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Spread Spectrum Receiver Electromagnetic Interference (EMI) Test Guide

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PREFACE

NASA antenna port interference requirements have historically been derived from requirements in military standards. Intermodulation, suppression of undesired signals, and crossmodulation test methods described in MIL-STD-462, Measurement of Electromagnetic Interference Characteristics, were referenced directly in NASA requirements documents. These methods, however, have now been deleted from the test method requirements section of MIL-STD-462D due to the wide diversity in receiver types and the need for requirements consistent with the signal processing characteristics of a given subsystem. General information on test methods are given in the appendix of the MIL-STD-462D and apply primarily for fixed frequency, tunable, and superheterodyne receivers. The development of specific test limits and methods is left to the procuring activity of a particular receiver. National agencies, such as the National Telecommunications and Information Administration, provide requirements for transmitters and receivers, but have fewer requirements for space based receiver systems than for ground or air based systems. Since the test methods documented in these standards do not directly apply to many of the receiver systems in use today, these intermodulation, rejection of undesired signals, and crossmodulation type requirements have been deleted from some NASA space systems specifications. This deletion has left a void of data for determining intrasystem and intersystem electromagnetic compatibility, especially when attempting to determine out-of-band interference problems.

One type of transmitter/receiver system that is becoming more common on NASA programs as well as commercial and military programs are spread spectrum receivers. These receivers have added immunity by their design, but a method is needed for testing the potential interference with potential sources of interference. The methods in this report are identified for direct sequence spread spectrum receivers since this is the major type of spread spectrum receiver used by NASA.

The research required for the preparation of this document was performed by personnel within the Electromagnetics and Antennas Division (EAD) of the Sensors and Electromagnetic Applications Laboratory (SEAL) of the Georgia Tech Research Institute (GTRI). This program was sponsored by the National Aeronautics and Space Administration / Marshall Space Flight Center (NASA/MSFC) under Contract No. H-28506D. This program was monitored by Ms. Dawn Trout of NASA/MSFC/EL23. This research effort was directed by Mr. Mark L. Wheeler, Project Director, under the technical supervision of Mr. David P. Millard, Chief of EAD. This test guide documents recommended test methods for EMI testing of spread spectrum receivers.

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1. INTRODUCTION

1.1 BACKGROUND

NASA primarily uses military standards as guides for developing electromagnetic interference (EMI) test techniques for NASA programs. However, because of the wide variety of modern receiver design architectures, these standards provide only very general test guidelines for receiver antenna port susceptibility tests. Currently, NASA has a need to develop appropriate EMI test methods for direct sequence (DS) spread spectrum receivers. Specifically, these test methods are required to evaluate S-band, Tracking and Data Relay Satellite System (TDRSS) receivers and transponder receiving systems at the unit level. Several TDRSS receivers/transponders will be used on the International Space Station (ISS). Unit level TDRSS receiver EMI data is needed to aid in the evaluation of the electromagnetic compatibility (EMC) of the TDRSS receivers in the ISS electromagnetic environment (EME).

1.2 OBJECTIVE AND SCOPE

The objective of this test guide is to document appropriate unit level test methods and techniques for the performance of EMI testing of DS spread spectrum receivers. Consideration of EMI test methods tailored for spread spectrum receivers utilizing frequency spreading techniques other than direct sequence (such as frequency hopping, frequency chirping, and various hybrid methods) is beyond the scope of the test guide development program and is not addressed as part of this document. EMI test requirements for NASA programs are primarily developed based on the requirements contained in MIL-STD-461D (or earlier revisions of MIL-STD-461), Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility [1]. The corresponding test method guidelines for the MIL-STD-461D tests are provided in MIL-STD-462D, Measurement of Electromagnetic Interference Characteristics [2]. These test methods are well documented with the exception of the receiver antenna port susceptibility tests (intermodulation, cross-modulation, and rejection of undesired signals) which must be tailored to the specific type of receiver that is being tested. Thus, test methods addressed in this guide consist only of antenna port tests designed to evaluate receiver susceptibility characteristics. MIL-STD-462D should be referenced for guidance pertaining to test methods for EMI tests other than the antenna port tests.

The scope of this test guide includes: (1) a discussion of generic DS receiver performance characteristics; (2) a summary of S-band TDRSS receiver operation; (3) a discussion of DS receiver EMI susceptibility mechanisms and characteristics; (4) a summary of military standard test guidelines; (5) recommended test approach and methods; and (6) general conclusions and recommendations for future studies in the area of spread spectrum receiver testing.

NASA is primarily interested in using this test guide for the evaluation of S-band TDRSS receivers and transponder receiving systems that will be implemented on the ISS. Therefore, brief discussions of TDRSS receiver performance characteristics and the specific tailoring of test techniques to evaluate TDRSS receiver performance in the expected ISS EME are also included in this guide.

2. DS SPREAD SPECTRUM RECEIVER CHARACTERISTICS

Before appropriate EMI test methods for DS receivers can be addressed, a basic understanding of receiver operation must be obtained. This section contains a brief overview of generic DS receiver operation. Information related to DS receivers and DS system operation can be found in many sources available in the open literature [3, 4, 5].

2.1 RF SIGNAL COMPOSITION

The primary objective of a spread spectrum system is to gain communication advantages by expanding the bandwidth of transmission. These advantages are various (depending on the system application) but commonly include: (1) increased transmit power efficiency; (2) multiple use of a designated frequency band with minimal interference among users; (3) reduced probability of intercept; and (4) increased interference resistance (interference margin) due to system processing gain. DS systems achieve frequency spreading by modulating the transmit carrier frequency with a pseudorandom noise (PRN) binary code sequence. Typically, some form of phase shift keying (PSK) is used to modulate the carrier with the PRN code. Balanced modulators are used to suppress the carrier signal. The effect of this modulation is to distribute the transmit power over a wide bandwidth (compared to the bandwidth of the information signal) which consequently lowers the power spectral density of the transmit signal. The DS signal's power spectral density has a $(\sin x/x)^2$ envelope with a main lobe bandwidth (null-to-null) of twice the clock (chip) rate of the PRN code modulating signal. The side lobes have a bandwidth equal to the PRN chip rate.

In addition to the PRN modulation, the carrier is also modulated by the information (message) data. The information data is in a binary coded format and generally has a data rate several orders of magnitude less than the PRN code chip rate. Most often the information data is modulo-2 added to the PRN code and the composite code (information + PRN) is used to modulate the carrier. At the receiver input, the DS signal power spectral density can be less than that of the receiver noise. Only after the receiver has correlated the DS signal with a replica of the transmit PRN code (to realize the processing gain) can the information data be extracted.

2.2 BASIC RECEIVER ACRHITECTURE

A functional block diagram depicting the basic receiver design architecture for a generic DS spread spectrum receiver is shown in Figure 1. The objective of this diagram is to illustrate the basic operating principles of a DS receiver and is not meant to be a detailed representation of any specific manufacturer's design. Variations of DS receiver designs are numerous and application driven. However, the vast majority of receivers are based on the general architecture of Figure 1.

The RF (front-end) section of a DS receiver is similar to the front-end section of conventional narrowband receivers. The RF signal is received with an antenna tuned to the receiver's band of operation, fed through a bandpass filter, and then amplified with a low noise preamplifier. The antenna may be impedance matched to the input impedance of the receiver via

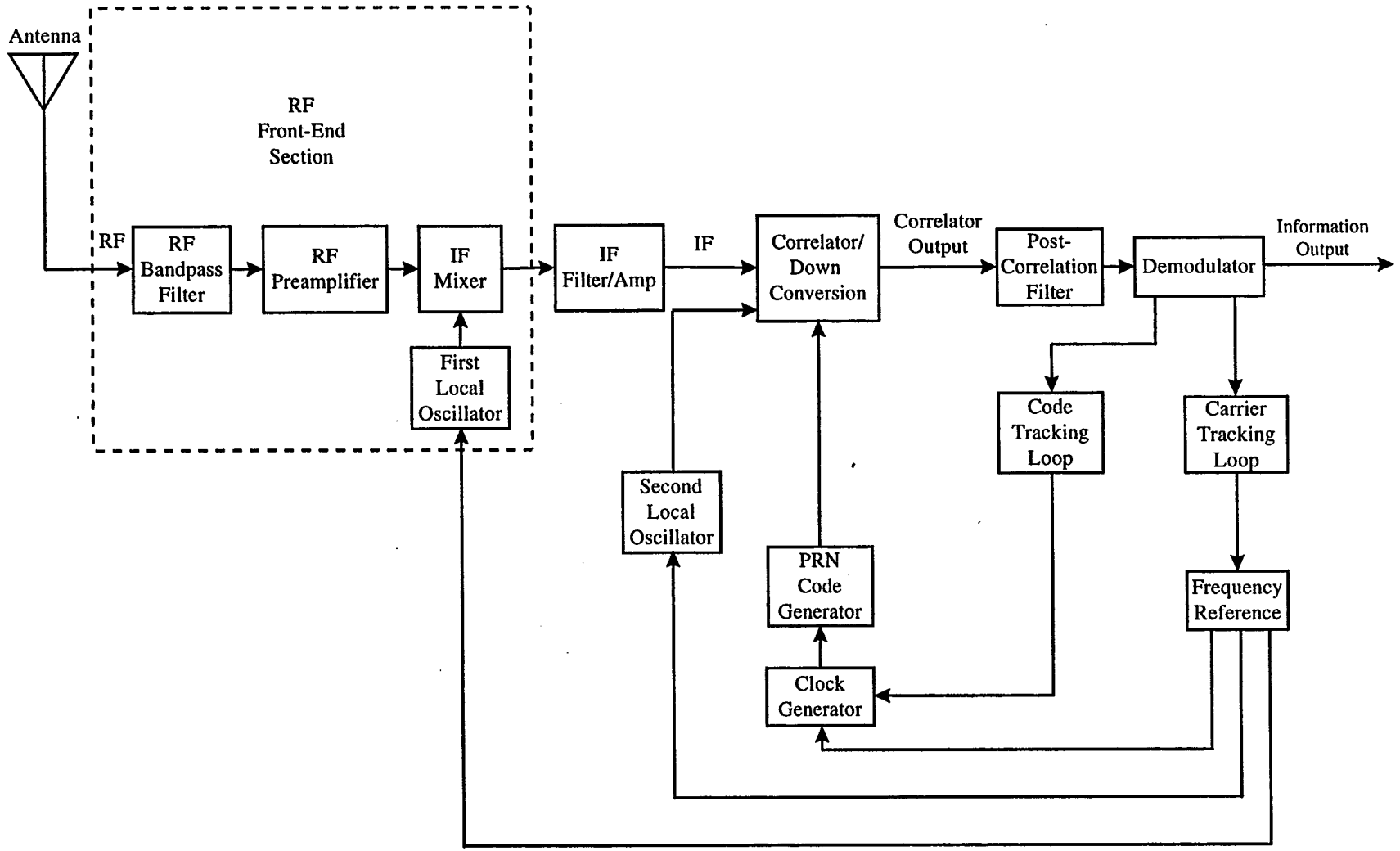

Figure 1. Generic Functional Block Diagram for a DS Spread Spectrum Receiver.

an antenna impedance matching network. Out-of-band inference rejection is provided by the tuned antenna, the bandpass filter, and the impedance matching network (if used). The power spectral density of the desired spread spectrum signal at the input to the preamplifier is often quite low and can be below the noise power level of the preamplifier. The output of the RF preamplifier is an amplified version of this broadband input signal plus noise along with its own internally generated noise. The preamplifier's additive noise (noise figure) in effect determines the noise figure of the receiver system. The output of the preamplifier is passed to a mixer stage where it is mixed with a local oscillator (LO) and down converted to an intermediate frequency (IF). The IF signal is passed through an IF bandpass filter which provides further rejection of out-of-band signals.

The IF signal is typically correlated and down converted to a lower correlator output frequency in a single stage heterodyne correlator. In this stage, the second LO signal is modulated with a replica of the received signal's PRN code. This signal is then mixed with the IF signal to produce a despread signal (information modulated signal only) that has been down-converted to the correlator output frequency. This signal is then passed through a post-correlation filter and demodulated to produce the output information. Most often the demodulator stage is implemented using a phase-lock loop (PPL) technique (Costas Loops are common) that will operate at low signal-to-noise ratios and generate a local reference carrier that can be used for code and carrier tracking functions.

