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Range
Commanders
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TELEMETRY GROUP

TELEMETRY SYSTEMS RADIO FREQUENCY HANDBOOK

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DUGWAY PROVING GROUND
ELECTRONIC PROVING GROUND
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REDSTONE TEST CENTER
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YUMA PROVING GROUND

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TELEMETRY SYSTEMS RADIO FREQUENCY HANDBOOK

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Prepared by

TELEMETRY GROUP
RF SYSTEMS COMMITTEE

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Preface

This document was prepared by the Range Commanders Council (RCC) Telemetry Group's (TG) Radio Frequency (RF) Systems Committee. The Committee's objective is to use this handbook as a tool for engineers and technicians working in the telemetry (TM) RF systems field.

This document is a "work in progress" and continues to be updated and improved over time. Therefore, the reader is encouraged to provide suggestions to identify additional areas of interest, areas needing more detail, and suggestions on content and presentation. Please forward your suggestions or material you feel may be helpful in updating this document using the contact information below.

The RCC gives special acknowledgement for this document's production to the RF Systems Committee. Please direct any questions to the RCC Secretariat as shown below.

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Acronyms and Initialisms

ac	alternating current
AFAS	antenna feed assembly subsystem
AFB	Air Force Base
AGC	automatic gain control
AM	amplitude modulation/amplitude modulated
AMT	Aeronautical Mobile Telemetry
ARDT	antenna radiation distribution table
ARTM	Advanced Range Telemetry
Az	azimuth
BER	bit error rate
BPSK	binary phase-shift keying
BW	bandwidth
coax	coaxial
CPM	continuous phase modulation
CSF	conical scan feed
CSFAU	conical scan feed assembly unit
CSMAC	Commerce Spectrum Management Advisory Committee
dc	direct current
DOC	Department of Commerce
DoD	Department of Defense
E-field	electric field
El	elevation
EL-CID	Equipment Location –Certification Information Database
EM	electromagnetic
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ERP	effective radiated power
ESFAU	electronically scanned feed assembly unit
ESG	Equipment Spectrum Guidance
FAU	feed assembly unit
FCC	Federal Communication Commission
FM	frequency modulation
GMF	Government Master File
GPS	Global Positioning System
IAM	incidental amplitude modulation
IF	intermediate frequency
IFM	incidental frequency modulation
IM	intermodulation
IP	intermodulation product
IP3	third-order intercept point
IRAC	Interdepartmental Radio Advisory Committee
IRIG	Inter-Range Instrumentation Group
LDPC	low-density parity check
LHCP	left-hand circular polarized

LNA	low-noise amplifier
LOS	line of sight
MC4EB	Military Command, Control, Communications, and Computers Executive Board
MRTFB	Major Range and Test Facility Base
NAS	Naval Air Station
NAVSTAR	Navigation Satellite Timing and Ranging
NRZ-L	nonreturn-to-zero-level
NRZ-M	nonreturn-to-zero-mark
NRZ-S	nonreturn-to-zero-space
NTH	Note-To-Holder
NTIA	National Telecommunications and Information Administration
OBW	occupied bandwidth
OQPSK	offset quadrature phase-shift keying
OSM	Office of Spectrum Management
OTA	over-the-air
PCM	pulse code modulation
PM	phase modulation
pre-d	predetection
post-d	postdetection
PVC	polyvinyl chloride
PWG	Permanent Working Group
QPSK	quadrature phase-shift keying
RBW	resolution bandwidth
RCC	Range Commanders Council
RF	radio frequency
RHCP	right-hand-circular-polarized
S/N	signal-to-noise
SCM	single channel monopulse
SFDR	spurious free dynamic range
SMA	SubMiniature-version A (RF connector-type)
SMO	Spectrum Management Office
SNR	signal-to-noise ratio
SOQPSK	shaped offset quadrature phase shift keying
SOQPSK-TG	shaped offset quadrature phase shift keying – Telemetry Group (Waveform variant of SOQPSK; adopted by the Range Commanders Council Telemetry Group [TG] in 2004)
SPS	Spectrum Planning Subcommittee
STC	Space-Time Coding
TED	tracking-error demodulator
TG	Telemetry Group
TNC	Threaded Neill-Concelman (RF connector type)
TTL	transistor-transistor logic
TM	telemetry
TV	television
US&P	United States and Possessions

VBW	video bandwidth
Vdc	volt direct current
VSWR	voltage standing wave ratio

UNITS

cm	centimeters
cps	cycles per second
dB	decibel
dBc	decibels referenced to the carrier (unmodulated)
dBi	decibels - isotropic
dBm	decibels – milliwatts
f/D	focal length/aperture dimension
G/T	gain/temperature; “figure of merit”
GHz	gigahertz
Hz	hertz
K	Kelvin
kbps	kilobits per second
kHz	kilohertz
m	meter
Mbps	megabits per second
MHz	megahertz
ms	millisecond
ns	nanosecond
ppm	parts per million
rms	root mean square

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CHAPTER 1

Overview and Radio Frequency Basics

1.1 Overview

The Radio Frequency (RF) Systems Committee within the Range Commanders Council (RCC) Telemetry Group (TG) has prepared this document to assist in the development of improved RF telemetry (TM) transmitting and receiving systems in use on RCC member ranges. The TG expects that improved system design, operation, and maintenance will result from a better understanding of the factors that affect RF systems' performance and, consequently, overall system effectiveness. Additional information can be found in RCC Document 119-06, *Telemetry Applications Handbook*.[1]

This document is not intended to be a tutorial or textbook on the theory of RF systems design. It is intended to be a living document used to convey ideas, suggestions, lessons learned, and other items of importance to the new TM systems engineer or technician working in the field of RF TM. This document is arranged into sections according to the basic RF TM system model shown in Figure 1-1.

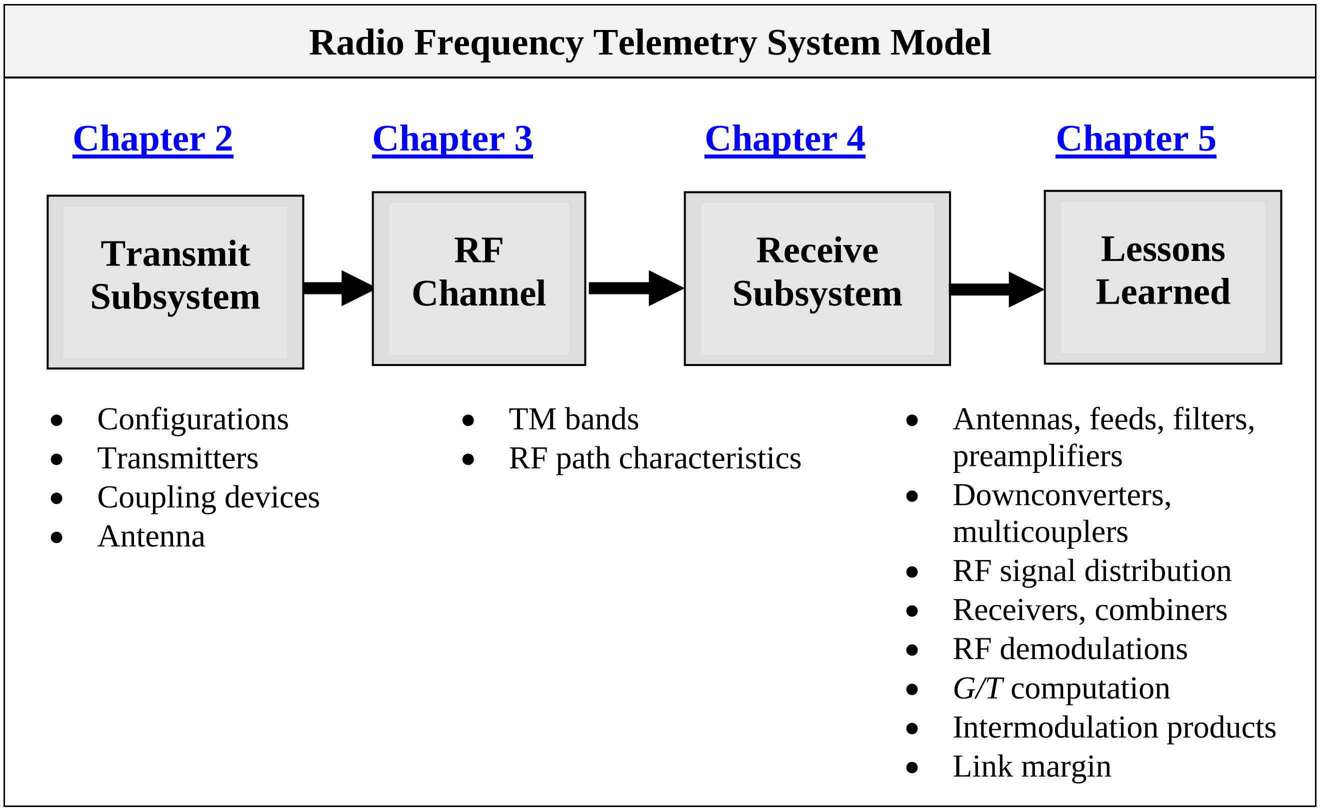

Figure 1-1. RF TM System Model

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[1] Range Commanders Council. *Telemetry Applications Handbook*. RCC 119-06. May 2006. May be superseded by update. Retrieved 6 January 2021. Available at https://www.trmc.osd.mil/wiki/x/h4u8Bg.

1.2 RF Basics

The RFs are electromagnetic (EM) waves that are propagated through space and are the basis for many different communication systems. Because of their varying characteristics, radio waves of different frequencies are used not only in radio broadcasting but also in wireless devices, telephone transmission, television (TV), radar, navigational systems, and other communication types such as TM systems.

Radio waves are usually identified by their frequency. The shortest waves have the highest frequency, or numbers of cycles per second (cps); while the longest waves have the lowest frequency, or fewest cps. In honor of German radio pioneer Heinrich Hertz, his name is used to refer to the cps (hertz, [Hz]); 1 kilohertz (kHz) = 1000 cps, 1 megahertz (MHz) = 1 million cps, and 1 gigahertz (GHz) = 1 billion cps. The EM energy useful for communication purposes ranges is roughly between 10 kHz and 100 GHz. In vacuum, all EM waves travel at a uniform speed of about 300,000 kilometers per second (about 186,000 miles per second).

Because EM waves in a uniform atmosphere travel in straight lines, and because the earth's surface is spherical, long-distance radio communication is made possible by the reflection of radio waves from the ionosphere. Radio waves shorter than about 10 meters (m) (about 33 feet) in wavelength (designated as very high, ultrahigh, and super-high frequencies) are usually not reflected by the ionosphere; thus in normal practice, such very short waves are received only within line-of-sight (LOS) distances. Wavelengths shorter than a few centimeters (cm) are absorbed by water droplets or clouds; those shorter than 1.5 cm (0.6 inches) may be absorbed selectively by the water vapor present in a clear atmosphere. In the atmosphere, the air's physical characteristics cause slight variations in velocity, which are sources of error in radio-communication systems such as radar. Also, storms or electrical disturbances produce anomalous phenomena in the propagation of radio waves.

A typical radio communication system has two main components; a transmitter and a receiver. The transmitter generates electrical oscillations at an RF called the carrier frequency. The amplitude, the frequency, or the carrier's phase may be modulated with the information to be transmitted. An amplitude-modulated (AM) signal consists of the carrier frequency plus two sidebands resulting from modulation. Frequency modulation (FM) and phase modulation (PM) produce pairs of sidebands for each modulation frequency. These sidebands produce the complex variations that emerge as speech or other sounds in radio broadcasting, alterations of light and darkness in TV broadcasting, and TM data in TM systems.

CHAPTER 2

Transmit Subsystem

2.1 Overview

This section addresses the RF transmit subsystem and its associated components. It is intended to provide information and general guidelines for the proper design setup of airborne RF TM transmit systems. The TM transmitters, antenna systems, coupling devices, cabling, and related issues are discussed.

2.2 System Configurations

The TM transmit systems can be simple or very complex depending on the needs of the engineers and analysts who use the data. Figure 2-1, Figure 2-2, Figure 2-3, Figure 2-4, Figure 2-5, and Figure 2-6 depict various configurations of airborne RF TM systems currently used on Department of Defense (DoD) test ranges. A short discussion of these configurations is provided to help identify areas of concern that an RF TM systems engineer must be aware of when making design decisions. System configurations will ultimately be determined by any number of factors, including the number of independent TM data streams to be transmitted, the test vehicle's flight characteristics, the space available for mounting transmitters and antennas, and the location of the ground station receiving the data.

2.2.1 Single Transmitter - Single Antenna

This configuration type (see Figure 2-1) represents the simplest form of an RF TM transmit system. In this configuration, a single TM transmitter, operating on a specific assigned carrier frequency, is connected to a single TM antenna using some form of transmission line.

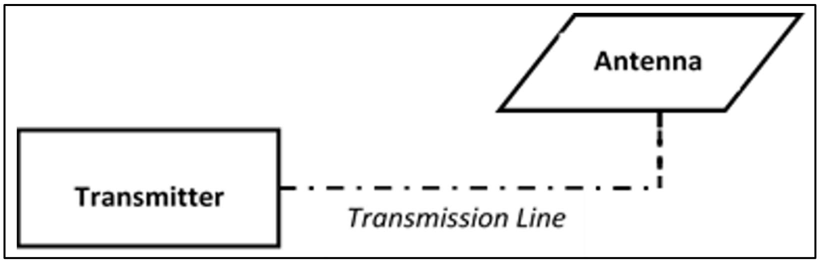

Figure 2-1. Configuration 1: Single Transmitter - Single Antenna

To ensure that transmit-power losses are minimized, careful consideration should be given to the selection of high-quality coaxial (coax) cables and connectors, as well as the transmitter location with respect to the antenna. Every decibel (dB) of transmit-power loss directly affects the received data's quality. The antenna's location is important since proximity to other systems may result in interference from or to other communication systems on board the test vehicle. For example, Global Positioning System (GPS) receiver interference from L-band (1435 - 1525 MHz) transmitters is highly possible since its operating frequency is close to that of the TM system. The TM antennas should be located as far as possible from other antennas, especially those used for receiving signals on frequencies near the TM bands. Antennas used only for transmitting are not as critical.

2.2.2 Multiple Transmitters - Independent Antennas

When the need exists to transmit multiple TM data streams, a configuration of this type may be used (see Figure 2-2). Each transmitter requires an additional TM frequency assignment. This configuration utilizes separate antennas.

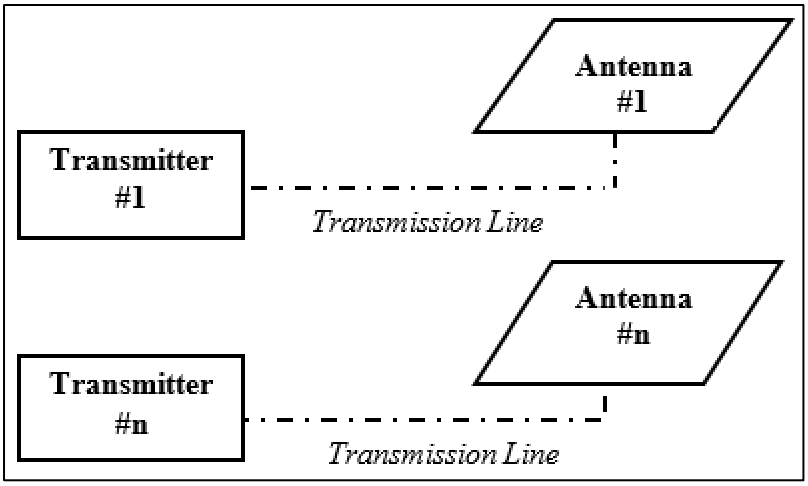

Figure 2-2. Configuration 2: Multiple Transmitters – Independent Antennas

2.2.3 Single Transmitter - Multiple Antennas

This configuration (see Figure 2-3) is commonly found on aircraft when a single TM data stream is required. Aircraft antennas tend towards directionality, and aircraft surfaces are more likely to cause some signal blockage during maneuvers. Typically, one antenna is mounted on the top of the aircraft, and one is mounted on the bottom. The power split between antennas is usually 10 to 20% top and 80 to 90% bottom to reflect the fact that ground-based TM receiving stations are generally looking at the aircraft's bottom. The top antenna comes into play when the aircraft is rolling or banking, causing the bottom antenna to be blocked by the fuselage or the aircraft's wings.

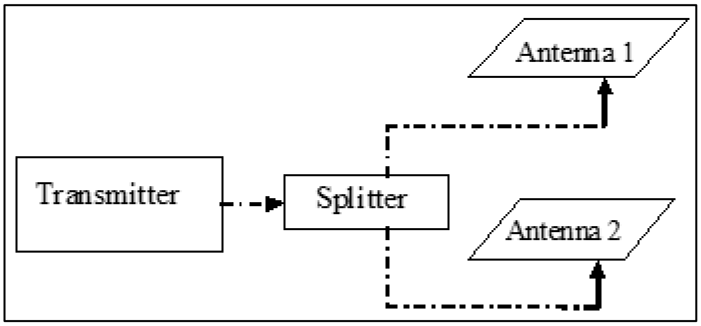

Figure 2-3. Configuration 3: Single Transmitter - Multiple Antennas

Ground stations can "see" both antennas at the same time. For this reason, 50/50 splits should be avoided to lessen the likelihood of having signal cancellation caused by both signals combining 180° out of phase at the ground station. To ensure that the correct power split is achieved, the designer should measure the actual power at the antenna inputs to account for varying amounts of cable loss to the antennas. Adjustment in cable lengths may be necessary to ensure that the correct power split is achieved; however, the difference in cable lengths should be kept to a small fraction of the bit period as possible to maintain the proper phasing of the transmitted signal. Other test vehicles, such as missiles, may require only one antenna, since it can be made to wrap around the missile’s body, providing coverage at most angles.

2.2.4 Multiple Transmitters - Single Antenna

A configuration that is more efficient in terms of using fewer antennas may be one in which an RF combiner allows multiple transmitters to drive one antenna. This configuration (see Figure 2-4) is applicable when more than one transmitter is required and only one TM antenna is required (or allowed). Problems that could result from this configuration are the possible generation of mixing products and/or the transmission of spurious signals. If the transmitters mix with each other (due to RF from one transmitter getting into the other transmitter’s output amplifier stage) spurious transmissions will occur. This may be avoided by the addition of isolators between the transmitters and the combiner outputs. There is a 3 dB loss through the combiner for each transmitter signal, and the combiner needs to be able to dissipate the heat associated with this loss. An RF diplexer may be used (instead of the combiner) to combine multiple signals without this 3 dB loss if the transmitter frequencies are known and fixed, and have sufficient frequency separation to allow for the proper filtering.

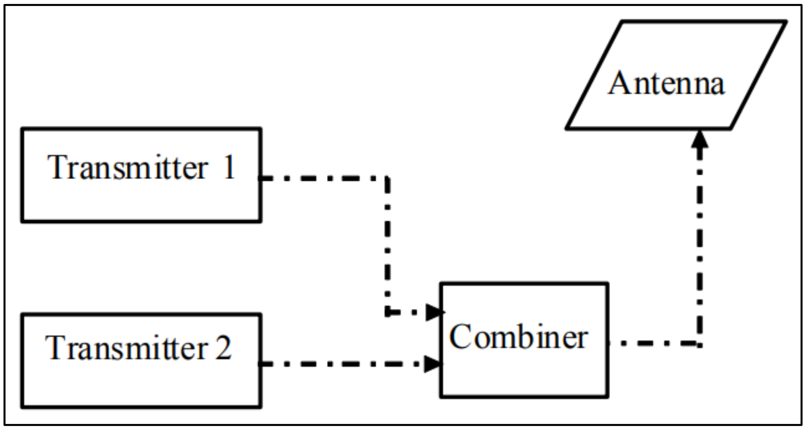

Figure 2-4. Configuration 4: Multiple Transmitters - Single Antenna

2.2.5 Multiple Transmitters - Multiple Antennas

This configuration (see Figure 2-5) is commonly used on ranges today. Some test vehicles have two to three TM transmitters on them and generally one to two antennas. This is a hybrid of the other systems previously described and the same precautions apply. If only two transmitters are required, the combiner and splitter may be replaced by a single four-port ring hybrid or a 90° hybrid.

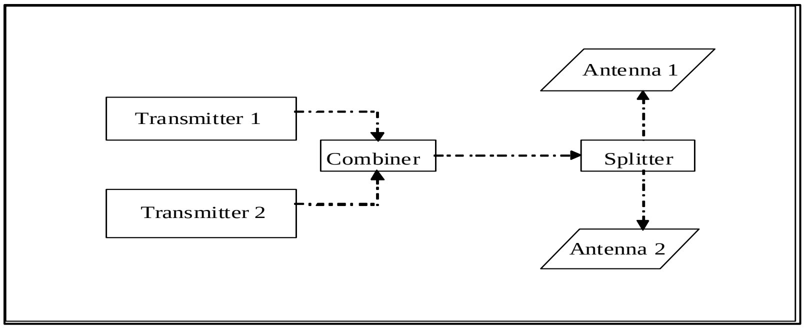

Figure 2-5. Configuration 5: Multiple Transmitters – Multiple Antennas

2.2.6 Complex TM Transmit Systems

This configuration (see Figure 2-6) illustrates how TM transmit systems can become quite complex to suit the needs of some test programs. It is a composite of the other systems with the addition of several other special-purpose components. In this illustration, directional couplers are used to tap off a low-level signal that could be used to monitor transmitter performance on a spectrum analyzer during ground tests. Combiners and splitters are used to send the outputs of multiple transmitters to upper and lower antennas, while another transmitter is connected to upper and lower antennas of its own. This can be utilized for one or more authorized frequency bands. Coax switches are used to send transmitter outputs to dummy loads for testing purposes. Figure 2-6 shows one illustration of many possibilities for complex configurations.

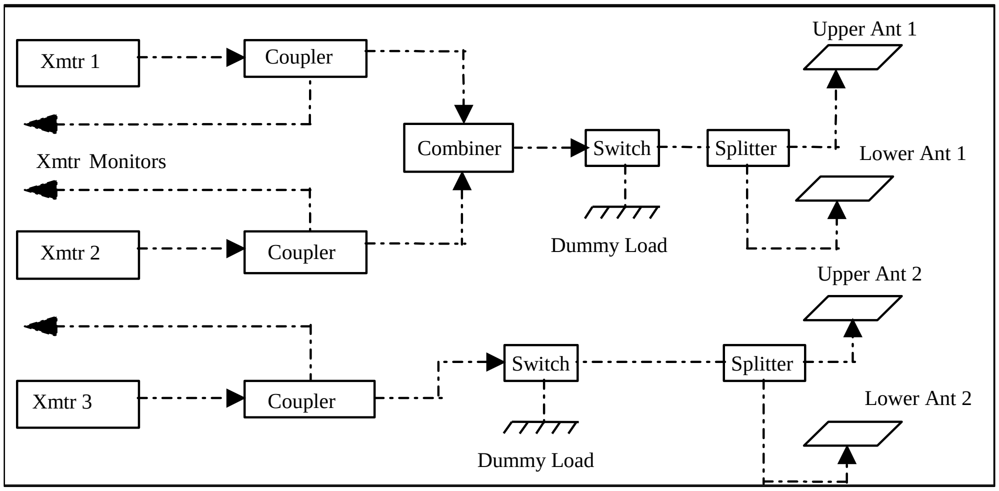

Figure 2-6. Configuration 6: complex TM transmit system

2.3 TM Transmitters

2.3.1 Introduction

Transmitters are used in TM systems for a variety of applications. They are utilized in stationary and mobile vehicle applications (including missiles and satellites) to relay data via digital or analog methods to a ground station, airborne station, or relay site. Data can include discrete or analog performance data, time-space-position-information, video, radar, GPS, onboard computer data, etc.

The TM transmitters are generally frequency-modulated. The transmitters generate a signal whose power output does not change with or without modulation. In some instances, phase-modulated transmitters are used, but this is less common. However, future high-bit-rate systems should make use of the higher bandwidth (BW)-efficient modulation techniques, such as shaped offset quadrature phase shift keying-Telemetry Group (SOQPSK-TG) and Advanced Range Telemetry continuous phase modulation (ARTM CPM).

This chapter is intended to provide an overview of transmitter characteristics important to consider when selecting or utilizing transmitters for TM applications in accordance with the most recent Inter-Range Instrumentation Group (IRIG)-Standard 106.[2] It is not a guide for TM transmitter design.

2.3.2 Transmitter Types

The TM transmitters are available in various types designed for specific applications. Transmitters designed for range applications have typically been FM transmitters with analog or digital modulation inputs. However, PM transmitters are also in use.

a. FM Transmitters. An FM transmitter modulates data onto a continuous carrier. The data is conveyed in the carrier frequency's deviation from nominal.

    (1) Digital FM. Digital FM TM transmission is illustrated in some textbooks as a system in which two oscillators, one operating at the lower deviation limit and the other at the upper limit, are switched by the input. Such an arrangement would lead to a phase discontinuity at the switching points. Rather, a digital modulator controls the frequency of a single local oscillator with a rapidly rising or falling square wave, making a frequency change without a phase discontinuity. The implication is that, even with an instantaneous switching between the two frequencies, the resulting signal's BW, however measured, is lower than that which would result from the two-oscillator situation.

    (2) Pulse Code Modulation (PCM) Systems. In binary PCM systems, the choice for a transmitted symbol is either a ONE or a ZERO; therefore, a direct current (dc) term exists if the average number of ONES and ZEROS is not identical. A nonreturn-to-zero-level (NRZ-L) transmission with a balance of the two symbols would still need a low-frequency response far lower than the bit rate to accommodate the longest run of ONES or ZEROS that might be encountered in the data. This also places a limit on how low the bit rate can be with respect to the low-frequency corner of an alternating current (ac)-coupled system. Different binary modulation types have various effects on transmitting spectra and, consequently, on transmitter and receiver system requirements.

b. PM Systems. A PM transmitter modulates its data onto a continuous carrier. The data is conveyed in the carrier phase's deviation from an initial reference phase. A PM transmitter can be smaller and less complex than an FM transmitter because the modulator has no direct connection to the oscillator. A phase modulator may well be a component of what might be called an FM system, but the modulation effect is to change only the carrier's phase, not the frequency.

    The signal's instantaneous frequency whose phase is being advanced or retarded in proportion to the modulating voltage is different from the frequency without modulation. A dc-voltage level fed into an FM modulator causes the output frequency to be different from the no-modulation condition. Any dc level applied to a phase-modulated transmitter produces only the carrier frequency itself. In this sense, FM and PM transmitters are similar, since a received signal consisting of a single sinusoid modulating a transmitter could appear the same coming from a PM or an FM transmitter. Generally, an FM transmitter fed a differentiated version of an input signal fed directly to a PM transmitter

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[2] Range Commanders Council. *Telemetry Standards*. RCC 106-20. July 2020. May be superseded by update. Retrieved 6 January 2021. Available at https://www.trmc.osd.mil/wiki/x/9AAGCg.

could produce identical output signals, and a PM transmitter fed an integrated version of the signal fed to an FM transmitter could also produce the same output signals.

(1) Binary Phase-Shift Keying (BPSK) Systems. A BPSK transmitter (Figure 2-7) is one in which the modulating data produces a phase shift of the carrier at two pre-defined states (0° and 180°). The BPSK also has a phase ambiguity problem so non-return-to-zero-mark (NRZ-M) or non-return-to-zero-space (NRZ-S) is sometimes used to solve this problem. Polarity ambiguity is caused by suppression of the transmitted carrier so the ground-station receiver must regenerate a reference carrier for demodulation. The generated reference carrier is obtained by squaring the entire signal in the receiver intermediate frequency (IF) BW resulting in the demodulator reference either at 0° or 180° with respect to the original carrier. The reference phase determines the receiver PCM stream output's polarity. Since NRZ-M or NRZ-S codes rely only on a bit change, and not the level, the polarity causes no ambiguity.

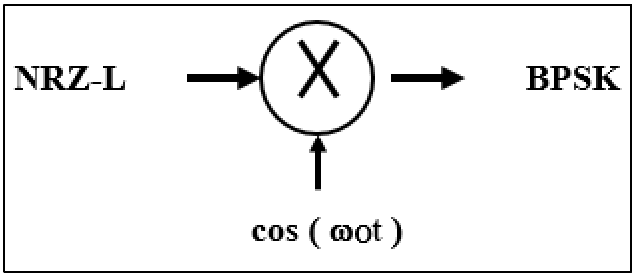

Figure 2-7. BPSK Block Diagram

(2) Quadrature Phase-Shift Keying (QPSK) Systems. A QPSK transmitter is one in which the modulating data produces a phase shift of the carrier at four predefined states, for example, 0°, 90°, 180°, and 270°. The transmission system (Figure 2-8) uses every other bit to modulate cosine and sine wave functions, and these are summed to produce the QPSK output. Phase ambiguity develops since the receiving system can only know the relative phase of the carrier and not the true phase. Coherent detection is often used with QPSK systems because the detection efficiency is typically better than non-coherent detection. In any event, the ambiguity problem must be solved by using methods such as differential encoding/ decoding.

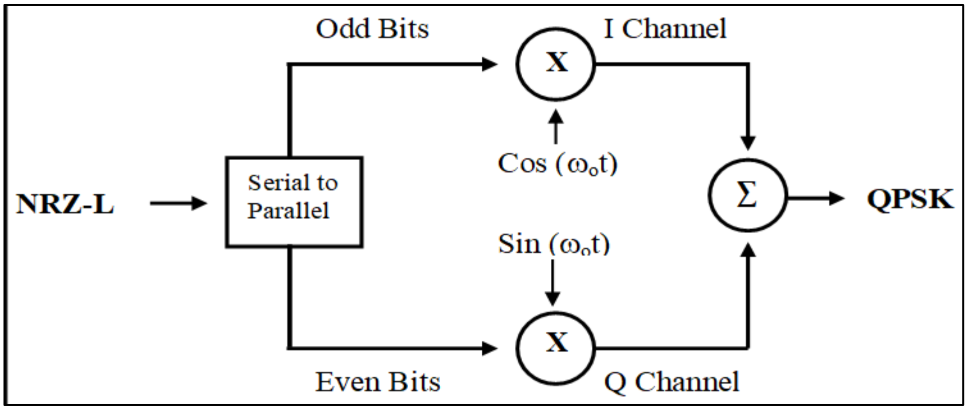

Figure 2-8. QPSK Block Diagram

A special QPSK case is asymmetric QPSK, where differing data at differing rates are sent on I and Q channels. To detect this case, four PCM bit synchronizers with four frame synchronizers must be used to determine correct I and Q signals, as well as polarity for real-time processing. During playback, a computer can detect the packet identification or frame synchronization pattern to find the desired data, but this requires lengthy computer processing times compared to the simple QPSK technique.

(3) Offset Quadrature Phase-Shift Keying (OQPSK) Systems. The OQPSK transmission system, also known as staggered QPSK, is similar to QPSK except that the even (or odd) bits are delayed so they don’t transition at the same time (see Figure 2-9). The result is that the cosine and sine waveforms don’t change amplitude simultaneously and, consequently, BW requirements due to spectral regrowth in nonlinear amplifiers is minimized.

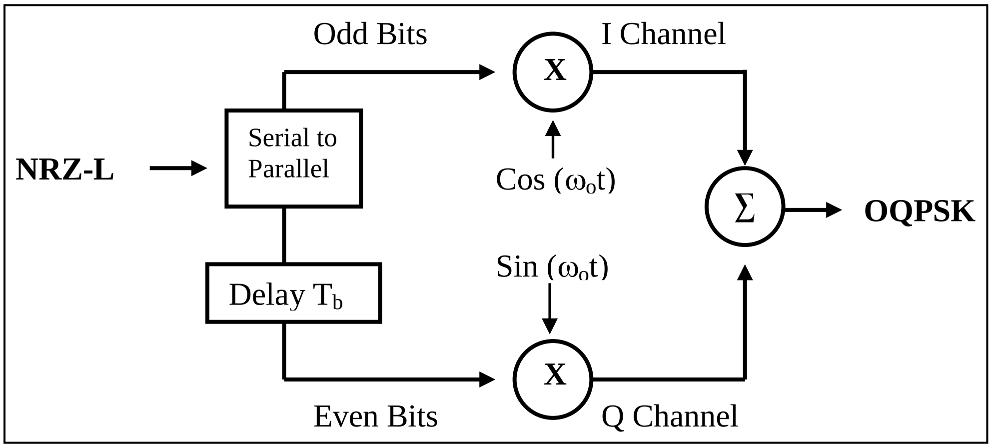

Figure 2-9. OQPSK Block Diagram

The OQPSK permits the receiver to identify I and Q signals (the Q clock is always delayed behind the I clock) so the demodulator can correct I and Q swapping caused by the 0° and 180° ambiguity of the regenerated reference carrier. The receiver must generate a reference carrier for demodulation because the carrier was totally suppressed at the transmitter (same reason as the polarity ambiguity problem for BPSK). Differential encoding is also required on both the I and Q signals to resolve the polarity ambiguity problem. Differential encoding does not resolve the I/Q swapping problem.

(4) SOQPSK System. The SOQPSK is a generic term for an infinite family of waveforms that shape (filter) the frequency pulse that precedes a frequency modulator. The filter for filtering the frequency pulse can assume an infinite number of shapes, thus a definition is required to insure interoperability.

The SOQPSK-TG is the preferred method of SOQPSK for BW and detection efficiency. The exact definition can be found in IRIG-Standard 106 Chapter 2, Subsection 2.3.3.

(5) CPM System. The CPM is a generic classification of waveforms where the signal envelope is constant and the phase varies in a continuous manner.

The ARTM CPM is a specific version of CPM where the frequency pulse shape, modulation indices, and data mapping are specifically defined. Refer to IRIG-Standard 106 Chapter 2, Subsection 2.3.3.

2.3.3 Transmitter Characteristics and Parameters

a. Modulation Characteristics (FM). An FM transmitter modulates data onto a continuous carrier. The data is conveyed in the deviation of the carrier frequency from nominal.

(1) Modulation Techniques

- Analog FM. The analog transmitters typically utilized for TM applications use the modulation input to control and change the local oscillator’s frequency. In a transmitter with an analog modulation input, the output frequency will linearly track the input signal’s instantaneous value.
- Digital FM. Current TM transmitters are not typically truly digital, but are a composite device with an analog transmitter with a digital modulation input. The circuitry in the modulation input converts the digital input signal to analog for transmission. The digital transmitter can be ac- or dc-coupled as in the case of the analog transmitter. The digital modulation input controls the local oscillator’s frequency and changes the frequency based on the input digital signal’s amplitude.

A digital transmitter has several advantages when compared to an analog transmitter. It is less sensitive to the modulation input signals’ wave shape and, therefore, the distance from the driver circuitry to the transmitter is less critical. Secondly, no premodulation filtering or deviation adjustment external to the transmitter is required. Thirdly, linearity is not an issue with digital modulation. The one disadvantage of digital transmitters is that they are optimized for a single bit rate.

(2) Coupling

- ac Coupling. An ac-coupled transmitter eliminates the input waveform’s dc component. In the case of randomized data, ac coupling will have a minimal effect on the input data as long as the bit rate is equal to 4000 times the −3 dB frequency of the low-pass filter at the transmitter’s modulation input. However, if the input data is not randomized, or is otherwise asymmetrical, the frequencies of the transmitted ONES and ZEROS will not be equally spaced from the average frequency. In this case, the carrier will be offset resulting in a possible increase in errors at the receiving station.

- dc Coupling. A dc-coupled transmitter tracks the input signal linearly and any dc-offset component will be reflected in the carrier output. The dc-coupled transmitters are typically harder to produce due to the requirement for a wider frequency response, starting at dc and increasing up to the bit rate frequency. Therefore, the best performance at the lowest cost is typically realized by utilizing an ac-coupled transmitter and randomized data.

(3) Modulation Frequency Response. The minimum and maximum frequency response required of a TM transmitter should be specified. Transmitters that do not meet the required frequency response for the data being transmitted adversely affect data quality due to amplitude reductions at high frequencies caused by transmitter-induced filtering. The frequency response can be determined from the change in peak deviation as a function of modulation frequency. If a carrier is modulated with a single sine or square wave, the carrier components' relative amplitudes can be used to determine the peak deviation. The carrier's relative amplitudes and observed sidebands can also be used to calculate the peak deviation in situations where it is not possible to vary parameters to achieve a null.

(4) Modulation Sense. The modulation or deviation sense should be as specified in the transmitter procurement document to prevent digital data inversion. The RCC standards specify that the carrier frequency shall increase when the voltage level on the modulation input increases and decrease when the modulation input voltage level decreases.

(5) Modulation Sensitivity. The correct modulation sensitivity, or carrier frequency shift relative to modulation input voltage, is critical for obtaining optimum data quality for a TM data link. The tolerance of the transmitter modulation sensitivity must be controlled to allow a given driver circuit to provide a consistent level of deviation of the transmitter (RF) output.

A transmitter has some sensitivity to input signals, which should be flat over the range of modulation frequencies that the transmitter is intended to operate. Typically, this is a small number of dB from the response at dc or some convenient mid-band frequency, often 1 or 10 kHz. While the flatness of the response is tightly controlled for transmitters, the actual sensitivity may not be. Thus transmitters from the same manufacturing lot may have a 2 dB (±10%) or more variation from one to another, unless the specification requires tighter tolerances. As a consequence, the transmitter's actual deviation must be set for each TM set produced, and then checked and readjusted when the transmitter, modulator, or transmitter interface is replaced. This adjustment must be made as an RF measurement, not as a voltage measurement at the transmitter input. A transmitter's input sensitivity may also be affected by temperature variations, which may be a concern if a wide operating temperature range is expected.

The transmitter's input sensitivity is expressed in several ways, which can result in significant confusion. Assuming that the output frequency is at center frequency when its input is shorted, deviation sensitivity can be expressed as the deviation resulting in a 1-volt dc (Vdc) signal: 180 to 220 kHz per volt. Then an ac signal of 2 volts peak-to-peak will cause a deviation in this example of 180 to 220 kHz, which is a true statement even if the transmitter doesn't have response down to dc. Assuming symmetrical modulation, there is a 2:1 difference between a peak voltage and a peak-to-peak voltage, so everything is still translatable into whatever system makes sense. If the transmitter deviation is specified as a deviation/voltage root mean square (V_{rms}) value, the deviation specified is for a sine-wave input, and the actual deviation will vary for different input waveforms.

(6) Modulation Linearity. The modulation input voltage range required is dependent upon the specific TM system. The transmitter requirements should be specified such that the transmitter operates linearly for the specified modulation voltage range. Thus the output carrier will linearly track the modulation input voltage for the required range.

Typically, a value is specified for an overvoltage condition on the modulation input to prevent the transmitter from being damaged if a noise spike or other event causes the modulation input voltage to go out of the specified modulation voltage range. The transmitter will not operate linearly when this voltage is applied; however, it will resume proper operation after the modulation input voltage returns to its specified range for linear operation.

(7) Input Impedance. The amplitude accuracy of transmitted data can be adversely affected by a load mismatch at the transmitter modulation input. Improper input impedance matching can also cause unwanted filtering and oscillations at harmonic frequencies. A load mismatch can also overload and damage the driver circuitry feeding the transmitter modulation input. High-frequency modulation passing through a multi-pin power connector can couple energy onto the power lines, making it difficult to control unwanted emissions.

(8) Distortion. Harmonic distortion is caused by nonlinearities in the transmitter and results in output harmonics other than the fundamental frequency component.

(9) Common Mode Rejection. The common mode rejection ratio defines the transmitter’s susceptibility to common mode input signals or common mode noise. This property is important in applications that require a differential amplifier at the transmitter's modulation input.

(10) Reverse Conversion. A TM transmitter output circuit can act as a frequency converter by creating a spurious output when a reverse signal at frequency f_2 is applied to the transmitter output. Of primary concern is the conversion product at a frequency of ($2 f_1 - f_2$). This conversion product is symmetrically spaced on the opposite side of the transmitter frequency from the interfering signal (f_2). The conversion loss is nearly power-independent, but does vary somewhat with frequency offset.

(11) Intermodulation Distortion (Two-Tone Intermodulation). Transmitters having nonlinear distortion can produce output frequencies equal to the sum and difference of multiples of the input frequencies.

(12) Frequency Deviation. The proper frequency deviation for a given bit rate is necessary to obtain optimum bit error rate (BER) performance. For example, the modulation input driver circuitry for an NRZ-L data stream must be set to provide a peak deviation of 0.35 times the bit rate for optimum PCM data transmission (Figure 2-10). Under-deviation (much less than 0.35) (Figure 2-11) will result in poor data quality and over-deviation (much greater than 0.35) (Figure 2-12) may result in adjacent channel interference and degraded data quality in conditions with low signal-to-noise ratios (SNRs).

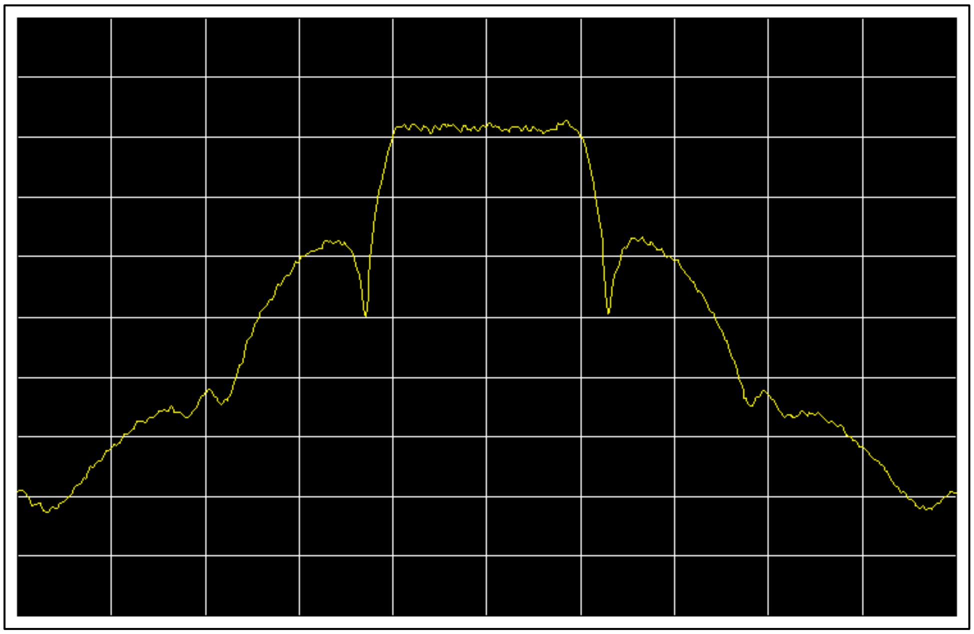

Figure 2-10. PCM/FM 1 Mb 350 kHz Deviation

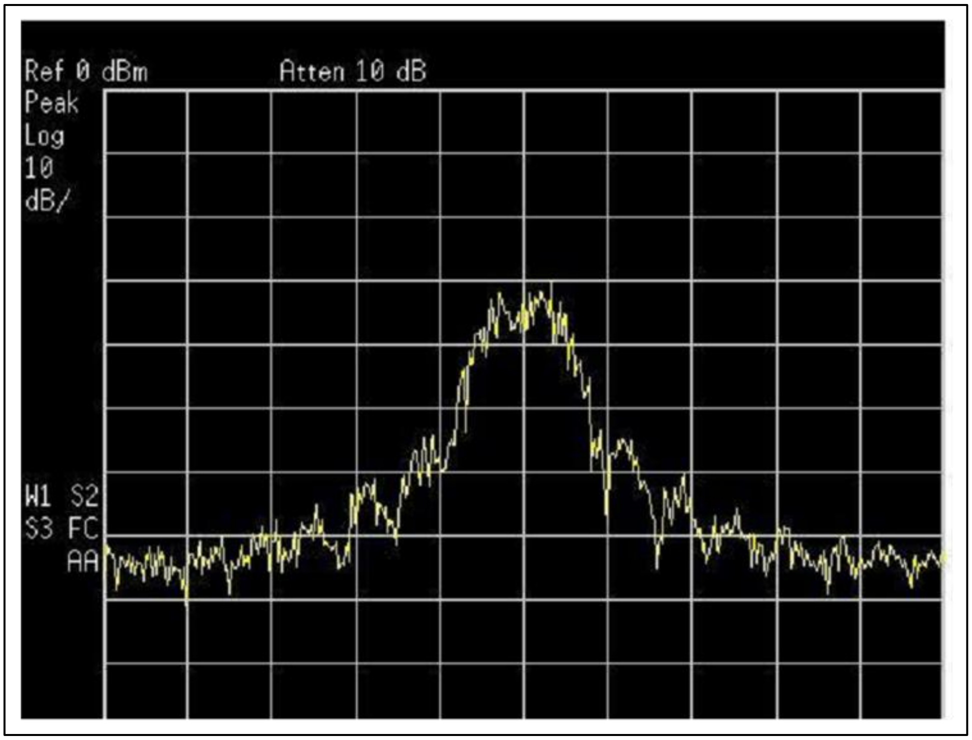

Figure 2-11. PCM/FM 1 Mb 250 kHz Deviation

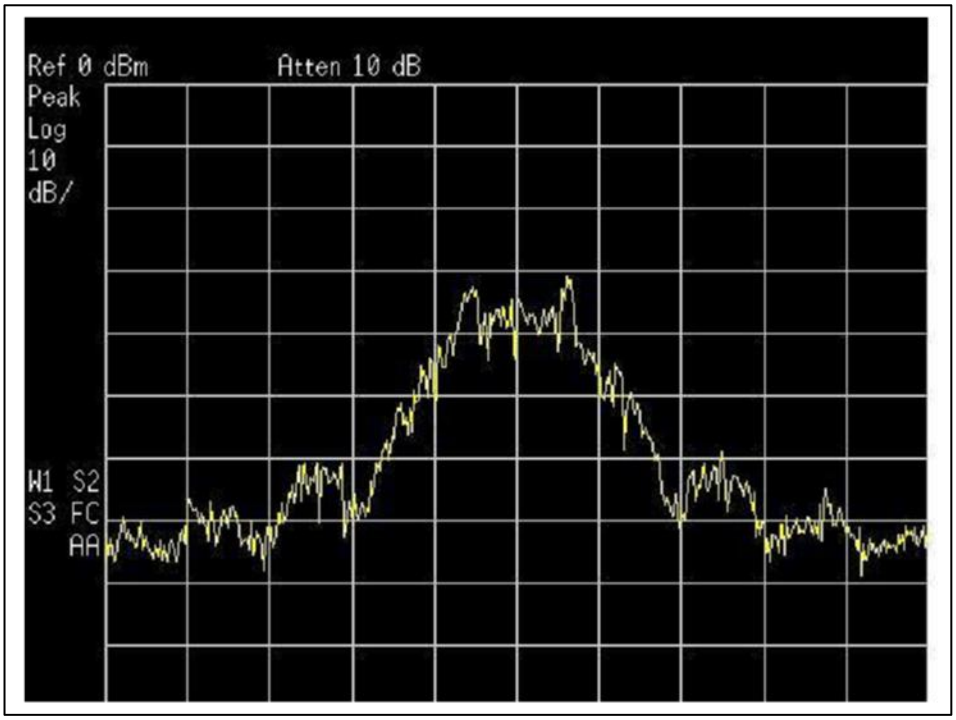

Figure 2-12. PCM/FM 1 MB 450 kHz Deviation

(13) Transition Threshold. The transition threshold required is dependent upon the logic device feeding the transmitter. It must be matched to the specified value in the transmitter procurement document to prevent the loss or unwanted addition of bit

transitions that would result in an increase in the BER for the system. This only applies to digital transmitters.

(14) Premodulation Filters. The premodulation filter utilized must have sufficient attenuation characteristics to ensure that the transmitter's RF spectrum will conform to the spectral mask requirements of IRIG-Standard 106, Appendix 2-A. The premodulation filter typically used for NRZ-L data is a six-pole Bessel filter with its −3 dB cutoff set at 0.7 times the bit rate.

b. Modulation Characteristics (PM)

(1) Modulation Sense. The modulation sense of PM systems is less standardized than that of PCM/FM systems, and it is important to specify the sense in transmitter-requirement documents.

(2) PM Deviation. The FM deviation (Figure 2-13) is expressed in terms of the change between the center frequency and the instantaneous frequency at any point. With PM, the center frequency never changes, and only the signal's phase with regard to some reference changes. However, when the phase is in the act of changing, the instantaneous frequency is, in fact, different from the center frequency. Frequency and PM are related by an integral (or a differential) such that an FM-like signal can be produced by integrating the modulation voltage and feeding it to a PM transmitter, and a PM-like signal can be produced by feeding the modulation voltage through a differentiator. For a single sinusoid input, therefore, it is impossible to determine if the transmitter is FM or PM.

