



**TELEMETRY GROUP**

**SPECIAL REPORT**

**WAVEFORM CHARACTERIZATION AND ADJACENT CHANNEL  
INTERFERENCE (ACI) TESTING OF SERIAL STREAMING  
TELEMETRY (SST) AND TACTICAL TARGETING NETWORK  
TECHNOLOGY (TTNT) SIGNALS**

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## PREFACE

This special report presents the results of work performed by members of the Telemetry Group (TG) of the Range Commanders Council (RCC). The work was performed under Task TG-99, "Tactical Targeting Network Technology (TTNT) Signal Characterization and Adjacent Channel Interference (ACI) Testing." The objectives of task TG-99 included characterizing the TTNT signal and providing guidance for same-band operation with serial streaming telemetry (SST). The telemetry (TM) community will benefit by having a better understanding of the TTNT system and by knowing the best methods for allowing simultaneous operation of the TTNT system and TM systems when air-to-ground TM signals are required. In particular, all ranges planning to deploy and test TTNT systems will benefit from this study.

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## ACRONYMS

ACI	Adjacent channel interference
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
BER	Bit error rate
C/I	Carrier to interference (ratio)
dB	Decibel
dBc	Decibels (relative to the carrier)
dBm	Decibel referenced to one milliwatt (mW)
dBr	Decibels relative to reference level
Eb/No	Energy per bit to noise power spectral density ratio
FM	Frequency modulation
GMSK	Gaussian Minimum Shift Keying
IRIG	Inter-range Instrumentation Group
Mbps	Megabits per second
MHz	Megahertz
mW	Milliwatt
NITS	Noise and Interference Test Set
OBW	Occupied bandwidth
PCM	Pulse code modulation
PRBS	Pseudo-random bit sequence
RBW	Resolution bandwidth
RCC	Range Commanders Council
RF	Radio frequency
SAW	Surface acoustic wave
SOQPSK	Shaped Offset Quadrature Phase-Shift Keying
SST	Serial streaming telemetry
TG	Telemetry Group
TM	Telemetry
TTNT	Tactical Targeting Network Technology
VBW	Video bandwidth

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## CHAPTER 1

### INTRODUCTION

The Tactical Targeting Network Technology (TTNT) system is an internet based, high-speed, ad hoc datalink network designed to enable tactical aircraft to target moving and time-critical targets quickly. The TTNT network also provides a high throughput and low latency solution for safety of flight and other applications requiring real-time information.

The TTNT system tests have included flights of early validation units and testing has progressed to the point of Phase 3 hardware requiring range time at test ranges. These ranges, which are in the western part of the United States (U.S.), include Edwards Air Force Base (AFB), Vandenberg AFB, the Naval Air Warfare Center Weapons Division, Point Mugu (NAWCWD-PM), and the Naval Air Warfare Center Weapons Division, China Lake (NAWCWD-CL). Because of the approved bands of operation and power levels in which the system can operate, interference with aeronautical serial streaming telemetry (SST) signals is a distinct possibility. This test report describes an initial series of tests that investigated and characterized the TTNT waveform and performed adjacent channel interference (ACI) testing with the TTNT waveform as the interferer. In addition to presenting test results, this report also presents preliminary channel spacing recommendations for accommodating the co-existence of TTNT and telemetry (TM) signals in a shared band scenario.

#### 1.1 Tactical Targeting Network Technology (TTNT) Physical Characteristics

Each node of TTNT has radio frequency (RF) ports for upper and lower antenna connections. Both ports can be transmitting simultaneously, or both can be off. Each port transmits at a peak level of 151 W, which equals +51.8 decibels referenced to one milliwatt (+51.8 dBm). The physical layer consists of a single carrier with Gaussian Minimum Shift Keying (GMSK) modulation; it frequency hops between a preconfigured set of center frequencies. The total number of available center frequencies is 16 (set prior to testing), but not all 16 frequencies have to be used. For this testing, a TTNT Phase 3 terminal is to be used



(Figure 1-1). Additional descriptive information is at Reference [1](#).  
Figure 1-1. TTNT Phase 3 terminal.

## 1.2 Bands of Operation

The TTNT system is capable of operating in one or all of three frequency bands, with 16 available channels as shown in Table 1-1.

<b>TABLE 1-1. TTNT FREQUENCY BANDS</b>		
<b>Frequency Band</b>	<b>Frequency Range (MHz)</b>	<b>Available Channels</b>
1	1755 – 1850	7
2	1435 – 1518	6
3	1350 – 1390	3
Total Channels 16		

## 1.3 TTNT Spectrum

Per Reference [2](#), the transmitted TTNT spectrum conforms to the mask described in Figure [1-2](#) and Table [1-2](#) for each transmission channel. The reader should note that channel spacing of the 16 channels is fixed to a center-to-center spacing of  $13\frac{1}{3}$  MHz. The term “decibels relative to reference level” (dBr) refers to the reference level that is set by determining the peak value of the modulated waveform. Spectrum analyzer settings for this measurement are resolution bandwidth (RBW) equal to 1 MHz and video bandwidth (VBW) equal to 3 MHz with peak hold enabled.

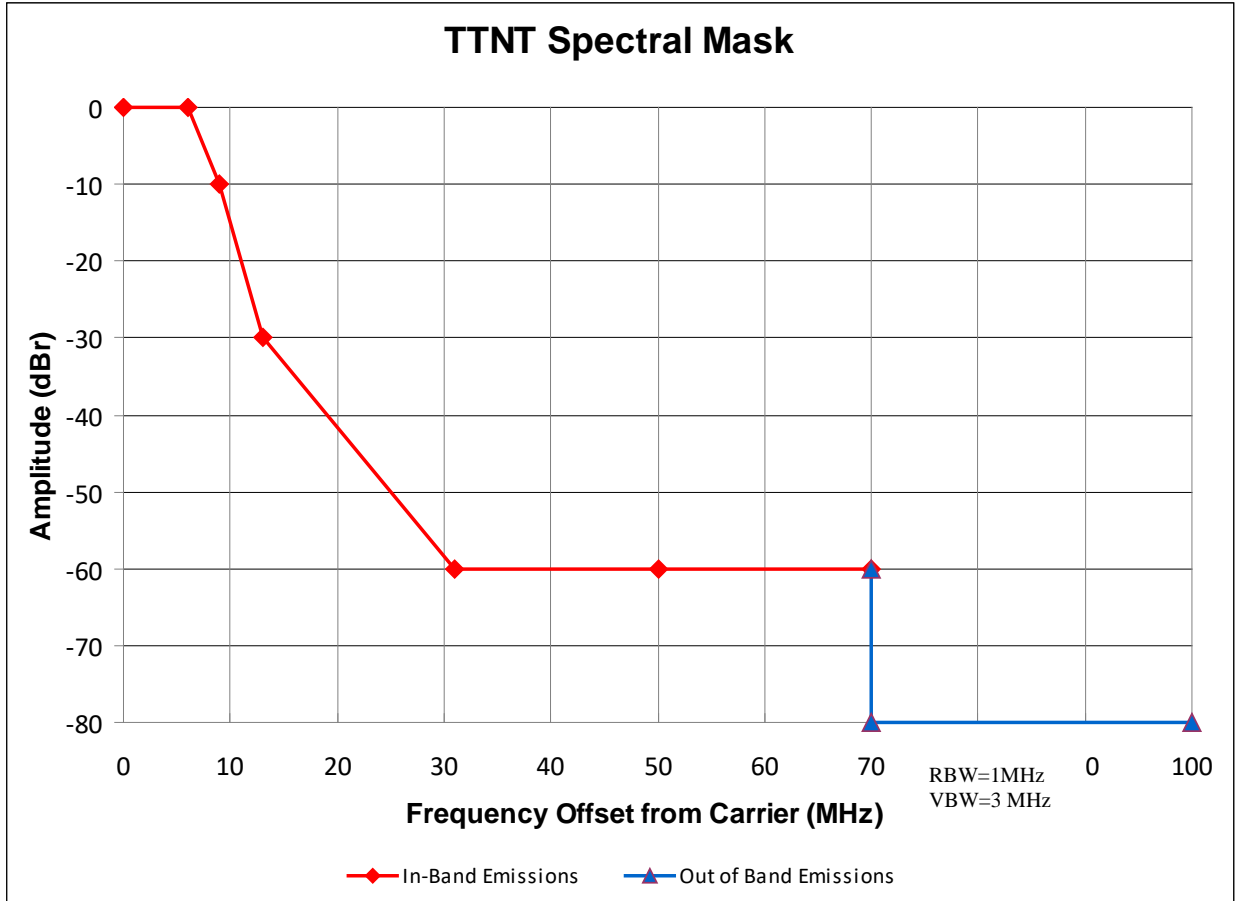


Figure 1-2. TTNT transmitted spectral mask.

