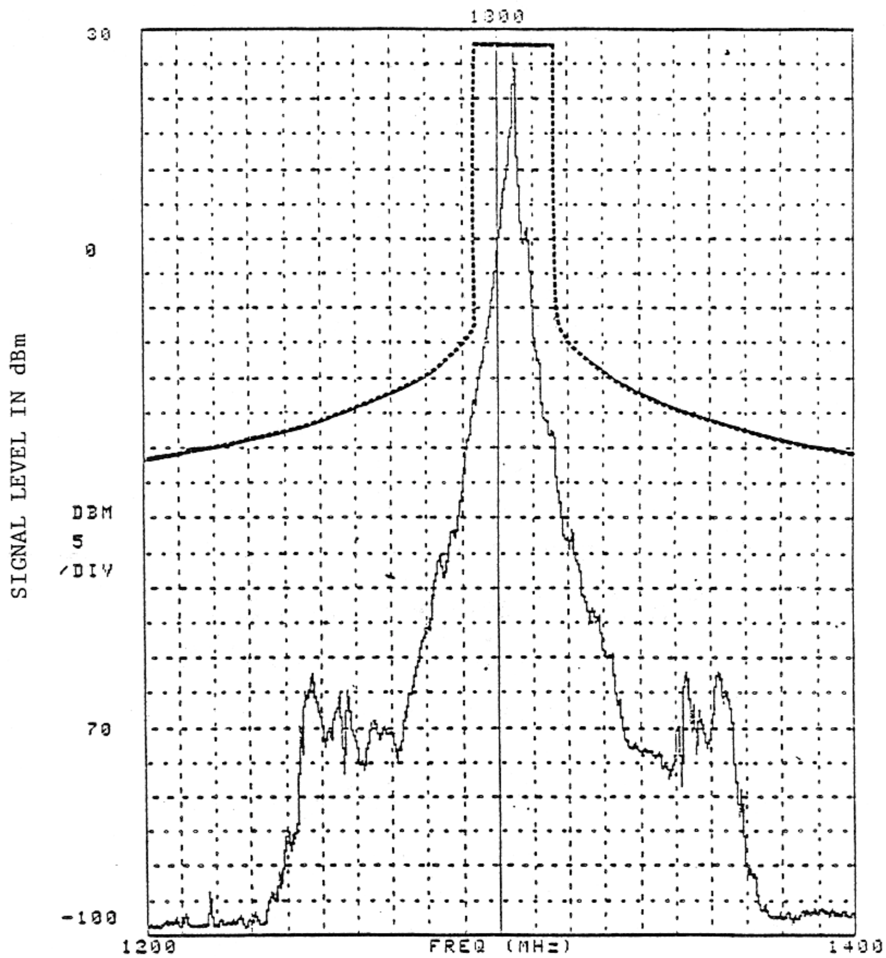


Figure 6-7. Wide-Dynamic Range Measurement of Radar Spectrum.

7. ANTENNA PATTERNS

7.1. Introduction

7.1.1. Objectives

This measurement procedure provides data on the spurious antenna characteristics which allow unwanted energy to be coupled into another system thereby causing interference. These characteristics also allow interfering energy from another system to be received. The main source of interference in radars occurs from mainbeam to sidelobe coupling between interfering and victim radars. The total elimination of sidelobe coupling could substantially reduce the amount of interference which occurs between radars. For this reason, the RSEC has placed limitations on the response of radar antennas with respect to reception or transmission of signals in unwanted directions (i.e., any direction except the intended mainbeam direction.)

Two types of information are provided by these test procedures. For antennas that rotate regularly about a vertical axis, scanning the horizon, the median gain of the antenna in the horizontal plane is measured. For other antennas, the values relative to the mainbeam gain, of sidelobes and other lobes are measured.

7.1.2. Definitions

The "median gain" of an antenna rotating through 360 degrees of the horizontal plane is defined as that level of antenna gain which is greater than the measured antenna gain for a total of half of the antenna rotation angles between 0 degrees and 360 degrees.

The absolute gain of the antenna is measured relative to the gain of an "isotropic" antenna, i.e., the gain of a theoretical antenna that radiates with 100 percent efficiency equally in all directions. This is expressed in terms of "decibels relative to an isotropic antenna," or "dBi."

The specifications for non-rotating antennas include a requirement for the "first three sidelobes" and for "all other lobes". These are to be defined for "pencil beam" antennas as being measured by 360 degrees rotation in any plane through the mainbeam. The first three sidelobes include the first three sidelobes on both sides of the mainbeam (i.e., a total of six lobes). "All other lobes" are defined as the remainder of the pattern measured in the selected plane. For radars whose antennas are not generally used in uniform rotation in the horizontal plane or which do not employ "pencil beam" antennas, or those employing multiple beams, etc., some other suitable definition will have to be employed.

7.1.3. Specifications and Limits

a. For antennas that rotate continuously, scanning the horizon, the median gain of the antenna must be -10 dBi or less, in the horizontal plane, as measured on an antenna test range in the principal horizontal plane.

b. For other antennas, the gain of the first three sidelobes must be at least 17 dB below the mainbeam gain, and the rest of the sidelobes and backlobes must be at least 26 dB below the mainbeam gain.

The above specifications apply to radars in Groups C and D. Other radars do not need to meet any RSEC antenna pattern specifications.

7.1.4. Test conditions

The above specifications should be met at all radar operating frequencies. For purposes of RSEC testing, it is recommended that a single frequency near to the midpoint of the range of radar operating frequencies be used for testing. The definitions of antenna gain also imply that the measured antenna pattern be that of the antenna alone, i.e., without measurable distortion from environmental reflections. This will generally be a difficult requirement to meet without a specially-prepared and specially-instrumented test range. Antenna patterns measured with the radar system typically deployed will often be substantially degraded, especially with respect to the -10 dBi median gain requirement. This problem is discussed further in the following section. The antenna beam elevation angle must be lowered to 0 degrees, so that the measurement is made in the principal plane of the antenna (a plane containing the mainbeam).

Although not specifically stated in the RSEC, it is desirable to have the antenna patterns measured in the exact configuration in which it is designed to be deployed. For example, if a search radar system normally is deployed with an interrogator antenna mounted directly above the radar antenna, this is the configuration in which the antenna should be tested.

7.1.5. Further Comments on Antenna Measurement

Errors associated with making accurate measurements of median antenna gain come from two major sources: 1) Instrumentation and calculation errors, especially when associated with the use of standard gain antennas, antenna alignment and measurement errors of various angles, distances, etc., and 2) Unwanted reflections from the surrounding landscape. The first source of errors can be reduced by meticulous care in calibration and calculation of various losses. The second source of errors is more difficult to reduce. A conceptually simple measurement of mainbeam gain can easily be 10 dB in error, depending on whether the reflection of the radar signal from the ground between the radar antenna and the test antenna is in phase or out of phase with the direct signal. Similarly, signals measured while the radar is pointed perpendicularly to the path of the test antenna may come directly from the sidelobes of the radar antenna, or they may be reflected to the test antenna from objects which are in the mainbeam of the antenna. It is generally difficult to rigorously separate the two sources of signal. The measurement of the median gain of the radar antenna rotating over 360 degrees is especially subject to the errors just discussed. An absolute gain level of -10 dBi is difficult to measure due to reflections from the surrounding landscape.

Two sets of measurements will be described to obtain the absolute median gain. The first set produces the desired data, but needs considerable specialized technical resources to accomplish. The second set of measurement procedures can be performed with a much lower level of technical resources, but it is not guaranteed to give good results.

7.2. Antenna Range Measurements

7.2.1. Instrumentation

The instrumentation used in these measurements is that associated with a well-instrumented antenna test range, as shown in Figure 7-1. The radar transmitter/receiver has been disconnected from the antenna and replaced by a calibrated signal source. At a measured distance from an antenna under test, in its far field region, a calibrated receiving system is set up. The calibrated receiving system contains a calibrated antenna, a measurement receiver, and a data recording system. The data recording system is also instrumented to receive information on the pointing angle of the radar antenna, so that a graph may be produced showing antenna gain vs. antenna pointing angle.

The test range itself is a carefully selected and prepared environment, with a minimum of objects near the radar antenna so as to minimize reflections of the test signals to the receiving antenna. These add reflections to the signal received from the direct path from the radar antenna and the calibrated receiving system. The area near the direct path has received special care in order to minimize ground reflections. Materials which absorb RF energy can be placed on the ground in strategic spots. The terrain may be selected to provide a large valley in the direct path, with the radar antenna and the calibrated receiver positioned on two hilltops. In some cases, time-of-arrival or other gating techniques can be used to reduce the effect of reflected signals.

7.2.2. Test Procedure

The test equipment and radar antenna are set up on the measurement range, and the measurement system is calibrated by means of the test range calibration procedures. The radar antenna is pointed directly at the receiving antenna and the radar antenna is mechanically scanned vertically to find the angle of maximum amplitude (mainbeam) received at the measurement system antenna. The antenna is left at this tilt angle and rotated over a 360 degrees azimuth angle.

The received amplitude is converted to absolute gain in dBi using suitable calibration factors and plotted on a graph of gain vs. angle for a 0 degree to 360 degree range. The graph is examined to determine for what portion of rotation the antenna gain is more than -10 dBi. If the antenna gain is less than -10 dBi for more than half of the angles between 0 degrees and 360 degrees, the antenna passes the RSEC standards. From this same graph, one can also determine by inspection how far the sidelobes and backlobes are suppressed.

7.2.3. Sample Data and Calculations

It is assumed here that the procedures used to calibrate the antenna range for normal antenna gain test will be used for these measurements. Since these will vary considerably among different test ranges. An attempt will not be made to reproduce those calculations here. It will be assumed that a graph of absolute gain (dBi) vs. degrees from mainbeam has been produced, as shown in Figure 7-2.

