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METHODOLOGY INVESTIGATION

PHASE II REPORT

COMPACT RANGE TEST APPLICATIONS

BY

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Range Support Division
Test Support Directorate

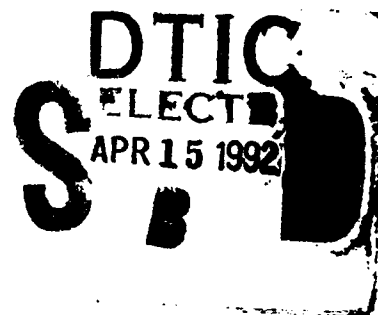
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2. Point of contact at this headquarters is Mr. Kenneth R. Balliet, AMSTE-TC-D, amstetcd@apg-9.apg.army.mil, DSN 298-3677.

FOR THE COMMANDER:

Frederick D. Mabanta

FREDERICK D. MABANTA
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FOREWORD

Georgia Tech Research Institute (GTRI) has designed and fabricated a large outdoor Compact Antenna Range for the US Army Electronic Proving Ground (USAEPG). This range enables USAEPG to test antenna systems of large ground vehicles or aircraft that weigh up to 70 tons and are up to 50 feet in size over a frequency range of 6 to 40 gigahertz (GHz). Ongoing investigation and study are being conducted to determine the compatibility and adaptability of this antenna pattern measurement range to measure other system parameters such as target return signals and system responses to specialized electromagnetic environments. A photograph of the USAEPG Compact Range appears below.



Photo. USAEPG Outdoor Compact Range.

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SECTION 1. INTRODUCTION

1.1 BACKGROUND

This Phase II investigation is a follow-on of an existing Mind which was funded in FY90. USAEPG has obtained a Compact Range facility which can provide a unique capability to irradiate large target systems (up to 70 tons) with a highly controlled and precisely oriented electromagnetic (EM) field. A significant potential application of this capability is the measurement of "upset events" produced by EM environments that couple directly into the components and circuits of electronic systems.

1.2 PROBLEM

A Compact Range is suitable for other measurements besides antenna patterns. The cost of performing these measurements could be reduced by integrated or combined testing. This process could replace the current procedure of measuring different characteristics of a test item at different facilities.

1.3 OBJECTIVE

The objective of this continuing investigation was to determine how the new Compact Range at USAEPG can be adapted to other measurements such as target return signals and equipment responses to specialized signal environments.

1.4 PROCEDURES

a. Radar Cross Section (RCS) Measurement Systems. Research current methodology and implementation of RCS measurement systems for compact antenna ranges.

b. Generation of Specialized EM Environments. Determine the necessary modifications to the existing Compact Range to generate specialized EM environments.

c. Instrumentation and Interfacing. Provide a development path for the implementation and integration of the technology and equipments necessary to upgrade the existing Compact Range to perform RCS measurements and generate specialized EM environments.

1.5 RESULTS

a. RCS Measurement Systems. RCS measurements can be made at a single frequency [continuous wave (CW)] and return signal data collected as a function of target rotation. The resulting data can look very much like an antenna radiation pattern.

Measurements can also be made at fixed target aspect angles while collecting return signal data across a band of frequencies. The resulting data can be transformed from the frequency domain

to the time domain by using Fourier transform techniques to display the target RCS as a function of range. This method is often referred to as down-range imaging.

In addition to the down-range target response, it is possible to take additional measurements and also calculate the cross-range image response of the target. These data can be used to create contour plots that detail the target RCS image.

The existing Compact Range could be upgraded to the following configurations to perform RCS measurements:

(1) Non-Pulsed Configurations.

(a) Monostatic. A monostatic configuration uses a single feed antenna for transmitting and receiving radio frequency (RF) energy. RF couplers and/or isolators are used to separate the transmit and receive signals. The calculated RCS sensitivity of a non-pulsed monostatic configuration ranges from -33 decibels per square meter (dBsm) at 6 gigahertz (GHz) to -14 dBsm at 40 GHz. The maximum dynamic range is 33 decibels (dB).

(b) Quasi-Monostatic. A quasi-monostatic configuration uses two feed antennas placed side-by-side for independent transmission and reception of RF energy. The calculated RCS sensitivity of a non-pulsed quasi-monostatic configuration ranges from -54 dBsm at 6 GHz to -36 dBsm at 40 GHz. The maximum dynamic range is 54 dB.

(2) Pulsed Configurations.

(a) Monostatic. The calculated RCS sensitivity of a pulsed monostatic configuration ranges from -49 dBsm at 6 GHz to -31 dBsm at 40 GHz. The maximum dynamic range is 49 dB.

(b) Quasi-Monostatic. The calculated RCS sensitivity of a pulsed quasi-monostatic configuration ranges from -51 dBsm at 6 GHz to -33 dBsm at 40 GHz. The maximum dynamic range is 51 dB.

b. Generation of Specialized EM Environments. The Hewlett-Packard (HP) 83640A RF source has an internal modulation generator that can provide sine, square, triangle, ramp, or noise waveforms for amplitude modulation (AM) or frequency modulation (FM). Sine waveforms can range in frequency from 1 hertz (Hz) to 1 megahertz (MHz). Square, triangle, and ramp, waveforms can range in frequency from 1 Hz to 100 kilohertz (kHz). These waveforms all have a frequency resolution of 1 Hz. AM depth can range from 0 to 99 percent and FM deviation ranges from 1 Hz to 10 MHz.

Pulse modulation can also be provided with the HP 83640A internal modulation generator. Pulse widths can range from

25 nanoseconds to 400 milliseconds. Pulse periods can range from 300 nanoseconds to 400 milliseconds [these periods correspond to pulse repetition frequencies (PRFs) ranging from 2.5 Hz to 3.333 MHz]. Pulse resolution is 25 nanoseconds with a specified accuracy of 5 nanoseconds.

c. Instrumentation and Interfacing. Due to the increased usage factor during this investigation, we purchased spares to back up the range's local oscillator (LO) amplifiers. Attenuators were purchased to balance the LO signals at the test and reference mixers. The new HP 83640A RF source was also acquired.

1.6 ANALYSIS

a. RCS Measurement Systems.

(1) Non-Pulsed Configurations.

(a) Monostatic. The low dynamic range of this configuration (33 dB, or less) is mainly caused by low signal channel isolation due to the use of couplers and/or isolators to separate the transmit and receive signals.

(b) Quasi-Monostatic. Changing the existing single RF feed to a dual-feed configuration is the major hardware change to the range geometry that must be implemented for the quasi-monostatic configuration. The increase in transmit-to-receive signal channel isolation, resulting from the use of a dual-feed configuration, provides a larger measurement dynamic range for RCS signals. The non-pulsed quasi-monostatic configuration can be upgraded to a pulsed quasi-monostatic configuration.

(2) Pulsed Configurations. By pulsing the transmit signal, receiver blanking (hardware gating) can be utilized during RF power transmission to increase receiver isolation and allow higher transmit power levels that would otherwise saturate the receiver front-end. Higher transmitter power levels up to 1000 watts can then be used to provide an additional 20 to 36 dB of dynamic range. Hardware gating can also remove large spurious range responses.

b. Generation of Specialized EM Environments. AM, FM, and pulse modulations that meet the specifications of the internal HP 83640A RF source can be generated using the existing Compact Range hardware configuration. The RF output can be increased by the use of additional linear amplifiers.

c. Instrumentation and Interfacing. No testing or study could be performed; therefore, no analysis is possible.

1.7 CONCLUSIONS

a. RCS Measurement Systems.

(1) Non-Pulsed Configurations. The low RCS sensitivity and dynamic range of the monostatic configuration makes this configuration adequate only for larger test targets. The use of two separate feeds in the quasi-monostatic configuration provides greater isolation between transmit and receive signals than most monostatic configurations. The quasi-monostatic configuration also has a significant advantage over the monostatic configuration in greater RCS sensitivity and dynamic range.

(2) Pulsed Configurations. If pulsed transmit capability is added to the monostatic or quasi-monostatic configuration, hardware gating can be utilized to significantly increase receiver isolation and dynamic range. Hardware gating can also remove large spurious range responses and allow the use of additional transmit signal amplifiers to further increase RCS sensitivity and dynamic range.

b. Generation of Specialized EM Environments. Some modulation formats can be generated internally by the HP 83640A RF source. Additional hardware and control software will be required in order to provide higher RF output power and generate more complex waveforms such as pulse chirp, stagger and jitter, coherent pulse, phase, quadrature modulation, and frequency hopping.

The generation of EM environment signals could benefit from the dual-feed setup required for the quasi-monostatic RCS configuration. With two feeds present, it would be possible to simulate multipath and clutter signals. Also, two independently simulated signals could be transmitted simultaneously.

c. Instrumentation and Interfacing. No testing or study could be performed; therefore, no conclusions are possible.

1.8 RECOMMENDATIONS

a. RCS Measurement Systems.

(1) We recommend implementing a quasi-monostatic (dual-feed) system for RCS measurements. This configuration yields high performance in terms of RCS sensitivity and dynamic range and also lends flexibility for the integration of equipment to generate specialized EM environments. Currently, six feed antennas are being used to cover the frequency range from 6 to 40 GHz. We have two complete sets of feeds that could be used to implement a quasi-monostatic RCS measurement system. Some redesign and realignment of the existing feed housing assembly will be required.

(2) We further recommend implementing a pulsed system in order to take advantage of hardware gating techniques and the increase in sensitivity and dynamic range that will come with using higher transmit power levels.

b. Generation of Specialized EM Environments. We recommend investigation of available signal simulation systems to augment the limited internal modulation capabilities of the HP 83640A RF source. One such system has been introduced in late 1991 by Hewlett-Packard, the HP 8791 Model 21 Frequency Agile Signal Simulator (HP FASS). Due to its late release date, the details of this system's operation and interfacing to the existing Compact Range have not been investigated in time for inclusion in this report. It is known that this system can generate exotic, agile test signals for advanced electronic warfare threat simulation, radar-target simulation, and secure communications testing. Modulation waveform simulations include: advanced spread-spectrum formats, phase-coherent frequency hopping, various intrapulse modulations, and antenna scans. Instantaneous modulation bandwidths up to 40 MHz are possible. Frequency switching time is 100 nanoseconds from 50 MHz to 18 GHz. Frequency coverage can be extended to 40 GHz with optional up-conversion.

c. Instrumentation and Interfacing.

(1) The following Phase I recommendations remain to be implemented:

(a) The acquisition of network analyzer test and calibration sets would allow checkout and troubleshooting of various equipment such as coaxial cables, filters, isolators, amplifiers, and mixers.

(b) The present HP 8510B range receiver should be upgraded to an 8510C model. The current firmware has several known deficiencies that would be corrected by the upgrade. The efficiency of the range would improve by increasing data throughput.

(2) Phase II Recommendations. We recommend further investigation to fully characterize the existing performance characteristics of the Compact Range before implementing the recommended RCS configuration. As a minimum, we recommend that the following tests and measurements be conducted:

(a) System sensitivity and dynamic range.

(b) Isolation between the test and reference channels.

(c) Detailed characterization of the quiet-zone field. Sufficient data should be collected with a precision field probe to enable analyses of the magnitude and location of any extraneous reflections from the reflector assembly and sources of multipath and range clutter.

SECTION 2. DETAILS OF INVESTIGATION

2.1 RCS MEASUREMENT SYSTEMS

a. There are three basic configurations commonly used for the measurement of RCS signals: monostatic, quasi-monostatic, and pulsed (monostatic or quasi-monostatic). Integration of any of these configurations will require both hardware and software modifications to the existing Compact Range.

b. The capability to measure small radar cross sections is limited by the noise floor of the receiver, transmitter power, and system losses. Table 1 and Figure 1, Compact Range Sensitivity, show the calculated versus measured system sensitivity of the Compact Range in its present configuration. This graph includes the losses associated with the remote mixer configuration. This graph does not include other losses associated with the receiver. The existing system uses an external low noise intermediate frequency (IF) amplifier. This graph reveals that the system sensitivity should be much lower than what has been previously measured. All calculations assume that the system responses are the limiting responses, and that no spurious signals are present.

TABLE 1. COMPACT RANGE SENSITIVITY

Frequency (GHz)	System Sensitivity (dBm)		
	Note 1	Note 2	Note 3
6.0	-108.38	-88	-55.4
7.0	-108.38	-88	-60.2
8.0	-108.38	-88	-61.0
10.0	-108.38	-88	-60.0
12.4	-108.38	-88	-60.3
15.0	-108.38	-88	-45.4
18.0	-93.38	-73	-48.0
20.0	-93.38	-73	-60.0
26.5	-93.38	-73	-57.0
35.0	-91.38	-71	-40.0
40.0	-91.38	-71	-50.0

NOTES:

1. Calculations include external IF amplifier (gain = 25 dB, noise figure = 2.7 dB).
2. Calculations do not include external IF amplifier.
3. Measured during acceptance testing.
4. dBm = decibels relative to one milliwatt.