TABLE 1-2. TTNT SPECTRAL MASK		
Frequency Offset from Carrier (MHz)	In-Band (dBr)	Out of Band (dBr)
6	0	
9	-10	
13	-30	
31	-60	-60
70	-60	-80
100	-60	-80

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## CHAPTER 2

### TEST CONDITIONS

Chapter 2 contains the procedural guidelines followed by the test personnel.

Testing of the TTNT system will be performed in two parts. The first part attempts to characterize the spectrum of the waveform and to search for out of band spurious emissions. The second part of the testing will be adjacent channel interference (ACI) testing. For this testing, the victim signal will be an aeronautical telemetry (TM) signal and the interferer will be the TTNT signal.

#### 2.1 Waveform Characterization

Waveform characterization will consist of two parts. The first part will measure and document the TTNT spectrum, compare the results to the spectral mask as called out in Reference 2, and provide occupied bandwidth (OBW) numbers. The second part will be concerned with spurious emission characterization. Since TTNT is a burst transmission system, spurious out of band content could potentially cause interference; therefore, an attempt will be made to search for such emissions.

2.1.1 Spectral Measurements. The test set up for waveform characterization is shown in Figure 2-1. The filters on the output of the TTNT terminals are part of a normal installation and thus included in this testing. In order to make the spectral measurements, one of the TTNT terminals will have to transmit continuously and on only one channel. The single channel will be selected and the “Red Sender” program application resident in the terminal will be used. Though this program does send continuous data, the data is indeed packet oriented and, therefore, burst transmissions do occur. This situation will be referred to as “burst/continuous” operation throughout this report. Settings for spectral measurements will have a resolution bandwidth (RBW) of 30 kHz, and a video bandwidth (VBW) of 3 kHz, with peak hold enabled. Additionally, the settings will be those that are familiar to the TM community and those that allow reasonable measurements of the burst-like TTNT waveform. To be consistent with TTNT requirements, TTNT spectral mask compliance measurements will have settings of RBW = 1 MHz and VBW = 3 MHz with peak hold enabled.

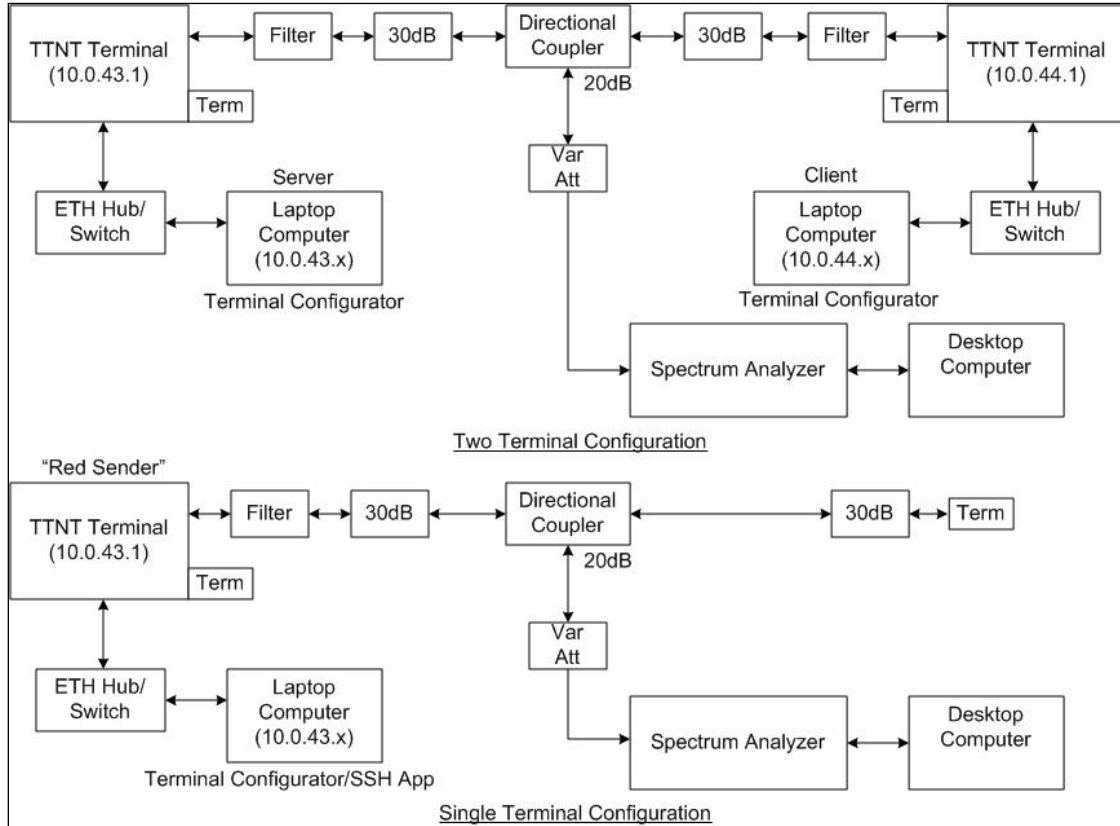


Figure 2-1. TTNT spectral analysis block diagram.

In order to assess spectral occupancy and to level the spectral mask correctly, zero decibels relative to the carrier (0 dBc) needs either to be measured or estimated. Since the TTNT hardware does not provide a mode to transmit an unmodulated carrier, 0 dBc will have to be estimated. Appendix A of Inter-Range Instrumentation Group (IRIG-106) (RCC Document 106, Telemetry Standards) provides a method for determining this level. To find the total power (unmodulated carrier peak value), the spectrum analyzer's resolution and VBWs are set to their widest settings and maximum hold is selected. The analyzer is allowed to make several sweeps and the maximum value of the trace will be a good approximation of the unmodulated carrier level.

Spectral measurements will be made only in Band 1 and Band 2. Several channels in each band will be measured and compared. If anomalies are encountered, more measurements will be made.

**2.1.2 Spurious Emission Measurements.** Spurious emissions (from the TTNT hardware) that reside in the TM bands have the potential to interfere with TM signals. Locating such emissions from a burst system is not a trivial task. For this testing, several specific TTNT transmit channels will be selected in each of the bands and a spurious search will be done in the lower L-Band (1435.5-1525.5 MHz) and the upper L-Band (1755-1850 MHz); both are aeronautical TM bands. For example, if a Band 3 channel is selected, a spurious search will take place in both lower and upper L-Bands (both TM bands). The TTNT terminal will be configured for "burst/continuous" operation with either one or two channels active. Various spectrum analyzer



settings, all with peak hold enabled, will trade sweep time and resolution with the emphasis on capturing a spurious response.

## 2.2 Adjacent Channel Interference (ACI) Characterization

The ACI testing will be done to determine acceptable spacing criteria between TM signals and channels of TTNT. The interferer in this case will be the TTNT signal and the victim will be the TM signal.

Appendix A of IRIG-106 has a formula for spacing TM signals based upon bit rate, modulation mode, and TM receiver filter characteristics. The metric that determines acceptable victim degradation is the relationship between energy per bit to noise power spectral density ratio ( $E_b/N_0$ ) and bit error rate (BER). To simplify this testing, a subset of these criteria will be used. Data rate from the victim signal will be set between one megabit per second (1 Mbps) and 20 Mbps, modulation mode dependant (see Table [2-1](#)). These data rates and modulation modes are typical of current test programs and of those expected in the near future.