DS receivers have two general feedback loops that maintain correlation to and tracking of the spread spectrum signal. These two loops are identified in Figure 1 as the code tracking loop and the carrier tracking loop. In order to acquire the spread spectrum signal, the phase difference between the received signal code and the internally generated code replica must be resolved to within one chip. Also, the center frequency of the correlator output (recovered carrier) must be resolved to the degree that the despread signal falls within the narrow passband of the post-correlation filter and the recovered carrier frequency must be accurate enough to work well with the PLL based demodulator.

The basic functions of the code tracking loop are to obtain initial synchronization with the received signal PRN code and then maintain phase lock with the incoming code. Initial synchronization is typically achieved using a sliding correlation technique. This technique involves varying the phase difference between the internally generated code and the received signal code at a constant rate. A feedback signal which indicates if a coherent output has been received from the correlator is provided to the tracking loop from the demodulator section of the receiver. As long as the two code streams are unsynchronized the correlator will output a broadband (band limited by the post-correlation filter) noise signal. However, once the internally generated code comes in synch with the incoming signal code, a coherent output will occur. The tracking loop senses this coherent output and the receiver switches from acquisition mode to tracking mode. To decrease acquisition time, the sliding correlation method is often augmented by additional techniques that use *a priori* information to limit the synchronization search to a limited section of the code.

Having acquired the code, the receiver switches to the code tracking mode in which the internally generated PRN code is matched with the incoming signal's PRN code as precisely as possible. Typically the code lock must be maintained to within a fraction of a clock cycle. This degree of synchronization can only be maintained by implementing an active tracking scheme because the phase lock between the two codes tends to drift over time due to Doppler shift effects and clock stabilization errors. Tracking techniques such as tau-dither and delay-lock loops (Figure 1 is more representative of the tau-dither loop) are commonly used for performing the code tracking function. These are error-signal-generating methods that result in a slight amplitude modulation of the correlator output signal. This amplitude modulation is detected in the demodulator section of the receiver and fed back to the tracking loop. Clock generator bias signals are derived based on the magnitude and sense (increasing or decreasing magnitude) of the amplitude modulated signal. These bias signals are used to control the receiver generated code chip phase and, thus, keep the receiver code locked to the incoming code.

The carrier frequency of a received DS signal will also drift due to various causes (primarily Doppler shift effects in dynamic space-based systems). Thus, DS receivers must also employ a carrier tracking loop to maintain lock to the received signal. This is usually accomplished by first detecting carrier phase shifts in the demodulator section of the receiver. The carrier tracking loop then uses this information to derive bias signals for the frequency reference oscillator based on the magnitude and sign of the carrier phase shift. The receiver frequency reference is then adjusted to compensate for the frequency drift of the incoming signal. Correspondingly, all receiver oscillator frequencies and clock rates (which are derived from the frequency reference) are also compensated by an appropriate amount.

The diagram in Figure 1 implies the use of an analog receiver system in an effort to simplify the explanation of basic DS receiver functionality. However it should be noted that modern receiver designs are mostly implemented using digital techniques. It is not unusual in modern receivers for an analog-to-digital (A/D) converter to be implemented immediately after the first IF section of the receiver and for all receiver functions after the A/D conversion to be implemented using digital circuitry and techniques. Also, the diagram of Figure 1 does not indicate any method for signal limiting or automatic gain control (AGC) due to the myriad of techniques used to implement this function. However, it is not uncommon for a DS receiver to use signal limiting and AGC circuits to protect the receiver front-end from saturation or damage, and to increase the dynamic range. Signal limiters are often located just ahead of the preamplifier to protect against damage. Bias signals for AGC are often fed back from the correlator or demodulator sections of the receiver to the preamplifier or IF amplifier to maintain a more constant signal amplitude, thereby increasing receiver dynamic range.

2.3 RANGING TECHNIQUES

Basic ranging techniques typically involve the use of two transponders to perform a two-way propagation time delay measurement (between the transponders). Measurement of the range between the two transponders is initiated when the interrogating transponder transmits a PRN code sequence for a period long enough to allow the responding transponder to synchronize with the code. Once the receiving system of the responding transponder is synchronized to the

interrogator's signal, the interrogating system instructs the receiving transponder to switch to the transmit mode at the reception of a specified signal. The responding transponder then relays the ranging signal back to the interrogating transponder. The interrogating transponder determines the chip offset of the received signal relative to its internal code reference. The number of chips that the transmitted and received signals are offset by is proportional to the two-way propagation delay between the transponders. Based on the known chip delay and chip rate, the one-way range can be calculated as:

$$R = (c*C_D *(1/C_R))/2 \quad (1)$$

Where,

R = range between the transponders,
c = the speed of light,
C_D = the number of chips offset between the transmitted and received codes, and
C_R = the code chip rate.

From Equation 1 it can be seen that the measurement resolution increases in proportion to the chip rate. The ultimate measurement resolution between the transmitted and received codes is one chip and, therefore, range resolution is limited to the period of one chip (one clock cycle period) multiplied by the speed of light. Also, it should be noted that range measurement systems require the use of a code sequence that is longer than the maximum two-way propagation time delay that the system is expected to measure. A shorter code could repeat during the measurement period and allow range ambiguities to enter into the measurement process.

The two-way ranging technique (and variations on this technique) described above is probably the most common technique in use. However, one-way ranging (implemented with a one-way link between a transmitter and receiver) can be accomplished if the clock rates of the transmitter and receiver are very precisely synchronized and highly stable. In this case, the time delay for the transmitted code can be determined based on time of transmit information provided to the receiver as part of the transmitter's data message. The most ubiquitous example of a system that utilizes one-way ranging techniques is the Global Positioning System (GPS) [5]. The GPS system is based on a very accurate and stable GPS system clock. The GPS system controllers determine any offsets that the GPS satellite clocks may have relative to the system clock. This clock offset information is always transmitted as part of the GPS satellite information message. Thus, the GPS receivers can determine the precise transmit time of the GPS PRN code. However, the receiver's internal clock is also offset by an unknown amount relative to the GPS system clock. The receiver determines this unknown clock offset (along with its unknown x, y, and z position coordinates) by measuring the code chip delays from four separate satellites and then solving a set of four simultaneous, nonlinear equations.

3. TDRSS RECEIVER OPERATION

The primary application of this test guide is to provide guidance for the EMI susceptibility testing of S-band TDRSS receivers and the receiver sections of S-band TDRSS

transponders. Subsequent sections of this guide include recommendations related to tailoring the general EMI test methods for specifically performing S-band TDRSS receiver testing. Thus, an overview of the TDRSS and TDRSS S-band receiver characteristics is provided in this section to give some background information from which the TDRSS specific test recommendations were derived.

3.1 TDRSS OVERVIEW

The TDRSS provides forward and return telecommunications services between low Earth-orbiting spacecraft and spacecraft user control and data processing facilities at the Goddard Space Flight Center (GSFC) in Maryland or to an communications service interface at the White Sands Complex (WSC) in New Mexico. In addition TDRSS provides scheduled tracking services in support of orbit determination requirements. The TDRSS space segment consists of up to four Tracking and Data Relay Satellites (TDRSs) in geostationary orbit at allocated longitudes. These satellites relay command and communications data from the user spacecraft to earth through several ground terminals located at the WSC and other ground support subsystems at other various locations.

The two primary TDRSS telecommunications services are termed multiple access (MA) and single access (SA). The MA service operates using two fixed S-band frequencies. The transmit frequency from the TDRSs to the user spacecraft (forward service) is 2106.4 MHz and the transmit frequency from the user spacecraft back to the TDRSs (return service) is 2287.5 MHz. The MA service is designed to support concurrent low data rate users (up to 10 kbs for forward service and up to 100 kbs for return service) requiring near continuous communication service. The SA service is available simultaneously in both S-band (2025-2120 MHz forward service/2200-2300 MHz return service) and K-band (13.775 GHz forward service/15.003 GHz return service) and is intended for support of medium to very high data rate users (up to 300 Mbps for K-band return service). In addition, a tracking service is provided to perform user spacecraft two-way-range and/or range-rate measurements or one-way range-rate measurements [6].

3.2 S-BAND TDRSS FORWARD LINK SIGNAL CHARACTERISTICS

The S-band TDRSS forward link carrier signal (transmit signal from a TDRS to a user spacecraft receiver) is modulated by two separate PRN codes using an unbalanced quadriphase shift keying (QPSK) technique. The two PRN codes are transmitted simultaneously at the same frequency. The first code (termed the command channel) is a data modulated 1023-chip Gold code and the second code (termed the range channel) consists of 261,888 chip linear maximal code, truncated from a normal 2^{18}-1 code length (262,143 chips). The information data is modulo-2 added to the command channel Gold code. The range channel code is not data modulated and its length was chosen to satisfy the range ambiguity resolution requirements of the TDRSS. Also, the range channel is transmitted at a power level that is 10 dB below the command channel. The PRN chip rate for both codes is 0.00146 times the transmit frequency which produces chip rates of approximately 3 MHz (3.08 MHz at the MA service transmit frequency of 2106.4 MHz). The S-band forward link data rates for the command channel can

range from 0.1 to 10 kbps for the MA service and up to 300 kbps for the SA service. The TDRS antenna polarization is left-hand circular (LHC) for the MA service and is right-hand circular (RHC) or LHC selectable for the SA service. A block diagram depicting the TDRSS forward link signal modulation process is shown in Figure 2 [3,6].

3.2 S-BAND TDRSS RECEIVER FUNCTIONAL CHARACTERISTICS

To date, there have been four generations of TDRSS transponder designs. The generational design improvements have been mainly in the areas of reduced power consumption; reduced weight; increased compatibility with communication modes other than TDRSS; and improved telemetry and data interfaces. However, the basic TDRSS receiver design (contained in these transponders) mirrors the generic architecture described in Section 2 and the functional characteristics of the receivers are essentially the same for all generations of the transponders. However, TDRSS receivers are somewhat more complex than the generic model in that they employ two separate PRN codes to reduce signal synchronization and acquisition time.

Code acquisition time is greatly enhanced in a TDRSS receiver by synchronizing the range channel (long) code with the repetition period of the 1023-chip command channel (short) code. In the transmitter, the short and long codes are started at the same time. The long code is truncated and started again after 256 repetitions of the short code. In the receiver, the short code is synchronized by performing a search through the 1023 chip sequence. At a 3 MHz chip rate, the complete search requires up to 0.33 msec. After command channel code lock is achieved, carrier acquisition and synchronization is performed. Upon completion of carrier lock, the receiver resets its long code generator each time the short code repeats and searches for long code lock over the duration of the short-code period. If it recognizes a long code lock with the incoming signal, it continues the long code without resetting. If long code lock has not been recognized by the time the short code repeats, the long code resets and starts again. Using this technique, the internally generated long code can systematically search through the entire incoming code length in not more than 256 repetitions of the short code. Thus, the search time is not more than 88 msec maximum (again assuming a 3 MHz chip rate).

S-band TDRSS receiver performance specifications are derived primarily from the TDRSS specifications detailed in the NASA Space Network User's Guide [6]. Therefore, in order to be compatible with the system, S-band receiver specifications should be consistent between manufacturer's or between different design generations. The following general design specifications are typical of S-band TDRSS receivers [7]:

(1) Input Frequency Range: 2025 to 2120 MHz for SA service, 2106.4 MHz for MA service
(2) Channel Bandwidth: 6 MHz (3 dB bandwidth)
(3) Noise Figure: < 2.5 dB typical
(4) VSWR: 1.5:1 maximum (relative to 50 ohms)
(5) Acquisition Dynamic Range: Acquires when the command channel power at the receiver input is between –138 and –99 dBm
(6) Acquisition Frequency Range: Doppler compensated forward link frequency within $\pm$ 1500 Hz. Frequency rate of change $\leq$ 75 Hz/sec.