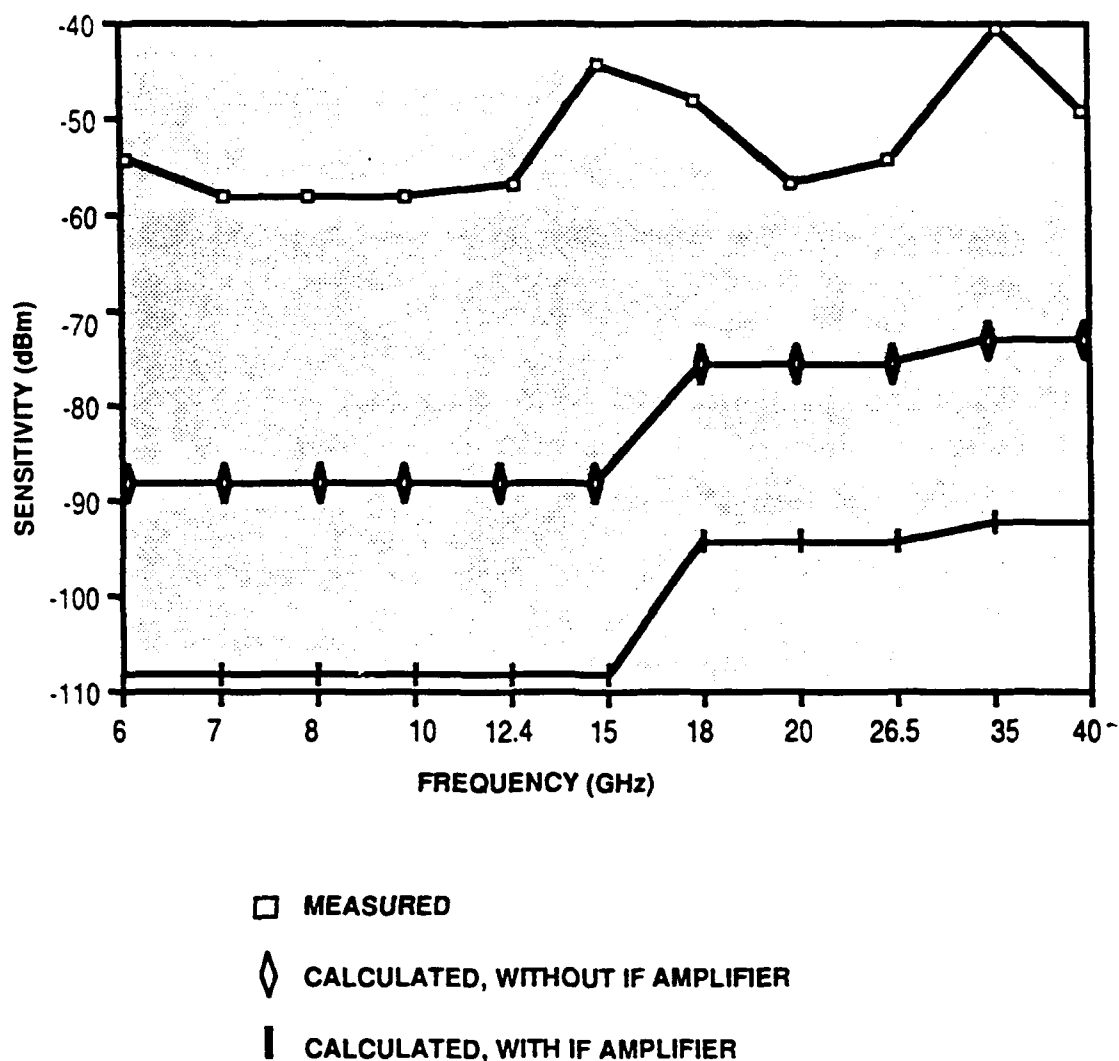


Figure 1. Compact Range Sensitivity.

c. Other factors that affect the ability of the Compact Range to perform RCS measurements are range related. These factors could affect the calculations included in this report. A specific area of consideration is the 'big bang' associated with any Compact Range. The 'big bang' is the reflection that occurs from the large reflector used in the Compact Range. A large reflected signal from the reflector can saturate a low noise receiver and limit the maximum amount of power that can be transmitted. However, a pulsed configuration can eliminate the 'big bang' from saturating a low noise receiver and allow higher power levels to be transmitted. Other responses that come into play are multipath signals and other range reflections.

d. The operation of the range to measure RCS signals is straightforward. The target is illuminated with a plane wave from the reflector. The target reflects an amount of energy that is dependent on its RCS. The power received from the target is given by the following radar equation:

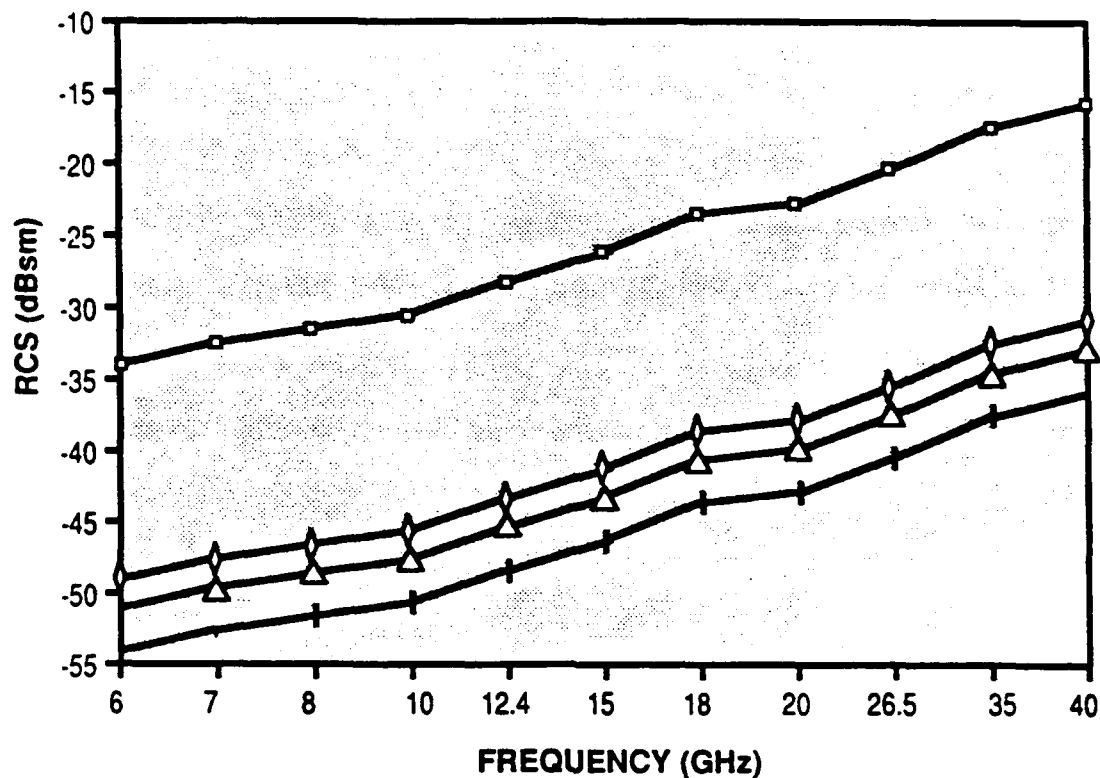
$$P_r = P_t * G_t * G_r * \text{System Losses} * \text{Target RCS} * (\text{Wavelength}^2) / [(4 * \pi)^3 * (R^4)]$$

Where P_r is the received power; P_t is the transmitted power; G_t is the transmit antenna gain; G_r is the receive antenna gain; $\pi=3.14159265$; and R is range distance.

e. The performance of the range to measure RCS signals is dependent on: the output power of the transmitter, the gain of the feeds, receiver system losses, the loss due to free space, and the reflection coefficient of the target in dB relative to one square meter (dBsm). The RCS of the target must be equal to or greater than the receiver's sensitivity. Therefore, the system sensitivity dictates the minimum RCS signal that can be measured for a given transmitter power level. Table 2 and Figure 2 show the minimum RCS signal level that can be measured, assuming ideal receiver conditions and that there are no other system losses except the remote mixer assembly. These values were generated using the RCS spreadsheet (see para 2.4.1).

TABLE 2. RCS SYSTEM SENSITIVITY (dBsm)

Frequency (GHz)	Non-pulsed Configurations		Pulsed Configurations	
	Monostatic	Quasi-Monostatic	Monostatic	Quasi-Monostatic
6.0	-32.71	-54.47	-49.11	-51.11
7.0	-31.37	-53.13	-47.77	-49.77
8.0	-30.21	-51.97	-46.61	-48.61
10.0	-28.27	-50.03	-44.67	-46.67
12.4	-26.40	-48.16	-42.80	-44.80
15.0	-24.75	-46.51	-41.15	-43.15
18.0	-23.16	-44.93	-39.57	-41.57
20.0	-22.25	-44.01	-38.65	-40.65
26.5	-19.80	-41.57	-36.21	-38.21
35.0	-15.39	-37.15	-31.79	-33.79
40.0	-14.23	-35.99	-30.63	-32.63



- MONOSTATIC
- ◇ PULSED MONOSTATIC
- △ PULSED QUASI-MONOSTATIC
- ┆ QUASI-MONOSTATIC

Figure 2. RCS System Sensitivity.

f. There are many factors that affect the performance of the Compact Range to measure RCS signals. The performance factors that are range related typically have to do with the capability of the Compact Range to produce a planar wave front. These factors need to be measured before accurate models can be used to specify the performance of the range to measure RCS signals. The factors that are required to accurately specify the RCS performance are: efficiency of power transfer, amplitude ripple and taper across the quiet zone, phase ripple and taper across the quiet zone, transmit-to-receive channel isolation, and the presence of any spurious or multipath signals. The performance factors that are system related are given in Table 3.

TABLE 3. RCS SYSTEM PERFORMANCE FACTORS

Frequency range	6 to 40 GHz
Transmitter power	25 dBm, 6 to 18 GHz 40 dBm, 18 to 40 GHz
Antenna gain	10 decibels related to isotropic (dBi)
System sensitivity	Configuration dependent
Alias free range	Greater than 150 feet
Amplitude stability	Component dependent
Phase stability	Component dependent
Receiver compression	0 dBm, 6 to 18 GHz -20 dBm, 18 to 40 GHz
Dynamic range	Configuration dependent
Dynamic accuracy	± 0.07 dB (receiver)
Response resolution	Configuration dependent
Signal processing features	Fast Fourier Transform (FFT)

g. The transmitter characteristics used for all calculations are based on the existing configuration. The system sensitivity is dependent on the configuration and components selected. In most cases the components have been selected to maximize the performance of the range to measure RCS signals without modifications to the existing transmitter. In some cases, typical values have been used. The response resolution defines the capability of the system to resolve multiple scattering areas from one target. This is sometimes referred to as spatial resolution. Signal processing capabilities can help resolve and improve the characteristics of the range. Signal processing includes both hardware and software capabilities, if applicable. Each configuration evaluated will compare these factors to determine the performance of the Compact Range to measure RCS signals.

2.2 COMPACT RANGE MODIFICATIONS FOR RCS MEASUREMENTS

a. In all cases, the existing Compact Range LO configuration must be modified in order to generate another 20 MHz IF signal for the HP 8510B processor. This will require another set of remote mixers. The b1 input to the HP 8510B needs to be available at the transmitter location. These new components are to be physically placed in the RF enclosure. These components are shown in Figure 3 and listed in Table 4.

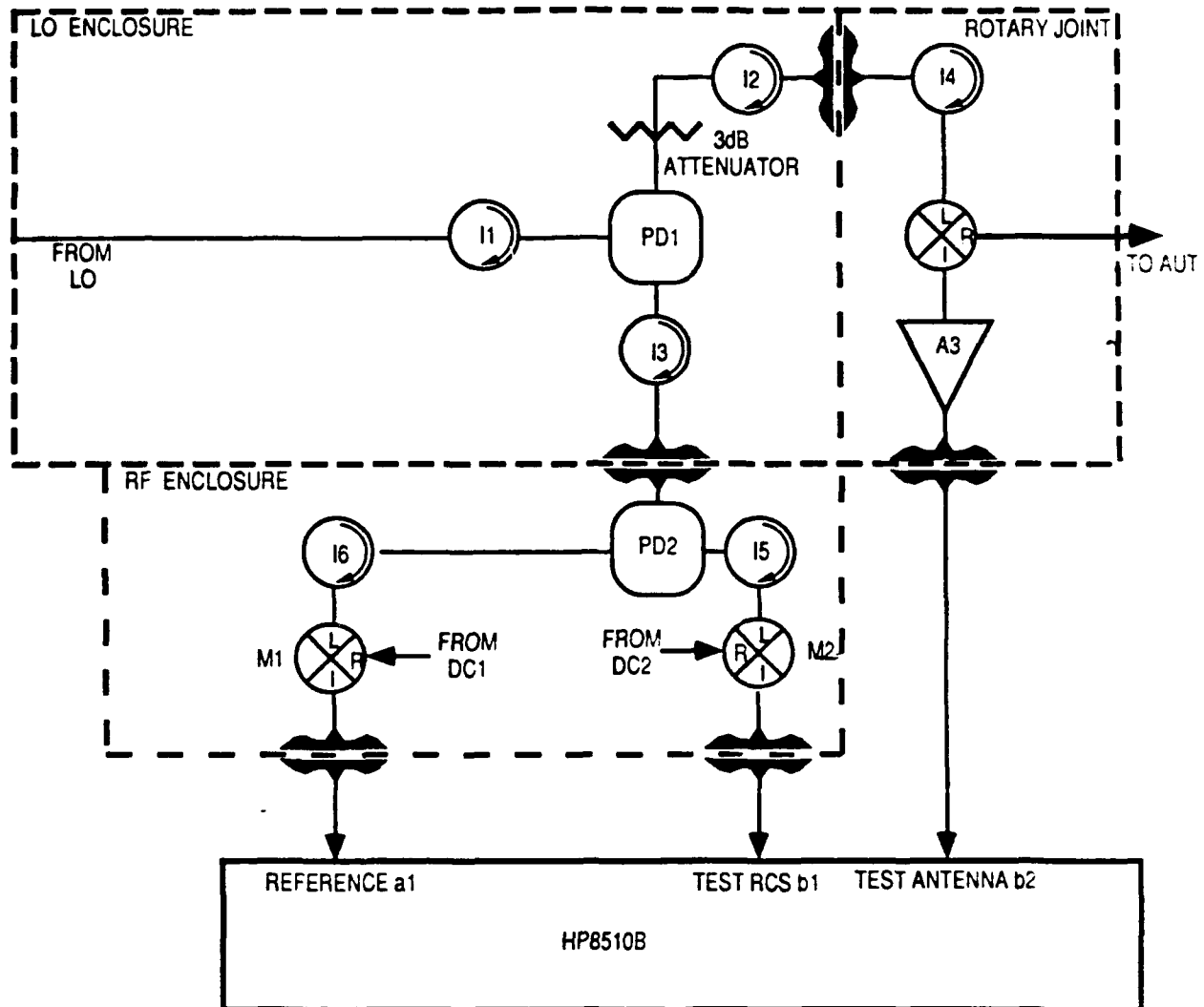


Figure 3. Local Oscillator Modifications for RCS Measurements.