An acceptable degradation level will be assessed in terms of  $E_b/N_0$  and BER. A difference of one decibel (1 dB) of required  $E_b/N_0$  to achieve an error rate of  $1 \times 10^{-5}$  as the victim is moved closer to the interferer will be the threshold interference criteria. The main assumptions for the spacing criteria will also be used with the following modification. The interfering signal is assumed to be no larger than 20 dB greater in amplitude than the victim's amplitude. This assumption is for equal power transmitters, typically 10 W (+40 dBm) operating in a near/far geometry. Since the output power of the TTNT terminal is much higher than that of traditional TM transmitters (+52 dBm), this assumption will also be used, though the TTNT terminal can be at a larger slant range (near case) than what was assumed in Law's works (Reference [5](#) and Reference [6](#)). If the carrier to interference (C/I) ratio equals -20 dB is found to be an unrealistic number, it can be adjusted towards -30 dB. It was noted that some TM receivers do not perform well with C/I values approaching 30 dB (Reference [6](#)).

To simulate another real world scenario, C/I will be set to 0 dB and a subset of tests will be conducted. This C/I ratio is meant to simulate the case of TTNT being within the side lobe of a ground station receiving antenna. A typical C/I number for side lobe attenuation is approximately between 15 dB and 20 dB. For a test article flying within the Edwards AFB test complex, this C/I seems a reasonable test point. See Table [2-1](#) for a summary of the ACI test conditions.

<b>TABLE 2-1. ACI TEST CONDITIONS</b>	
<b>Victim Bit Rate</b>	<b>5/10/20 Mbps (SOQPSK) 1/5 Mbps (PCM/FM)</b>
Victim Modulation Mode 1	PCM/FM, peak deviation 0.35 (bit rate)
Victim Modulation Mode 2	SOQPSK-TG
Interferer	Single channel operation
Interference Criteria	1 dB change in Eb/No to achieve bit error rate of BER = $1 \times 10^{-5}$
C/I	-20 dB, 0 dB
Telemetry Receiver IF Filtering	Surface acoustic wave (SAW) filters assumed, no wider than 1.5 times the data rate

2.2.1 Adjacent Channel Interference (ACI) Test Method. The test configuration will be as shown in Figure 2-2. As stated above, the TM signal is the victim signal and the TTNT signal is the interferer. The TTNT signal will be configured for one channel of operation and will stay active by utilizing the Red Sender application resident on the terminal, resulting in the burst/continuous operation. The TM transmit and receive system will be configured per standard set up procedures. Based upon the channel of operation for the TTNT terminal, a starting TM frequency will be set and Eb/No will be adjusted. The TM signal will be frequency agile, start at a lower frequency than that of the TTNT signal, and will be moved closer to the TTNT signal until the threshold interference level is found; the spacing will be noted. The test will be repeated by starting at a higher in frequency. The resulting spacing will be noted and compared. If no difference is noted, the victim signal will start lower in frequency for the remainder of the testing. To verify the observed data is representative of all TTNT terminals, a few data points will be repeated with the other TTNT terminal.

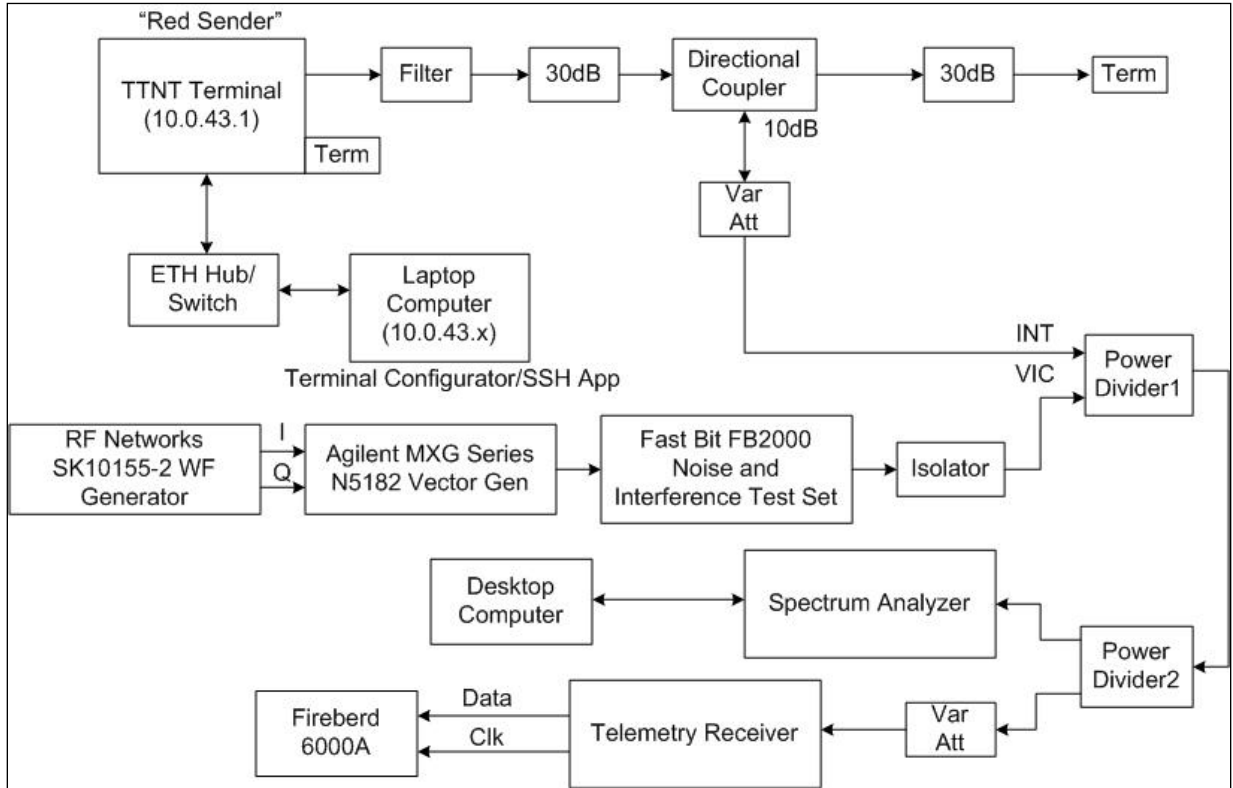


Figure 2-2. ACI block diagram.

**2.2.2 Set Up Test Procedure.** The level into the FastBit<sup>®</sup> Noise and Interference Test Set (NITS) will be such that the unit is operating in its linear range of operation. The purpose of the NITS is to set  $E_b/N_0$  to a value resulting in a BER of  $1 \times 10^{-5}$  for both modulation schemes and all bit rates. The C/I will be set manually. The interferer level will be determined by measuring the total power of the TTNT waveform after “Power Divider2” with the TM signal off, per the method called out in paragraph 2.1.1. Total power will be measured for both TTNT and TM signals. The TM signal level will be adjusted to give an initial C/I = -20 dB. The TTNT terminal network will be configured for continuous one-way traffic using the local “Red Sender” program. Since the TTNT signal can be set on one or more of 16 channels, several will be chosen in the lower L-Band and subsequently in the upper L-Band, and interference results will be recorded. Since the TTNT signal is fixed, it will require moving the victim signal as opposed to the interfering signal. Note that this will add time to the testing due to the continual re-tuning of the NITS and TM receiver. The TM signal will be generated with a pseudo-random bit sequence of length  $2^{15}-1$  (PRBS15) in either one of two modulation methods. The methods are pulse code modulation/frequency modulation (PCM/FM) and Shaped Offset Quadrature Phase-Shift Keying, Telemetry Group (SOQPSK-TG). For each modulation method tested utilizing the NITS,  $E_b/N_0$  will be adjusted to achieve a BER of  $1 \times 10^{-5}$ . Starting at a frequency higher than that of the interferer, the TM signal will be brought closer to interferer frequency until a 1 dB difference is required in  $E_b/N_0$  to achieve a BER of  $1 \times 10^{-5}$  (as observed on the BER tester). The carrier-to-carrier spacing will be noted and the test will be repeated with the TM signal starting at a lower frequency. Spacing numbers will be compared and, if they are the same, only one method (higher or lower in frequency) will be used for the remainder of testing.