From Figure 7-2 it can be seen that the mainbeam gain is 30 dB. According to one of the RSEC limits, the first three sidelobes must be at least 17 dB down (less than 13 dBi), and the rest of the lobes must be at least 26 dB down (less than 4 dBi). These limit lines have been drawn on the graph, and visual

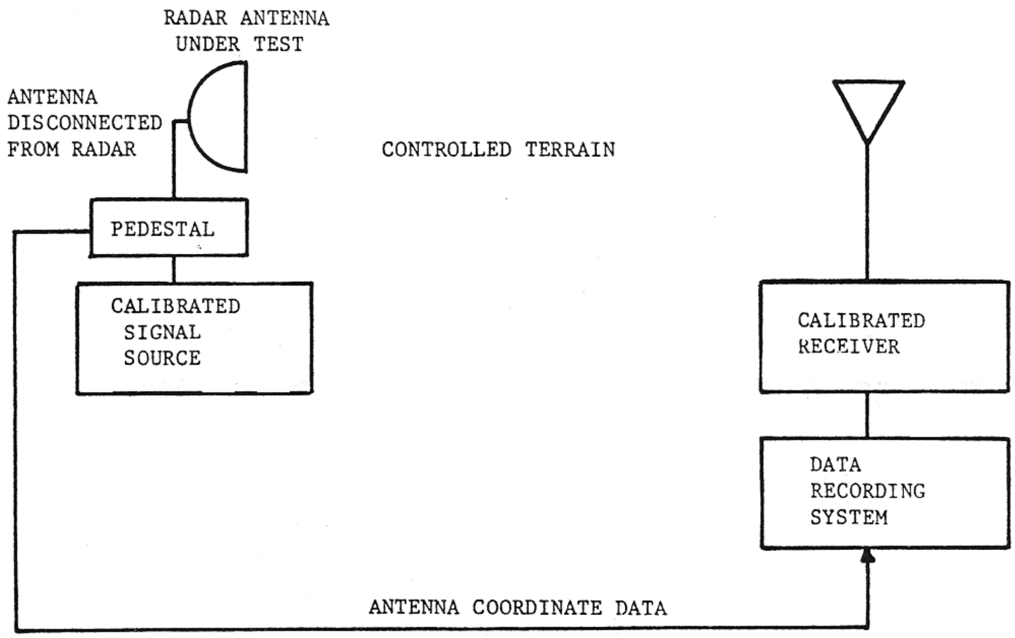


Figure 7-1. Instrumentation for Accurate Median Gain Measurement.

inspection shows that these conditions are indeed met. Since the FPN-395A is a radar of the type whose antenna rotates continuously to scan the horizon the previously mentioned limits do not apply to it. Instead, the limit which applies to it is a median antenna gain of -10 dBi or less. A dashed line has been drawn at the -10 dBi limit. When the antenna pattern is examined relative to this limit, it can be seen that the antenna pattern is above the line for 33 percent of the angles and below the line for 67 percent of the angles. Therefore, the antenna meets the specification for median gain.

7.3. Approximate Median Antenna Gain Patterns

7.3.1. Comments on Test Validity

This method of measuring median antenna gain eliminates most of the requirements of the previous test for the absolute calibration of test equipment. Instead, it uses the radar transmitter as a signal source and is based on the assumption that the mainbeam gain of the radar antenna can be used as a reference point to calibrate the gain of the rest of the antenna pattern. Using this assumption entails some risk, but probably not as much risk as attempting to make absolute direct antenna gain measurements without adequate technical resources.

Assuming that the mainbeam gain is correct, there remains the major problem of dealing with reflections from the environment, which may cause the mainbeam signal (as well as the sidelobes) to be erroneously measured. These reflections remain a major problem as they can only be minimized, but usually not eliminated. Techniques of adjusting the radar antenna and the test antenna to minimize the reflections will be given as part of the test procedure. This measurement technique is in some respects a more realistic measure of the antenna system performance, since the reflections which make antenna measurements difficult also affect the real-world operation of the radar system.

In general, this measurement technique would be expected to produce median antenna gain measurements which are within 3 dB of the measurements obtained on an antenna range, if the reflections can be controlled. The measured sidelobe levels will tend to be higher using this test method, due to reflections from nearbybuildings, etc. The measured mainbeam gain amplitude may be higher also, however, due to the constructive reinforcement which takes place between the direct and reflected signal path (which will be at the point of the test antenna if the radar antenna and the test antenna are carefully adjusted for maximum response.) If reflections cannot be carefully controlled, measurement errors may increase measured sidelobe levels to values higher than allowed by the RSEC.

7.3.2. Instrumentation

The instrumentation for the measurement of the approximate median antenna gain is shown in Figure 7-3. From an instrumentation standpoint, the measurement is very simple since only a spectrum analyzer and a receiving test antenna are needed. No absolute calibration is needed because the nominal radar antenna gain will be used as a calibration point. The receiver test antenna should be of the same polarization as the radar antenna and should have a relatively narrow beamwidth. The use of a relatively narrow beamwidth will tend to decrease the number of reflected signals which are measured and which distort the true antenna pattern. The spectrum analyzer will be tuned to the signal from the radar transmitter. It must have sufficient dynamic range to measure the radar mainbeam

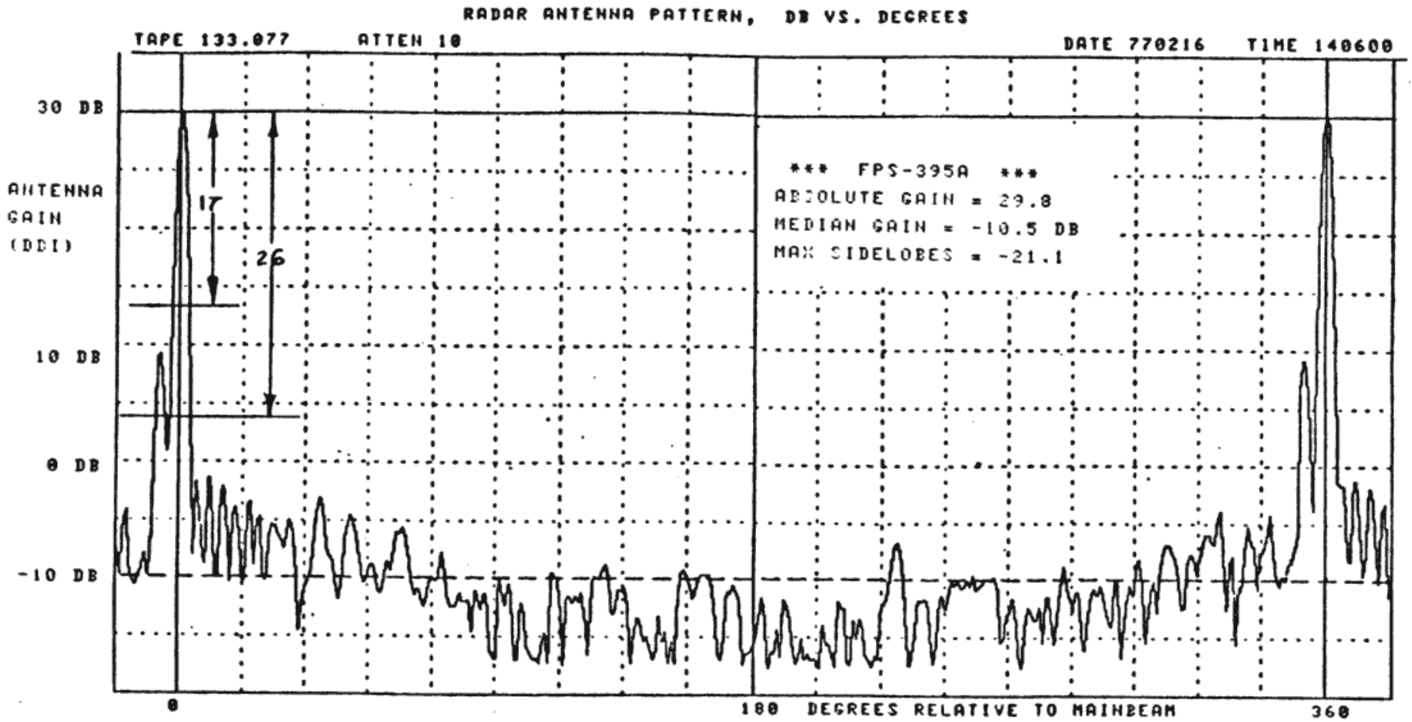


Figure 7-2. Radar Antenna Pattern.

as well as to measure a signal. corresponding to a gain of -10 dBi. For example, if the radar antenna has a nominal gain of 38 dBi, the spectrum analyzer must have a dynamic range of at least 48 dB. Since the radar signal has a low-duty-cycle, it will be necessary to observe the peaks on the spectrum analyzer display when the pulses occur. This can be effectively accomplished by adjusting the brightness, etc. of the CRT display so that the envelope of the pulse peaks can be clearly seen. As an alternative, a peak detector or quasi peak detector can be used instead of the display envelope. The latter has the advantage of providing a spectrum analyzer output which can be used to drive an X-Y plotter.

An oscilloscope camera is used to photograph the display for further analysis. (Because of the low duty cycle of the radar and the short duration of the radar pulse, an X-Y plotter cannot adequately follow the display unless a peak detector or similar circuit is used.)

One major component of this measurement set-up is the landscape surrounding the radar antenna and the test antenna. It should afford a direct line-of-sight path between the radar antenna and the test antenna. A minimum distance of D, as given below, is required between test antenna and radar antenna to ensure that the far field pattern of the radar antenna is being observed, where:

$$D = 2\,[D(1)\ \mathrm{EXP2} + D(2)\ \mathrm{EXP2}]/\lambda.$$

where:

D(1) = maximum radar antenna aperture in meters

D(2) = maximum test antenna aperture in meters

λ= wavelength in meters

Ideally, the test antenna should be located so that buildings, etc., illuminated by the radar antenna during its rotation, are hidden from the direct view of the test antenna. Note that this requirement rules out any large buildings directly behind the radar antenna. Finally, the terrain directly under the path between the radar antenna and the test antenna should be selected to minimize the amount of signal reflected from the ground and received by the test antenna. A steep valley between the radar antenna and the test antenna is ideal, but any broken terrain or shrubbery which reduces the amount of reflected signal is desirable. The degree to which these measures are successful will largely determine the accuracy of the measurement.

Test Procedure 7.3.3.

The most important single operation of this measurement is the selection of a suitable measurement location, where unwanted reflections can be controlled but which offers a direct path to the radar antenna. A simple way to start the selection process is to compute the minimum distance, D, between the radar antenna and the test antenna, according to the formula in the previous section. Then draw a circle on a map with the radar antenna as center and D as a radius. The interior of this circle contains locations which are too close to be used as measurement sites. Finally, carefully explore several candidate sites to see which offers best protection from reflected radar signals, either because sources