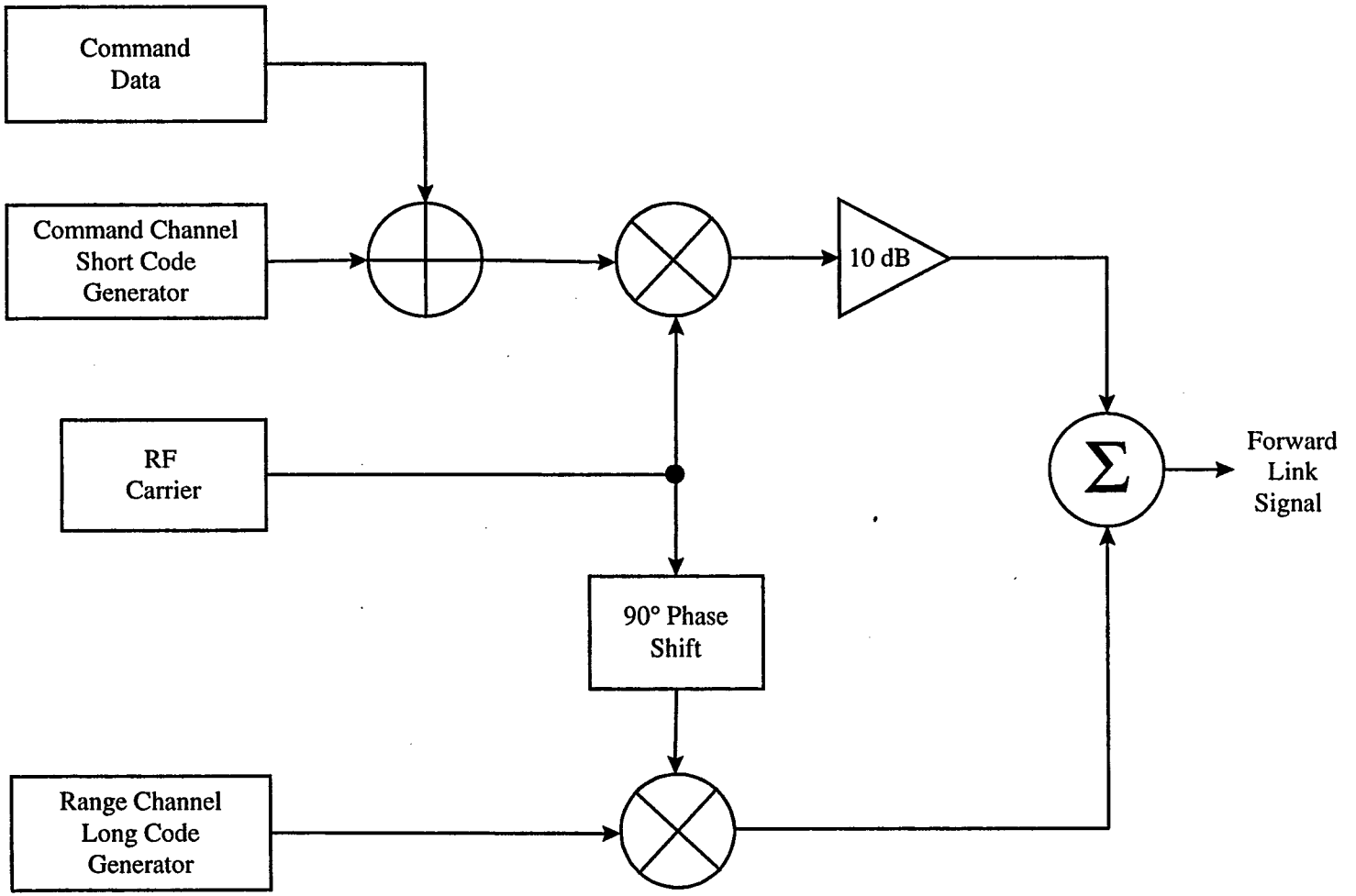

Figure 2. TDRSS Forward Link Signal Modulation.

(7) Complete Acquisition Time: Will complete short code lock, carrier lock, and long code lock in ≤ 22 sec typical

(8) Carrier Tracking Threshold: Dependant on command data rate. Typical threshold is -140 dBm at a data rate of 125 bps. For higher data rates the threshold increases by 10 • log(data rate/125 kbps). For example the threshold for a data rate of 10 kbps = - 121 dBm.

(9) Command Threshold: To maintain a bit-error rate of ≤ 10^{-5}, Typical threshold is –138 dBm for a data rate of 125 bps. Again the threshold is dependant on the data rate and varies as 10 • log(data rate/125 kbps).

These specifications are not intended to be an exhaustive list of TDRSS receiver performance specifications but, rather, is intended to give a general impression of typical TDRSS receiver performance. Detailed performance specifications for specific receivers or transponders can usually be obtained from the manufacturer or procuring agency and should be obtained prior to the performance of any independent EMI testing of the receiver.

4. DS RECEIVER EMI MECHANISMS AND CHARACTERISTICS

4.1 INTERFERENCE SUPPRESSION CHARACTERISTICS

DS spread spectrum receivers inherently provide a certain level of rejection to in-band interference signals. The mechanism for the rejection of unwanted signals is termed processing gain and is developed in the system's signal correlation (de-spreading) process. When the desired DS signal is correlated with the receiver's internally generated code, it collapses back to its original narrow bandwidth. On the other hand, all unwanted signals (that have not been modulated with the designated PRN code) are spread by the correlation process. The narrowband post-correlation filter (which is matched to the de-spread desired signal) will then reject the vast majority of the energy of the spread interfering signal. As a rule of thumb, processing gain for DS receivers can be estimated as the ratio of the PRN chip rate to the information data rate.

A receiver's interference margin, or interference-to-signal (I/S) ratio, is defined as the amount of power by which an interference signal (which has not been spread by the designated direct sequence code) must exceed the code modulated spread spectrum signal in order to cause degradation in the receiver. The interference margin is always less than the processing gain. This is because the receiver interference margin is dependent on the required system signal-to-noise ratio and system implementation losses. The I/S ratio can be calculated as follows:

$$I/S = G_p - (L_{sys} + S/N) \qquad (2)$$

where,

I/S = The ratio of the interference signal level to the desired spread spectrum signal level (in dB) at the receiver input required to cause receiver degradation;

G_p = The theoretical processing gain of the receiver (in dB) – [estimated as 10log(chip rate/data rate)];

L_{sys} = Receiver system losses (in dB) – [includes overall receiver noise figure and correlator losses and;

S/N = Signal-to-noise ratio (in dB) at the information output required to maintain desired level of performance.

It is not unusual for DS spread spectrum receivers to generate 40 to 50 dB of interference margin. This appears to be a formable amount of interference immunity until it is considered that DS receivers generally operate at very low input signal levels, often –130 dBm or less. Thus, an in-band interfering signal having a power level as low as –80 to –90 dBm has the potential to cause upset in the receiver.

Interference suppression due to receiver processing gain effects apply similarly to all types of interference signals (CW, broadband noise, pulsed, etc.). However, DS receivers may have additional immunity (a higher threshold) to low duty cycle pulsed interference signals (such as radar signals). In general, receivers with well designed code and carrier tracking loops will not fail due to low duty cycle interference signals, even when the peak signal levels exceed the receiver interference margin. However, degradation of performance will occur if the interference signal is of sufficient magnitude to saturate or (for extreme power levels) damage the RF preamplifier. If the receiver has been designed to include a signal limiter implemented just ahead of the RF preamplifier to protect against these excessive signal levels, very large pulsed signals may be tolerated with little or no adverse effect to receiver performance.

Filtering techniques used to suppress out-of-band interference in DS receivers are essentially the same as those used in narrowband receivers. As was mentioned previously, DS receiver designs typically include a front-end RF bandpass filter, bandpass filters in each IF section, and a post-correlation filter. The combined effects of these filters determine the out-of-band signal response of the receiver system.

4.2 INTERFERENCE MECHANISMS IN AN OPERATIONAL ENVIRONMENT

It is not unusual for DS receivers to be deployed on a common platform with numerous RF transmitting systems which cover a large range of power levels, frequencies, modulations, and functions (such as will be the case on the ISS). Proper spectrum management will preclude the intentional operation of any of these transmitters in the frequency band of the receiver. However, in a dense electromagnetic environment, there are several mechanisms by which out-of-band transmissions can cause upset to receivers. The most common interference mechanisms are harmonic interference effects, intermodulation effects, spurious response effects, and cross modulation effects.

All transmitters produce emissions at frequencies that are harmonics of the carrier frequency. These harmonic signal levels are usually filtered at the transmitter output; however, it is typical for low order harmonics to be transmitted at a level of –60 to –80 dB relative to the carrier output power level. As discussed in the previous section, DS receiver interference thresholds can be as low as -80 to –90 dBm. Therefore, even a relatively low power transmitter

(ERP of 30 to 40 dBm) that is located within a few meters of the receive antenna would have a significant chance of causing interference to the receiver if one of its harmonics falls within the receiver passband.

Intermodulation interference effects are produced in a receiver when two or more out-of-band signals are mixed in such a way as to produce an intermodulation (IM) product at a frequency that falls within the passband of the receiver. These IM products are a result of the nonlinear characteristics of the active devices commonly used in receiver mixer and amplifier designs. The third-order IM product is the most commonly observed response in receivers and can be expressed as:

$$f_o = 2f_1 - f_2 \tag{3}$$

where,

f_o = the tuned frequency of the receiver;
f_1 = the frequency of the first out-of-band signal; and
f_2 = the frequency of the second out-of-band signal.

For example, two TDRSS transponders transmitting simultaneously at frequencies of F_1 = 2205 MHz and F_2 = 2295 MHz would have the potential of producing third-order IM product interference in any TDRSS receiver whose RF passband encompasses 2115 MHz. However, if the RF bandpass filter rejects one or both of these signals, no interference would likely occur.

Spurious responses commonly occur at receiver IF frequencies, LO frequencies, and image frequencies. In addition, due to receiver nonlinear characteristics, out-of-band signals occurring at harmonics of the receiver's LO and tuned RF frequencies can mix to produce spurious responses. Spurious responses occur primarily when the receiver's bandpass filtering measures are not sufficient to keep high level out-of-band signals from exceeding the receiver's interference threshold.

Cross modulation effects are produced when the modulation of an out-of-band signal is transferred to the desired in-band signal. Like IM responses, these effects are due to the nonlinear characteristics of the receiver's active components. Classic cross modulation interference is not applicable to DS receivers. However, these receivers can be susceptible to a somewhat analogous form of interference generally referred to as cross-correlation effects. This problem may occur when a pair of DS transponders are located close to each other and operating in a common system (such as TDRSS). If the signal level of the transmit signal (from the first transponder) is high enough to overwhelm the out-of-band filtering measures of the second transponder's receiver system; the code modulated interfering signal will be fed (along with the desired signal) into the correlator section of the receiver. In theory, the desired code and the interfering code should be orthogonal to each other and the receiver should not lock to the interfering code. However, it is typical that the minor correlation peaks generated during the receiver synchronization process will be higher when an PRN modulated interfering signal is present (when compared to correlation in the presence of a non-coded interfering signal) and the probability of a false lock is increased. In effect, the receiver's processing gain may be reduced

for this type of interference and thus have a lower false lock threshold for a PRN coded interfering signals than for other types of interference (such as broadband random noise or CW interference).

5. MILITARY AND ISS EMI TEST REQUIREMENTS

An appropriate set of EMI tests for the unit level evaluation of a space system receiver can be defined based on the guidelines contained in MIL-STD-461D, Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility [1]. Typically, unit level EMI test requirements developed for electronic equipment to be deployed under specific NASA programs will mirror the MIL-STD-461 requirements. However, test applicability, test limits, and test frequencies are usually tailored to reflect the EME and operational characteristics of the platforms (spacecraft) on which the electronic equipment is to be used. ISS EMI test requirements are contained in NASA Document SSP 30237, Space Station Electromagnetic Emissions and Susceptibility Requirements [8]. This document does, indeed, appear to be based on MIL-STD-461 (although the test requirement nomenclature mirrors the older MIL-STD-461C nomenclature). The MIL-STD-461D requirements for space system receivers and the ISS EMI test requirements are listed in Table 1.