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## CHAPTER 3

### RESULTS

The results presented in this chapter were determined to be representative of all Phase 3 TTNT hardware. This determination was verified by taking data with two different terminals and comparing the results. In addition, the adjacent channel interference (ACI) data taken should be considered representative to real world performance given the TM receivers chosen are like existing TM receivers in use at the Air Force Flight Test Center (AFFTC) and many other test ranges.

#### 3.1 Waveform Characterization

Two types of spectral data were captured. The first type was from the TTNT waveform on different transmission channels. The second type came from spurious emission spectral plots specifically looking for spurious emissions within the TM bands.

3.1.1 TTNT Spectral Mask and Occupancy. Figure 3-1 shows a comparison of the TTNT spectrum to the spectral mask defined in paragraph 1.3. Several channels were measured and all channels provided similar spectral data.

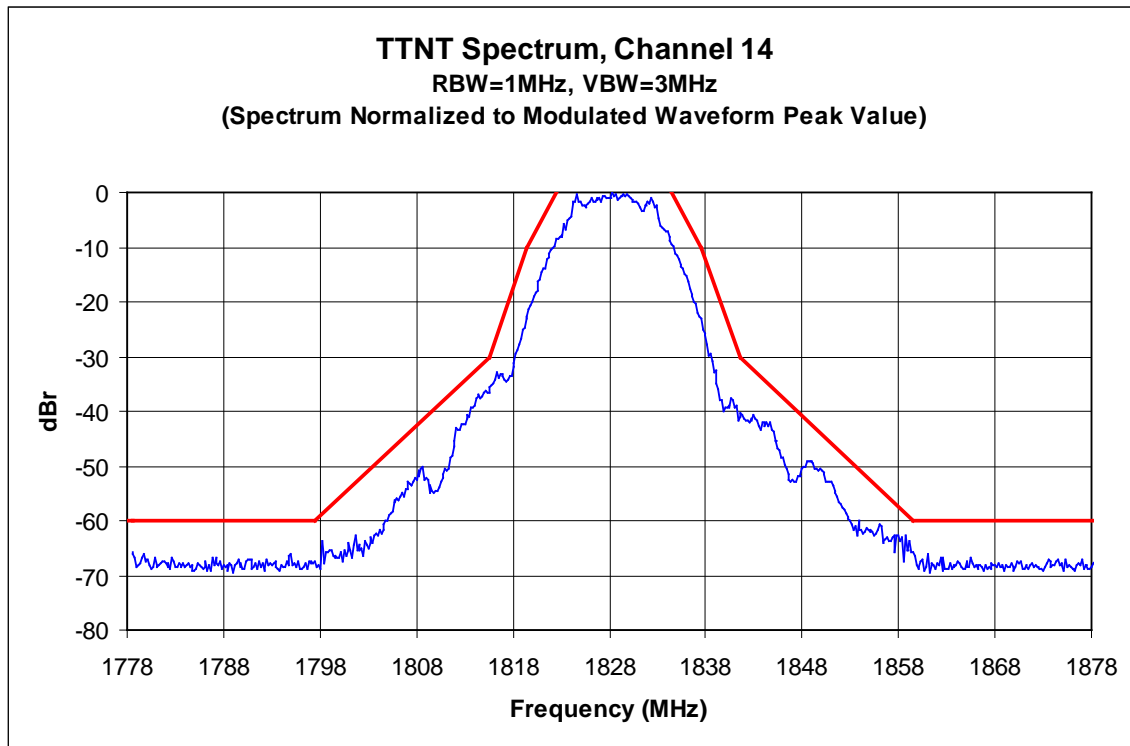


Figure 3-1. TTNT spectrum with spectral mask.

Figure 3-2 shows the TTNT waveform with the spectrum analyzer adjusted to 0 dBc. The measurement of the total power transmitted was made using the technique in paragraph 2.1.1 and the measurement was then used to set the reference level on the spectrum analyzer.

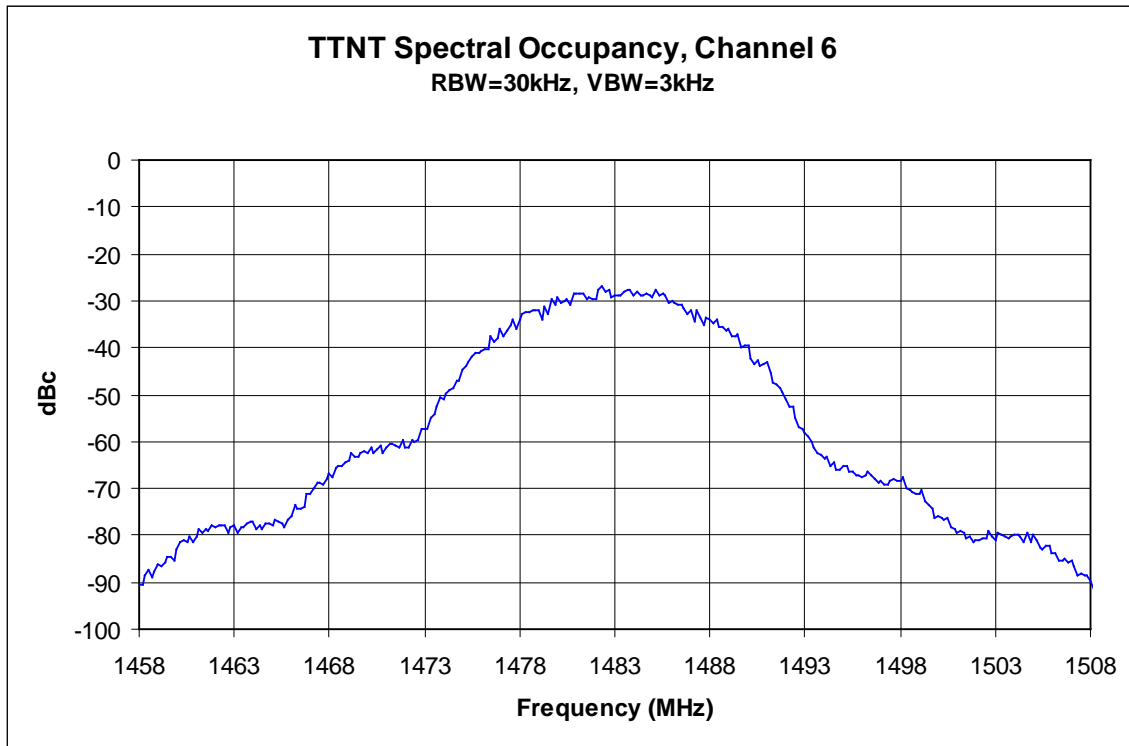


Figure 3-2. TTNT spectral occupancy.

The test ranges evaluate spectral occupancy for determining the amount of bandwidth to be scheduled for flight-testing when transmitting TM signals. A very important action is to determine how closely the channels can be packed when spectrum availability becomes an issue. Making this determination is the reason for testing to see how closely TTNT and TM signals can be spaced. To determine the first number, the occupied bandwidth (OBW) of the TTNT signal is measured. Several bandwidth criteria are used throughout the TM community, with the most accepted ones being the 99 percent and 99.9 percent OBW criteria used in IRIG-106.

Sometimes individual ranges determine OBW by other means. Frequency management personnel at the AFFTC use the width of the spectrum at the -60 dBc point to determine the amount of required "scheduled bandwidth." See Table [3-1](#) for the complete list and bandwidth values associated with the TTNT waveform.

<b>TABLE 3-1. TTNT SPECTRAL OCCUPANCY PER CHANNEL</b>	
<b>Spectral Occupancy Criteria</b>	<b>Width (MHz)</b>
99.0% OBW <sup>1</sup>	14.3
99.9% OBW <sup>1</sup>	18.5
-60 dBc	23
<sup>1</sup> Occupied bandwidth	

Figure 3-3 gives another example of the TTNT spectrum when tuned to another channel.