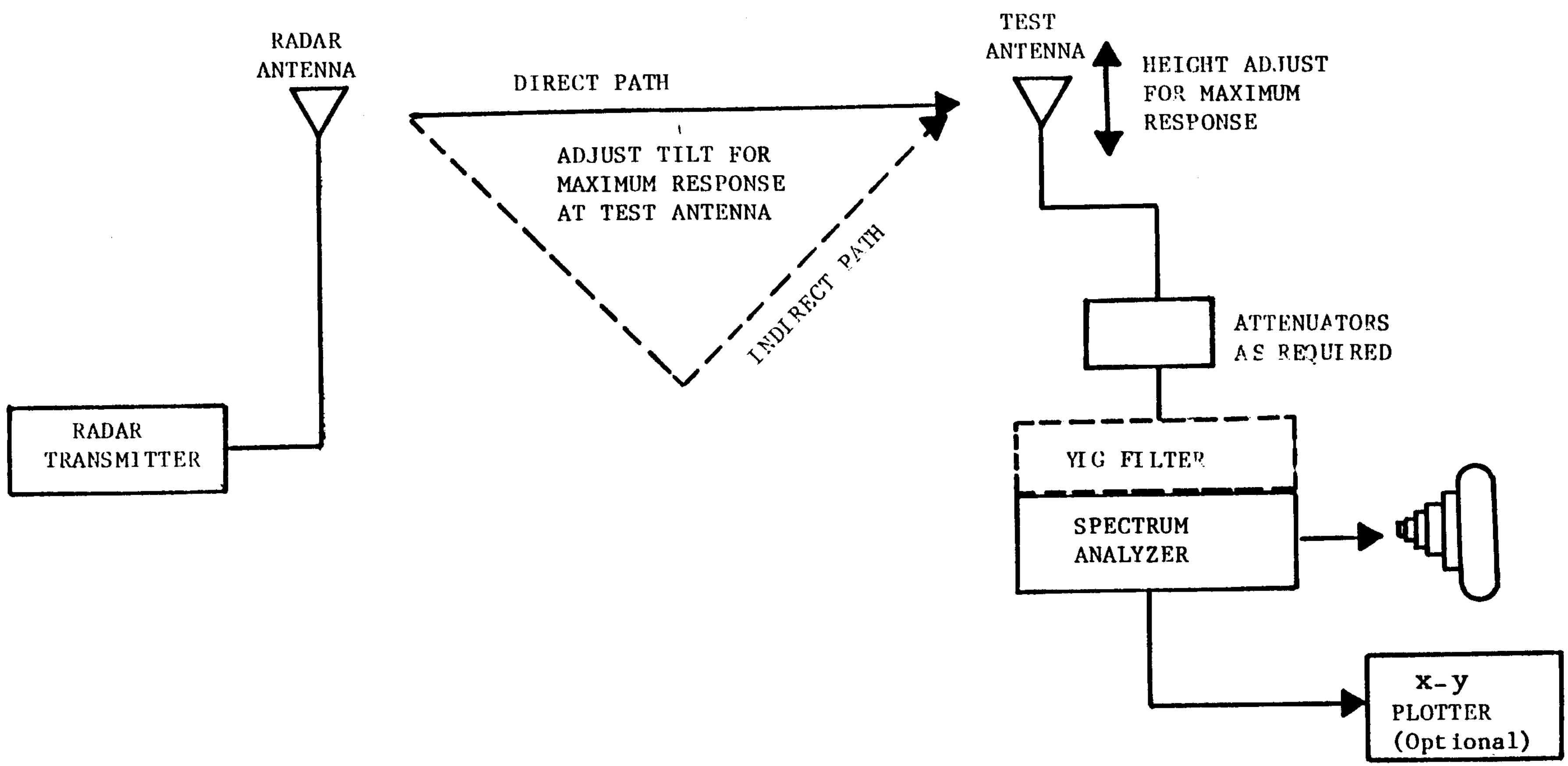


Figure 7-3. Instrumentation for Approximate Median Gain Measurement.

of reflected signals are screened from the test antenna or because the horizon is free from buildings within the beamwidth of the test antenna. If a suitable site cannot be found, it is pointless to proceed with the rest of the test procedure.

a. Once a suitable site has been located, set up the test instrumentation as shown in Figure 7-3. Before actually connecting the spectrum analyzer to the test antenna, be sure that the spectrum analyzer is protected against damaging levels of RF. Use a YIG-tuned preselector, if available, to eliminate out-of-band signals and to function as a limiter. Adjust internal spectrum analyzer RF attenuation to maximum, and place additional RF attenuation in front of the preselector. Some or all of the attenuation can be removed later when signal levels are more accurately known.

b. Turn the radar transmitter on, allowing the radar antenna to rotate. Tune the spectrum analyzer to the approximate radar frequency, using a sufficiently wide frequency span to include any errors in the selection of the radar frequency. A measurement bandwidth of at least 1/t should be used (t = pulse width of the radar), or as wide a bandwidth as is available on the spectrum analyzer. Use no video filtering, since the radar signal pulse peak is the desired measurement. Remove no more attenuation than is necessary to observe the radar signal since the radar signal level may increase substantially in the next step.

c. Aim the test antenna at the radar. Aim the radar antenna at the test antenna and adjust both antennas to obtain a maximum signal level. The process will require communication between the two antenna sites in order to aim the antennas optimally. Note that many radars have interlocks which must be defeated to allow radiation when the antenna is not rotating. Both antennas must be adjusted in azimuth and in elevation to obtain a maximum signal.

In addition to the above adjustment, the receiving antenna should be moved in elevation or along a radial to the radar antenna to produce a maximum signal. If there is substantial reflection from the ground, deep nulls may be experienced at particular elevation/distance combinations, which will substantially change the apparent antenna pattern. Although it is preferable to be near the maximum levels of signal, the major reason for this adjustment is to assure that the initial locations were not in the area of nulls. Height should be searched over a continuous interval of:

$$\Delta(H) = \lambda d/2h(m)$$

where:

d = distance from radar antenna in meters

λ = wavelength in meters

(H) = search height of test antenna in meters

h(m) = height of test antenna in meters

If radial distance is varied instead of height, the distance should be tested continually over the range of:

$$\Delta(D) = d/[(2h(1)h(2)/\lambda d) - 1]$$

where:

h(1) = height of radar antenna in meters

h(2) = height of test antenna in meters

$\Delta(D)$ = radial distance over which test antenna is varied in meters

If there is more than 3 dB change in maximum amplitude at the final location, the antenna orientation should be readjusted for maximum signal gain before proceeding with the next step.

d. When maximum signal alignment has been achieved, switch the spectrum analyzer to manual frequency tuning (no frequency scanning) and tune for maximum response. Adjust other spectrum analyzer controls (and external attenuation, if necessary) to obtain almost full scale peak indication on the spectrum analyzer display, using a 10 dB div. scale calibration. Disconnect the test antenna and note the amplitude of system noise to be sure that the spectrum analyzer display has at least G(1)+20 dB dynamic range, where G(1) is the nominal gain of the radar antenna.

e. Rotate the radar antenna continuously. Adjust the spectrum analyzer scan time (no frequency scanning) so that the scan time from one edge of the spectrum analyzer display to the other corresponds to slightly more than the rotation time of the radar. Adjust the brightness and persistence controls of the display so that the envelope of the pulse peaks (which is the desired antenna pattern) can be clearly seen in a photograph of the display.

f. When all adjustments have been made and tested, start the scanning of the spectrum analyzer just before the mainbeam of the radar antenna appears on the display. If the spectrum analyzer time-base controls have a single-scan mode, they will facilitate starting the sweep at the correct time. If everything has been done properly, one mainbeam pattern of the radar should be displayed near the left-hand edge of the graticule with the next mainbeam pattern occurring near the right-hand edge. Take a picture of this display. The picture will provide all of the necessary information for data analysis.

g. The output of a spectrum analyzer or a field intensity meter with a peak or quasi-peak detector will follow the pulse peak envelope which will provide a suitable output for use with an X-Y plotter with which to record antenna patterns. The X-Y plot will provide a record which is considerably easier to work with than a small photograph and its use is recommended if it is available.

h. Often the antenna pattern measured at a given location will show peaks which do not seem likely to belong to the pattern of the antenna being tested. To check for origin of these peaks, measure the antenna pattern from another site. This will cause the reflection-produced peaks to shift with respect to the peaks belonging to the radar antenna.

7.3.4. Sample Data and Calculations

The photograph of the antenna pattern can easily be analyzed to find the median gain. Figure 7-4 shows an example of a typical photograph, enlarged to show the details more clearly.

a. Draw vertical lines through each of the antenna mainbeam responses. Measure the distance between these two lines (4.2" on this photograph).

b. Draw a gain scale on the graph, using the known mainbeam gain of 38 dBi as a calibration point. Extend a dashed line across the antenna pattern at the -10 dBi level (i.e., 48 dB below the level of the mainbeam response).

c. Measure the total cumulative length of the -10 dBi line between the mainbeam points for which the antenna pattern is above the -10 dBi line. In this case, the cumulative length is about 1.0". Therefore, the antenna response is above the -10 dBi level 1.0/4.2 = 23 percent of the time. The median level (50 percent point) must, therefore, be below the -10 dBi level, and the antenna pattern meets the requirements of the RSEC.

7.4. Relative Sidelobe Measurements

7.4.1. Comments on Test Validity

For a radar whose antenna is not rotated through 0 to 360 degrees in the horizontal plane, the first three sidelobes must be at least 17 dB below the mainbeam gain and the remainder of the pattern must be at least 26 dB below the mainbeam. For a typical radar antenna, a comparison against these criteria can be easily made, because the mainbeam serves as a reference. Also, for most radar antennas, the direct signal received by the sidelobes 17 dB and 26 dB are well above most reflections from the landscape, so it is not as difficult to control reflections. Note, however, that the use of these criteria is not an optional substitute for the median gain measurement in the case of antennas that rotate uniformly in the horizontal plane.

7.4.2. Instrumentation

This measurement requires exactly the same instrumentaton as that described in 7.3.2, except that several test requirements are not as stringent in this test. In particular, the requirement of the spectrum analyzer is only 30 dB dynamic range, and control of reflections from objects near the radar is not quite as important.

7.4.3. Test Procedure

The test procedure is identical to the procedure in 7.3.3 up to part d, where only a 30 dB dynamic range is required. Continue the test procedure through part g, which delineates how to photograph the entire antenna pattern as the antenna is rotated through 360 degrees. In addition, carry out the procedure below:

Readjust the scan time on the spectrum analyzer display so that about 40-60 degrees of antenna pattern is included on one scan. Synchronize the display so that the mainbeam is centered, with 20-30 degrees of pattern on either side. Photograph the display.

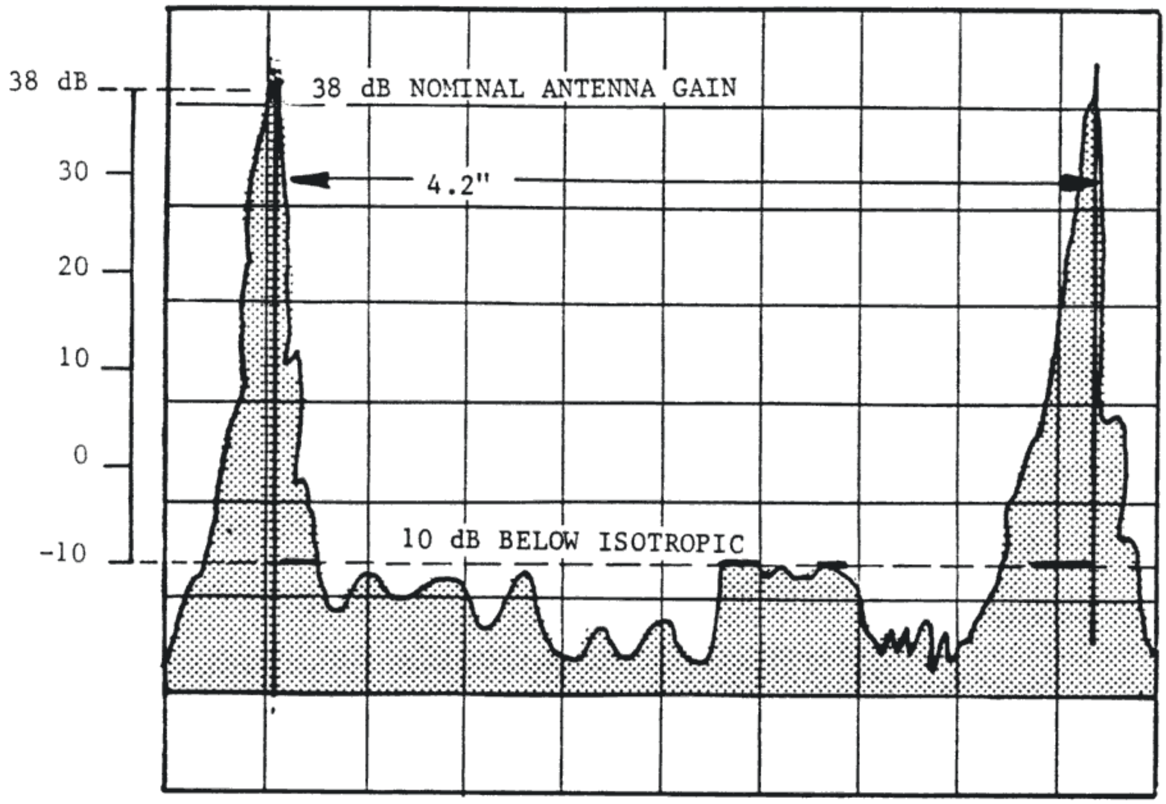


Figure 7-4. Antenna Pattern of Uniformly-Rotating Radar Showing Responses Greater than -10 dBi.