TABLE 4. LOCAL OSCILLATOR MODIFICATIONS FOR RCS MEASUREMENTS

Qty	Part Number	Description
1	DME4-18 28-061-1	RHG high-level double balanced mixer
1	HP 11970 K	Harmonic mixer
1	HP 11970 A	Harmonic mixer
1	TBD	Two-way power divider
1	TBD	3 dB attenuator
1	TBD	RF Isolator
1	Miscellaneous	Cables and adapters

NOTE: Parts selected for compatibility with existing configuration.

b. Other modifications to the existing transmitter assembly are also required. These modifications will be dependent on the configuration chosen for the RCS signal measurements. All of these modifications will be made to the existing transmitter assembly and/or the RF enclosure.

c. All configurations will require additions and/or modifications to the system software for total automation. Different types of outputs from a typical RCS signal measurement could include such things as contour mapping, down-range imaging, and cross-range imaging. Implementation of the time domain capability of the HP 8510B range receiver is required for any configuration that utilizes a software gate to resolve multiple target responses.

2.2.1 Monostatic Configuration Modifications

a. The monostatic configuration is shown in Figure 4. The additional component used for the monostatic configuration is a directional device. This is shown as DC2 in Figure 4. The specific requirements for this device are forward and reverse insertion loss, and isolation. In the case of a directional coupler, the reverse insertion loss includes the coupling factor. The isolation should be at least 10 dB better than the coupling factor. If the HP 8510B is calibrated before every measurement, the isolation error term will be mathematically subtracted from the measurement data. Waveguide couplers typically have better performance for this application than do coaxial couplers. Typical directional couplers have isolation/directivity specifications ranging from 10 to 30 dB, and coupling factors ranging from 3 to 60 dB.

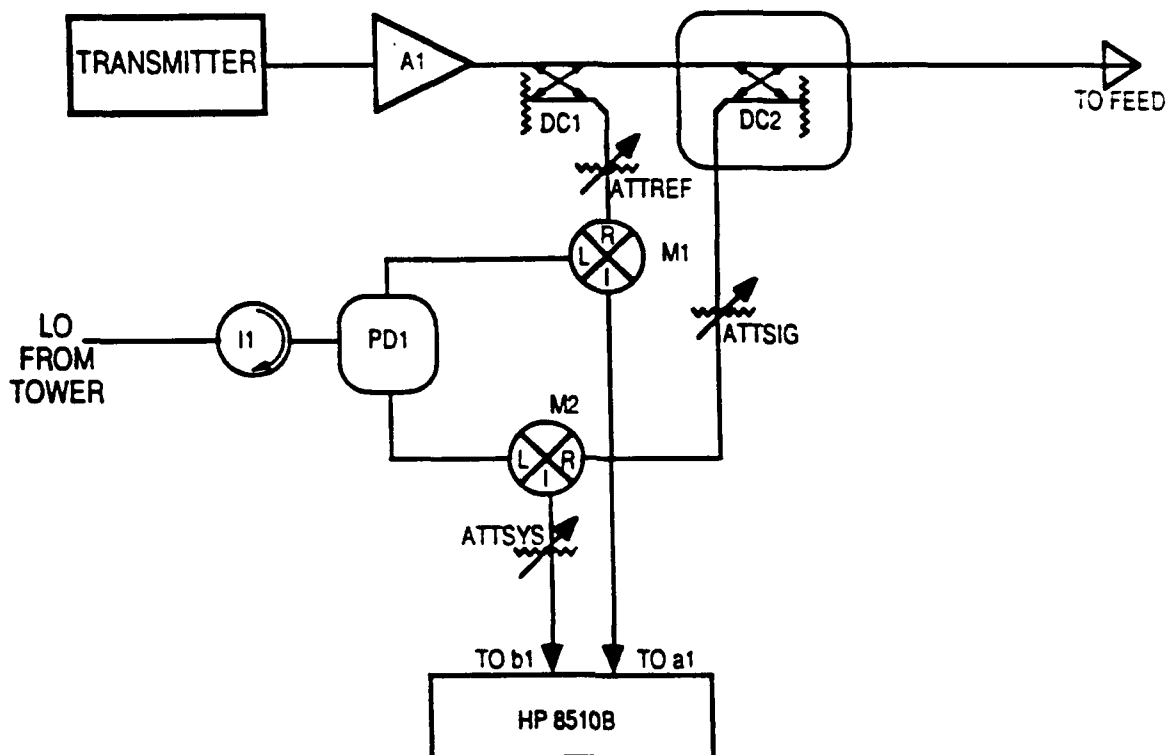


Figure 4. Monostatic Configuration.

b. In the case of a circulator, the reverse insertion loss refers to the loss from the output (port 2) to the third port (port 3). These devices offer good isolation and low reverse insertion loss. Circulators are typically ferrite devices and some types have limited bandwidths. Waveguide circulators typically have better performance for this application than do coaxial circulators. Typical circulators have isolation specifications ranging from 30 to 40 dB, and reverse insertion losses less than 1 dB.

2.2.2 Quasi-Monostatic Configuration Modifications

a. The quasi-monostatic configuration is shown in Figure 5. This configuration requires the addition of another antenna feed horn. This requires additional feeds to complement the existing antennas. The critical specification in this configuration is the mutual coupling between the two horns. Poor horn-to-horn coupling limits the dynamic range and increases the noise figure of the receiver. The major advantage of a dual feed configuration is better system performance for low level RCS signal measurements. Typical dual feed antenna configurations have horn-to-horn coupling factors ranging from 30 to 60 dB, with antenna gains ranging from 10 to 50 dBi.

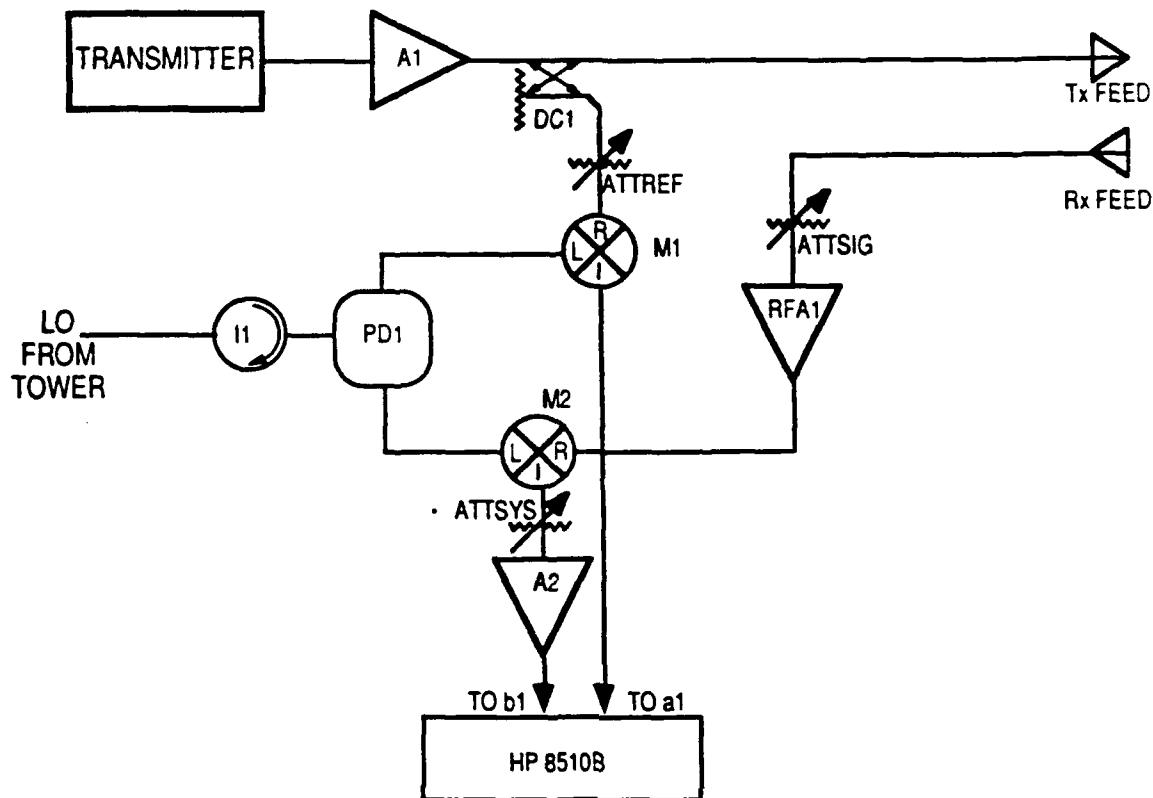


Figure 5. Quasi-Monostatic Configuration.

b. An IF amplifier A2 and supporting attenuator ATTSYS should be added to maximize system performance. ATTSYS should be set to a minimum value dependent on the RCS of the test target.

2.2.3 Modifications for Pulsed Configurations

a. A pulsed configuration, either monostatic or quasi-monostatic, requires the addition of a pulse modulator and a receiver gating circuit. The modulators are typically fast PIN diode switches. A pulse generator is also required to drive the modulator and the receiver gate. The pulse generator must generate high fidelity pulses and have selective pulse width and PRFs to get maximum capability. Non-ideal pulse characteristics appear as clutter in the receiver when making RCS signal measurements. The critical requirement for this configuration is the blanking leakage signal. Typical PIN diode switches provide transmitter blanking levels ranging from 80 to 100 dB. The pulsed monostatic and pulsed quasi-monostatic configurations are shown in Figures 6 and 7, respectively.

b. A pulsed configuration will allow higher transmitter power levels because of the excellent isolation associated with the pulse modulators. Transmitter power levels up to 1 kilowatt can be used with this configuration.

c. This configuration offers the maximum measurement capabilities and also allows for good measurement resolution. The addition of PIN diode modulators and receiver timing circuits is required. The addition of a pulse generator is also required.

2.3 RCS PERFORMANCE CONSIDERATIONS

a. The capability of the Compact Range to perform RCS signal measurements requires additional hardware and software in order to provide maximum capabilities. The free space loss due to the physical layout of the Compact Range dictates the dynamic range of the existing system for a given effective radiated power (ERP) level. The amount of power available at the feed antenna determines the amount of energy received for either antenna patterns or RCS signal measurements. The receiver's equivalent noise figure determines the minimum signal level that can be resolved. In general, the following characteristics will maximize the range performance for RCS: high transmitter power levels; maximum isolation between test and reference signals and between the LO, RF, and IF signals; a low noise figure receiver; good amplitude and phase stability; low range clutter level; and no spurious range responses.

b. The maximum amount of transmitted power is determined by the components used in the transmitter assembly and the gain of the feed antenna. The transmitter power is assumed to be the combination of the signal generator power plus the gain of the antenna. The maximum available transmitter power of the Compact Range instrumentation in its current configuration is:

$$+25 \text{ dBm} + 10 \text{ dBi} = +35 \text{ dBm ERP, from 6 to 18 GHz}$$

$$+40 \text{ dBm} + 10 \text{ dBi} = +50 \text{ dBm ERP, from 18 to 40 GHz}$$

c. Low isolation between the RF, LO, and IF signal paths can lead to unwanted signals in the receiver and receiver saturation. These unwanted signals can mix with the received signal and fold back into the receiver's passband. This will generate non-reproducible results and limit the accuracy of the measurements.

d. A low noise figure receiver allows for very low level signals to be measured. The receiver's configuration should be flexible enough to ensure the lowest noise figure with the maximum gain for a given test target. This implies automation for the control of the IF signal processing components. The addition of a signal channel attenuator (ATTSIG) and ATTSYS is required to achieve maximum capability for a given configuration. These attenuators need to be programmable for total automation.

e. Currently, there are a number of manual operations that must be performed prior to performing measurements on the Compact Range. Where possible, these steps should be automated. This will improve repeatability and save test time. These changes will benefit antenna pattern measurements and should also be implemented for RCS signal measurements.

f. With the existing range configuration, the signal generator must be manually switched from the input to the HP 8349A amplifier into the Logimetrics Traveling Wave Tube Amplifier (TWTAs). This change needs to be made when the operating frequency exceeds 18.0 GHz. A switch should be used for the 18.0 to 26.5 GHz range. This is only applicable for the 18.0 to 26.5 GHz range because switches are readily available. Above 26.5 GHz, manual switching of the signal generator may be required.

g. With the existing range configuration, when the remote mixers need to be changed, the current mixer has to be removed from the system and replaced with another mixer. These change-over points occur at 18.0 and 26.5 GHz. The RCS system should incorporate a switch so that the LO and the IF mixers are switched automatically. The only port that would need to be changed is the RF input port. This operation could be automated from 6.0 to 26.5 GHz.

h. The system should incorporate an automatic routine that can measure and adjust various system components so maximum dynamic range can be achieved for a given RCS.

i. Parameters that change due to temperature should be isolated from the environment as much as possible. These changes will affect both the accuracy and repeatability of the measured RCS signal and antenna patterns.