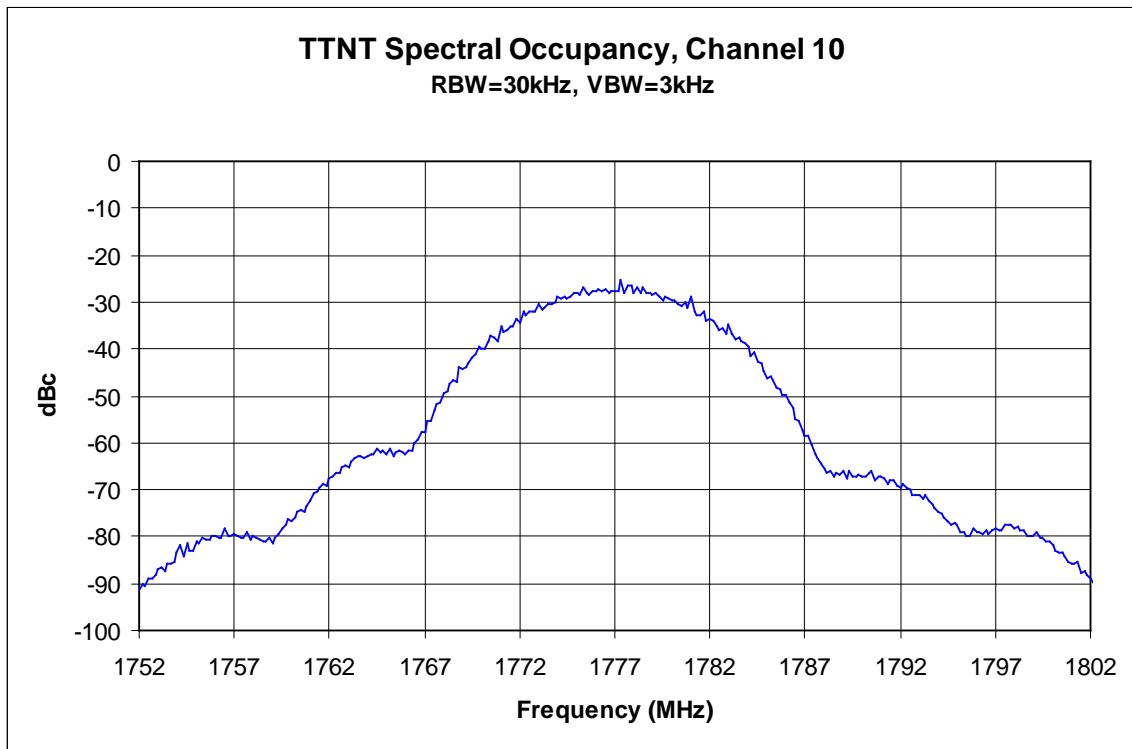


Figure 3-3. TTNT spectrum.

Figure 3-4 compares the spectra between channel 6 and channel 10, which lie in different bands. This plot demonstrates that the spectral characteristics are similar for all bands of operation.

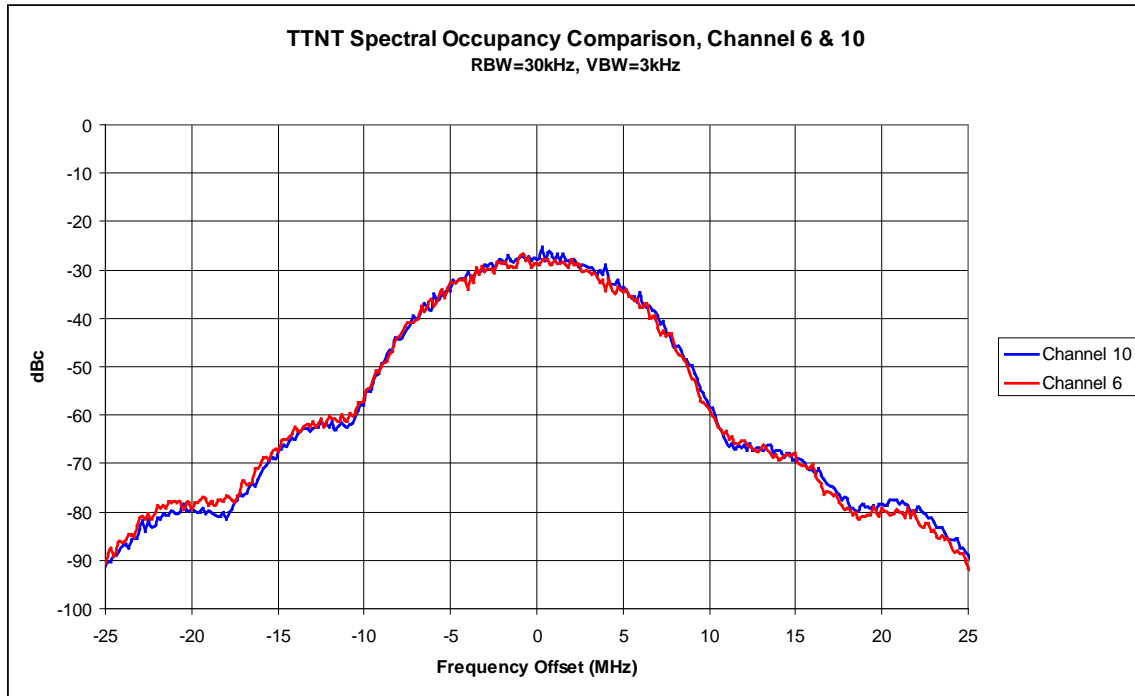



Figure 3-4. TTNT spectrum comparison.

3.1.2 TTNT Spurious Measurements. Wideband spectral measurements were made to see whether spurious content existed outside the modulated waveform. Figure 3-5 through Figure 3-7 display captured spectrum within the lower and upper L-Band TM bands and show no spurious emissions around the carrier. Spectrum analyzer settings for these tests were RBW = 30 kHz and VBW = 30 kHz, with peak hold enabled. Figure 3-8 through Figure 3-11 have different spectrum analyzer settings (RBW = 8 MHz, and VBW = 50 MHz, peak hold enabled) with a span that covers the entire TM spectrum looking for spurious responses within the TM bands. These figures show no indication of spurious content within the TM bands.

Although not within the TM spectrum, harmonics of the selected channels were investigated and none was observed. This may be due in part to the external filters shown in Figure 2-1.

 <p><b>NOTE</b></p>	<p>Figure 3-11 shows several channels active at once. There is about a 2 dB difference in total power output between the lower channels and the higher channels. An adjustment for this power output difference were made during the ACI testing.</p>
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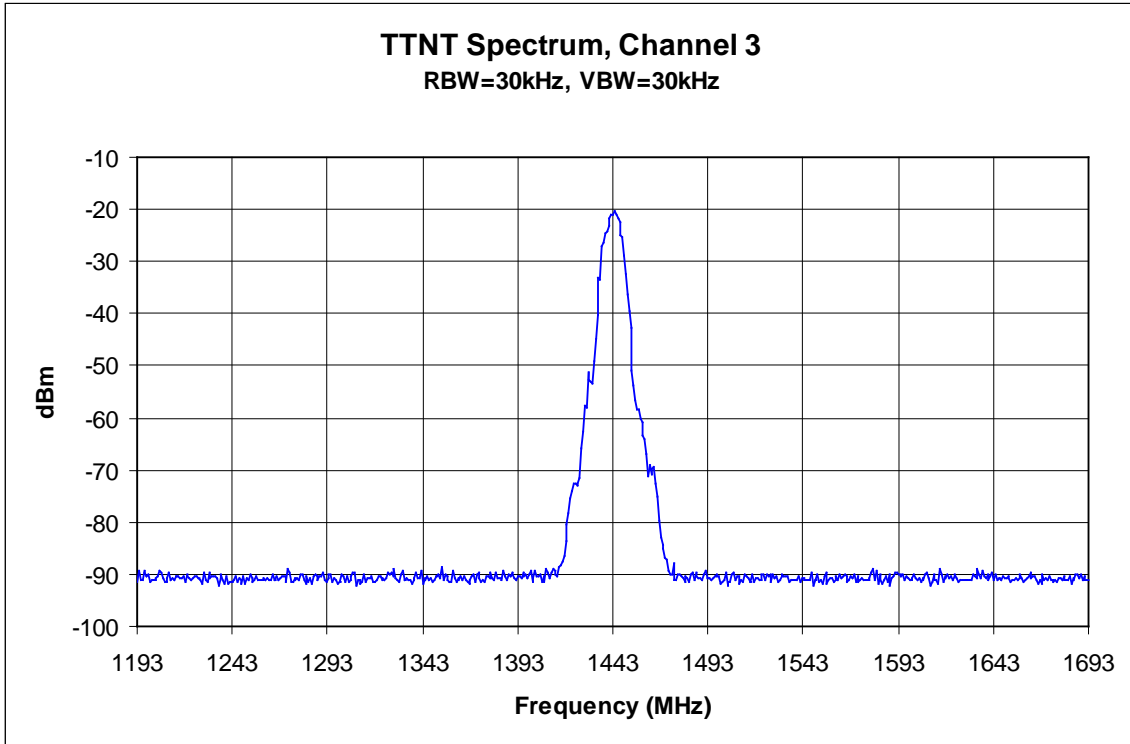