The corresponding test methods for the MIL-STD-461D tests and the ISS program are provided in MIL-STD-462D, Measurement of Electromagnetic Interference Characteristics [2] and NASA Document SSP 30328, Space Station Electromagnetic Techniques [9], respectively. It should be noted that the ISS test methods in SSP 30328 are well documented but do not contain any receiver antenna port test methods (as none are called out in SSP 30327). Similarly, the test methods in MIL-STD-462D are well documented with the exception of the receiver antenna port conducted susceptibility tests (intermodulation, cross-modulation, and rejection of undesired signals). MIL-STD-462D recommends that the test methods, frequency ranges, and limit requirements for these tests be specified by the procuring agency.

6. RECOMMENDED DS RECEIVER EMI TEST APPROACH

6.1 GENERAL APPROACH

The overall objective of the unit level EMI test approach is to define a reasonable and cost effective set of test methods that will evaluate the equipment's compatibility with its expected operational EME. In addition, the test methods should generate data that are useful for EMC analyses, spectrum management, and the development of improved EMI "hardened" equipment designs. To accomplish these objectives for DS receivers, it is recommended that receivers which are not subject to specific NASA program EMI requirements meet the tests requirements of MIL-STD-461D for space systems (as listed in Table 1). However, the three MIL-STD-461D antenna port conducted susceptibility tests (CS103, CS104, and CS105) should be replaced with the set of antenna port tests specified in this test guide. MIL-STD-462D should be referenced for guidance pertaining to the non-antenna port test methods. TDRSS receivers (or the receiving systems of TDRSS transponders) procured for ISS use, should meet the test requirements of SSP 30237 and, in addition, should also be evaluated for antenna port

Table 1: MIL-STD-461D and ISS EMI Test Requirements

MIL-STD-461D Test Requirements		International Space Station Requirements	
Requirement	**Description**	**Requirement**	**Description**
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz	CE01	Conducted Emissions, DC Power Leads, 30 Hz to 15 kHz
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz	CE03	Conducted Emissions, DC Power Leads, 15 kHz to 50 MHz
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 50 kHz	CE07	Conducted Emissions, DC Power Leads, Spikes, Time Domain
CS103	Conducted Susceptibility, Antenna Port, Intermodulation	CS01	Conducted Susceptibility, DC Power Leads, 30 Hz to 50 kHz
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals	CS02	Conducted Susceptibility, DC Power Leads, 50 kHz to 50 MHz
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation	CS06	Conducted Susceptibility, DC Power Leads, Spikes
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 400 MHz	RE02	Radiated Emissions, Electric Field, 14 kHz to 10 GHz and 13.5 GHz to 15.5 GHz
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation	RS02	Radiated Susceptibility, Magnetic Induction Field
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz	RS03	Radiated Susceptibility, Electric Field, 14 kHz to 20 GHz
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz	LE01	Leakage Emissions, AC Power Leakage Current
RS103	Radiated Susceptibility, Electric Field, 10 kHz to 40 GHz	----	----

susceptibilities using the test methods in this test guide. Test methods used for the SSP 30327 tests should be based on the techniques and procedures contained in SSP 30328. It should be noted that the intent of the radiated susceptibility tests contained in Table 1 is to evaluate the equipment-under-test (EUT) for inter-connect cable coupling and box enclosure penetration susceptibilities (back-door effects). Usually it is unreasonable to test receivers in their operational frequency band at the field levels specified in the test standards. For receiver equipment radiated susceptibility testing, it is typical to terminate the EUT antenna port with a shielded load or to not radiate the EUT over the frequency range of its operational bandwidth.

To fully evaluate a receiver's EMI characteristics, antenna performance data will be required in addition to the receiver EMI data obtained via this test approach. This test guide does not address antenna test methods. However, the types of antenna data required for receiver system evaluation will be discussed briefly in Section 6.3.

6.2 RECOMMENDED ANTENNA PORT EMI TESTS

The recommend set of antenna port tests to be used for the evaluation of DS receiver EMI susceptibility characteristics consist of the following tests:

(1) Receiver Sensitivity Test
(2) In-Band Interference Margin Test
(3) Cross-Correlation Test
(4) Near-Band Signal Rejection Test
(5) Out-of-Band Signal Rejection Test
(6) Out-of-Band Intermodulation Test

Again, this set of tests was developed based on the goal of using the test results to generate data that are useful for EMC analyses, spectrum management, and the development of improved EMI "hardened" equipment designs. The proposed test methods for these test will be described in Section 7 of this guide.

6.3 ANTENNA CHARACTERIZATION TESTS

In order to completely evaluate the EMI characteristics of a receiver system, receiver antenna performance data is required in addition to the receiver EMI data. Antenna characterization tests should be performed separately (if possible) from the receiver EMI tests. Often, in-band antenna performance data is readily available from the manufacturer. This data will generally include peak gain, VSWR, polarization, and pattern plots for principal plane cuts at a few discrete frequencies. However, for EMI and EMC analyses, out-of-band antenna performance data is also required in addition to the in-band data. Out-of-band antenna testing is not usually performed by the manufacturer. Due to the limited scope of this test guide development program, out-of-band antenna performance test methods are not addressed. It would be beneficial, at some future date, to define a set of antenna test methods for the purpose of generating useful data for receiver system EMI and EMC analyses.

7. ANTENNA PORT TEST METHODS

7.1 GENERAL DISCUSSION

7.1.1 Receiver Test Methods

The antenna port test methods defined in this guide are based, in part, on the information contained in several reference documents [10-16] identified during the literature search phase of this test guide development program. The objective of these test methods is to provide test results that will provide useful receiver EMI susceptibility information (for use in EMC prediction and evaluation) while also keeping the required test time and test complexity within reasonable limits. The antenna port tests recommended for DS receiver evaluation have been provided in Section 6.2 of this guide. The proposed test methods for these tests are detailed in the subsequent sections of this guide. Test method discussions are divided into five areas: (1) test objective and rationale; (2) test set-up; (3) test procedure; (4) S-band TDRSS receiver/ISS EME tailoring; and (5) test output. The test objective and rationale section will define the objective and purpose of the test and will give the rationale for the selection of test parameters and modes. The test set-up section will specify general test equipment configurations and, where applicable, will include discussions of potential test equipment effects on the measurements. The test procedures section will consist of a generalized set of steps required to perform the test. The intent of this section is to provide an understanding of the sequence of actions required to perform the tests. It is not intended to be a exhaustive test procedure which accounts for every detail of the test sequence. The TDRSS receiver/ISS EME tailoring section will include discussions of issues specific to the testing of TDRSS receivers that are expected to operate in the ISS EME. The test output section will define the measured data that should result from the performance of the test.

7.1.2 Receiver EUT Configuration

The antenna port tests defined in this guide are conducted tests in which the desired and interfering signals are injected directly into the receiver's antenna port. The receiver antenna should not be included as part of the EUT; but rather, should be evaluated separately using appropriate antenna characterization tests. However, any external receiver system components such as external RF filters or (in the case of a transponder) a diplexer, should be included as part of the receiver EUT. It is expected that most receiver systems can be tested using a conducted test signal technique, which is certainly preferable. However, if a receiver design includes an integral antenna (cannot be detached from the receiver electronics to allow direct signal injection) or an antenna module that contains filters and/or pre-amplifiers, it may be necessary to perform the receiver tests using a radiated method. This is a more complicated test method in which all test signals are radiated and care must be taken to verify that all observed responses are due to the receiver and not generated by the test equipment or facility. The conducted signal test methods detailed in this guide can be converted to radiated methods with proper consideration of test areas (anechoic chambers) and antenna parameters such as polarization, gain, and pointing angle. However, in general, tests performed using radiated signal techniques are more difficult to control, monitor, and obtain verifiable results in comparison to tests performed using conducted signal methods.

7.1.3 Receiver Test Modes

A DS receiver operates in two basic modes generally termed acquisition/synchronization (A/S) mode and tracking mode. The antenna port test methods will be performed, when appropriate, for receiver operation in both these modes. Susceptibility thresholds are usually lower for the A/S mode than for the tracking mode. Susceptibility thresholds for both A/S and tracking modes are required for thorough platform-level EMC analyses.

A DS receiver may operate at several data rates. If this is the case, the receiver should be tested using a sufficient number of data rates to obtain a reasonable characterization of the device. Often it is sufficient to test at a high, medium, and low data rate (selected from the total number of available data rates).

Generally, DS receiver designs operate using a single RF channel. One of the basic differences between spread spectrum systems and conventional communications systems is that spread spectrum systems use code division multiple access techniques rather than using separate channels (frequency division multiple access techniques) to accommodate multiple users. However, a DS receiver may operate over with different RF bandwidths and/or different center frequencies. If there are significant differences in the channel characteristics (in particular, if the RF bandwidths are different) it may be appropriate to test each channel (or a representative number of channels) of the receiver.

7.1.4 Spread Spectrum Signal Simulators/Test Sets

The performance of the antenna port tests will require the use of a spread spectrum transmitter or signal simulator test set designed for the communications system in which the receiver EUT operates. The test set will be used to simulate the desired spread spectrum signal during the EMI tests. For TDRSS testing, a TDRSS User Test Set (TURFTS) [17] was identified as a suitable test set for providing the simulated forward link TDRSS signal. The TURFTS: (1) provides a forward link signal at any carrier frequency in the 2025 to 2120 S-Band frequency range; (2) modulates the carrier with any of the 85 designated TDRSS PRN codes (selectable by the user); (3) generates information data messages internally or accept externally provided data messages to add to the forward link signal; (4) provides an output port for monitoring internally generated information data; and (5) provides an output RF signal power level that is adjustable from –163 dBm to +5 dBm in 1 dB steps. TURFTS development and procurement is managed by the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.

It should be mentioned that the cross-correlation and interference margin tests, specified in this guide, will require the generation of two differently coded system signals. This may be accomplished with two test sets, or possibly with one test set and a system PRN code generator/modulator. An extensive evaluation of receiver cross-correlation and self interference characteristics would require the simultaneous generation of many coded signals to fully simulate a multiple user environment. However, this type of test is not included in this guide because of the severe test equipment requirements.

7.1.5 Receiver Standard Response

All of the susceptibility tests described in this test guide, except the cross-correlation test, require that the receiver's desired signal and potential interference signal(s) be simultaneously injected into the receiver antenna port. Prior to the start of testing, an appropriate power level (at the input of the receiver) for the desired signal should be defined. The desired signal injected at this power level is termed the "standard response signal" and should be used throughout the susceptibility testing. Ideally, the standard response level should be chosen based on nominal receiver RF input levels specified for normal (or typical) system operation. If this information is unavailable or the typical input level for the receiver varies over a wide dynamic range, the standard response level should be at least several dB above the receiver's sensitivity level. A level of 10 dB above the sensitivity level is a reasonable choice. This ensures that the receiver is operating well above its internal noise level and decreases the probability that any receiver upset effects are due to random noise fluctuations rather than the interference signal(s). As a result, this greatly increases the repeatability of the susceptibility tests when compared to performing the tests using a standard response level very close to the receiver's sensitivity level.

7.1.6 EUT Performance Upset Criteria and Monitoring

During susceptibility testing, the standard response signal (desired signal) and the interference signal(s) will be simultaneously injected into the receiver antenna port. Receiver upset will be determined by monitoring either the receiver's telemetry and/or information output data. Often, DS receivers will output telemetry data that will give indications related to the integrity of the received signal. This telemetry data may provide indications verifying acceptable code lock, carrier lock, detector lock, S/N ratio, and AGC performance. An unacceptable indication of one or more of these parameters can be used as an upset criteria when the degradation corresponds to the activation or increase in power level of an interfering signal.

Another method for determining degradation due to EMI is to use a bit error rate (BER) monitor to monitor the receiver output data message. The BER monitor compares the injected information data message at the receiver's input to the detected message data at the receiver's output. An EMI upset can be defined as occurring when the receiver bit error rate exceeds the maximum allowable limit for the system (and BER degradation corresponds to the activation of the interfering signal). In practice, determining receiver upset based on telemetry data (health of receiver data) indications is the simplest method to use for EMI testing. However, depending on the design of the receiver EUT, a BER monitor may have to be implemented to determine specific interference effects.