2.3.1 Monostatic Configuration Performance

a. The use of the Compact Range to measure RCS signals will require the use of a signal separation device to measure the amount of reflected energy. There are three basic device types that could be adapted to the existing range: a directional coupler, a circulator, or a magic-tee coupler.

b. The limiting factors for the monostatic configuration are the reflection coefficient of the feed assembly, and the isolation specification of the signal separation device. The voltage standing wave ratio (VSWR) of the feeds is specified to be 1.2:1 maximum.

c. In a monostatic configuration, the signal separation device at the input to the feeds samples the reflected energy from the target. This measured reflection is composed of at least two vectors: one from the feeds, and one from the RCS signal of the target. The vector sum of these two signals is displayed on the HP 8510B network analyzer. RCS calibration will

measure the vector generated by the feed antennas. The resultant vector magnitude is mathematically subtracted. The final amplitude of this response must be considered when specifying components for this configuration.

d. In a monostatic configuration, the receiver will measure the vector sum of all inputs. The combined power levels of these signals will dictate the amount of power at the receiver's input. A transmitter power of 40 dBm will produce a signal of 19 dBm at the output port to DC2, assuming no reverse insertion loss. This power level can cause the mixer M2 to be in compression. The mixers presently being used have a maximum RF input power of 0 dBm from 6 to 18 GHz, and -20 dBm from 18 to 40 GHz.

e. The attenuator ATT SIG must be used to ensure that the receiver's front-end is not in compression. This additional attenuation directly adds to the noise figure of the receiver. The reverse insertion loss of the reflected energy through DC2 also adds directly to the noise figure of the receiver. Therefore, the reverse insertion loss of DC2 should be kept as low as possible.

f. One solution is to select a directional coupler for DC2 with a high coupling factor. This will lower the amplitude of the reflected energy due to the feeds at the input to the receiver. This adds to the reverse insertion loss of DC2. This in turn adds to the receiver's noise figure and places stringent requirements for the directivity of the directional coupler that is used. Therefore, a directional coupler is not recommended for DC2. The performance factors that affect the system requirements when using a directional coupler are: forward insertion loss, directivity, and coupling factor.

g. Another solution is to use a three-port circulator for DC2. The use of a circulator will typically provide the best performance for this configuration. A circulator has low forward insertion loss and low reverse insertion loss as well. Isolation is typically equal to that of a directional coupler, or better. These devices typically have narrow bandwidths.

h. If waveguide components are used, at least three devices would be required in order to cover the system bandwidth. This would limit automation capabilities, but performance would be better. If coaxial components are chosen, broadband devices are readily available.

i. The calculated RCS sensitivity for this configuration can be found in Table 2 and Figure 2 (pgs 2-3 and 2-4). Three-port circulators were used for DC2. The specifications used for the circulators were 40 dB of isolation and 1 dB reverse insertion loss. The same performance was assumed for all frequency bands. This configuration does not gain any advantage from the use of an external low noise RF front-end for the receiver.

j. The target resolution for this configuration will be defined by the software gate applied to the target response (see Section 2.3.4, Software Gating). The dominant signals using this configuration are system responses. Calibration to remove these system responses is required for this configuration.

2.3.2 Quasi-Monostatic Configuration Performance

a. Another approach would be to use a separate receive antenna at the transmit site. This would improve the performance for RCS signal measurements. The term quasi-monostatic is used for this configuration because of the close proximity of the receive antenna to the transmit antenna.

b. This configuration requires both mechanical and electrical changes to the existing system. The present antenna feed housing unit would have to be redesigned and realigned. The dual feed assembly will benefit EM signal generation capabilities (see Section 2.6). Additional components would be required as well. This configuration adds a great deal of dynamic range to the RCS system.

c. The calculated RCS sensitivity for this configuration can be found in Table 2 and Figure 2 (pgs 2-3 and 2-4). The limiting factor for this configuration is the leakage path from the transmit antenna to the receive antenna. The horn-to-horn isolation used was 70 dB. This allows for an external low noise RF front-end to be used for the 6 to 18 GHz frequency range. This is shown as RFA1 in Figure 5 (pg 2-9). This configuration also allows for an external IF amplifier to be used for the entire frequency range of operation (6 to 40 GHz). This graph also includes an estimated 3 dB of IF losses. The spreadsheet used a value of 10 dBi for the transmit and receive antenna gains.

d. The target resolution for this configuration is defined by the software gate applied to the target response (see Section 2.3.4, Software Gating). The dominant signals using this configuration may or may not be system responses. System calibration is also required for this configuration.

2.3.3 Performance for Pulsed Configurations

a. A pulsed system can be used with either a monostatic or a quasi-monostatic configuration. In a pulsed system, the transmitted signal is pulsed modulated and the receiver is then gated on at the approximate time of the echo or RCS signal. Pulsed systems have many technical advantages, including:

(1) Target resolution is controlled by the pulse characteristics and/or software gating.

(2) An external low noise receiver front-end can be used.

(3) Hardware gating allows the use of higher peak transmitter output power.

(4) The system has good immunity to spurious responses.

b. A pulsed configuration in some cases may be limited by the performance of the HP 8510B receiver. The HP 8510B is a narrowband receiver. The IF center frequency is 20 MHz with a 10 kHz detection bandwidth. In a pulsed configuration, only the CW carrier of the pulsed spectrum can be in the receiver's pass-band. This requirement places a minimum requirement on the PRF to be greater than 30 kHz. The maximum PRF is limited by the physical length of the range to approximately 2 MHz.

c. The average power from the transmitter is lowered by a factor of $20 \cdot \log_{10}[\text{duty cycle}]$. This means the average output power is lowered by 6 dB for a 50 percent duty cycle. All things considered, this configuration gives the range very good resolution and system sensitivity.

d. The calculated RCS sensitivity for these configurations can be found in Table 2 and Figure 2 (pgs 2-3 and 2-4). A blanking isolation of 80 dB, a PRF of 2 MHz, and a 50 percent pulse duty cycle were used. This configuration allows the use of an external low noise RF amplifier for all frequency bands. In all cases an RF amplifier (RF1, RF2, or RF3) was specified to have a 20 dB gain and a 3 dB noise figure. These configurations also allow the use of an external low noise IF amplifier. This IF amplifier was specified to have 30 dB of gain with a noise figure of 2.7 dB.

e. The major advantage is that in a pulsed configuration large, unwanted spurious signals are gated out. The range could be upgraded to provide more output power without modification to existing components except for A1. A pulsed configuration also decreases alias free range requirements for broadband measurements. The target resolution is determined by the transmitted pulse characteristics. For both pulsed configurations, hardware and software gating can be implemented.

2.3.4 Software Gating

a. Software range gating is accomplished by taking the frequency domain responses and performing an inverse fast Fourier transform (FFT). This allows the measurement system to view the responses in the time domain (down-range image). The HP 8510B option 010 allows for this transform to be accomplished without the need for the controller to perform the inverse FFT. The firmware allows the operator to set a gate around the response of interest. Once the gate is set, the analyzer mathematically subtracts all responses outside of the target zone. This gated time domain data can then be transformed back into the frequency domain for display.

b. When using the time domain gate, the accuracy and resolution are dependent on the HP 8510B instrument state. Another consideration is that the transmitter frequency must be swept in order for the time domain option to operate. The HP 8510 option 010 will not allow the gating feature to operate with a CW measurement.

c. The software gating procedure used with the inverse FFT is bound by three factors, the alias free range (AFR), the maximum frequency span that satisfies the AFR criterion, and the number of data points that satisfy target resolution requirements.

d. The HP 8510B option 010 is a sampled system. Using the built-in inverse FFT, an alias response will be generated at $1/(\text{step size})$. The AFR of the HP 8510 is given by:

$$\text{Range (secs)} = [\text{number of data points} - 1] / [\text{frequency span (Hz)}]$$

$$\text{Range (meters)} = \text{Range (seconds)} * 2.997925 * 10^8 \text{ meters/second}$$

$$\text{Range (feet)} = \text{Range (seconds)} * 984 * 10^6 \text{ feet/second}$$

e. The AFR determines the maximum frequency span and number of data points. Figure 8, AFR for Software Gating, shows the minimum frequency span required for an AFR greater than or equal to 150 feet using the HP FFT function with a fixed number of data points. The graph depicts the relationship between the number of data points and the AFR. As the number of data points increase, the frequency span of the HP receiver must increase.

f. Figure 9, Response Resolution for Software Gating, shows the capability of the HP 8510B to resolve different scattering locations associated with the test target. The capability to resolve individual target responses is determined by $1/2$ the impulse width (window) or -6 dB bandwidth of the inverse FFT. The $1/2$ impulse width is determined by the frequency span and the number of data points. The frequency span is determined by the AFR.

The response resolution (bandpass mode) is approximately given by:

$$\text{Resolution (ft)} = (0.6 / [\text{freq span (GHz)}]) * \begin{matrix} 1.0 \text{ (minimum window)} \\ 1.6 \text{ (normal window)} \\ 2.4 \text{ (maximum window)} \end{matrix}$$

This graph reveals that for a given frequency span, the response resolution is dependent on the window function being applied. The window function will determine the capability to resolve different scattering surfaces associated with the target.

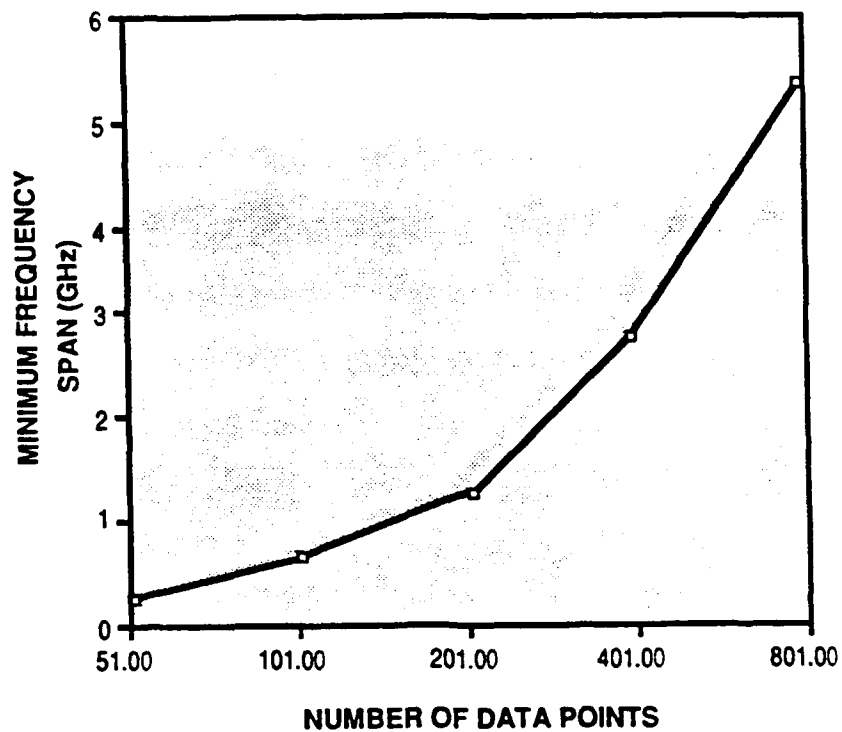
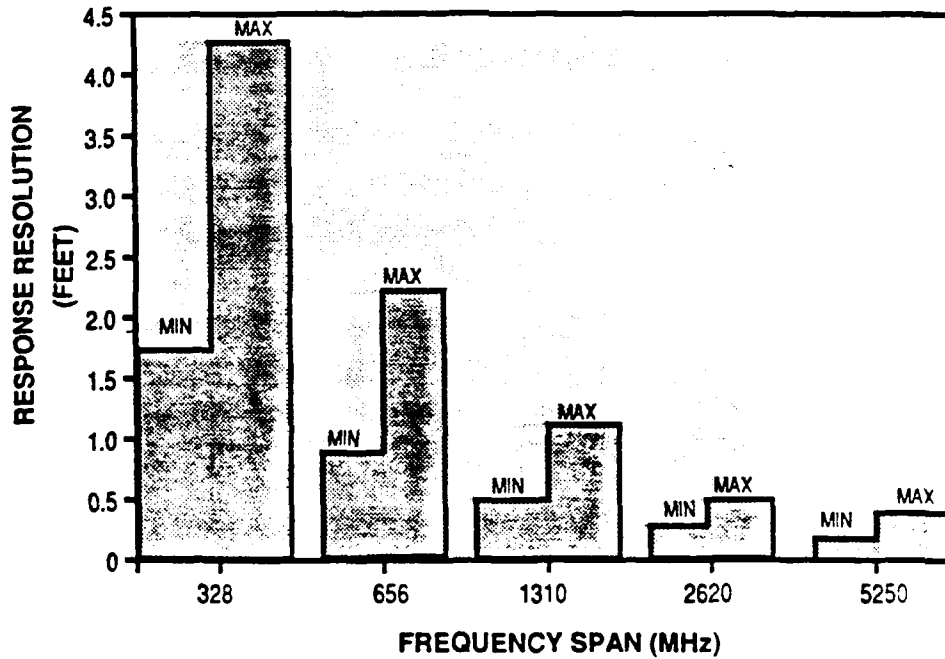


Figure 8. Alias Free Range for Software Gating.