Figure 3-5. TTNT spectrum, channel 3.

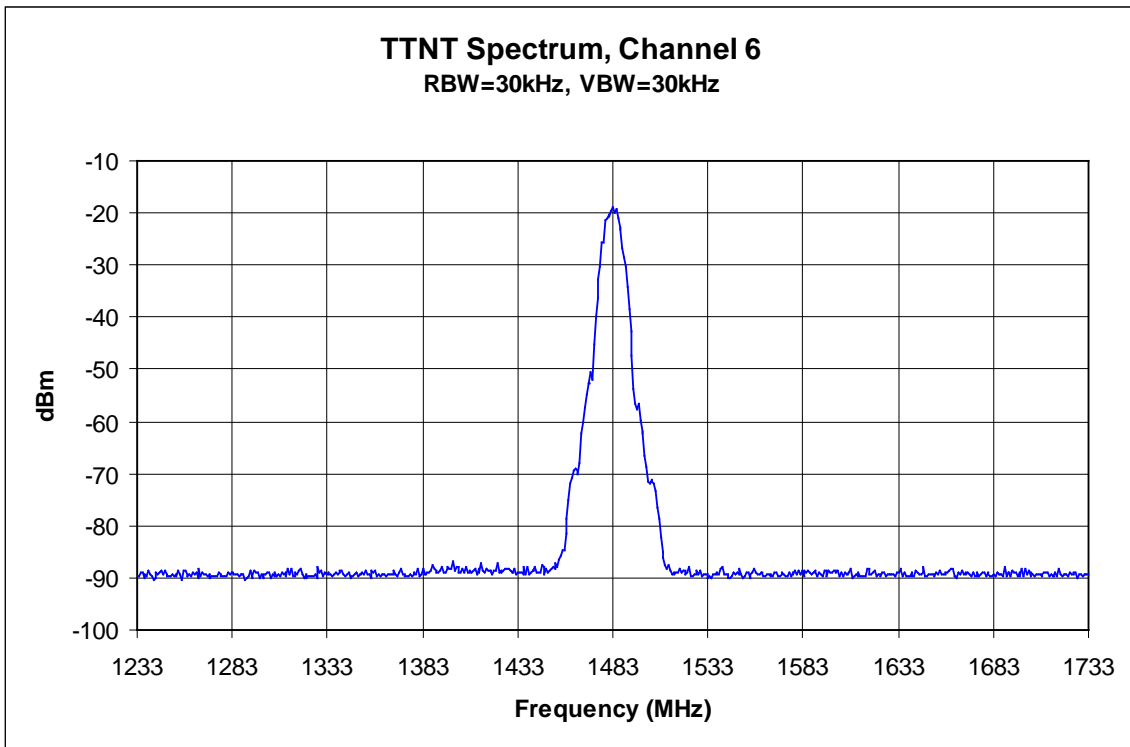


Figure 3-6. TTNT spectrum, channel 6.

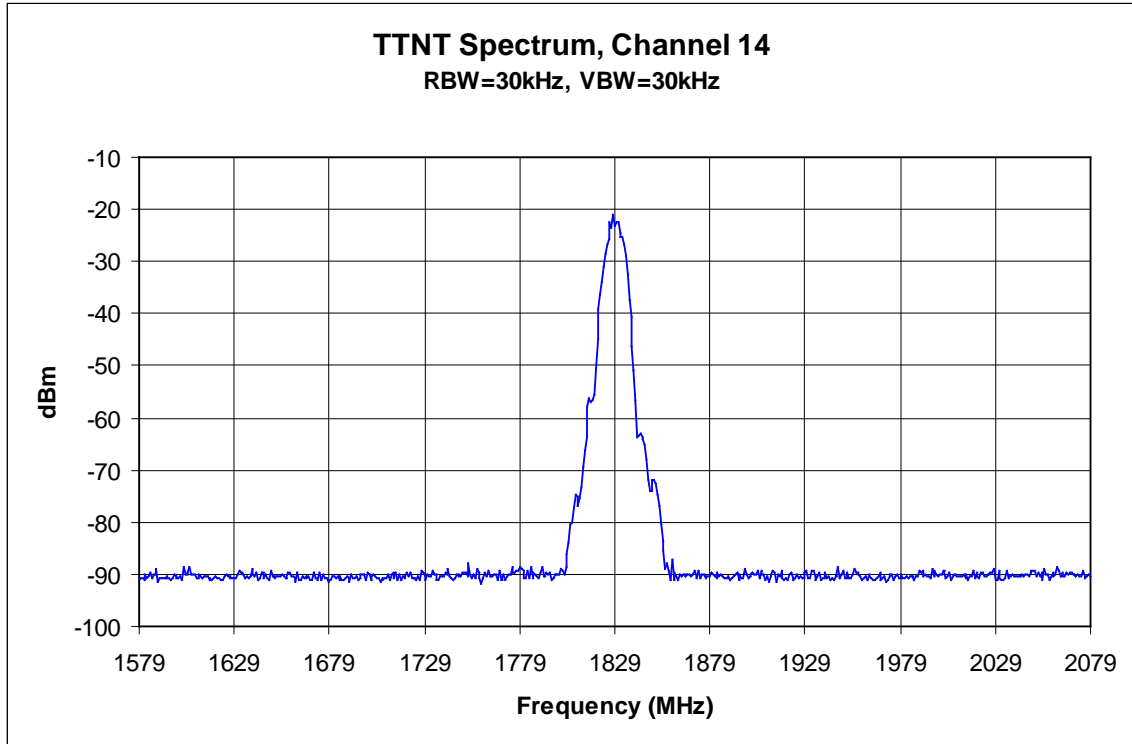


Figure 3-7. TTNT spectrum, channel 14.