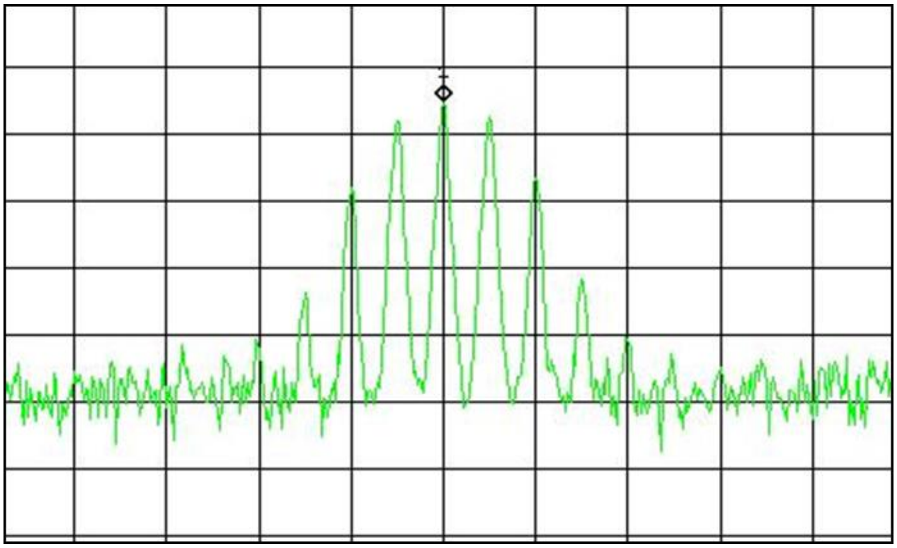

Figure 2-13. Phase Modulation

(3) PM Deviation. The FM deviation (Figure 2-13) is expressed in terms of the change between the center frequency and the instantaneous frequency at any point. With PM, the center frequency never changes, and only the signal's phase with regard to some reference changes.

The PM is essentially a linear up-conversion while demodulation is a linear down-conversion. The input modulation spectrum display at baseband should provide the same spectrum display centered on the RF carrier frequency. The receiver IF will also provide the same spectrum display as the carrier, only at the lower center frequency. Change of deviation only affects the carrier suppression. The BPSK, QPSK, and the minimum shift keying are also linear modulation with the RF spectrum display identical to the baseband spectrum display. The FM is a nonlinear modulation method that is apparent in the marked difference between the baseband and carrier spectrum display. Change of deviation causes great change in the carrier spectrum display. The FM's transfer function is parabolic so the demodulator in the receiver must be parabolic as seen in the parabolic curve of noise or signal (baseband amplitude or demodulated output increases with frequency). Pre-emphasis, or an additional baseband gain, is used as frequency increases to maintain the same SNR for all frequencies.

c. Modulation Characteristics (PSK) and Modulation Sense. The SOQPSK-TG modulation sense, which is a preferred method for BW-efficient transmission, is defined in IRIG-Standard 106.

2.3.4 How to Measure Power Relative to the Unmodulated Carrier Power Level

A common requirement is the need to measure a TM signal with respect to the unmodulated carrier level (units of decibels referenced to the carrier [dBc]), but only the modulated signal may be available. To measure power with respect to the unmodulated carrier power, the unmodulated carrier power must be known. This power level is the 0 dBc reference (commonly set to the top of the display). Since angle modulation (FM or PM) by its nature spreads the spectrum of a constant amount of power, a method to estimate the unmodulated carrier power is required if the modulation cannot be turned off. For most practical angle modulated systems, the total carrier power at the spectrum analyzer input can be found by setting the spectrum analyzer's resolution bandwidth (RBW) and video bandwidth (VBW) to their widest settings, setting the analyzer output to max hold, and allowing the analyzer to make several sweeps. The maximum value of this trace will be a good approximation of the unmodulated carrier level.

One can then set the spectrum analyzer to the IRIG-Standard 106 Chapter 2 conditions for measuring the TM spectra (RBW = 30 kHz, VBW = 300 Hz, max hold off). After measuring the signal spectrum, one can verify the 0 dBc level by finding the measured spectrum's nominal peak level, which should be about (X−10logR) dBc where X = −16 for PCM/FM with correct peak deviation, −12 for SOQPSK, −11 for ARTM CPM, and R is bit rate (megabits per second [Mbps]). A more general approximation[3] for the spectral energy near center frequency for randomized NRZ PCM/FM is:

$$-10\log\left(\frac{B_{SA}\,f_b}{\pi^2(\Delta f)^2}\right)\ \text{dBc} \qquad \text{(Eq. 2.3-1)}$$

Where B_{SA} is spectrum analyzer RBW in kHz
f_b is the bit rate in kilobits per second (kbps)
Δf is the peak deviation in kHz

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[3] Eugene Law. "RF Spectral Characteristics of Random PCM/FM and PSK Signals," in *Proceedings of the 1991 International Telemetering Conference*, Las Vegas, NV, 4-7 November 1991, pp. 109-119.

Δf can be estimated using $\Delta f = f_b - \frac{null\,spacing}{2}$

Where null spacing is the frequency spacing between the closest spectral nulls on each side of the center frequency.

Examples: If one measures the spectrum of a 10 Mbps randomized NRZ PCM/FM signal with a 3.5 MHz peak deviation, one should get a maximum level of approximately −16−10log(10) = −26 dBc, which matches quite well with the spectral plot shown in Figure 2-14. Using the equation, one would get −10log(30*10000/(9.87*3500*3500) = −26.05 dBc or essentially the same value.

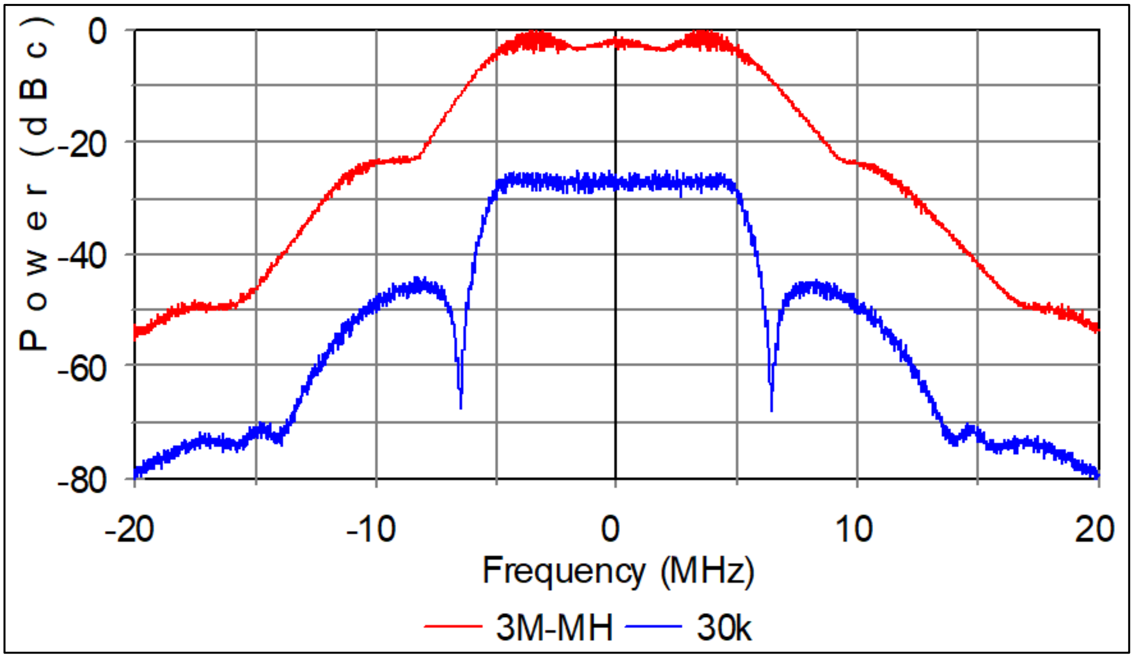

Figure 2-14. 10 MBps NRZ PCM/FM

If one measures the spectrum of a 10 Mbps SOQPSK-TG signal, the maximum level of the spectrum should be about −12 −10log(10) = −22 dBc (the tolerance should be about ± 1 dB). Figure 2-14, Figure 2-15, and Figure 2-16 show the measured spectra for 10 Mbps signals with both wide spectrum analyzer settings (red traces, to find 0 dBc level) and IRIG-Standard 106 settings (blue traces). The actual 0 dBc values were found by removing the modulation. The approach presented here appears to work reasonably well for these modulation methods and bit rates up to at least 20 Mbps.

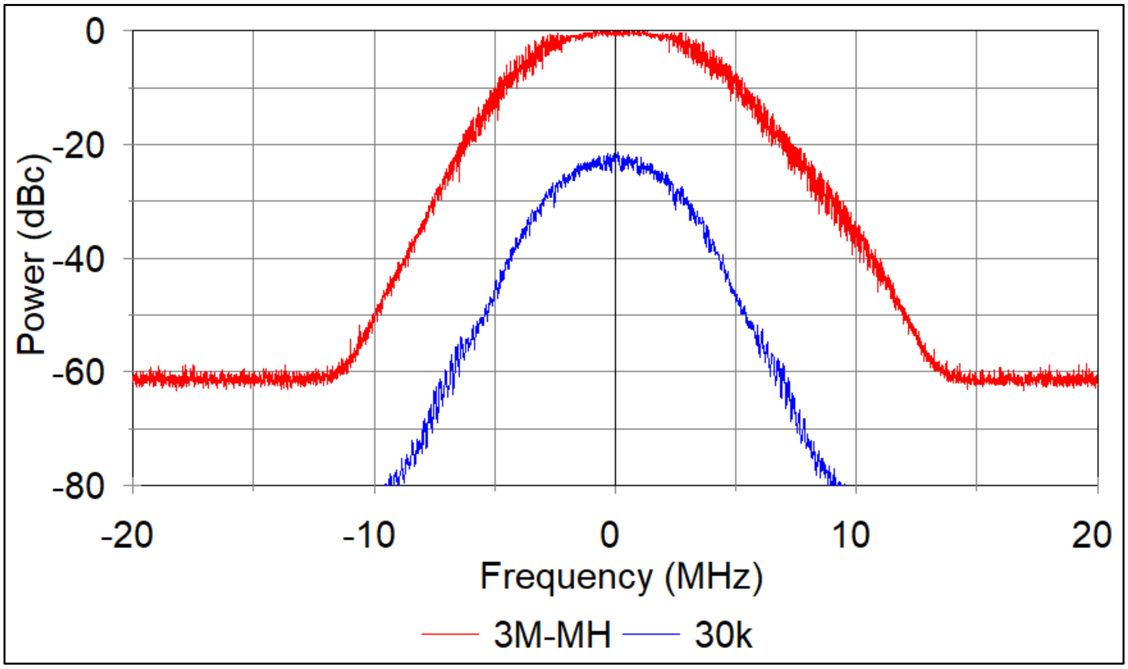

Figure 2-15. 10 MBps SOQPSK TG

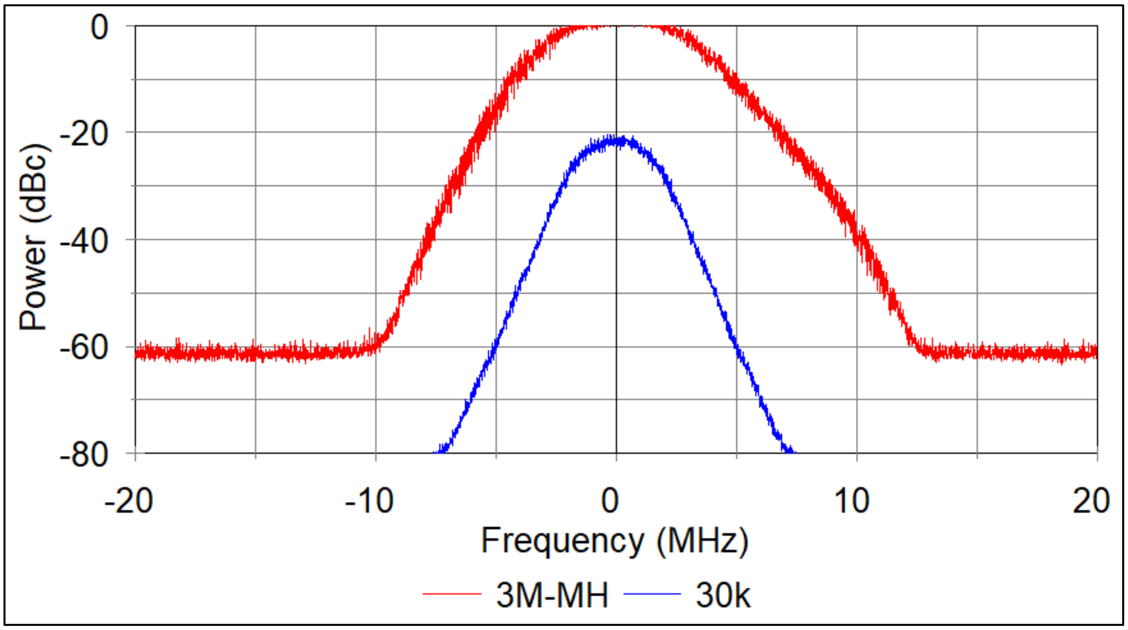

Figure 2-16. 10 MBps ARTM CPM

2.3.5 Power Source Considerations

a. Input Voltage. The input voltage range of typical TM transmitters is 24 to 32 Vdc. The TM transmitters for missile applications are typically powered by a battery, and for aircraft applications, by converted aircraft power. Therefore, in aircraft systems, the noise immunity of the transmitters’ primary power input is more critical.

Transmitters typically use shunt regulators rather than dc-to-dc converters. Therefore, efficiency drops at higher operating voltage as the current drawn from the supply is relatively constant at any voltage at which the transmitter operates.

b. Input Current. The input current required by the transmitter is related to output power and efficiency. The current source must be of low enough impedance to prevent variations in input voltage that could cause unwanted modulation within the transmitter.

c. Overvoltage/Undervoltage. The RF output and center frequency should meet requirements at the limits of the primary power voltage range to ensure that the transmitter will operate as specified over the entire range of expected operating conditions. The transmitter should be designed so the output stage shuts down in a low-voltage condition to prevent transmission outside the specified band of operation.

d. Reverse Polarity. The application of reverse voltage during testing and installation can damage a TM transmitter if it is not properly protected. Circuitry to provide reverse voltage protection is typically built into TM transmitters.

e. Power Supply Ripple. The transmitter's performance should be specified such that any expected ripple on power supply lines is rejected and doesn't cause spurious emissions, unwanted frequency components, or modulation effects.

f. Tolerance. The transmitter power supply or battery must be of sufficient capacity to provide the required voltage at full load under all environmental conditions. Typically, the transmitter will require a higher input current at high temperature.

g. Induced Power-Supply Noise. TM systems typically operate in an environment where unwanted frequency components are present on the dc power leads to the TM transmitter. The transmitter must be designed such that induced power-supply noise does not cause unwanted frequency products within the transmitter. If the transmitter produces incidental AM and incidental FM components as a result of power-line noise, the received data quality will be adversely affected.

h. Power On/Off Characteristics. The transmitter's turn-on and turn-off characteristics must be such that no out-of-band emissions are generated during application or removal of primary power. In-band spurious emissions must be less than −25 decibel-milliwatts (dBm). This requirement is necessary to meet Federal Communications Commission regulations and to prevent interference with other users.

i. On/Off Switching (Standby/Operate). Transmitters may require on/off switching by logic circuitry to prevent the transmitter from drawing excessive current from a system battery when not needed (to avoid overheating), or to prevent radiating when several transmitters have the same frequency. Turning the transmitter power on and off directly is often inconvenient because of the high currents and voltages involved, or because the transmitter would require time to warm up to power and get within frequency tolerance from a cold start.

   Consequently, transmitters can be provided with a logic-controlled on/off lead that can be activated by discrete or monolithic logic, or a combination of the two. The circuit is typically arranged so grounding the control lead turns the transmitter on, and a logic ONE (or an open circuit) turns it off. With a load that approximates a transistor-transistor logic (TTL) unit load, or about 3 kiloohms (k ohms) through the grounded lead. Especially if rapid start is required, the on/off circuit may control only the output stages, with the oscillator and modulator powered at all times power is applied, in which case, a specification may limit the amount of power output produced when the transmitter is not turned on.

2.3.6 Grounding

The ground isolation at the TM transmitter should be specified to meet the TM system design requirements. The lack of a proper grounding scheme at the system level will typically cause noise that affects data quality and overall system performance.

The transmitter's input ground may or may not be connected directly or indirectly to the case, modulator circuit ground, or RF ground, although, in most situations, it is common to all others. When a differential input is specified, the ground associated with the input leads may or may not be common to the system case, and may be referred to a different voltage than case ground. The case ground will be common to the RF ground and probably the power ground. In most instances, the transmitter case is also common to the return of the input signal and control lines, if any.

2.3.7 Efficiency

A modern FM TM transmitter's efficiency in the 1 to 20 watt (W) operating range is on the order of 20%, up from the 8 to 10% found in designs from the 1960s. Efficiency is usually quoted at +24 Vdc, and typically decreases with increasing supply voltage. Since approximately 80% of power consumed by a transmitter must be dissipated as heat, a 5 W transmitter dissipates 25 W of the 30 W drawn from the external power. The 25 W must be dissipated through a proper heatsink if the transmitter is operated for more than a few seconds. Transmitter overheating drastically shortens the life of the output stages. Efficiency considerations also limit the maximum output that can be obtained in a given system. The use of higher-power transmitters is generally precluded by restrictions of size, available power, and heat dissipation.

2.3.8 RF Output Characteristics

a. Carrier Frequency. Center frequency and frequency stability are critical for avoiding interference with adjacent channels and for obtaining optimum data quality at the TM receiver.

    (1) Center Frequency. Typically, the unmodulated carrier output of an analog transmitter is at the center frequency with no modulation input voltage, and it shifts up and down depending on the level of the modulation input voltage. In contrast, a digital transmitter, whose input is dc-coupled internally, has two possible output frequencies, *f*-lower and *f*-upper, and reaches frequencies between these two limits only when switching between states. Because the channel on which the transmitter operates is specified in terms of center frequency, the center frequency is specified as the average of *f*-lower and *f*-upper. This frequency would actually be the center frequency only when the transmitter was deviated with a square wave having exactly 50% duty cycle. For frequency management purposes, the band-edges with modulation (which are, in general, beyond those frequencies defined by *f*-lower and *f*-upper) are of far greater importance than some frequency in between.

    (2) Carrier Noise. The unmodulated (and the modulated) carrier will have changes in amplitude, frequency, and phase regardless of which attribute is actually used for modulation. To the extent that the carrier exhibits the noise variations in the attribute used for modulation, the noise has a direct effect on SNR on the demodulated signal. The effects of amplitude noise on an FM transmitter, for

example, are more subtle and exhibit themselves when the received-signal strength is low. The effects will vary with the type of receiver used and the nature of the modulation itself. For these reasons, the frequency, amplitude, and phase noise of any transmitter should be specified and measured.

b. <u>Frequency Tolerance and Stability</u>. The transmitter should meet specification requirements for each variation in operating environment. If the transmitter's operation is adversely affected by specified temperature or power variations, the quality of received data may be unacceptable.

   An FM transmitter will, when fed an open or short circuit instead of a modulated input, produce a signal that may be at or near the transmitter center frequency. In the case of tunable transmitters, the frequency should be the center or assigned frequency, although it may not be in the center of the frequency band when modulated. If the transmitter is ac-coupled (whether digital or analog), the frequency should be the center frequency, but in most cases it will not be exact. With dc-coupled analog transmitters, unless specified otherwise, the center frequency should be produced when the input voltage is 0 Vdc. With PM transmitters, the center frequency doesn't change with modulation, but instantaneous frequency does, so measurement without modulation is required for accuracy.

c. <u>Output Power</u>. The TM system designer should complete a link analysis to ensure that the specified transmitter power is sufficient for the expected maximum range of the TM system from the receiving site. However, the use of power in excess of the amount required should be limited as much as possible. Typically, output power will decrease at higher temperatures.

d. <u>Output Impedance</u>. The expected output load impedance of almost all TM transmitters is 50 ohms and the output stage is tuned for such a load. That is not quite the same as saying that the output stage itself has an impedance of 50 ohms, but often an isolator is used between the output stage and the load, so power reflected by the load will not be bounced back to the output stage.

e. <u>Output Load Mismatch</u>. Typically, antennas will not be perfectly matched to the transmitter output impedance. This could be due to the antenna design or to external influences such as the plasma that develops around a vehicle during a reentry situation. In a mismatch condition, if inadequate output isolation exists, the transmitter may oscillate causing unwanted harmonics at its output, or it may fail to meet the minimum specified output power for a required mismatch condition. The transmitter may also shift in frequency if the output is not sufficiently isolated.

f. <u>Isolation</u>. Transmitter output isolation protects the transmitter from power that is fed or reflected back into its output. Any extraneous load due to antennas, power splitters, and cables will not equal 50+j0 ohms, so a load voltage standing wave ratio (VSWR) greater than 1.0:1 will result. This VSWR will generally vary with frequency.

   Transmitters without isolation will perform oddly when encountering reflected loads, either by greatly decreasing power output, or by generating spurious frequencies. The exact nature of this operation deviation will vary with the amplitude and phase of the reflected component, the temperature, and other extraneous factors that cannot be easily traced. Hence, the transmitter must be specified to withstand a VSWR greater than the worst case expected at any phase angle.

A typical requirement might be VSWRs as great as 3:1, which is half the power reflected. Some specifications go so far as to require near-infinite VSWRs due to open and short conditions on the transmitter output. Even an antenna that provides a particular maximum VSWR will cause a larger VSWR when loaded if it is in the proximity of other objects, such as a calibration stand or launch tube. This effect is exacerbated by a low-loss, high-efficiency antenna system. Therefore, a transmitter specification must take into account worst-case VSWRs.

g. Open and Short Circuit. The malfunction of an antenna component or operator error during testing and installation may cause the transmitter to be subjected to an open or short condition. The relatively high cost of TM transmitters makes it desirable that the transmitter not be damaged should this condition occur.

Transmitters that have circulators or isolators at their outputs are normally capable of withstanding open- or short-circuited outputs. Assuming a perfect open or short, the entire transmitter output power is reflected back into the transmitter, to be dissipated at the dummy load in the circulator, which must be able to withstand the transmitter power for some length of time. If the dummy load is incapable of withstanding the transmitter output for long periods of time and/or at high temperatures or input power, permanent damage can occur even though the output is isolated. If the transmitter’s output is coupled to another transmitter’s output, the likelihood of permanent damage is further increased.

Not all transmitters contain isolators or circulators at their output because of possible size restrictions and the fact that internal load resistors need a heatsink. Transmitters in which small size is a consideration often omit these output protection devices. Transmitters that are not equipped with isolators or circulators internally are less stable with regard to output impedance and load mismatch, and are consequently more subject to damage or erratic performance when the antenna is detuned or being affected by proximity to other forces.

h. Maximum Carrier Deviation. The transmitter’s BW must be sufficient to allow transmission of data at the maximum expected data rate. The optimum carrier deviation for NRZ-L PCM/FM is 0.35 times the bit rate, and the actual maximum carrier deviation for the transmitter must be greater than this value to ensure that data is not degraded by nonlinearities in the transmitter. The optimum carrier deviation varies depending on the modulation waveform selected.

i. Incidental Frequency Modulation (IFM). The IFM components created within the transmitter may cause distortion that can degrade TM data and yield unacceptable quality data at the receiver. The IFM is typically greater during vibration.

A spectrum display of adequate resolution will show that the observed center frequency is not a single spike but a tight bell-shaped curve. This phenomenon is partially due to the finite frequency characteristics of the filters used in the analyzer, but these can be minimized. It is also due to actual frequency modulation caused by thermal effects. A demodulated signal will show noise whose amplitude typically rises at 6 dB per octave due to white noise at the demodulator input, the same effect that would be noted for intentional phase modulation with a Gaussian white-noise source. The root mean square (rms) deviation value for a typical FM TM transmitter in a 1 MHz BW is around 1 to 2 kHz. The rms measure is used because of the noise's statistical nature.

j. Incidental Amplitude Modulation (IAM). The IAM occurring in a TM transmitter will adversely affect the data quality at the output of a TM receiver through variations in transmitter power and the SNR. The IAM can also affect the accuracy of an antenna system that uses the TM signal for tracking. The use of a class-C amplifier eliminates most IAM in TM transmitters.

k. Spurious Emissions. The occurrence of unwanted spurious and harmonic emissions from a TM transmitter can adversely affect the system that is being monitored or systems outside the transmitter's intended band of operation. It is, therefore, important that these emissions are controlled. The GPS systems tend to be especially susceptible to TM systems operating in L-band.

The spurious emissions from the transmission system's output should conform to the requirements set forth in IRIG-Standard 106. Spurious emissions can be generated within a transmitter. They can also result from improper termination or from multiple transmitter outputs terminating into a common antenna system, especially if the transmitter lacks sufficient output isolation.

l. dc Response and Linearity. Transmitters that are dc-coupled may be required for some TM system types. Systems transmitting nonrandom PCM or some event marker data may require this transmitter type.

m. ac Response and Linearity. The demodulated receiver output must accurately reflect the amplitude of the input to the transmitter or data quality will be adversely affected. In PCM systems using an analog transmitter, poor ac-modulation linearity will increase the received data's BER. In FM/FM systems, poor ac-modulation linearity will have a greater adverse effect on the quality of received data.

n. Eye Pattern Response. The proper eye pattern response is a good indication that the transmitter deviation, and the transmitter premodulation and receiver filtering are properly matched to provide acceptable BER performance. A digital transmitter should have the proper eye pattern when modulated with a randomized NRZ-L signal at the maximum specified bit rate. Figure 2-17 represents a good eye pattern for a 5 Mbps PCM/FM signal.

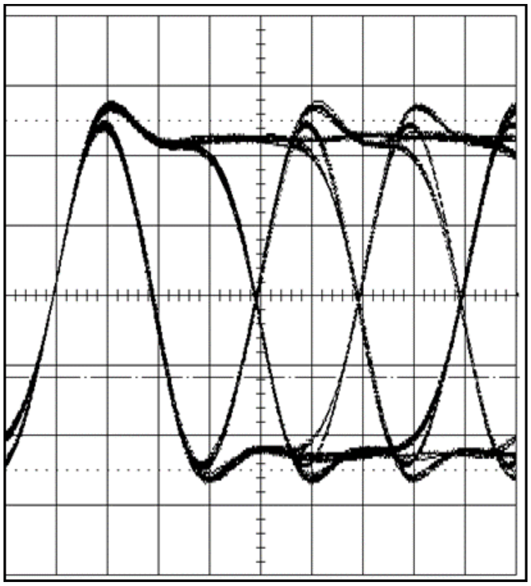

Figure 2-17. 5 MBps PCM Eye Pattern

o. Spectral Occupancy. The pre-modulation filter and peak deviation must be properly tuned to avoid interference with users on adjacent channels and transmission of RF components outside the allocated frequency range of operation.

The BW definitions are included in IRIG-Standard 106. The TM transmission system’s BW should be minimized by filtering and other methods, and conform to the spectral mask requirements included in IRIG-Standard 106.

(1) Occupied Bandwidth (OBW). The OBW (99%-power BW) of a TM transmitting system can be used to determine if the system complies with its RF spectral occupancy requirements.

(2) −25 dBm BW. The −25 dBm BW of a TM transmitting system can be used to determine if the system complies with its RF spectral occupancy requirements. Spurious emissions must be less than −25 dBm to minimize interference levels to other systems.

p. Warm-up (Turn-on Time). The transmitter typically must meet specified requirements during the warm-up period. Any spurious emissions emitted during the warm-up period shall be limited to −25 dBm.

(1) Start-up. Because the transmitter contains an oscillator, its start-up response time also affects signal output. Ideally, the oscillator should start and be up to full power instantaneously, but, in fact, the power output starts after some delay and rises more or less exponentially. The initial frequency is other than specified and may produce a signal that interferes with other RF spectrum users.

Typical transmitter specifications include a requirement that the transmitter center frequency be within the passband occupied by its spectrum after output power has exceeded −25 dBm, and also be within the required tolerances for the carrier within the specified number of seconds, typically 0.4 to 1.0. Power output is specified to be at or greater than the required minimum in two to ten seconds as well. The IRIG-

Standard 106 requirement should be considered the minimum acceptable performance.

(2) Cold start. Start-up or warm-up takes longer when the transmitter is in a colder environment. Since oscillators are triggered by thermal noise, the possibility exists that, if the transmitter encounters a colder temperature than that for which it is designed, it may not start up at all. Hence, testing of a transmitter whose warm-up time is critical is performed at the low-temperature limit. A dc-coupled receiver of known precision can be used to indicate the center frequency.

2.3.9 Environmental Considerations

The TM data are often most important when the system in which the transmitter is being utilized begins acting outside its expected performance environment due to a failure or anomaly. These are typically the times when TM data collection is critical. Environmental considerations are, therefore, extremely important factors. The transmitter must be capable of performing in more adverse conditions than the system in which it is operating. The following are some environmental factors requiring assessment:

a. Vibration. The transmitter should be tested to verify that all performance parameters are satisfied under the maximum expected vibration environment. Transmitters are particularly susceptible to increased IFM during vibration.

b. Shock. The transmitter should be tested to verify proper operation after the maximum expected shock event and/or proper operation during the shock event if measurement of shock is part of the test. The transmitter is often not required to meet all performance parameters if high shock levels are anticipated due to pyrotechnic events. However, spurious emissions must be limited to −25 dBm at all times.

c. Acceleration. The transmitter should be tested to verify that all performance parameters are met during maximum expected acceleration environments.

d. Altitude/Pressure. The transmitter should be tested to ensure that its structure will survive and performance requirements will be met during maximum expected altitude and pressure environments. At high altitude, the transmitter/antenna should be tested to verify that corona, arcing, and other effects do not occur at the antenna causing degraded performance.

Transmitter operation at high altitudes presents certain problems not encountered at ambient pressures, including outgassing from foam potting materials, which can (if the pressure change occurs quickly enough) deform shapes associated with tuning and frequency determination. Transmitters used in TM applications are seldom hermetically sealed, so the air spaces on the inside of the transmitter eventually adjust to the external air pressure. Gasses at low pressures are more inclined to develop a plasma between two points of different potential, a mechanism similar to that found in a neon tube. The most likely points at which such an effect might occur are in the output stages. The greatest problem in testing transmitters at high equivalent altitudes is getting an altitude chamber with an adequate seal, especially if operating power for the transmitter is applied from the outside.

e. Temperature. The transmitter should be tested to verify proper operation under all expected temperatures. The transmitter’s cold-start characteristics should be tested, and the system should be designed to allow for sufficient heatsinking of the transmitter under high-temperature conditions to ensure that the transmitter is not damaged.

(1) High Temperatures. Transmitters are more affected by high environmental temperatures than any other TM component, including power supplies. Because the TM transmitter is called upon to supply relatively high power at its output (typically several watts), and has an efficiency of 20% or less, it must dissipate 80% or more of the power fed to it. This is typically through intimate thermal contact with its mounting. Since frequencies and efficiencies are affected by temperature, the transmitter must be made of materials that do not change size or shape significantly at temperature extremes. Transmitters capable of withstanding 70 °C base plate temperatures are quite common. Transmitters that will operate at base-plate temperatures of 80 to 90 °C are available at higher costs. Temperatures in excess of these involve use of exotic semiconductor materials and shouldn't be specified unless absolutely necessary.

(2) Low-Operating Temperatures. Operation at low temperatures, apart from start-up at low temperatures, is fairly standard for most transmitter designs. Maintaining frequency tolerance over a large temperature range can be difficult, so it may be necessary to relax the low temperature requirement if an unduly high temperature is required. If the expected low temperature is of a transitory nature, requiring a transmitter that is already operating when taken to the low temperature extreme, or a 'cold soak' of four hours or less, will decrease the complexity of the transmitter and the price. Typical TM transmitters are characterized for operation down to −20 °C by manufacturer's data sheets, to −40 °C by most specifications, and have been specified to temperatures as low as −54 °C.

(3) Low-Non-Operating Temperatures. Transmitters kept at cold temperatures for storage may experience permanent damage when heated up too quickly or if brought up to a minimum operating temperature and activated. Problems of this nature are a matter of packaging and construction not particularly unique to transmitters.

(4) Ionizing Radiation. The transmitter should be tested to verify that all performance parameters are satisfied during exposure to ionizing radiation. Current transmitters employ frequency synthesizers and other digital integrated circuits, which are particularly susceptible to upset or latch-up during radiation exposure. The transmitter should be tested to verify that it will not latch-up, and that the performance parameters return to normal after exposure.

2.3.10 Testing Methods

a. BER Testing. The BER testing is a simple method used to verify proper transmitter operation. It cannot be used as a substitute for the testing of individual performance parameters. RCC Document 118-20, Volume 1[4], Chapter 5 outlines the BER methods.

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[4] Range Commanders Council. *Test Methods for Telemetry Systems and Subsystems Volume 1: Test Methods for Vehicle Telemetry Systems*. RCC 118-20 Volume 1. October 2020. May be superseded by update. Retrieved 7 January 2021. Available at https://www.trmc.osd.mil/wiki/x/eou8Bg.

b. Deviation Measurements. The transmitter's deviation can be measured by several methods outlined in RCC Document 118-20, Volume 2[5], Chapter 5. The proper deviation is necessary to guarantee optimum system performance, spectral containment, and minimum BER.

c. Spectral Response. The transmitter transmission system's output spectrum should conform to the limits of spectral masks as specified in the 106. This assures that the required minimum BW is utilized and that adjacent channel interference with other users in the TM band will be minimized.

d. rms Measurements. Because transmitter input sensitivities are sometimes specified in terms of peak deviation per input V_{rms}, a temptation exists to set transmitter deviation by adjusting the modulating signal's rms value such that the desired deviation is obtained. This acceptable for initial power-up and checks, but the actual deviation should be measured per the guidelines in RCC 118-20, Volume 2, Chapter 5.

2.3.11 GPS/TM Compatibility

Several articles have been written and studies completed about interference problems between GPS and TM on aircraft/missiles since GPS systems became standard on these airborne platforms. The problem is always one-sided since the TM signals are of a greater magnitude than the GPS received signals. Installing filters to remove the interference has become the desired practice, but this is not always possible or feasible with a production GPS receiver. Also, the practice of moving the antennas as far as possible from one another has produced favorable results. This is not always possible because of the test article's size or where space has been allocated for the antennas. It must be noted that if both antennas are utilizing the vehicles outer skin for a ground plane (common antenna mounting practice), antenna coupling is still present through the conductive skin and will produce some interference. Thus the only effective way to reduce interference is by placing filters between the transmitter/receiver and their associated antennas (Figure 2-18). Other studies (RCC, 118 V.2) have shown that interference can be minimized by utilizing a steered beam GPS antenna. Once again this may not be possible if the aircraft/missile is utilizing a production GPS system that cannot be modified.

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[5] Range Commanders Council. *Test Methods for Telemetry Systems and Subsystems Volume II: Test Methods for Radio Frequency Systems*. RCC 118-20 Volume 2. June 2020. May be superseded by update. Retrieved 7 January 2021. Available at https://www.trmc.osd.mil/wiki/x/fIu8Bg.

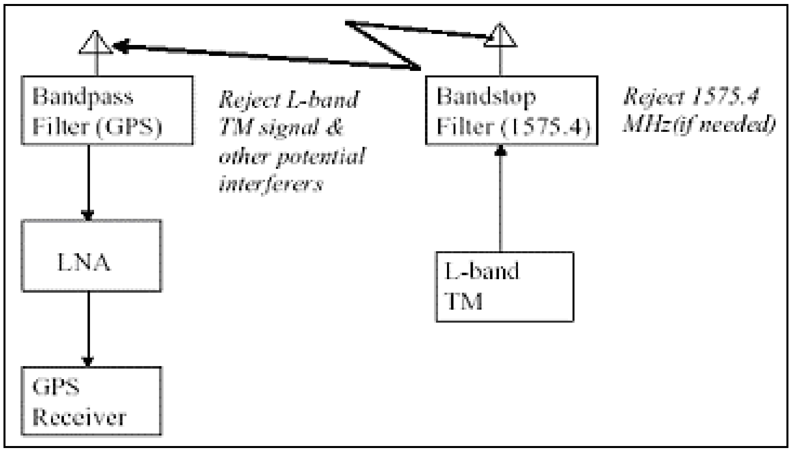


Figure 2-18. GPS Filtering

It should be noted that the majority of studies have focused on L-band TM interference, but that any transmitter may exhibit spurious signals in the GPS bands. Documentation has shown that S-band transmitters can also exhibit these characteristics, but in theory, any RF transmitter could also produce a harmonic at these frequencies.

Typically, at least 90 dB of attenuation (100 dB preferred) of the main TM signal and at least 40 to 50 dB of attenuation of the TM transmitter's noise at 1575.42 MHz is required. The TM transmitters that have spurious outputs close to 1575.4 MHz may require more than 50 dB of isolation at 1575.4 MHz. The typical specification for spurious signals at the output of a TM transmitter is −25 dBm; however, levels much lower than −25 dBm can cause problems if the frequency is close to the GPS frequencies. Problems are less likely to exist when S-band TM transmitters are used, but problems can occur if the transmitter has spurs close to the GPS frequencies or if the TM transmitter saturates the GPS low-noise amplifier (LNA).

Many typical antenna configurations do not provide sufficient isolation. Therefore, both a good bandpass filter before the GPS LNA and possibly a bandstop or bandpass filter at the L-band TM transmitter output will be required for good GPS performance. The TM transmitters with lower output levels near GPS frequencies would reduce the probability of needing the bandstop filter.

2.3.12 Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC)

The transmitter should be tested in accordance with system EMI/EMC requirements to verify that the transmitter and other system components don't interfere with each other's proper operation.

2.3.13 TM Frequency Bands

At the writing of this document, TM systems are in the 1435-1525 MHz (L-band), 2200-2290 MHz (lower S-band), and 2360-2395 MHz (upper S-band) portions of the frequency spectrum. The actual spectrum assignments are dependent on the range at which the TM system is to be used. Local frequency managers will coordinate actual frequency assignments.

Some transmitters are programmed to operate at more than one frequency or more than one band. The exact frequency or frequency range for the transmitter is factory-set and must be specified when ordering.

2.3.14 Form DD-1494

The application form DD-1494 is used to request a frequency allocation for TM systems and all other military RF systems. Appendix A contains a sample (completed) DD-1494 and guidance on how to download blank forms.

a. Authorization to Acquire. Because the transmitter’s operation produces a signal that competes with other signals on the EM spectrum, authorization to purchase or use transmitters requires that certain types of paperwork be completed in advance. While this authorization must theoretically be obtained prior to the transmitter’s purchase, in TM systems, the procurement is usually allowed if the appropriate forms have been submitted, since the process often takes up to a year to complete (form DD-1494).

b. Authorization to Radiate. Permission to radiate, even from the ground or inside a building, requires coordination with the local frequency management group. This is necessary because there are many potential users and a limited number of channels. Without coordination, the probability of a clash is significant and the consequences are serious.

2.3.15 Connectors

Transmitters typically have two or three connectors. The transmitter output is provided on a coax connector or on a short pigtail terminated in an RF connector. Typical connectors for this purpose are the SubMiniature Version A (SMA) type or the larger Threaded Neill-Concelman (TNC) type, although others can be used. The modulation input to the transmitter may be on the same connector used for power and control leads, or may be a separate multi-pin or coax connector.

Connectors for power, modulation, and frequency selection are more variable in type and size. Power to the transmitter, ON/OFF (standby/operate; key up/key down) control, and forward/reverse power indications (if supplied) are generally in the same connector, even if the modulation input is separate. Since connectors, even miniature ones, take up space, transmitters can also be supplied with connections made by ‘solder hooks’ fed through hermetic glass insulating beads.

2.4 Couplers and Cabling

Coupler and cabling components utilized in TM transmit systems can vary from one installation to another. This aspect of TM system design is often overlooked or underestimated by the novice system engineer. Proper selection of coupler and cabling materials can make or break an otherwise well-engineered system. Listed below are some frequently used components found in the transmit subsystem along with typical uses and important characteristics to consider when purchasing and/or using them.

2.4.1 Coax Cable

Coax cable is the primary means by which TM transmitters, antennas, and other RF components are interconnected in virtually all RF TM subsystems. Coax cable comes in hundreds of different types, each designed with a specific application in mind. Unless a special circumstance exists, almost all RF TM applications will use low-loss 50-ohm impedance coax cable. Most will meet Mil-C-17 requirements as well. The most important coax cable properties a TM systems engineer should consider are the impedance, signal attenuation (usually measured in dB per 100 feet at specific frequencies), power handling capability, shielding properties, velocity factor, bend radius, and insulation.

When selecting coax cable for an application, the system designer will need to consider the impedance of the signal source and load, the frequency range over which the cable will be used, and the allowable amount of signal loss at the frequencies of interest. Then other factors will help guide your cable selection. In most cases, maximum power handling capability won't be a key factor, but it should still be considered. If the user is concerned about EMI/EMC issues, selecting a cable with 100% shielding is essential. This will limit the amount of signal leakage from the cable to neighboring cables and also limit the cable's susceptibility to outside interference sources. Another consideration is minimum bend radius. This can be a factor when selecting a cable for use in tight spaces, such as on aircraft or missiles. Exceeding the minimum bend radius will damage the cable and cause other factors, such as impedance, to be compromised.

On occasion, cable velocity factor will be of importance. Velocity factor is the ratio of the speed of signal propagation through the cable to signal propagation in a vacuum (the speed of light). Velocity factors around 66% are common with most polyvinyl chloride (PVC) dielectric cables. Velocity factors in the 80% to 95% range are common in foam or air dielectric cables. The velocity factor will have to be known when trying to phase match cables together or build a coax cable delay line.

Coax cable insulation is important to consider when running them in a vent or plenum or on an aircraft. The PVC-jacketed cables give off a toxic gas when heated. Teflon-jacketed cables are a better choice in high-temperature applications or on aircraft where fires are a possibility.

2.4.2 Connectors and Adapters

Proper selection of connectors and adapters is an essential step in system design. When possible, choose the right connector for the type of cable and type of mating requirements of the equipment involved. Adapters should be avoided, if possible. They tend to be lossy, and they also have a tendency to fail at the most inopportune time. If they are critical to the system design, then use a high-quality adapter designed for the impedance and frequency range required.

Connectors come in a wide range of styles. The specific application will determine the need for constant impedance connectors, high-power connectors, threaded or bayonet connectors, weatherproof outdoor or indoor connectors, and the mating requirements of the equipment and cable being used. Precision connectors are also available for applications where very low losses are desirable.

2.4.3 Coax Switches

Coax switches are uniquely designed for switching RF circuits. They are constructed in a manner that preserves the circuit's constant impedance, usually 50 ohms. Coax switches have very low insertion loss and high isolation between ports. This makes them ideal for low-signal-level or high-level RF applications. Coax switches are the preferred type of switch for high-power applications. The maximum number of switch cycles will be higher if the coaxial switch is operated with the RF power turned off. The PIN (positive-intrinsic-negative) diode switches are much faster than coax switches, but they do not hold up well in high-power circuits where VSWRs exceed 1.5:1.

2.4.4 Terminations

Terminations are used when you want a device to "see" a proper load at its inputs or outputs. Most terminations used in the RF TM world are low-power 50 ohm loads. Terminations are used on the unused ports of directional couplers and on hybrid couplers. Terminations, also known as dummy loads, are also used on the outputs of transmitters during laboratory tests. The main considerations when specifying terminations are impedance and power dissipation. Terminations are usually purely resistive since a reactive termination would have impedance that would vary with frequency. Improperly terminated test equipment could yield erroneous results.

2.4.5 Attenuators

Attenuators are used to lower signal levels to be compatible with more sensitive devices. Attenuators are typically made to cover specific frequency bands and are generally 50 ohm devices. Attenuators come in fixed values ranging from several dB up to 60 or more dB. There are also attenuators of the continuously variable (linear) type or the step variety with discrete steps of 1 or 10 dB.

2.4.6 Directional Couplers

Directional couplers are used in several different ways. One common use is to sample RF signals that are passing through the coupler without disconnecting cables or breaking the RF path. Directional couplers can also be used in a reverse fashion to inject a signal into the primary RF path through the coupler. Directional couplers have an RF input, RF output, and one or two sample ports. The sample ports are coupled to the forward and reverse direction of signal flow through the coupler. They are used to tap signals for monitoring purposes or to inject signals for system testing. Selection of which port you use depends on the direction of signal flow desired. Unused sample ports are frequently terminated with dummy loads.

Primary parameters to consider in the selection of directional couplers are the frequency range, through-path insertion loss, coupling loss, the amount of coupling at the sampled ports (values of 10 to 30 dB are common), and the port-to-port isolation.

2.4.7 Splitters and Combiners

An RF splitter and an RF combiner (not to be confused with a diversity combiner) use essentially the same process to either split or combine signals. Splitters are used to split an RF signal to multiple loads while maintaining the circuit's impedance match. The split is usually 3 dB for a two-way splitter and 6 dB for a four-way splitter, etc. In addition to the signal loss from the split, insertion losses are also encountered.

Conversely, combiners are used to add or combine signals together. The combining is generally in-phase combining of RF signals. These also exhibit an insertion loss.

2.4.8 Isolators and Circulators

An isolator is a device, frequently a ferrite device, which allows RF to flow through it freely in one direction while exhibiting a high degree of attenuation to RF flowing through in the opposite direction. Isolators are commonly used to prevent RF energy from feeding back into the output circuitry of transmitters and amplifiers.

A circulator is a more complex form of isolator that allows RF energy to circulate through it in only one direction and attenuate signals that are traveling in the opposite direction. The important parameters to consider for isolators and circulators are insertion loss (in the intended direction) and isolation of RF traveling in the opposite direction.

2.4.9 Diplexers and Triplexers

These devices are complex networks effectively composed of splitters, combiners, and filters interconnected to achieve a high degree of isolation in a multiband system such as an antenna feed assembly. Diplexers are dual-band devices; triplexers are triband devices. These special devices are frequently used in antenna systems where the antenna is simultaneously receiving and transmitting RF signals. A high degree of isolation is required in this instance to keep the high-level RF signals from saturating the sensitive receive components connected to the same antenna.

2.4.10 Hybrid Couplers

A hybrid coupler is a specific type of coupler used to perform a special function, usually in an antenna system. The most common type of hybrid coupler used in TM applications is the quadrature or the “90°” hybrid. The quadrature hybrid is used to combine two orthogonal signals, usually linear RF signals, (vertical and horizontal polarization) to create a circularly polarized signal from antenna feeds.

2.4.11 Filters

Filters used in TM systems come in many different types for many different applications. The most common types are the bandpass filter, low-pass filter, high-pass filter, and bandstop or “notch” filters. Of these, the most common types in the RF TM world are the bandpass and bandstop filters. Bandpass filters are used in TM antenna feed assemblies to limit the amount of out-of-band RF that enters the sensitive preamplifiers. High-level RF signals, either in-band or out-of-band, will cause the preamplifiers to saturate and become nonlinear. This will result in a huge increase in intermodulation distortion in the receive system.

The bandstop or “notch” filter is used to eliminate a specific band of frequencies from a system. When a specific frequency band is expected to cause interference to your system, use of a notch filter to reduce the level of those signals may be advisable.

Low-pass filters pass all frequencies below a certain cut-off frequency. They are found many times in the output stages of transmitters and amplifiers to limit the spurious and harmonic content of the transmitted spectrum. High-pass filters are used to pass all frequencies above a certain cut-off frequency. They can also be used to limit the amount of RF energy from strong transmitters that enter the front end of an RF TM receive system.

2.5 Transmit Antennas

The most common TM antenna types utilized for aircraft and missile applications are the blade, slot, and several variations of conformal antennas as listed below. The type of test vehicle, flight dynamics, and/or the “available real estate” will dictate the type of antenna to be utilized.

2.5.1 Blade Antenna

Blades are commonly found on aircraft. Blade antennas are simple and relatively inexpensive compared to other antenna styles. Blades can be purchased for any TM band and can also be purchased as multiband antennas (i.e., lower and upper S-bands in one antenna). Blade antennas have an omnidirectional pattern in the azimuth (Az) plane and generally have more limited coverage in the elevation plane. Some designs try to fill in the elevation plane in an attempt to fill the void that typically exists on monopole antennas. The overhead portions of the antenna pattern tend to have many nulls in them.

2.5.2 Slot Antenna

This is a common form of antenna found on missiles, drones, and occasionally on aircraft. The antenna is a flat conformal antenna capable of being attached to the test vehicle's surface. The antenna is sometimes made up of several sections that are fed through a power divider network of some kind to create the desired radiation pattern. Slot antennas are used when the test vehicle's aerodynamics must be preserved, and when it is desired to steer a beam in a particular direction.

2.5.3 Conformal Antenna

This is a common form of antenna found on missiles, rockets, launch vehicles, bombs, and artillery rounds. The antenna is built into the test vehicle's body and often is indistinguishable from the body itself. The antenna is sometimes made up of several sections that are fed through a power divider network of some kind to create the desired radiation pattern. Wrap-around or microstrip antennas are used when the test vehicle's aerodynamics must be preserved and space and weight are prime considerations. Figure 2-19 and Figure 2-20 depict a typical pattern from these types of antennas.