7.2 RECEIVER SENSITIVITY TEST METHOD

7.2.1 Objective and Rationale

The objective of this test is to determine the minimum RF input power level at which the receiver can function properly. It should be noted that sensitivity levels for DS receivers will increase proportionally to increases in the receiver data rate. Thus, receivers that can operate at various data rates will have different sensitivity levels for each data rate mode. Also, it is typical,

for DS receiver operation, that the A/S mode sensitivity level is higher than the tracking mode sensitivity level.

Receiver sensitivity level will be required to determine an appropriate standard response level (if no other guidance for choosing this level is available). It is recommended that the receiver standard response be at a level that is 10 dB above the sensitivity level. Also, receiver sensitivity information is essential for platform level EMC analyses and evaluation. Specifications for receiver sensitivity are typically available from the receiver manufacturer and can be used without verification by independent test, if desired. However, often times the details of the manufacturer's test procedures used to determine the specifications are not available. In addition, the sensitivity measurement can be used as a validation of the test setup, procedures, and calibration methods. Therefore, it is often advantageous to verify the manufacturer's receiver sensitivity specifications as part of the EMI tests. The additional test time require to perform the sensitivity test does not add significantly to the total time required to perform the overall set of EMI tests.

7.2.2 Test Set-Up

The test set-up diagram for the receiver sensitivity test is shown in Figure 3. A spread spectrum signal simulator is used to generate the data and PRN code modulated spread spectrum standard response signal used for the test. A spectrum analyzer is used to monitor and measure the signal level at the input to the receiver EUT. A pre-amplifier connected at the input of the spectrum analyzer may be required to observe the spread spectrum signal during the sensitivity test. Alternatively, after the sensitivity level is established, the signal level can be raised by a known, fixed amount (e.g., 60 dB) to enable the spectrum analyzer measurement to be made. Spectrum analyzer levels should be corrected for the pre-amplifier gain (if used) plus coupler and/or cable losses that exist in the measurement system. Note that the spectrum analyzer's resolution and video bandwidths should be set to be at least as wide as the RF bandwidth of the spread spectrum signal. If this cannot be achieved, empirical or calculated power calibration factors should be used to correct the readings. Satisfactory receiver operation is determined by monitoring the receiver's telemetry output and/or measuring the BER of the information data.

7.2.3 Receiver Sensitivity Test Procedure

The general test procedure for determining receiver sensitivity is as follows:

(1) Set the spread spectrum signal simulator to its minimum output power level. The simulator's output frequency should be set to the tuned frequency of the receiver EUT. The simulated signal should be coded with the receiver's internal code. The simulator and receiver should be operating at the receiver's slowest data rate mode. Verify that the receiver is not locked-on (is in A/S mode) to the low level signal.

(2) Increase the signal simulator power level until the receiver acquires the signal and enters into the tracking mode. Be sure to pause between each increase in signal power by an

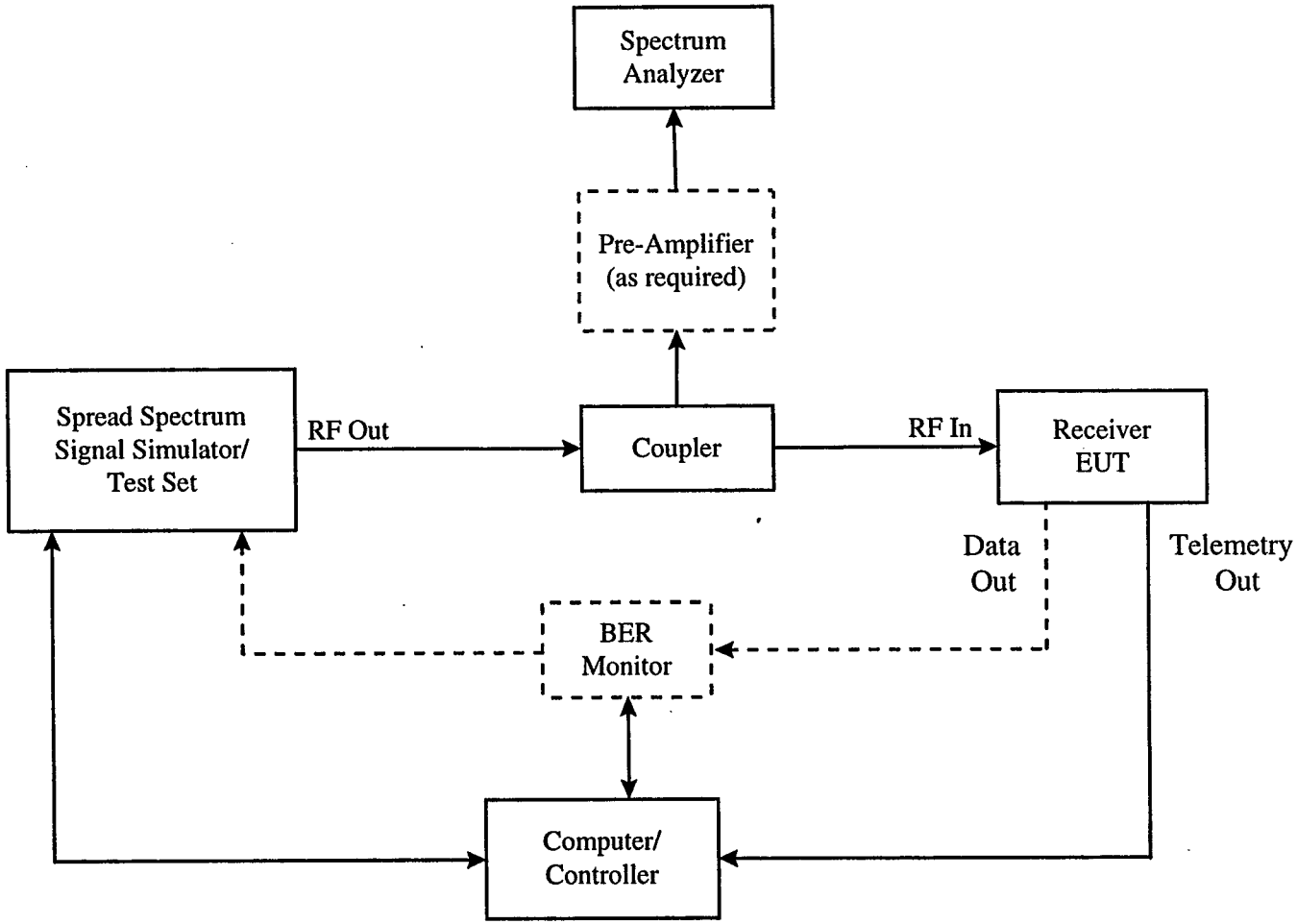

Figure 3. Receiver Sensitivity Test Set-Up.

amount exceeding the maximum specified acquisition time for the EUT. Acquisition of the signal corresponds to receiver operation in which all receiver "health indications" (such as code lock, carrier lock, data detector lock, S/N ratio, and BER) are within acceptable limits. Document the input power level at which the standard response was first observed. This power level is defined as the A/S sensitivity threshold.

(3) Increase input power level an additional 10 dB above the A/S threshold.

(4) Decrease the input power level until the desired signal is lost. Typically, loss of carrier lock is the first indicator of received signal degradation. Document the input power level at which loss of the standard response was first observed. This level is termed the tracking sensitivity threshold.

(5) Repeat Steps 1 through 4 a minimum of three times. NOTE: Sensitivity threshold levels are inherently statistical and thus multiple trials of this procedure should be conducted to obtain an representative sample of the threshold level.

(6) If the receiver operates at multiple data rates, repeat Steps 1 through 5 while the receiver is operating at a representative number of data rates (e.g., minimum, maximum, and nominal).

7.2.4 S-Band TDRSS Receiver/ISS EME Tailoring

There is no TDRSS receiver tailoring required for this test. However, a review of a third generation TDRSS transponder design specification [7] indicates that expected sensitivity levels are in the –135 to –140 dBm range for a 125 bps data rate.

7.2.5 Test Output

The required results from the receiver sensitivity test consist of documenting the A/S sensitivity threshold and the tracking sensitivity threshold at a representative number of data rates. An average threshold value should be specified if significant differences exist between the thresholds determined in the multiple test trials. A/S and tracking standard response levels, to be used in the subsequent tests, can be determined based on the sensitivity levels.

7.3 IN-BAND INTERFERENCE MARGIN TEST METHOD

7.3.1 Objective and Rationale

The objective of the interference margin test is to verify and quantify the inherent interference rejection provided by a DS receiver to signals that are not modulated by the unique PRN code assigned to the receiver. Interference margin, or interference-to-signal ratio (I/S) can be calculated using Equation 2 (see Section 4) if the receiver's processing gain, required S/N ratio, and system losses are known. However, the values for these parameters are often not known precisely and consequently Equation 2 constitutes only a good first order estimate of

interference margin which may vary in accuracy by several dB depending on the specific design characteristics of the receiver. In addition, the interference margin level is dependant on the receiver mode of operation (A/S interference margin is generally less than the tracking interference margin) and the modulation characteristics of the interference signal. For these reasons, it is very beneficial to characterize receiver interference margin by test. The interference margin data derived from this test will be very useful in performing platform analyses and prediction of receiver EMC in the operational EME.

Again, this test should be performed for both the A/S and tracking modes of receiver operation. The interference signal modulations used will be CW, pulsed, and an orthogonal PRN code chosen from the set of system codes. In lieu of an orthogonal PRN code modulated signal, a band-limited noise source may be used. It is recommended that the pulse modulation parameters (pulse repetition frequency (PRF) and pulse width) be varied over a range that covers that of potential interfering emitters that are part of the platform EME in which the receiver is intended to operate. If the receiver EME is unknown, then a generic PRF of 1 kHz and pulse width of 1 μs (which corresponds to a 0.1% duty cycle) should be used. These parameters are representative of typical radar system transmissions.

If the RF bandwidth of a DS receiver is fixed and the IF bandwidth increases with data rate (as is usually the case), interference margin will decrease as the data rate is increased. The interference margin reduction is due to the reduction in processing gain. However, as the data rate increases, the sensitivity level of the receiver is increased proportionally (minimum input power level required to generate a standard response increases in proportion to the data rate). Thus, the absolute interference power level required to disrupt a standard response signal at the receiver sensitivity level should remain constant. If the receiver EUT can operate at multiple data rates, this characteristic should be verified by testing at the minimum and maximum data rates. Additional data rates can be evaluated if desired.

If the receiver has multiple spread spectrum channels (channels at different carrier frequencies) with different RF bandwidths, it is recommended that the interference margin test be performed for each channel (or a representative sample of channels). If the channel bandwidths are the same, it is reasonable to assume that receiver architecture is similar for each channel and testing of only one channel should be adequate to characterize the receiver.