MIN = MINIMUM SOFTWARE WINDOW

MAX = MAXIMUM SOFTWARE WINDOW

Figure 9. Response Resolution for Software Gating.

g. The minimum window provides the best results for resolving different scatters of equal amplitudes. This window places limitations on resolving scatters of different amplitudes. The FFT generates a $\sin(x)/x$ distribution due to the fact that the FFT uses a finite number of frequency points. The system's ability to resolve scattering areas of different magnitudes will be limited to this non-ideal effect of the FFT. Figure 10, Amplitude Resolution for Software Gating, shows the different sidelobe levels associated with the different windows functions provided by the HP 8510B. These calculations are for the band-pass mode of operation.

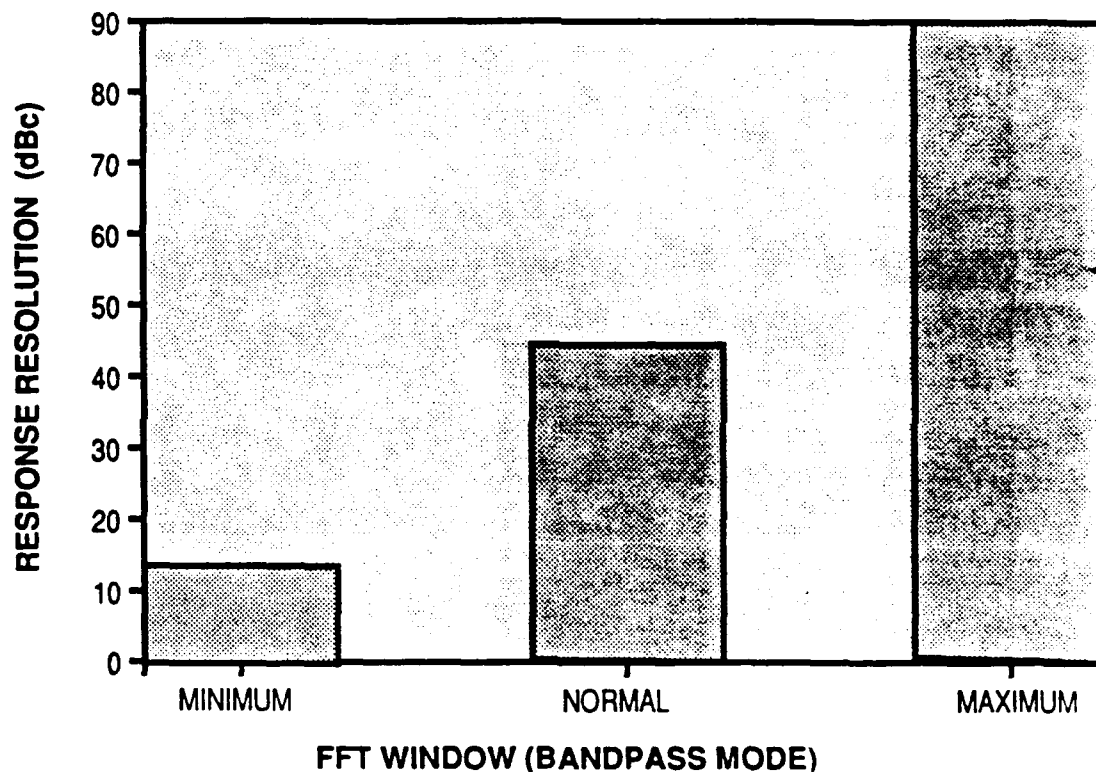


Figure 10. Amplitude Resolution for Software Gating.

h. The inverse FFT provides good response resolution with a wide frequency span. The drawback to software range gating is that the time domain responses that are measured are average responses of the target over the measured frequency span. To find the RCS at a particular frequency, the time domain data must be transformed back into the frequency domain.

2.3.5 Hardware Gating

a. The purpose of using pulse modulation for antenna and RCS signal measurements is to eliminate undesired signals on a time-of-arrival basis. Hardware gating is similar to software gating in that it aids in the resolution of multiple scattering surfaces on the test target.

b. The Compact Range could have stray signals that can saturate the receiver and limit measurement dynamic range. One source of spurious signals is what is referred to as the 'big bang'. Other sources that can add to the big bang could be due to limited transmit-to-receive channel isolation, multipath, and other range generated reflections. At this time, the amplitudes of these responses are not known. These effects will create measurement distortion and can limit the maximum transmitter power. The use of hardware gating can minimize or eliminate many of these unwanted responses.

c. A pulsed configuration is required for hardware gating. The transmitter is pulsed on with a pulse width dependent on the required target response resolution. The HP receiver is a narrow bandwidth receiver that measures the average power of the target RCS signal. The amount of average power that can be generated is lowered by a factor of $20 \cdot \log_{10}[\text{duty cycle}]$. Figure 11, Pulse Desensitization for Hardware Gating, shows the amplitude of this pulse desensitization factor as a function of duty cycle.

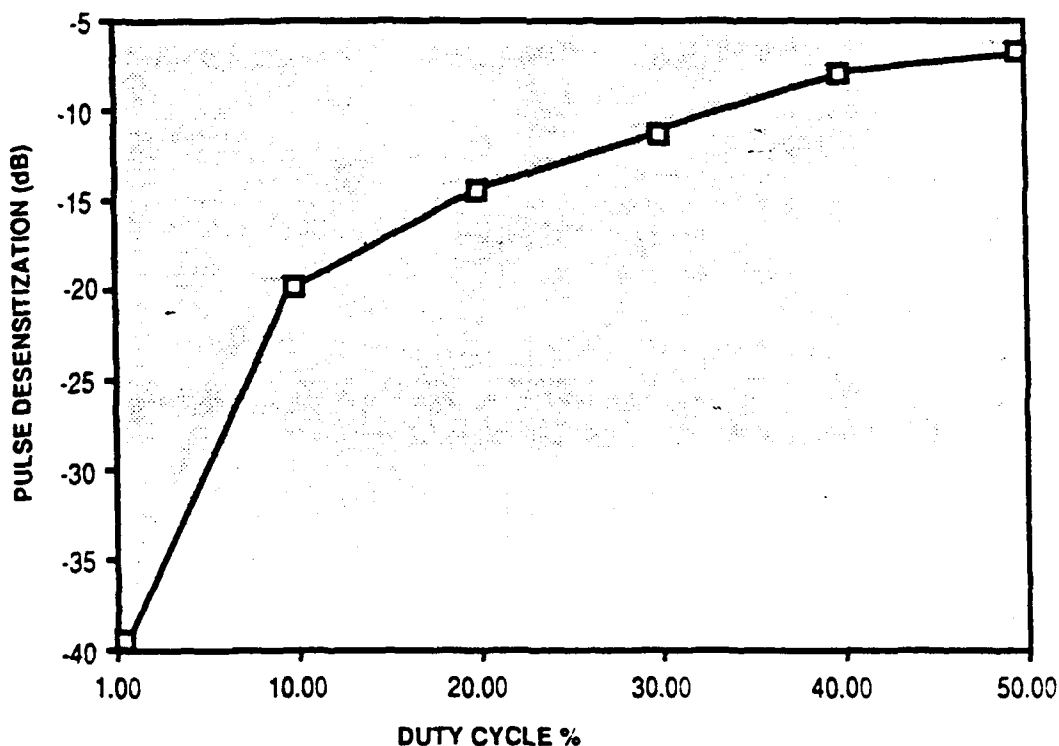


Figure 11. Pulse Desensitization for Hardware Gating.

d. In a pulsed configuration, the AFR is determined by the PRF. Figure 12, PRF Requirements for Hardware Gating, shows the range of PRFs that could potentially be used for the Compact Range.

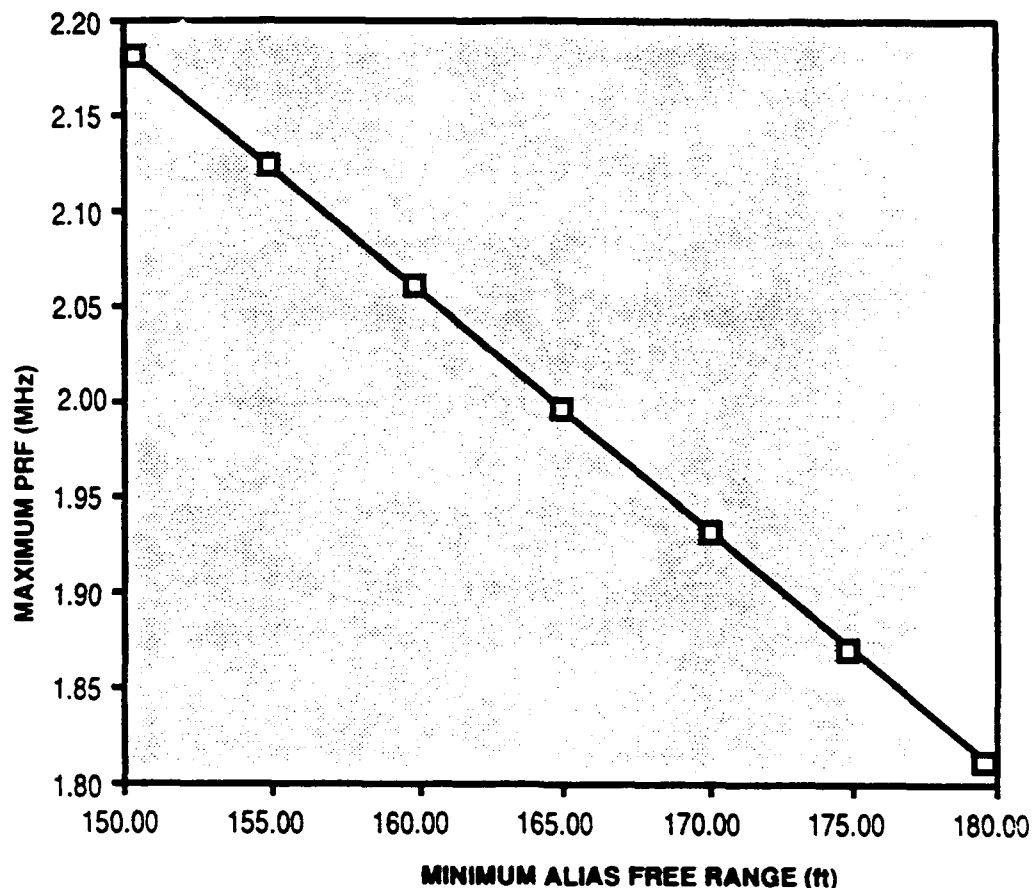


Figure 12. PRF Requirements for Hardware Gating.

e. The receiver is a narrow bandwidth system. The IF bandwidth of the HP 8510B is 10 kHz. The receiver is designed to measure CW signals only. The pulsed transmitter generates a $\sin(x)/x$ response that spreads the transmitted energy over a larger bandwidth. These are major considerations when selecting the range of PRFs that can be used. When using the HP receiver, only the CW carrier of the pulse spectrum can be in the receiver passband when measurements are being made. Since unwanted modulation sidebands will occur at the PRF, the minimum PRF that can be used with the HP receiver is 30 kHz. Also, since the present range configuration uses harmonic mixers in the remote mixer assembly, certain PRFs will be unusable. The maximum PRF that can be used is dependent on the range to the target area and is given by $\text{PRF}(\text{max}) = C/(2 \cdot R)$. Where C is velocity of propagation in free space and R is range distance.

f. The use of hardware gating allows the system to base target resolution as a function of target size, rather than on the number of frequency points as is the case for software gating. The maximum transmitter power is limited by the receiver PIN switch isolation. Typically, in this configuration a pulsed TWTA is used as the transmitter. The HP receiver is an average measurement system and not a peak system. Therefore, the system's dynamic range is degraded by a factor of $20 \cdot \log_{10}[\text{duty cycle}]$. This degradation is minimized by keeping the PRF and pulse width as high as possible. Ranges greater than 25 meters in length that require less than two inches of down-range image resolution require hardware gating.

g. Hardware gating can minimize or eliminate multipath and background reflections and other spurious responses. The alias free range in a pulsed configuration is dependent only on the PRF. The response resolution is determined by the characteristics of the transmitted pulse. Any pulse instabilities will lead to an apparent increase in the range clutter levels.

2.4 RCS PERFORMANCE CALCULATIONS

a. An outdoor range has many spurious signals that cannot be included in the calculations. The 'big bang', multipath, and other reflections cannot be included in RCS calculations until these spurious signals have been identified and evaluated. All calculations included as part of this study assume that the system response is the major response that will affect the ability of the range to perform RCS signal measurements. A thorough evaluation of the range is required before accurate modeling and calculations can be performed.

b. All calculations included as part of this study use the following assumptions about the Compact Range and the instrumentation used for the measurement system:

- (1) Focal point distance: 150 feet.
- (2) Transmitter is signal generator plus amplifier A1.
- (3) Transmit antenna gain is 10 dBi.
- (4) Maximum power output: 6 to 18 GHz, 25 dBm (3.2 watts).
- (5) Maximum power output: 18 to 40 GHz, 40 dBm (10 watts).
- (6) Remote mixer insertion losses are:
 - 9 dB, 6.0 to 18.0 GHz
 - 20 dB, 18.0 to 26.5 GHz
 - 24 dB, 26.5 to 40.0 GHz

(7) Test and reference channel isolation greater than 100 dB.