7.4.4. Sample Data and Calculations

Figures 7-5a and 7-5b show a 360 degree pattern and an enlarged view of the mainbeam lobe, respectively. From Figure 7-5a, it can clearly be seen that most of the antenna pattern is well below the 26 dB limit, with the most salient lobe being a backlobe of about 35 dB down. Figure 7-5b shows the details of the mainbeam lobe, including the first three sidelobes on either side. All of these are more than 17 dB below the mainbeam lobe.

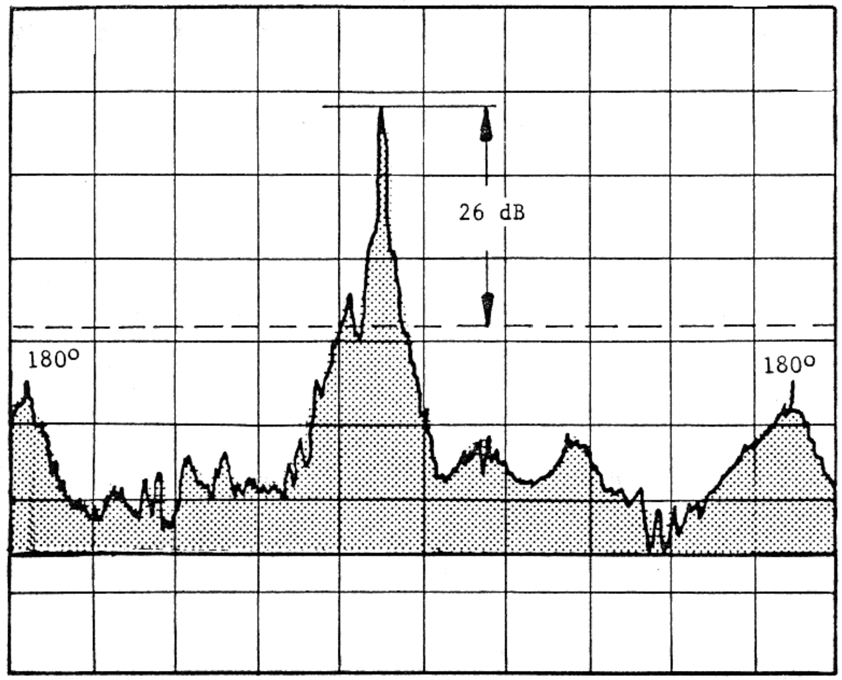


Figure 7-5a. 360-Degree Pattern of a Non-Rotating Antenna.

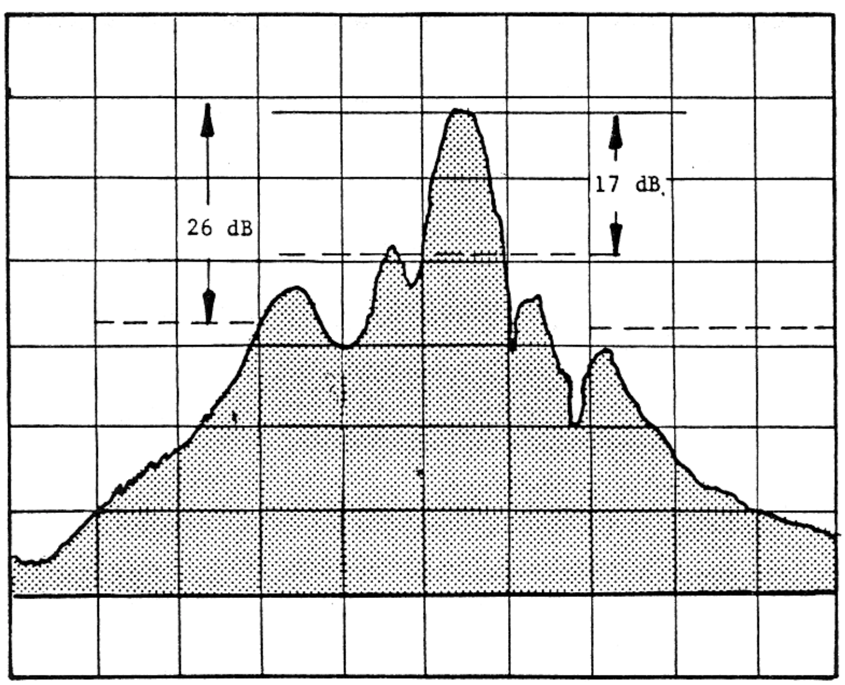


Figure 7-5b. Expanded View of Mainbeam of a Non-Rotating Antenna.

8. FREQUENCY TOLERANCE

8.1. Introduction

8.1.1. Objectives

The objective of this measurement is to measure the frequency drift of the radar transmitter.

8.1.2. Definitions

Frequency drift is the change in average transmitter output frequency which occurs without any deliberate intention to change operating frequency. It does not include the effects of magnetron frequency pulling, frequency modulation, or frequency hopping, but is the change in the operating frequency at some fixed point in the radar successive pulses over a relatively long period of time. The maximum allowable frequency drift is called "frequency tolerance" and is measured in parts per million (ppm) of the operating frequency.

8.1.3. Specifications and Limits

Frequency tolerance for Groups B, C and D radars is given in the following list:

Frequency range (MHz)	Tolerance (Parts per million)
Below 960 (Criteria C only)	400
960-2900 (Criteria C and includes D Criteria)	800
2900-4000	800
4000-10,500	1250
10,500-30,000	2500
30,000-40,000	5000

8.1.4. Test Conditions

The RSEC does not impose any specific test conditions for frequency tolerance. However, the RSEC assumes that the radar will be operating within its frequency tolerance wherever and whenever it is operating. This includes any normal operational cycle from a beginning warmup period through the end of operational life of the system. It is suggested that a reasonably complete range of operating parameters be tested for their effect on frequency drift, including ambient temperature, power supply voltage range, equipment warm-up time, and component aging. If long-term drifts are identified as due to component aging, a standard calibration and adjustment procedure or other measures should be instituted to correct for frequency drift before it exceeds the frequency tolerance.

If several individual operating parameters are discovered to have a major effect on frequency drift, these factors should be tested together to see whether a cumulative frequency drift for these factors will exceed the frequency tolerance.

8.2. Measurements

8.2.1. Instrumentation

Figure 8-1 shows the required instrumentation for frequency drift measurements. It should be noted that the instrumentation shown in Figure 8-1 is only that part of the instrumentation used for the radar frequency measurement. In practice, other instrumentation are used to measure the test condition variables, e.g., a thermometer to measure ambient temperature, an AC voltmeter to measure input electrical service voltages, a running time meter to measure the effect of output tube aging, etc. The spectrum analyzer is connected to a convenient waveguide coupler test point. Sufficient attenuation is added to the signal path to protect the spectrum analyzer from the possibility of damage from signal overload. The signal generator is used to calibrate the frequency scale of the spectrum analyzer at the radar operating frequency. The frequency counter is used to calibrate the signal generator operating frequency, and will not be needed if the signal generator itself is sufficiently well calibrated in frequency (internal counter or frequency synthesizer).

The recommended procedure in the following paragraphs reflects the difficulty of directly measuring the frequency of a pulsed radar signal. However, frequency counters with a capability to measure the carrier frequency within a pulse are commercially available and can be used to simplify measurement of the transmitter frequency.

8.2.2. Measurement Procedure

a. Assemble the test instrumentation as described in Figure 8-1, and any additional instrumentation needed for measurement of operating parameters which may cause frequency drift.

b. Measure the radar operating frequency for each set of operating parameters in the following manner: Adjust the spectrum analyzer controls so that the radar signal appears at exactly the center of the display, or at some other convenient graticule marking. The spectrum analyzer bandwidth in MHz should be about 0.1 x 1/t and the total scan width in MHz should be about 10 x 1/t, where t is the pulse width in microseconds. Connect the signal generator to the spectrum analyzer and tune it until the signal is displayed at exactly the same graticule line used to mark the radar frequency. Now the signal generator is tuned to the same frequency as the radar. Measure and record the signal generator frequency with the counter.

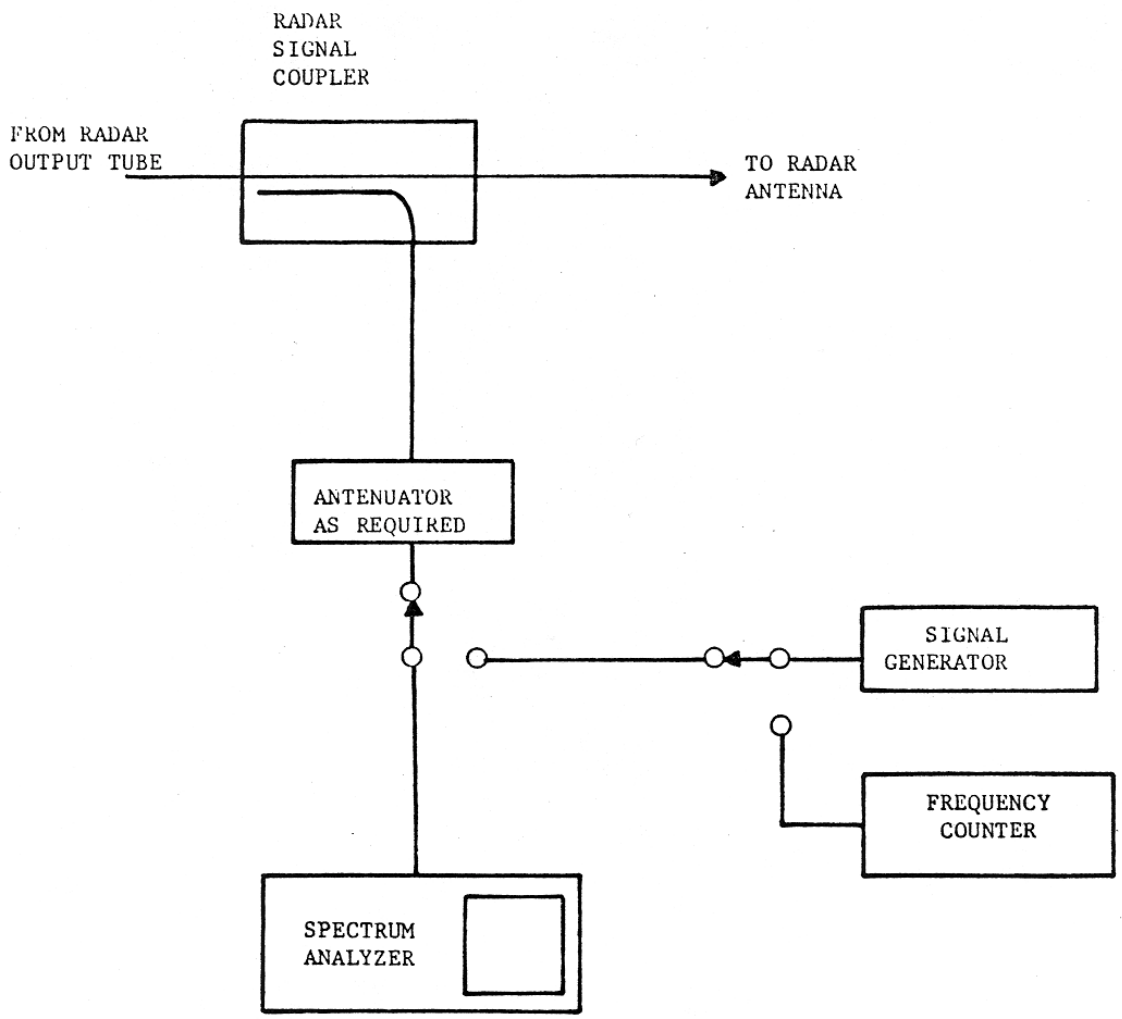


Figure 8-1. Instrumentation to Measure Drift.