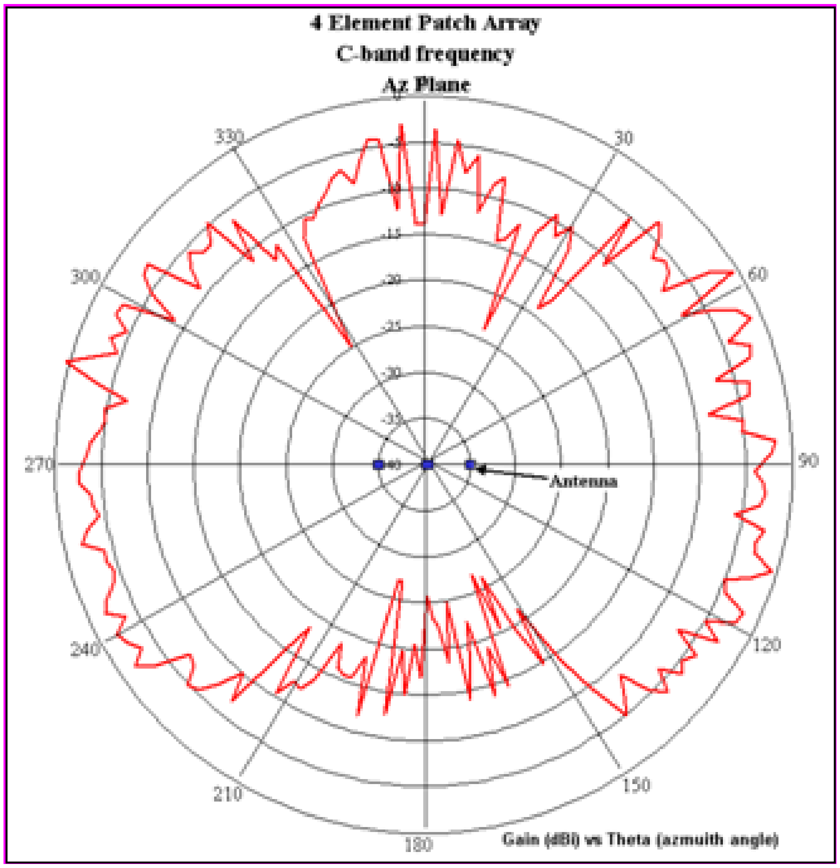


Figure 2-19. Four-element Patch Array Az Plane

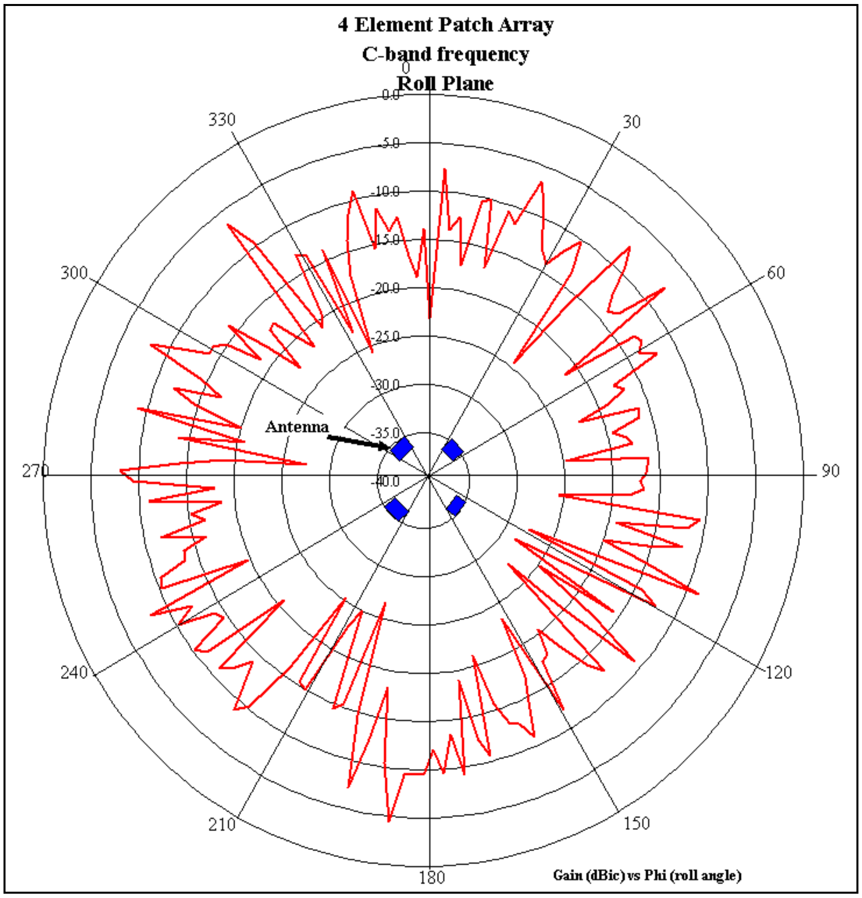


Figure 2-20. Four-element Patch Array Roll Plane

2.5.4 Important Antenna Characteristics

The main electrical (RF) parameters to consider in an antenna are listed below. In addition to these parameters there are other important mechanical, aerodynamic, and environmental parameters to consider when selecting an antenna.

a. Operating Frequency. Operating frequency, or "operating BW," is a critical antenna parameter. This is generally the frequency range over which the antenna will be expected to perform with regard to pattern, gain, impedance matching, etc. The BW is either specified between some upper and lower frequency or as a percentage of center frequency. The operating BW is usually the point where the impedance falls outside the range for a 1.5:1 or 2.0:1 VSWR.

b. Impedance. The antenna impedance must match the transmission line impedance feeding it. In terms of RF, it is generally 50 ohms. If the antenna impedance doesn't match the transmission line impedance, there will be a mismatch (a high VSWR) and reflections will occur. A significant portion of the RF signal will never be radiated by the antenna. Instead, it will be reflected back into the transmitter output, potentially causing the transmitter to fail or causing any number of other problems to occur, such as spurious transmissions or EMI/EMC problems. Matching impedance levels will facilitate maximum power transfer.

c. VSWR. As mentioned above, VSWR is a very important parameter to consider and measure on any antenna system. A poorly matched antenna or transmission line will alter results and may, in fact, cause harm to the transmitter system and perhaps other systems via spurious transmitter outputs. An incorrectly installed antenna can result in a poor VSWR match even if the antenna itself is proper for your application. This is usually the result of improper grounding of the antenna to the test vehicle's ground plane. A good quality VSWR meter will measure the antenna system's match prior to transmitting RF into it.

d. Power Capability. This capability is the maximum amount of continuous or peak power that the antenna can handle without causing damage to itself. For most TM applications, a maximum of 10 W is adequate.

e. Connector Types. The type of RF connector on the antenna is another important item to be aware of. For the most part, connectors at TM frequencies are SMA or TNC connectors. On occasion you may find a type-N connector. The SMA or TNC connectors are preferred over other RF connector types because they are constant impedance, have low insertion loss, and are small in size.

f. Antenna Pattern and Gain

(1) Coordinate System. The vehicle has its own coordinate system (roll, yaw, and pitch) as shown in Figure 2-21. The roll axis is orthogonal to the roll plane. The pitch axis is orthogonal to the pitch plane. The yaw axis is orthogonal to the yaw plane. Angle theta (θ) is measured along the roll axis from the nose (0°) of the vehicle to the tail (180°). Phi (φ) is the measured angle along the yaw vector that starts at 0° and is measured in the counterclockwise direction around the vehicle to 358°. If the object "rolls," it is described as a rotation about the roll vector. Left or right movements are described as movements about the yaw vector. Up and down movements are described as movements about the pitch vector. All three vectors are orthogonal to each other.

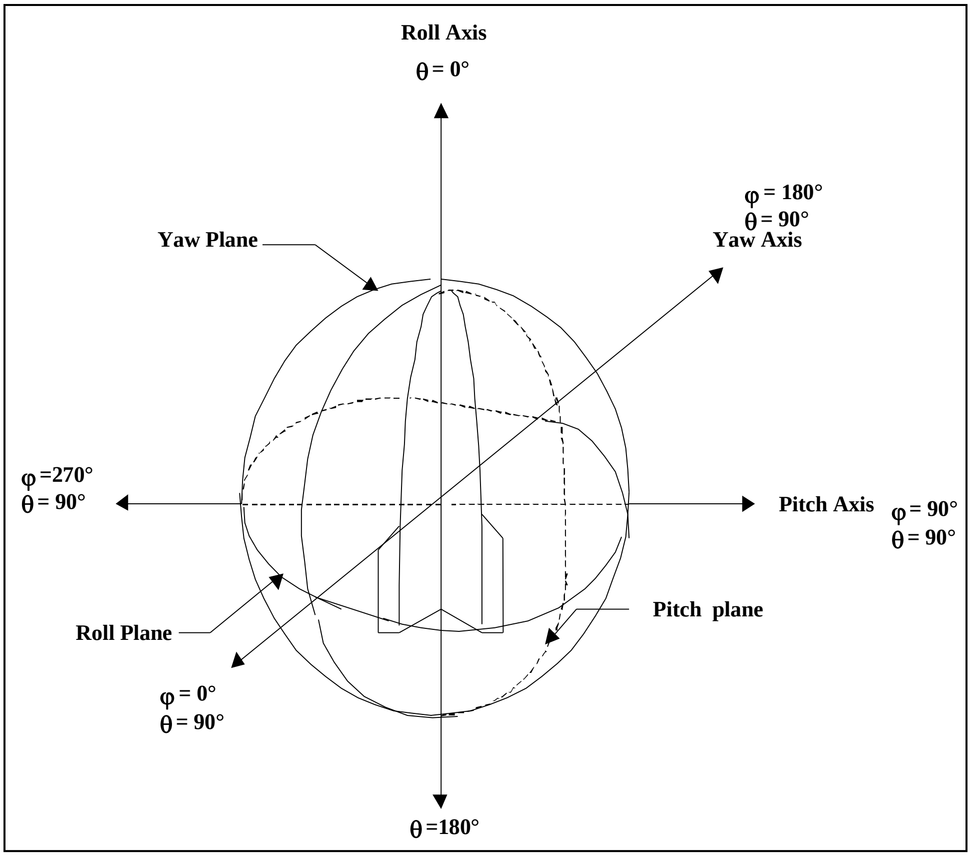


Figure 2-21. Vehicle Coordinate System

(2) Antenna Pattern. Transmit antenna gain values (from the antenna pattern) vary due to deformities in the vehicle's body (shape, wings, etc.). A polar plot of the transmitting antenna plotted with respect to its location on the vehicle shows where maximum and minimum gain values occur for a particular "cut." Figure 2-22 illustrates a vehicle's polar plot for the pitch plane, a principal coordinate plane.

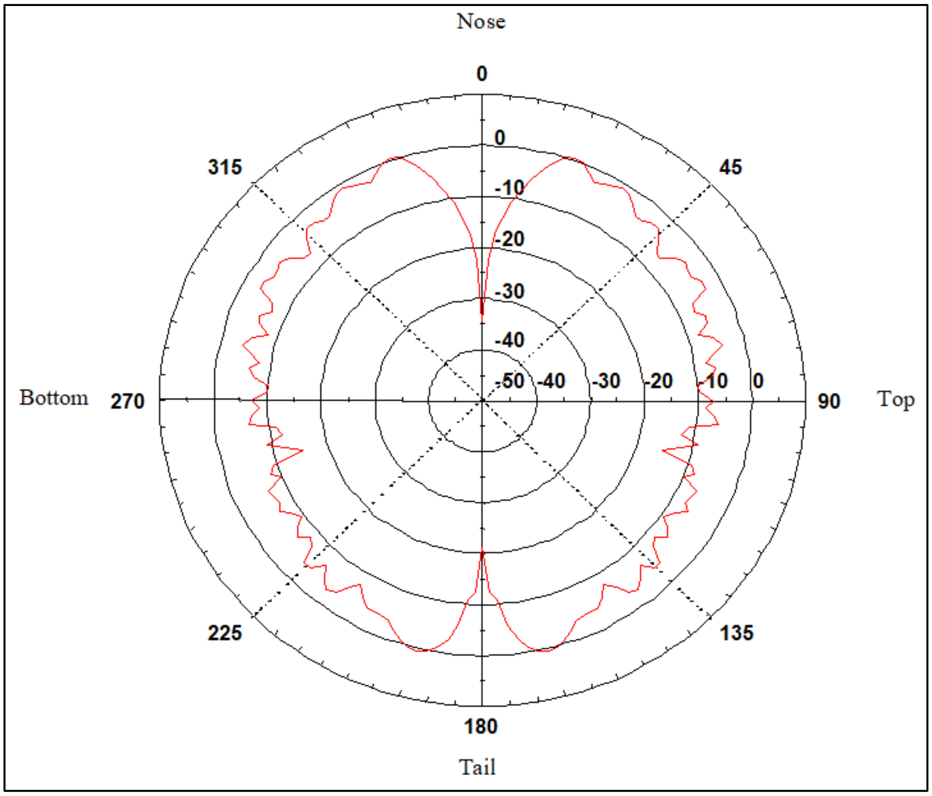
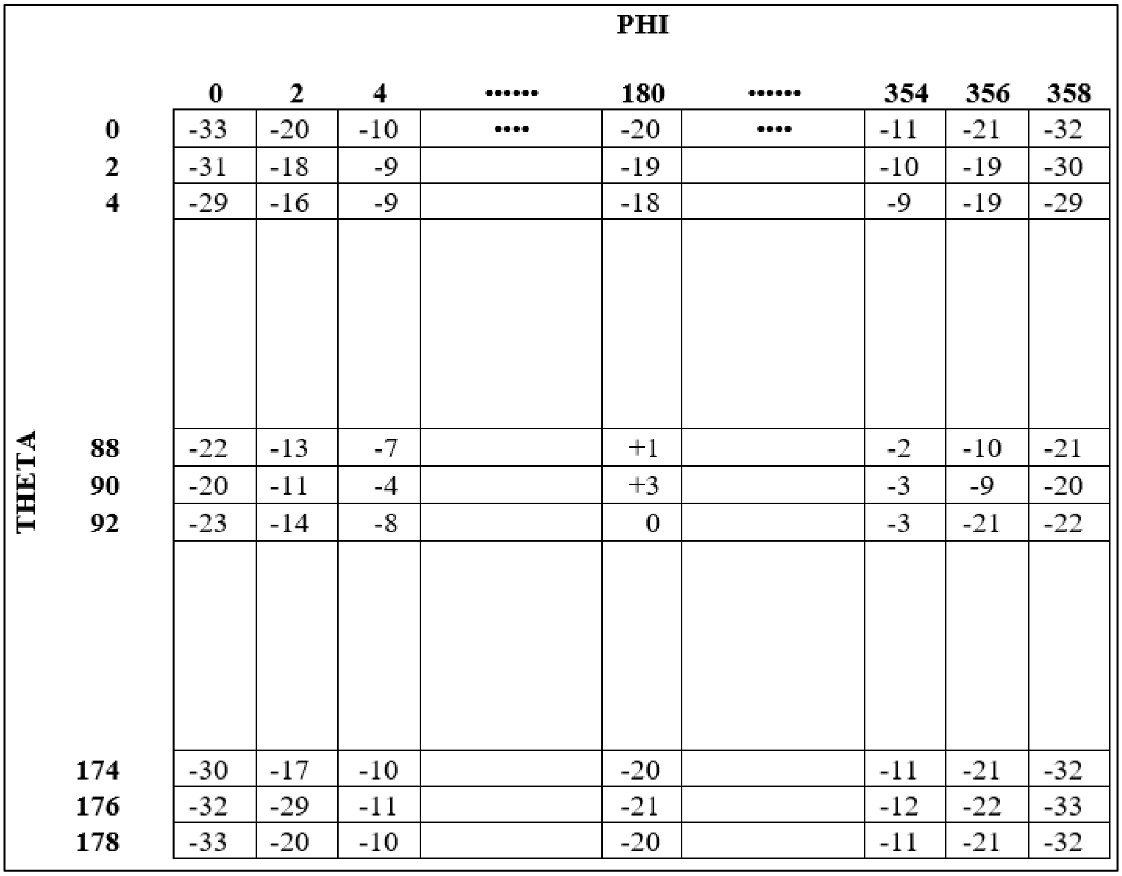


Figure 2-22. Antenna Pattern for Pitch Plane

(3) Antenna Radiation Distribution Table (ARDT). An ARDT consists of the gain values along the sphere of the theta and phi plane. One polar plot set of values for a given theta with phi from 0° to 358° will constitute a row of values in an ARDT as illustrated in Figure 2-23. A complete set of antenna gain values measured every 2° for theta and rotated 360° on phi would yield 90 rows of gain values, or:

$$90 \cdot 180 = 16{,}200 \text{ values}$$

For example, the polar plot in Figure 2-22 yields 180 values for theta and phi from 0° to 360°. The values can be checked on the polar plot shown. The circular levels identify gain values below the antenna's highest value (reference value of 0 dBi [decibel isotropic]). These polar plots are antenna patterns that identify deep nulls. The nulls may not be seen in other pattern types, such as gain values from an antenna radiation table, if the increment value of theta and phi is too high. The polar plot's major disadvantage is that the gain identifies only a particular theta and phi and cannot be programmed to evaluate the entire sphere that characterizes the vehicle.



		PHI								
		0	2	4	••••••	180	••••••	354	356	358
THETA	0	-33	-20	-10	••••	-20	••••	-11	-21	-32
	2	-31	-18	-9		-19		-10	-19	-30
	4	-29	-16	-9		-18		-9	-19	-29
	88	-22	-13	-7		+1		-2	-10	-21
	90	-20	-11	-4		+3		-3	-9	-20
	92	-23	-14	-8		0		-3	-21	-22
	174	-30	-17	-10		-20		-11	-21	-32
	176	-32	-29	-11		-21		-12	-22	-33
	178	-33	-20	-10		-20		-11	-21	-32

Figure 2-23. Sample antenna radiation distribution table

The ARDT illustrated in Figure 2-23 overcomes the problem inherent in polar plots by digitizing the gain values as a function of theta and phi. The major problem with this type of antenna pattern data is that, if the incremental measurements are spaced far apart, nulls could be missed in the evaluation. Gain measurements are normally made in increments of 0.5°, 2.0°, or 5.0° for theta and phi. The smaller the increment, the better the evaluation. The disadvantage is that the smaller the increment, the higher the cost.

Figure 2-23 illustrates this type of antenna pattern table for the polar plot shown in Figure 2-22. Phi (φ) is shown along the horizontal-axis starting at 0° up to 358° in increments of 2°. Theta (θ) is measured along the vertical axis from 0° to 180°, also in increments of 2°. Incremental values of 10° can be used but yield lower resolution values. The recommended increment is 2°.

The table entries represent the gain, in decibels, below and above the reference level. In this example, the reference level is 0 dBi. The gain values are from Figure 2-22 for 0° to 90° in phi at theta = 0°. If you study the polar plot in Figure 2-22 and look at the values entered in Figure 2-23, you can see that most of the low-gain values are found at the vehicle's nose and the tail.

For small missiles, the ARDT is measured in a controlled environment, such as an anechoic chamber. The missile is oriented such that the missile's nose faces the transmitting source. The measurement-start-angle for theta and phi is 0°. The missile is rotated 360° about the center (roll) axis while theta is fixed at 0°. Antenna gain measurements are made at each predetermined increment. After the first set of measurements, theta is increased by the predetermined increment angle and phi-rotated. The process continues until the missile has been rotated 180° in the roll axis (theta). There are occasions when the missile (or object, such as an aircraft) is too large or awkward for this procedure.

g. Polarization. All antennas radiate EM energy, which by definition, is a composite wave consisting of an electric field (E-field) and a magnetic field. An antenna's polarization generally refers to the orientation of its radiated E-field with respect to the earth. The most common forms of polarization are linear and circular. A less common form is elliptical.

Linear polarization can be further broken down to "horizontal" and "vertical" (the E-field propagates parallel or perpendicular to the earth's surface). The antenna's designation as vertically or horizontally polarized is most meaningful for stationary antennas whose orientation isn't changing with respect to the earth. For aircraft and missiles, which are spinning or constantly changing orientation, these terms aren't particularly meaningful. The important aspect would be that they are linearly polarized. Blade antennas, which are common on aircraft, are generally linearly polarized.

Circularly polarized antennas are ones in which the E-field rotates circularly as the signal propagates through the atmosphere. These antennas are either right-hand-circular polarized (RHCP) or left-hand-circular polarized (LHCP) as dictated by the E-field's rotation direction. Some antennas, such as the helix antenna, generate circularly polarized signals due to their mechanical (spiral) construction. Others generate a circularly polarized wave by combing horizontal and vertical linear elements through a 90° polarization hybrid.

h. Radiation Efficiency. The antenna's radiation efficiency is a measure of how much of the RF signal, applied to its input, is radiated rather than dissipated by some other means. Generally speaking, this can be directly related to the antenna's input impedance. Most antennas are designed to have an input impedance of 50 ohms. This is primarily because most radio systems and coaxial cable transmission lines are also 50 ohms. When your signal source (transmitter) matches your transmission line and your transmission line matches your antenna, maximum power transfer and minimum VSWR are achieved.

Antennas are tuned circuits. They exhibit a 50-ohm impedance at their resonant (design) frequency, where the input impedance is purely resistive and any reactive components are canceled out. When operated above or below their operating BW, they begin to exhibit significant capacitive or inductive reactance properties. An antenna's input impedance under these circumstances has a resistive and reactive component to it. Antenna radiation efficiency is highest when the reactive components are at a minimum, and the purely resistive components are at a maximum. This is because the resistive portion of the antenna impedance is the only part capable of radiating energy. The reactive component will generally dissipate the energy as heat.

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CHAPTER 3

RF Channel

3.1 TM Bands

Specific frequency bands (listed below) are allocated for TM use in the United States (U.S.). Additional information regarding TM frequency bands and spectrum utilization can be found in IRIG-Standard 106. Frequency allocations for TM and other services change occasionally, so the user is advised to contact their local frequency management office prior to planning any new system designs and/or tests to ensure compliance with current regulations.

3.1.1 Lower L-band (1435 – 1525 MHz)

This band is commonly used for aircraft and other “manned” flight tests that require TM support. L-band users are advised to pay close attention to the potential of L-band transmitters interfering with GPS receivers on board their test vehicles. Steps can be taken to ensure compatibility. This is also a common band used by targets and drones.

3.1.2 Upper L-band (1755 – 1850 MHz)

This band is occasionally used for TM, but not on a wide scale. It is generally used for video applications. It is not an official band allocated for TM use, but it can be considered when planning a new flight test program if the local frequency management office approves it.

3.1.3 Lower S-band (2200 – 2290 MHz)

This band is commonly used for missile, spacecraft, and other “unmanned” flight tests requiring TM support.

3.1.4 Upper S-band (2360 – 2395 MHz)

This band is slowly being reallocated for other non-DoD uses. There is currently only 30 MHz of the original 80 MHz remaining for aeronautical TM usage. This band has not been designated specifically for manned or unmanned use, so either application is acceptable.

3.2 TM Channel Model (Multipath)

Multipath is an everyday occurrence at test ranges that telemeter data from airborne test articles to ground stations. Multipath interference is a problem in most wireless communication systems and occurs when there are multiple paths between the transmitter and receiver causing signal fading and signal outages (see Figure 3-1). With direct LOS being the exception, these other propagation paths are the result of reflections due to the physical environment and its geometry relationship with transmitting and receiving locations. The amount in which these reflections cause distortions is dependent upon the relative amplitude and phase of the reflected signals and the receiving antenna’s characteristics.

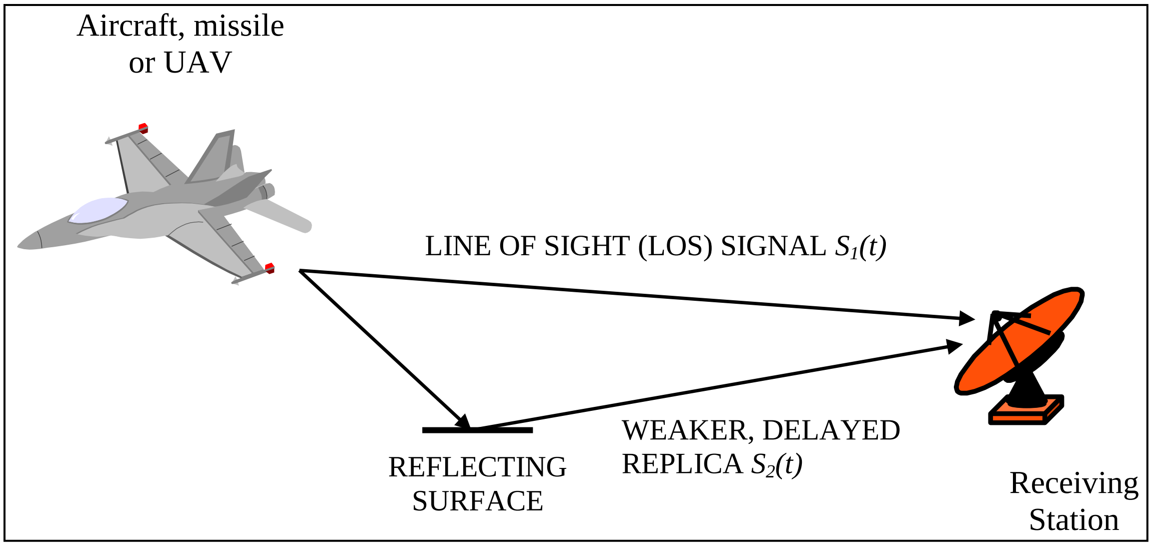

Figure 3-1. Multipath

Channel models are mathematical representations of how the physical environment affects the transmitted signal. Another way of saying it is that the model should represent how the multipath will affect the received (and transmitted) signal. They are important for assessing modulation schemes, equalization strategies, and coding techniques for a given environment. Without these models, multipath mitigation simulation of these methods and others would have little value. Models are broken into two types: narrowband and wideband.

Coherence BW will be discussed when explaining these models, so a definition is required. Coherence BW is a statistical range of frequencies measure in which the channel is considered “flat” (i.e., the channel passes the signals with equal gain and linear phase).

- Narrowband channel models are appropriate for situations where the signal BW is much less than the coherence BW of the multipath fading process. This means that the individual reflections due to terrain are not resolvable in the signal BW. For example, such models are the Rayleigh and Rice channel models.
- Wideband channel models are used when the signal BW is close to or exceeds the coherence BW of the multipath fading process. For this case, individual reflections are resolvable in the signal BW. This can be modeled as a tap delay line with time varying coefficients to account for the time variations in the multipath.

Many channel sounding flights over Edwards Air Force Base (AFB) took place in both the land S-band TM bands to illuminate the TM spectrum and measure how the environment affected the transmitted signal. This information was delivered to the Telemetry Lab at Brigham Young University for analysis and to derive a model for the aeronautical TM channel. In most test cases, an airborne platform radiates the modulated carrier through an omnidirectional antenna. It should be obvious that energy is transmitted in all directions with the receive station being in one of these directions. It should also be obvious that multiple rays will be received at the receive antenna dispersed in time. When the data was analyzed, this was indeed found to be the case.

The wideband channel model for aeronautical TM is composed of three propagation paths: one LOS direct path and two specular reflection paths. Equation 3.2-1 for the wideband channel transfer function can be defined as:

$$h(t) = \delta(t) + \sum_{k=1}^{L-1} \Gamma_k \exp\left\{-j\omega_c\tau_k\right\} \delta\left(t - \tau_k\right) \qquad \text{(Eq. 3.2-1)}$$

Where:

$\delta(t)$ is the direct path modeled as a unit impulse function
L is the number of rays, 3 for the complete model
Γk is the amplitude of the k-path
τk is the delay of the k-path

The first reflection path is characterized by a relative amplitude of 70 to 96% of the direct LOS path amplitude with a propagation delay of 10 to 80 nanoseconds (ns). This path is the result of reflections caused by ground terrain, mostly by the large lake bed present at the range. The second path has a much lower amplitude and longer delay. The relative amplitude is approximately 2 to 8% of the direct LOS path amplitude with the mean delay on the order of 155 ns with an rms spread of 74 ns. This second reflection is dependent upon flight profile and terrain.

For most TM signals, the applicable model to use is the wideband model. The other choice is the narrowband model. Flight data from Edwards AFB, Patuxent River Naval Air Station (NAS), and White Sands Missile Range were analyzed and the following model is presented.

The narrowband channel received signal (Equation 3.2-2), $y(t)$, when assuming a narrowband model, can be represented by:

$$\begin{aligned} y(t) &= As_0(t) + Bs_0(t-\tau_{\text{sp}})\exp\{j\Delta\omega_{\text{sp}}(t-\tau_{\text{sp}})\} + \sum_k a_k s_0(t-\tau_k)\exp\{j\Delta\omega_k(t-\tau_k)\} \\ &= \underbrace{As_0(t)}_{\text{line-of-sight component}} + \underbrace{Bs_0(t-\tau_{\text{sp}})\exp\{j\Delta\omega_{\text{sp}}(t-\tau_{\text{sp}})\}}_{\text{specular reflection component}} + \underbrace{\xi(t)\exp\{j\Delta\omega_{\text{diff}}(t-\tau_{\text{diff}})\}}_{\text{diffuse multipath component}} \end{aligned}$$

(Eq. 3.2-2)

The LOS component has $s_o(t)$ as the transmitted signal with A amplitude. The specular reflection component has the transmitted signal with τ_{sp} average time delay with B amplitude and $\Delta\omega_{\text{sp}}$ Doppler shift. The diffuse multipath component consists of all other low level multipath reflections, which gets modeled as a random component $\xi(t)$, τ_{avg} average delay, and $\Delta\omega_{diff}$ average Doppler shift.

If a narrowband model is assumed, per the coherence BW criteria, the transmitted signal's OBW must be small. If this is the case, the transmitted signal is probably PCM/FM (or continuous phase frequency shift keying). The PCM/FM Signal Definition (Equation 3.2-3), $s_o(t)$ can be expressed as shown:

$$s_o(t)=exp\{j\pi hbnt/Tb\} \qquad \text{(Eq. 3.2-3)}$$

Where:

h is the modulation index, 0.7 for IRIG-Standard 106 recommended PCM/FM
bn is the information bit (+1 or −1)
Tb is the bit time.

After data analysis of the channel characteristics, it is noted that the channel is a function of three parameters, relative Doppler shift Δω, and two quantities defined in Equation 3.2-4 as:

$\Gamma = B^2/A^2$, which is the specular to direct power ratio, and (Eq. 3.2-4)
$\kappa = A^2/2\sigma d^2$, which is the direct to diffuse power ratio

For the test ranges analyzed, the specular to direct power ratio, Γ, varies from 0 to 1, the direct to diffuse power ratio, κ, varies from −48 to 25 dB with most values between 10 to 20 dB, and the relative Doppler shift, Δω, varies from 0 to 1.45 Hz.

The equations given above mathematically describe the TM channel and explain the anomalies that are present in everyday flight operations. To better understand the channel effects, lab experiments were conducted to represent what is typically visualized in TM receive stations and control rooms during flight test activities. The following examples are representative of modulated signals that have been corrupted by the transmission channel.

Figure 3-2 and Figure 3-3 represent PCM/FM and SOQPSK-TG waveforms with and without channel impairments. The three plots show:

- The unimpaired waveform or “reference” in the plots.
- A second ray incident on the receive site delayed by 50 ns and attenuated by 1 dB from the LOS path.
- A second ray incident on the receive site delayed by 300 ns and attenuated by 1 dB from the LOS path.

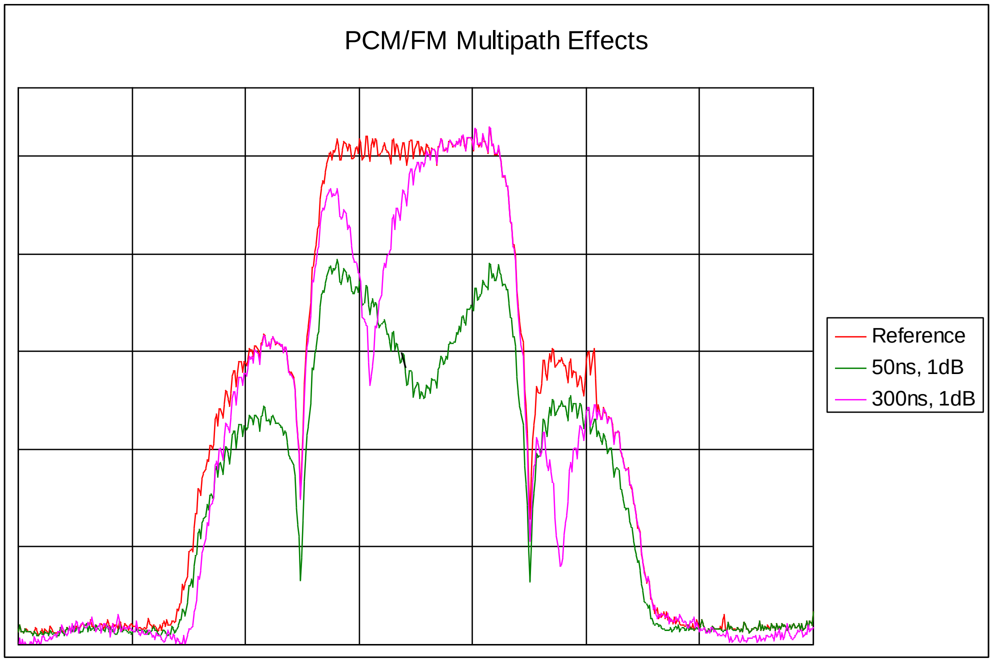

Figure 3-2. PCM/FM Channel Impairments

These plots are intended to show what the spectrum may look like under multipath situations. During these times, the demodulator may interpret the waveform incorrectly leading to bit errors, or, for a very severe event, such as those depicted, lose synchronization entirely.

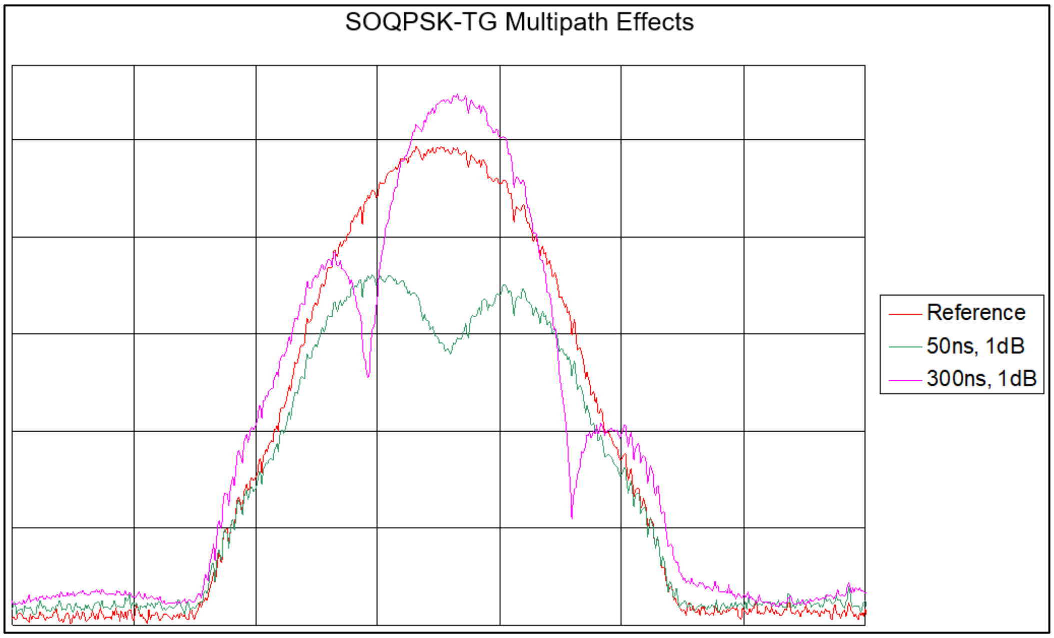

Figure 3-3. SOQPSK-TG Channel Impairments

Figure 3-4 is shown to illustrate the receiver automatic gain control (AGC) variations through a known flight path. Though nulls in AGC can be attributed to antenna tracking error or poor antenna patterns on-board the aircraft, this particular AGC log shows only nulls caused by multipath events. Each null or dip in the AGC value can be attributed to multipath events. For the deeper nulls, the multipath event is such that it appears to be a flat fade at the ground station.

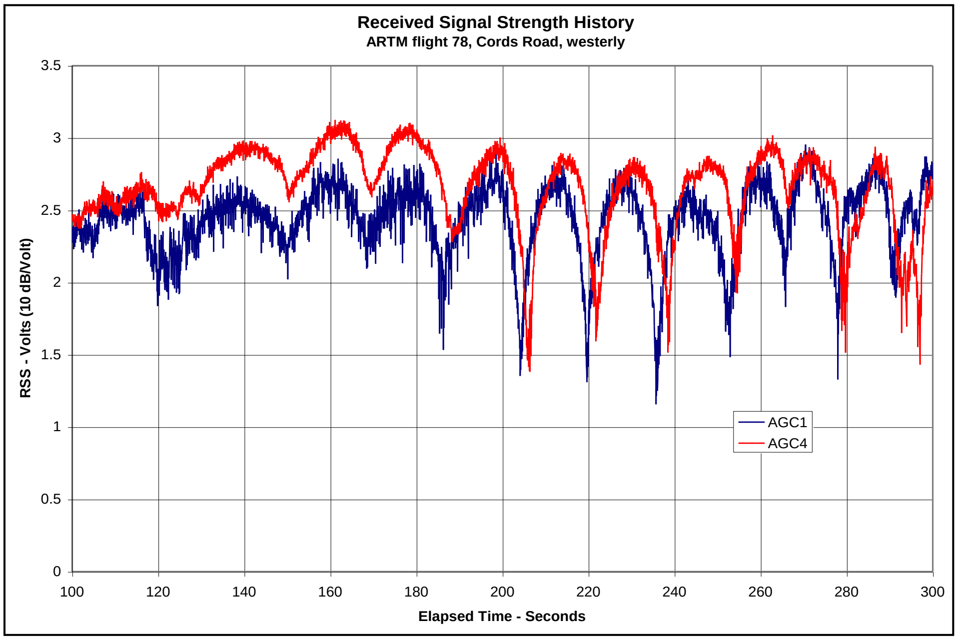

Figure 3-4. Receiver AGC

3.3 Other Channel Anomalies

The TM RF path characteristics can vary significantly from one test range to another. In addition to multipath, other RF path characteristics that may be encountered that could severely limit an RF link's quality. Several significant examples of these are described below. These can be major obstacles requiring careful consideration in the test-planning portion of any mission. Steps can also be taken to reduce the effects of these phenomena when designing TM ground stations.

3.3.1 Shadowing

Shadowing is a physical blockage of the LOS RF path between the transmit antenna and the ground station receive antenna. This is generally caused by obstruction or blockage by terrain, or by fuselage and/or wings. When maneuvering aircraft or missiles fly behind hills or into valleys, or when aircraft taxi behind buildings, a physical blockage or attenuation of the RF path occurs. Since TM signal propagation is almost totally dependent on the LOS path, this blockage will result in a near total loss of signal at the receive site. The only way to combat this form of path anomaly is to augment your primary receive site with additional sites having different coverage areas.

When aircraft or missiles maneuver, their own surfaces (i.e., wing or tail sections) can block or attenuate the LOS path for brief periods of time. These dropouts in signal will generally be short in duration, but still unacceptable to most test programs. The most common way to combat this problem is by the installation of multiple, strategically located, TM antennas on the test vehicle as specified in Section 1. The transmitter outputs are then split between the antennas, increasing the likelihood that at least one antenna will always be in view of the ground station at any given time. There is, however, a down side to this approach. When multiple antennas are used in an array, the resulting radiation pattern may be completely different than expected. The RF energy from the individual antennas will combine, in and out of phase, creating peaks and nulls in the antenna pattern. This can be modeled and measured. Care should be taken to ensure that the resulting pattern is desirable for your specific application.

3.3.2 Plume Attenuation

Plume effects occur when TM receive antennas are pointed at the plume of a rocket or missile to receive TM data. Plume studies are done on every new missile or rocket, but the reports are typically classified. The distortion caused by the plume is heavily dependent upon the motor type. Solid propellant motors normally have more severe effects on the TM signal than liquid propellant motors. This is due to the quantity of the particles within the plume and their size. Through measurements, studies, and analysis, the TM signal fades have been characterized to occur randomly over a range of 500 to 25 kHz with fade durations as small as 0.04 milliseconds (ms) but averaging 0.1 ms.

One mitigation technique is to not position the receive antenna where its look angle is looking through the plume. Side-look TM receive antennas are typically deployed to mitigate the plume look angle problem. A second mitigation technique involves polarization diversity. In the past, the observation has been made that signal fades when received through RHCP and LHCP receive antennas are sometimes independent. There is a drawback to these two techniques though. How do you determine which antenna is receiving the best TM signal, and how and when do you switch? One way to determine this is a combining technique that uses TM receivers' AM-detected IF signals and AGC voltages along with its own phase lock loop. Keep in mind that for any combining technique to work, independent (diverse) sources of the TM signal are required. For mitigating plume effects, the diversity combiner circuitry must be able to correctly determine and select the best channel at a very high sampling rate to recognize independent channel dropouts of perhaps 0.04 ms duration.

3.3.3 RF Blackout

This condition typically occurs during spacecraft or ballistic missile reentry into the earth’s atmosphere. During reentry, highly ionized gases surround the vehicle resulting in the RF energy’s absorption. As the ionized gasses dissipate, the vehicle’s RF energy can again propagate outside the vehicle’s bounds. The RF blackout periods can last up to several minutes in duration.

3.3.4 Ducting

Ducting is a phenomenon in which an RF signal propagates along a path as if controlled by some form of guide or “duct.” This can cause problems in that the signal could possibly skip over its intended target since it is constrained by the duct. The most common example of this occurs when a signal is propagating through a nonhomogeneous atmosphere where there are several distinctly different layers of atmospheric density. For example, this can occur when there is a layer of hot air rising up from a very hot ground in summer. Depending on the frequencies involved, the RF signal will have a tendency to bounce off the different density mediums, causing it to travel as if it were in a “duct.”

3.3.5 Radio Horizon

Radio waves at TM band frequencies generally travel a direct LOS path unless affected by some other phenomena as described above. However, there is a slight bending of radio waves that can occur as the signal propagates through a medium (other than a vacuum) such as the earth’s atmosphere. The end result is a lengthening or extension of the radio horizon slightly beyond the optical horizon. The radio horizon’s distance will depend on a number of factors, but it is generally about 10 to 15% farther than the optical horizon.

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CHAPTER 4

Receive Subsystems

4.1 Scope

This section provides an overview of receiving system characteristics that are important for obtaining TM data from a radiating source. The emphasis is on the RF receiving system and subsystems. The information is intended as a guide to ensure that the receiving system performance is optimized to receive sufficient signal-to-noise (S/N) for a given bit rate. This overview will address subsystem operations, problems, and proven correction methods.

4.2 Introduction

A receiving system receives data via a transmitted modulated carrier. It demodulates the TM carrier, records, and/or relays the data. The received data must be of very high fidelity and as close as possible to a direct replica (error free) of the transmitted data. The transmitted carrier can be in a vehicle that is moving or stationary. A moving vehicle can present four possible challenges to obtaining quality data:

a. Vehicle and tracking system dynamics.

b. Receiving the signal through antenna nulls.

c. Data degradation due to plume effects on the transmitting source.

d. Multipath effects.

Transmitted carrier from a stationary vehicle can be presented with effects from item b and/or item d above.

NOTE	For testing procedures and methods applicable to any subsystem, refer to RCC 118-20 Volume II.

4.3 Antenna Subsystem

The TM tracking systems typically use parabolic antennas/reflectors. The goal is for the reflector to intercept as much energy as possible in the “mainlobe,” but some energy spills over the edges creating sidelobe levels. Sidelobes can be described as wasted or unwanted power levels that could actually interfere with automatic tracking.

Reflector selection is governed by TM requirements, such as desired gain, sidelobe performance, system dynamics, and cost. The antenna should also be of a size, as large as practical, to meet the mobile or fixed-site requirements.

The major problem with reflector antennas is obtaining a good relationship between the tracking feed and the reflector. When the feed is defocused along the axis of symmetry, the condition is known as a quadratic or “square-law” phase error. The parameters affected are antenna gain and the first sidelobe amplitude levels. The phase errors can cause the nulls between the sidelobes and the main beam to disappear. The main beam looks like a roll-off and the first sidelobe amplitudes are no longer distinct. When the feed of a paraboloidal reflector is displaced from its focal point and off-axis, the main beam moves in opposite direction. This yields lower gain and higher sidelobe levels. The end result is poor tracking performance.

The following describes the antenna feed assembly subsystem (AFAS) structure.

a. Purpose. The AFAS' purpose is twofold. The primary purpose is to receive the RF signal from the intercepted space wave that is within the antenna elements' designed RF BW. The second purpose is to produce error signals that generate the torque (current) to the Az and El drive motors that rotate the antenna enabling it to follow the source of the carrier frequency automatically if it is moving in space.

The AFAS unit should be located at the focal point of a typical parabolic reflector to maximize the received signal level while minimizing the tracking error. The tracking errors at antenna boresight, or RF center, should indicate low (if any) amount of (Az/El) crosstalk. The first sidelobes should be 16 to 22 dB down from the mainlobe to enhance low-elevation, automatic tracking and to minimize interference.

There are three basic types of tracking feed assembly subsystems. One is the single channel monopulse (SCM), which is a diode-switching scanned feed designed to generate the tracking errors. The second one is a conical-scan feed (CSF). As the name implies, a cone, which is derived from a nutation (or "wobble") effect from a moving part (typically a horn antenna), is used to generate the tracking errors. The third type is an electronically scanned feed. It combines the best features of the SCM and CSF to generate the tracking errors. Application and cost considerations will govern the selection process.

b. *f*/D Ratio. Regardless of the feed type used, a very important factor to consider is the *f*/D ratio (focal distance of the dish [*f*] divided by the diameter [D]). This parameter is a function of the focal length and aperture dimension (see Figure 4-1). The feed should be located at the focal point along the axis of symmetry. At this location, you optimize the antenna gain and have good sidelobe performances. That is, the first sidelobe peaks are optimized. They are located several dBs below the main beam's peak. The first sidelobes' peak amplitude at 18 dB below the main beam's peak is considered a good measure. The lower the first sidelobes' peak, the better the antenna's performance.

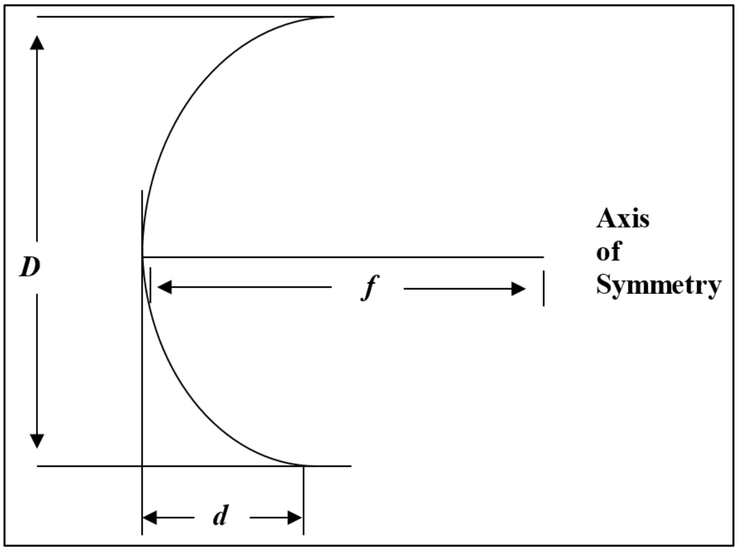


Figure 4-1. Measurements Used to Calculate *f*/D Ratio

The latest designs of feed assemblies have shown typical sidelobe peak levels at 21 dB below the mainlobe beam. Also, proper location of the feed assembly at the focal point will yield deep, sharp nulls between the first sidelobes and the mainlobe. Optimizing these parameters will also minimize the effects of multipath transmissions.

A range user decides the size of antenna he needs. The antenna could be used to track satellites, aircraft, missiles, helicopters, etc. If the system will be used to track all of the above, the recommended optimization should be for tracking high-dynamic vehicles, such as missiles.

The *f*/D ratio's determination now becomes more critical. This ratio represents the relationship between the tracking error modulation and the tracking error gradient. The tracking error modulation should be high enough to allow a linear error-tracking gradient for the RF band(s) in which the system will operate. Optimizing these parameters will decrease crosstalk between the Az and El tracking errors. Optimizing the tracking error gradient involves the curvature (depth) of the parabolic reflector.

NOTE	Some equations in this section are presented in MSWord Equation Editor format. When downloading this document into a software program that does not contain Equation Editor, there may be some alterations in the equations. Please review those equations carefully.

From equation:

$$f = D2 /(16 \bullet d) \qquad \text{(Eq. 4.3-1)}$$

where:

f = focal length
D = antenna's diameter
d = antenna's depth

and the focal point is a function of the antenna's depth and diameter. The depth is measured from the rear of the reflector to the front as shown in Figure 4-1. The *f*/D ratio will be a value greater than zero and less than 1.0.

$$0.0 < f/D < 1.0$$

The higher the *f*/D ratio, the sharper the tracking error modulation. An *f*/D ratio from 0.5 to 0.7 should yield tracking modulation with minimum crosstalk. Optimization of the *f*/D ratio can be seen on feed assembly units (FAUs) that use scanners for beam switching or conical scanning.

The scanned beams' secondary antenna patterns, when plotted together, will show the main beam crossover point. If one beam pattern has a higher gain level than the other, the overall antenna gain will decrease and the system will exhibit crosstalk within the linear tracking error gradient. All parameters must be optimized together, which is a difficult, but not impossible, task. Once optimized, the spars should be pinned to the reflector and the feed assembly cage to allow feed removal and reassembly at the same focal point. This will also keep the feed from becoming skewed or defocused.

c. <u>SCM</u>. This type of tracking feed assembly consists of a sum channel (Σ) and a difference channel (Δ). The sum channel is also known as the data channel for receiving the carrier frequency (modulated or unmodulated). The difference channel (Δ) generates signals (known as tracking error signals) for automatic tracking. Dipole antennas are typically used and tuned to the frequency band(s) assigned for TM. If the frequency band is very wide, such that it covers more than one band, as from 1400 - 2400 MHz, it becomes difficult to tune the dipole antennas. The end result could be unwanted crosstalk, lower gain, a higher axial ratio, and possibly a decrease in the tracking error gradient linearity.