(8) No spurious responses.

c. The amount of power reflected by a target is referred to as its radar cross section, or RCS. The amount of energy reflected by a target with a 0 dBsm cross section can be given by:

$$P_r = P_t * G_t * G_r * \text{System Losses} * \text{Target RCS} * (\text{Wavelength}^2) / [(4 * \pi)^3 * (R^4)]$$

$$P_r(\text{dB}) = 10 * \log_{10}[P_t * G_t * G_r * \text{System Losses}] - 43.43 - 20 * \log_{10}[f(\text{GHz})] - 40 * \log_{10}[R(\text{meters})]$$

Where P_r is the received power; P_t is the transmitted power; G_t is the transmit antenna gain; G_r is the receive antenna gain; $\pi = 3.14159265$; R is range distance; f is frequency.

d. The amount of power reflected is subtracted from the system sensitivity to calculate the measurement sensitivity relative to 0 dBsm. The minimum RCS signal that can be measured with each configuration can be found in Section 2.3. These graphs were generated assuming that the test system has been calibrated, the receiver uses the HP 8510B remote mixer configuration, the system sensitivity is equal to the calculated values, and the pulse desensitization is equal to 6 dB (50 percent duty cycle).

e. All calculations are calculated using an IF averaging factor of 1,024 samples. This correlates to a processing gain of approximately 30 dB. The monostatic configuration assumes that the noise figure is that of the HP 8510B plus system insertion losses. This calculation does not include other losses associated with DC2. The quasi-monostatic and the pulsed calculations assume that an external low noise IF amplifier is used. The gain of the IF amplifier is assumed to be 25 dB with a noise figure of 2.7 dB.

2.4.1 RCS Spreadsheet

a. Included as part of this report is the RCS Spreadsheet. This is a Lotus 123 spreadsheet that allows the user to enter in various parameters and component selections for the different configurations listed in this report. This spreadsheet was developed using Lotus Revision 2.01. The spreadsheet calculates system sensitivity and RCS capabilities for the inputted variables. The four RCS configurations to choose from are: monostatic, quasi-monostatic, pulsed monostatic, and pulsed quasi-monostatic.

b. The spreadsheet will calculate the power levels at the input to the remote mixer assembly. If there is 20 dB or more of dynamic range available for the given configuration, the operator will have the opportunity to input parameters for an external low

noise front-end for the receiver. The spreadsheet will then plot the RCS sensitivity and the system sensitivity. The spreadsheet also calculates values for ATTSYS and ATTSIG.

c. The variables that need to be entered for the monostatic configuration are:

- (1) Transmitter power 6 to 18 GHz.
- (2) Transmitter power 18 to 40 GHz.
- (3) The reflection coefficient of the antenna feed.
- (4) DC2 isolation and coupling factor or reverse insertion loss for each frequency band: 6-18 GHz, 18.0-26.5 GHz and 26.5-40.0 GHz.
- (5) If an external low noise receiver front-end can be used, a prompt for the gain and noise figures of the external RF and IF amplifiers appears.

d. The variables that are entered for the quasi-monostatic configuration are:

- (1) Transmitter power 6 to 18 GHz.
- (2) Transmitter power 18 to 40 GHz.
- (3) Transmit antenna gain.
- (4) Receive antenna gain.
- (5) Horn-to-horn coupling.

e. The variables that are entered for the pulsed configurations are identical to the non-pulsed counterpart. However, additional prompts for PRF and duty cycle or pulse width are included. Blanking isolation is used instead of directivity or horn-to-horn coupling.

2.4.2 Monostatic Configuration Performance Calculations

a. For the monostatic configuration, the minimum RCS signal that can be measured will be dictated by the signal separation device and input reflection coefficient of the feed antenna. The reverse insertion loss of the signal separation device will degrade the RCS sensitivity by the amount of loss. At present the VSWR of the feed horns is specified to be 1.2:1 maximum. This will present a vector approximately 21 dB down plus system losses at the receiver. The power at the input to the remote mixers due to system responses is given by:

$$P_{in}(M2) = P_t - \text{Isolation}(DC2)$$

$$- 20 \cdot \log_{10}[\text{reflection coefficient of the feed}]$$

$$- \text{Coupling factor}(DC2)$$

Assuming infinite isolation and a coupling factor of 3 dB;

$$P_{in}(M2) = 25 \text{ dBm} - 21 \text{ dB} - 3 \text{ dB} = 1 \text{ dBm}$$

$$:: \text{ATTSIG} = 1 \text{ dB (6-18 GHz)}$$

$$P_{in}(M2) = 40 \text{ dBm} - 21 \text{ dB} - 3 \text{ dB} = 16 \text{ dBm}$$

$$:: \text{ATTSIG} = 36 \text{ dB (18-40 GHz)}$$

Where P_{in} is input power; M2 is the signal channel mixer;
 P_t is the transmitted power; DC2 is the signal channel directional coupler.

b. No additional power output in the transmit signal can be used with the monostatic configuration without a corresponding decrease in system sensitivity. In all cases evaluated, the reflection from the feeds becomes the limiting factor in system sensitivity. The addition of ATTSIG will increase the system noise figure by the amount of the attenuation.

c. The system sensitivity for the monostatic configuration is equal to:

$$\text{System Sensitivity (dBm)} =$$

$$-130 \text{ dBm} + \text{IL}(DC2) + \text{IL}(M1) + \text{RFL} + \text{NF}(\text{IF})$$

Where IL is the insertion loss; DC2 is the signal channel directional coupler; M1 is the reference channel mixer; RFL is the RF losses; NF is the noise figure.

The reverse insertion loss of DC2 is assumed to be equal to the coupling factor. The insertion loss of M1 is assumed to be that of the manufacturer's specifications. The other RF losses are the amount of attenuation needed to keep the HP receiver or the remote mixers from going into compression.

d. Under the best circumstances, a noise floor of approximately -88 dBm can be achieved using this configuration. This will be acceptable for targets with an RCS signal of greater than -33 dBsm. All of the system losses severely limit this configuration for the measurement of RCS signals.

2.4.3 Quasi-Monostatic Configuration Performance Calculations

a. The limiting factor for this configuration is the horn-to-horn coupling and spurious range responses. The horn-to-horn isolation is assumed to be greater than 60 dB. The power at the input to the remote mixers due to system responses is given by:

$$P_{in}(M2) = P_t + \text{Antenna gain} - \text{Horn isolation} - \text{RF system losses}$$

Assuming an isolation of 60 dB;

$$P_{in}(M2) = 35 \text{ dB} - 60 \text{ dB} - 5 \text{ dB} = -30 \text{ dBm}$$

$$:: \text{ATT SIG} = 0 \text{ dB (6-18 GHz)}$$

$$P_{in}(M2) = 50 \text{ dB} - 60 \text{ dB} - 5 \text{ dB} = -15 \text{ dBm}$$

$$:: \text{ATT SIG} = 5 \text{ dB (18-40 GHz)}$$

$$\text{Max Gain of signal amplifier (RFA1)} = 20 \text{ dB (6-18 GHz)}$$

$$\text{Max Gain RFA1} = 0 \text{ dB (18-40 GHz)}$$

Assuming no additional RF amplifiers;

$$\text{Max Gain of signal amplifier A2} = 25 \text{ dB (6-18 GHz)}$$

$$\text{Max Gain A2} = 30 \text{ dB (18-40 GHz)}$$

b. The system sensitivity for the quasi-monostatic configuration is equal to:

$$\text{System sensitivity(dBm)} = -130 \text{ dBm} + \text{RFL(dB)} + \text{NF(IF)}$$

c. The response resolution for the HP receiver would be as calculated in Section 2.3.4, Software Gating. This configuration can take advantage of an external low noise IF amplifier, and will measure much smaller RCS signals than the monostatic configuration. The smallest RCS signal that can be measured using this configuration is -53 dBsm.

2.4.4 Performance Calculations for Pulsed Configurations

a. In the case of a pulsed configuration, the system performance and calculated results are approximately equal for the monostatic and quasi-monostatic configurations. The only difference is that with a monostatic configuration the reverse insertion loss of DC2 needs to be included in the calculations. The VSWR of the feed antenna does not come into play because the receiver is gated off while the transmitter is turned on.

b. This configuration allows for high performance RCS signal measurements to be made with the addition of a directional device (DC2) and a pulsed modulated transmitter and a gated receiver. The limiting factor in this configuration is the isolation when the transmitter is gated on. This is typically referred to as blanking isolation. The maximum PRF that can be used is approximately 2 MHz. The transmitted output power is degraded by $20 \cdot \log_{10}[\text{duty cycle}]$. The best resolution is achieved with narrow pulse widths.

c. In this configuration, a trade-off exists between lower power levels and response resolution. A high PRF allows for the best target response resolution. This requires a very fast PIN diode switch to be used as the receiver gate. The higher the PRF, the narrower the pulse width that can be used to achieve a desired target resolution while minimizing the pulse desensitization factor.

d. This system can provide very good range performance. The loss of power due to the pulse desensitization factor can be recovered somewhat by the use of an external low noise RF front-end for the receiver. Assuming that the clutter level is much higher than the receiver sensitivity, the noise power is reduced by a factor of approximately $10 \cdot \log_{10}[\text{duty cycle}]$, which improves signal-to-noise ratio.

e. The power at the input to the remote mixers due to system responses for the pulsed monostatic configuration is given by:

$$P_{in}(M2) = P_t - \text{Transmitter blanking} - \text{DC2 loss} - \text{RF losses}$$

Assuming a transmitter blanking of 70 dB and DC2 coupling = 3 dB;

$$P_{in}(M2) = 25 \text{ dBm} - 70 \text{ dB} - 3 \text{ dB} - 5 \text{ dB} = -53 \text{ dBm}$$

$$:: \text{ATTSIG} = 0 \text{ dB (6-18 GHz)}$$

$$P_{in}(M2) = 40 \text{ dBm} - 70 \text{ dB} - 3 \text{ dB} - 5 \text{ dB} = -38 \text{ dBm}$$

$$:: \text{ATTSIG} = 0 \text{ dB (18-40 GHz)}$$

$$\text{Max Gain RFA1} = 43 \text{ dB (6-18 GHz)}$$

$$\text{Max Gain RFA1} = 18 \text{ dB (18-40 GHz)}$$

Assuming no additional RF gain;

$$\text{Max Gain A2} = 40 \text{ dB (6-18 GHz)}$$

$$\text{Max Gain A2} = 25 \text{ dB (18-40 GHz)}$$

f. The power at the input to the remote mixers due to system responses for the pulsed quasi-monostatic configuration is given by:

$$P_{in}(M2) = (P_t - \text{transmitter blanking}) - \text{RF losses}$$

$$P_{in}(M2) = 25 \text{ dBm} - 70 \text{ dB} - 5 \text{ dB} = -50 \text{ dBm}$$

$$:: \text{ATTSIG} = 0 \text{ dB (6-18 GHz)}$$

$$P_{in}(M2) = 40 \text{ dBm} - 70 \text{ dB} - 5 \text{ dB} = -35 \text{ dBm}$$

$$:: \text{ATTSIG} = 0 \text{ dB (18-40 GHz)}$$

$$\text{Max Gain RFA1} = 40 \text{ dB (6-18 GHz)}$$

$$\text{Max Gain RFA1} = 20 \text{ dB (18-40 GHz)}$$

Assuming no additional RF gain;

Max Gain A2 = 49 dB (6-18 GHz)

Max Gain A2 = 49 dB (18-40 GHz)

g. For both pulsed configurations, the system sensitivity is equal to:

$$\begin{aligned} \text{System sensitivity(dBm)} = \\ -130 \text{ dBm} + \text{RFL(dB)} + \text{NF(IF)} - 10 \cdot \log_{10}[\text{duty cycle}] \end{aligned}$$

Both pulsed configurations yield excellent system performance.

2.5 RCS RANGE CALIBRATION TECHNIQUES

a. There are two major sources of error when using the HP 8510B network analyzer as the range receiver. The first source of error is the signals that arrive in parallel with the main signal from the target (isolation errors). These are due to residual reflections from the range and leakage from the transmit-to-receiver signal paths. The second source of error is the frequency response of the test and reference channels (response errors), often referred to as the tracking error. This will create errors for the amplitude and phase of the measured response.

b. The measurement error model is shown in Figure 13, RCS Error Model. All configurations will benefit from the capabilities of the HP 8510B's internal calibration capabilities. The response and isolation calibration method is the preferred technique for RCS. This calibration routine measures the error terms and mathematically subtracts these terms from the measured data. Calibration will require software changes and some additional hardware.

c. The isolation term includes system and range related spurious signals. For the monostatic configuration, this isolation term relates to such things as: antenna return loss, coupler or circulator directivity, and feed antenna direct path coupling. For the quasi-monostatic configuration, this isolation term includes horn-to-horn coupling, target mount, and other range reflections.

d. To measure the isolation error term, the range is measured with no targets on the mount. This measures the response of the empty range. The only remaining responses are that of any leakage signals and any spurious range responses.