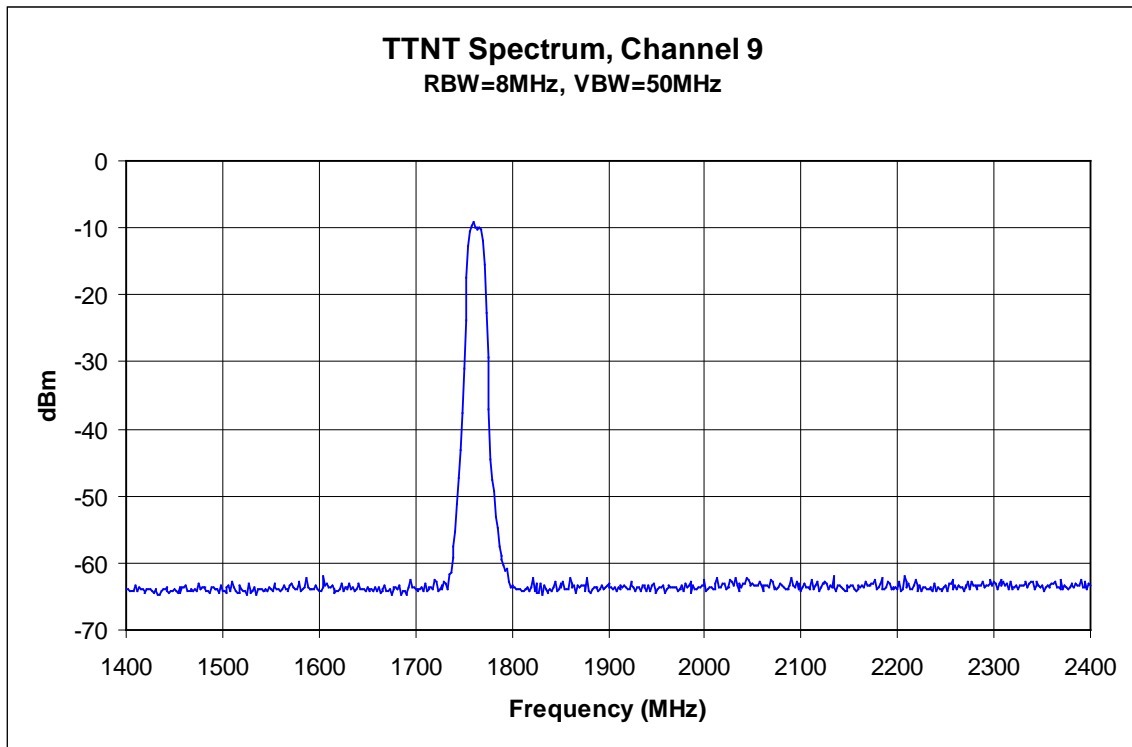


Figure 3-8. TTNT spectrum, channel 9.

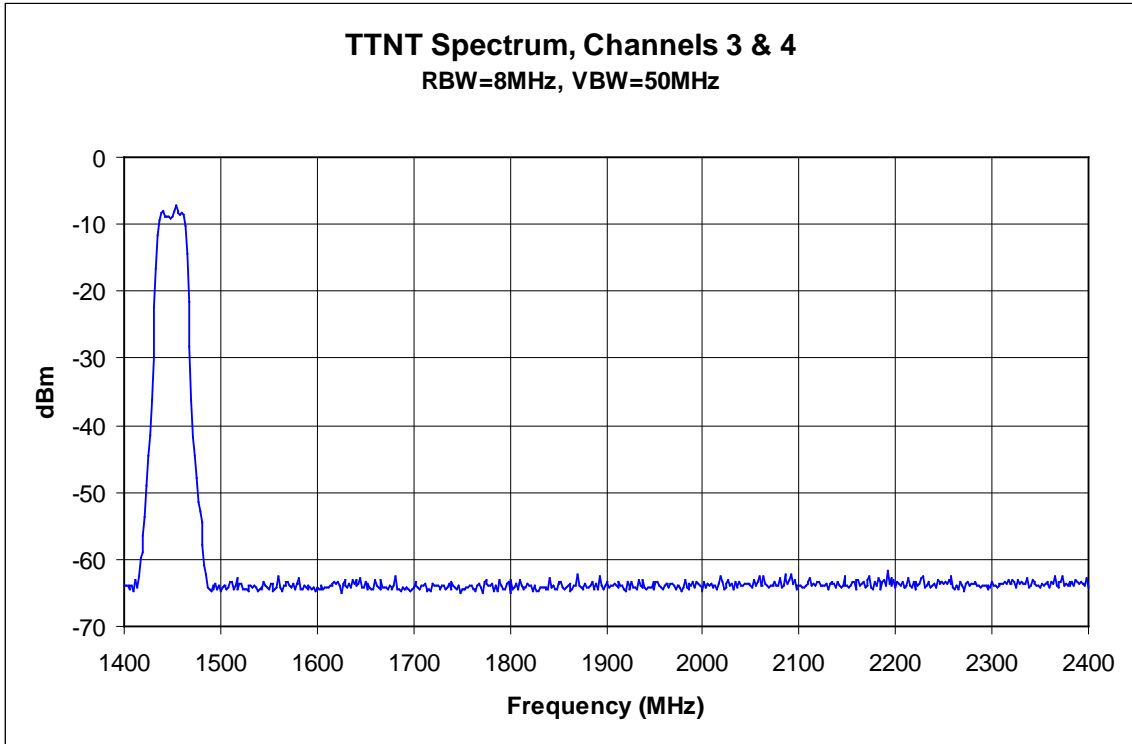


Figure 3-9. TTNT spectrum, channel 3 and channel 4.

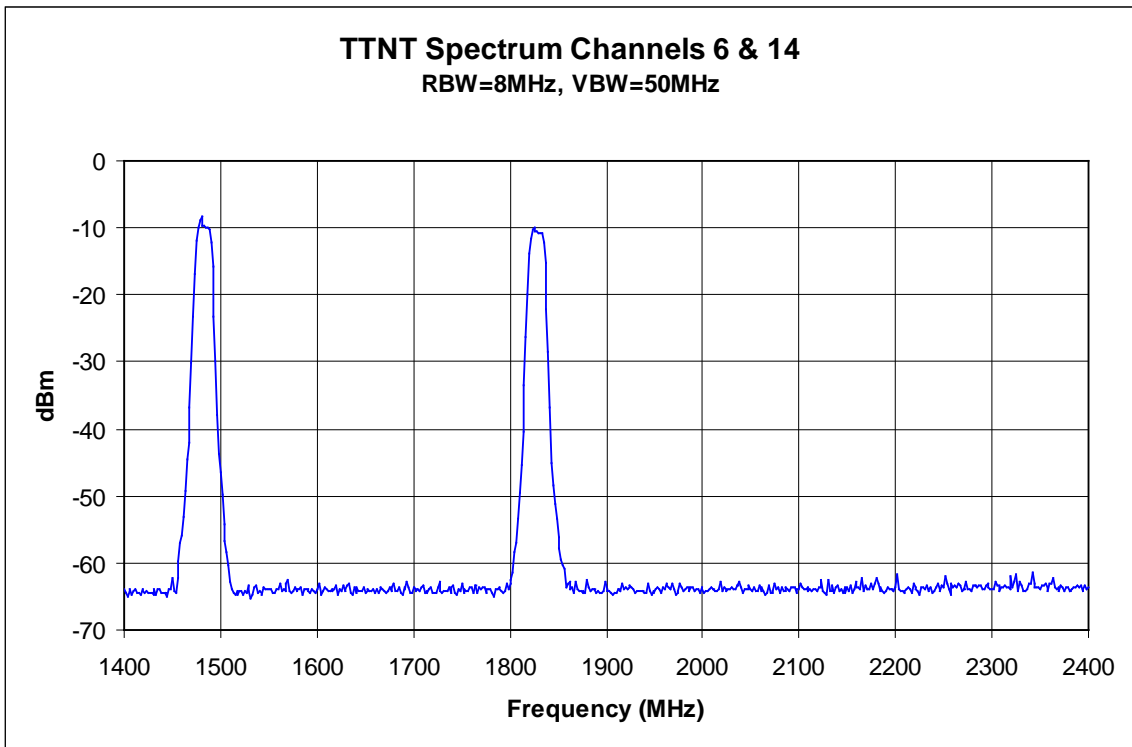


Figure 3-10. TTNT spectrum, channel 6 and channel 14.