The sum channel dipole antennas are usually in a crossed dipole configuration as illustrated in Figure 4-2. The crossed dipoles are orthogonal to each other and referenced as vertical and horizontal. The difference channel dipole antennas are also in a crossed dipole configuration, and situated around the sum channel dipole antennas with some isolation for minimizing antenna crosstalk. The sum channel receives the maximum signal level when it is properly boresighted since it is located at the focal point. This position corresponds to where the difference channel generates a minimum tracking error. The sum channel is amplitude-modulated with the difference channel signals that represent the amount of error in Az and El from boresight.

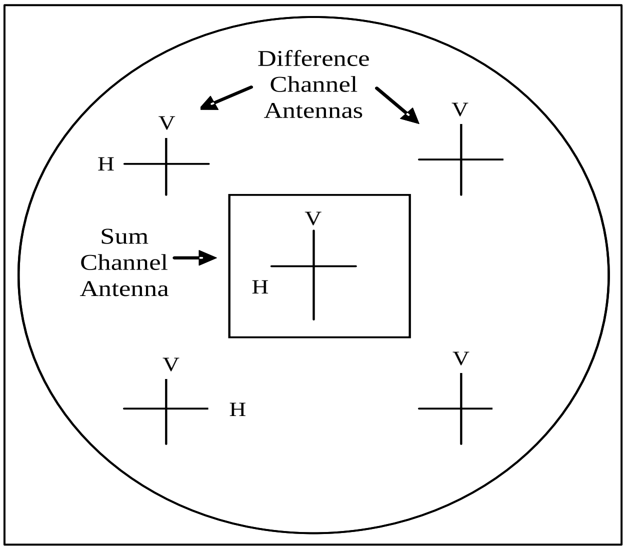
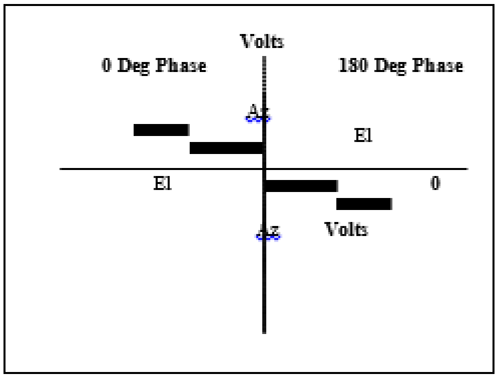


Figure 4-2. Single channel monopulse dipole antennas

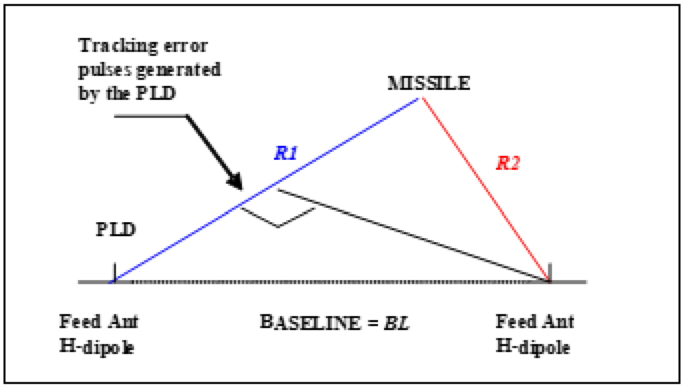
The tracking error signals generated by the difference channel will eventually be converted to a current (torque) to rotate the Az and El servomotors and reposition the antenna back to boresight center. The difference channel is best described as the phase error derived from comparing the arrival of the signal at two dipole antennas. A horizontal movement of the antenna or the source will generate the Az errors, while a vertical movement will generate the El error.

Figure 4-3 illustrates the tracking errors generated by the horizontal and vertical dipole antennas in the FAU. An error is generated from the resulting phase difference between two antennas spaced “x” wavelengths apart. The further the antenna is from boresight center, the greater the error.



NOTE:

The farther the Az/El error pulses are from the reference point, the greater the error. Note that the 0-degree phase equals the "mirror image" at 180 degrees.



PLD:	Path length difference; generates the error that represents how much server oh correction is needed to rotate the antenna back to boresight center; stated in multiples of wavelengths were fractions of a wavelength and equal to r1 – r2.
c/f:	*Wavelength.*
R1, R2:	*Range between missile and antennas at any given time.*
BL:	*Baseline distance between antennas (approximately six inches).*

Figure 4-3. Tracking Errors Generated by Dipole

The error signals use synchronized scanning signals that can operate from low frequencies (Hz) up to high frequencies (kHz). The low scan rate is typically greater than any expected vehicle spin rate to prevent generating errors due to a vehicle spinning. The scanning rates operate in the fixed or swept mode. The fixed mode is usually used for monitoring error pulses while the swept mode is recommended for tracking as it minimizes the effects of multipath. The scanning signals synchronize the developed tracking errors between the scan modulators in the AFAS and the tracking-error demodulator (TED). The TED separates the Az error from the El error.

(1) Antenna Patterns for SCM. The secondary antenna pattern for the sum channel follows the sin x/x waveform. Figure 4-4 illustrates the typical antenna patterns for sum channel (solid line) and difference channel (broken line). Deep nulls should be evident between the mainlobe and succeeding sidelobes if the AFAS is at the focal point. Succeeding sidelobe amplitudes should be lower than their preceding sidelobe level. The first sidelobes should be at least 16 dB down from the mainlobe.

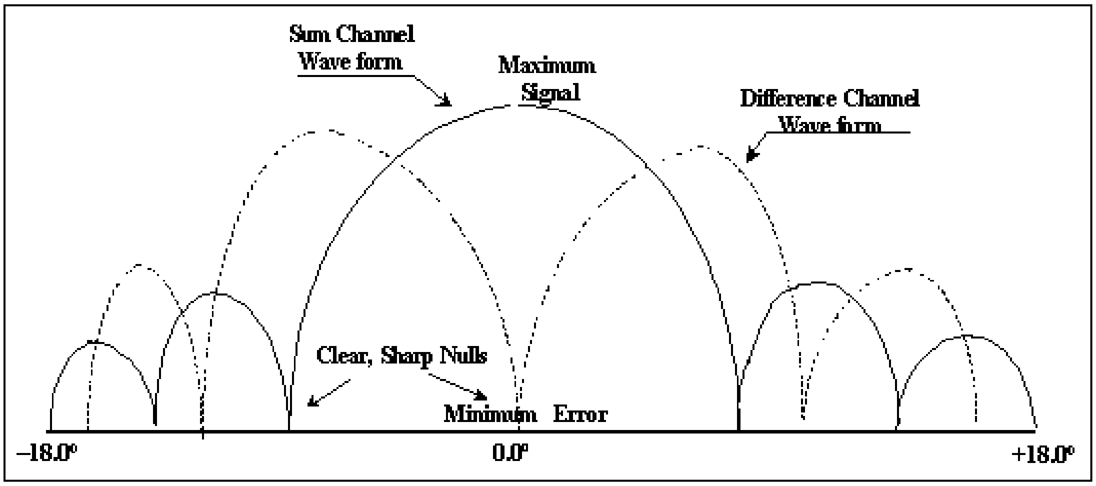


Figure 4-4. Typical Sum Channel and Difference Channel Patterns (Unscaled)

The difference pattern is just the opposite of the sum channel pattern. A deep null in the difference pattern should occur everywhere that the sum channel pattern indicates a maximum signal. Care should be taken to prevent “sidelobe shoulders” where there is no deep null between sidelobes.

Figure 4-4 shows pattern limits to be from −18.0° to +18.0° for examining the mainlobe, and at least the first two sidelobe levels. Antenna patterns can extend from −360° to +360° where backlobes would be evident, but resolution is not very good.

(2) Skew Condition for SCM. The FAU’s skew condition is an example of a phasing problem and may not be obvious to the naked eye. A skew condition can be assessed through an antenna pattern measurement using a boresight source. Knowing the exact Az and El angle between the receive system and the boresight source can help the assessment.

A skew condition can be evaluated by tracking an RF source (using the autotrack mode) radiating from a known, surveyed point, and monitoring the receiver AM output or the input to the TED. The typical four-tracking error pulses (Az/El) for 0° and 180° should be almost a straight line (RCC, 118 V.2). The autotrack Az and El angles between the tracking system and the boresight source should be within 5% (static error) of the position angles to the source for maximum signal. If the antenna movement about the true position angles is greater than the gradient linearity limit, or if the tracking errors indicate a wide dispersion while in the autotrack mode, the system is a good candidate for feed realignment. It is important to confirm that the antenna spars are not loose and causing the FAU to skew. Also, the transmitting source should be located at a distance for far-field analysis, which is determined by the receiving reflector's diameter.

(3) Error Crosstalk for SCM. Error crosstalk in an "elevation over azimuth" system is a very serious problem that can prevent autotracking. Crosstalk occurs when you generate the tracking error in one axis only and the other axis indicates an error that can cause movement. A common symptom is a spiraling movement of the antenna due to the attempts to correct the generated tracking error from an error that is not real. There should not be a crosstalk error indication on the axis that has not been rotated. The tracking error gradient limit should be free of crosstalk. This limit is referenced at the antenna's −3 dB beamwidth. Error crosstalk should be monitored during acceptance testing. Areas of assessment should include the following:

- The parabolic reflector should have an *f*/D ratio set to optimize the tracking performance by increasing the tracking error modulation. The *f*/D ratio is the ratio of the focal length divided by the diameter antenna's (aperture).
- The system's error crosstalk condition should be evaluated using linear polarization and circular polarization transmission sources.
- Error crosstalk conditions should also include verification that multipath is not a source or a result of crosstalk.

A valid check of these conditions should be made if you are not convinced that the feed assembly components are individually or collectively in working order.

d. Conical Scan Feed Assembly Unit (CSFAU). This type of tracking feed is based on the principle of a rotating horn coupled to a motor. Typically, two dipole antennas are orthogonal to each other and directly behind the horn to receive the space energy. The dipole antennas are tuned to the frequency band of interest and can be subject to crosstalk or nonlinear tracking error gradient similar to an SCM feed. The rotation is known as "nutation" or a "wobbling" motion. Most FAUs of this type use a fixed motor speed (usually fixed at 30 Hz) to rotate the horn.

The latest feed units can have variable, rotating speeds to offset any missile rotation that can interfere with the motor rotation speed that affects the generation of the tracking error. The horn is offset to cause the secondary pattern's beam to be reflected off-axis. The rotating horn amplitude modulates the incoming RF energy. The resulting amplitude and phase of the modulation is indicative of the error's magnitude that corresponds to the amount of angular offset from center.

The error information is processed by the tracking receiver AM circuit and separated by a TED into the Az and El position errors. This feed assembly type has an optical commutator that provides two quadrature square waves for reference. The reference signals are synchronized with the receiver AM output to derive the Az and El tracking error signals. The error signals are used to command the antenna to track the radiating source.

(1) Antenna Patterns. Two different types of antenna pattern measurements should be conducted. The first one is with the scanners turned off. This pattern checks for symmetry, sidelobe levels, and beamwidth. The second one involves two sets of measurements with the scanners on. For the first set of patterns, the antenna should

be rotated from right-to-left. For the second set, the antenna should be rotated from left-to-right for the same start/stop angles.

With scanners on, the two traces will look similar to those illustrated in Figure 4-5. Notice that on one trace, one sidelobe is higher than the other. On the second measurement, the opposite sidelobe is higher. The crossover at peak signal should be at the same point. One sidelobe being higher is a condition called "coma lobe." The opposite sidelobe is suppressed. This is due to the nutation movement. The nutation causes the focal point to be displaced off-center as it scans around the main focal point. The crossover point of both patterns should be at the same point. Any displacement of the crossover point indicates decreased gain and error modulation that is not very linear.

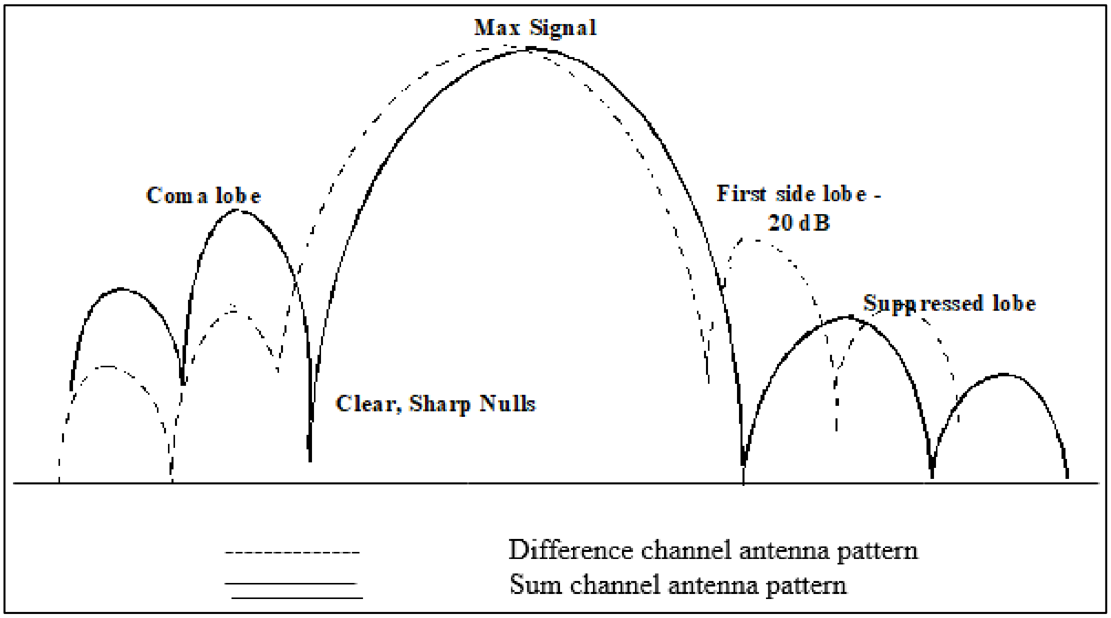


Figure 4-5. Typical Antenna Pattern for CSFAUs

(2) Skew Conditions. A CSFAU's skew condition is an example of phasing problems similar to the SCM feed. The skew condition may not be obvious to the naked eye. It can be assessed by conducting an antenna-pattern measurement using a boresight source. The antenna pattern should be conducted with the scanners turned off to assess symmetry. This ensures that the focal point is centered about the crossed dipoles.

The autotrack Az and El angles between the tracking system and the boresight source are normally within 5% (static error) of the position angles to the source indicating maximum signal. If the antenna movement about the true position angles is greater than 5% of the tracking error gradient, or if the tracking errors indicate a wide dispersion while in the autotrack mode, the system should be checked for skew. The servo subsystem should be checked for any extraneous error that could cause the feed to try to correct a large error that is not related to true angle boresight. It is important to confirm that the antenna spars are not loose and causing the CSFAU to skew.

(3) Error Crosstalk. Error crosstalk occurs when an Az/El tracking error is developed on that axis where no real error has been generated. The optical commutator (rotating disc) has one-half of the disc polished for light reflection and the other half is black anodized for light absorption; hence, it generates a series of square pulses.

The commutator provides the space position references for the scanning antenna feed. The disc is rotated with respect to the horn to maintain correct phasing with the amplitude modulation generated from the horn rotation. By maintaining the signals in-phase, the crosstalk is minimized. Figure 4-6 illustrates the perfect alignment between the reference square wave and the generated sine wave depicting the AM error signal.

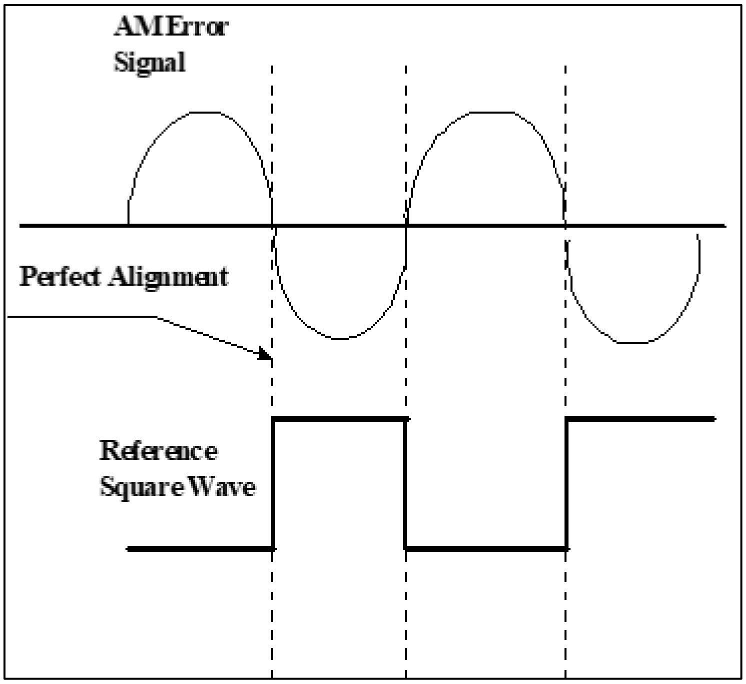


Figure 4-6. AM Error Signal

Crosstalk is also an *f*/D ratio function. The smaller the *f*/D ratio, the less error modulation that can lead to high crosstalk.

e. Electronically Scanned Feed Assembly Unit (ESFAU)

(1) Antenna patterns. The antenna patterns for an ESFAU resembles the patterns for a CSFAU as seen previously in Figure 4-5. This is because the pattern measurements are conducted such that the center cross dipole antennas (sum channel) are scanned along with two of the four difference channel crossed dipole antennas. (The antennas resemble the SCM feed antennas as shown previously in Figure 4-2). This action offsets the focal point to one side, similar to the nutation motion of the CSF's rotating horn. Antenna pattern measurements are conducted by rotating the antenna from the side that has the scanners turned on. One "coma lobe" sidelobe will be seen on one side while the opposite sidelobe is suppressed.

Reverse the process and turn on the opposite difference channel antennas. When the pattern is measured on the same plot as the previous pattern, the results should show the coma lobe on the opposite side of the other coma lobe. The crossover point between the two patterns should be centered and occur at the same point. This indicates good error modulation and maximum gain. One big difference between SCM and electronic scan feeds is that you do not conduct difference channel patterns in the electronic scan feed.

(2) Skew Condition. The information on skew conditions for the SCM (paragraph 4.3.1c(2)) also applies to ESFAUs.

(3) Error Crosstalk. The information on crosstalk for the SCM (paragraph 4.3.1.c(3)) applies here.

4.4 RF Subsystem

The RF subsystem's main function is to amplify the signal the antennas intercept. This subsystem usually consists of a directional coupler, preselector filters to reject out-of-band frequencies, RF preamplifiers, possibly a postamplifier, multicouplers, and the receiver/tuner.

The AFAS selected for the particular tracking system in use receives the maximum signal radiated when it is placed at the focal point. This signal is coupled directly to the filter circuit's input through a directional coupler with the only losses attributed to connections and insertion.

The following describes aspects of the RF distribution subsystem.

a. Directional Coupler. The directional coupler has two inputs. The main input is a straight, minimum-attenuation (insertion loss) path to the filter section. This connection is usually via semirigid cables. The second input is a test signal input via an attenuation path (usually −20 dB) used to attenuate the signal from a signal generator. This is done to prevent overdriving the preamplifiers and to measure the system noise floor or to conduct swept frequency amplitude measurements.

b. RF Semirigid Cables. It is necessary to use short cables to connect the above components to minimize losses. Cables should have at least a ¾ inch length from each end before any shaping is done. The connectors should be torqued to specifications. Over tightening can lead to connection shorting. The cables should be measured for a return loss of no less than 20 dB before AND after shaping.

c. Bandpass Filters. Bandpass filters are based on the AFAS' frequency response. For example, the TM operating bands are L-bands and S-bands. The L-band covers frequencies from 1435 - 1540 MHz. The S-band covers frequencies from 2200 – 2400 MHz. The bandpass filters should correspond to these bands and exclude all other frequencies. The filters' insertion losses are approximately 0.3 dB with band isolation skirts of at least 50 dB.

In lieu of filters, or, in some cases, in addition to using bandpass filters, some systems will have diplexers or triplexers to cover the RF bands. The use of these two components provides the option of using only one RF preamplifier per polarization instead of one amplifier per RF band.

d. Preamplifiers. Preamplifiers should correspond to the AFAS' frequency response. The preamplifier is the first active device in the RF loop. It is the most important component for amplifying signals and for minimizing the effects of noise. This will be further evident in subsequent discussions about noise and the overall gain/temperature (*G/T*) "figure of merit".

The preamplifier should have a flat response over the band where it will be used plus high gain to optimize the overall system gain. It should also have a low noise figure. An amplifier with a noise figure of 0.3 dB is not uncommon and can significantly lower the system temperature and contribute to high *G/T*.

e. Postamplifiers. Postamplifiers are typically used in receive systems to overcome high cable losses where the distance between the RF subsystem and the multicouplers (and receivers) is far. Far is any distance where a line amplifier is needed to overcome high-line losses. The gain is usually between 20 and 25 dB with a noise figure of 5 dB. It should be noted that this amplifier's purpose is to provide an adequate signal strength to the TM receivers. This amplifier's use will not affect the receive system's *G/T* and therefore, can exhibit a higher noise figure.

f. Multicouplers. Multicouplers are active devices with gain ranging from 0 to +10 dB and noise figures of at least 10 dB. They must have a flat frequency response over the same frequency band as the FAU. These devices have one or more inputs and up to eight outputs per input. If the receiving system is configured with tracking receivers and separate data receivers, the multicoupler feeds both.

g. Down Converters. Down converters are used mainly to overcome line losses over long distances. Losses at IFs are much lower than at RF. Down converters also allow for utilization (and selective upgrading) of most equipment as TM moves up in frequency bands.

4.5 TM Receiver Subsystems

The TM receivers convert the RF input signal, usually at L-band or S-band, to an IF signal, usually at 20 or 70 MHz, where it is easier to demodulate the data and to perform receiver checkout tests. The TM receivers can be used for tracking, data demodulation, or both. Tracking receivers are used to drive the autotrack antenna system by way of tracking error signals from the receiver's built-in AM detector. In a TM receiver configured as a tracking receiver, critical parameters include AM (tracking video) performance, AGC setting, AGC time constant, and IF BW filter selection.

In a TM receiver configured as a data receiver, critical parameters also include the demodulator and VBW filter settings. Receivers can perform both functions (tracking, data collection); however, the AGC time constant should be chosen for optimum tracking performance.

4.5.1 Tracking Receivers

Tracking receivers are used to extract the AM (tracking video) signal. The RF input signal is down-converted to an IF where most measurements, such as *G/T*, noise floors, data, and tracking demodulation, take place. The following outlines the key circuitry used for the automatic tracking mode.

a. 2nd IF Bandpass Filters. Tracking receivers are occasionally configured with 2nd IF bandpass filters that are different from those in the data receivers. This is frequently the case when tracking receivers are not also functioning as data receivers. The data receiver

2nd IF bandpass filter selection is generally based on the modulation type involved. For PCM data, the bit rate and code determine the filter size.[6] If the bit rate for a mission is low (up to 2 Mbps), the recommended IF BW filter for a tracking receiver and a data receiver are the same. If the bit rate is high, the following criterion is suggested.

(1) Tracking receiver IF BW filter selection should be based on the minimum IF BW filter necessary to maximize the signal level for autotracking. A good test is to have the antenna respond to pedestal dynamic tests while the radiating source is modulated with the expected bit rate.[7] The tracking receiver is only interested in extracting the AM (or tracking video) and using the correct AGC time constant. A slow time constant (10 or 100 ms) should be used for correct recovery of the error signals. A fast time constant will differentiate the error signals and could give a false indication of no amplitude modulation, with no error signals.

(2) Note that too narrow of a filter tends to mask the AM tracking error signal. This does not mean that the tracking errors are lost. To monitor the error signals, use the IF BW filter for the tracking receiver similar to the filter you will use for the data receivers. After confirming the error signals are present and respond correctly to antenna movements, reconfigure the tracking receiver to the narrow IF BW filter. The narrower the tracking receiver IF BW filter, the lower the noise power.

b. Graphical Representations. In Figure 4-7, Graph A illustrates the AM output with a bit rate of 256 kbps passing through a 100 kHz IF BW filter. The tracking errors are masked. Graph B illustrates the same tracking errors and bit rate, but passed through a wider IF BW filter. The tracking errors are clearer. With the filter BW opened further, as shown in Graph C, the error signals are well defined. However, the noise power has increased as shown in Table 4-1.

Figure 4-8 is similar to Figure 4-7 except that it illustrates different IF BW filters for passing 13 Mbps. In this scenario, if you select the IF BW filter based on the bit rate (1.5 • BR), the filter would have to be 20 MHz! You must be careful not to use too low an IF BW filter even if error signals are present. This could result in narrowing the signal BW and also getting Doppler interference.

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[6] Eugene Law. *Pulse Code Modulation Telemetry: Properties of Various Binary Modulation Types*. TP000025. June 1984. Retrieved 12 January 2021. Available at https://apps.dtic.mil/sti/tr/pdf/ADA147214.pdf.

[7] Moises Pedroza. “Tracking Receiver Noise Bandwidth Selection”, in *International Telemetering Conference Proceedings* 32, pp. 85-92, 1996.

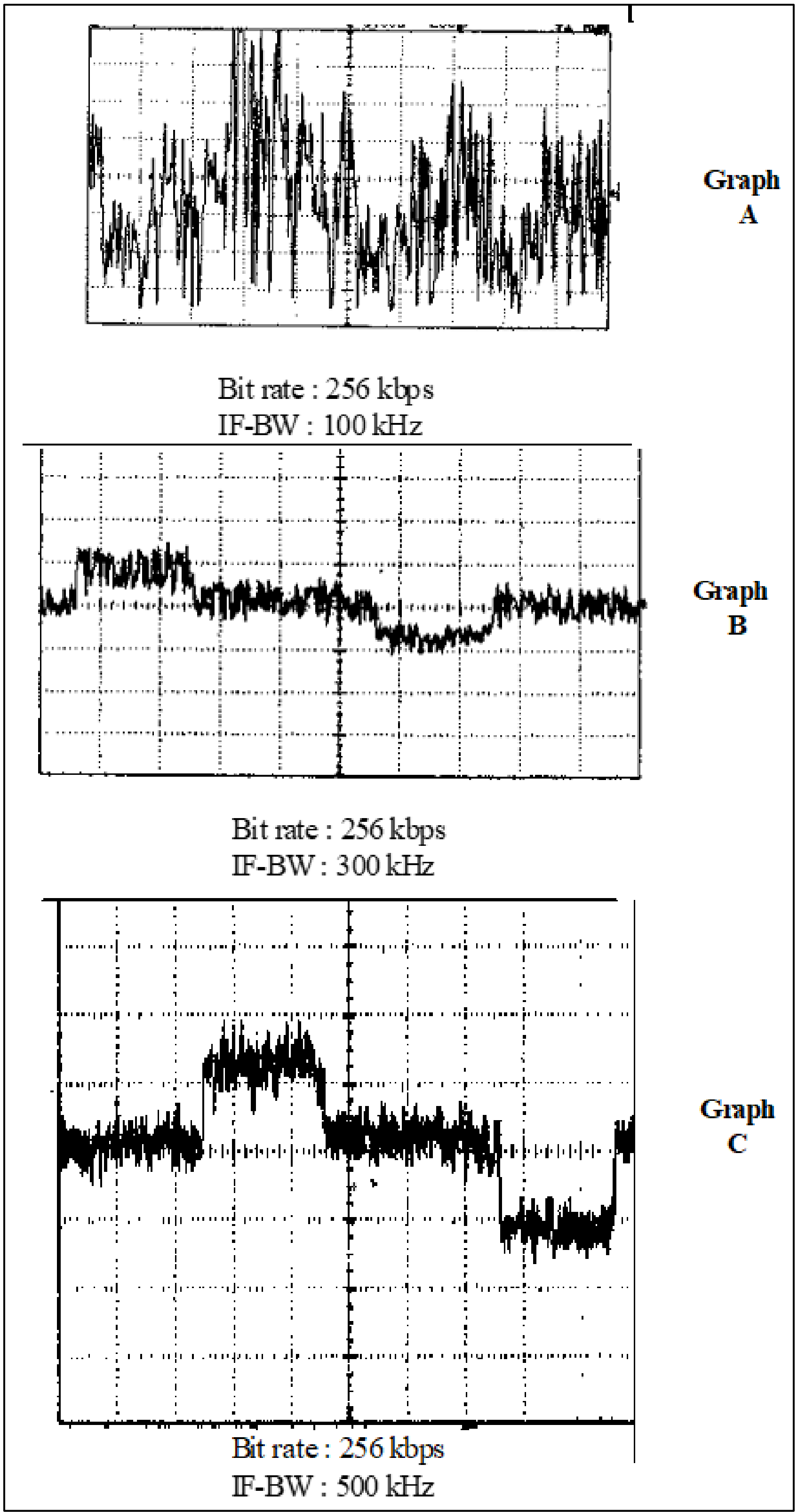
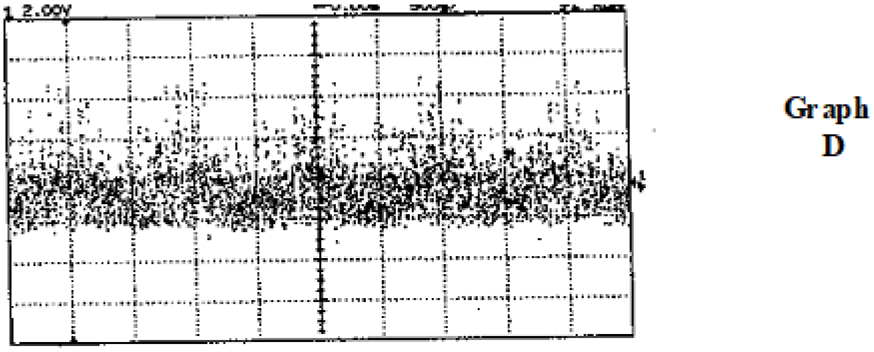
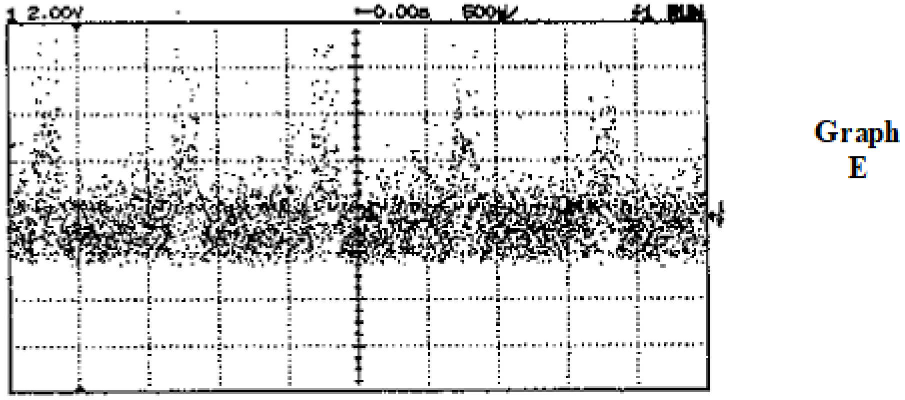


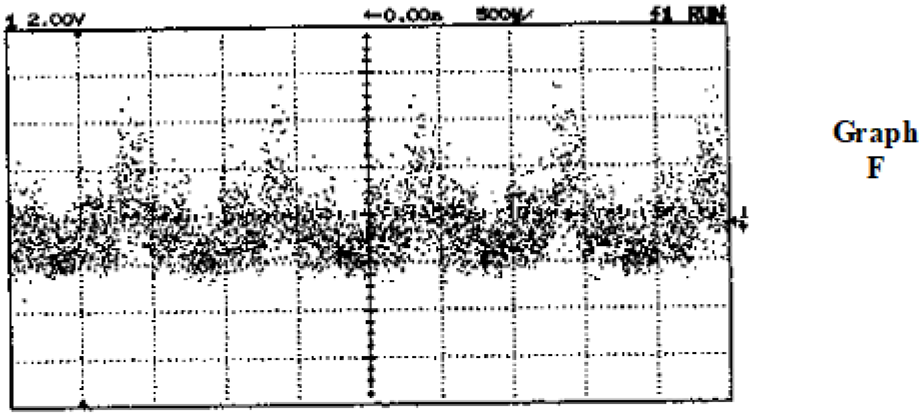
Figure 4-7. Tracking Error Signals A-C



Bit rate: 13Mbps IF-BW: 100 kHz



Bit rate: 13Mbps IF-BW: 1.5 MHz



Bit rate: 13 Mbps IF-BW: 10 MHz

Tracking error signals passing through a 100 kHz, 1.5 MHz IF bandwidth filters. Carrier frequency is 2250.5 MHz modulated with 13 Mbps.

Figure 4-8. Tracking Error Signals D-F

Table 4-1 illustrates the difference in noise power between a narrow IF BW filter based on dynamic response tests and one based on the bit rate. Room temperature of 290 K is used for this example.

Table 4-1. Comparison of Expected Noise Power For Different Bit Rates

Bit Rate (bps)	Filter Criteria 1.5 • Bit Rate	IFBW (Hz)	Noise Power (dBm)
256k	384k	500k	−117.00
500k	750k	1.0M	−114.00
1.0M	1.5M	2.0M	−110.98
1.8M	2.7M	3.3M	−108.80
3.2M	4.8M	6.0M	−106.20
4.0M	6.0M	6.0M	−106.20
6.0M	9.0M	10.0M	−104.00
10.0M	15.0M	15.0M	−102.20
13.0M	19.5M	20.0M	−100.98

Table 4-2 lists the noise contributed by different IF BW filters (B_{2if}) based on $10 \bullet \log_{10} B_{2if}$. It can be seen that the noise contribution increases considerably as the BW increases.

Table 4-2. Noise Contributed by Different IF BW Filters

IF Filter No.	IF Bandwidth (Hz)	Noise Contribution (dB)
1	100k	50.00
2	300k	54.77
3	500k	56.99
4	750k	58.75
5	1.0M	60.00
6	1.5M	61.76
7	2.2M	63.42
8	3.3M	65.19
9	4.0M	66.02
10	6.0M	67.78
11	10.0M	70.00
12	15.0M	71.76
13	20.0M	73.01

4.5.2 Data Receivers IF BW Filters

The criteria for selecting the correct IF BW filters have been well documented (Law, 1991) for PCM data. The same author has an excellent technical publication entitled *Analog Frequency Modulation Telemetry*.[8]

4.5.3 Diversity Combiner

Diversity combiners are used to reduce the RF signal's fading and polarization changes that affect the received data's quality. The RF problems that contribute to fading and polarization are associated with the following:

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[8] Eugene Law. *Analog Frequency Modulation Telemetry*. TP000042. October 1987. Retrieved 12 January 2021. Available to DoD personnel and their contractors at https://search.dtic.mil/#/.

- Signal nulls and polarization changes due to vehicle maneuvering
- Signal nulls due to antenna placement
- Multipath caused by signal reflection
- Ionization caused by exhaust plumes of engines
- Atmosphere's ionization, which can cause fluctuation in the RF signal's amplitude and polarization

A diversity combiner is designed to work with a pair of TM receivers to enhance the signal level. This process is called "optimal ratio combining." The theory behind this method of signal improvement is based on the vector addition of the IF signals or two video signals from two receivers. Data quality can be improved up to 3.0 dB in theory, and 2.5 dB in practice, if the input signals are equal in amplitude and phase and are above the signal threshold, usually set at 6 dB carrier-to-noise above the noise floor. An improvement can be seen if one of the two receivers has a lower signal. When both signals are above threshold, but not equal in amplitude and phase, the combiner can provide some improvement (> 2.5 dB). A further improvement from using a combiner is seen when the signal in one of the two receivers drops below the threshold and becomes too noisy. The diversity combiner will shut off the noisy receiver and use only the signal from the receiver with the stronger signal.

There are two types of diversity combiners used for signal improvement. A predetection (pre-d) (meaning before demodulation) combiner uses IF signals and AGC voltages from each receiver. A postdetection (post-d) (meaning after detection or demodulation) combiner uses video output signals and AGC voltages from each receiver. Pre-d combiners are more complex because of the phase-lock loops required to bring the two signals in phase to achieve an S/N improvement. These are not required for post-d combining. Pre-d or post-d combining can be used with polarization diversity combining.

Post-d combining is the preferred method when using frequency diversity combining. Post-d combining must not be used for BPSK or QPSK modulation schemes, unless you are using a common-phase reference in the associated demodulators, because a data polarity inversion would be possible and a signal cancellation would be the end result. Since post-d combiners may not improve data quality in the presence of impulse noise generated using FM systems when the receivers are operating below threshold, it is preferred that pre-d combining be used for FM systems.

4.6 System Sensitivity

System sensitivity (Law, 1991) is one of the most important characteristics of a receiving system. There is no universal or "standard" definition for this quantity. The most often used criterion is noise floor. Noise floor is where the S/N = 1 (0 dB), or when the signal level is equal to the noise level. The noise floor can be specified for automatic tracking or for processing PCM data based on the IF-BW filter used. The tracking threshold is then set to a minimum value where the servo system will respond to a signal rather than to noise. It can also be set where automatic tracking will not take place if the signal falls below a value where re-acquisition could cause the antenna to lock on a sidelobe.

For a data receiver, the signal sensitivity is equal to the power needed to get acceptable data quality for the given bit rate. This important parameter varies due to external and internal noise. The major contributors are the system noise figure converted to system temperature (T_{sys})

and the receiver 2nd IF BW filter (B_{2if}). The available noise power of a thermal noise source is stated in equation 4.6-1:

$$P = kT_{sys} B_{2if} \qquad \text{(Eq. 4.6-1)}$$

Where:

P = thermal noise power in watts
k = 1.38 • 10−23 joules/K
T_{sys} = system temperature in degrees kelvin
B_{2if} = 2nd IF-BW in hertz

In decibels,

$$P = 10 \cdot \log(k) + 10 \cdot \log(T_{sys}) + 10 \cdot \log(B_{2if}) \qquad \text{(Eq. 4.6-2)}$$

4.7 Signal Margin

Signal margin is the signal level(s) above the power needed to get acceptable data quality. A link analysis predicts the power at the receiver input. The BER test determines the threshold for obtaining acceptable data quality. The use of high bit rates in the missile and aircraft-testing environments requires that the receiving TM system(s) have the sufficient signal margin for no PCM bit errors.[9] This requirement, plus the fact that the use of “redundant systems” is less prevalent, has made it necessary to select the minimum number of tracking sites that will gather the data with the required signal margin.

4.8 Link Analysis

A link analysis is based on the Friis transmission equation (see Eq. 4.8-1). A link analysis is done to determine the received power level between two antennas. The analysis is made using the maximum and minimum gain values from the transmitting antenna pattern. Another common method is to determine the transmit antenna gain that has exceeded some percentage of the time (90 to 95%) and use this value. The best method is to evaluate the transmitting antenna gain along a trajectory based on the missile aspect angles.

$$P_r = P_t + G_t + G_r - L_t \qquad \text{(Eq. 4.8-1)}$$

Where:

P_r = power received in dBm
P_t = power transmitted in dBm
G_r = gain of the receive antenna in dB
G_t = gain of the transmit antenna in dB
L_t = space losses in dB

Most of the time, the link analysis parameters such as a system G/T, transmit power, receive antenna gain, and distance between the source and receive system are easy to obtain. The main assumption is that the transmitting antenna gain is uniformly equal around the transmitting source. If the assumption is true, then a link analysis for a tracking system at a particular site can yield the expected signal margin with the only variable being distance. This assumption can lead

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[9] Moises Pedroza. “Antenna Pattern Evaluation for Link Analysis”, in *International Telemetering Conference-Proceedings* 32, pp. 111-118, 1996.

to disastrous results if the antenna gain is below the minimum signal level required for no errors in the PCM data. The transmitting antenna gain should be evaluated from the ARDT (as in Figure 2-23), as a function of the aspect angles with respect to a proposed tracking site for expected signal margin.

The overall transmitted power is the effective radiated power (ERP). This is determined by the transmitter power (W converted to dBm) minus the line losses between the transmitter and the transmitting antenna plus the transmit antenna gain. The transmit antenna gain is rarely constant as shown in Figure 2-22 and Figure 2-23. Most of the time the transmit antenna gain is affected (lower value) by nulls caused by missile fins, aircraft wings, and overall design of the missile or aircraft body. A main consideration is the receive antenna's location with respect to the proposed trajectory to minimize looking through nulls. The last parameter to consider is the space loss (L_t) in dB as shown in Eq. 4.8-2.

$$L_t = 36.58 + 20 \bullet \log D_m + 20 \bullet \log f \text{ (dB for statute miles)} \qquad \text{(Eq. 4.8-2)}$$

Where:

D_m = distance in statute miles
f = frequency in MHz.

NOTE	Replace the value 36.58 in the above equation with 32.45 if D_m is in kilometers and 37.8 if D_m is in nautical miles.

A quick check of the above equation indicates that the attenuation due to distance increases by 6 dB as the distance doubles. The space loss equation shown above (Eq. 4.8-2) is a special case of the following general expression (Eq. 4.8-3) for space loss (L_t):

$$L_t = 20 \log [(4\pi D_m f)/c] \text{ dB} \qquad \text{(Eq. 4.8-3)}$$

Where:

D_m = distance in meters
f = frequency in hertz
c = speed of light in meters/second

4.8.1 Mathematical Analysis

A mathematical analysis can be used to determine the signal margin resulting from a radiating source along a nominal trajectory. The mathematical analysis calculates the vehicle aspect angles (theta, phi, and alpha) from the vehicle to the TM tracking system that yields the transmitting antenna gain. Figure 4-9 illustrates a missile located at a launcher and later in space, and depicts the parameters needed to evaluate the gain from missile to tracking system. The antenna pattern is given in theta (θ) and phi (φ). Phi (φ) depicts the angle around the vehicle. Theta (θ) depicts the angle from the nose of the vehicle toward the tail.

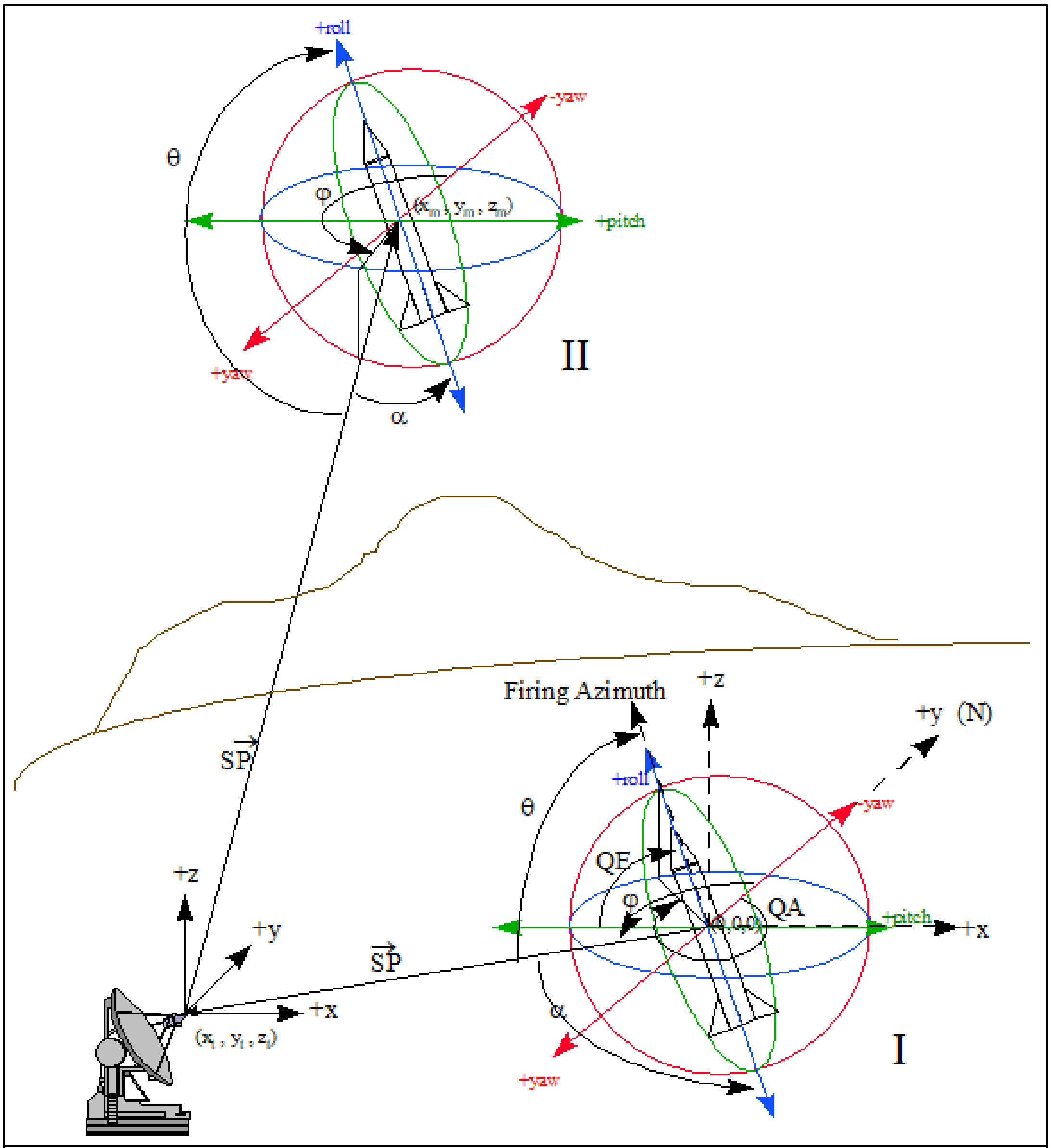


Figure I:	Position of missile on launcher in relation to the tracking antenna	
Figure II:	Position of missile in space in relation to the tracking antenna	
Vector SP:	Space position vector from telemetry antenna to missile antenna	
x,y,z:	Coordinates of tracking antenna to the missile-transmitting antenna	
φ:	Angle around the vehicle	QA: Firing azimuth
θ:	Angle from nose toward tail	QE: Firing elevation
α:	Angle between LOS and vehicle roll vector	

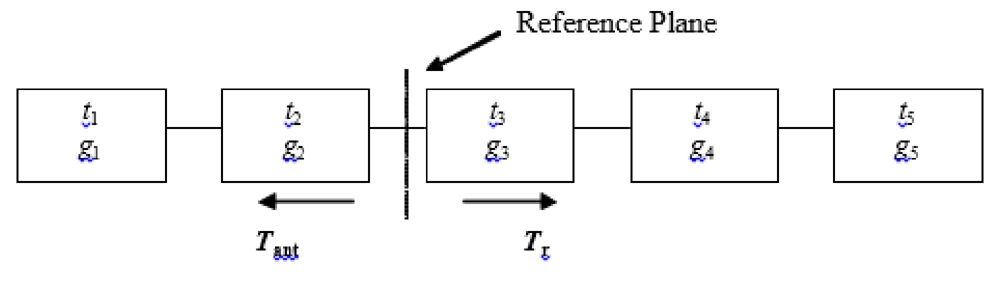
Figure 4-9. Pictorial of Parameters Needed for Measurement of Transmitted Gain

Alpha (α) is the angle between the LOS vector between the tracking system and the vehicle roll vector at the tail end. As alpha decreases, the LOS to the transmit antenna will be obstructed by deeper nulls. The gain is obtained from the ARDT that is stored in a computer file. An entire trajectory can be evaluated for signal margin before an actual flight. For post-mission analysis, the expected signal-strength level can be compared to the actual signal-strength level from the flight. This information can also be used to evaluate any plume effects on the received signal level. The start point is the reference vector along the −yaw vector direction; QA is the firing Az and QE is the firing El.

4.8.2 Figure of Merit (G/T)

The "figure of merit" (or "system goodness") is an indication of system sensitivity and is represented by the ratio of the antenna gain to the system noise temperature. The value, in dB/Kelvin (K), can be obtained by calculation of known gains and line losses or by measurements. To determine *G/T* from calculations, a reference plane for the net antenna gain is first established. The reference plane is usually the input to the preamplifier. The RCC 118-20 V2, Appendix C gives a procedure for measuring *G/T*.

a. *G/T* from System Losses. The *G/T* can be obtained by calculating system losses and gains. The net antenna gain is determined by adding the antenna gain to the line losses up to the reference plane (see Figure 4-10 and equations 4.8-13 through 4.8-18). The system temperature can be calculated from system losses from the reference plane to the receiver second IF BW filter.



LEGEND:

T_{ant} = Sum of noise temperatures of units between the antenna and LNA (Reference Plane).
T_r = Sum of noise temperatures of units in receiver system.
t_n = Noise temperature of each unit.
g_n = Gain of each unit.