9. RADAR TUNABILITY

No specific tests are described for this requirement. Instead, a test for the requirement is covered in other tests, shown in Table 3-1, which indicates that tests are to be made at the upper and lower limits and the midpoint of the radar operating band. All that is necessary to meet the tunability requirement is to ascertain that the radar is, indeed, tunable by means of a simple crystal change or by other adjustments over the tuning range required by the RSEC.

Normally, the use of the word "tunable" would imply that the radar could not only be tuned to a given frequency, but that it would function properly at the given frequency, e.g., meeting specifications for receiver sensitivity or transmitter output power. The RSEC, however, does not contain standards for operational performance, since its function is only to assure compliance with the EMC aspects of operation. To test radar tunability in the operational sense would considerably expand the area of applicability for the RSEC. Therefore, testing tunability in this broader sense is left to the individual agency, who alone can determine the degree of operational variation which is permissible at various frequencies in the radar band. In lieu of operational performance testing, the tunability requirement is considered to be adequately covered as a portion of the remainder of the RSEC testing.

10. OVERALL RECEIVER SELECTIVITY

10.1. Introduction

10.1.1. Objectives.

The purpose of this test is to measure the selectivity of the radar receiver. The selectivity is important from an EMC standpoint since the wider the bandpass, the more frequency separation that is required to avoid degradation from adjacent radars.

10.1.2. Definitions.

The term "overall receiver selectivity" is meant to include all components which might affect the shape of the bandpass of the radar receiver, from the antenna to the display on the radar scope. In the context of this test, however, it will be assumed that essentially' all of this selectivity is determined by the IF bandpass of the radar. This assumption is usually justified because the RF bandpass of a typical radar is usually at least ten times as great as the IF bandpass and has negligible effect on the overall selectivity of the receiver. Signal processing following the IF may also affect the overall radar response to signals near the radar-tuned frequency. A study of signal processing characteristics is often very complex and will not be considered here.

10.1.3. Specification Limits.

The receiver selectivity is required to be "commensurate with the transmitter bandwidth." In the case of radars belonging to Group B, the term "commensurate with or narrower" is used. In the case of radars belonging to Groups C and D, it is also required that a change in pulse width be associated with a corresponding change in receiver bandwidth.

The term "commensurate with" implies that the receiver bandpass should be approximately equal to the emission bandwidth of the radar. The actual numerical ratio between these two quantities has not been specified. The selectivity will be measured at the 3 dB, 20 dB, 40 dB, and 60 dB points.

10.1.4. Test Conditions.

The receiver selectivity will be measured at one test frequency near the midpoint of the radar operating frequency band. If more than one receiver bandwidth is used, either for different pulse widths or for different receiver signal processing (normal, MTI, etc.), all available receiver bandwidths shall be measured. The exact receiver input and output test points are not specified and are to be selected to facilitate the measurement technique. As a minimum, the IF bandpass filters must be included between the input and output tests points. In many cases, it will be necessary to turn off or bypass electronic gain controls used to attenuate returns from nearby objects. In the case of more complex radars, it may be necessary to develop other measurement techniques.

10.2. Measurements

10.2.1. Instrumentation.

The instrumentation used in this test is shown in Figure 10-1. The exact configuration shown will be determined by the radar block diagram and construction. It will be necessary to choose a test configuration for the radar so that it:

a. operates with constant gain;

b. operates at a fixed frequency;

c. has the same amplitude calibration for pulsed and CW signals;

d. utilizes test points which exist and are accessible.

It should be noted that the above conditions are usually not met by radars in their normal operating modes, these conditions can often be met by the proper selection of test point and radar functions. For example, most radars use STC or some other similar function to compensate for the stronger returns from close-in targets. Under normal operating conditions, these radars have a rapidly changing gain. If the STC is performed by a gain-changing PIN-diode attenuator at the input to the receiver, the gain change could be negated by injecting the test signal at some point following the diode. If the STC function is produced in many circuits spread throughout the system, it may be necessary to turn off the STC function in the radar. Similarly, in a frequency hopping radar, the RF portion of the radar operates at a constantly changing frequency. In this case the frequency hopping feature must be disabled or the test signal must be injected following the mixer (where the radar operates at constant frequency).

Although a measurement of this type is usually best made by injecting a test signal at the RF input to the radar receiver, it may be easier with some radar receivers to inject a test signal at the IF frequency. IF measurements will by-pass some of the difficulties with variations in RF gain or RF frequency that are present in some radars. Furthermore, since the overall receiver bandwidth in most radars is almost entirely determined by the IF selectivity, a measurement of IF bandwidth is sufficient to characterize the bandwidth of the receiver.

For the above and other reasons, it will be desirable to measure the bandwidth of some radars by injecting a test signal at the RF input while other receivers will be best measured by injecting a signal at the IF frequency. The following test procedure allows the use of either test frequency (RF or IF). The test procedure will be described in terms of the RF method, with the IF procedure modifications enclosed in parentheses.

A portion of the receiver for the (hypothetical) FPN-395A radar is shown in Figure 10-1. If the RF test method is used, the signal generator, tuned to the RF frequency of the radar, should be coupled into the receiver input through existing couplers, etc. If the test signal is to be injected at the IF, a signal generator tuned to the IF frequency should be connected to the IF amplifier immediately following the first mixer. A spectrum analyzer is connected to the

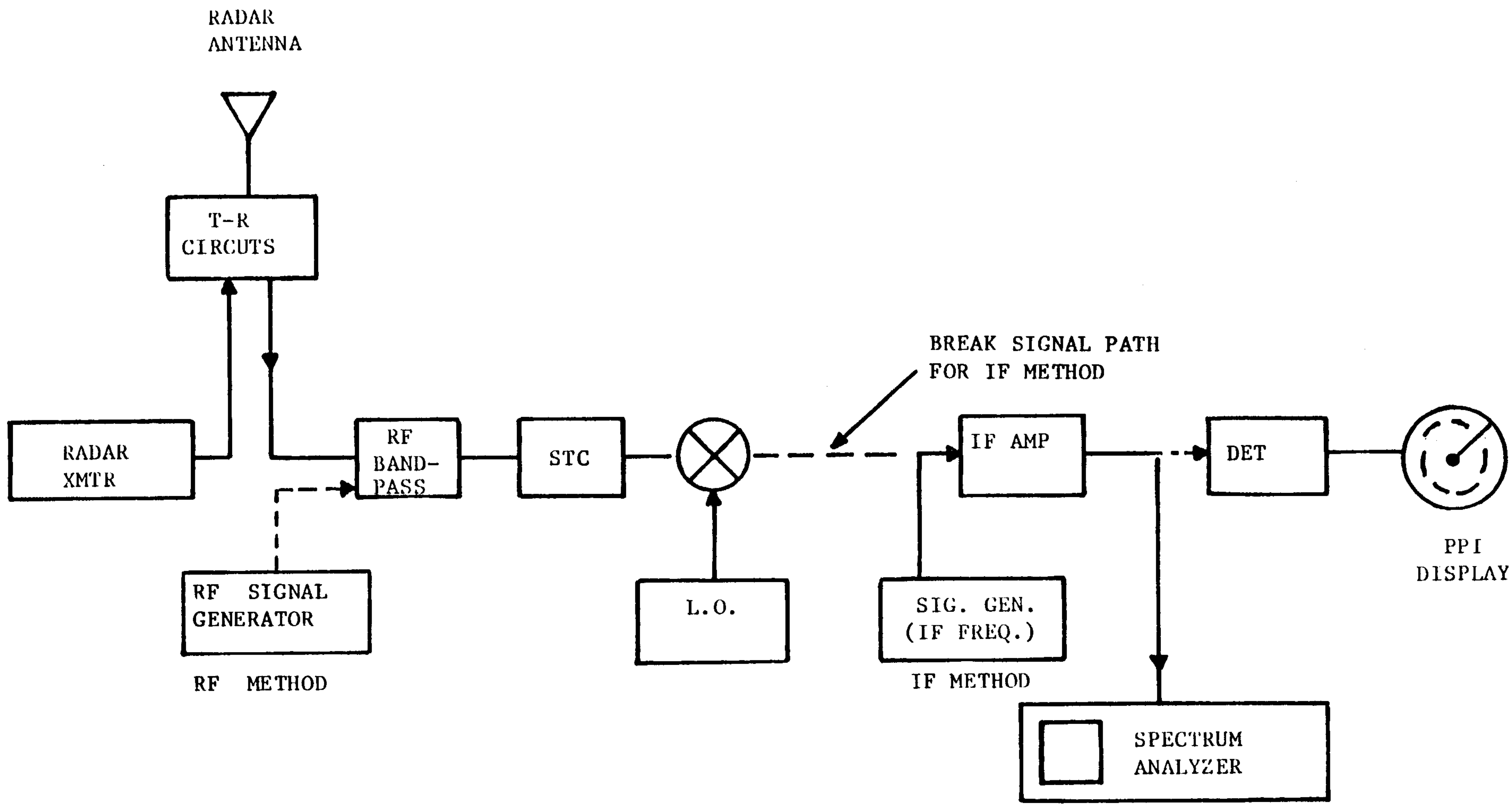


Figure 10-1. Instrumentation to Measure Receiver Selectivity.

IF output, so that as much of the IF selectivity as possible is included in the test path. The radar transmitter may be turned on or off, but in either case tests should be made to determine that the RF and IF stages are operating normally. (Only the IF stages are important if the test signal is injected at IF.) If AGC causes receiver gain to change with a test signal, it may be necessary to modulate the test signal with a duty cycle similar to the normal PRF and a pulse about 10 times as long as the transmitted pulse.