7.3.2 Test Set-Up

A generic test set-up for the antenna port conducted susceptibility tests that utilizes a single interference source (all except the intermodulation test) is shown in Figure 4. As before, a spread spectrum signal simulator is used to generate the data and PRN code modulated spread spectrum standard response signal used for the test. For the interference margin test, both pulse and PRN code modulation sources will be required. In the diagram, the PRN code modulation is shown as being implemented with a PRN code source and a PSK modulator. However this function could more easily be accomplished with a second spread spectrum signal simulator. A spectrum analyzer is used to monitor and measure the test signal levels at the input to the receiver EUT. Spectrum analyzer levels should be corrected for the pre-amplifier gain, coupler losses,

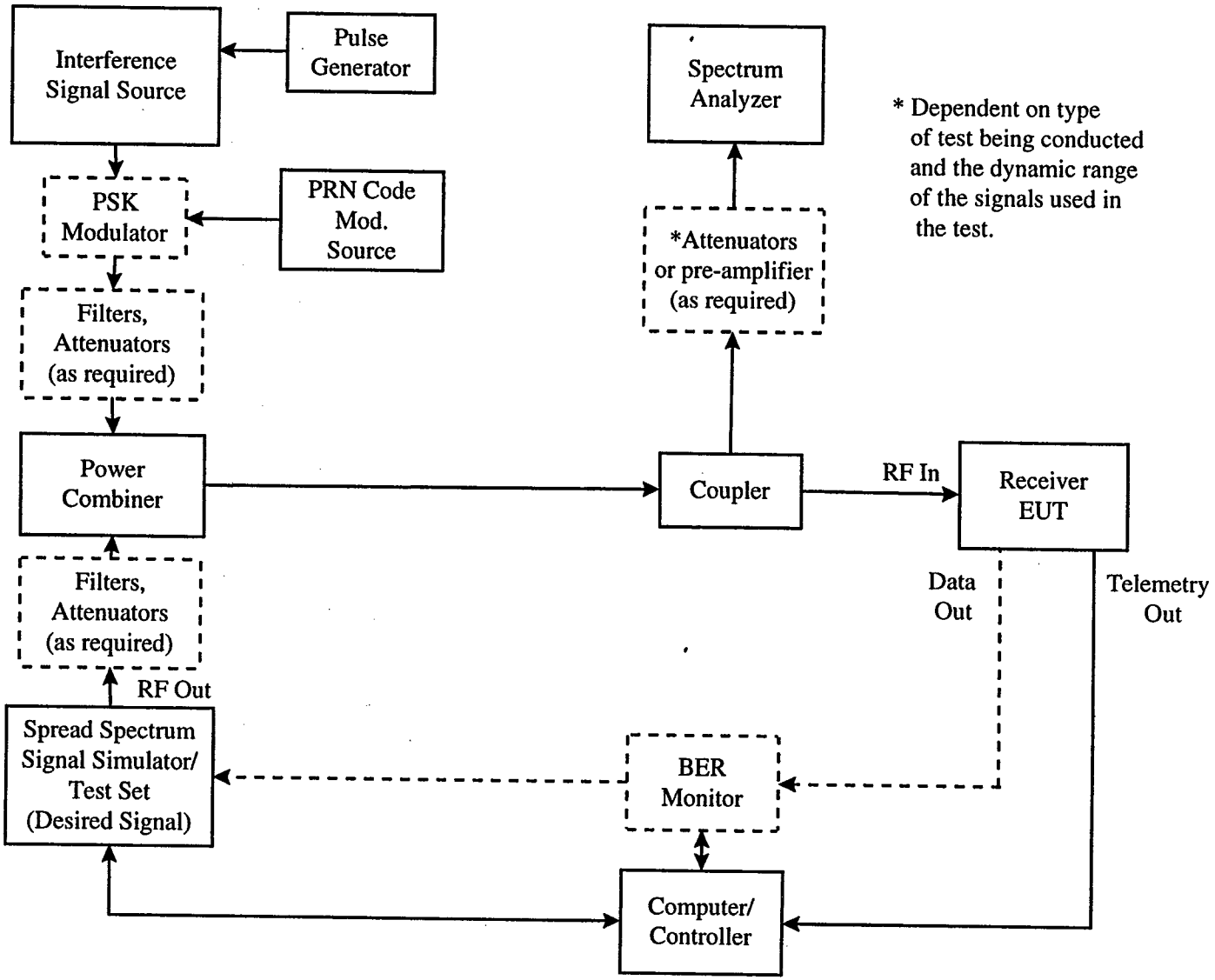

Figure 4. Single Interference Source Conducted Susceptibility Test Set-Up.

and/or cable losses as required. Interference thresholds are determined by monitoring the receiver's telemetry output and/or measuring the BER of the information data.

7.3.3 Test Procedure

The general test procedure for determining receiver interference margin levels is as follows:

(1) Set the spread spectrum signal simulator to the output power level required to produce the tracking mode standard response level at the input to the EUT. The simulator's output frequency should be set to the tuned frequency of the receiver EUT. Verify that the receiver has locked onto the desired signal and that all tracking parameters are within acceptable limits.

(2) Beginning with a CW signal, activate the interference signal source at a power level that is equivalent to the receiver sensitivity level. The interference signal source frequency should be set to the tuned frequency of the receiver EUT.

(3) Increase the interference signal power level until the first indication of loss of receiver carrier tracking is observed. Document this I/S ratio as the "carrier break-lock" I/S threshold.

(4) Continue to increase the interference signal power until code lock with the desired signal has been interrupted and the receiver has returned to the A/S (signal search) mode. Document this I/S ratio as the "code break-lock" I/S threshold.

(5) Decrease the interference signal power until the receiver has reacquired lock to the desired signal and all tracking parameters are within acceptable limits. Remember to pause at each power level by an amount exceeding the maximum specified acquisition time for the EUT. Document this I/S ratio as the "reacquisition" I/S threshold.

(6) Set the interference signal power level at the "code break lock" level as determined in Step 4.

(7) Set the spread spectrum signal simulator to the A/S mode standard response level. The simulator's output frequency should be set to the tuned frequency of the receiver EUT. Verify that the receiver has not locked onto the desired signal and is in the signal search mode.

(8) Reduce the interference signal power level until the receiver has locked onto the desired signal and all receiver tracking parameters are within acceptable limits. Document this I/S ratio as the "acquisition" I/S threshold.

(9) Repeat Steps 1 through 8 using a pulsed modulated interference signal and a PRN code modulated interference signal (a PRN code orthogonal to the receiver's code and chosen

from the set of system codes). NOTE: DS receivers are typically more resistant to interference from a pulsed source (on a peak power basis) than to other types of modulation. Do not let the peak interference signal power level exceed the damage threshold level of the receiver.

(10) Repeat Steps 1 through 9 for different receiver data rate modes and spread spectrum channels, as deemed appropriate.

7.3.4 S-Band TDRSS Receiver/ISS EME Tailoring

A review of TDRSS related documentation [6,7] indicates that reasonable estimates for S-band receiver minimum S/N ratio and system losses are 10 dB and 3 dB, respectively. The TDRSS S-band chip rate is approximately 3 MHz. Typical receiver data rates (for MA service) range from 125 bps to 10 kbps. Thus, a first order estimate of interference margins would be in the range of 12 to 31 dB. However, it is anticipated that the interference margin to pulsed interference (on a peak power basis) will be significantly higher. Documents specifying expected emitters on the ISS [19] were reviewed to determine pulse parameters that could be used to tailor the pulsed interference margin test to be representative of the on-board ISS radar characteristics. Russian Soyuz tracking radars were found to have pulse widths of 1 μs and PRFs of 3300 Hz, producing a duty cycle of 0.33%. It is recommended that these pulse parameters be used for testing of receivers to be used on the ISS.

7.3.5 Test Output

The required results from the in-band interference margin tests consist of documenting the I/S ratios for the carrier break-lock threshold, the code-break lock threshold, the reacquisition threshold, and the acquisition threshold for all interference signal modulations and receiver modes that are tested.

7.4 CROSS-CORRELATION TEST METHOD

7.4.1 Objective and Rationale

The objective of this test is to determine the input signal levels at which a receiver could possibly cross-correlate and exhibit a false lock to an interfering signal modulated with a PRN code (an orthogonal code selected from the system set of codes) different from the receiver's intended code. This test is included to simulate the condition of closely located transmitters and receivers that operate in the same DS communications system. It is possible that if an orthogonally coded signal is processed by the receiver, the minor correlation peaks may be of sufficient amplitude to cause a false lock in the receiver. Also, data from this test could be useful in evaluating the required isolation between receiver and transmit channels for full-duplex DS transponders. It is recommended that this test be performed for both an in-band interfering signal (at the receiver tuned frequency) and a near-band interfering signal (chosen based on the expected operational EME, if possible). This test should be performed for a representative number of data rates (if the receiver has multiple data rate modes).

7.4.2 Test Set-Up

The test set-up for the cross-correlation test is shown in Figure 4. A spread spectrum signal simulator is used to generate the data and PRN code modulated spread spectrum standard response signal (desired signal) used for the test. The interference source is modulated by an orthogonal PRN code. In the diagram, the PRN code modulation is shown as being implemented with a PRN code source and a PSK modulator. However this function could more easily be accomplished with a second spread spectrum signal simulator, if available. A spectrum analyzer is used to monitor and measure the test signal levels at the input to the receiver EUT. Spectrum analyzer levels should be corrected for the pre-amplifier gain (if used), coupler losses, and/or cable losses as required. False lock thresholds are determined by monitoring the receiver's telemetry output.

7.4.3 Test Procedures

The general test procedure for the cross-correlation test is as follows:

(1) Power off the spread spectrum signal generator and verify that the EUT is in the signal search mode.

(2) Activate the interference source, at the tuned frequency of the EUT, and set to a power level that approximates the EUT minimum sensitivity level. Verify that the receiver is still in search mode.

(3) Increase the interference output power until code lock is indicated by the receiver. Do not increase above the receiver's damage threshold. Remember to pause at each power level by an amount exceeding the maximum specified acquisition time for the EUT. Document the power level at which false lock occurs.

(4) Repeat Steps 1 through 3 with the interference source tuned to a near-band frequency (but outside the 3 dB RF bandwidth of the receiver). If possible, the near-band frequency should be selected based on the expected operational EME of the receiver.

(5) Repeat Steps 1 through 4 for different receiver data rate modes and spread spectrum channels, as deemed appropriate.

7.4.4 S-Band TDRSS Receiver/ISS EME Tailoring

For S-band TDRSS receiver evaluation, the near-band interfering frequency should be chosen from the TDRSS return link band of 2200 to 2300 MHz. The near-band frequency portion of this test should be conducted with the receiver set to its highest tuned frequency and the interfering signal frequency set to the lowest TDRSS return link frequency that is expected to be used in the receiver's EME (or vice versa).

7.4.5 Test Output

The required output from this test are false lock levels (if they are observed) for an in-band and a near-band interference signal.

7.5 NEAR-BAND SIGNAL REJECTION TEST METHOD

7.5.1 Objective and Rationale

The objective of this test is to determine the interference rejection characteristics of the DS receiver at frequencies close to its intended passband. The receiver is to be tested over a frequency range that is ±5 times the 3 dB RF bandwidth of the receiver channel (with the frequency range centered at the tuned frequency of the receiver). This frequency range will be loosely termed the near-band frequency range. This near-band test can be used to infer filter response information for the receiver and also used to determine possible spurious response levels in the near-band frequency range. In addition, data from this test will be used to determine test limits for the out-of-band signal rejection test and intermodulation test (to be performed after the completion of this test).

This test is analogous to a selectivity measurement for conventional narrowband receivers and is primarily intended to characterize the frequency response of the receiver's RF and IF filters. For conventional receiver evaluation, this test is performed using the desired standard response signal, which is tuned to several frequencies both above and below the receiver's tuned frequency. The selectivity response is determined by measuring (at several near-band frequencies) the increase in signal level required to produce the same standard response output that is observed at the receiver's tuned frequency. However, it is expected that this method will not work with DS receivers. The carrier tracking loop of a DS receiver will only maintain lock over a very limited frequency range about the carrier frequency. A tracking range of few hundred kilohertz about the assigned carrier frequency is common, which is typically much less than the RF passband of the receiver. If the desired signal is tuned outside of the tracking range, receiver lock to the PRN coded standard response signal will be lost. As a result, the desired standard response signal cannot be used to characterize the near-band signal rejection of a DS receiver. However, the measurement of interference signal power levels over the near-band frequencies can be used to estimate the signal rejection characteristics of the receiver. The increase in the interference signal power level required to upset the receiver at near-band frequencies relative to the level required for upset at the tuned frequency will provide an indication of the receiver's near-band signal rejection capability.

It is recommended that this test be performed at 20 equally spaced discrete frequencies over the near-band range; ten above the receiver tuned frequency and ten below the tuned frequency. In addition, interference threshold levels should be determined at any likely spurious response frequencies (such as IF frequencies, LO frequencies, image frequencies, master oscillator frequency, clock frequency) and their lower-order harmonics that happen to fall in the near-band range.

7.5.2 Test Set-Up

The test set-up for the near-band signal rejection test is shown in Figure 4. A spread spectrum signal simulator is used to generate the data and PRN code modulated spread spectrum standard response signal (desired signal) used for the test. The interference source will not be modulated for this test (CW signal) A spectrum analyzer is used to monitor and measure the test signal levels at the input to the receiver EUT. Spectrum analyzer levels should be corrected for the pre-amplifier gain (if used), coupler losses, and/or cable losses as required. Interference thresholds are determined by monitoring the receiver's telemetry output and/or measuring the BER of the information data.