Figure 4-10. Block Diagram of RF Units in the RF Assembly

The losses are then converted to system temperature. System *G/T* is calculated as follows:

$$G/T = \frac{System\ Gain}{System\ Temperature} \qquad \text{(Eq. 4.8-4)}$$

Where:

$$\text{System Gain} = 10^{\left(\frac{Antenna\ gain\ in\ dB - System\ loss\ to\ reference\ plane\ in\ dB}{10}\right)} = (g_1)(g_2) \qquad \text{(Eq. 4.8-5)}$$

System temperature is calculated as follows:

$$\text{System temperature} = T_{sys} = T_{ant} + T_r \qquad \text{(Eq. 4.8-6)}$$

T_{ant} is the equivalent noise temperature looking backwards to antenna:

$$T_{ant} = \frac{t_1 + (l_2 - 1)t_2}{l_2} \qquad \text{(Eq. 4.8-7)}$$

Where l_2 is the loss between the antenna and the reference plane:

$$l_2 = \frac{1}{g_2} = 10^{\left(\frac{Loss\ in\ dB}{10}\right)} \qquad \text{(Eq. 4.8-8)}$$

t_2 = ambient temperature (290K) and
T_r = the equivalent noise temperature looking forward to receiver 2nd IF BW:

$$T_r = t_3 + \frac{t_4}{g_3} + \frac{t_5}{g_3 g_4} + \Lambda + \frac{t_n}{g_3 g_4 g_5 \Lambda\ g_{n-1}} \qquad \text{(Eq. 4.8-9)}$$

For an attenuator (such as a coax cable, waveguide, etc.)

Where:

$$g_n = \frac{1}{l_n} = 10^{\left(\frac{Loss\ in\ dB}{10}\right)} \qquad \text{(Eq. 4.8-10)}$$

If the noise figure for a component is provided instead of equivalent temperature, calculate the equivalent temperature as follows:

$$t_n = (F\text{-}1)T_o \qquad \text{(Eq. 4.8-11)}$$

Where:

$$F = \frac{(Carrier\ to\ Noise\ Ratio)_{in}}{(Carrier\ to\ Noise\ Ratio)_{out}} = 10^{\frac{Noise\ Figure\ in\ dB}{10}} = \text{Noise figure} \qquad \text{(Eq. 4.8-12)}$$

T_o = ambient temperature (290K)

Figure 4-11 illustrates an example of parameters necessary to calculate *G/T*. An 8-foot parabolic reflector TM system is chosen for the above example. The antenna gain is 32.52 dB with an efficiency of 54% at 2250.5 MHz. The reference plane is selected as the input to the preamplifier. The sum of losses from the antenna elements to the LNA is 2.9 dB.

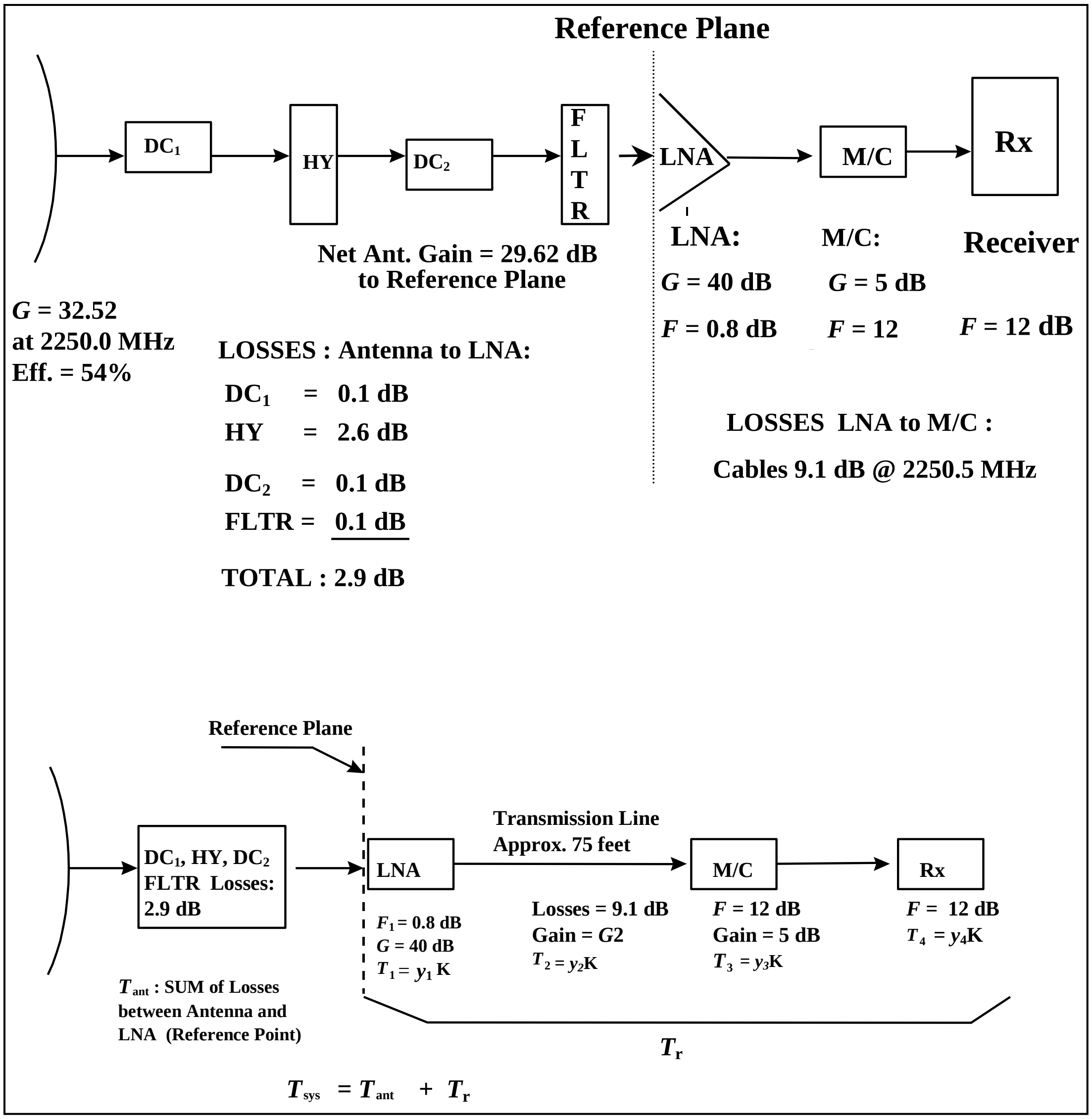


Figure 4-11. Block Diagram of a Sample RF Subsystem

The net antenna gain (G_{net}) is calculated:

$$G_{\text{net}} = G_a - \text{line losses to reference plane} \qquad \text{(Eq. 4.8-13)}$$
$$G_{\text{net}} = 32.52 - 2.9$$
$$G_{\text{net}} = 29.62 \text{ dB}$$

The temperature of the sky (T_{sky}) is 10 K for an elevation angle of 10° at 2250.0 MHz.

The following equations determine the system temperature (T_{sys}) by adding the antenna temperature (T_{ant}) to the receiver temperature (T_r):

$$T_{\text{sys}} = T_{\text{ant}} + T_r \qquad \text{(Eq. 4.8-14)}$$

$$l_n = 10^{(Ln/10)} \qquad \text{(Eq. 4.8-15)}$$

$$T_{ant} = \frac{(l_a - 1)290 + T_{sky}}{l_a} \qquad \text{(Eq. 4.8-16)}$$

$$T_r = y_1 + \frac{y_2}{g_1} + \frac{y_3}{g_1 g_2} + \frac{y_n}{g_1 g_2 g_n} \qquad \text{(Eq. 4.8-17)}$$

$$g_n = 10^{(G/10)} \qquad \text{(Eq. 4.8-18)}$$

Where:

L_a = sum of line losses in dB
l_a = sum of line losses expressed as anti-log of the dB value
G_n = gain of any amplification circuit in dB
g_n = gain of amplification expressed as anti-log of the dB value
$1/g_{ll}$ = inverse of numeric line losses
y_n = temperature for any individual element in K
T_{sky} = temperature of the sky at different elevation angles (K)
T_{ant} = temperature of the antenna (K)
T_r = temperature of the remaining receiving system (K)

Therefore, for T_{ant}:

Losses between the antenna and the preamplifier (L_a) are 2.9 dB:

$$l_a = 10^{(2.9/10)} \qquad \text{(Eq. 4.8-19)}$$

$$l_a = 1.95$$

$$T_{ant} = \frac{(1.95 - 1) \bullet 290 + 10}{1.95} \qquad \text{(Eq. 4.8-20)}$$

$$T_{ant} = 146.41 \text{ K}$$

Referencing the above example calculation (Figure 4-11), note that T_r is comprised of the following components:

(1) Preamplifier.

Gain (G_{lna}) = 40 dB

Noise figure (F_1) = 0.8 dB

$$g_{lna} = 10^{(40/10)} \qquad \text{(Eq. 4.8-21)}$$
$$g_{lna} = 10000$$

$$F_1 = 10 \bullet \log(1 + t_1 / 290) \qquad \text{(Eq. 4.8-22)}$$
$$t_1 = (10^{(F/10)} - 1) \bullet 290$$
$$t_1 = 58.66 \text{ K}$$

(2) Sum of Line Losses. Approximately 90 feet from feed assembly to multicoupler (L_2):

$$L_2 = 9.1 \text{ dB} \qquad \text{(Eq. 4.8-23)}$$

$$l_2 = 10^{(9.1/10)} \qquad \text{(Eq. 4.8-24)}$$
$$l_2 = 8.128$$

$$t_2 = (l_2 - 1) \bullet 290 \qquad \text{(Eq. 4.8-25)}$$

$t_2 = 2067.12$ K

(3) Multicoupler

Gain ($G_{\mathrm{m/c}}$) = 5.0 dB

Noise figure (F_3) = 12 dB

$g_3 = 10^{(5/10)}$ (Eq. 4·8-26)

$g_3 = 3.16$

$t_3 = (10^{(12/10)} - 1) \bullet 290$ (Eq. 4.8-27)

$t_3 = 4306.2$ K

(4) Line Losses between Multicoupler and Receiver

$L_4 = 1.83$ dB

$l_4 = 10^{(1.83/10)}$ (Eq. 4.8-28)

$l_4 = 1.52$

$t_4 = (1.52 - 1) \bullet 290$ (Eq. 4.8-29)

$t_4 = 150.8$ K

(5) Receiver Input (Tuner)

Noise figure (F_5) = 12 dB (Eq. 4.8-30)

$T_{\mathrm{e(rx)}} = 4306.2$ K

Total T_e:

$T_\mathrm{r} = t(_{\mathrm{lna})} + t_{(\text{transmission lines})} + t_{(\mathrm{M/C})} + t_{(\text{lines between M/C and Rx})} + t_{(\mathrm{Rx})}$ (Eq. 4.8-31)

$T_\mathrm{r} = 58.66 + 0.206712 + 3.5 + .00039 + 1.68$

$$Tr = 58.66 + \left(\frac{2067.12}{10000}\right) + \left(\frac{4306.2}{10000 \times \left(\frac{1}{8.128}\right)}\right) + \left(\frac{150.8}{10000 \times \left(\frac{1}{8.128}\right) \times 3.16}\right)$$

$$+ \left(\frac{4306.2}{10000 \times \left(\frac{1}{8.128}\right) \times 3.16 \times \left(\frac{1}{1.52}\right)}\right)$$

$T_\mathrm{r} = 64.047$ K

Then:

$T_{\mathrm{sys}} = \mathrm{T_{ant}} + \mathrm{T_r}$ (Eq. 4.8-32)

$T_{\mathrm{sys}} = 146.41 + 64.047$

$T_\mathrm{e} = 210.457$

$G/T = 29.62 - 10 \bullet \log (210.457)$ (Eq. 4.8-33)

$G/T = 29.62 - 23.23$

$G/T = 6.39$ dB / K

b. Parameters Influencing *G/T*. Parameters that have the most influence on the *G/T* are:

- Antenna gain;
- Line loss between the antenna and preamplifier;
- Elevation angle (temperature decreases as the elevation angle increases);
- Preamplifier gain and noise figure.

4.9 Dynamic Range

Dynamic range is one of two most important receiver characteristics, the other one being the system sensitivity. Dynamic range indicates a range of signal levels from the noise floor to the 1-dB compression point. This value is expressed as a ratio in decibels.

Strong in-band signals can cause intermodulation products to occur, which can interfere with the normal operation of a receiver or other active device such as a preamplifier. The stronger the in-band signal, the higher the level of interference. Strong interference signals can cause desensitization, which, by definition, reduces the gain of the receiver or amplifier. Desensitization is related to the 1 dB gain compression point and, therefore, the linearity of the receiver or amplifier.

The spurious free dynamic range (SFDR) can be determined for any IF BW as follows:

$$\mathrm{SFDR} = 0.67 \bullet (\mathrm{IP3} - \mathrm{kTsB})\ \mathrm{dB} \qquad \text{(Eq. 4.8-34)}$$

Where:

kTs = −114 dBm per MHz at 290 K

B = IF bandwidth in MHz

IP3 = system third-order input intercept point (output intercept minus gain = input intercept)

4.10 Intermodulation (IM) Products Example

The IM products are spurious emissions that can be generated internally in an amplifier or a receiver that is being overdriven, or from mixing two or more signals in a nonlinear device such as an amplifier. The higher the number of frequencies in the mix, the greater the possibility of interference. Third-order IM products and the sum and difference combinations that result are the highest amplitude level signals. Figure 4-12 illustrates the interference from five frequencies in the 2200 - 2300 band (different bit rates for each) occurring simultaneously with the expected interfering spurious emissions. The five frequencies are used to illustrate what can happen when more than one frequency can pass through the amplifiers. Figure 4-12 demonstrates a worst-case scenario where there is major interference within 99% BW. Many of the emissions are right on top of center.[10]

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[10] *Reference RCC Document 118-97 for more information on intermodulation products.*

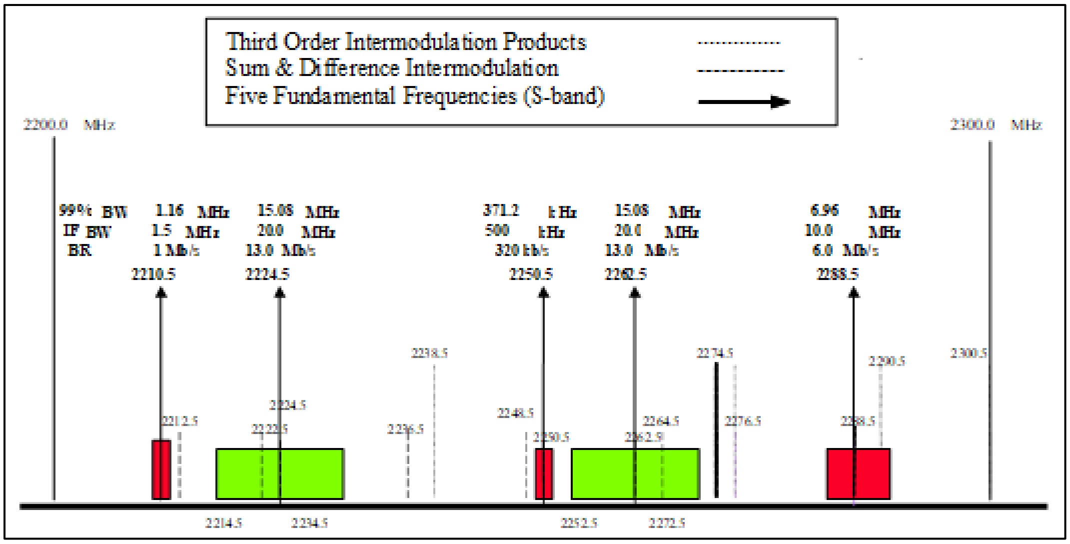

Figure 4-12. Frequency Band Interference

Table 4-3 is a list of five frequencies plotted on Figure 4-12. The listing shows that some spurious emissions could be generated and fall right on top of some carrier frequencies or very near. Table 4-4 also shows the sum and difference harmonics. The magnitudes of the spurious emissions depend on power levels and distances between transmitter and receiver.

Table 4-3. Frequency Band Interference

Lower Frequency	Fundamental 1	Fundamental 2	Upper Frequency
2196.5	2210.5	2224.5	2238.5
2158.5	2210.5	2262.5	2314.5
2170.5	2210.5	2250.5	2290.5*
2132.5	2210.5	2288.5	2366.5
2186.5	2224.5	2262.5	2300.5
2198.5	2224.5	2250.5	2276.5
2160.5	2224.5	2288.5	2352.5
2238.5	2250.5	2262.5	2274.5
2236.5	2262.5	2288.5	2314.5
2212.5	2250.5	2288.5	2326.5

*Intermodulation product within 2 MHz of a fundamental frequency

Table 4-4. Sum and Difference IM Products

2210.5	+	2224.5	–	2262.5	=	2172.5
2210.5	+	2224.5	–	2250.5	=	2184.5
2210.5	+	2224.5	–	2288.5	=	2146.5
2210.5	+	2262.5	–	2224.5	=	2248.5*
2210.5	+	2262.5	–	2250.5	=	2222.5
2210.5	+	2262.5	–	2288.5	=	2184.5
2210.5	+	2250.5	–	2224.5	=	2236.5
2210.5	+	2250.5	–	2262.5	=	2198.5

2210.5	+	2250.5	−	2288.5	=	2172.5
2210.5	+	2288.5	−	2224.5	=	2274.5
2210.5	+	2288.5	−	2262.5	=	2236.5
2210.5	+	2288.5	−	2250.5	=	2248.5*
2224.5	+	2262.5	−	2210.5	=	2276.5
2224.5	+	2262.5	−	2250.5	=	2236.5
2224.5	+	2262.5	−	2288.5	=	2198.5
2224.5	+	2250.5	−	2210.5	=	2264.5*
2224.5	+	2250.5	−	2262.5	=	2212.5
2224.5	+	2288.5	−	2210.5	=	2302.5
2224.5	+	2288.5	−	2262.5	=	2250.5*
2224.5	+	2288.5	−	2250.5	=	2262.5*
2262.5	+	2250.5	−	2210.5	=	2302.5
2262.5	+	2250.5	−	2224.5	=	2288.8*
2262.5	+	2250.5	−	2288.5	=	2224.5*
2262.5	+	2288.5	−	2210.5	=	2340.5
2262.5	+	2288.5	−	2224.5	=	2326.5
2262.5	+	2288.5	−	2250.5	=	2300.5
2250.5	+	2288.5	−	2210.5	=	2328.5
2250.5	+	2288.5	−	2224.5	=	2314.5
2250.5	+	2288.5	−	2262.5	=	2276.5

* Intermodulation product within 2 MHz of a fundamental frequency

The second-order IM products created by mixing two frequencies (f_1 and f_2) together are:

$$f_1 + f_2 \text{ and } f_1 - f_2 \qquad \text{(Eq. 4.9-1)}$$

The third-order IM products resulting from mixing the same two frequencies would be:

$$2\,f_1 + f_2,\ 2\,f_1 - f_2,\ 2\,f_2 + f_1, \text{ and } 2\,f_2 - f_1 \qquad \text{(Eq. 4.9-2)}$$

Table 4-3 represents the third-order intermodulation products for five RF links:

- RF1 at 2210.5 MHz
- RF2 at 2224.5 MHz
- RF3 at 2262.5 MHz
- RF4 at 2250.5 MHz
- RF5 at 2288.5 MHz

Table 4-4 presents the sum and difference intermodulation products for five fundamental frequencies:

- RF1: 2210.5
- RF2: 2224.5
- RF3: 2262.5
- RF4: 2250.5
- RF5: 2288.5

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CHAPTER 5

Lessons Learned

5.1 Scope

This section describes several lessons learned by the RF systems committee members. Additions or deletions will take place during subsequent revisions to this handbook.

5.2 Permanently Installed RF Cables Testing

5.2.1 Abstract

The RF cables, which are part of a permanent TM installation, are usually assumed to have nominal loss and no phase distortion. However, RF cables may degrade due to mechanical damage to the cable itself or its connectors. The RF cables may be tested after installation using a variety of techniques.

5.2.2 Driving Event Description

The RF cables installed to route S-band TM signals for prelaunch TM have degraded due to kinking and connector damage. This damage occurred during initial cable installation and later during the normal attachment of other cables and equipment.

5.2.3 Lesson Learned

Degraded cables may pass low-speed signals with little degradation, but may pass high-speed signals with phase distortion, which is significant enough to result in corrupted data.

5.2.4 Recommendation

Periodically inspect and test RF cables to verify that loss, VSWR, and group delay are within acceptable limits using a vector network analyzer, if possible. If the two ends of a cable are physically separated by a great distance, the two RF cables can be connected together at one end and then tested together as one double-length cable; or a scalar network analyzer can be used with a special long-control cable attached to the detector. Another scalar technique is to use a swept RF source or RF noise source at one cable end and a spectrum analyzer at the other. Note that the cable’s insertion loss amplitude will give an indication of group delay bumps without having to measure the group delay directly. Portable analyzers that use Time and Frequency Domain Reflectometry techniques to measure “distance to fault” can be purchased commercially. These measurements can be made with the cables properly terminated to determine fault locations or with the cables open to determine cable length. Measurements can be stored in a database to track trends in cable degradation.

5.3 Prelaunch TM from Encapsulated Missiles Radiation

5.3.1 Abstract

Radiation of TM from a missile enclosed in an RF-tight canister before launch is sometimes necessary for missile exercises. Various techniques have been developed to couple the signal from the missile/canister, amplify its power to several watts, and radiate it for reception by the TM sites, with good but not 100% success.

5.3.2 Driving Event Description

In many circumstances a missile is enclosed in an RF-tight canister for environmental and logistical reasons and is launched from this same canister. Normal TM operations require that the missile telemeter be energized and its signal received by multiple sites before the missile can be launched. When the missile telemeter is energized, the missile antenna radiates the TM RF signal inside the canister, and it is this signal that must be picked up and retransmitted to the receiving sites.

5.3.3 Lesson Learned

Coupling the S-band RF signal from the missile antenna out of the canister through free-space radiation with no distortion has been the biggest challenge. Some distortion can be tolerated with low-speed PCM/FM streams, but this same distortion will corrupt a high-speed stream. A consistent signal from the canister can also be a problem due to mechanical positioning and temperature effects, especially when this parameter is not tested in production. One way to obviate the distortion is to use a coax cable connection between the missile and the canister that pulls away or breaks during launch, but that is not always an option. When multiple TM signals are being amplified during a test exercise, intermodulation products caused by single amplifier saturation will cause interference at other frequencies. The power output from the amplifier and antenna radiating the signal may not guarantee the correct ERP toward the receiving site. Unwanted feedback caused by the canister not being perfectly RF-tight can cause oscillation of the electronics.

5.3.4 Recommendation

Retransmitting the prelaunch signal can usually be accomplished but each part of the proposed system must be examined in detail to prevent a “weak link” in the system.

If connecting a coax cable from the missile to the canister is not viable, then using a pickup antenna located close to the missile antenna may give the best results. This is because it tends to reduce the “canister multipath” phenomenon caused by the complex paths the RF signal takes in going from the missile antenna to the pickup antenna inside the canister. This applies to one radiator in one canister (enclosure) and does not address multiple radiators in one enclosure. Once the signal has been coupled from the canister, then it can be combined with other canister signals (at other frequencies) easily using passive RF combiners. The composite signal can be amplified using an S-band amplifier and radiated via an S-band antenna. The amplifier may need to have AGC to provide a constant output power, and the amplifier’s drive level needs to be considered if intermodulation products occur at frequencies of interest. The radiation antenna can be chosen to increase the ERP in a particular direction, but may need to be positioned and pointed accurately.

5.4 Data Routing using Electronic Switching

5.4.1 Abstract

Data routing using electronic switching is used to replace patch panels. Conventional (frequency response up to 100 MHz) routers only pass low-voltage signals such as IFs. They cannot pass TTL signals without increasing the IF noise floor and decreasing the signal level.

5.4.2 Driving Event Description

The solution is to use TTL data routers to pass Data and Clock. The TTL data routers cannot pass the 70 MHz IF signal. The IF noise level increases by 10 dB and the signal level decreases by the same amount.

5.4.3 Lessons Learned

When using electronic routers, make sure you not only measure the signal level, but the voltage level as well.

5.4.4 Recommendation

The solution is to use conventional switchers that pass IF signals with low-voltage levels and TTL electronic switchers for Data and Clock signals.

5.5 LNA Characteristics

5.5.1 Abstract

The LNAs are usually characterized by gain, frequency response, a 1 dB compression point, and dynamic range. There are other characteristics that must be measured to ascertain the above named parameters to meet not only short-term specifications, but to also meet specifications under the desired operating temperatures.

5.5.2 Driving Event Description

The LNAs show flat frequency response for the TM bands and meet the gain and noise figure specifications. Testing the LNAs within the RF FAU shows noise floor measurements and autotracking parameters are not stable. Further symptoms show that phasing increases and changes the LNA’s characteristics that create cross-talk problems as temperatures increase.

5.5.3 Lesson Learned

The problem is solved by properly grounding the LNA’s input stage to allow correct amplitude and phasing to improve the tracking modulation and minimize cross-talk.

5.5.4 Recommendation

Measure the LNA input and output impedance at different temperatures and not just ambient temperatures.

5.6 Antenna Feed Dipole Design and Proper Phasing

5.6.1 Abstract

The TM bands cover approximately one octave of frequency (1435 - 2400 MHz). Antenna pattern measurements meet specifications as well as the axial ratio measurements at lower and upper L-bands. As frequency increases into S-band, the axial ratio and gain measurements do not meet specifications.

5.6.2 Driving Event Description

The cables between the dipoles and the hybrid are hard or impossible to have good phasing. Wrong cable phasing causes excessive crosstalk and will not allow autotracking.

5.6.3 Lesson Learned

The dipoles are found to be connected in such a way that the wire between the dipoles and the tuning elements have capacitance reactance that make it hard to tune for all three bands. The wire between dipoles is flat and is changed to an “upside down V” bend such that the capacitance reactance does not change significantly as frequency increases. All axial ratio and gain measurements meet specifications after changing the wire.

5.6.4 Recommendation

When testing a tracking FAU, maintain a record of the crosstalk as frequency increases. If the crosstalk is erratic, check all input and output impedances.

APPENDIX A

Application for Equipment Frequency Allocation for Aeronautical Mobile Telemetry Systems

A.1 Overview

The DoD spectrum management program has a principal goal to develop and efficiently manage the DoD's use of the EM spectrum during the spectrum-dependent systems life cycle. To achieve this goal, all aeronautical mobile telemetry (AMT) systems must complete the National Telecommunications and Information Administration (NTIA) Spectrum Certification and Assignment process. This process minimizes the potential for interference between systems during the fielding and employment of spectrum-dependent systems. The DoD acquisition policy based on DoD Instruction 4650.01[11], Office of Management and Budget Circular A-11[12], and the NTIA Redbook, Revision 2017[13] generally state you must obtain a certification by NTIA, Department of Commerce (DOC) that the RF required is available before you submit estimates for the development or procurement of major radio spectrum dependent communications electronics systems (including all systems employing space satellite techniques).

The Equipment Spectrum Guidance (ESG) Permanent Working Group (PWG) of the U.S. Military Command, Control, Communications, and Computers Executive Board (MC4EB) reviews the NTIA approved certification and characteristics of RF equipment purchased or developed by the DoD and documents the operational guidance on its use within the U.S. and Possessions (US&P). This review process is called the Spectrum Certification and Assignment Process, more commonly known within the AMT community as the J-12, J/F-12 or "1494" process.

The form that has historically been used to submit system information for frequency allocation approval is the DD Form 1494, *Application for Equipment Frequency Allocation*. This form documented the system's technical information required for certification. Although the form is no longer used, the system information required to fill out the form is still valid and required. The only change is that other tools are now available to capture and convey this information. All DoD systems operating in the EM spectrum, as defined in Chapter 10 of the NTIA Redbook, which specifically addresses AMT systems, are reviewed using the J-12 process.

In summary, all DoD spectrum-dependent systems are evaluated by the DoD spectrum community, then by NTIA, and finally by the MC4EB. All AMT systems fall under this process.

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[11] Department of Defense. *Policy and Procedures for Management and Use of the Electromagnetic Spectrum*. DoDI 4650.01. 9 January 2009. Incorporating Change 1, October 17, 2017. Retrieved 3 June 2021. May be superseded by update. Available at https://www.esd.whs.mil/portals/54/documents/dd/issuances/dodi/465001p.pdf.

[12] Office of Management and Budget. *Preparation, Submission, and Execution of the Budget*. Circular A-11. April 2021. Retrieved 3 June 2021. Available at https://www.whitehouse.gov/wp-content/uploads/2018/06/a11.pdf.

[13] National Telecommunications and Information Administration. *Manual of Regulations and Procedures for Federal Radio Frequency Management (Redbook)*. September 2017. May be superseded by update. Retrieved 2 June 2021. Available at https://www.ntia.gov/publications/redbook-manual.

A.2 Spectrum Management at the National Level

To understand how the approval system works from a user's perspective, it is important to understand the process at a high level. The Communications Act of 1934 established a duality in spectrum management in the U.S. between the President for federal government stations and the Federal Communications Commission (FCC) under the direction of Congress. By executive order, the President delegated his spectrum management responsibilities under the Communications Act to the NTIA under the Secretary of Commerce.

The FCC is an independent federal regulatory agency responsible directly to Congress. The FCC assigns and regulates frequencies for nonfederal users within the US&P using the Code of Federal Regulations as their guideline. Nonfederal users include private citizens, companies, and state and local government users. The NTIA, which is under the U.S. DOC, assigns and regulates frequencies for all federal (including DoD) users within the US&P. The NTIA, established in 1978 as part of an Executive Branch reorganization, governs the EM spectrum using the Redbook as the guide. The Interdepartmental Radio Advisory Committee (IRAC), first created by President Herbert Hoover in 1922, continues to serve as the practical body to manage frequency use.

In summary, the FCC manages spectrum for commercial, state, and local government interests. The DOC (via NTIA) manages spectrum for federal government activities. Figure A-1 illustrates the relationship between the two organizations, sometimes referred to as the dual-agency management organization.

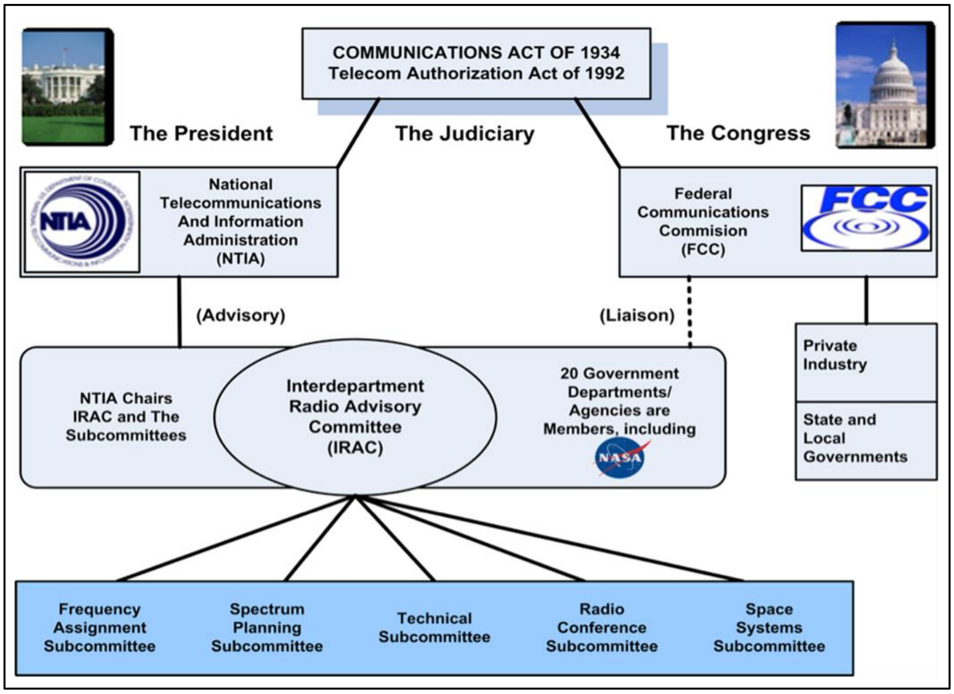

Figure A-1. NTIA and FCC Dual Agency Management

Since the NTIA assigns and regulates military frequency usage, it is important to understand how it performs this function. The NTIA performs its spectrum management function through the Office of Spectrum Management (OSM); see Figure A-2. Two committees advise and provide assistance to the OSM: the IRAC and the Spectrum Planning Subcommittee (SPS).

The IRAC's basic function is to assist the NTIA in assigning frequencies to U.S. Government radio stations and in developing and executing policies, programs, procedures, and technical criteria pertaining to the allocation, management, and use of spectrum. This includes coordinating federal spectrum use and resolving interference conflicts among federal agencies.

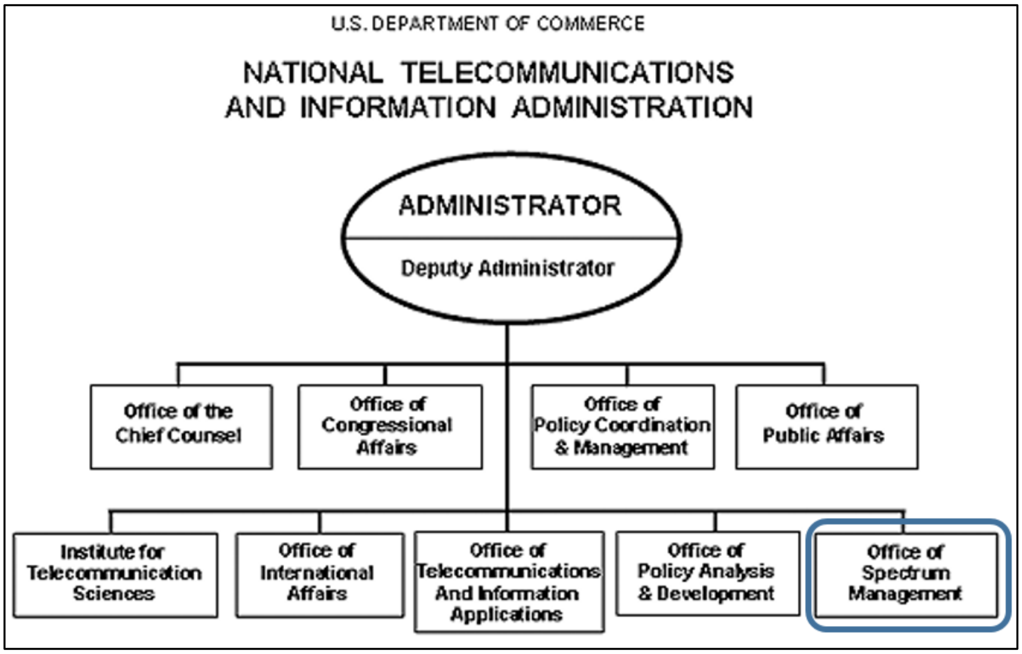

Figure A-2. NTIA Organization Chart

The NTIA chairs the IRAC with the following agencies as members: the Departments of Agriculture, Army, Air Force, Commerce, Energy, Health and Human Services, Homeland Security, Interior, Justice, NASA, Navy, State, Treasury and Veterans Affairs, U.S. Coast Guard, the General Services Administration, National Science Foundation, Broadcasting Board of Governors, and the U.S. Postal Service. Figure A-3 depicts the committee members. The FCC is not a formal member, but has a designated liaison to the committee.

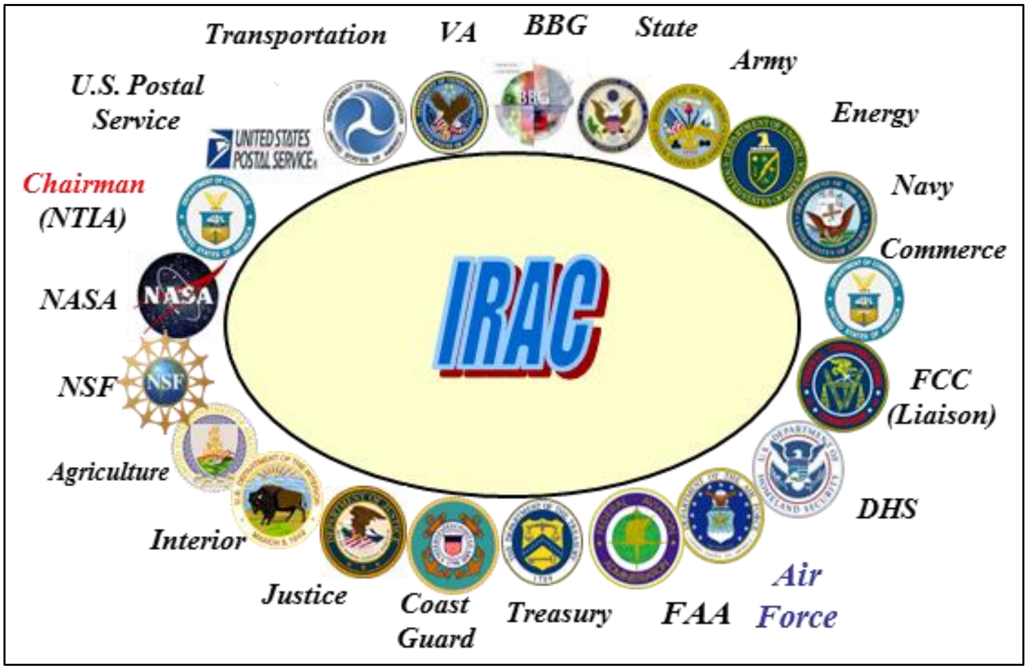

Figure A-3. Members of the Interdepartmental Radio Advisory Committee

The NTIA reaches its decisions by using the consensus advice from the IRAC, the NTIA staff, technical and policy analyses, and public input when required. This allows each agency to review proposals for new radio services and stations from other federal users to determine if the new proposals will have an impact on existing and planned systems. Affected users can then negotiate directly and develop a technical resolution to any potential problems.

The NTIA and FCC are on a level playing field; neither one oversees the other. This dual-agency management system makes arriving at a single position more challenging, but it ensures that private and government concerns are both considered. The commercial spectrum use potential is ever increasing. The dual-agency management system is seen as a benefit because it ensures that decisions concerning commercial interests are made only after considering their impact on government uses of spectrum. Similarly, decisions concerning government interests are made while taking into account commercial interests. The process generally results in U.S. proposals that reflect the overall national interest.

Though not tied directly into the spectrum certification from a DoD perspective, one other committee deserves mention. The Commerce Spectrum Management Advisory Committee (CSMAC) advises the Office of Communications and Information on a broad range of spectrum policy issues. The members are spectrum-policy and system-level experts typically from outside the federal government. Committee members offer expertise and perspective on reforms to enable new technologies and services, including reforms that expedite the American public’s access to broadband services, public safety, and long-range spectrum planning. Members are selected based on their technical background and expertise, as well as NTIA’s commitment to ensure diversity and balance in points of view. Members serve in a personal capacity and do not represent any organization or interest. The CSMAC is a federal advisory committee created in 2004. Given this background, this appendix will explain the process that gets a new system requiring EM spectrum use to the IRAC for review and approval.

A.3 Joint Frequency Allocation-to-Equipment Process

Once a need to radiate in the EM spectrum is established, the process for attaining a frequency allocation and subsequent assignment is well documented and well understood by those working within the spectrum certification process. To the end user, this process is nebulous, has many steps, is called by many different terms, and requires a significant amount of time. Some misconceptions can be corrected with a better understanding of the process. The frequency allocation process exists to determine answers to the following questions.

a. Can the equipment operate in the spectrum bands per the national and international tables of spectrum allocation?

b. Does the equipment conform to applicable spectrum management regulations, directives, standards, and specifications?

The process for DoD systems is known as the Joint Frequency Allocation-to-Equipment Process. It is also known as the Spectrum Certification and Assignment process, SPS submission process, J-12 process, or more generically the “1494” process. It begins with any one of the military Services defining a need for a system operating in the EM spectrum. Historically this requirement was specified using a DD Form 1494, which characterizes the system’s technical performance system. Today, there are other software platforms (i.e., Equipment Location-Certification Information Database [EL-CID] and Stepstone) available that capture this exact system information. This form is routed through the local spectrum manager who then reviews and submits it to the appropriate Spectrum Management Office (SMO).

There are three offices responsible for carrying out spectrum policy within the military services: the Air Force SMO (AFSMO), the Army SMO (ASMO), and the Navy/Marine Corps Spectrum Center. Once it gets to the Military Department SMO level, the J-12 process is exactly the same and generally described in more detail below.

Because the Air Force, Army, and Navy processes are so diverse before reaching their respective SMOs, each of their processes will not be covered in this document. Further information on the Services’ processes can be found in Air Force Instruction 17-220[14], Army Regulation 5-12[15], and Office of the Chief of Naval Operations (OPNAV) Instruction 2400.20.[16]

These instructions/regulations have detailed information on roles and responsibilities within each Service when EM spectrum is required for a system development. Even a cursory look through the documents gives the reader an understanding of the allocation process’ complexity. These Service documents provide guidance to an expected timeline from submission to receiving an approved J-12. All Services are in agreement that, from start to finish, the process will be no shorter than 6 months and could last up to 18 months or longer depending on the data

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[14] Secretary of the Air Force. *Spectrum Management*. AFI 17-220. 16 March 2017. Superseded by *Spectrum Management*. DAFI 17-220. Superseding document retrieved 6 June 2024. Available at https://static.e-publishing.af.mil/production/1/af_a2_6/publication/dafi17-220/dafi17-220.pdf.

[15] Department of the Army. *Army Use of the Electromagnetic Spectrum*. AR 5-12. 8 February 2020. May be superseded by update. Retrieved 2 June 2021. Available at https://armypubs.army.mil/epubs/DR_pubs/DR_a/ARN37511-AR_5-12-001-WEB-3.pdf.

[16] Department of the Navy. *Electromagnetic Environmental Effects and Spectrum Supportability Policy and Management*. OPNAVINST 2400.20G. 7 January 2021. May be superseded by update. Retrieved 2 June 2021. Available at https://www.secnav.navy.mil/doni/Directives/Forms/AllItems.aspx.

adequacy provided by the SMOs. It is essential for this timeline to be considered early in the system's development and fielding.

A.3.1 Frequency Allocation, Assignment, Certification, and Authorization

To understand the J-12 process some terms need to be defined. Allocation, assignment, certification, and authorization are typically used interchangeably when discussing process portions. Though they may sound similar, when used in this context each have a very specific meaning. An understanding of each term is extremely important.

a. Allocation. Entry in the FCC's Table of Frequency Allocations of a given frequency band for its use by one or more terrestrial or space radio communication services or the radio astronomy service under specified conditions. This term also applies to the frequency band concerned. An allocation is the output of the J-12 process. Completing and submitting a DD Form 1494 was the first step in the spectrum certification process with the intent of attaining an allocation. Sometimes this is also referred to as equipment certification. Today either Stepstone or EL-CID format are directly used instead of DD Form 1494.

b. Assignment. Once an allocation is approved, a frequency assignment is made consistent with the allocation decision and local requirements. Then the user can radiate. This is the license to radiate. All RF emitters must have a frequency assignment prior to operation. Additionally, once the NTIA reviews and assigns a number to the SPS submittal, this number can then be used to request a 3-month temporary frequency assignment. This can be done while waiting for a finalized submission approval with signed certification (see below).

c. Certification. The MC4EB process verifies that a proposed system complies with the appropriate rules, regulations, technical standards, and military specifications. The MC4EB guidance page constitutes an approved spectrum certification as referenced by the J/F-12 document.

d. Authorization. Strictly speaking, this term is not used in the context of the J-12 process. In reality, authorization to radiate is achieved once an assignment is made. It is the permission to radiate or use an RF channel under specified conditions.

A.3.2 The Spectrum Certification Process

Within the AMT community, the terms spectrum certification process, J-12 process, J/F-12 process, and 1494 process all refer to the same thing, which is the process for requesting a frequency allocation within the DoD. This process is initiated by the end user or acquisition program office with the requirement for procuring equipment that utilizes the EM spectrum to operate. This general process is shown in Figure A-4. Historically, the process was started with the DD Form 1494.

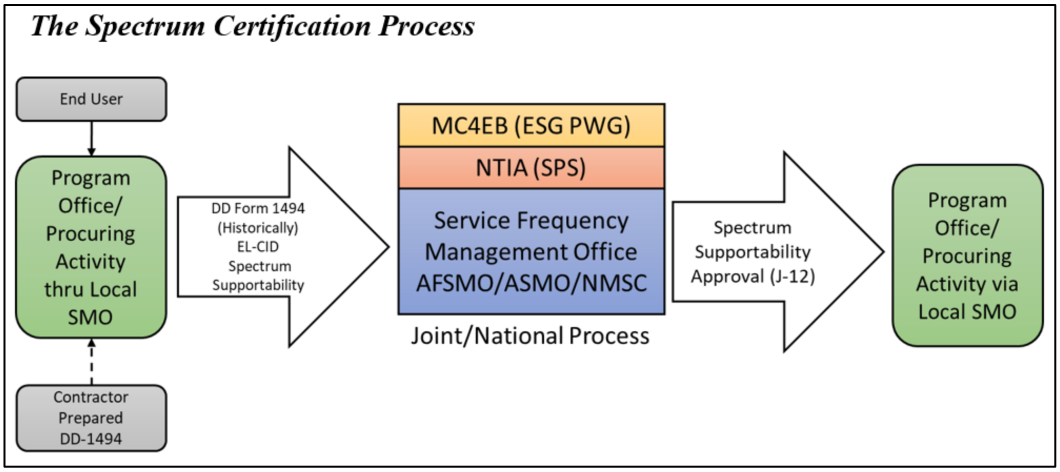

Figure A-4. General Process

There were various methods available to populate and convey the information in the form with the method varying with the submitting organization. These methods ranged from directly filling out the PDF or Word version forms to utilizing software programs specifically designed to capture the information requested in the DD Form 1494. These software programs, briefly discussed below, are EL-CID and the proposed Stepstone application. Since the data in the application is critical to the subsequent review by reviewing and determination authorities, it is imperative that someone knowledgeable about the system and the form requirements is responsible for its contents. Depending on the level of expertise within the program office or procuring activity, the end user will either fill out the form or rely on the manufacturing contractor or support contractor to furnish the required data.

Once the form has been filled out, the SMO reviews the application to ensure data accuracy and adequacy. In addition, the SMO assesses compliance with known U.S. and DoD EM standards and with the National and International Tables of Frequency Allocation from the NTIA Redbook. The SMO can also initiate a Spectrum Supportability assessment, which determines if there will be EM spectrum necessary to support the system's operation during its expected life cycle.

If the data in the form is deemed sufficiently adequate, the application is assigned a J-12 tracking number by the SMO. This number is used for tracking throughout the process. The SMO officially submits the application to the MC4EB ESG PWG. Refer to Figure A-5 for a process overview. The MC4EB develops policy, provides direction on military communications-electronics matters, and provides expert technical advice in the areas of RF engineering and EM spectrum management. The MC4EB reviews the characteristics of the submission being purchased or developed by the DoD through the ESG PGW.

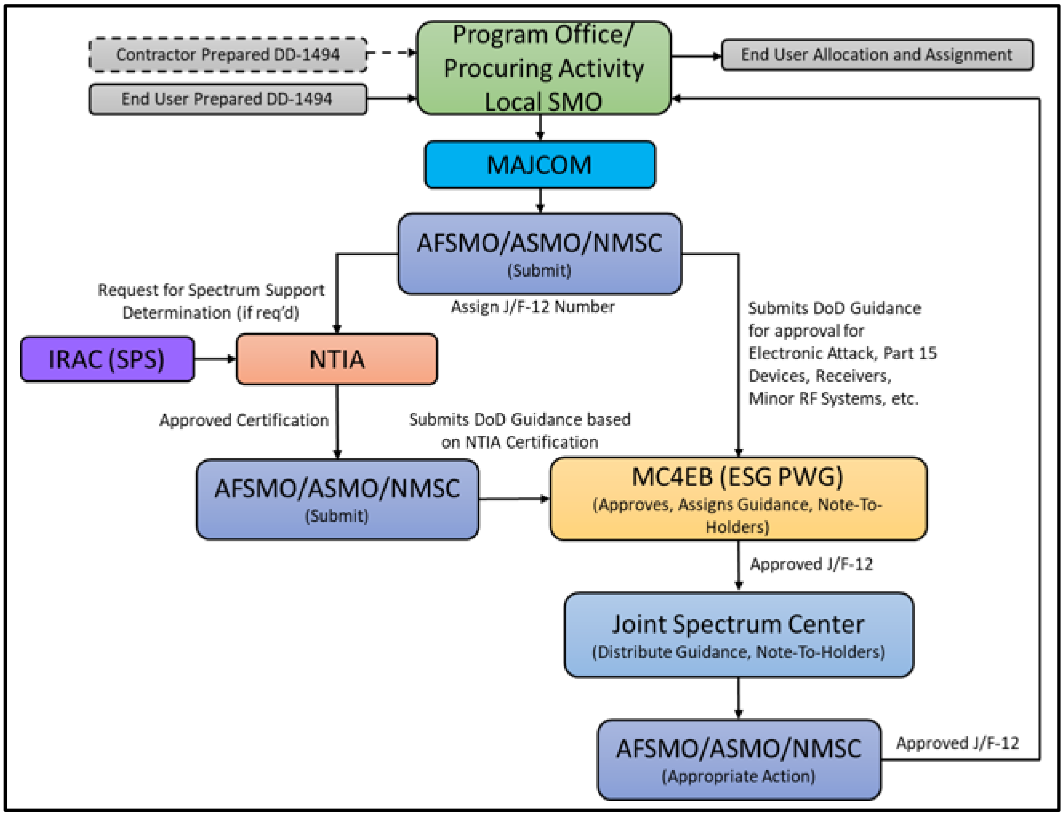

Figure A-5. Detailed J-12 Process

Once approved by the ESG PWG, the SMO then routes the allocation approval to the original requesting user and then works with that user to gain an assignment, or more specifically, a frequency assignment. Only when an approved J-12 is returned via the SMO with a locally approved assignment can the user radiate in the EM spectrum. It is important to note that the equipment must not operate until an approved J-12 is received (the allocation) and a frequency assignment is granted. Once a system has an approved and signed J-12 with a frequency assignment, that system is then certified for DoD operation.