10.2.2. Test Procedures.

The test equipment is connected as shown in Figure 10-1 and the radar receiver is adjusted so that the IF amplifier functions normally.

1. The spectrum analyzer is tuned to the IF frequency, giving a display similar to Figure 10-2. System noise through the IF amplifier will cause a relatively broad noise peak to appear at the IF frequency. Center the spectrum analyzer display on this peak. For this initial adjustment, use a measurement bandwidth approximately 0.1 x the nominal radar IF bandwidth and use a spectrum analyzer scan width of approximately l0x-100x the nominal radar bandwidth.

2. Manually adjust the signal generator frequency and amplitude so that the signal appears at the center of the spectrum analyzer display with an amplitude about 10 dB higher than the noise. Adjust the vertical position of the spectrum analyzer display so that the top of the signal response touches one of the horizontal graticule markings, which will be called the reference level. Note the signal generator amplitude for the reference level.

3. Increase the signal generator amplitude by 60 dB. Tune the signal generator higher in frequency until the amplitude of the signal displayed on the spectrum analyzer equals the reference level established in step 2. If necessary, increase the spectrum analyzer span so that the frequency of the desired signal is within the frequency span. Repeat the process by decreasing the frequency of the signal generator until the display signal equals the reference level on the low side of the center frequency. Increase the frequency span if necessary or decrease it if possible so that the upper and lower frequency points occur within, but as near as possible to the outer edges of the spectrum analyzer display. (Use only the calibrated span settings, so that frequencies are easy to read exactly.)

4. After readjusting the spectrum analyzer display in step 3, tune the signal generator back to the center frequency again, reducing the signal generator to the reference level. With the signal generator output held constant in amplitude, observe the spectrum analyzer display as the frequency is tuned through a frequency range on either side of the center frequency. If necessary, retune the spectrum analyzer so that the area of highest spectrum analyzer displayed is at the center of the graticule. Readjust the spectrum analyzer gain and the display of the signal generator output if necessary, so that the display of the signal generators signal is at the center of the display, 10 dB above system noise, and exactly touching one of the horizontal display graticule lines. Record the signal generator

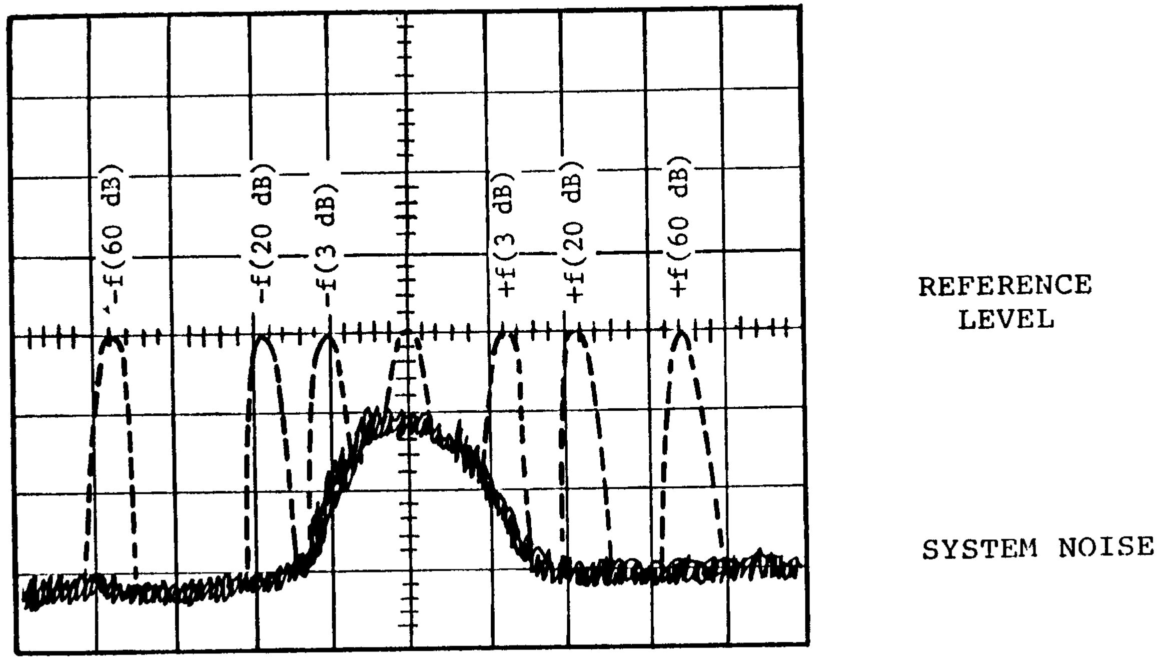


Figure 10-2. Spectrum Analyzer Display For IF Selectivity, Showing Test Responses.

amplitude as the reference amplitude and the associated graticule as the reference line. The display is now calibrated and ready for measuring selectivity.

5. Increase the signal generator amplitude to 3 dB above the reference amplitude established in step 4. Decrease the signal generator frequency until the signal in the display is exactly equal to the reference line. The frequency of the signal generator is the frequency at which IF bandpass response is 3 dB down on the lower side of the center frequency. Read the frequency from the spectrum analyzer display (in terms of separation from the center frequency of the display) and label this frequency "-f(3 dB)." Increase the signal generator frequency to find the corresponding frequency on the upper side of the IF bandpass and label this frequency "+f(3 dB)."

6. Increase the signal generator output to reference +20 dB. Repeat step 5 to find the frequencies above and below the center frequency at which the displayed response crosses the reference line. These two frequencies are the points at which the IF bandpass response is 20 dB below the response at the center of the bandpass. Label these points -f(20 dB) and +f(20 dB).

7. Increase the signal generator to reference the +40 dB, and repeat step 5 to measure the 40 dB down point, -f(40 dB) and +f(40 dB).

8. Increase the signal generator amplitude to reference +60 dB, and repeat step 5 to measure the 60 dB down point, -f(60 dB) and +f(60 dB).

10.3. Sample Data and Calculations

The frequency difference between -f(3dB) and +f(3dB) is the 3 dB bandwidth of the radar, with similar relationships holding for the 20 dB, 40 dB and 60 dB bandwidths. Figure 10-3 shows data measured for the FPN-395A radar.

10.4. Alternative Measurement Methods

There are many alternative methods closely related to the method described above. These methods will not be described in detail here, but enough information will be given to allow the method described above to be adapted to them. In a particularly convenient measurement method, the signal generator is replaced with a tracking generator designed to operate with the spectrum analyzer. This method has the advantage of enabling the entire bandpass characteristic to be photographed in a single scan. The major disadvantage with this method is that it cannot be used to measure many IF amplifiers which are designed to saturate before a 60 dB signal range is injected; the use of much smaller spectrum analyzer resolution bandwidths (possibly .001 x the IF bandwidth) will help overcome this disadvantage.

Other alternative measurement methods employ the injection of the test signal in the RF signal path. These are more accurate methods because using them a larger part of the radar receiver IF is tested; they may be necessary if a substantial part of the radar bandwidth is determined by the RF circuits. The major disadvantage of the RF measurement methods is that they require the disabling of certain system features (such as frequency agility, STC, as described above) or the synchronization of the measurement system with radar trigger pulses.

SIGNAL GENERATOR REFERENCE LEVEL		-87.0 dBm			
+3dB REFERENCE LEVEL		-84.0 dBm			
-f(3dB) =	-1.2 MHz	+f(3dB) =	+1.3 MHz	BW_{3dB} =	2.5 MHz
-f(20dB) =	-1.9 MHz	+f(20dB) =	+2.1 MHz	BW_{20dB} =	4.0 MHz
-f(40dB) =	-2.1 MHz	+f(40dB) =	+2.7 MHz	BW_{40dB} =	4.8 MHz
-f(60dB) =	-2.8 MHz	+f(60dB) =	+3.4 MHz	BW_{60dB} =	6.2 MHz

Figure 10-3. Data Summary Sheet.

11. RECEIVER IMAGE AND SPURIOUS RESPONSES

11.1. Introduction

11.1.1. Objectives

The purpose of this test is to determine the response of the radar receiver to signals of frequencies far removed from the nominal radar receiver frequency. These responses are divided into the response at the IF image frequency (called the image response) and the rest of the responses (called spurious responses).

11.1.2. Definitions

The image and spurious responses are defined as the responses of a radar receiver to signals at the image frequency and other frequencies, respectively, compared with the radar receiver response to a signal at the radar receiver tuned frequency. The responses will be measured in terms of "dB below the desired response" or simply as dB suppression. This test applies only to the receiver RF and IF characteristics; signal processing rejection is not included.

11.1.3. Specification limits

For radars in Group B, all spurious responses shall be suppressed at least 50 dB except for image responses, which have no specification limit. For radar receivers in Groups C and D, the image response shall be at least 50 dB down. All other spurious responses shall be at least 60 dB down.

11.1.4. Test conditions

Radar receiver spurious and image response shall be measured by injecting the test signal in the signal path between the radar antenna output and the input to the receiver. The receiver shall be tested over the frequency range shown in section 3.3, while the radar is tuned to near the high and low edges and the midpoint of the radar operating frequency band.

11.2. Measurements

11.2.1. Instrumentation

The instrumentation used in this test is shown in Figure 11-1. The details of this instrumentation will have to be changed depending on the type of instrumentation available for the test. During an actual test, for example, several signal generators might be required to cover the frequency range. The signal generators might have built-in pulse generation capability adequate to perform without an external pulse modulator, etc.

In this test, a pulsed RF signal is injected into the radar receiver at frequencies relatively far away from the radar operating frequency. The selection of a point in the signal path to inject a test signal should be made as close to the radar antenna as is convenient. The test point should include any bandpass filters in the signal path, but it must exclude the possibility of test equipment damage caused by the radar transmitter output pulsed signal. If an RF