7.5.3 Test Procedures

The general test procedure for the near-band signal rejection test is as follows:

(1) Set the spread spectrum signal simulator to the output power level required to produce the tracking mode standard response level at the input to the EUT. The simulator's output frequency should be set to the tuned frequency of the receiver EUT. Verify that the receiver has locked onto the desired signal and that all tracking parameters are within acceptable limits.

(2) Beginning with a CW signal, activate the interference signal source at a power level that is equivalent to the receiver sensitivity level. The interference signal source frequency should be set to the tuned frequency of the receiver EUT.

(3) Verify the "carrier break-lock" level by increasing the interference signal power level until the first indication of loss of receiver carrier tracking is observed. Document this level and reduce the interference signal power level back to the receiver's sensitivity level. Verify that the receiver has reacquired the standard response signal and that all tracking parameters are within acceptable limits.

(4) Increase the frequency of the interference source by an amount equal to one-half the receiver's 3 dB RF bandwidth. The specified 3 dB RF bandwidth should be available from the manufacturer and can be used to set the interference frequency.

(5) Increase the interference signal power level until the first indication of loss of receiver carrier tracking is observed. Document this interference signal power level and frequency at which the carrier break-lock is observed. Reduce the interference signal power level back to the receiver's sensitivity level and verify that the receiver has reacquired the standard response signal. All tracking parameters should be within acceptable limits.

(6) Repeat steps 4 and 5 until data has been collected up to and including a frequency that is approximately five times the upper 3 dB passband frequency of the receiver (10 near-band frequencies total).

(7) Repeat Steps 4 through 6 for a set frequencies below the passband of the receiver. Thus, the first test frequency is at the lower edge of the receiver's 3 dB RF bandwidth and the interference signal frequency is decreased (instead of increased) by increments equal to one-half the 3 dB RF bandwidth of the receiver.

7.5.4 S-Band TDRSS Receiver/ISS EME Tailoring

The 3 dB bandwidth of a TDRSS receiver is nominally 6 MHz. Thus this test should be performed over a 60 MHz bandwidth about the receiver's tuned frequency. For TDRSS MA service the forward link frequency is at 2106 MHz. Therefore, for a MA receiver, this test would be performed in the frequency ranges of 2109 to 2136 MHz and 2076 to 2103 MHz.

7.5.5 Test Output

The required results of this test are to obtain interference threshold levels at 20 discrete frequencies over a bandwidth that is ±5 times the receiver's 3 dB passband. Front-end filter attenuation will approximate the interference margin determined at each frequency. Interference margin is determined by subtracting the standard response level from the interference threshold level. If the interference margins are relatively low (e.g. less than 60 dB) for the uppermost and lowermost test frequencies; a larger bandwidth can be investigated.

7.6 OUT-OF-BAND SIGNAL REJECTION TEST METHOD

7.6.1 Objectives and Rationale

The objective of this test is to determine out-of-band frequencies, if any, at which an interference signal may produce a spurious response in the receiver. Rejection of out-of-band frequencies (or stopband frequencies) is primarily determined by the attenuation response of the receiver's RF and IF filters. Thus, any spurious responses that are identified may be an indication of possible resonances or "holes" in the front-end filtering frequency response. Spurious responses also commonly occur at receiver IF frequencies, LO frequencies, and image frequencies. In addition, due to receiver nonlinear characteristics, out-of-band signals occurring at harmonics of the receiver's LO and tuned RF frequencies can mix to produce spurious responses. Out-of-band interference effects may also be observed at master oscillator and clock frequencies if the interference manages to leak around the receiver front-end via an unsuspected path.

If possible, the interference signal power level for this test should be chosen based on the expected operational EME for the receiver. However, if EME information is unknown, a reasonable level can be selected based on thresholds determined in the interference margin and near-band signal rejection tests. An out-of-band response would not be expected unless the interfering signal power level exceeds the attenuation level provided by the front-end filters plus the interference margin provided by the DS receiver. For example, if at a given frequency the filtering provides 60 dB of attenuation and the interference margin is 40 dB, receiver upset would not be expected unless the interference signal exceeds the standard response signal by at least

100 dB. The interference margins determined in the near-band signal rejection test are a measure of interference suppression due to the combined effects of filter rejection and interference margin immunity (due to processing gain). Thus, for this test, the interference signal power level should be set to the interference threshold level determined for the band edge frequencies of the bandwidth (bandwidth of 10 times the 3 dB RF passband of the receiver) investigated in the near-band signal rejection test. This can be considered the default level for this test. Any spurious responses observed at test frequencies outside this bandwidth is an indication that the filtering response (attenuation level) may be degraded at that particular frequency. If the receiver exhibits no spurious responses at this test level, the test level can be increased (not to exceed the damage threshold of the receiver) to determine the actual interference thresholds. Of course, each additional scan (over the complete frequency range) will increase the test time. However, the measurement of interference thresholds of a few individual frequencies of interest (possibly chosen based on the expected receiver operational EME) should not cause a substantial increase in test time. The decision to test at higher levels should be left to the judgement of the test director.

A reasonable frequency range for this test would be from 1 MHz to 20 times the receiver's tuned frequency, excluding the near-band frequency range (±5 times the receiver's 3 dB passband) that was evaluated in the near-band signal rejection test. This frequency range would include all potential spurious response frequencies for the majority of DS receivers. The interference signal should be swept or stepped through this frequency range using sweep rates/step sizes specified in MIL-STD-462D. Dwell times should be based on upset criteria and definition . This test should be conducted using a CW interference signal only. Upset thresholds for other modulations (pulsed and orthogonal PRN code) can be estimated based on differences in interference thresholds determined in the interference margin test.

The full frequency range stepped or swept measurement is to be performed with the receiver in the tracking mode. However, it is also recommended that this test be performed with the receiver in the A/S mode at a small set of expected worst case frequencies (such as LO, IF, and image frequencies).

7.6.2 Test Set-Up

The test set-up for the out-of-band undesired signal rejection test is shown in Figure 4. A spread spectrum signal simulator is used to generate the data and PRN code modulated spread spectrum standard response signal (desired signal) used for the test. The interference source is not be modulated for this test (CW signal). A spectrum analyzer is used to monitor and measure the test signal levels at the input to the receiver EUT. Spectrum analyzer levels should be corrected for the pre-amplifier gain (if used), coupler loses, and/or cable losses as required. Spurious responses are determined by monitoring the receiver's telemetry output and/or measuring the BER of the information data. For any receiver responses that are observed during this test, it is important to verify that the responses are caused by the interference source tuned frequency and not produced by interference source harmonics or spurious emissions. Interference source spurious emissions can be controlled with appropriate filtering at the output of the interference source and can be monitored with the spectrum analyzer. However, it should

be noted, that implementing appropriate filtering measures for a broadband swept measurement will be difficult.

7.6.3 Test Procedures

The general test procedure for out-of-band signal rejection test is as follows:

(1) Set the spread spectrum signal simulator to the output power level required to produce the tracking mode standard response level at the input to the EUT. The simulator's output frequency should be set to the tuned frequency of the receiver EUT. Verify that the receiver has locked onto the desired signal and that all tracking parameters are within acceptable limits.

(2) Configure the interference signal source to sweep or step in frequency over the upper frequency range (as defined in Section 7.6.1) and set the interference signal source power output to the default level recommended in Section 7.6.1.

(3) Initiate the interference signal scan and monitor the EUT output for any indications of interference. Determine the interference threshold level at frequencies where interference effects are observed.

(4) Configure the interference signal source to sweep or step in frequency over the lower frequency range (as defined in Section 7.6.1) and set the interference signal source power output to the default level recommended in Section 7.6.1.

(5) Initiate the interference signal scan and monitor the EUT output for any indications of interference. Determine the interference threshold level at frequencies, if any, where interference effects are observed.

(6) Initiate testing of A/S mode operation (at discrete frequencies determined by the test director) by appropriately tuning the interference source frequency and increasing the interference signal source power output to a level 10 dB below the receiver damage threshold.

(7) Set the spread spectrum signal simulator to the output power level required to produce the A/S mode standard response level at the input to the EUT. The simulator's output frequency should be set to the tuned frequency of the receiver EUT.

(8) If the receiver locks to the desired signal, it can be concluded that the receiver has no out-of-band interference response at the test frequency. If the receiver does not lock onto the desired signal (and remains in the signal search mode), reduce the interference signal power level until the receiver has locked onto the desired signal and all receiver tracking parameters are within acceptable limits. Remember to pause at each power level by an amount exceeding the maximum specified acquisition time for the EUT. Document this

interference signal power level at which the receiver acquires the standard response signal.

(9) Repeat Steps 1 through 8 for different receiver data rate modes and spread spectrum channels, as deemed appropriate.

7.6.4 S-Band TDRSS Receiver/ISS EME Tailoring

Likely spurious response frequencies such as LO, IF and image frequencies may vary somewhat depending on specific TDRSS receiver designs and manufacturers. If possible, spurious response information should be obtained from the receiver manufacturer prior to testing. For example, during the course of this test guide development program, a performance specification for a specific third generation transponder [7] was obtained and reviewed. This particular TDRSS receiver operates at the MA service frequency of 2106.4 MHz. The performance specification document indicated that it has an IF frequency of 136.5 MHz and an LO frequency of 1969.9 MHz. This corresponds to an image frequency at 1833.4 MHz for this particular receiver. Also, this receiver has a master oscillator frequency of 4 MHz. The code clock for TDRSS operation (and thus all receivers) is nominally 3 MHz. Thus, for this receiver, the above listed frequencies should be monitored carefully during the tracking mode tests and would be likely candidates for the discrete frequency A/S mode testing.

7.6.5 Test Output

The required output from this test is to document any out-of-band spurious responses that are observed during the course of the test.

7.7 OUT-OF-BAND INTERMODULATION TEST METHOD

7.7.1 Objective and Rationale

The objective of the out-of-band intermodulation (IM) test is to determine possible receiver IM product responses that result from the mixing of two out-of-band undesired signals in the non-linear elements in the front-end of the receiver. This unintentional mixing of two undesired signals has the potential to generate a third signal at the receiver tuned frequency. Pairs of potential interfering frequencies that can produce IM products at the receiver tuned frequency are determined using the following relationship:

$$f_o = \left| mf_a \pm mf_b \right| \qquad (4)$$

where,

f_o = the tuned frequency of the receiver;
f_a = the frequency of the interfering source nearest to the tuned frequency;
f_b = the frequency of the second interfering source; and
m, n = positive integers whose sum specify the order of the IM product.

As can be seen from Equation 4, an infinite number of combinations of frequency pairs and IM product orders can be selected to produce an IM product near the desired tuned frequency. However, in practice, second and third order IM products generated by frequencies relatively close to the tuned frequency are by far the most likely to cause receiver upset.

It would be best to choose interfering frequencies and power levels for this test based on the expected receiver operational EME. However, if the EME is unknown, it is recommended that this test be performed for at least four pairs of potential interfering frequencies. These four pairs would consist of two frequency pairs below the tuned frequency and two frequency pairs above the tuned frequency. The frequencies should be chosen to generate both second and third order IM products. The relationships of these interfering pairs can be expressed as follows:

(1) $f_o = |f_a - f_b|$, second order product, f_a and f_b above f_o, $f_b = f_a + f_o$.
(2) $f_o = f_a + f_b$, second order product, f_a and f_b below f_o, $f_b = f_o - f_a$.
(3) $f_o = 2f_a - f_b$, third order product, f_a and f_b above f_o, $f_b = f_o + 2(f_a - f_o)$.
(4) $f_o = 2f_a - f_b$, third order product, f_a and f_b below f_o, $f_b = f_o - 2(f_a - f_o)$.

A reasonable choice for f_a would be frequencies offset from the tuned frequency by ± 5 times the receiver 3 dB bandwidth (the edge frequencies of the bandwidth investigated in the near-band test).

Again, a reasonable test level (given that a level can't determined based on receiver EME data) would be the same level as used in the out-of-band signal rejection test that was described previously. This test level is equivalent to the interference threshold level determined for the band edge frequencies of the "10 times the receiver 3 dB passband" that was investigated in the near-band signal rejection test. As before, the test level can be increased if no intermodulation responses are observed at this "default" test level. It is recommended that this test be performed for both the tracking and A/S mode. This test should be conducted using a CW signal for both interference signals.