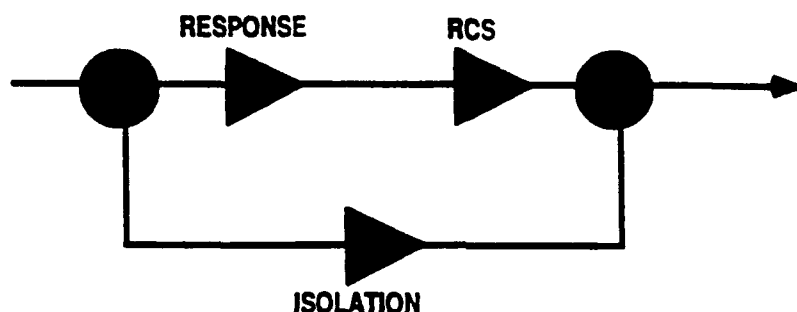
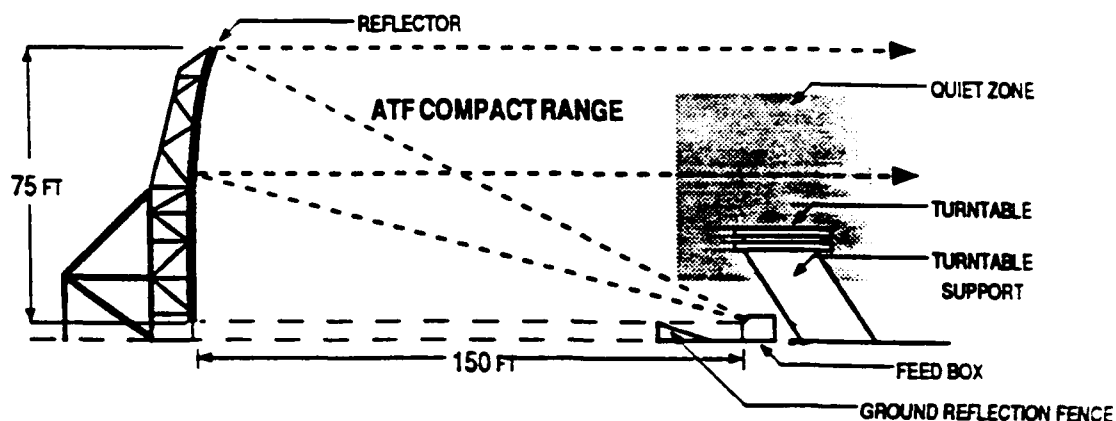


Figure 13. RCS Error Model.

e. In order to measure the response error term of the range, a known good reference target must be measured. Types of RCS reference targets are objects with known RCSs. Typical devices used are spheres, trihedral corner reflectors, and cylinders. The reference targets must be mounted on the support structure where the test target is to be mounted. The RCS reference target can be made in any shape. Typically, spheres are used. The RCS signal of a target is dependent on its cross sectional area and frequency of operation. It is recommended that at least three devices be used for calibration.

f. The calibration of the range mathematically subtracts non-ideal characteristics of the range from the measured data. The effect of the calibration is to subtract range clutter, and normalize the frequency response term. This calibration produces a reference amplitude of 0 dB, equal to the RCS of the reference target, and zero degree phase response.

g. The calibration routines subtract the major error terms, but cannot improve the sensitivity of the measurement. Large spurious responses can still saturate a low noise, high gain receiver.

h. In the time domain, the reference target will produce a response at time = zero second and an amplitude of zero dB. This shifts the target zone to time = zero second. This minimizes the amount of software required to use the FFT to characterize RCS.

2.6 GENERATION OF SPECIALIZED EM ENVIRONMENTS

a. The Compact Range can be used to provide 'upset' signal testing for very large devices. The generation of EM field signals for this application are as varied as the imagination. The existing Compact Range will provide for these signals to be generated as a far-field response. In order to generate these signals, additional hardware and software may be required. There are many different configurations that could be implemented. For the purpose of this study, the Compact Range configuration is assumed to be as it currently exists, with the addition of the components required to implement a quasi-monostatic configuration for RCS signal measurements. This configuration allows for maximum flexibility in generating the EM signals.

b. All configurations will require additional hardware. Additional software will also be required if automation is desired. The configurations evaluated are designed such that manual operation is possible. In some cases, the amount of automation required will be determined by the instrumentation.

2.6.1 EM Environment Performance Considerations

a. In general, it is assumed that the device under test is located on top of the support structure. This is not a requirement for the configurations included. In all configurations evaluated the device under test can be the transmitter and normal type antenna measurements can be performed to measure the far-field response of the device under test.

b. The system should be able to generate many different modulation formats. As a minimum, AM, FM, and pulsed signals need to be generated. More extensive requirements are modulations such as coherent pulse, phase, quadrature modulation, and frequency hopping.

2.6.2 EM Environment Generation Systems

a. The capability to generate EM environment signals will require modifications to the transmitter assembly. There are a number of different ways to add this EM environment capability. For any EM generation configuration, the transmitter interface should provide any required signal switching, have low insertion losses, provide linear signal amplification, provide for monitoring of the modulation signal, allow for manual or automatic modes of operation, and allow complete control of the RF transmitter.

b. Switching is required to allow the operator to select the various inputs and outputs. This switching should also control the use of the RF amplifier A4.

c. Low insertion losses will allow for more transmit power to be generated. These configurations do not drive the LO port for up-conversion, therefore, high power modulating signals are not required.

d. Linear amplification is required for both baseband signals and RF signals. This amplification should not distort the signal being generated.

2.6.2.1 RF Configuration

a. Figure 14, RF Configuration for EM Environment Generation, shows a block diagram of this configuration. The RF configuration uses a transmitter interface located in the underground instrumentation room. This interface provides for any switches and amplification that may be required when driving the modulation inputs of the HP 83640A signal generator.

b. The HP 83640A can be used as a stand-alone generator. Its internal modulation capabilities will allow for many different waveforms to be generated without adding additional hardware. The internal modulation capabilities can be controlled manually by the front panel or with additional software.

c. The performance of the HP source may be adequate for the mission at hand and a baseband modulator may not be required. If additional modulation formats are required, a function generator can be connected to the modulation inputs of the HP source through the transmitter interface. This configuration takes advantage of the amplifiers that exist for both antenna pattern measurements and RCS signal measurements. The RF configuration requires that only the baseband modulator be added to the existing hardware. The existing transmitter configuration could be used with the RF configuration to allow for many different types of modulation formats to be generated with little additional hardware and software. This configuration allows for the existing transmitter assembly to work to 40 GHz with only minor modifications.

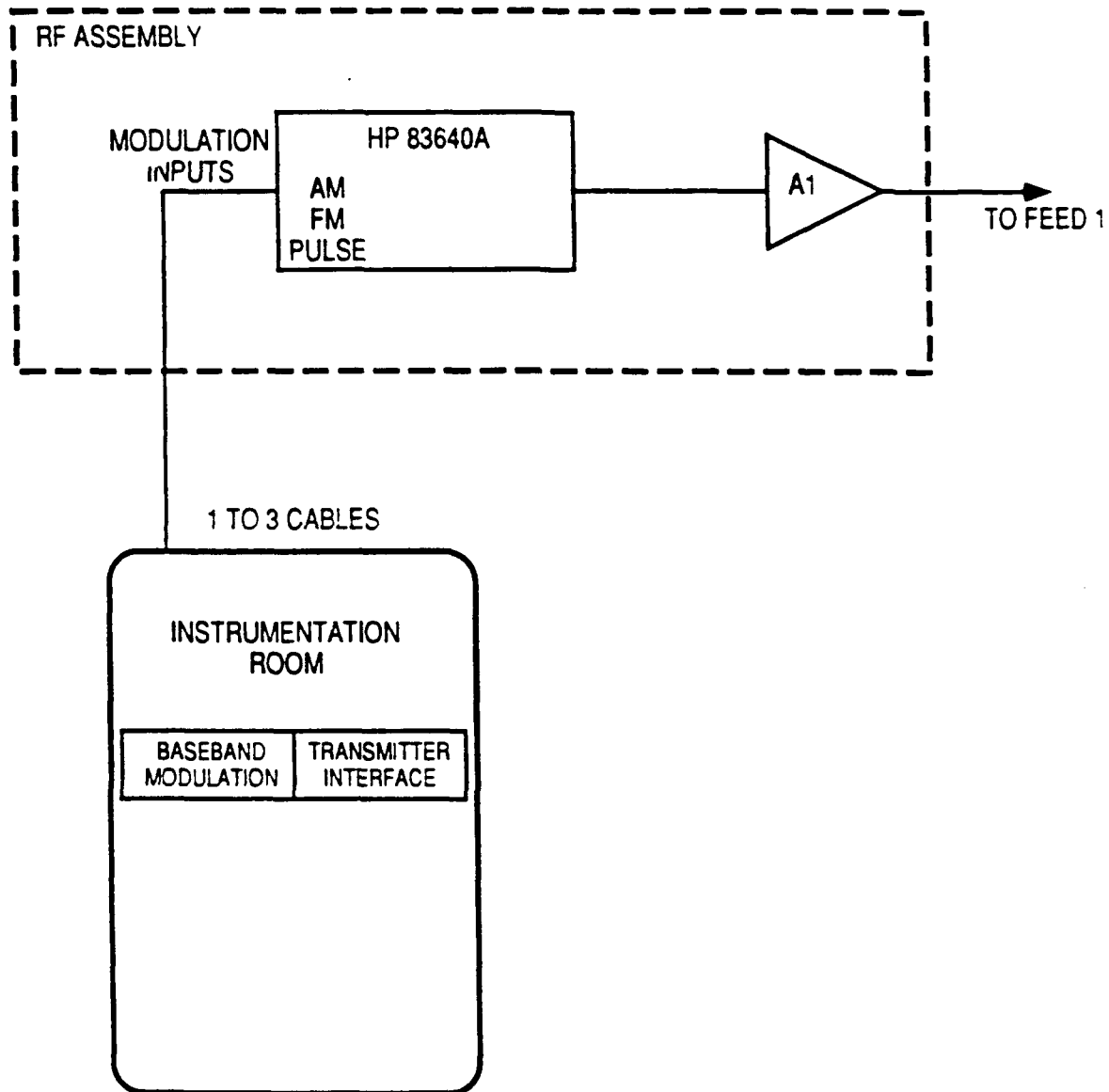


Figure 14. RF Configuration for EM Environment Generation.

d. The baseband modulator can provide wider bandwidth signals using the external modulation inputs of the HP source. In the case of the HP source, simultaneous modulation can be transmitted. The baseband modulator could conceivably consist of three independent generators. One generator could be used for the AM input, one could be used for the FM input, and yet another could be used to drive the pulse modulation input. Appropriate switching and amplification could be included in the transmitter interface.

e. The RF output of the HP 83640A is then amplified by A1. Amplifier A1 is the same amplifier used for the transmitter configuration required for RCS signal measurements. No additional amplifiers will be required. Using these amplifiers, the transmitter will be able to generate 25 dBm from 6 to 18 GHz, and 40 dBm from 18 to 40 GHz. The output of A1 is fed directly to the transmitter feed antenna.

f. The transmitted signal could be monitored by switching the reference channel from the HP 85201A to a monitoring device. The maximum bandwidth using this reference channel will be determined by the bandwidth of the remote mixers.

2.6.2.2 IF Configuration

a. Figure 15, IF Configuration for EM Environment Generation, shows a block diagram of this configuration. In this configuration there are several different modes of operation. All modes could be operated manually or automatically.

b. The IF configuration allows for the existing remote mixer configuration to be used as an up-converter for the EM environment signals generated at baseband. The operating frequency with this configuration is dependent on the baseband signals and the LO frequency. The baseband signal generators can be inexpensive function generators or signal generators.

c. The drawback to this configuration is that multiple mixing products will be generated by the up-conversion process. These unwanted mixing products should be filtered; however, this would require a multitude of different filters and does not lend itself to maximum flexibility or automation. A switch can be used to bypass the remote mixer. This would allow the modulation source to produce the required signal frequency without the degradations to signal integrity associated with up-conversion. This would also allow for actual transmitters to be used as the modulation source.

d. This configuration uses the existing remote mixers for RCS signal measurements. In this mode of operation the baseband modulator can be generated by any source. The modulating source could be the baseband modulator from an existing radio, or can be made up of commercially available instrumentation. Again the bandwidth of these baseband signals will be limited by the remote mixers.

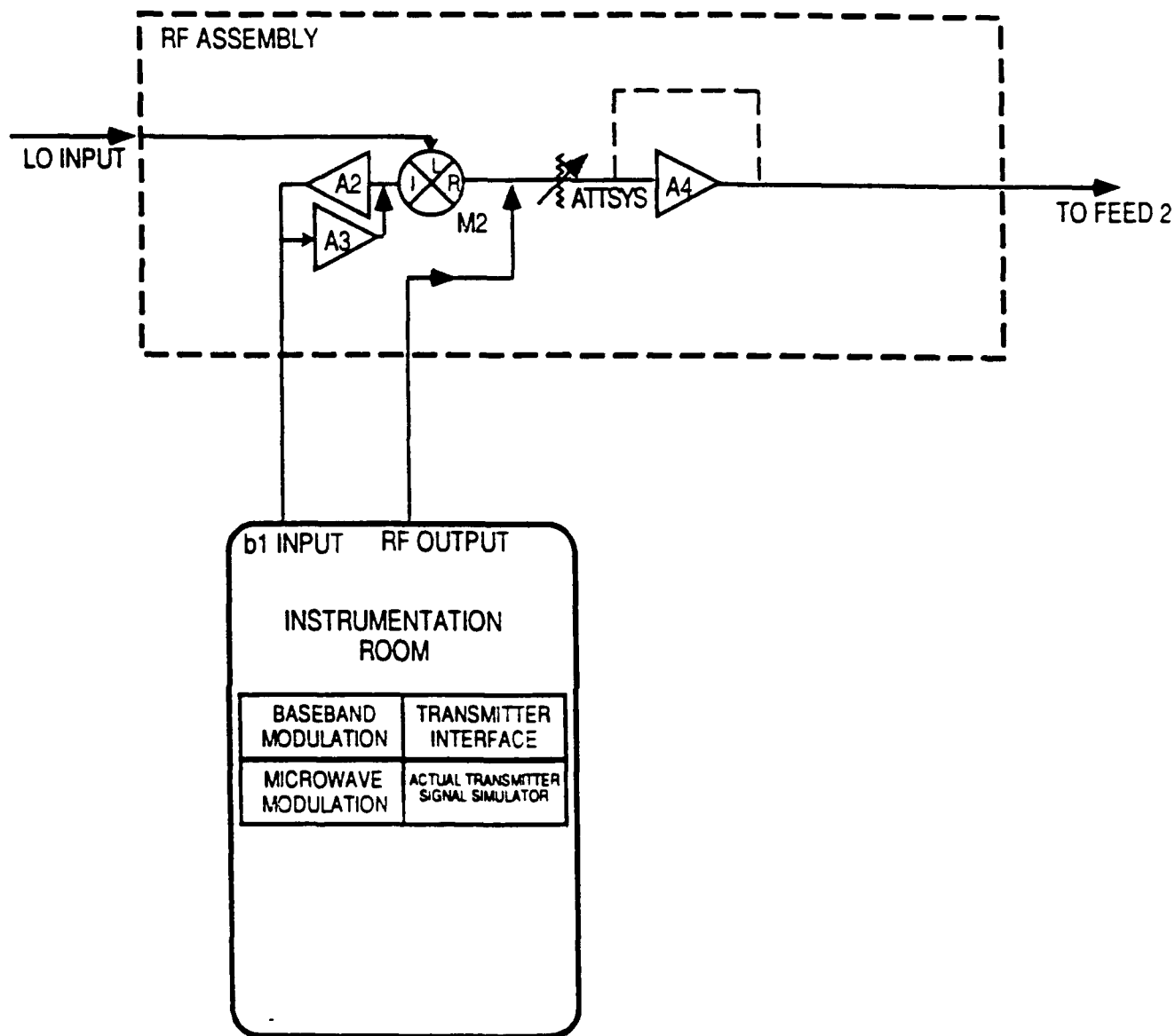


Figure 15. IF Configuration for EM Environment Generation.