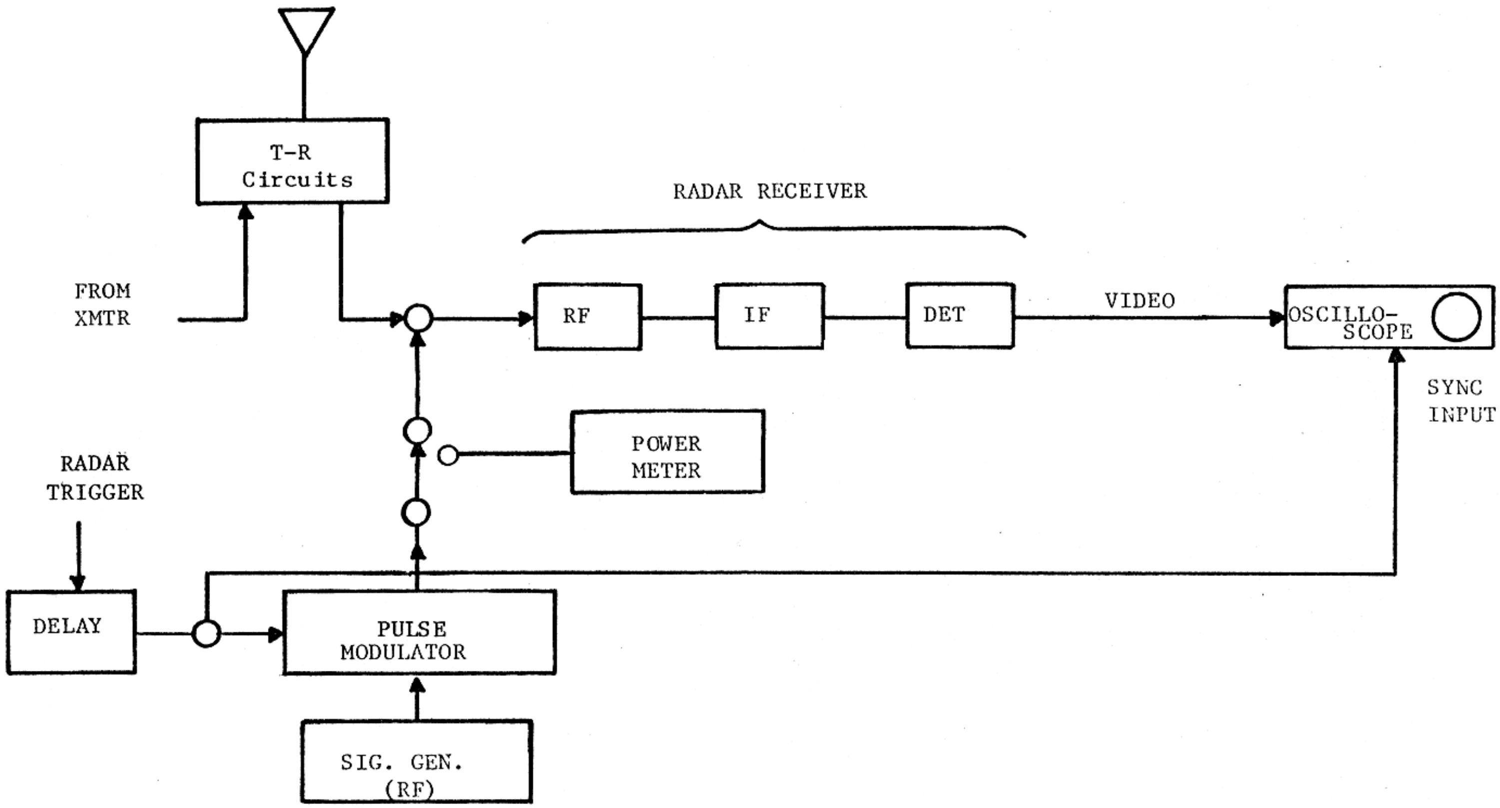


Figure 11-1. Instrumentation to Measure Receiver Spurious Responses.

filter is used in a signal path shared by the transmitted and received signals, it may be necessary to turn off the transmitter while these measurements are being made. The connection to the receiver input should be carefully made, using an existing waveguide coupler or installing a suitable waveguide adapter or coaxial cable, as required.

A detector and oscilloscope is connected at the output of the IF strip to identify any responses caused by the input test signal. In many radars, this equipment is already present in the form of a detector and "A-scope" or similar system monitor. The oscilloscope, triggered by the radar system trigger is adjusted so that the test pulse appears in a stable position on the display.

The test signal is produced by a signal generator (or a combination of signal generators) which covers the required frequency test range. The signal generator is pulsed with a pulse whose duration is comparable to the nominal pulse width of the radar. The test pulses must be synchronized to the radar receiver operation with a delay such that they are placed within the time window of maximum receiver sensitivity. The same trigger pulse is used to synchronize the oscilloscope display to the pulse generation. Frequency-hopping radars are tested on one fixed channel at a time. Chirp radars are tested with a CW signal.

Determine the required test frequency range from the table in 3.3. Examine the radar characteristics and determine where connections can be made to the receiver input, the IF output, and the radar trigger pulse. Set up the necessary equipment as required, and indicated in Figure 11-1. If the radar has an STC (Sensitivity Time Control) or a similar function, disable the function to give maximum receiver sensitivity or add enough delay to the radar pulse trigger so that the test pulse will arrive at the radar input when the receiver has maximum sensitivity.

11.2.2. Test Procedures

1. Calculate expected image and spurious response frequencies based on the formula:

$$F(sp) = (p \times F(LO) \pm F(IF))/q$$

where:

p, q are integers 1,2,...

F(LO) is the local oscillator frequency

F(IF) is the frequency of the first IF

These frequencies should be calculated for all values of p and q up to 10 or until F(sp) is out of the frequency range in Table 3.3. The receiver should be tested at these frequencies with special care when the frequencies are encountered in the next several test steps, since spurious responses are possible at these frequencies. Signals at frequencies associated with low values of p + q equal to (three or less) are especially likely to produce responses when they fall within the normal operating range of the radar.

2. Tune the radar to a frequency near the lower edge of the operating band. Adjust the pulse modulator to give a duty cycle of 100% (CW). Tune the signal generator to the radar operating frequency and note the signal generator setting required to deliver 0 dBm to the power meter at the input to the receiver. Tune the signal generator over the complete test frequency range and note the difference in output settings required to deliver 0 dBm at about 20 frequencies in the test frequency range. This will give a table of generator correction factors which can be used to produce a constant test signal amplitude at the receiver input.

3. Tune the signal generator to the radar operating frequency and inject sufficient signal amplitude to produce an observable trace on the oscilloscope. Adjust the pulse modulator to produce pulses with approximately the same duration and PRF as those of the radar under test. Synchronize the pulse modulator to the radar using the pulse trigger for the radar. Decrease the signal amplitude so that the IF amplifier is not saturating. Adjust frequency and time delay to maximize the pulse display on the oscilloscope. Choose a pulse height that is easily visible above system noise and below saturation, and adjust the oscilloscope display so that the top of the pulse falls exactly on a graticule marking. Call this amplitude the detector reference amplitude. Disconnect the signal generator from the reciever input; adjust the pulse modulator for 100% duty cycle; and measure the signal generator power level at the receiver input with a power meter. (Note that it may be necessary to increase the signal level by some known amount in order to measure it on the power meter). Label this amplitude the receiver reference amplitude.

4. Increase the signal generator level by 60 dB (radars in Group B) or 70 dB (radars in Group C or D). Tune above the radar receiver frequency by about 10 times the bandwidth of the radar receiver. Slowly increase the signal generator frequency, adjusting approximately for the loss in the cabling and pulse modulator so as to keep a constant amplitude input at the radar receiver. Watch the oscilloscope constantly for any pulsed signals which occur above the detector reference level. Note the frequency of the signal generator and keep a list of all such frequencies. Continue the process until the entire frequency range above the radar frequency has been tested. Repeat the process for frequencies below the radar frequency.

5. For each frequency on the list at which a response was detected, measure the suppression. At each frequency, adjust the signal generator so that the oscilloscope trace to exactly touch the detector reference line. Use the power meter to measure the amplitude of the signal required to produce a detector reference response. (It may be necesary to increase the signal generator output by several steps of 10 dB to measure it on the power meter.) Compare this amplitude to the receiver reference amplitude measured in step 2. The difference, in dB, between these amplitudes is the suppression at that frequency.

6. Inspect the list of frequencies and corresponding suppressions. Any suppressions smaller than the requirements in the RSEC should be noted on the radar test report.

7. Repeat the above steps with the radar tuned to a frequency near the midpoint of the operating frequency band and for a frequency near the top of the operating frequency band.

11.3. Sample Data and Calculations.

The (hypothetical) FPN-395A radar operates over the 2900-3100 MHz band. Therefore, table 3.3 shows that tests should be performed from about 2.0 GHz to about 15 GHz.

Figure 11-2 shows a table of correction factors used to compensate for insertion losses of a pulse modulator and cables over the frequency range. In the case of this test the signal generator contained an internal pulse modulator and a single generator provided coverage over the entire frequency range. Therefore, the correction factors are relatively small. With such small variations in adjacent correction factors it probably would not be necessary to measure at 20 frequencies as several frequencies which are especially likely to produce measurable responses have been marked with an asterisk.

Figure 11-3 shows a portion of the list of calculated possible spurious responses suggested in step 2.

11.4. Alternative Measurement Methods.

More complex radars may require substantial modification of the measurement method described above. Such modifications may be made necessary because of signal processing options which cause the radar to ignore interfering signals or various other self-adaptive features which interact with the radar signal environment. Since this test is intended to be only a test of RF and IF hardware, it may be difficult to sufficiently decouple the radar hardware from the overall radar system performance. In these cases, it will be necessary to design tests which measure the hardware as well as practicable and to provide a description of those tests.

Radar Type: FPN-395A

Operating Frequency: 2900 MHz

Test Frequency Range: F(MIN) = 1500 MHz, F(MAX) = 15 GHz

Frequency	Correction Factor (dB)
1.5 GHz	-0.5
2.0 GHz	-0.4
3.0 GHz	0.8
3.5 GHz	0.6
4.0 GHz	1.1
5.0 GHz	0.7
6.0 GHz	1.2
7.0 GHz	2.3
8.0 GHz	1.4
9.0 GHz	2.1
10.0 GHz	3.1
12.0 GHz	4.3
15.0 GHz	3.5

Note: + factors mean that the test generator output should be increased above nominal, -factors require generator output to be decreased.

Figure 11.2. Correction Factors for Receiver Spurious Response Test.

Radar Type FPN-395A
Operating Frequency = 2905 MHz
First IF Frequency F(IF) = 160 MHz
Local Oscillator F(LO) = 3065
Test Frequency Range F(MIN) = 1500 MHz, F(MAX) = 15,000 MHz

Calculate spurious responses using:

$$F(SP) = (p \times F(LO) \pm F(IF))/q$$

For p = 1

Value of q	- F(IF)	+ F(IF)
1	2905 (1)	3225 (2)
2	1432.5*	1612.5*
3	968.3	1075
4		
5		
6		
7		
8		
9		
10		

For p = 2:

1	5970*	6290*
2	2985	3145
3	1990	2096.6
4	1492.5	1572.5
5		1258
6		
7		
8		
9		
10		

For p = 3:

1	9335	9655
2	4667	4827
3	3111	3218
4	2333	2413
5	1867	1931
6	1555	1609
7	1333	1379
8		
9		
10		

(1)Fundamental response for the FPN-395A
(2)Image response
*Frequencies that are likely to produce responses

Figure 11-3. Calculation of Image and Spurious Responses.

12. RECEIVER LOCAL OSCILLATOR RADIATION

12.1. Introduction

12.1.1. Objective

The objective of this test is to determine whether the level of local oscillator signal radiated from the radar receiver is excessive.

12.1.2. Definitions.

None.

12.1.3. Specification limits.

Local oscillator emission from the receiver input shall be less than -40 dBm for radars belonging to Group B, Group C or D.

12.1.4. Test conditions.

Local oscillator emission shall be measured with the radar operating normally at frequencies near the lower and upper limits and near the midpoint of the radar operating frequency band.

12.2. Measurements

12.2.1. Instrumentation

Figure 12-1 shows the instrumentation required for this test. The receiver input point selected should be the same point selected for spurious response test. Use suitable waveguide to coax adapters if the receiver input is connected with waveguide. The power meter may be omitted if the signal generator output is accurately calibrated.