One process not discussed yet, but used extensively in the certification process, is the Note-To-Holder (NTH), which is a mechanism to permit minor changes, updates, or amendments to a previously approved frequency allocation application (approved J-12). The NTH alleviates restarting the entire process for small changes. These requests are sent through the SMO and follow the same process as the original J-12.

This process is streamlined as the entire allocation authorization request is not reviewed again in its entirety (only small changes are reviewed). When technical data is part of the NTH, the information within the J-12 is updated via the EL-CID record. The differences are then highlighted and submitted to the NTIA (via the SPS) as a replacement request for that J-12. Once approved, an ESG PWG memorandum is generated stating the changes are within the original MC4EB guidance page (if applicable) and an amended EL-CID file is submitted. This updates the record for that J-12 in the Government Master File (GMF).

To summarize, the process serves two functions.

a. It provides a uniform method to capture technical data and some operational parameters of a spectrum-dependent system in a format that is easily provided to the national spectrum authorities (e.g., NTIA and below).

b. It standardizes the required technical data format to be added to DoD and national databases to generate frequency assignment approvals, enables initial EMC analyses, and checks for compliance with military and national spectrum standards.

A.4 AMT Submissions

The form that historically has been used to submit systems information to start the J-12 process for frequency allocation approval is the DD Form 1494. Today either EL-CID is used directly or Stepstone is used to document the system's technical parameters. Even though the DD Form 1494 may not be the mechanism to convey technical information about the TM link, the knowledge on how to derive the numbers and input parameters into the various blocks within the DD Form 1494 is still required.

Ultimately, the EL-CID file is submitted in stages that coincide with the DoD acquisition process phases. A short description of the stages follows.

a. <u>Stage 1: Conceptual</u>. The initial planning effort has been completed, including identification of proposed frequency bands and other available characteristics. Certification of spectrum support for systems at Stage 1 provides initial guidance on the feasibility of obtaining certification of spectrum supportability at subsequent stages.

b. <u>Stage 2: Experimental</u>. The preliminary design has been completed. Radiation using "bread-board" equipment or preliminary models may be required. Certification of spectrum supportability for RF systems at Stage 2 is a prerequisite for receiving a frequency assignment.

c. <u>Stage 3: Developmental</u>. The major design has been completed and radiation may be required from "brass-board" models during testing. Certification of spectrum supportability for RF systems at Stage 3 is a prerequisite for national authorization of radiation in support of developmental testing of systems. It also provides guidelines for assuring certification of spectrum supportability at Stage 4. At this point, the intended frequency band will normally have been determined and certification at Stage 3 will be required for testing of proposed operational hardware and potential equipment configurations.

d. <u>Stage 4; Operational</u>. Identify the final operating constraints or restrictions required to ensure compatibility when development has been essentially completed. Certification of spectrum supportability for RF systems at Stage 4 is a prerequisite for a frequency assignment for an operational system.

A.5 The Form and Available Tools

A.5.1 <u>DD Form 1494</u>

The DD Form 1494 is a multipage document used to coordinate applications for equipment frequency allocations, both nationally and internationally. The form is composed of the six pages and may be assembled in different order depending on the forum to which it is being submitted for evaluation. One very important aspect of the form is that the back of each page contains detailed instructions for completing each question block. Completeness and accuracy are critical factors in obtaining a timely approval.

a. Page 1: DoD General Information. The application's first page contains general information concerning the nomenclature, use, number of equipment types that make up the system, and the frequency requirements.

b. Page 2: Transmitter Equipment Characteristics. The second page documents transmitter equipment characteristics. All technical characteristics required here, such as the tuning range, output power, RF channeling capability, emission BW, and so forth, are evaluated in accordance with DoD requirements to determine the system's suitability for operation in the intended EM environment.

c. Page 3: Receiver Equipment Characteristics. This page consists of information related to receiver characteristics. The required data items are evaluated against performance requirements to determine the equipment's ability to discern and process desired signals in the intended operational environment. With a multi-receiver system, a copy of the receiver page should be submitted for each different receiver.

d. Page 4: Antenna Equipment Characteristics. It is very common for separate receiver and transmitter antennas to be employed or for several different antennas to be associated with the same transmitter. No attempt should be made to describe several antennas on the same page. Use the "Remarks" block to describe any unusual antenna characteristics, particularly as they relate to EMC assessment, and to clarify any other antenna information provided.

e. Page 5: NTIA General Information. The information contained in this page mimics the information in the DoD General Information page; however, it provides a format acceptable to the IRAC SPS along with other specific required information. The DoD general information page is removed prior to submitting the application to the SPS. The NTIA page is used to begin U.S. national coordination with other government agencies via the SPS review process. Any agency that is an SPS member can impact approval of an application based on the information provided or left out. Block 14 is for the line diagram. This is one of two blank pages that the DD Form 1494 provides to allow for further system description. Sometimes the line-diagram page is referred to as page 5a.

f. Page 6: Foreign Coordination General Information. This page is intended only for equipment that will be operated outside the US&P. Foreign disclosure authority is required for coordination to obtain spectrum support from countries where the equipment may operate. Consequently, release of technical information contained in DD Form 1494 to these countries is necessary. Such information, however, may not be released without first obtaining foreign disclosure approval. Action must be initiated to obtain foreign disclosure authority in accordance with Military Department regulations and policies for the release of appropriate data to the proposed host nations. A foreign coordination version of DD Form 1494 is treated as a completely separate document from a U.S. coordination version. This page should not be completed unless foreign coordination of the system is intended.

Continuation pages are acceptable wherever needed. They can be used to provide or continue any remarks needed in reference to any of the other six pages. Continuation pages are highly encouraged to provide necessary information for the analysis and documentation that will take place in the approval process.

A.5.2 Equipment Location-Certification Information Database

The EL-CID was developed to provide an automated tool to support electronic processing of spectrum certification requests at the NTIA. The database structure and design are based on the new comprehensive database (the OSM Data Dictionary) being developed at NTIA to replace the GMF database that is currently used to support various spectrum management activities, particularly the frequency assignment process. The system information submitted using the DD Form 1494 is used to populate data fields in the EL-CID application. Most submissions to the SMO offices are in the EL-CID format.

A.5.3 Stepstone Editor

Stepstone Editor is a proposed spectrum certification tool supporting the DoD’s equipment spectrum certification process. It is a web-based application to aid in starting the frequency allocation approval process using the information contained in DD Form 1494. It provides tools for the Services (located on a secure server) and industry to create, validate, process, and approve spectrum certification requests. This includes a supportability editor, NTIA regulatory compliance checks to assure data quality and validity, collaboration and workflow capabilities, and certification process metrics. It also provides a centralized database of supportability information for the Services, which allows browsing and search capabilities.

A more useful feature is the direct output file conversion to an EL-CID format. It steps the user through the application process asking the same questions that must be answered when manually filling out a DD Form 1494. Compliance checks are integrated into the application to verify the proper data input format and that the data is within the proper ranges. A lot of information that resides in the NTIA Redbook has been provided within the application.

A.6 Example DD Form 1494 for AMT

The intent of the allocation authorization process and use of EL-CID is to document the entire link including transmitter, transmitting antenna, receiving station, and the TM receiver. This allows an accurate accounting within the GMF, the database of federal users, and frequencies assigned and maintained by the NTIA/OSM. An accurate accounting of AMT operations is vital as the frequency assignments contained in the GMF may be used by federal agencies for spectrum management activities such as spectrum sharing and utilization. Historically, some AMT submissions have only included the link’s transmitting side (i.e., the transmitter and transmitting antenna). It was understood these emitters would be received by DoD test ranges that are already documented.

The 1494 preparation guide[17] is available for aiding in the completion of a DD Form 1494. It provides a form overview and steps through every block on every page providing an

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[17] M. Makowski. *DD Form 1494 Preparations Guide*. Retrieved 2 June 2021. October 2005. Available at https://govtribe.com/file/government-file/w91crb21r0012-attachment-20-dd1494-preparationguide-dot-pdf.

explanation or a data definition that should be entered into those blocks. It also provides a guide to the minimum data requirements for each stage of allocation authorization request. As the system progresses from conceptual to operational the amount of data and the fidelity of that data increases.

This document supplements the preparation guide by providing a detailed example of an AMT submission. It provides AMT-specific technical parameters for the fields/blocks in each page along with the rationale behind those parameters. For the purposes of this example, assume this is an operational program that, based on differing flight profiles, plans on using all available technologies standardized in Chapter 2 of IRIG 106. To fly at multiple ranges, the transmitter is able to tune within all available TM bands. This is an unclassified program flying within the Western Test Range encompassing Edwards AFB, China Lake NAS, Point Mugu NAS, and Vandenberg AFB. These test ranges are all outfitted with 8-foot parabolic conical scan receive antennas with commonality in the receive chain (filtering, pre-amplification, receiver).

A.6.1 Page 1: DoD General Information

Page 1 is the DoD general information page. Most of these blocks are program-specific, not AMT-specific, or require any special mention. In the “To” block, the local frequency management office should be identified. The “From” block should be the submitting organization or the program of record. The information required in the following blocks should be readily available programmatic information:

- Block 1 Application Title
- Block 2 System Nomenclature
- Block 3 Stage of Allocation
- Block 8 Number of Units
- Block 12 Names and Telephone Numbers
- Classification

a. Block 4 Frequency Requirements. This block asks for frequency bands and AMT link emission designators.

   (1) Block 4a. Frequency(ies). See the example DD Form 1494, page 1, block 4.a. for the example given: 1435 - 1535 MHz, 1750 - 1855 MHz, 2200 - 2395 MHz, 4400 - 4950 MHz, and 5091 - 5150 MHz.

   (2) Block 4b. Emission Designator(s). The rationale for the emission designators will be covered extensively for page 2 in the next section. For now, an emission designator for each modulation scheme is given for the TM system’s maximum over-the-air (OTA) bit rate. For example, if the maximum rates are 20 Mbps for PCM/FM and 40 Mbps for SOQPSK-TG and ARTM CPM, then the input for block 4.b. will be 23M2F1DBN, 31M2G1DDN, and 22M4G1DDN, respectively.

   Alternatively, a reference OTA bit rate of 1 Mbps can be used. In this case, the input for block 4.b. will be 1M16F1DBN, 780KG1DDN, and 560KG1DDN. The explanation is captured in block 13 remarks with the following statement: “For using the maximum OTA bit rate capability of the TM system.”

These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate. Enter the maximum OTA bit rates for each modulation scheme in this field. Appendix B includes an explanation of the multiplier "n" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG-106 necessary BW factor to create the new emission designator. See RCC WP-21-001[18] for further information.

For a reference bit rate of 1 Mbps, these designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate of 1 Mbps. Refer to WP-21-001 for the multiplier "n" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG-106 necessary bandwidth factor to create the new emission designator. See WP-21-001 for further information.

b. <u>Block 5 Target Starting Date for Subsequent Submissions</u>. Based on the stage descriptions above, enter dates for each stage. If documenting a new AMT link utilizing existing AMT technologies, this submission would be a Stage 4 submission. If the form is being used for a TM-related development, then stages 1 - 3 would be applicable. This would also be true for block 9, which requests information on the number of units for each stage.

c. <u>Block 6 Extent of Use</u>. Describe extent of use that will apply to Stage 4 (e.g., continuous or intermittent). If intermittent, provide information including the expected number of hours of operation per day or other appropriate time period; scheduling capability; and any conditions governing the times of intermittent use (e.g., used only during terminal guidance phase, used only as required for calibration of test range equipment). This input is highly subjective and based on a lot of programmatic assumptions. A best estimate is all that is needed. Inputs to this block would be vastly different for submitting a transmitter change versus a range infrastructure upgrade. A sample input is given in the example submission.

d. <u>Block 7 Geographical Area For</u>. In the initial assumptions, this was a ☒ Stage 4 submission for Western Test Range encompassing Edwards AFB, China Lake NAS, Point Mugu NAS, and Vandenberg AFB.

e. <u>Block 9 Number of Units Operating Simultaneously in the Same Environment</u>. Again, a best estimate is all that is needed. Depending on the side of the link being submitted, inputs could be quite different.

f. <u>Block 10 Other J/F-12 Application Numbers</u>. Coordination with the local frequency manager is required to determine if an existing J/F-12 is being superseded or related to an existing J/F-12 by the submission, coordination with the local frequency manager is required. If this is found to be the case, refer to the existing J/F-12 number in either block 10.a. or 10.b.

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[18] Range Commanders Council. *Additional Data to Support Spectrum Certification Requests for Aeronautical Mobile Telemetry Systems*. WP-21-001. June 2021. May be superseded by update. Retrieved 22 June 2021. Available at https://www.trmc.osd.mil/wiki/x/iYu8Bg.

g. Block 11 Operational Requirement. This block documents whether or not this equipment will operate with the same or similar equipment used by other U.S. Military Services, DoD components, U.S. Government agencies, or allied nations. Given the nature of AMT operations and how important range interoperability is to the range commanders, the block should be marked ☒ YES and the block 13 remarks should have the following entry: "11. OPERATIONAL REQUIREMENT - *Air Force, Army, Navy."*

A.6.2 Page 2 – Transmitter Equipment Characteristics

This page gets used the most when organizations request allocation authorization for AMT links. Most believe this is the only page necessary, as it describes the OTA TM link characteristics. Filling out this form for traditional single frequency, fixed bit rate, and modulation mode transmitters is straightforward. The AMT links that are being fielded today are bit rate agile (typically 50 kbps to 40 Mbps), modulation agile, have three modulation mode selections (PCM/FM, SOQPSK, ARTM CPM), and offer differing coding selections (low-density parity check [LDPC] forward error correction and Space-Time Coding [STC]) all in one transmitter. This, coupled with multiband tuning capability, makes for a very capable and mission-configurable transmitter. Some blocks in this page are straightforward (manufacturer, installation, and type) while others are very specific to AMT applications. These blocks are described below with a typical value given where appropriate. The AMT-related interpretations and clarification for each block are also provided where required.

a. Block 1 Nomenclature, Manufacturers Model No. This block is self-explanatory with the exception of the manufacturer's model number. In past submissions the entire part number was listed here, making the approved J/F-12 only applicable to this part number. The model number for this block should be chosen carefully with input from the manufacturer. The submission should describe the transmitter model in general. Any options selected for this model transmitter should not affect the data in the form (thus invalidating the approved J/F-12). The data presented in the DD Form 1494 should be broad enough to cover most, if not all model number options used in this block.

b. Block 2 Manufacturer's Name/Block 3 Transmitter Installation/Block 4 Transmitter Type. These blocks are self-explanatory. See the example for potential inputs.

c. Block 5 Tuning Range. This block specifies the transmitter's tuning range. For this example, the transmitter is capable of providing a carrier within all TM bands, so each band should be identified in this block. The input to the block would be: 1435 – 1535 MHz, 1750 - 1855 MHz, 2200 - 2395 MHz, 4400 - 4950 MHz, and 5091 – 5150 MHz.

d. Block 6 Method of Tuning. The instructions for this block state: Enter the method of tuning (e.g., crystal, synthesizer or cavity). If the equipment is not readily tunable in the field, indicate in Block 25 remarks the complexity of tuning. Include complexity factors such as skill levels involved, major assemblies involved, time required, and location (factory or depot) where equipment is to be tuned. Most of these instructions apply to transmitting equipment, such as a radar beacon where depot level maintenance is required to retune the operating frequency. Since AMT transmitters are frequency-agile with most being band-agile also, most of these instructions for the block do not apply. A typical input for this block would be Synthesizer.

e. Block 7 RF Channeling Capability. This block requires five inputs characterizing how the AMT transmitter will be tuned within the AMT bands. These bands have allowable center frequencies on 0.5 MHz steps in 1 MHz increments.

(1) Lowest channel/frequency. The value for this block should be the lowest center frequency the transmitter is able to tune to in an AMT band. (Note, this value does not account for band-edge back-off calculation as specified in IRIG 106 Chapter 2). For this example, input to this block is 1435.5 MHz.

(2) Tuning increments. The AMT transmitters can typically tune in much finer increments than the channeling plan for AMT bands. Because of this, the channeling plan is specified in this block rather than the tuning increments of the transmitter as this represents a real-world use condition. Input to this block would be 500 kHz/1 MHz channeling for AMT.

(3) Number of channels. The total amount of channels within all AMT bands can be calculated using 1 MHz as the minimum BW, but this does not characterize actual use. Each link (tied to the emission designator, see description for block 7) will require a different bandwidth affecting the number of channels daily. To account for this, only the minimum channel width is given. An example input for this block would be 1 MHz channel (for each tuning band).

(4) Number of frequencies required for operation. The AMT links are single-carrier links. Input for this block is 1.

(5) Minimum frequency separation. The recommendations for adjacent channel separation based on modulation mode and OTA bit rate as specified in IRIG 106 Chapter 2 Appendix 2A are an appropriate input here.

f. Block 8 Emission Designator. The data in this block changes depending on input data rate, modulation mode, and coding selection, which are variable and can change on a per-mission basis. No longer are TM users flying with only one configuration. Links are being tailored per the link requirements for the test. Test missions are able to change the data to the transmitter (affecting bit rate to the transmitter), modulation scheme, and coding based on flight profile, resulting in an infinite number of emission designators.

The emission designator consists of the necessary BW (designator’s first part) and the emission classification symbols (designator’s second part). See Figure A-6.

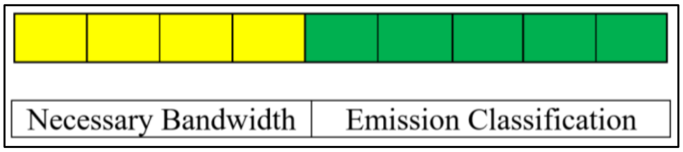

Figure A-6. Emission Designator

There are five fields in the Emission Classification field.

(1) The first symbol indicates the type of main carrier modulation. Only two apply to AMT: symbol “**F**” for PCM/FM and symbol “**G**” for SOQPSK-TG and ARTM CPM.

(2) The second symbol indicates the nature of signal(s) modulating the main carrier. The symbol for AMT is “**1**.”

(3) The third symbol indicates the type of information being transmitted. The correct symbol is “**D**” as TM is directly mentioned in the chart in the NTIA Redbook.

(4) The fourth symbol indicates the details of the signal. This will be modulation mode specific; “**B**” (indicating a two condition modulation scheme) is used for PCM/FM and “**D**” (indicating a 4 condition modulation scheme) for SOQPSK-TG and ARTM CPM.

(5) The fifth symbol indicates the nature of multiplexing, if applicable. Since multiplexing (time/frequency/code) is not applicable, the correct symbol to use is “**N**.” Using the criteria above, examples of emission designators for various AMT links are shown in Table A-1.

Table A-1. Emission Designator Examples for AMT Links

AMT Transmission Link	Emission Designator
4.5 Mbps, SOQPSK-TG	3M51G1DDN
10 Mbps, PCM/FM	11M6F1DBN
8 Mbps, ARTM CPM	4M48G1DDN
5 Mbps SOQPSK-TG, STC	4M06G1DDN

Notice that once you determine the necessary BW, the last five symbols of the emission designator are consistent for each modulation scheme.

- xxxxF1DBN for PCM/FM
- xxxxG1DDN for SOQPSK-TG
- xxxxG1DDN for ARTM CPM

This makes the necessary BW the only variable in determining the emission designator.

NOTE

For a definition of necessary BW, refer to Annex J of the NTIA Redbook. Annex J also illustrates methods used to calculate necessary BWs. (Doppler shift shall not be included in the frequency tolerance or necessary BW.) Chapter 2, Subsection 5.1.3 of IRIG 106 directly addresses necessary BW for TM waveforms. This section defines the necessary BW used in the DD Form 1494 for each TM waveform. This is shown in Table A-2 in terms of modulation scheme and OTA bit rate.

Table A-2. Necessary BW Calculation for AMT Waveforms

Modulation	Necessary BW (DD Form 1494)
PCM/FM	1.16*(OTA bit rate)
SOQPSK-TG	0.78*(OTA bit rate)
ARTM CPM	0.56*(OTA bit rate)

Five numbers and one letter can be used to express the emission designator’s necessary BW portion. For AMT waveforms, three numbers and one letter are sufficient. The letter occupies the decimal point position and represents the BW unit (“H” for hertz, “K” for kilohertz, “M” for megahertz, “G” for gigahertz).

NOTE	For AMT systems, the emission designator for block 8 in the DD Form 1494 for each modulation scheme is specified at the maximum OTA bit rate.

An alternate method is to specify the emission designator for block 8 in the DD Form 1494 for each modulation scheme at a reference bit rate of 1 Mbps.

The necessary BW for each waveform at the link's maximum capability can be found using Table A-3. For example, if the AMT system can operate at 20 Mbps for PCM/FM, 40 Mbps for SOQPSK-TG, and ARTM CPM, the resulting emission designators follow.

- PCM/FM - 23M2F1DBN
- SOQPSK-TG - 31M2G1DDN
- ARTM CPM - 22M4G1DDN

Table A-3. Modulation/Coding Multiplier

Modulation/Coding	Multiplier *n*
PCM/FM/SOQPSK/ARTM CPM	1
SOQPSK-STC	26/25
LDPC Code Rate ***R***=4/5	21/16
LDPC Code Rate ***R***=2/3	25/16
LDPC Code Rate ***R***=1/2	33/16
SOQPSK-STC/LDPC ***R***=4/5	273/200
SOQPSK-STC/LDPC ***R***=2/3	13/8
SOQPSK-STC/LDPC ***R***=1/2	429/200

For an input bit rate of 1 Mbps, resulting emission designators are presented in this list.

- PCM/FM - 1M16F1DBN
- SOQPSK-TG - 780KG1DDN
- ARTM CPM - 560KG1DDN

The input bit rate must be known to determine any emission designator. Using the input bit rate, Table A-3, and Figure A-7, the OTA bit rate and necessary BW can be calculated. As an example, if the input bit rate is 5 Mbps (***R***=5 Mbps), OTA bit rate ***nR*** = 5 Mbps (in this case the multiplier ***n*** in Table A-3 is **1**) resulting in the necessary BW of 5M80, 3M90, and 2M80 respectively for each modulation scheme. These new numbers are then coupled with the emission classification for the appropriate waveform arriving at the new emission designator.

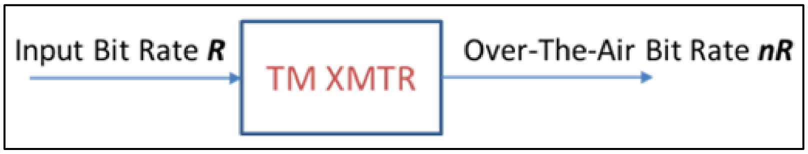

Figure A-7. OTA Bit Rate Determination

If coding is applied to the link, the OTA bit rate changes, which in turn requires a new calculation for necessary BW. A multiplier ***n*** can be applied to the input bit rate ***R*** to find the OTA bit rate as shown in Figure A-7. This new OTA bit rate is then used with Table

A-3 for the appropriate modulation mode to calculate the new necessary BW. Table A-3 specifies the multiplier ***n*** to be used based on all available combinations of coding. This new necessary BW is then used with the emission classification for the waveform to arrive at the new emission designator.

In addition, a note will be added in block 25 remarks explaining the emission designators for AMT links and how to arrive at a new necessary BW and thus a new emission designator. An example of two versions of this note is below. The WP-21-001 white paper should be provided as an attachment explaining the rationale and this process.

(1) Emission designators for using the TM system's maximum OTA bit rate capability. These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate. Enter the maximum OTA bit rates for each modulation scheme in this field. Refer Table A-3 and Figure A-7 for the multiplier "**n**" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG-106 necessary bandwidth factor to create the new emission designator. See RCC WP-21-001 for further information.

(2) Emission Designators for a reference bit rate of 1 Mbps. These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate of 1 Mbps. Refer to Table A-3 and Figure A-7 and chart for the multiplier "n" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG-106 necessary bandwidth factor to create the new emission designator. See RCC WP-21-001 for further information.

g. Block 9 Frequency Tolerance. This is an important parameter as it is a contributor to carrier frequency error, which eventually needs to be compensated for in the receiver. The value requested is in parts per million (ppm), meaning the absolute frequency tolerance will change within each AMT band. Typical value for this block for AMT transmitters can span ±1 to 20 ppm depending on the type of transmitter, digital versus analog. If available this parameter should be specified over temperature and age (time).

h. Block 10 Filter Employed. This block asks for information on any filtering in the transmitter. The NTIA is very interested in the technical details of this block since it affects out-of-band emissions. The information in this block is manufacturer-specific, which may require the vender to supply the information. Any filtering details are added to block 25 remarks if further explanation is required. An example on the type of information that may go into block 25 is provided in the sample DD Form 1494. If a filter is employed ☒ **YES** should be checked.

Filtering is applied in three steps:

- Digital premodulation filtering, scaled automatically with the bit rate.
- Multiple stages of discrete component and stripline filtering in the upconversion circuits.
- 7-pole Butterworth low-pass filter after the final output stage.

i. Block 11 Spread Spectrum. The AMT systems are not spread spectrum system so this block should be checked as ☒ **NO**.

j. Block 12 Emission BW. Block 12 is for providing the modulated waveform’s emission BW, which is defined as that emission appearing at the antenna terminals and includes any significant attenuation contributed by filtering in the output circuit or transmission lines. Values of emission BW specified should be indicated as calculated or measured by marking the appropriate box. Be sure to indicate units used (e.g., Hz, kHz or MHz). Measurements or calculations are made at the −3 dB/−20 dB/−40 dB/−60 dB points of the modulated waveform. For AMT applications, these measurements are referenced to the peak of the modulated waveform using the RBW and VBW settings for the spectrum analyzer as recommended within IRIG 106, which are RBW=30 kHz and VBW=300 Hz. The span should be selected to capture the entire waveform. A good rule of thumb is for the span to be four to six times the OTA bit rate. See Figure A-8 for an example. In addition, block 12 also requires OBW be input. The OBW for AMT waveforms is directly addressed in IRIG 106, chapter 2, Appendix 2-A.

NOTE	For AMT waveforms the terms “occupied BW” and “necessary BW” are interchangeable.

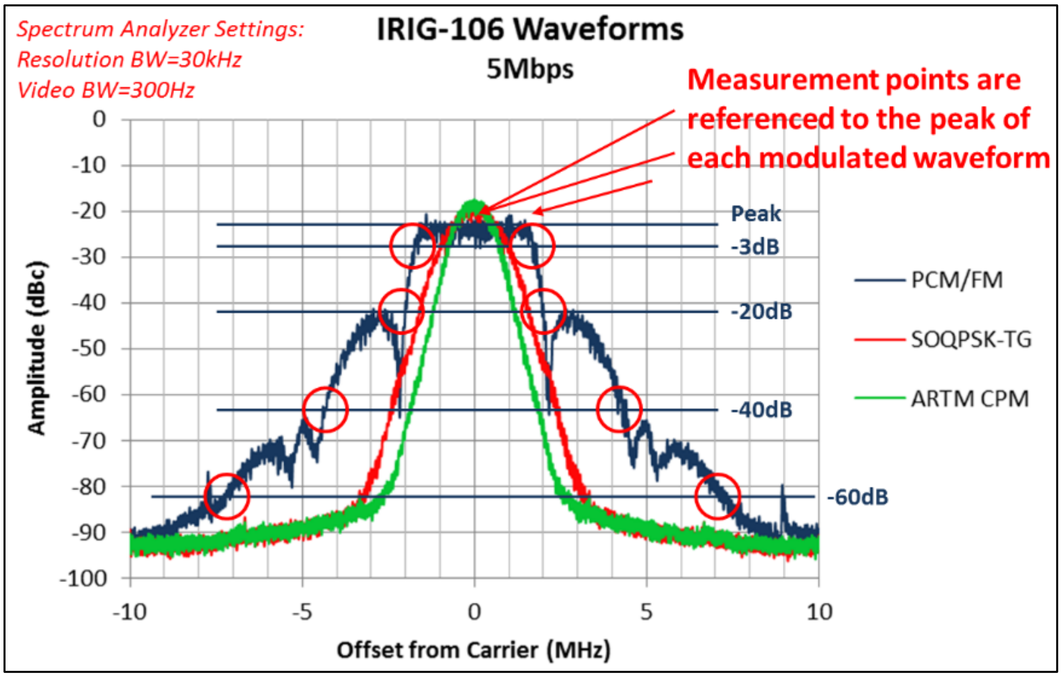

Figure A-8. Emission BW Example for AMT Waveforms

As is the case with the emission designator, emission BW and OBW varies with input bit rate, modulation mode, and coding selections. This results in endless combinations of required waveform measurements. To account for this, the same strategy is employed as the emission designator (i.e., the emission BW) at each measurement point (−3 dB/−20 dB/−40 dB/−60 dB/OBW) is given for each modulation scheme at a reference bit rate of 1 Mbps. These numbers for ideally generated waveforms are given in Table A-4. Note, these numbers should be verified with the actual transmitter. The PCM/FM generated via analog means can vary widely depending on the deviation ratio, data filtering type, and transmitter. It is recommended that, for this type of transmitter, these values be determined by measurement. The numbers are in the Table A-4 scale if the maximum OTA bit rates are used.

Table A-4. Emission Bandwidths for AMT Waveforms

Waveform	−3 dB	−20 dB	−40 dB	−60 dB	OBW
PCM/FM	1.02 MHz	1.22 MHz	2.68 MHz	3.96 MHz	1.16 MHz
SOQPSK-TG	0.35 MHz	0.93 MHz	1.43 MHz	1.99 MHz	0.78 MHz
ARTM CPM	0.24 MHz	0.66 MHz	1.05 MHz	1.54 MHz	0.56 MHz

NOTE If for some reason the emission BWs need to be determined for the AMT link at another input bit rate (e.g., the maximum OTA bit rate), it can be recalculated at each point for the appropriate waveform. Determine *R* and *n* (from Table A-3), then use *n***R* to determine the new emission BW for each point for the appropriate waveform. The OBW can also be determined by using *n***R* and applying that to Table A-2. If an analog PCM/FM transmitter is used, it is recommended these measurements be accomplished again at the new input bit rate or at the maximum OTA bit rate.

k. Block 13 Maximum Bit Rate. This is specified as the maximum information bit rate. With this definition, the data input to this block is the maximum bit rate in which the AMT transmitter can input data and modulate a carrier. This value may depend on modulation mode and coding scheme also. For this example, 20 Mbps PCM/FM and 40 Mbps SOQPSK-TG/ARTM CPM is assumed regardless of coding scheme. If specific bit rate limitations per modulation scheme/coding exist, use block 25 remarks to further explain the data in block 13.

l. Block 14 Modulation Techniques and Coding. This block is for describing in detail the modulation and/or coding techniques employed. Historically this field dealt with only the three modulation schemes in IRIG 106 - PCM/FM, SOQPSK-TG, and ARTM CPM. With the addition of IRIG-106 appendices 2D and 2E, coding must now be described. Block 25 remarks are used to provide the required detail. This is one example of this description.

14. Modulation Techniques and Coding - PCM/FM (binary FM with premodulation filtering), SOQPSK-TG (offset QPSK with premodulation filtering), ARTM CPM (4-ary frequency shift keying with premodulation filtering), STC (Alamouti space-time block code applied to SOQPSK-TG), LDPC (systematic linear block code with differing information block sizes and code rates)

m. Block 15 Modulation Frequency. The maximum or minimum modulation frequency for each AMT waveform is input into this block. The definition of maximum and minimum is given for this block as:

- Maximum - For frequency or phase-modulated transmitter enter the maximum modulation or baseband frequency. This frequency is assumed to be the frequency at −3 dB point on the high-frequency side of the modulator response curve. Indicate the units (e.g., Hz, kHz, or MHz).

- Minimum - Enter the lowest frequency in the baseband modulating signal when analog modulation is employed

For AMT waveforms the definition for minimum is not applicable; therefore, ☒ **MAXIMUM** should be checked. The values used for F_{max} for PCM/FM and SOQPSK-TG are derived using equation A-1.

$$F_{max} = \frac{hR_b}{2log_2(M)} \qquad \text{Eq. A-1.}$$

where h is the modulation index (in this case the deviation ratio)
M is the order of the modulation scheme
R_b is the input bit rate

The value used for F_{max} for ARTM CPM is derived using equation A-2.

$$F_{max} = \frac{h_1R_b}{4} + \frac{h_2R_b}{2} \qquad \text{Eq. A-2.}$$

These values can be input directly into Block 15 as plain text, such as the following, or they can be entered as a simple table into Block 25 remarks, such as Table A-5.

> 15. Modulation Frequency (maximum) - PCM/FM (F_{max}=0.35*bit rate), SOQPSK-TG (F_{max}=0.25*bit rate), ARTM CPM (F_{max}=7/32*bit rate)

Table A-5. Modulation Frequency (Maximum) for AMT Waveforms

Modulation Mode	M	Maximum Modulation Frequency
PCM/FM	2	$F_{max} = 0.35*R_b$
SOQPSK-TG	4	$F_{max} = (1/4)*R_b$
ARTM CPM	4	$F_{max} = (7/32)*R_b$

n. Block 16 Pre-emphasis. Pre-emphasis (and de-emphasis) are primarily used in the transmission (and reception) of audio signals. The IRIG 106-compliant AMT transmitters do not apply pre-emphasis. This block should be marked ☒ **NO**.

o. Block 17 Deviation Ratio. For a frequency or phase modulated transmitter, enter the deviation ratio computed with the formula:

$$DeviationRatio = \frac{MaximumFrequencyDeviation}{Maximum\ Modulation\ Frequency}$$

In terms of IRIG 106, block 17 is the modulation index, h, for each AMT waveform. These values are known to be 0.7 for PCM/FM, 0.5 for SOQPSK-TG, and {4/16, 5/16} for ARTM CPM. See Table A-6. These values can be input directly into block 17 or a table can be added into block 25 remarks.

Table A-6. Deviation Ratio for AMT Waveforms

Modulation Mode	Deviation Ratio (h)
PCM/FM	0.7
SOQPSK-TG	0.5

ARTM CPM	{4/16, 5/16}

p. Block 18 Pulse Characteristics. The AMT transmitters compliant with IRIG 106 modulation schemes do not offer pulse modulation; therefore, all the subblocks characterizing the pulse are N/A.

q. Block 19 Power. Power output of AMT transmitters is stated in terms of mean power and not peak envelope power. So ☒ **MEAN** should be checked and the mean power value is input for each emission designator. Unit of power is watts. If the transmitter is capable of variable output power up to a maximum output level, state that in the block. For this example, 10 W (max)/output (variable) is used for each emission designator.

NOTE	An STC-enabled transmitter has two RF outputs.

Any unique capabilities that affect output power should also be annotated in block 25 remarks. An example is shown below.

> 19. Power - Output power is variable between +40 dBm and +10 dBm in 1 dB steps.

r. Block 20 Output Device. This block requires entering a description of the device used in the transmitter output stage (e.g., ceramic diode, reflex klystron, transistor, or a traveling-wave tube [TWT]). Most current AMT transmitter designs have a **TRANSISTOR** final output stage.

s. Block 21 Harmonic Level/Block 22 Spurious Level. These blocks are inter-related and deal with harmonic-related and spurious emissions from the AMT transmitter. Block 21a/b requires the input to be the harmonic level in dB, relative to the fundamental frequency (the carrier frequency) of the second and third harmonics. Block 21c is for the relative level in dB of the largest harmonic above the third harmonic. Block 22 defines the point in which an emission is spurious and no longer part of the modulated spectrum. Enter the maximum value of spurious emission in dB relative to the fundamental, which occurs outside the −60 dB point on the transmitter fundamental emission spectrum and does not occur on a harmonic of the fundamental frequency. These emissions are limited by two standards, IRIG 106 and MIL-STD 461.[19] The IRIG 106 identifies two types of spurious emissions. The first type of emission is from the transmitter RF port (specifically "from the transmitter case"), which is limited by MIL-STD 461. The other type is from the transmitting antenna (specifically "emissions from the antenna"). These emissions are limited to an absolute limit of −25 dBm.

The test for conducted emissions from the antenna terminal, MIL-STD 461 CE106, has a limit of −80 dBc for compliance. For a 10 W transmitter this level is −40 dBm. The second and third harmonics are specifically addressed and limited to 20 dBm or −80 dBc,

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[19] Department of Defense. "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment." MIL-STD-461-G. 11 December 2015. May be superseded by update. Retrieved 17 May 2021. Available at https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=35789.

whichever is less restrictive. In the case of 5/10/20 W transmitters, typical AMT transmitter power levels, −20 dBm is less restrictive.

For both cases of emission, the most restrictive limit is applied and input into blocks 21 and 22. It should be noted that these are the emission limits; measured data should be less than these limits.

- Block 21a/b - Second and third harmonic emissions are limited to −25 dBm (−20 dBm vs −25 dBm). This value must be referenced to the carrier power; for a 10 W transmitter this value would be −65 dBc.
- Block 21c – All other harmonic emissions are limited to −80 dBc (these are now considered spurious emissions).
- Block 22 - Spurious emissions are limited to −80 dBc (−80 dBc vs −25 dBm)

t. Block 23 FCC Type Acceptance Number. The AMT transmitters do not go through FCC testing for certification as the FCC is on the public side, as opposed to the government side of Figure A-1. The FCC has different processes for different types of approvals: certification, type acceptance, notification, verification, and declaration of conformity. This block should be left blank or filled with **N/A**. For information purposes a description of each type acceptance is given.

(1) FCC Certification. Requires an application submittal that includes a complete technical product description and a measurement report showing compliance with FCC technical standards. A manufacturer supplies test data to the FCC, usually from a laboratory that the FCC knows and trusts, and certification is usually issued on the basis of the test data and other information about the product. Devices subject to certification include low-power transmitters (i.e., cordless telephones, garage door opener controls, radio control toys, security alarm systems, scanning receivers, etc.).

(2) Type Acceptance. Similar to certification, except that it typically applies to radio transmitter equipment that will be used in a licensed radio service. Devices subject to type acceptance include land mobile transmitters (i.e., cellular transmitters; police, fire, and business transmitters; transmitters used in the maritime and aeronautical safety services; and citizen band and other transmitters used in the personal radio services). It is interesting to note that type acceptance has actually been written out of the FCC rules. Devices that were type accepted under the old rules are now subject to certification or a declaration of conformity.

(3) Notification. Requires submittal of an abbreviated application for equipment authorization, which does not include a measurement report, to the FCC. A measurement report showing product compliance with the FCC technical standards must be retained by the applicant and must be submitted upon request by the commission. Devices subject to notification include: point-to-point microwave transmitters; AM, FM, and TV broadcast transmitters; certain microwave auxiliary broadcast transmitters; and other receiver types.

(4) Verification. Verification is a self-approval process where the applicant performs necessary tests and verifies they have been done on the device to be authorized, and that the device is in compliance with the technical standards. Devices subject to

verification include business computer equipment (Class A); TV and FM receivers; and nonconsumer industrial, scientific, and medical equipment. Verified equipment requires that a compliance label be affixed to the device as well as information included in the operating manual regarding the device’s interference potential. The wording for the compliance label and the information statement regarding interference problems is included in Part 15 of the FCC rules. Verified devices must be uniquely identified with a brand name and/or model number that cannot be confused with other devices on the market.

(5) Declaration of Conformity. In a declaration of conformity, the manufacturer issues a formal statement to the FCC that the device has been tested at an accredited laboratory and that it complies with the rules. This is typically used for personal computers and peripherals.

u. Block 24 NAVSTAR GPS Band Measurement. The potential for GPS interference from AMT transmitters is now being addressed in DD Form 1494. Block 24 requires an assessment of additive noise in the Navigation Satellite Timing and Ranging (NAVSTAR) GPS bands of L1 and L2 generated by the AMT transmitter. For a Stage 1 submission, this will be a calculated estimated value. For Stage 2, Stage 3, and Stage 4 submissions, these will be actual measurements, though only in Stage 4 submissions are these measurements required. Federal agencies requesting spectrum certification for systems operating in the 960 - 1710 MHz (and 390 - 413 MHz, not applicable for AMT systems) frequency bands must provide measurements of the emission levels generated in the frequency bands used by the NAVSTAR GPS. For AMT systems with the ability to tune in the lower L-band, this means these measurements must be accomplished and the results placed in block 24.

Block 24 requires both wideband and narrowband measurements be accomplished. Per the units in block 24.a. and 24.b. wideband measurements are referenced to a 1 MHz BW. For AMT systems, narrowband refers to any spurious content at either L1 or L2 and is referenced to a 1-Hz BW. If no spurious emissions are located as the transmitter is tuned throughput lower L-band, then adjust the wideband measurement accordingly (subtract 60 dB). The IRIG 118 vol. 1, chapter 5.31 provides the information and procedure for performing this test. Block 24.e. is not applicable to AMT systems. Some typical numbers for an STC-enabled transmitter are included in the sample form.

v. Block 25 Remarks. If the recommendations from above are followed, Block 25 remarks could include clarifications and further explanations for the following fields.

- Block 8 Emission Designators
- Block 10 Filter Employed
- Block 12 Emission Bandwidth
- Block 14 Modulation Techniques and Coding
- Block 15 Modulation Frequency (Maximum)
- Block 17 Deviation Ratio (if required, chart of Deviation Ratio is used)

A.6.3 Page 3 – Receiver Equipment Characteristics

Page 3 has the technical details describing the AMT receiver equipment. The AMT submissions historically have not included the receiver, as the ground infrastructure is assumed to have the receive capability required by the transmitter. As with the transmitter side, the information for the receiver can get quite large with three modulation modes, differing data rates, forward error correction, space-time coding, tuning range, etc. The explanations for the content required for each block are informative and provide enough information to complete the page. Most items on this page can be derived from the receiver procurement specification or via the receiver manufacturer directly. There are some blocks that are AMT-specific, which are addressed below. Most Major Range Test and Facility Bases (MRTFBs) are equipped and able to receive any IRIG 106 compliant signal so this capability should be reflected in page 3.

It should also be noted that this page is only for the AMT receiver and NOT the entire receive system. When AMT receive system performance is stated it is in terms of *G/T* (dB/K) for the entire receive and demodulation chain, not just the receiver. The AMT receive systems are not characterized in terms of receiver performance only (i.e., receiver sensitivity) but as a receiving system.

a. Block 1 Nomenclature, Manufacturer's Model Number, Block 2 Manufacturer's Name/Block 3 Receiver Installation. These blocks are self-explanatory and should contain the same information as in page 2 of the DD form 1494. See the example for potential inputs to these blocks.

b. Block 4 Receiver Type. Most AMT receivers employ some kind of downconversion scheme to arrive at the standard IF of 70 MHz. If this is the case, heterodyne or super heterodyne are appropriate values for this block. If direct RF-IF conversion is accomplished, then DIRECT would be a valid input. For this example, super heterodyne, which is a dual-conversion scheme, is used.

c. Block 5 Tuning Range. Enter the frequency range in which the receiver is capable of being tuned. For equipment designed to operate only at a single frequency, enter this frequency. Indicate units (e.g., kHz, MHz, or GHz). The specified tuning range should, at a minimum, match that of the transmitter (page 2, block 5).

d. Identify C-band IF tuning capability, if applicable. Example input: 400 - 1150 MHz, 1435 - 1535 MHz, 1750 - 1855 MHz, 2200 - 2395 MHz, 4400 - 4940 MHz, or 5091 - 5150 MHz.

e. Block 6 Tuning Method. Because of the AMT receiver's very wide tuning range, basically C-band IF to mid C-band, synthesized tuning is required. Input for this block would be **SYNTHESIZER**.

f. Block 7 RF Channeling Capability. The RF channel capability, block 7 has five sub-blocks. Each block is to inform the NTIA of the AMT receiver's tuning capability.

    (1) Lowest channel/frequency. The lowest tuned frequency of the transmitter frequency band(s) at which the transmitter is capable of operating. For AMT operations, this would be the lowest frequency in lower L-band, 1435.5 MHz. Even though an AMT signal can't have this center frequency due to band edge back-off requirements, the receiver is still able to tune to this center frequency. If the

receiver implements C-band IF tuning, then a note can be added that 400 MHz is the lowest frequency; though this is not received OTA.

(2) Tuning increments. The frequency separation between tuned frequencies for equipment with uniformly spaced steptuned capability. Though the receiver's tuning increments will typically be less than 1 MHz, AMT operations are scheduled on 0.5 MHz centers spaced at a minimum of 1 MHz apart. For AMT operation, this value is 1 MHz/500 kHz centers.

(3) Number of channels. For uniformly spaced channels, enter the center frequency of the first channel and channel spacing. The AMT operations are scheduled on 1-MHz increments starting at the lowest frequency in each TM band. This is true for all TM bands. Example input: 1 MHz channel (for each tuning band).

(4) Number of frequencies required for operation. Enter the number of frequencies required for nominal operation. The AMT links are typically simplex links with no frequency division multiplexing required. The value for this block is 1.

(5) Minimum frequency separation. The required frequency separation between the different radio sets operated at one transmitter or receiver location. Minimum frequency separation is dependent on modulation mode and OTA data rate of the signals in question. Chapter 2 Appendix 2A of IRIG 106 details how to schedule AMT waveforms in AMT bands so this reference should be placed in this block.

g. Block 8 Emission Designators. The instructions for block 8 ask for the emission designator(s) including the necessary BW(s) for each designator (e.g., 16K0F3E). For systems with a frequency hopping mode, as well as a nonhopping mode, enter the emission designators for each mode. (Since AMT links are not frequency hopping, the second sentence does not apply.) For an AMT submission, the emission designators placed in block 8 should be identical to the emission designators specified for the transmitter (page 2, block 8). These designators are for the maximum OTA bit rate the TM system can support. For example, if the AMT system can operate at 20 Mbps for PCM/FM and 40 Mbps for SOQPSK-TG and ARTM CPM, the resulting emission designators are:

- PCM/FM - 23M2F1DBN
- SOQPSK-TG - 31M2G1DDN
- ARTM CPM - 22M4G1DDN

An alternate method is to reference the emission designator to an OTA bit rate of 1 Mbps for each modulation scheme. For an input bit rate of 1 Mbps, resulting emission designators follow.

- PCM/FM - 1M16F1DBN
- SOQPSK-TG - 780KG1DDN
- ARTM CPM - 560KG1DDN

A similar note should be added in block 24 remarks regarding the determination of the emission designator. Two examples are provided here.

(1) For using the maximum OTA bit rate capability of the TM system for emission designators. These designators are for each modulation scheme (PCM/FM,

SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate. Enter the maximum OTA bit rates for each modulation scheme in this field. Refer Table A-3 and Figure A-7 for the multiplier “n” to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG-106 necessary BW factor to create the new emission designator. See RCC WP-21-001 for further information.

(2) For a reference bit rate of 1 Mbps for emission designators. These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, and ARTM CPM respectively) at an uncoded OTA bit rate of 1 Mbps. Refer to Table A-3 and Figure A-7 for the multiplier “n” to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG 106 necessary BW factor to create the new emission designator. See RCC WP-21-001 for further information.

h. Block 9 Frequency Tolerance. This number should be readily available in the product specification, owner’s manual, or from the manufacturer. A typical value would be ±1 ppm.

i. Block 10 IF Selectivity. Block 10 requires the BW for each IF stage be entered at the −3 dB, −20 dB, and −60 dB levels with the proper units of BW indicated (e.g., kHz or MHz). The TM receivers typically employ a dual frequency conversion (RF-IF1-IF2) resulting in two IFs: the first IF and the second IF. Each IF can have multiple filtering choices associated with it, which are selected based on OTA bit rate and modulation mode. Other filtering may also exist in the receiver based on the architecture so the manufacturer will have to be contacted.

The filter(s) characteristics required for this block that are associated with the first IF typically are not accessible externally, making a direct measurement impossible. To attain these values, the manufacturer will have to be consulted. This is not true of the second IF, as it is accessible, typically at 70 MHz, as an output from the receiver. The −3/−20/−60 dB BW values can be measured or, as in the case with the first IF filter(s), the manufacturer can be consulted. An example of the results was given in Figure A-8 if the measurements are made for each second IF filter selection available. The number of IF BW selections shown in Figure A-9 is typical so inserting the required information into block 10 is impractical. Block 24 remarks can be used to enter the filter characteristics for each IF filter employed. Refer to the example below.