e. The baseband signal is up-converted by mixer M2. The output of M2 is then amplified by amplifier A4. The path losses from the instrumentation room to the feed could be as much as 10 to 40 dB. This amplifier is only required when a higher power level is required. This configuration does not use the normal transmit amplifier A1. The signal from the mixer M2 or amplifier A4 is fed to the antenna normally used as the receive antenna in a quasi-monostatic configuration. This requires additional switches and amplifiers.

f. In this mode of operation the baseband signal is switched to the IF input of M2. This is normally the received signal during RCS signal measurements. The transmitter interface should incorporate the appropriate switching and amplification for the baseband signal.

g. The external filter inputs allow for the baseband signal to be filtered by external filters before up-conversion. This will allow for performance tests of system performance using different IF filters. These filters could be applied to the output of the function generator before up-conversion. If the baseband modulator is the device under test, these filters can be used to prove or improve performance of the device during development or if modifications to the test target are required.

h. The b1 input to the HP 85201A is switched to the baseband modulation source. This takes advantage of the existing LO configuration. Amplifier A3 should be used in order to achieve acceptable power levels. The transmit antenna is the receive antenna used for RCS signal measurements. The required modulation format is generated at the IF frequency. The existing mixers will allow signals from dc to 500 MHz to be generated. These baseband signals are then up-converted to the microwave frequency of interest. This configuration can potentially generate modulation bandwidths of up to approximately 400 to 500 MHz. The amplifier A3 would be a baseband amplifier with a bandwidth of 500 MHz. After up-conversion, the modulated RF signal is then amplified by A4. This should be a high power amplifier, preferably a TWTA.

2.6.2.3 Other EM Environment Generation Modes

a. Another mode of operation is to generate the RF signal in the instrumentation room and transmit this signal through the second feed antenna. Again A4 is not required, but is recommended for this mode of operation because of the high insertion losses associated with the transmission of the microwave energy from the instrumentation room to the RF enclosure. The amplifier A4 should be added to the RF enclosure.

b. In this mode (para a above), the modulation capabilities can be that of the RF signal sources, or with the appropriate switching, a baseband modulator can be used to drive the RF signal source. This configuration allows for almost any signal generator to be used and with no limitations on system bandwidth.

2.6.3 EM Environment Modulation Formats

a. The HP 83640A has an internal modulation generator that is capable of producing AM, FM, and pulse modulation formats. Table 5 lists the specifications of the internal modulation generator.

TABLE 5. HP 83640A INTERNAL MODULATION CAPABILITIES

Pulse Modulation

Pulse On/Off Ratio:	80 dB
Rise/Fall time:	50 nanoseconds
Pulse width:	25 nanoseconds to 400 milliseconds
Pulse periods:	300 nanoseconds to 400 milliseconds
Pulse resolution:	25 nanoseconds
Pulse accuracy:	5 nanoseconds
PRF:	2.5 Hz to 3.333 MHz

AM and FM Modulation

Waveforms:	Sine, Square, Triangle, Ramp, Noise
Modulation Frequency:	1 Hz to 1 MHz (Sine) 1 Hz to 100 kHz (Square, Triangle, Ramp)
Modulation depth:	AM: 0 to 99% FM: 1 Hz to 10 MHz

b. Ideally, an arbitrary waveform generator/synthesizer should be used. This will add additional capabilities for more exotic modulation formats and combinations of formats. The principal limitation in using a function generator is the maximum bandwidth that can be obtained is typically less than 50 MHz.

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SECTION 3. APPENDICES

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APPENDIX A. METHODOLOGY INVESTIGATION PROPOSAL
AND DIRECTIVE

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TEST CENTER: EP6

FUNDING \$(K)

PRIMARY MISSION AREA

SUPPORTED: CSS

PRIOR FY91 FY92 FY93 FY94 FY95 FY96 FY97

100 0145

TITLE: COMPACT ANTENNA RANGE TEST APPL II

BACKGROUND: This is a follow on of an existing Mnd which was funded in FY90. USAEPG has recently had a Compact Range installed for the purpose of producing antenna patterns in various environments. A potential use of this facility is to measure the Upset Effects, created by stray Electromagnetic signals produced by these environments, on the Patterns

PROBLEM: There are other measurements besides antenna Patterns for which the Compact Range can be used. The cost of making these measurements could be reduced by integrated or combined testing. This process could replace the current procedures at various facilities.

OBJECTIVE: To determine if the Compact Range at USAEPG can be adapted to other measurements such as target return signals, and equipment responses to specialized signal environments.

FY91

Test Center: EPG

MISSION AREA SUPPORTED: CSS

Title: COMPACT ANTENNA RANGE TEST APPL II

PRINCIPAL INVESTIGATOR: FRANCIS L. DAVIS

Office: EPG -STEEPETU

Email Address: steepetu@epgl-hua.arpa

Autovon: 879-6674

BACKGROUND: This is a follow on of an existing Mind which was funded in FY90. USAEPG has recently had a Compact Range installed for the purpose of producing antenna patterns in various environments. A potential use of this facility is to measure the Upset Effects, created by stray Electromagnetic signals produced by these environments, on the Patterns

PROBLEM: There are other measurements besides antenna Patterns for which the Compact Range can be used. The cost of making these measurements could be reduced by integrated or combined testing. This process could replace the current procedures at various facilities.

OBJECTIVE: To determine if the Compact Range at USAEPG can be adapted to other measurements such as target return signals, and equipment responses to specialized signal environments.

IMPACT/JUST: The impacts of Upset Effects will not be available, and the full potential of the Compact Range may not be realized. Some of the expected potentials are data on Target Return Measurement, Special specular reflection measurements, and signal Environment measurements.

(for complete BRIEF information see "MASTER MIND" page)

PROCEDURES:

Target Date	Achievement
10/31/90	Contract for follow-on effort to complete the study.
01/31/91	Coordinate with contractor to purchase necessary hardware and software to accomplish this task.
02/31/91	Receive interim report on status of study and make final determination on the direction to pursue which will provide the greatest benefits to the USAEPG.
03/30/91	Review draft final report and recommendations.

Target Date

Achievement

01/01/92 Provide final report.

COST CATEGORIES:

Personnel Compensation:	\$30K
Travel:	\$5K
Contractual Support:	\$85K
Consultants & Services:	\$0K
Materials & Supplies:	\$0K
Equipment:	\$25K
General & Admin costs:	\$0K

Man-hours Required:

IN-HOUSE DIRECT LABOR:	1250
CONTRACT LABOR:	3600

OBLIGATION PLAN:

Obligation rate	FQ	1	2	3	4	TOTAL
(Thousands)		0.0	7.5	7.5	7.5	\$145K

Test Operating Procedures to be revised as a result of this investigation:
TOP-6-2-604

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DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005-8085

REPLY TO
ATTENTION OF

AMSTE-TC-D (70-10p)

25 OCT 1990

MEMORANDUM FOR Commander, U.S. Army Electronic Proving Ground,
ATTN: STEEP-RM-F, Fort Huachuca, AZ 85613-7110

SUBJECT: Test Execution Directive, Test Technology Development
and Test Process Improvement Programs

1. Reference:

a. Draft TECOM Regulation 70-17, 1 Jul 89, TECOM Methodology Improvement and Standardization Programs.

b. Draft TECOM Regulation 70-18, 1 Jul 89, Research, Development and Acquisition, Instrumentation Development and Acquisition.

2. This memorandum authorizes the execution of the projects listed in enclosure 1 under the TECOM Test Technology Development and Test Process Improvement (formerly Research and Development of Instrumentation and Methodology Improvement) programs. Detailed project descriptions listed in the FY91-97 Master Mind and IDAP database are the basis for headquarters approval of the projects.

3. Upon receipt of this directive, review TRMS II database test milestone schedules established for the projects and enter any necessary reschedules directly into the TRMS database with appropriate justifying narrative.

4. All safety, health, energy, and environmental issues associated with the project will be considered and necessary documentation or support studies/information/approvals required will be accomplished/prepared prior to project initiation. Security/OPSEC requirements will be adhered to.

5. All reporting, including final technical reports prepared by contractors, will be in accordance with the requirements and appropriate formats as specified in the references. Final reports will be reviewed and approved by the headquarters technology program panel. Test centers must be prepared to send the project officer or a representative to brief the panel if necessary. All Methodology projects must specifically result in either a TOP, a software/simulation program, or an IDAP submission in order to be approved.

25 OCT 1990

AMSTE-TC-D

SUBJECT: Test Execution Directive, Test Technology Development
and Test Process Improvement Programs

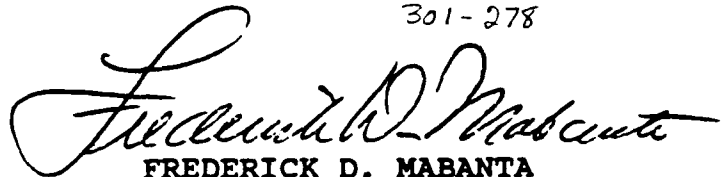
6. FY91 RDTE funds authorized for the projects are listed on enclosure 1. GOA form 1006 will be forwarded by the TECOM Directorate for Resource Management, and will be updated to reflect all changes to current program. A cost estimate is to be submitted within 30 days following receipt of this directive.

7. Point of contact at this headquarters is Mr. James Piro, AMSTE-TC-D, amstetcd@apg-9.apg.army.mil, DSN 298-3677/2170.

FOR THE COMMANDER:

301-278

Encl



FREDERICK D. MABANTA
C, Technology Development Division
Directorate for Technology

APPENDIX B. ABBREVIATIONS

a1	HP 8510B reference channel input
AFR	alias free range
AM	amplitude modulation
A1 thru A4	signal amplifiers
ATTREF	reference channel attenuator
ATTSIG	signal channel attenuator
ATTSYS	system attenuator
b1	HP 8510B signal channel input 1
b2	HP 8510B signal channel input 2
C	velocity of propagation in free space
CW	continuous wave, single frequency
dB	decibels
dB _i	decibels relative to isotropic
dB _m	decibels relative to one milliwatt
dB _{sm}	decibels per square meter
DC1	reference channel directional coupler
DC2	signal channel directional coupler
EM	electromagnetic
ERP	effective radiated power
f	frequency
FFT	fast Fourier transform
FM	frequency modulation
GHz	gigahertz
G _r	receive antenna gain
G _t	transmit antenna gain
GTRI	Georgia Tech Research Institute
HP	Hewlett-Packard
Hz	hertz
IF	intermediate frequency
IL	insertion loss
I1 thru I6	RF isolators/circulators
kHz	kilohertz
LO	local oscillator
MHz	megahertz
M1	reference channel mixer
M2	signal channel mixer
NF	noise figure
π	3.14159265
PD1	LO signal power divider

P_{in}	input power
PM1	transmitter gate pulse modulator
PM2	receiver gate pulse modulator
P_r	received power
PRF	pulse repetition frequency
P_t	transmitted power
R	range distance
RCS	radar cross section
RF	radio frequency
RFA1	signal amplifier
RFL	RF losses
TWTA	traveling wave tube amplifier
USAEPG	US Army Electronic Proving Ground
VSWR	voltage standing wave ratio

APPENDIX C. DISTRIBUTION LIST

<u>Addressee</u>	<u>Number of Copies</u>
Commander US Army Test and Evaluation Command ATTN: AMSTE-TC-D Aberdeen Proving Ground, MD 21005-5055	3
Defense Technical Information Center ATTN: FDAC Cameron Station Alexandria, VA 22304-6145	2
Commander White Sands Missile Range ATTN: STEWS-TE-AG White Sands Missile Range, NM 88002-5000	1
Commander Vulnerability Analysis Laboratory ATTN: SLCVA-TAC White Sands Missile Range, NM 88002-5000	1
Headquarters Aviation Systems Command ATTN: AMSAV-ESE 4300 Goodfellow Boulevard St. Louis, MO 63120-1798	1
Commander US Army Avionics Research and Development Activity ATTN: SAVAA-D Fort Monmouth, NJ 07703-5000	1

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