7.7.2 Test Set-Up

The test set-up for the out-of-band intermodulation test is shown in Figure 5. A spread spectrum signal simulator is used to generate the data and PRN code modulated spread spectrum standard response signal (desired signal) used for the test. Two separate interference sources will be used to generate the intermodulation test signals. The interference sources will not be modulated for this test (CW signal). A spectrum analyzer is used to monitor and measure the test signal levels at the input to the receiver EUT. Spectrum analyzer levels should be corrected for coupler losses, and/or cable losses as required. Intermodulation responses are determined by monitoring the receiver's telemetry output and/or measuring the BER of the information data. Care should be taken to prevent unwanted interference signal source outputs (harmonics or spurious emissions) from creating undesired receiver responses or IM products. Interference source spurious emissions can be controlled with appropriate filtering at the output of the interference source. Also, if responses are observed, it should be verified that the response is due to the IM product and not to one or both of the individual test signals. This can be verified by

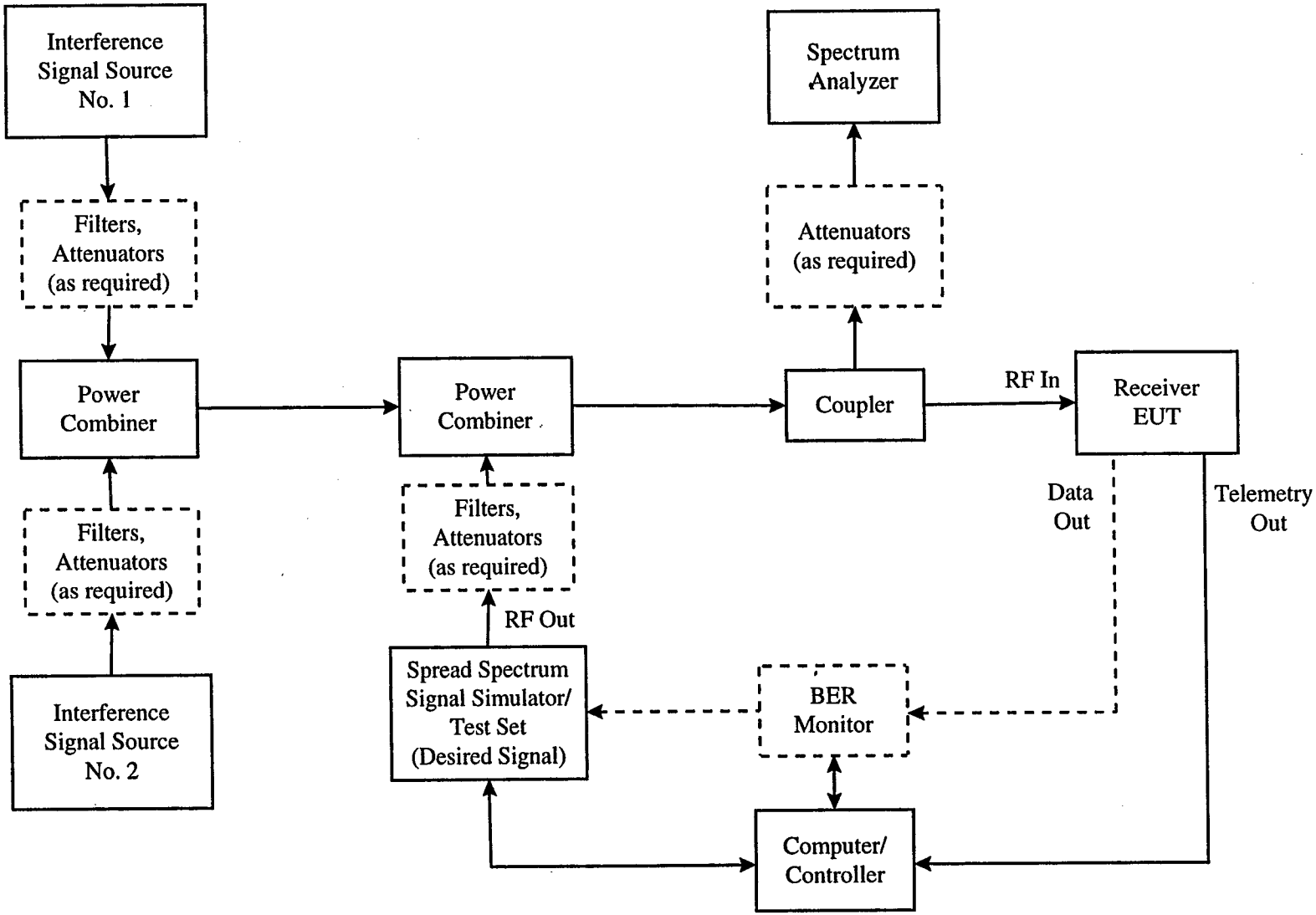

Figure 5. Out-of-Band Intermodulation Test Set-Up.

turning the test signals off in sequence. If the response goes away when each signal is turned off, the response is assumed to be due to the IM product.

7.7.3 Test Procedures

The general test procedure for out-of-band intermodulation test is as follows:

(1) Set the spread spectrum signal simulator to the output power level required to produce the tracking mode standard response level at the input to the EUT. The simulator's output frequency should be set to the tuned frequency of the receiver EUT. Verify that the receiver has locked onto the desired signal and that all tracking parameters are within acceptable limits.

(2) Tune the two interference signal sources to the frequencies required for the first of the second order IM tests (as defined in Section 7.7.1) and set the interference signal source power output to the default level recommended in Section 7.7.1.

(3) Monitor the EUT output for any indications of interference and determine the interference threshold levels at frequencies where interference effects are observed (keeping the amplitude of the interference sources equal.

(4) Repeat Steps 1 through 3 for the remaining second-order IM test and the two third-order tests as specified in Section 7.7.1.

(5) Initiate testing of A/S mode operation by tuning the two interference signal sources to the frequencies required for the first second-order IM test and increasing the power levels of the interference signal sources to a level 10 dB below the receiver damage threshold.

(6) Set the spread spectrum signal simulator to the output power level required to produce the A/S mode standard response level at the input to the EUT. The simulator's output frequency should be set to the tuned frequency of the receiver EUT.

(7) If the receiver locks to the desired signal, it can be concluded that the receiver has no out-of-band interference response at the test frequencies. If the receiver does not lock onto the desired signal (and remains in the signal search mode), reduce the interference signal power level until the receiver has locked onto the desired signal and all receiver tracking parameters are within acceptable limits. Remember to pause at each power level by an amount exceeding the maximum specified acquisition time for the EUT. Document this interference signal power level, at which the receiver is no longer jammed as the interference threshold for A/S mode operation.

(8) Repeat Steps 5 through 7 for the remaining second order IM test and the two third order tests as specified in Section 7.7.1.

(9) Repeat Steps 1 through 8 for different receiver data rate modes and spread spectrum channels, as deemed appropriate.

7.7.4 S-Band TDRSS Receiver/ISS EME Tailoring

It is anticipated that there will be several S-band TDRSS transmitters or transponders co-located on the ISS. It is recommended that pairs of these frequencies be used for the IM product tests, if any combination of two of these frequencies happen to fall in the passband of the EUT.

7.7.5 Test Output

The required output of this test is to document any out-of-band intermodulation product responses that are observed during the course of the test.

8. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

This EMI test guide recommends an overall approach for evaluating DS spread spectrum receivers which consists of performing antenna port susceptibility tests (as specified in this guide) in addition to testing the receivers to existing applicable standards. It is recommended that receivers which are not subject to specific NASA program EMI requirements meet the test requirements of MIL-STD-461D for space systems. However, the set of antenna port tests defined in this document should replace the three MIL-STD-462D antenna port conducted susceptibility tests (CS103, CS104, and CS105). MIL-STD-462D should be referenced for guidance pertaining to the non-antenna port test methods. TDRSS receivers (or the receiving systems of TDRSS transponders) procured for ISS use, should meet the test requirements of SSP 30237 and, in addition, should also be evaluated for antenna port susceptibilities using the tests and test methods specified in this document. Test methods used for the SSP 30327 tests should be based on the techniques and procedures contained in SSP 30328.

The recommended antenna port tests developed in this document consist of the following:

(1) Receiver Sensitivity Test
(2) In-Band Interference Margin Test
(3) Cross-Correlation Test
(4) Near-Band Signal Rejection Test
(5) Out-of-Band Signal Rejection Test
(6) Out-of-Band Intermodulation Test

The objective of these tests and corresponding test methods is to generate data that are useful for EMC analyses, spectrum management, and the development of improved EMI "hardened" equipment designs. It should be noted that the determination of maximum allowable susceptibility test levels (to indicate universal acceptable receiver performance) for these tests is difficult. What is believed to be "reasonable" test level limits were specified for the out-of-band tests. They are based on the results of the near-band signal rejection test. Test level limits for the in-band interference margin, cross-correlation, and near-band signal rejection tests were not

specified in this document. Rather, the objective of these tests is to determine interfering threshold information. Ideally, all receiver performance specifications, and thus test limits, should be based on the expected operational EME for receiver EUTs. However, this is rarely achieved in practice and it is thus beneficial to define test level limits that indicate a reasonable level of EMI performance for DS receivers. Reasonable test level limits should be defined based on past DS receiver test experience. However, at this point in time there appears to be little, if any, documentation of actual DS test data in the open literature. Thus, one of the primary objectives for future studies is to compile representative EMI test data for various DS receiver designs.

The following four areas are recommended for future study:

(1) The test methods developed under this program were based on analytical assessments of DS receiver EMI/EMC characteristics and on information available in the open literature. No receiver hardware was investigated in the laboratory. Thus, it would be beneficial to verify these test methods with a DS receiver EMI measurement program. Specifically, a S-band TDRSS EMI measurement program is recommended.

(2) Presently, measured EMI data for DS receivers are not well documented in the open literature. It would be beneficial to develop a database that contains EMI data for DS receiver systems and designs that are of interest to NASA. It is envisioned that this database would consist of manufacturer test data, as well as, independently compiled test data.

(3) As was mentioned in this test guide, receiver antenna EMI test data must also be available to perform EMC analyses and assessments. It particular, out-of-band antenna performance data is required for accurate and complete analyses. This type of test data is rarely available from the antenna manufacturer. Thus, it is recommended that receiver antenna EMI test guidelines be developed for this purpose.

(4) Due to the limited scope of this test guide development program, only test methods for DS spread spectrum receivers were investigated. However, frequency hopping (FH) receivers constitute another significant area of spread spectrum receiver design. Therefore, it is recommended that EMI test methods and techniques also be investigated for FH receivers.

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13. ABSTRACT *(Maximum 200 words)*

The objective of this test guide is to document appropriate unit level test methods and techniques for the performance of EMI testing of Direct Sequence (DS) spread spectrum receivers. Consideration of EMI test methods tailored for spread spectrum receivers utilizing frequency spreading techniques other than direct sequence (such as frequency hopping, frequencing chirping, and various hybrid methods) is beyond the scope of this test guide development program and is not addressed as part of this document. EMI test requirements for NASA programs are primarily developed based on the requirements contained in MIL-STD-461D (or earlier revisions of MIL-STD-461). The corresponding test method guidelines for the MIL-STD-461D tests are provided in MIL-STD-462D. These test methods are well documented with the exception of the receiver antenna port susceptibility tests (intermodulation, cross modulation, and rejection of undesired signals) which must be tailored to the specific type of receiver that is being tested. Thus, test methods addressed in this guide consist only of antenna port tests designed to evaluate receiver susceptibility characteristics. MIL-STD-462D should be referred for guidance pertaining to test methods for EMI tests other than the antenna port tests.

The scope of this test guide includes: (1) a discussion of generic DS receiver performance characteristics; (2) a summary of S-band TDRSS receiver operation; (3) a discussion of DS receiver EMI susceptibility mechanisms and characteristics; (4) a summary of military standard test guidelines; (5) recommended test approach and methods; and (6) general conclusions and recommendations for future studies in the area of spread spectrum receiver testing

14. SUBJECT TERMS
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