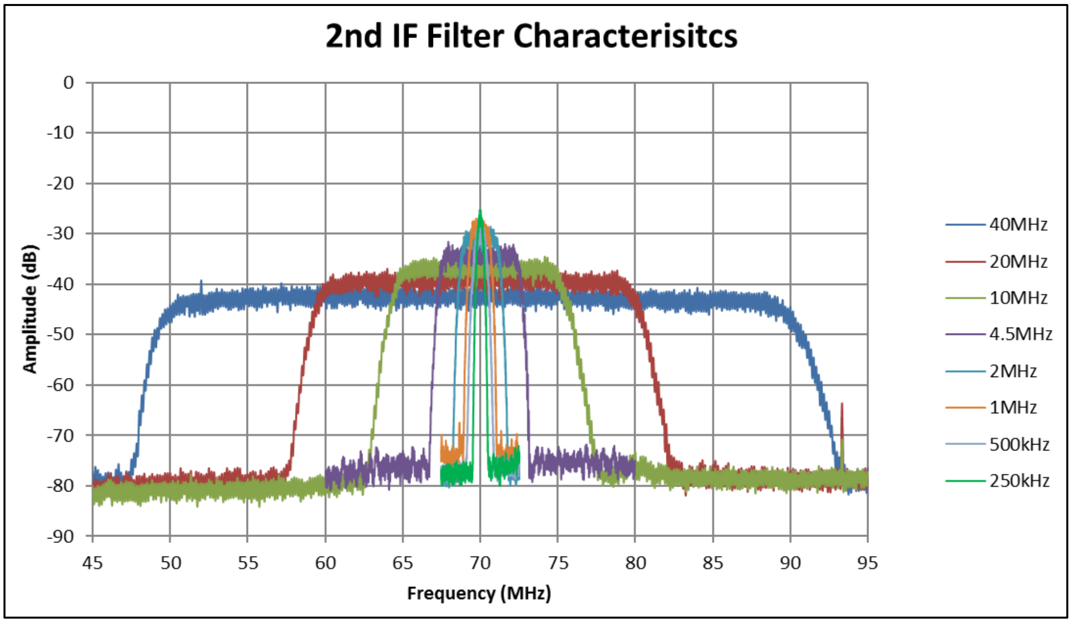

Figure A-9. Sample Second IF Filter Characteristics

The TM receivers select the appropriate second IF filter based on data rate and modulation mode also trading detection efficiency and adjacent channel rejection. Exact values depend on the manufacturers.

<u>10. IF Selectivity</u> - Receiver has a single first IF filter and multiple 2nd IF filters available based on modulation scheme and OTA bit rate.

1st IF Filter:	a. −3 dB: 40 MHz	b. −20 dB: 45 MHz	c. −60 dB: 50 MHz
2nd IF Filter:	a. −3 dB: 2 MHz	b. −20 dB: 3 MHz	c. −60 dB: 3.5 MHz
2nd IF Filter:	a. −3 dB: 4.5 MHz	b. −20 dB: 5.8 MHz	c. −60 dB: 6.7 MHz
2nd IF Filter:	a. −3 dB: 10 MHz	b. −20 dB: 12.7 MHz	c. −60 dB: 15 MHz
2nd IF Filter:	a. −3 dB: 1 MHz	b. −20 dB: 1.8 MHz	c. −60 dB: 2.1 MHz
2nd IF Filter:	a. −3 dB: 4.5 MHz	b. −20 dB: 5.8 MHz	c. −60 dB: 6.7 MHz
2nd IF Filter:	a. −3 dB: 4.5 MHz	b. −20 dB: 5.8 MHz	c. −60 dB: 6.7 MHz
2nd IF Filter:	a. −3 dB: 10 MHz	b. −20 dB: 12.7 MHz	c. −60 dB: 15 MHz

j. <u>Block 11 RF Selectivity</u>. Block 11 requires the BW at the −3 dB, −20 dB, and −60 dB levels. The RF BW includes any significant attenuation contributed by filtering in the input circuit or transmission line. Values of RF BWs specified should be indicated as calculated or measured by marking the appropriate block indicating the BW units (e.g., kHz or MHz). Enter the preselection type (e.g., tunable cavity). For TM receivers, block 11 is treated as the input filtering <u>prior</u> to the first IF. Receiver manufacturers will have to be consulted as these filters cannot be characterized externally to the receiver. The values for block 11 will typically be a measured quantity by the receiver manufacturer so the ☒ **MEASURED** block should be checked. The location on page 3 where the block 11 information is entered depends on the number of RF front-end filters. Use block 11 if the data can fit in the field or use block 25 remarks. An example is given in Table A-7. A note should also be included with the table.

Table A-7. RF Selectivity

SAW Filter	−3 dB	−20 dB	−60 dB
Filter 1	100 MHz	110 MHz	115 MHz
Filter 2	50 MHz	60 MHz	65 MHz
Filter 3	25 MHz	30 MHz	35 MHz
Filter 4	12.5 MHz	17.5 MHz	22.5 MHz

11. RF Selectivity - Receiver has four front-end filters available based on modulation scheme and OTA bit rate.

For modern TM receivers the preselection type of filter (block 11.d.) is typically Surface Acoustic Wave, but other filter designs have been implemented.

k. Block 12 IF Frequency. Most TM receivers employ a dual-conversion scheme to convert RF to IF. Given the wideband nature of current AMT links, 70 MHz has become the standard for the final IF though 20 and 160 MHz have also been implemented. If a direct RF to IF conversion is done, input just the final IF into block 12. If a dual-conversion scheme is implemented, input both IFs into block 12. Refer to the receiver block diagram or contact the receiver manufacturer to determine if the first IF is a dual-conversion receiver.

l. Block 13 Maximum Postdetection Frequency/Block 14 Minimum Postdetection Frequency. These block are N/A for AMT receivers and AMT TM systems in general that conform to IRIG 106. If inputting this form for a legacy FM to FM system, this block would need to be reinvestigated.

m. Block 15 Oscillator Tuned. Mark the appropriate block to indicate the location of the first, second, and third oscillator frequencies with respect to the associated mixer input signal. This block is concerned with the location in frequency of the local oscillator in relation to the input RF signal. This is sometimes referred to as high-side or low-side injection. The manufacturer will have to be consulted for this information or consult the frequency-conversion block diagram, if available.

n. Block 16 maximum bit rate. This block is for the maximum bit rate (bits per second) that can be used. For AMT receivers this is interpreted as meaning the maximum OTA bit rate that can be received and demodulated/decoded. This number should be at least as large as the rate specified for the transmitter (page 2, block 13) including coding if applicable. Also provide any information regarding bit rate limitations per modulation mode, if applicable. Since this receiver is assumed to have STC and LDPC decoding capabilities, a reference to IRIG 106 for the definition of these coding schemes is entered into block 23 remarks (see example). For this example, 40 Mbps is used.

16. Maximum Bit Rate – STC and LDPC detection and decoding per IRIG 106 Chapter 2 Appendices 2D and 2E.

o. Block 17 Sensitivity. Block 17 requires the receiver’s sensitivity to be stated in terms of signal level (dBm) and the criteria used to determine this level. For AMT systems, this level depends on modulation scheme, data rate, and if forward error correction is implemented. The metric typically used to determine acceptable performance is BER at an error rate of 1^{-5}. To determine the sensitivity, the E_b/N_0 at the required BER is required as is the bit rate (R_b) and noise figure (NF) of the receiver. Use equation A-3 to determine the range of input signal levels given these variables.

$$Receiver\ Sensitivity = -174(dBm/Hz) + \frac{E_b}{N_0}(dB) + NF(dB) + 10\log\left(R_b\right)(bps) \qquad \text{A-3}$$

For AMT waveforms, at typical OTA bit rates, with reasonable receiver noise figures, typical range of values would be −85 to −100 dBm for a BER = 1 X 10^{-5}. This assumes no forward error correction is applied. If the receiver's NF is unknown, the manufacturer will have to be contacted or it will have to be measured and input into block 17.c. Typical values would range from 3 to 10 dB. This value does not set the noise figure for the receive system. Block 17.d. is for the receiver's noise temperature, but this information is only required for space or satellite ground-station receivers, making it not applicable for AMT receivers.

p. Block 18 De-Emphasis. AMT systems apply no pre-emphasis so de-emphasis should be marked ☒ **NO** in this block. (See page 2, block 16).

q. Block 19 Image Rejection/Block 20 Spurious Rejection. These blocks characterize the receiver's ability to reject spurious signals and images created during the down conversion process. The spurious signal's frequency is defined to be all frequencies outside the −60 dB IF BW. These values are typically supplied by the receiver manufacturer or can be found in the original receiver procurement specification. Typical values for each is 70 dB of rejection.

r. Block 21 – Adjacent Channel Selectivity. The guidance for this block states "*A ratio in (dB) that compares signal strength received against a similar signal on another frequency*." To provide a number, or to conduct a test to determine a value for this block, some assumptions are required. For AMT applications, the carrier and interfering signals are assumed to be equal. Stated another way: C/I = 0 dB, R_b (carrier) = R_b (interferer), modulation/coding (carrier) = modulation/coding (interferer). In addition, signal spacing should be at least one IF BW higher or lower in frequency. Given these assumptions, a typical value for AMT receivers defaults to the selected IF filter's stopband attenuation, typically 50 dB (minimum).

The assumptions made to arrive at this number should be stated in block 24 remarks. An example follows.

> 21. Adjacent Channel Selectivity – Carrier and interfering signals are assumed to be identical, spaced at least one IF BW apart.

s. Block 22 Intermodulation Rejection Level. For AMT applications, this block is interpreted to identify the rejection of an in-band intermodulation product. Guidance for this block states "*A measure of RF input threshold before intermodulation products occurs (expressed in dB).*" This can be tested by following IRIG 118 Vol. 2 Test 3.3 for multicouplers, but, as with block 21, assumptions are required. In order for the intermodulation product to be within the IF BW passband (preferably at the passband's center for a worst case) with sufficient amplitude to cause distortion, the third-order product {$3(f_1-f_2)$, $3(f_2-f_1)$} has to be evaluated and used. Amplitude of f_1 and f_2 are assumed to be equal. The limiting factor will typically be the third-order intercept point (IP3) of the input to the receiver. (Note: With antenna system filtering before the receiver and within the AMT receiver, this scenario will typically never be realized.) For calculation purposes, a typical value for the two interferers, f_1 and f_2, is −20 dBm. A typical value for an in-band, on-channel third-order product of sufficient amplitude to cause intermodulation distortion would be −100 dBm (max). Using these numbers, the resulting rejection level would be −20 dBm −(−100 dBm) = 80 dB.

The assumptions made to arrive at this number should be stated in block 24 remarks. An example calculation with typical receiver values follows.

- IP3 for the input to the receiver: +20 dBm
- In-band, on-channel intermodulation product (IP) to cause distortion: −100 dBm
- Amplitude of f_1 and f_2 are assumed to be equal
- The interferers' power level is: IP3−(IP3−IP)/3 = −20 dBm
- Expressing this as rejection level: −20 dBm − (−100 dBm) = 80 dB

22. Intermodulation Rejection Level – Value represents the rejection should two equal amplitude signals result in an in-band third-order product causing interference.

t. Block 23 Conducted Undesired Emissions. This block is only required when employing wideband fixed, land, mobile, or portable transmitters in the fixed or mobile service between 29.7 and 50, 162 and 174, or 406.1 and 420 MHz. For an AMT submission, this block is N/A.

u. Block 24 Remarks. The remark block has been used to further describe some of the blocks on page 3. These remarks could be used to clarify the following items.

- Block 8 Determination of Emission Designators
- Block 10 IF Selectivity
- Block 11 RF Selectivity (if block 11 is not used directly)
- Block 16 Error Detecting/Correcting schemes available within the receiver
- Block 21 Adjacent Channel Selectivity
- Block 22 Intermodulation Rejection Level

A.6.4 Page 4 – Antenna Equipment Characteristics

Page 4 has the technical details generally describing both the transmitting and the receiving antennas. Historically, AMT submissions, if they include a page 4, only include the transmitting antenna as the ground infrastructure (in this case the receiving antenna) is assumed. When both transmit and receive antenna characteristics are included in the DD Form 1494 package, the information is input on two separate sheets. Separate page fours are used for each antenna, which is identified in block 1. First the transmitting antenna will be addressed, then the receiving antenna.

a. Transmitting Antenna Characteristics

(1) Block 1 Transmitting. For this example, values for a typical wideband blade antenna are used. These antennas are ubiquitous throughout the flight test

community and are an excellent example of a typical transmitting antenna for AMT applications.

(2) Block 2 Nomenclature, Manufacturers Model No./Block 3 Manufacturers Name. Self-explanatory.

(3) Block 4 Frequency Range. 1400 - 5200 MHz. Transmit antennas are typically tuned dipole elements for the specific AMT band though multiband wideband antennas are available.

(4) Block 5 Type. Dipole Blade.

(5) Block 6 Polarization. Linear.

(6) Block 7 Scan Characteristics. – N/A.

(7) Block 8 Gain. The information requested in this block was not meant for an omnidirectional dipole antenna, rather an antenna with directivity. Block 8.a. asks for main beam gain. Realistically this value changes with Az, El, and frequency. For the purposes of this form, 0 dBi in AZ and EL is an appropriate input. Block 8.b. is concerned with the first sidelobe gain and angular displacement from boresight. For the transmitting dipole antenna this is N/A. The definition of AZ and El views of the gain pattern are as follows:

- Azimuth – top view, looking horizontally
- Elevation – side view, looking vertically

(8) Block 9 Beamwidth. Gain patterns for an antenna(s) installed on the test vehicle are rarely known and are typically estimated based on theoretical patterns or measured patterns in reference to some ground plane. Typical gain pattern for a dipole can be characterized as constant (and maximum) in AZ and maximum at 0° and 180° in EL. For this block, the 3 dB beamwidth in degrees is required. Since 3 dB beamwidth is not applicable to a dipole transmit antenna, the following is used as an input: horizontal – 360° (Az), vertical – 60° (El).

b. Receiving Antenna Characteristics

(1) Block 1 Receive ☒. Parabolic receive antennas at the test ranges that support AMT operations or the reception of AMT signals can vary in size, performance, and frequency range. Dish size can vary from 1.2 to 30 m depending on the range and the mission being supported. Some ranges support all of the AMT bands, and some only support a portion of the available bands. Feed scan technologies and feed designs also vary between the ranges. To provide a representative example, a 5 m parabolic, mechanical scan, multiband receive antenna is assumed with the ability to tune to all available AMT bands.

(2) Block 2 Nomenclature, Manufacturers Model No./Block 3 Manufacturers Name. Self-explanatory.

(3) Block 4 Frequency Range. 1435 – 1535 MHz, 1755 – 1850 MHz, 2200 – 2395 MHz, 4400 – 4940 MHz, or 5091 – 5150 MHz.

(4) Block 5 Type. Enter the generic name or describe general technical features (e.g., horizontal log periodic, Cassegrain with polarization twisting, whip, phased array,

or conformal array). For this example, a 5 m parabolic reflector with prime/ Cassegrain subreflector, conical scan feed with tracking capabilities is used, but many other configurations are present on the test ranges. For example, SCM designs are available that do not required a secondary reflector or mechanical scanning.

(5) Block 6 Polarization. Most MRTFB AMT parabolic receive antennas have a cross-dipole configuration in the feed's front end. These signals are then sent to a 90° hybrid (sometimes called a quadrature coupler) to synthesize RHCP and LHCP. Knowing this, an appropriate input for this block would be synthesized RHCP/LHCP. This input would also be appropriate for an SCM antenna as these designs also derive RHCP and LHCP.

(6) Block 7 Scan Characteristics. In the strictest sense, per the definition for block 7, the term "scan" does not apply to AMT receive antennas. The AMT antennas do not continually scan in Az and/or El. Once the AMT signal is located, that signal is tracked to the best of the antenna's capability. If a definition of scan is used that could apply to AMT receive antennas, then it could be interpreted two ways.

i. Scan Reacquisition. Manual Az/El scanning used during AMT signal reacquisition signal after a track loss event. These values will be the antenna limits.

ii. Scan Auto-Track

  - Conical Scan. Dithers the antenna beam in Az and El as it autotracks the AMT signal source through space. These values will be based on the maximum the main beam is dithered determined by using the lowest frequency of reception.
  - Electronic Scan (SCM). This technology does not dither the antenna beam, but measures tracking errors in Az and El within the main beam. Because the main beam does not dither, blocks 7.a. and 7.b. do not apply.

If these AMT definitions are used to provide values for block 7, then the following could be used for blocks 7.a. to 7.d. If these definitions are not used, then block 7 is N/A.

iii. Block 7.a. Type.

  - Conical Scan. Mechanical conical scan, variable scan rate 15 - 40 Hz, independent Az and El control
  - Electrical Scan. SCM, electrical scan, 500 - 1000 Hz update rate, independent Az and El control

iv. Block 7.b. vertical scan. For an AMT submission, vertical scan is broken into scan acquisition and scan auto track. An example of scan acquisition values would be −2° to 90° at a rate of 25° per second. The values used for scan auto track depend on the parabolic dish size, frequency, and the amount of warble in the mechanical scan feed. For this example, the scan auto track value would be 2°.

v. Block 7.c. Horizontal Scan. For an AMT submission, horizontal scan is also broken into scan acquisition and scan auto track. An example of scan acquisition values would be 0° to 360° at a rate of 25° per second. For this example, the value for scan auto track value would be 2°.

vi. Block 7.d. Sector Blanking. ☒ No

(7) Block 8 Gain. The AMT receive stations are characterized as "systems," thus an overall *G/T* (dB/K) is stated rather than a single antenna gain. The *G/T* is AMT band and dish size dependent. List all the receiving antenna system's *G/T* values per the frequency bands identified in block 4. This information is documented in block 10 remarks. An example for the 5 m dish would be: 1435 – 1525 MHz (9.4 dB), 1755 – 1850 MHz (12.2 dB), 2200 – 2395 MHz (13.7 dB), 4400 – 4940 MHz (19.1 dB), or 5091 – 5150 MHz (20.1 dB).

(8) Block 9 Beamwidth. Beamwidth is dish size and frequency dependent. The beamwidth values should be listed per the frequency bands identified in block 4. For an AMT submission, the full 3 dB beamwidth is assumed. This information is documented in block 10 remarks. An example for the 5 m dish would be: 1435 – 1525 MHz (2.7°), 1755 – 1850 MHz (2.25°), 2200 – 2395 MHz (1.8°), 4400 – 4940 MHz (0.9°), or 5091–5150 MHz (0.8°).

(9) Block 10 Remarks. The remark block has been used to further describe some of the blocks on page 3. These remarks could be used to clarify three receive antenna items.

- Scan characteristics
- Antenna gain in AMT terms of *G/T*
- Beamwidth

A.6.5 Page 5 – NTIA General Information

Page 5 contains the submittal's general information for the NTIA. It can be thought of as the submittal's summary page and the page the NTIA can refer to for a brief description of the entire AMT link. It briefly describes the system's purpose, cost, stage of development with dates, operating frequencies, and location, and it contains a block diagram. It is an important page for someone trying to get a general feel for the submission. Most information required for page 5 already resides in pages 1 through 4 and is very similar to page 1, DoD General Information. As with page 1, some blocks require programmatic information. Those that are not self-explanatory are discussed below.

a. Block 1 Application Title. Block 1 required the government nomenclature of the equipment or the manufacturer's name and model number, and a short descriptive title. Since AMT systems typically have several manufacturers supplying equipment that comprise the AMT link (i.e., transmitter, antennas, and receivers), for AMT submissions provide just the government nomenclature for the AMT link.

b. Block 2 System Nomenclature. See page 1 block 2.

c. Block 3 Stage of Allocation. See page 1 block 3.

d. Block 4 Frequency Requirements

(1) Block 4.a. Frequency(ies). The information in this block should match the information placed in block 4.a. of page 1, block 5 of page 2, and block 5 of page 3.

(2) Block 4.b. Emission Designator(s) – As with page 1 and page 2, the emission designators are derived using either the maximum OTA bit rate the TM system can support or is referenced to an input bit rate of 1 Mbps for each modulation scheme. For the example given previously, the emission designators follow.

- PCM/FM - 23M2F1DBN
- SOQPSK-TG – 31M2G1DDN
- ARTM CPM – 22M4G1DDN

If referenced to an input bit rate of 1 Mbps, the resulting emission designators follow this information.

- PCM/FM - 1M16F1DBN
- SOQPSK-TG - 780KG1DDN
- ARTM CPM - 560KG1DDN

A note will be added in the block 18 remarks explaining the emission designators for AMT links and how to implement the multiplier to arrive at a new necessary BW and thus a new emission designator. The note will be as stated in previous sheets informing the NTIA on how emission designators are created for AMT submissions.

i. For using the maximum OTA bit rate capability of the TM system for emission designators. These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, and ARTM CPM respectively) at an uncoded OTA bit rate. Enter the maximum OTA bit rates for each modulation scheme in this field. Refer to Table A-3 and Figure A-7 for the multiplier “**n**” to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG-106 necessary BW factor to create the new emission designator. See RCC WP-21-001 for further information.

ii. For a reference bit rate of 1 Mbps for emission designators. These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, and ARTM CPM respectively) at an uncoded OTA bit rate of 1 Mbps. Refer to Table A-3 and Figure A-7 for the multiplier “**n**” to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA bit rate is multiplied with the IRIG-106 necessary BW factor to create the new emission designator. See RCC WP-21-001 for further information.

e. Block 5 Purpose of System, Operational, and System Concepts. Block 5 provides a summary description of the system or subsystem function. Also include information on operational and system concepts. Mark whether the system has a wartime function, typically not the case for AMT systems supporting a developmental flight test. An example input for an AMT system might be, “Support AMT operations, transmission of real-time flight test data from aircraft or missiles to ground receiving stations for real-time display and decision making.”

f. Block 6 Information Transfer Requirements. This block describes the link's required character rate, data rates, circuit quality, reliability, etc. This information has generally been described in blocks 13 on page 2 and block 17.a. on page 3, but these were maximum values. This value is for typical range operations. An example input is shown below.

- Data Rates – 1 - 20 Mbps
- Reliability – Bit Error Rate = 1e−6 (minimum)

g. Block 7 Estimated Initial Cost of the System. Though programmatic in nature, an explanation of the information in this block is justified. This block is for information to show the system's general size and complexity, though it is not intended to be a determining factor in system review. The cost to be entered is based on the stage of development.

- Stage 2 – Enter an estimate of the research cost.
- Stage 3 – Enter a development cost estimate.
- Stage 4 – Enter the unit cost of equipment and expected number of equipment or systems to be procured.

h. Block 8 Target Date. Three dates are requested in this block, which should be determined by the program. Most AMT submissions, unless the DD Form 1494 is for a specific test program with a set test schedule, do not have specific need dates. The three dates determined by the program are provided below.

- Application Approval
- System Activation
- System Termination

For the stage review requested, enter the appropriate dates. Funds must not be obligated prior to the approval of this application. If foreign coordination is not required, then approximately one year must be allowed for application approval. Make note of this timeline. If foreign coordination is required, approximately two years must be allowed for application approval.

i. Block 9 System Relationship and Essentiality. This block is once again program-specific. Enter the essentiality and a statement of the relationship between the proposed system and the operational function it is intended to support. If general range support is the operational requirement, state that. If the "from" is being submitted for a TM link to support a future (or existing) program, state that.

j. Block 10 Replacement Information. Identify existing system(s) that may be replaced by the proposed system. State any known additional frequency requirements. This has applicability for AMT systems that are range upgrades (receivers and antennas) and transmitter replacements utilizing newer technology transmitters.

k. Block 11 Related Analysis and/or Test Data. During the development of some AMT hardware, MIL-STD-461 testing may have occurred. If this information is available, reference the test data here and provide a copy with the DD Form 1494 submission. Any information of this type that can be provided makes NTIA's understanding of the system more complete and potentially speeds up their assessment.

l. Block 12 Number of Mobile Units. This number refers to the number of mobile systems. Though aircraft TM links could certainly be characterized as mobile, for AMT submissions this block is interpreted to apply to only receive systems that are mobile, deployable range assets. This is important as the GMF not only catalogs fixed AMT receive sites, but also mobile receive sites mainly for the purpose of interference analysis.

m. Block 13 Geographical Area. Enter geographical location(s) or area(s) of use for this and subsequent stage(s), (e.g., Gilfillan Plant, Los Angeles, California, and White Sands Missile Range, New Mexico [Stage 2]; US&P [Stage 3]; US&P, NATO Countries and Korea [Stage 4]). Provide geographical coordinates (degrees, minutes, seconds) if available. Once again, this is important information for documenting in the GMF. For this example, the initial assumption for the submission was that it was a Stage 4 submission supporting missions in the Western Test Range encompassing Edwards AFB, China Lake NAS, Point Mugu NAS, and Vandenberg AFB.

n. Block 14 Line Diagram. The line diagram can also be considered the block diagram of the AMT link from transmitter to receiver. It is important that the diagram stays simple. The NTIA will review this for a general idea of the components and how the system works. Any extraneous information could cause confusion and delay the review process. Figure A-10 is a simple line diagram example. If applicable, existing J/F-12 numbers for any link portion can be added within the diagram. If using Stepstone, a line diagram will be created for you.

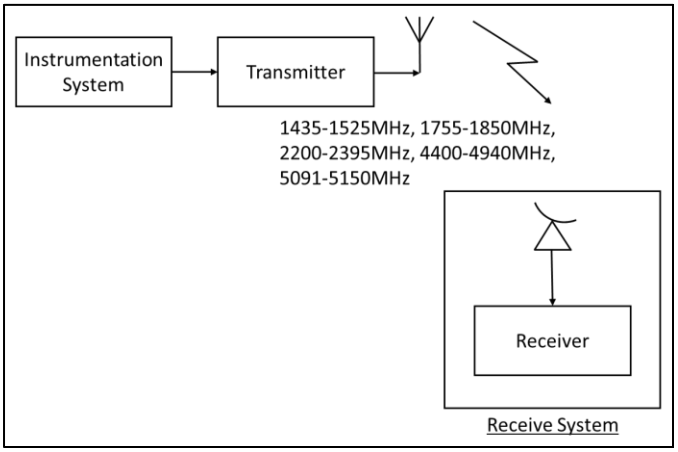

Figure A-10. Simple Line Diagram Example

o. Block 15 Space Systems. For AMT submissions, this block is N/A.

p. Block 16 Type of Service(s) for Stage 4. Enter the appropriate type of service(s) that applies or will apply to the equipment in the operational stage (Stage 4), as described in chapter 6 of the NTIA Manual. For Stage 4 AMT systems, type of service is mobile, aeronautical mobile.

q. Block 17 Station Class(es) for Stage 4. For Stage 4 AMT systems, station classes are FLEA or FAT. These station classes are described here and follow the Redbook definitions.

- FLEA – Aeronautical Telemetering Land Station: A telemetering land station used in flight testing of manned or unmanned aircraft, missiles, or major components thereof.
- FAT – Flight Test Station: An aeronautical station used for the transmission of essential communications in connection with the testing of aircraft or major components of aircraft.

A.6.6 Page 6 – Foreign Coordination General Information

For most AMT-related submissions, this page is not used because AMT links are not operated outside the US&P. If the system operation does fall outside of the US&P, this page must be completed. For systems to be operated outside the US&P, foreign disclosure authority is required to coordinate and obtain RF spectrum support from those countries where this equipment may operate. Action must be initiated to obtain foreign disclosure authority in accordance with Military Department regulations and policies for the release of appropriate data to the proposed host nations.

Do not complete this page unless you are preparing a foreign coordination version of the DD Form 1494. A foreign coordination version of this form is treated as a completely separate document from a U.S. coordination version, and in the general information content will/can be different. Frequency allocation processing for U.S. coordination can be initiated without submitting a foreign coordination version of the DD Form 1494. In any case, submission of the U.S. coordination version should not be delayed simply because a foreign coordination version has not been completed.

APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION	**CLASSIFICATION** **UNCLASSIFIED**	**DATE** Enter Date	J/F 12 No. Page No. 1

The public reporting burden for this collection of information is estimated to average 24 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Services Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number, **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION. RETURN COMPLETED FORM TO THE USING AGENCY OR CONTRACTING AGENCY, AS APPROPRIATE.**

DOD GENERAL INFORMATION

TO (Insert local Frequency Management organization)	**FROM** (Insert Program of Record)

1. APPLICATION TITLE
DD-1494 AMT System Example for L/S/C-Band Operations

2. SYSTEM NOMENCLATURE
Aeronautical Mobile Telemetry Multi-Mode Multi-Band Telemeter

***3. STAGE OF ALLOCATION** (X one)*

a. STAGE 1 - CONCEPTUAL   b. STAGE 2 - EXPERIMENTAL   c. STAGE 3 - DEVELOPMENTAL   d. STAGE 4 - OPERATIONAL

4. FREQUENCY REQUIREMENTS

Add Another Frequency

a. FREQUENCY(IES):	1435-1535MHz, 1750-1855MHz, 2200-2395MHz, 4400-4950MHz, 5091-5150MHz		
b. EMISSION DESIGNATOR(S):	23M2F1DBN (PCM/FM)	31M2G1DDN (SOQPSK-TG)	22M4G1DDN (ARTM CPM)

5. TARGET STARTING DATE FOR SUBSEQUENT STAGES

a. STAGE 2:	b. STAGE 3:	c. STAGE 4: Enter Date

6. EXTENT OF USE
Daily, Test Range data acquisition system data transmission and reception

7. GEOGRAPHICAL AREA FOR

a. STAGE 2:

b. STAGE 3:

c. STAGE 4: Western Test Range encompassing Edwards AFB, China Lake NAS, Pt. Mugu NAS, and Vandenberg AFB

8. NUMBER OF UNITS

a. STAGE 2	b. STAGE 3	c. STAGE 4 50 (estimate)

9. NUMBER OF UNITS OPERATING SIMULTANEOUSLY IN THE SAME ENVIRONMENT 2 to 10 units

10. OTHER J/F 12 APPLICATION NUMBER(S) TO BE a. SUPERSEDED J/F 12/ N/A b. RELATED J/F 12/ N/A	**11. IS THERE ANY OPERATIONAL REQUIREMENT AS DESCRIBED IN THE INSTRUCTIONS FOR PARAGRAPH 11?** a. YES b. NO c. NAvail

12. NAMES AND TELEPHONE NUMBERS

a. PROGRAM MANAGER (Insert PM)	(1) COMMERCIAL PHONE	(2) DSN
b. PROJECT ENGINEER (Insert PE)	(1) COMMERCIAL PHONE	(2) DSN

13. REMARKS
4b. EMISSION DESIGNATORS - These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate of 20 Mbps for PCM/FM and 40 Mbps for SOQPSK-TG/ARTM CPM. Refer to the attached diagram and chart for the multiplier "**n**" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA is multiplied with the IRIG-106 Necessary Bandwidth factor to create the new Emission Designator. See RCC WP-21-001 for further information.
11. OPERATIONAL REQUIREMENT - Air Force, Army, Navy

APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION	**CLASSIFICATION**	**DATE**	J/F 12 No. Page No.
DOWNGRADING INSTRUCTIONS	**CLASSIFICATION** **UNCLASSIFIED**		J/F 12 No. Reset Page

INSTRUCTIONS FOR COMPLETING DD FORM 1494 "APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION"

GENERAL INFORMATION

CLASSIFICATION: This form must be classified in accordance with appropriate agency security directions. Downgrading instructions must be indicated. The highest classification for each item or subitem as required must be indicated by a (U), (C), or (S) alongside the item or sub-item title, for classified applications.

APPLICATION PURPOSE: This is an application for development or procurement of equipment with RF emitters. It is not a frequency assignment request for operation of RF emitters. Funds must not be obligated prior to the approval of an application for frequency allocation.

DATA REQUIREMENT: All applicable data items shall be submitted for all stages. Estimated values or ranges of values may be submitted for Stage 1 and 2 in the absence of calculated or measured values and shall be annotated (EST). Values for Stages 3 and 4 should be measured.

STANDARDS: Technical parameters of the application will be evaluated against the appropriate DOD, National and International EMC standards.

REMARKS ITEMS: Use the remarks item located at the bottom of each page of the form to amplify or clarify the entries. Add continuation pages as required.

ABBREVIATIONS:

Hertz	**Hz**	**microseconds**	µsec
kilohertz	kHz	decibel	dB
megahertz	MHz	dB isotropic	dBi
gigahertz	GHz	pulses per second	pps
milliwatt	mW	parts per million	ppm
watt	W	peak envelope power	PEP
nanoseconds	nsec	not applicable	NA
National Telecommunications & Information Administration	NTIA	not available	NAvail
		occupied bandwidth	OC-BW

HOW TO ASSEMBLE THE FORM:

FOR US COORDINATION:

1. DOD General Information Page
2. Transmitter Page(s)
3. Receiver Page(s)
4. Antenna Page(s)
5. Line Diagram(s)
6. Space Systems Data, if applicable
7. Continuation Page(s) (cross reference pages)
8. NTIA General Information Page

FOR FOREIGN COORDINATION: If this form is used to obtain foreign national frequency supportability comments, see the instructions on the back of the Foreign Coordination General Information Page.

DOD GENERAL INFORMATION PAGE

ITEM 1 - Application Title. Enter the Government nomenclature of the equipment, or the manufacturer's name and model number, and a short descriptive title.

ITEM 2 - System Nomenclature. Enter the nomenclature of the system for which this equipment is a subsystem, e.g., PATRIOT or Global Positioning System.

ITEM 3 - Stage of Allocation. Mark the appropriate block using the following NTIA definitions.

Stage 1 - Conceptual. The initial planning effort has been completed, including proposed frequency bands and other available characteristics.

Stage 2 - Experimental. The preliminary design has been completed, and radiation, using test equipment or preliminary models, may be required.

Stage 3 - Developmental. The major design has been completed, and radiation may be required during testing.

Stage 4 - Operational. Development has been essentially completed, and final operating constraints or restrictions required to assure compatibility need to be identified.

ITEM 4 – Frequency Requirements.

a. Enter the required frequency band(s). For equipment designed to operate only at a single frequency, enter this frequency. Indicate units, e.g., kHz, MHz, or GHz.

b. Enter the emission designator(s) including the necessary bandwidth for each designator, as described in Chapter 9 of the NTIA Manual e.g., 40M0PON. Identify each mode as hopping or non-hopping, e.g. 64M0F3E (Hopping).
Enter in Item 13, "Remarks," any other information pertinent to frequency requirements, such as minimum frequency separation or special relationships involving multiple discrete frequencies.

ITEM 5 - Target Starting Date for Subsequent Stages. Enter proposed date of application submission for each subsequent stage.

ITEM 6 - Extent of Use. Describe extent of use that will apply to Stage 4, e.g., continuous or intermittent. If intermittent, provide information including the expected number of hours of operation per day or other appropriate time period; scheduling capability; and any conditions governing the times of intermittent use, e.g., used only during terminal guidance phase, used only as required for calibration of test range equipment.

ITEM 7 - Geographical Area. Enter geographical location(s) or area(s) of use for this and subsequent stage(s), e.g., Gilfillan Plant, Los Angeles, California, and White Sands Missile Range, New Mexico (Stage 2); US&P (Stage 3); US&P, NATO Countries and Korea (Stage 4). Provide geographical coordinates (degrees, minutes, seconds) if available.

ITEM 8 - Number of Units. Enter total number of units planned for the stage review requested and the subsequent stages.

ITEM 9 - Number of Units Operating Simultaneously in the Same Environment. Enter maximum number of these units planned to be operating simultaneously in the same environment during Stage 4 use.

ITEM 10 - Other J/F 12 Application Number(s). Mark appropriate block(s) and enter J/F 12 number(s) for superseded and/or related application(s).

ITEM 11 - Operational Requirement. If this equipment will operate with the same or similar equipment used by other US Military Services, DOD Components, US Government Agencies or Allied Nations, mark "Yes," and specify in Item 13, "Remarks," the Services, Agencies or countries (to include the country's services).

ITEM 12 - Self explanatory.

ITEM 13 - Remarks. Use this item to amplify or clarify any of the information provided above.

CLASSIFICATION
UNCLASSIFIED

PAGE
2

TRANSMITTER EQUIPMENT CHARACTERISTICS

1. NOMENCLATURE, MANUFACTURER'S MODEL NO.
AMT Transmitter, (Insert Model Number)

2. MANUFACTURER'S NAME
(Insert Manufacturer)

3. TRANSMITTER INSTALLATION
Airborne Test Platforms

4. TRANSMITTER TYPE
Aeronautical Mobile Telemetry (AMT)

5. TUNING RANGE
1435-1535MHz, 1750-1855MHz, 2200-2395MHz,
4400-4950MHz, 5091-5150MHz

6. METHOD OF TUNING
Synthesizer (consult manufacturer)

7. RF CHANNELING CAPABILITY:

a. Lowest channel/frequency	1435.5MHz
b. Tuning increments	500kHz/1MHz channeling for AMT
c. Number of channels	1MHz channel (for each tuning band)
d. Number of frequencies required for operation	1
e. Minimum Frequency Separation	per IRIG 106

8. EMISSION DESIGNATOR(S) Add AnotherEmission

23M2F1DBN	31M2G1DDN	22M4G1DDN

9. FREQUENCY TOLERANCE
+/-1ppm over temperature, +/-1ppm over time (consult manufacturer)

10. FILTER EMPLOYED *(X one)*
a. Yes b. No

11. SPREAD SPECTRUM *(X one)*
a. Yes b. No

12. EMISSION BANDWIDTH *(x and complete as applicable)*

	CALCULATED	MEASURED	
a. -3 dB	20.4MHz	14.0MHz	9.6MHz
b. -20 dB	24.4MHz	37.2MHz	26.4MHz
c. -40 dB	53.6MHz	57.2MHz	42.0MHz
d. -60 dB	79.2MHz	79.6MHz	61.6MHz
e. OC-BW	23.2MHz	31.2MHz	22.4MHz

13. MAXIMUM BIT RATE
20Mbps PCM/FM, 40Mbps SOQPSK-TG/ARTM CPM

14. MODULATION TECHNIQUES AND CODING
Modulation - PCM/FM, SOQPSK-TG, ARTM CPM per IRIG 106, Coding - STC, LDPC per IRIG 106 (see remarks)

15. MODULATION FREQUENCY
a. Maximum b. Minimum
(See Remarks)

16. PRE-EMPHASIS *(X one)*
a. Yes b. No

17. DEVIATION RATIO
PCM/FM=0.7, SOQPSK-TG=0.5, ARTM CPM={4/16, 5/16}

18. PULSE CHARACTERISTICS

a. RATE	N/A		
b. WIDTH	N/A		
c. RISE TIME	N/A		
d. FALL TIME	N/A		
e. COMP RATIO	N/A		

19. POWER *(X one)* a. MEAN b. PEP

10W (max)/output (var)	10W (max)/output (var)	10W (max)/output (var)

20. OUTPUT DEVICE
Transistor

21. HARMONIC LEVEL
a. 2ND
-25dBm (maximum)
b. 3RD
-25dBm (maximum)
c. OTHER
-80dBc

22. SPURIOUS LEVEL
-80dBc (maximum)

23. FCC TYPE ACCEPTANCE NO.
N/A

24. NAVSTAR GPS BAND MEASUREMENT

a. GPS WIDEBAND EMISSION LEVEL (1164-1240 MHz): dBw/MHz	-92.3dBW/MHz (measured when tuned between 1435-1535MHz)
b. GPS WIDBAND EMISSION LEVEL (1559-1610 MHz0: dBw/MHz	-84.2dBW/MHz (measured when tuned between 1435.5-1535MHz)
c. GPS NARROWBAND EMISSION LEVEL (1164-1240 MHz): dBw	-152.3dBW/Hz (measured when tuned between 1435-1535MHz)
d. GPS NARROWBAND EMISSION LEVEL (1559-1610 MHz) : dBw	-144.2dBW/Hz (measured when tuned between 1435-1535MHz)
e. PULSE SYSTEMS	N/A

25. REMARKS
8. EMISSION DESIGNATORS - These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate of 20Mbps for PCM/FM and 40Mbps for SOQPSK-TG/ARTM CPM. Refer to the attached diagram and chart for the multiplier "**n**" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA is multiplied with the IRIG-106 Necessary Bandwidth factor to create the new Emission Designator. See RCC WP-21-001 for further information.
10. FILTER EMPLOYED - Filtering is applied in three steps:
1. Digital premodulation filtering scaled with bit rate.

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2. Multiple stages of LC and stripline filtering in the upconversion chain.
3. 7-pole Butterworth low pass filter after the final output stage.
12. EMISSION BANDWIDTH - Measurements are referenced to the peak of the modulated waveform. These values will scale with the Emission Designator when changes in bit rate, modulation mode, and coding scheme are applied using the multiplier "n" in the attached chart. See attached white paper for further information.
14. MODULATION TECHNIQUES AND CODING - PCM/FM (binary FM with premodulation filtering), SOQPSK-TG (Offset QPSK with premodulation filtering), ARTM CPM (4-ary FSK with premodulation filtering), STC (Alamouti space-time block code applied to SOQPSK-TG), LDPC (systematic linear block code with differing information block sizes and code rates)
15. MODULATION FREQUENCY (MAXIMUM) - PCM/FM (F_{max}=0.35*bit rate), SOQPSK-TG (F_{max}=0.25*bit rate), ARTM CPM (F_{max}=7/32*bit rate)
19. POWER – Output power is variable between a maximum of +40dBm and a minimum of +10dBm in 1dB steps.

EMISSION DESIGNATOR						
EMISSION BANDWIDTH						
a. -3 dB						
b. -20 dB						
c. -40 dB						
d. -60 dB						
e. OC-BW						
PULSE CHARACTERISTICS						
a. RATE						
b. WIDTH						
c. RISE TIME						
d. FALL TIME						
e. COMP RATIO						
POWER						

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Add a new Transmitter Page **Remove a Transmitter Page**

Attachment 1 – Necessary Bandwidth Determination

The emission designator consists of the necessary bandwidth (first part of designator) and the Emission Classification Symbols (second part of the designator).

For each modulation mode, either the maximum OTA bit rate for the TM system or an OTA bit rate of 1 Mbps was used to determine the necessary bandwidth for the emission designator. The necessary bandwidth for each waveform in terms of OTA bit rate are shown in Table AT 1. Without coding applied, input bit rate ***R*** equals the OTA bit rate ***n*R*** (or ***n***=1, see Table AT 2). This is shown pictorially in Figure AT 1. If another input bit rate ***R*** is supplied to the transmitter, use Table AT 1 to calculate the new necessary bandwidth portion of the emission designator.

Table AT 1. Necessary Bandwidth Calculation for AMT Waveforms

Modulation	Necessary Bandwidth (DD Form 1494)
PCM/FM	1.16*(OTA bit rate)
SOQPSK	0.78*(OTA bit rate)
ARTM CPM	0.56*(OTA bit rate)

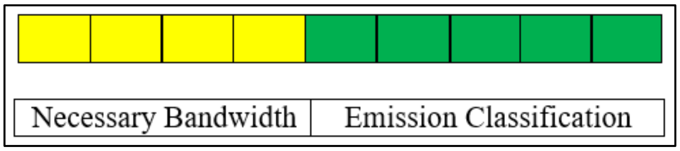

Figure AT 1. Emission Designator

If coding is applied to the link, the OTA bit rate changes, which in turn requires a new calculation for necessary bandwidth. A multiplier ***n*** can be applied to the input bit rate ***R*** to find the new OTA bit rate; see Figure AT 2. This new OTA bit rate is then used per Table AT 1 for the modulation scheme used to calculate the new necessary bandwidth. Table AT 2 specifies the multiplier to be used based on all available combinations of modulation and coding.

Figure AT 2. OTA Bit Rate Determination

Table AT 2. Modulation/Coding Multiplier

Modulation/Coding	Multiplier ***n***
PCM/FM/SOQPSK/ARTM CPM	1
SOQPSK-STC	26/25
LDPC Code Rate ***R***=4/5	21/16
LDPC Code Rate ***R***=2/3	25/16
LDPC Code Rate ***R***=1/2	33/16
SOQPSK-STC/LDPC ***R***=4/5	273/200
SOQPSK-STC/LDPC ***R***=2/3	13/8
SOQPSK-STC/LDPC ***R***=1/2	429/200

INSTRUCTIONS FOR COMPLETING DD FORM 1494
APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION
TRANSMITTER EQUIPMENT CHARACTERISTICS PAGE

ITEM 1 - Nomenclature, Manufacturer's Model No. Enter the Government assigned alphanumeric equipment designation. If above is not available, enter the manufacturer's model number, e.g., MIT 502, and complete Item 2. If above is not available, enter a short descriptive title, e.g., ATS-6 telemetry transmitter.

ITEM 2 - Manufacturer's Name. Enter the manufacturer's name if available. If a manufacturer's model number is listed in Item 1, this item must be completed.

ITEM 3 - Transmitter Installation. List specific type(s) of vehicle(s), ship(s), plane(s) or building(s), etc., where the transmitter(s) will be installed.

ITEM 4 - Transmitter Type. Enter the generic class of the transmitter, e.g., Frequency Scan, Scan While Track Radar, Monopulse Tracker, AM or FM Communications.

ITEM 5 - Tuning Range. Enter the frequency range through which the transmitter is capable of being tuned, e.g., 225-400 MHz. For equipment designed to operate only at a single frequency, enter this frequency. Indicate units, e.g., kHz, MHz or GHz.

ITEM 6 - Method of Tuning. Enter the method of tuning, e.g., crystal, synthesizer or cavity. If the equipment is not readily tunable in the field, indicate in Item 25, "Remarks," the complexity of tuning. Include complexity factors such as skill levels involved, major assemblies involved, time required, and location (factory or depot) where equipment is to be tuned.

ITEM 7 - RF Channeling Capability.
a. Lowest channel/frequency: Proposed Definition - The lowest tuned frequency of the transmitter frequency band(s) at which the transmitter is capable of operating.
b. Tuning increments: Proposed Definition - The frequency separation between tuned frequencies for equipment with uniformly-spaced step-tuned capability.
c. Number of channels: Proposed Definition - For uniformly spaced channels, enter the center frequency of the first channel and channel spacing.
d. Number of frequencies required for operation: Proposed Definition - Enter the number of frequencies required for nominal operation.
e. Minimum Frequency Separation: Proposed Definition - The required frequency separation between the different radio sets operated at one transmitter or receiver location

ITEM 8 - Emission Designator(s). Enter the emission designator(s) including the necessary bandwidth for each designator as described in Chapter 9 of the NTIA Manual, e.g., 16K0F3E. For systems with a frequency hopping mode as well as a nonhopping mode enter the emission designators for each mode. Identify each mode as hopping or nonhopping.

ITEM 9 - Frequency Tolerance. Enter the frequency tolerance, i.e., the maximum departure of a transmitter from its assigned frequency after normal warm-up time has been allowed. Indicate the units in parts per million (ppm) for all emission types except single sideban, which shall be indicated in Hertz (Hz).

ITEM 10 - Filter Employed. Mark the appropriate block. Provide the characteristics of any filter used in Item 24, "Remarks."

ITEM 11 - Spread Spectrum. Mark the appropriate block. If "Yes," see instructions for Item 14.

ITEM 12 - Emission Bandwidth. Enter the emission bandwidths for which the transmitter is designed at the −3, −20, and −60 dB levels and the occupied bandwidth. The bandwidth at −40 dB shall also be entered for pulse radar transmitters. The emission bandwidth is defined as that appearing at the antenna terminals and includes any significant attenuation contributed by filtering in the output circuit or transmission lines. Values of emission bandwidth specified should be indicated as calculated or measured by marking the appropriate block. Indicate units used, e.g., Hz, kHz or MHz. Note that the Occupied Bandwidth (Item 12.e.) is defined as the frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers radiated are each equal to 0.5% of the total mean power radiated.

ITEM 13 - Maximum Bit Rate. Enter the maximum information bit rate for digital equipment, in bits per second. If spread spectrum is used, enter the bit rate after encoding.

ITEM 14 - Modulation Techniques and Coding. Describe in detail the modulation and/or coding techniques employed. For complex modulation schemes such as direct sequence spread spectrum, frequency hopping, frequency agile, etc., enter full details in Item 25, "Remarks."

ITEM 15 - Modulation Frequency. - a. Maximum - For frequency or phase modulated transmitter enter the maximum modulation or baseband frequency. This frequency is assumed to be the frequency at −3 dB point on the high frequency side of the modulator response curve. Indicate the units, e.g., Hz, kHz or MHz. b. Minimum - Enter lowest frequency in the baseband modulating signal when analog modulation is employed.

ITEM 16 - Pre-emphasis. For frequency or phase modulated transmitters mark the appropriate block to indicate whether pre-emphasis is available.

ITEM 17 - Deviation Ratio. For frequency or phase modulated transmitter enter the deviation ratio computed with the formula

$$\text{Deviation Ratio} = \frac{\text{Maximum Frequency Deviation}}{\text{Maximum Modulation Frequency}}$$

ITEM 18 - Pulse Characteristics. For pulse modulated transmitters:
a. Enter the pulse repetition rate in pulses per second (pps).
b. Enter the pulse width at the half voltage levels in microseconds (usec).
c. Enter the pulse rise time in microseconds (usec). This is the time duration for the leading edge of the voltage pulse to rise from 10% to 90% of its peak amplitude.
d. Enter the pulse fall time in microseconds (usec). This is the time duration for the trailing edge of the voltage pulse to fall from 90% to 10% of its peak amplitude.
e. Enter the maximum pulse compression ratio, if applicable.

ITEM 19 - Power. Enter the mean power delivered to the antenna terminals for all AM and FM emissions, or the peak envelope power for all other classes of emissions. If there are any unique situations such as interrupted CW, provide details in Item 24, "Remarks." Indicate the units, e.g., W or kW.

ITEM 20 - Output Device. Enter a description of the device used in the transmitter output stage, e.g., ceramic diode, reflex klystron, transistor or TWT.

ITEM 21 - Harmonic Level. Enter the harmonic level in dB relative to the fundamental of the 2nd and 3rd harmonics. Enter in Item c. the relative level in dB of the highest powered harmonic above the 3rd.

ITEM 22 - Spurious Level. Enter the maximum value of spurious emission in dB relative to the fundamental which occurs outside the −60 dB point on the transmitter fundamental emission spectrum (Item 12) and does not occur on a harmonic of the fundamental frequency.