12.2.2. Test procedures

1. Connect the equipment as shown in Figure 12-1. Although spectrum analyzer settings are not particularly critical in this measurement procedure, the following list of settings is an adequate starting point for most radars.

Scan width	100 MHz
Center frequency	Local Oscillator
Bandwidth	100 kHz
Scan time (total)	100 ms (10 ms/div if 10 divisions)

After the LO is located and centered on the spectrum analyzer, it will be possible to decrease the scan width and, if necessary, the bandwidth.

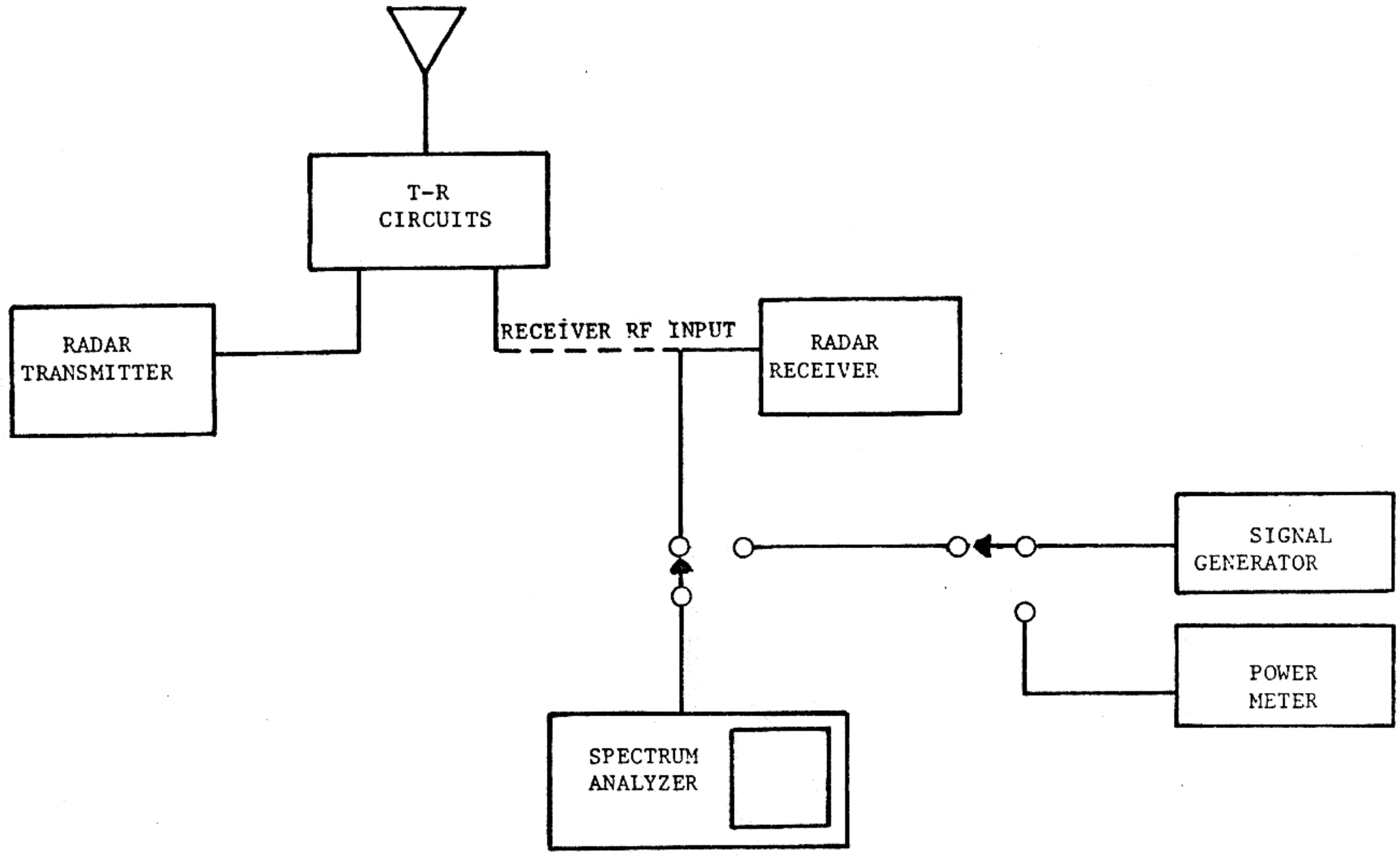


Figure 12-1. Instrumentation to Test Receiver LO Emissions.

2. Tune the radar to an operating frequency near the lower edge of the operating frequency band, and center the spectrum analyzer display at the nominal LO frequency. Calibrate the spectrum analyzer and cable combination at the LO frequency by disconnecting the test cable from the receiver input and applying a -40 dBm signal at the LO frequency to the receiver end of the cable.

3. Reconnect the test cable to the receiver input. Tune the spectrum analyzer to the LO frequency and use the calibration derived in step 2 to calculate the LO emission referred to the receiver input.

4. Repeat the above steps with the radar tuned to mid-band and upper band edge frequencies.

12.3. Sample Data and Calculations.

None.

12.4. Alternative Measurement Methods.

If the input to the receiver is not easily accessible, it may be necessary to measure the receiver LO through one of the waveguide couplers which are normally part of the radar equipment. This measurement technique is identical to the technique previously described, except that the amount of coupler loss must be known to refer the measured LO amplitude back to the receiver input. For example, a -40 dBm LO emission at the receiver input would be reduced to -90 dBm if the coupler had a 50 dB loss, and the -90 dBm amplitude at the coupler output would represent the new limit on LO emission.

If it is necessary to measure the LO using an existing waveguide coupler, two potential problems must be specifically addressed. First, transmitter pulses may be present at this point which will have sufficient amplitude to damage the spectrum analyzer. Therefore, it will be necesary to turn the transmitter off before this measurement is made. In some radars, however, transmitter operation is necessary for proper operation of the L0. For these radars it will be necessary to reduce the amplitude of the transmitted pulses with the use of a notch filter or similar technique.

Second, the coupler loss may reduce the -40 dBm leakage signal to levels below the sensitivity of the spectrum analyzer. This may be measured by calibrating the spectrum analyzer and cable responses with a test signal amplitude equal to 40 dBm minus the coupler loss. If a response at least 5 dB above the noise is not seen, it will be necessary to improve the spectrum analyzer sensitivity. This can be done by inserting a pre-amplifier ahead of the spectrum analyzer or by reducing the spectrum analyzer bandwidth.

13. RADAR RECEIVER FREQUENCY STABILITY

13.1. Introduction

13.1.1. Objectives

The purpose of this test is to measure the frequency stability of the radar receiver.

13.1.2. Definitions

Receiver frequency stability includes all of those factors which affect the frequency of maximum receiver sensitivity. For most radars receivers, the frequency of the local oscillator will be the most important factor in the received frequency, and will be assumed to hold in this test. Therefore, receiver frequency stability is assumed equivalent to local oscillator frequency stability.

13.1.3. Specification limits

For radars in Group B or Group C, the frequency stability of radar receivers shall be "commensurate with, or better than, that of the associated transmitters." Frequency tolerance for transmitters is shown in Section 8.

13.1.4. Test conditions

The receiver frequency stability test conditions are identical to the test conditions for Transmitter frequency drift. These conditions include warm-up, component aging, power supply voltages, etc. It is recommended that receiver frequency stability testing be done concurrently with transmitter frequency stability testing.

13.2. Measurements

13.2.1. Instrumentation

Figure 13-1 shows the instrumentation for this test. It is recommended that this test be done concurrently with transmitter frequency stability testing (section 8). The frequency counter shown here can be time-shared with the frequency counter shown with the transmitter tests. Depending on the Local oscillator sampling point, it may be necessary to include a preamplifier to provide a sufficiently strong signal to allow the frequency counter to count properly.

13.2.2. Test Procedures

This test should closely follow the transmitter frequency tests described in Section 8. Local oscillator frequency should be measured whenever the transmitter frequency is measured, providing a simultaneous, but independent record of receiver drift. As with transmitter drift, no specific schedule of test sampling conditions is recommended here. The schedule should reflect the operational schedule of the radar.

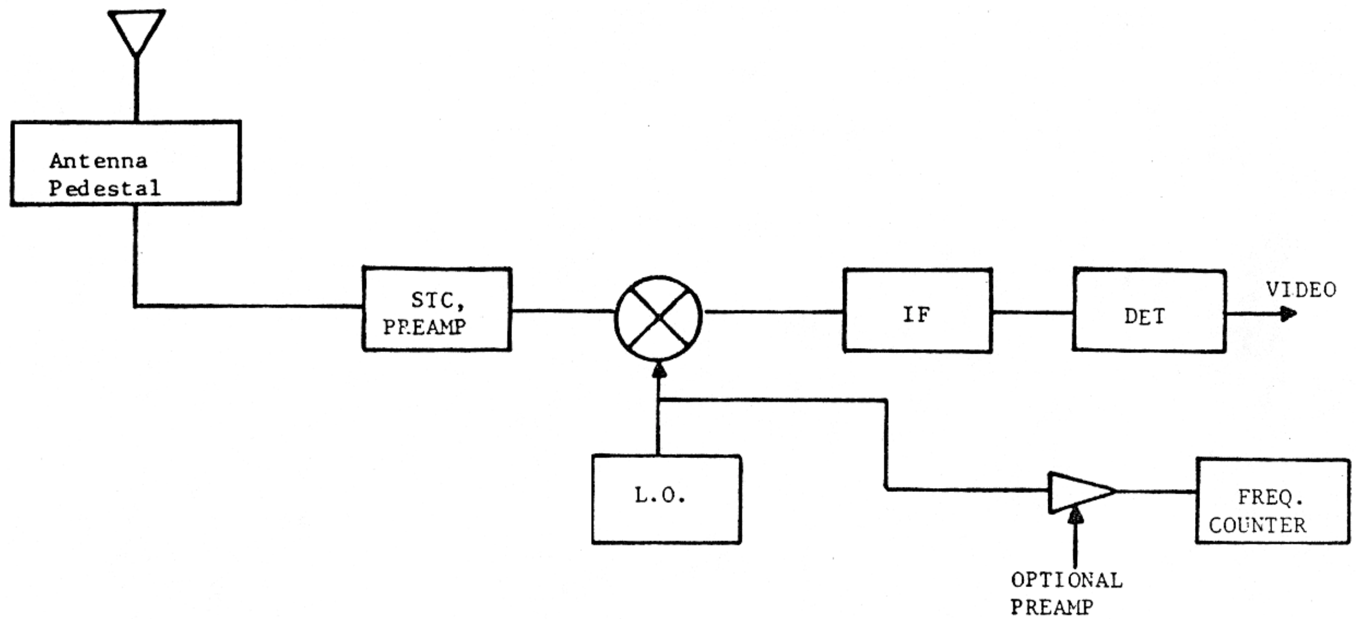


Figure 13-1. Instrumentation to Test Radar Receiver Frequency Drift.

13.3. Sample Data and Calculations

None.

13.4. Alternative Measurement Methods

The measurement method outlined previously depends on the assumption that the significant part of the frequency drift is due to Local Oscillation drift and ignores other sources of drift. If other sources of drift are not insignificant, it will be necessary to inject a test signal of known frequency at the radar receiver input and measure its amplitude at the detector output.