ITEM 23 - FCC Type Acceptance No. Enter the FCC type acceptance number if applicable

ITEM 24 - NAVSTAR GPS Band Measurement. Federal agencies requesting Spectrum Certification for systems operating in the 390-413 MHz, and 960-1710 MHz frequency bands must provide measurements of the emission levels generated in the frequency bands used by the Navstar Global Positioning System. Provide measurements in wideband and narrowband
a. GPS WIDEBAND EMISSION LEVEL (1164-1240 MHz): dBw/MHz
b. GPS WIDEBAND EMISSION LEVEL (1559-1610 MHz): dBw/MHz
c. GPS NARROWBAND EMISSION LEVEL (1164-1240 MHz): dBw
d. GPS NARROWBAND EMISSION LEVEL (1559-1610 MHz): dBw
e. For Pulse Systems, provide measurements of the temporal characteristics of the emissions in the 1164.45-1188.45 MHz, 1215.6-1239.6 MHz and 1563.42-1587.42 MHz band

ITEM 25 - Remarks. Use this item to amplify or clarify any of the information provided above.

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RECEIVER EQUIPMENT CHARACTERISTICS

1. NOMENCLATURE, MANUFACTURER'S MODEL NO.
AMT Receiver, (Insert Model Number)

2. MANUFACTURER'S NAME
(Insert Manufacturer)

3. RECEIVER INSTALLATION
AMT receive stations

4. RECEIVER TYPE
Dual Conversion Super Heterodyne (consult manufacturer)

5. TUNING RANGE
400-1150MHz, 1435-1535MHz, 1750-1855MHz, 2200-2395MHz, 4400-4940MHz, 5091-5150MHz

6. METHOD OF TUNING
Synthesizer (consult manufacturer)

***7.* RF CHANNELING CAPABILITY:**

a. Lowest channel/frequency	1435.5MHz (400MHz C-Band IF)
b. Tuning increments	1MHz/500kHz centers
c. Number of channels	1MHz channel (for each tuning band)
d. Number of frequencies required for operation	1
e. Minimum Frequency Separation	per IRIG-106

8. EMISSION DESIGNATOR(S)
23M2F1DBN (PCM/FM)
31M2G1DDN (SOQPSK)
22M4G1DDN (ARTM CPM)

9. FREQUENCY TOLERANCE
±1ppm

10. IF SELECTIVITY	**1ST**	**2ND**	**3RD**
a. −3 dB	See Remarks		
b. −20 dB			
c. −60 dB			

11. RF SELECTIVITY *(X and complete as applicable)*

	CALCULATED	MEASURED
a. −3 dB	100MHz (FL1), 50MHz (FL2), 25MHz (FL3), 12.5MHz (FL4)	
b. −20 dB	110MHz (FL1), 60MHz (FL2), 30MHz (FL3), 17.5MHz (FL4)	
c. −60 dB	115MHz (FL1), 65MHz (FL2), 35MHz (FL3), 22.5MHz (FL4)	

d. PRESELECTION TYPE
Surface Acoustic Wave (SAW)

12. IF FREQUENCY

a. 1ST	160MHz (consult manufacturer)
b. 2ND	70MHz
c. 3RD	

13. MAXIMUM POST DETECTION FREQUENCY
N/A

14. MINIMUM POST DETECTION FREQUENCY
N/A

15. OSCILLATOR TUNED	**1ST**	**2ND**	**3RD**
a. ABOVE TUNED FREQUENCY	X		
b. BELOW TUNED FREQUENCY		X	
c. EITHER ABOVE OR RELOW TUNED FREQUENCY			

16. MAXIMUM BIT RATE
40Mbps (see remarks)

17. SENSITIVITY

a. SENSITIVITY	−85 to −100dBm (per mode/coding)	dBm
b. CRITERIA	Bit Error Rate = 1e−5	
c. NOISE FIG	10dB (maximum), 5dB (typical)	dB
d. NOISE TEMP	N/A	Kelvin

***18.* DE-EMPHASIS** *(X one)*
a. Yes b. No

19. IMAGE REJECTION
70dB (minimum)

20. SPURIOUS REJECTION
70dB (minimum)

21. ADJACENT CHANNEL SELECTIVITY (dB)
50dB (min.) See Remarks

22. INTERMODULATION REJECTION LEVEL (dB)
−20dBm (max.) See Remarks

23. CONDUCTED UNDESIRED EMISSIONS (dBm)
N/A

24. REMARKS
8. EMISSION DESIGNATORS - These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate of 20Mbps for PCM/FM and 40Mbps for SOQPSK-TG/ARTM CPM. Refer to the attached diagram and chart for the multiplier "**n**" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA is multiplied with the IRIG-106 Necessary Bandwidth factor to create the new Emission Designator. See RCC WP-21-001 for further information.
10. IF SELECTIVITY - Receiver has a single 1st IF filter and multiple 2nd IF filters available based upon modulation mode and bit rate.
1st IF Filter: a. −3dB: 40MHz, b. −20dB: 45MHz, c. −60dB: 50MHz

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2nd IF Filter: a. -3 dB: 4.5 MHz, b. -20 dB: 5.8 MHz, c. -60 dB: 6.7 MHz
2nd IF Filter: a. -3 dB: 10 MHz, b. -20 dB: 12.7 MHz, c. -60 dB: 15 MHz
2nd IF Filter: a. -3 dB: 1 MHz, b. -20 dB: 1.8 MHz, c. -60 dB: 2.1 MHz
2nd IF Filter: a. -3 dB: 4.5 MHz, b. -20 dB: 5.8 MHz, c. -60 dB: 6.7 MHz
2nd IF Filter: a. -3 dB: 4.5 MHz, b. -20 dB: 5.8 MHz, c. -60 dB: 6.7 MHz
2nd IF Filter: a. -3 dB: 10 MHz, b. -20 dB: 12.7 MHz, c. -60 dB: 15 MHz

16. MAXIMUM BIT RATE - STC and LDPC detection and decoding per IRIG 106 Chapter 2 Appendices 2D and 2E.

21. ADJACENT CHANNEL SELECTIVITY - Carrier and interfering signals are assumed to be identical, spaced at least one IFBW apart.

22. INTERMODULATION REJECTION LEVEL - Value represents the rejection should two equal amplitude signals result in an in-band third-order product causing interference.

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Add a new Receiver Page **Remove a Receiver Page**

INSTRUCTIONS FOR COMPLETING DD FORM 1494
"APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION"
RECEIVER EQUIPMENT CHARACTERISTICS PAGE

ITEM 1 - Nomenclature, Manufacturer's Model No. Enter the Government assigned alphanumeric equipment designation. If above is not available, enter the manufacturer's model number, e.g., MIT 502, and complete Item 2. If above is not available, enter a short descriptive title, e.g., GPS Receiver, Director Station RX.

ITEM 2 - Manufacturer's Name. Enter the manufacturer's name if available. If a manufacturer's model number is listed in Item 1, this item must be completed.

ITEM 3 - Receiver Installation. List specific type(s) of vehicle(s), ship(s), plane(s) or building(s), etc., where the receiver(s) will be installed.

ITEM 4 - Receiver Type. Enter the generic class, e.g., Dual Conversion Superheterodyne or Homodyne.

ITEM 5 - Tuning Range. Enter the frequency range through which the receiver is capable of being tuned, e.g., 225-400 MHz. For equipment designed to operate only at a single frequency, enter this frequency. Indicate units, e.g., kHz, MHz or GHz.

ITEM 6 - Method of Tuning. Enter the method of tuning, e.g., crystal, synthesizer or cavity. If the equipment is not readily tunable in the field, indicate in Item 23, "Remarks," the complexity of tuning.
Include complexity factors such as skill levels involved, major assemblies involved, time required, and location (factory or depot) where equipment is to be tuned.

ITEM 7 - RF Channeling Capability.
a. Lowest channel/frequency: Proposed Definition - The lowest tuned frequency of the transmitter frequency band(s) at which the transmitter is capable of operating.
b. Tuning increments: Proposed Definition - The frequency separation between tuned frequencies for equipment with uniformly-spaced step- tuned capability.
c. Number of channels: Proposed Definition - For uniformly spaced channels, enter the center frequency of the first channel and channel spacing.
d. Number of frequencies required for operation: Proposed Definition - Enter the number of frequencies required for nominal operation.
e. Minimum Frequency Separation: Proposed Definition - The required frequency separation between the different radio sets operated at one transmitter or receiver location

ITEM 8 - Emission Designator(s). Enter the emission designator(s) including the necessary bandwidth(s) for each designator, e.g., 16K0F3E. For systems with a frequency hopping mode as well as a nonhopping mode enter the emission designators for each mode.

ITEM 9 - Frequency Tolerance. Enter the frequency tolerance, i.e., the maximum departure of a receiver from its assigned frequency after normal warm-up time has been allowed. Indicate the units in parts per million (ppm) for all emission types except single sideband which shall be indicated in Hertz (Hz).

ITEM 10 - IF Selectivity. Enter the bandwidth for each IF stage at the −3, −20 and −60 dB levels. Indicate units, e.g., kHz or MHz.

ITEM 11 - RF Selectivity. Enter the bandwidth at the −3, −20 and −60 dB levels. The RF bandwidth includes any significant attenuation contributed by filtering in the input circuit or transmission line. Values of RF bandwidths specified should be indicated as calculated or measured by marking the appropriate block. Indicate units, e.g., kHz or MHz. Enter the preselection type, e.g., tunable cavity.

ITEM 12 - IF Frequency. Enter the tuned frequency of the first, second and third IF stages. Indicate units, e.g., kHz or MHz.

ITEM 13 - Maximum Post Detection Frequency. Enter the maximum post detection frequency. This is the nominal frequency at the −3 dB point on the high frequency side of the receiver base band. Indicate units, e.g., kHz or MHz.

ITEM 14 - Minimum Post Detection Frequency. For multichannel FM systems enter the minimum post detection frequency. This is the nominal frequency at the −3 dB point on the low frequency side of the receiver base band. Indicate units, e.g., kHz or MHz.

ITEM 15 - Oscillator Tuned. Mark the appropriate block to indicate the location of the 1st, 2nd and 3rd oscillator frequencies with respect to the associated mixer input signal.

ITEM 16 - Maximum Bit Rate. Where applicable, enter the maximum bit rate (bps) that can be used. If spread spectrum is used, enter the bit rate after encoding. Describe any error detecting/correcting codes in Item 23, "Remarks."

ITEM 17 - Sensitivity.
a. Enter the sensitivity in dBm.
b. Specify criteria used, e.g., 12 dB SINAD (Signal to Interference plus Noise and Distortion).
c. If the receiver is used with terrestrial systems, enter the receiver noise figure in dB.
d. If the receiver is used with space or satellite earth stations, enter the receiver noise temperature in Kelvin.

ITEM 18 - De-emphasis. For frequency or phase modulated receivers mark the appropriate block to indicate whether de-emphasis is available.

ITEM 19 - Image Rejection. Enter the image rejection in dB. Image rejection is the ratio of the image frequency signal level required to produce a specified output, to the desired signal level required to produce the same output.

ITEM 20 - Spurious Rejection. Enter the spurious rejection in dB. Enter the single level of spurious rejection that the receiver meets or exceeds at all frequencies outside the −60 dB IF bandwidth. Spurious rejection is the ratio of a particular out-of-band frequency signal level required to produce a specified output, to the desired signal level required to produce the same output.

ITEM 21 - Adjacent Channel Selectivity. A ratio in (dB) that compares signal strength received against a similar signal on another frequency.

ITEM 22 - Intermodulation Rejection Level. A measure of RF input threshold before intermodulation products occurs (expressed in dB).

ITEM 23 - Conducted Undesired Emissions. Those undesired signals generated in the receiver and leaving the receiver by way of the receiving transmission line. Only required when employing wideband Fixed, Land, Mobile, or portable transmitters in the Fixed or Mobile service between 29.7 and 50, 162 and 174, or 406.1 and 420 MHz (expressed in dBm).

ITEM 24 - **Remarks**. Use this item to amplify or clarify any of the information provided above

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ANTENNA EQUIPMENT CHARACTERISTICS

1. ■ a. TRANSMITTING ☐ b. RECEIVING ☐ c. TRANSMITTING AND RECEIVING

2. NOMENCLATURE, MANUFACTURER'S MODEL NO. AMT Blade Antenna, (Insert Model Number)	**3. MANUFACTURER'S NAME** (Insert Manufacturer)
4. FREQUENCY RANGE 1400-5200MHz	**5. TYPE** Dipole Blade Antenna
6. POLARIZATION Linear	**7. SCAN CHARACTERISTICS** a. TYPE N/A
8. GAIN	b. VERTICAL SCAN
a. MAIN BEAM 0dBi nominal in azimuth and elevation	(1) MAX ELEV (2) MIN ELEV
b. 1ST MAJOR SIDE LOBE AND ANGULAR DISPLACEMENT N/A	(3) SCAN RATE
9. BEAMWIDTH	c. HORIZONTAL SCAN
a. HORIZONTAL 360 degrees (azimuth)	(1) SECTOR SCANNED (2) SCAN RATE
b. VERTICAL 60 degrees (elevation)	d. SECTOR BLANKING *(x one)* ☐ a. Yes ■ b. No

10. REMARKS

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Add a new Antenna Page **Remove a Antenna Page**

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4

ANTENNA EQUIPMENT CHARACTERISTICS

1. ☐ a. TRANSMITTING ☒ b. RECEIVING ☐ c. TRANSMITTING AND RECEIVING

2. NOMENCLATURE, MANUFACTURER'S MODEL NO.
AMT Receive Antenna, (Insert Model Number)

3. MANUFACTURER'S NAME
(Insert Manufacturer)

4. FREQUENCY RANGE
1435-1525MHz, 1755-1850MHz, 2200-2395MHz,
4400-4940MHz, 5091-5150MHz

5. TYPE
5m parabolic reflector with prime focus/sub-reflector.
Conical scan feed with tracking capabilities

6. POLARIZATION
Synthesized Right-Hand and Left-Hand Circular (RHCP, LHCP)

7. SCAN CHARACTERISTICS

a. TYPE See Remarks

b. VERTICAL SCAN

(1) MAX ELEV

(2) MIN ELEV

(3) SCAN RATE

c. HORIZONTAL SCAN

(1) SECTOR SCANNED

(2) SCAN RATE

d. SECTOR BLANKING *(x one)*

☐ a. Yes ☒ b. No

8. GAIN

a. MAIN BEAM
See Remarks

b. 1ST MAJOR SIDE LOBE AND ANGULAR DISPLACEMENT

9. BEAMWIDTH

a. HORIZONTAL
See Remarks

b. VERTICAL

10. REMARKS

7. SCAN CHARACTERISITICS
7.a. Mechanical conical scan, 15-40Hz variable scan rate, independent azimuth and elevation control
Scan for an AMT receive antenna is divided into Scan Acquisition and Scan Auto-Track.
Scan Acquisition: 7.b. Vertical Scan: -2 to 90 degrees, 7.c. Horizontal Scan: 0 to 360 degrees, 7.b.3/7.c.2 Scan Rate: 25 degrees/sec
Scan Auto-Track: 7.b. Vertical Scan: 1 degree, 7.c. Horizontal Scan: 1 degree, 7.b.3/7.c.2 Scan Rate: 15-40Hz

8. GAIN
AMT receive antennas are characterized as a system thus G/T (dB/K) is specified rather than strictly antenna gain.
G/T per Band: 1435-1525MHz (9.4dB), 1755-1850MHz (12.2dB), 2200-2395MHz (13.7dB), 4400-4940MHz (19.1dB), 5091-5150MHz (20.1dB)

9. BEAMWIDTH
Full 3dB beamwidth per band of operation.
Beamwidth per Band: 1435-1525MHz (2.7 degrees), 1755-1850MHz (2.25 degrees), 2200-2395MHz (1.8 degrees), 4400-4940MHz (0.9 degrees), 5091-5150MHz (0.8 degrees)

CLASSIFICATION **UNCLASSIFIED**

J/F 12 No.

Reset Page

Add a new Antenna Page **Remove a Antenna Page**

INSTRUCTIONS FOR COMPLETING DD FORM 1494
"APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION"
ANTENNA EQUIPMENT CHARACTERISTICS PAGE

ITEM 1 - Function. Mark the appropriate block to indicate the type of function the antenna performs. For multi-antenna system, use one page for each antenna.

ITEM 2 - Nomenclature, Manufacturer's Model No. Enter the Government assigned alphanumeric equipment designation. If above is not available, enter the manufacturer's model number, e.g., DS6558, and complete Item 3. If above is not available, enter a short descriptive title, e.g., ATS-6 telemetry antenna.

ITEM 3 - Manufacturer's Name. Enter the manufacturer's name if available. If a manufacturer's model number is listed in Item 2, this item must be completed.

ITEM 4 - Frequency Range. Enter the range of frequencies for which the antenna is designed. Indicate units, e.g., kHz or MHz.

ITEM 5 - Type. Enter the generic name or describe general technical features, e.g., Horizontal Log Periodic, Cassegrain with Polarization Twisting, Whip, Phased Array or Conformal Array.

ITEM 6 - Polarization. Enter the polarization; if circular, indicate whether it is right or left hand.

ITEM 7 - Scan Characteristics.

a. If this antenna scans, enter the type of scanning, e.g., vertical, horizontal, vertical and horizontal.

b. (1) Enter the maximum elevation angle in degrees (positive or negative referenced to the horizontal) that the antenna can scan.

(2) Enter the minimum elevation angle in degrees (positive or negative referenced to the horizontal) that the antenna can scan.

(3) Enter the vertical scan rate in scans per minute.

c. (1) Enter the angular scanning range in scans per minute.

(2) Enter the horizontal scanning rate in scans per minute.

d. Indicate if antenna is capable of sector blanking. If yes, enter details in item 10, "Remarks."

ITEM 8 - Gain.

a. Enter the maximum gain in dBi.

b. Enter the nominal gain of the first major side lobe of the main beam in dBi and the angular displacement from the main beam in degrees.

ITEM 9 - Beamwidth. Enter the 3 dB beamwidth in degrees.

ITEM 10 - Remarks. Use this item to describe any unusual characteristics of the antenna, particularly as they relate to the assessment of electromagnetic compatibility. Use this item to amplify or clarify any of the information provided above.

APPLICATION FOR SPECTRUM REVIEW	**CLASSIFICATION** **UNCLASSIFIED**	**DATE**	**PAGE** 8

NTIA GENERAL INFORMATION

1. APPLICATION TITLE
(Insert Application Title)

2. SYSTEM NOMENCLATURE
Aeronautical Mobile Telemetry

3. STAGE OF ALLOCATION *(X one)*
☐ a. STAGE 1 - CONCEPTUAL ☐ b. STAGE 2 - EXPERIMENTAL ☐ c. STAGE 3 - DEVELOPMENTAL ☒ d. STAGE 4 - OPERATIONAL

4. FREQUENCY REQUIREMENTS Add Another Frequency

a. FREQUENCY(IES): 1435-1535MHz, 1755-1850MHz, 2200-2390MHz, 4400-4940MHz, 5091-5150MHz

b. EMISSION DESIGNATOR(S): 23M2F1DBN (PCM/FM), 31M2G1DDN (SOQPSK-TG), 22M4G1DDN (ARTM CPM)

5. PURPOSE OF SYSTEM, OPERATIONAL AND SYSTEM CONCEPTS **(NSEP USE)** *(X one)* ☐ a. YES ☒ b. NO

Support AMT operations, transmission of real-time flight test data from aircraft/missiles to ground receiving stations for real-time display and decision making.

6. INFORMATION TRANSFER REQUIREMENTS
1-20Mbps @ BER=1e−6

7. ESTIMATED INITIAL COST OF THE SYSTEM
(Insert Cost based upon Stage)

8. TARGET DATE FOR

a. APPLICATION APPROVAL	b. SYSTEM ACTIVATION	c. SYSTEM TERMINATION
(Insert Required Dates)	(Insert Required Dates)	N/A

9. SYSTEM RELATIONSHIP AND ESSENTIALITY
Airborne flight testing of Developmental systems for future DOD operational weapons systems

10. REPLACEMENT INFORMATION
N/A, supplementing existing AMT systems

11. RELATED ANALYSIS AND TEST DATA
(If EMI/EMC report is available for the transmitter, reference that here)

12. NUMBER OF MOBILE UNITS
(Insert value if appropriate)

13. GEOGRAPHICAL AREA FOR

a. STAGE 2:

b. STAGE 3:

c. STAGE 4: Western Test Range encompassing Edwards AFB, China Lake NAS, Pt. Mugu NAS, and Vandenberg AFB

14. LINE DIAGRAM *(See Page(s))* Attach Diagram

15. SPACE SYSTEMS
(X and complete SPACE SYSTEMS DATA field if applicable) ☐ Yes ☒ No

16. TYPE OF SERVICE(S) FOR STAGE 4
Mobile, Aeronautical Mobile

17. STATION CLASS(ES) FOR STAGE 4
FLEA, FAT

18. REMARKS

4.b. EMISSION DESIGNATORS-These designators are for each modulation scheme (PCM/FM, SOQPSK-TG, ARTM CPM respectively) at an uncoded OTA bit rate of 20 Mbps for PCM/FM and 40 Mbps for SOQPSK-TG/ARTM CPM. Refer to the attached diagram and chart for the multiplier "**n**" to be applied to the uncoded bit rate associated with each combination of modulation scheme and coding selected. This new OTA is multiplied with the IRIG-106 Necessary Bandwidth factor to create the new Emission Designator. See RCC WP-21-001 for for further information.

a. FREQUENCY(IES): 1435-1535MHz, 1755-1850MHz, 2200-2390MHz, 4400-4940MHz, 5091-5150MHz

b. EMISSION DESIGNATOR(S):	23M2F1DBN (PCM/FM)	31M2G1DDN (SOQPSK-TG)	22M4G1DDN (ARTM CPM)

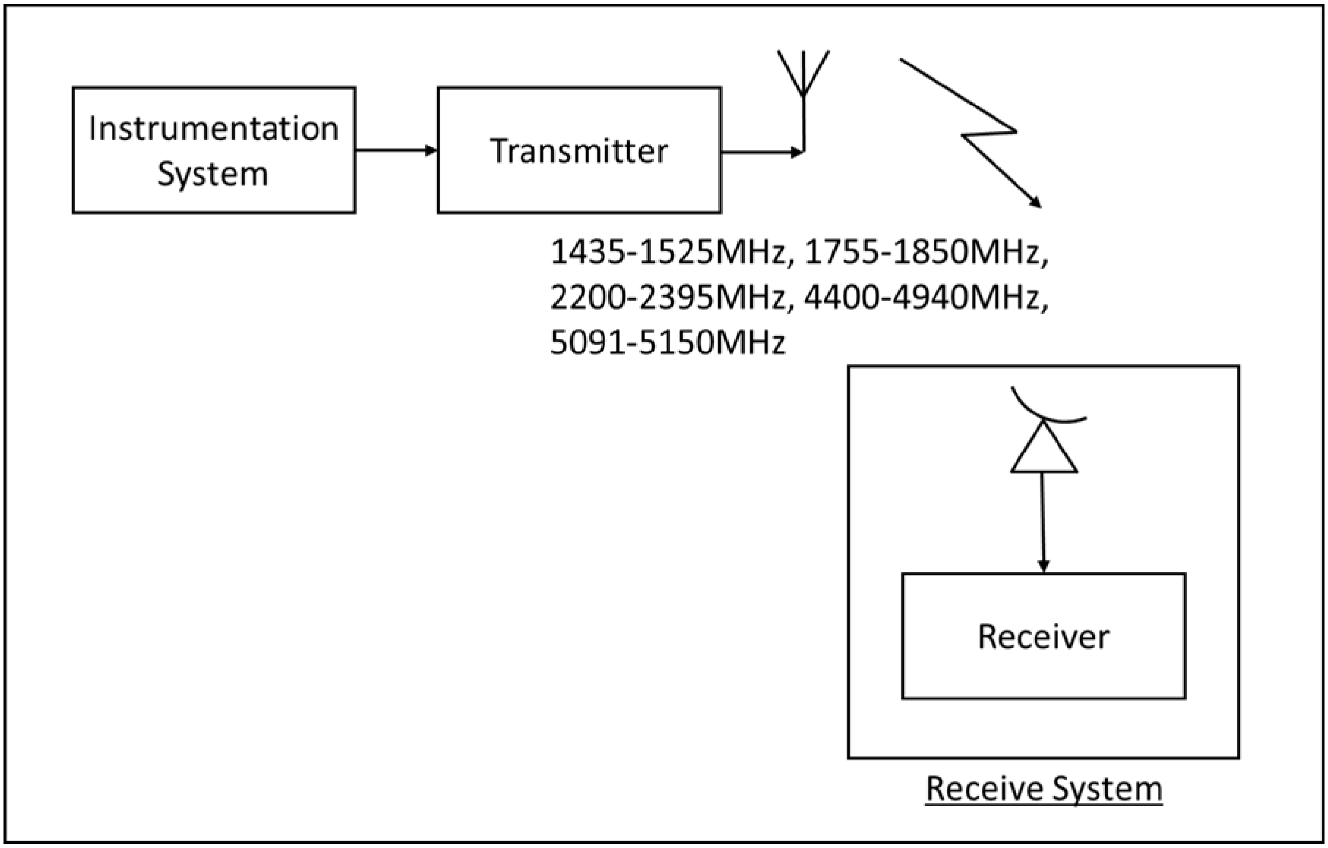
APPLICATION FOR SPECTRUM REVIEW	**CLASSIFICATION** **UNCLASSIFIED**	**DATE**	**PAGE**

DOWNGRADING INSTRUCTIONS	**CLASSIFICATION** **UNCLASSIFIED**	J/F 12 No. Reset Page

APPLICATION FOR SPECTRUM REVIEW LINE DIAGRAM	CLASSIFICATION **UNCLASSIFIED**	DATE	PAGE

NTIA GENERAL INFORMATION

Click on the space below to add your line diagram image



LINE DIAGRAM

Add Line Diagram Pages

Remove this Line Diagram Page

DOWNGRADING INSTRUCTIONS

INSTRUCTIONS FOR COMPLETING DD FORM 1494 "APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION" NTIA GENERAL INFORMATION PAGE

ITEM 1 - Application Title. Enter the government nomenclature of the equipment, or the manufacturer's name and model number, and a short descriptive title.

ITEM 2 - System Nomenclature. Enter the nomenclature of the system for which this equipment is a subsystem, e.g., PATRIOT or Global Positioning System.

ITEM 3 - Stage of Allocation. Mark appropriate block.

ITEM 4 - Frequency Requirements.
a. Enter the required frequency bands. For equipment designed to operate only at a single frequency, enter this frequency. Indicate units, e.g., kHz, MHz, or GHz.

b. Enter the emission designators including the necessary bandwidth for each designator, as described in Chapter 9 of the NTIA Manual e.g., 40M0PON.

Enter in Item 18, "Remarks," any other information pertinent to frequency requirements, such as minimum frequency separation for full duplex links or repeaters; or special relationships involving multiple discrete frequencies.

ITEM 5 - Purpose of System, Operational and System Concepts. Enter a summary description of the function of the system or subsystem, e.g., collect and disseminate meteorological data using satellite techniques; transmission of radar data for air traffic control; a remote control of ATC radars; provide for the transmission and reception of digital voice and data by means of LOS or tropo modes of propagation; provide navigational signal from which a broad spectrum of users are able to derive navigation data. Also include information on operational and system concepts.

Mark whether the system has a wartime function.

ITEM 6 - Information Transfer Requirements. Enter the required character rate, data rates, circuit quality, reliability, etc.

ITEM 7 - Estimated Initial Cost of the System. This item is for information to show the general size and complexity of the system. It is not intended to be a determining factor in system review. For Stage 2 enter research cost, for Stage 3 enter development cost, for Stage 4 enter unit cost of equipment and expected number of equipments/systems to be procured.

ITEM 8 - Target Date. For the stage review requested, enter the appropriate dates. Funds must not be obligated prior to the approval of this application. If foreign coordination is not required, then approximately one year must be allowed for application approval. If foreign coordination is required, approximately two years must be allowed for application approval.

ITEM 9 - System Relationship and Essentiality.
Enter the essentiality and a statement of the relationship between the proposed system and the operational function it is intended to support.

ITEM 10 - Replacement Information. Identify existing system(s) which may be replaced by the proposed system. State any known additional frequency requirements.

ITEM 11 - Related Analysis and/or Test Data. Identify reports that can be made available documenting previous EMC studies, predictions, analyses, or prototype EMC testing that are relevant to the assessment of the system under review.

ITEM 12 - Number of Units. (For mobile systems) - Self explanatory.

ITEM 13 - Geographical Area. Enter geographical location(s) or area(s) of use for this and subsequent stage(s), e.g., Gilfillan Plant, Los Angeles, California, and White Sands Missile Range, New Mexico (Stage 2); US&P (Stage 3); US&P, NATO Countries and Korea (Stage 4). Provide geographical coordinates (degrees, minutes, seconds) if available.

ITEM 14 - Line Diagram. Enter the page number of the line diagram(s). Attach as another page the line diagram showing the links, direction of transmissions, frequency band(s), and associated equipment with J/F 12 numbers.

ITEM 15 - Space Systems. Enter the page number of the space system data. Attach as another page the space system data as described in the NTIA Manual, Paragraph 8.3.7. Data Requirement.

ITEM 16 - Type of Service(s) for Stage 4. Enter the appropriate type of service(s) that applies or will apply to the equipment in the operational stage (Stage 4), as described in Chapter 6, Table of Services, Station Classes, and Stations of the NTIA Manual. If the service is not in accordance with the allocation tables full justification must be entered.

ITEM 17 - Station Class(es) for Stage 4. Enter the appropriate station class(es) as described in Chapter 6 of the NTIA Manual.

ITEM 18 - Remarks. Use this item to amplify or clarify any of the information provided above

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APPENDIX B

Radio Frequency (RF) Related Terms

1-dB Gain Compression: (1-dB GCP, gain compression point, P1dB): The maximum output power of an amplifier at which amplification is nearly linear (high-power levels result in compression). As input power applied to an amplifier is increased, some point will be reached where a 10 dB increase in input signal results in only 9 dB of output signal increase – this is the 1-dB gain compression point. Other compression points such as 0.1 dB or 2 dB are sometimes specified.

3 dB Bandwidth (BW): The frequency span (in MHz) between the points on the selectivity curve at which the insertion loss is 3 dB greater than the minimum insertion loss. Also called 3-dB passband.

3 dB 90° Hybrid Coupler: A four-port device that is used either to equally split an input signal with a resultant 90° phase shift between output signals or to combine two signals while maintaining high isolation between them. These are typically used to convert a linear input/out to a circular output.

Adapter: A waveguide or coaxial device used to mate two dissimilar transmission lines or connectors.

Amplitude Modulation (AM): A method of broadcasting in which the desired audio or video signal modulates the amplitude of a ‘carrier’ signal; analog information that is reproduced using a continuously varying electronic signal.

AM-PM Conversion: An AM-PM conversion represents a shift in the phase delay of a signal when a transistor changes from small-signal to large-signal operating conditions. This parameter is specified for communications amplifiers, since AM-PM conversion results in distortion of a signal waveform.

Anechoic Chamber: A test room in which all surfaces are lined with an RF-absorbing material that absorbs radio waves at a particular frequency or range of frequencies.

Attenuator: A device or network that absorbs part of a signal and passes the remainder with minimum distortion of the signal.

Automatic Gain Control (AGC): A feedback control circuit that maintains the output power level of an amplifier constant over a wide range of input signal levels. These circuits are typically found in telemetry receivers.

Binary Phase-Shift Keying (BPSK): A method of modulating an RF carrier so data is translated into 90° phase shifts of the carrier.

Capacitor: A device that blocks dc while allowing ac or signals to pass; used when joining two circuits.

Carrier-to-Noise Ratio (CNR): The ratio of the magnitude of the carrier to that of the noise after bandlimiting but before any nonlinear process such as amplitude limiting.

Channel: The width of the spectrum band taken up by a radio signal; usually measured in kilohertz (kHz). Most analog cellular phones use 30-kHz channels.

Circulator: A passive RF device, consisting of three ports, that allows the signal entering each port to pass to the port adjacent to it (either clockwise or counter-clockwise) but not to the port in the other direction.

Coaxial Cable: A cable consisting of one center conductor to carry a signal, surrounded concentrically (coaxial) by an insulating dielectric and a separate outer conductor (braid or metal jacket) which acts as a shield.

Coma Lobe: Sidelobe that occurs in the radiation pattern of a microwave antenna when the reflector alone is tilted back and forth to sweep the beam through space because the feed is no longer always at the reflector's center.

Coupling: A setup that permits energy transfer through wire, transformer, capacitor, or other device.

Crosstalk: Interference in a given transmitting or recording channel that has its origin in another channel. Undesired signal energy appearing in one signal path as a result of coupling from other signal paths.

dB (decibel): A logarithmic expression of ratios of two values of power, current, or voltage. Can be found by taking ten times the common logarithm of the ratio of two power levels, or 20 times the common logarithm of the ratio of two voltage levels. It is normally used for expressing transmission gains, losses, levels, and similar quantities.

dBc: Decibel referenced to the carrier signal level.

dBi: Decibels referenced to isotropic radiator; it relates the gain of an antenna relative to an isotropic (perfectly spherical pattern) antenna.

dBm: Decibels relative to 1 mW; the standard unit of power level used in RF work;
(e.g., 0 dBm = 1 mW, +10 dBm = 10 mW, +20 dBm = 100 mW).

Desensitization: The compression in the IF output power from a desired RF input signal caused by a second high-level signal being simultaneously applied to the RF port of a mixer. As a rule of thumb, in low-level mixers, a desired RF input 3 dB below the mixer conversion compression point will begin to cause desensitization.

Digital Modulation: A method of transmitting an analog (continuously variable) signal using the computer's binary code, ZEROS and ONES. Digital transmission offers a cleaner signal than analog technology. Cellular systems providing digital transmission are currently in operation in several locations.

Diplex/Diplexers: The simultaneous transmission or reception of two signals using a common feature such as a single antenna or carrier. Typically, two transmitters operate alternatively (coupled to a diplexer) at approximately the same RF using a common antenna.

Directional Coupler: A device used to sample RF signals by means of coupling (combining) signals asymmetrically. May be of the crossguide or directional variety. Available at various coupling levels (typically 10 to 50 dB below the signal of interest).

Dish: The parabolic reflector (microwave reflector) that is part of a radar antenna system and used for transmitting and receiving signals.

Distortion: Changes in a signal that involve the addition of spurious tones at frequencies not present in the original signal. In harmonic ‘distortion,’ the spurious tones are at integral multiples of the original frequency. In ‘intermodulation’ distortion, discordant tones appear at the sums and differences of two original frequencies.

Downconverter: Integrated assembly of components required to convert RF signals to an intermediate frequency range for further processing. Generally consists of an input filter, local oscillator filter, IF filter, mixer and frequently an LO frequency multiplier, plus one or more stages of IF amplification. May also incorporate the local oscillator, AGC/gain-compensation components and RF preamplifier.

Dummy Load: A dissipative but essentially nonradiating substitute device having impedance characteristics simulating those of the antenna. This allows power to be applied to the radar transmitter without radiating into free space. Dummy loads are commonly used during EMCON conditions or when troubleshooting a transmitter at a workbench away from it’s normal environment.

Dynamic Range: The range from the minimum, which is at a level at or below the amplifier’s internally-generated noise, to a maximum input signal level that a component can accept and amplify without distortion. In regard to mixers, the range of RF input power levels over which a mixer can operate within a specified range of performance. The upper limit of the mixer dynamic range is controlled by the conversion compression point (also a function of LO drive), and the lower limit is set by the mixer noise figure.

Effective Radiated Power (ERP): Input power to the antenna in watts times the gain ratio of the antenna. When expressed in dB, ERP is the transmitter power, in dBm (or dBW) plus the antenna gain in dB. The term EIRP is used sometimes and reiterates that the gain is relative to an isotropic radiator.

Error Signal: In servomechanisms, the signal applied to the control circuit that indicates the degree of misalignment between the controlling and the controlled members. In tracking radar systems, a voltage dependent upon the signal received from a target whose polarity and magnitude depend on the angle between the target and the center axis of the scanning beam.

Eye Pattern: The pattern that results, as displayed on an oscilloscope, from the superpositioning of ONES and ZEROS in a digital data sequence, when the time base of the oscilloscope is synchronized to the bit rate clock.

Federal Communications Commission (FCC): The U.S. government agency responsible for allocation of radio spectrum for communication services.

Ferrite: The term “ferrite” refers to various iron-containing compounds. Most commonly, in the field of electronics, the term refers to cores of various shapes, which are made of these materials. One property of inductors that have ferrite cores is that their inductance varies with the current through them.

Frequency: The number of cycles per second (cps) of an electromagnetic transmission. 1 hertz (Hz) = 1 cps; 1 kilohertz (kHz) = 1,000 cps; 1 megahertz (MHz) = 1,000,000 cps; 1 gigahertz (GHz) = 1 billion cps.

Frequency Modulation: A method of transmission in which the desired signal modulates (varies) the frequency of a ‘carrier’ signal.

Frequency Range: Usually presented as the minimum and maximum frequencies between which a particular component will meet all guaranteed specifications.

Fundamental Frequency: Used synonymously for tuned frequency, carrier frequency, center frequency, or operating frequency.

GaAs FET: Gallium Arsenide Field Effect Transistor - (also called GaAs MESFET for metal Epitaxial Semiconductor Field Effect Transistor). A field-effect transistor with a reverse-biased Schottky-barrier gate fabricated on a gallium arsenide substrate. Roughly equivalent to a silicon MOSFET, GaAs FETs are depletion-mode devices. Because charge carriers reach approximately twice the velocity as in silicon, for a given geometry, a given gain can be reached at about twice the frequency.

Hertz (Hz): The unit of measurement of frequency that equals one cycle per second (cps).

Horn Antenna: A flared, open-ended section of waveguide used to radiate the energy from a waveguide into space. Also termed ‘horn’ or ‘horn radiator.’ It is usually linearly polarized, but will be vertically polarized when the feed probe is vertical, or horizontally polarized if the feed is horizontal. Circular polarization can be obtained by feeding a square horn at a 45° angle and phase shifting the vertical or horizontal excitation by 90°.

Impedance: Opposition or resistance to the flow of electrical current. Impedance is the term used in non-direct current (dc) applications, while resistance is used for dc.

Incidental FM: The peak-to-peak variations of the carrier frequency due to external variations with the unit operating at a fixed frequency at any point in the tunable frequency range.

Insertion Loss: The transmission loss measured in dB at that point in the passband that exhibits the minimum value.

Intercept Point: A figure (expressed in dBm) that indicates the linearity and distortion characteristics of an RF component. It represents the point where the fundamental output and spurious responses (usually 3rd order) intersect, when plotted on a log-log scale with output power ordinate and input power as abscissa.

Intercept Point 3rd Order: The intersection point of the fundamental Pout vs. Pin extrapolated line and the third-order intermodulation products extrapolated line. IP3 is highly dependent on the LO and RF frequency, the LO drive level, and the impedance characteristics of all terminations at the operating frequency.

Intermediate Frequency (IF): In superheterodyne receiving systems, the frequency to which all selected signals are converted for additional amplification, filtering and eventual direction.

Isolation: The ratio (in dB) of the power level applied at one port of a mixer to the resulting power level at the same frequency appearing at another port. Commonly specified isolation parameters of mixers are:

> <u>LO to RF port</u>: The degree of attenuation of the LO signal measured at the RF port with the IF port properly terminated.
>
> <u>LO to IF port</u>: The degree of attenuation of the LO signal measured at the IF port with the RF port properly terminated.

<u>RF to IF port</u>: The degree of attenuation of the RF signal measured at the IF port with the LO port properly terminated.

Normally the inverse isolation characteristics (such as RF to LO, IF to LO, and IF to RF) are essentially equivalent in a double-balanced mixer.

Isolator: A device that permits RF energy to pass in one direction while providing high isolation to reflected energy in the reverse direction. Used primarily at the input of communications-band RF amplifiers to provide good reverse isolation and minimize VSWR. Consists of an RF circulator with one port (port 3) terminated in the characteristic impedance.

Local Oscillator (LO): An oscillator used in superheterodyne receiver which, when mixed with an incoming signal, results in a sum or difference frequency equal to the intermediate frequency of the receiver.

Mainlobe: A part of the radiation pattern of a directional antenna representing an area of stronger radio signal transmission.

Microstrip (Microstripline): A transmission line consisting of a metallized strip and a solid ground plane metallization separated by a thin, solid dielectric. This transmission-line configuration is used since it permits accurate fabrication of 50 transmission line elements on a ceramic or PC board substrate.

Microwaves: High frequency radio waves lying roughly between infrared waves and radio waves (above 1 GHz = 1 billion cycles per second). Microwaves are generated by electron tubes, such as the klystron and the magnetron, or solid-state devices with built-in resonators to control the frequency or by oscillators. Microwaves have many applications, including radio, television, radar, test and measurement communications, distance and location measuring.

Mixing: The generation of sum and difference frequencies that result from applying two ac waveforms to a nonlinear circuit element. In mixer applications, with a signal of frequency Frf applied to the RF port and a signal fLO applied to the LO port, the resulting signal at the IF port will consist of two carriers (or sidebands) of frequencies Frf + fLO and Frf - fLO with internally generated LO and RF harmonics.

Modulation: The process whereby some characteristic of one wave is varied in accordance with some characteristic of another wave. The basic types are angle modulation (phase and frequency) and amplitude modulation. In missile radars, it is common practice to amplitude modulate the transmitted RF carrier wave of tracking and guidance transmitters by using a pulsed wave, and to frequency modulate the transmitted RF carrier wave of the illuminator transmitters by using a sine wave.

Monopulse: A type of tracking radar that permits the extracting of tracking error information from each received pulse and offers a reduction in tracking errors as compared to a conical-scan system of similar power and size.

Multipath: Reception of one or more reflected signals along with a direct broadcast signal, producing distortion in stereo FM and ghost images in televisions.

Network Analyzer: A microwave test system that characterizes devices in terms of their complex small-signal scattering parameters (S-parameters). Measurements involve determining the ratio of magnitude and phase of input and output signals at the various ports of a network with the other ports terminated in the specified characteristic impedance (generally 50 ohms).

Noise Figure (NF): The ratio (in dB) between the SNR applied to the input of the RF component and the SNR measured at its output. It is an indication of the amount of noise added to a signal by the component during normal operation. Lower noise figures mean less degradation and better performance.

Noise Floor: The lowest input signal power level that will produce a detectable output signal from a RF component, determined by the thermal noise generated within the RF component itself. The noise floor limits the ultimate sensitivity to the weak signals of the RF system, since any signal below the noise floor will result in an output signal with a SNR of less than one and will be more difficult to recover.

Noise Temperature: The amount of thermal noise present in a system. Used in RF communications and sometimes radar, it is the equivalent of noise figure expressed in Kelvin (e.g., an amplifier with 1.5 dB noise figure has an effective noise temperature of 120 K).

Nulls: The azimuth or elevation reading on a navigational device indicated by minimum signal output. Also, any nodal points on the radiation patterns of some antennas.

Output Frequency: The frequency of the component’s desired output. The undesired frequency components may include harmonics, subharmonics, 3/2 harmonics, or nonharmonic spurious signals.

Output Power: The minimum and/or maximum output power at the output frequency under all specified conditions. Usually the specified conditions are temperature, load, VSWR and supply voltage variations. It is typically expressed in dBm or milliwatts (mW).

Output Power at 1 dB Gain Compression (P1dB): Essentially, the maximum output power available from the transistor while providing linear amplifications. Also designated: PO-1 dB, and in numerous other ways. See also G1dB.

Phase Modulation: A special form of modulation in which the linearly increasing angle of a sine wave has added to it a phase angle that is proportional to the instantaneous value of the modulating wave (message to be communicated).

Phase Noise: A frequency-domain view of the noise spectrum, or random phase fluctuations, around an oscillator signal. Normally measured with properly equipped spectrum analyzers or specific phase noise test sets, the measurement characterizes the one sided spectral density of phase fluctuations per unit bandwidth. The single sideband measurement is made by integrating over a 1 Hz bandwidth at offsets from the carrier, dividing by total carrier power and subtracting 3 dB (see NIST definition for phase noise, L(f)). Units for phase noise measured this way is dBc/Hz. Phase noise degrades system performance, most notably in phase modulated signals.

PIN Diode: A diode made by diffusing the semiconductor so a thin, intrinsic layer exists between the P and N-doped regions (positive-intrinsic-negative). Such diodes do not rectify at RF frequencies but behave as variable resistors controlled by the applied dc bias.

Power Divider: A passive-resistive network that equally divides power applied to the input port between any number of output ports without substantially affecting the phase relationship or causing distortion.

Q (Quality Factor): Generally a measure of the sharpness of the resonance or frequency selectivity of a tuned circuit or filter. Also, a quantitative ratio of the resonant frequency to the bandwidth used to provides an indication of the quality of a frequency response

Quadrature: Having a characteristic 90° phase shift. Used to describe a coupler in which the two output signals are 90° out of phase, and in telecommunications for modulation techniques such as QPSK.

Quadrature Phase-Shift Keying (QPSK): A method of modulating an RF carrier with two parallel streams of NRZ digital bit streams so data is translated into 90° phase shifts of the carrier.

Radio Frequency (RF): Generally, this refers to any frequency at which the radiation of electromagnetic energy is possible. Also used as a designation for frequencies at which the radiation of electromagnetic energy is possible. Also used as a designation for frequencies below approximately 50 to 100 MHz (100 - 300 MHz is very high frequency, 300 MHz - 1000 MHz is ultra-high frequency, 1000 MHz and up is RF).

Return Loss: When expressed in dB, it is the ratio of reflected power to incident power. It is a measure of the amount of reflected power on a transmission line when it is terminated or connected to any passive or active device. Once measured, it can be converted by equation to a reflection coefficient that can be converted to VSWR.

Selectivity: A measure of a tuner’s ability to receive stations at closely spaced frequencies without mutual interference.

Signal-to-Noise Ratio (S/N or SNR): The ratio of signal power to noise power in a specified bandwidth, expressed in dB.

Skirt (bandpass): The portions of the passband curve above the upper and below the lower frequency points at which full off-resonance isolation is achieved.

S-Parameters (scattering parameters): Scattering parameters are a group of measurements taken at different frequencies which represent the forward and reverse gain, and the input and output reflection coefficients of an RF component when the component’s input and output ports are terminated in a specified impedance – usually 50 ohms; measured in terms of magnitude (length of the vector in the polar plane) angle (the direction of the vector in the polar plane) and dB (10 log 10 {power}).

Spectrum: The complete range of electromagnetic waves that can be transmitted by natural sources such as the sun, and man-made radio devices. Electromagnetic waves vary in length and, therefore, have different characteristics. Longer waves in the low-frequency range can be used for communications, while shorter waves of high frequency show up as light. Spectrum with even shorter wavelengths and higher frequencies are used in X-rays.

Spurious-Free Dynamic Range: The range of input signals lying between the tangential sensitivity level and an upper signal level at which generated in-band spurious outputs exceed the tangential level.

Spurious Signal and Outputs: Undesired signals produced by an active RF component, usually at a frequency unrelated to the desired signal or its harmonics. Spurious outputs are both harmonically and nonharmonically related signals. Their tolerable amplitude should be specified within and out of the frequency range of the oscillator. Typical values range from −60 dBc to −80 dBc.

Stripline: A transmission line consisting of a conductor above or between extended conducting surfaces.

Suppression: The minimization of undesired side effects in circuit operations (e.g., two-tone intermodulation suppression, usually through a design compromise or the addition of specialized components).

Telemetry (TM) (telemetering): Transmission of readings from instruments to a remote location by means of wires, radio waves, or other means. Also known as remote metering.

Termination: A circuit element or device such as an amplifier, divider, resistor, or antenna, placed at the end of a transmission line.

Transmission Line: The conductive connections between circuit elements that carry signal power. Wire, coaxial cable and waveguide are common examples.

Two-Tone, Third-Order Intermodulation Distortion: The total amount of distortion (dB relative to desired waveform) to the output signal waveform that exists when two simultaneous input frequencies are applied to the RF port of a mixer. Two-tone, third-order intermodulation distortion products are described by 2fR2-Fr1± fLO and by 2fR1-Fr2±fLO. The higher the third-order intercept point and conversion compression of a mixer, the lower the intermodulation for given input signals will be.

Velocity Factor: Velocity factor is the ratio of the speed that RF signals propagate on a transmission line to that of free space. Typical values range from 66% for foam dielectric cables to 95% for air dielectric cables. This is an important factor to consider when attempting to measure the “electrical length” of a cable verses its physical length.

Voltage Standing Wave Ratio (VSWR): When impedance mismatches exist, some of the energy transmitted through will be reflected back to the source. Different amounts of energy will be reflected back depending on the frequency of the energy. VSWR is a unit-less ratio ranging from one to infinity, expressing the amount of reflected energy. A value of one indicates that all of the energy will pass through, while any higher value indicates that a portion of the energy will be reflected.

Watt (W): A unit of electrical or acoustical power. Electrical power is the product of voltage and current. Acoustical power is proportional to sound-pressure intensity.

Waveguide: A transmission line specific to RF communications consisting of a conducting metal outer shell, and filled with air or a vacuum. Waveguide is also used as the basis for numerous components such as crossguide couplers, filters, hybrid combinersand circulators/isolators.

APPENDIX C

Citations

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