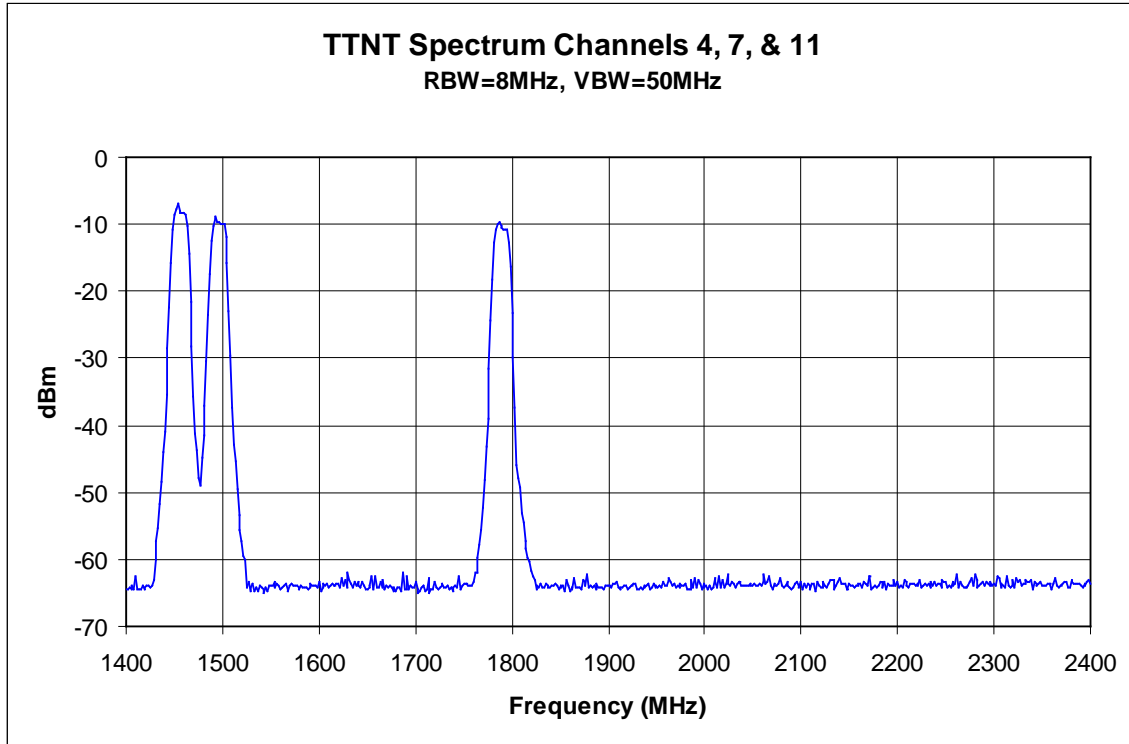


Figure 3-11. TTNT spectrum, channel 4, channel 7, and channel 11.

### 3.2 ACI Characterization

The ACI testing is conducted in order to characterize channel separation for a given level of tolerable interference. The information gathered from this testing will result in minimum channel spacing requirements. After the range frequency managers have this information, they can schedule channel assignments to best utilize the given TM spectrum. The ACI testing for this report was done with channels that resided in the lower and upper L-Band TM bands. Various TTNT channels were selected as interfering source(s). First, SOQPSK-TG with data rates of 5/10/20 Mbps was used as the victim, and then PCM/FM with data rates of  $1/5$  Mbps was used. The bulk of the testing was performed by TTNT terminal 43; however, terminal 44 was used to verify a few data points. Although the bulk of the testing was accomplished with one TM receiver, various test points were used to verify similar performance. This combination of TTNT hardware, TM hardware, TTNT channels, TM modulation modes, and data rates were chosen to provide a good cross section of TTNT-TM ACI performance.

3.2.1 Carrier to Interference (C/I) Level. Total power levels of both signals must be determined in order to set the C/I level. Referring to Figure 2-2, total power of the TTNT system after "Power Divider2" was determined and the level of the TM signal was set in order to achieve a C/I = -20 dB. See Figure 3-12 for an example of the total power measurement for both signals.

Once the proper level of C/I was set, various TTNT channels were tested with differing TM modulation modes and data rates. The C/I was verified and adjusted for each TTNT channel tested; as Figure 3-11 above indicates there is a slight output power variation of approximately 2 dB, from lower to higher channels. See Table 3-2 for a complete test matrix for C/I = -20 dB.

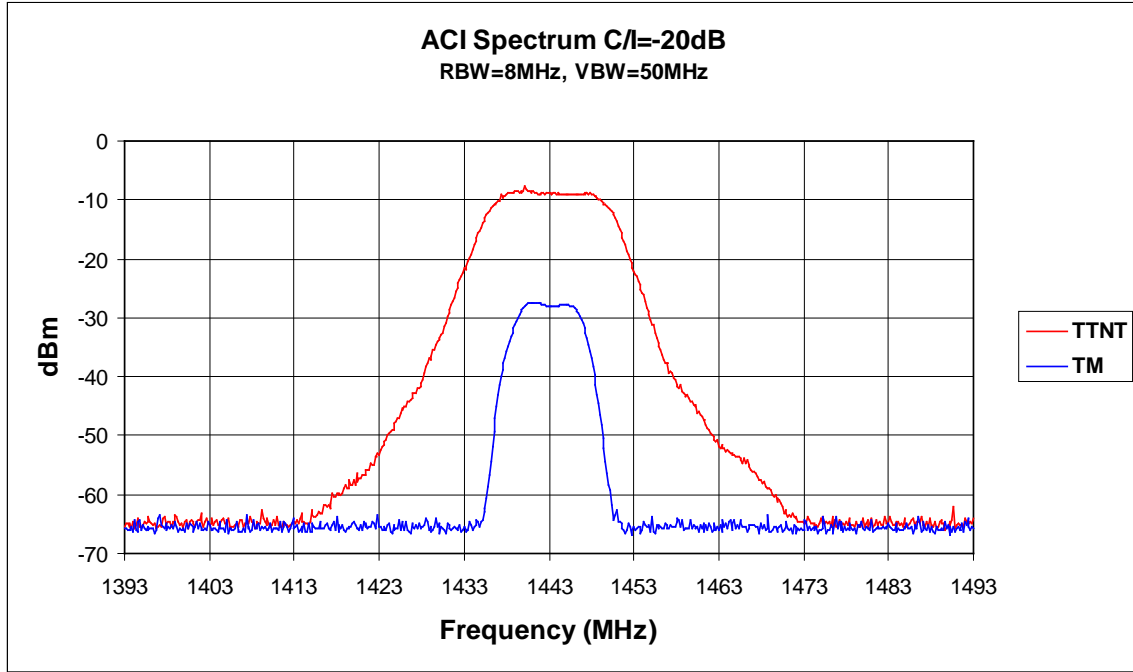


Figure 3-12. ACI total power measurement.

TABLE 3-2. ACI TEST MATRIX, C/I = -20 dB		
TTNT Channel	Modulation	Data Rate (Mbps)
3	SOQPSK-TG	5
6	SOQPSK-TG	5
13	SOQPSK-TG	5
4	SOQPSK-TG	10
7	SOQPSK-TG	10
13	SOQPSK-TG	10
5	SOQPSK-TG	20
7	SOQPSK-TG	20
14	SOQPSK-TG	20
3	PCM/FM	1
6	PCM/FM	1
13	PCM/FM	1
4	PCM/FM	5
8	PCM/FM	5
14	PCM/FM	5

3.2.2 ACI Test Results. ACI testing was done with two TM receivers, various TTNT channels, TM modulation modes, and baseband data rates. The two TM receivers used during the testing were a Microdyne RCB2000 and a Semco RC-600A. These are the predominant TM receivers used at the AFFTC and are thought to be representative of receivers used at most of the test ranges. An effort was made to keep front-end filter selection consistent between receivers (based on data rate and modulation mode) because this selection greatly affects ACI performance. Both receivers implement front-end surface acoustic wave (SAW) filters with similar pass band and roll-off characteristics.

- a. SOQPSK-TG ACI Results. The SOQPSK-TG was the first TM waveform tested at rates of 5, 10, and 20 Mbps. The results of the 5 Mbps testing are at Figure 3-13. Figure 3-13 shows the relationship between center frequency separation of the TTNT and TM signal and the required change in  $E_b/N_0$  to maintain a BER of  $1 \times 10^{-5}$ . To verify spacing symmetry of the TTNT signal, the TM signal started at both higher and lower frequencies, and separation numbers were compared.

Figure 3-13 shows that separation data is consistent for each receiver, although ACI performance is better with receiver number 2. Both high side and low side interference tests were run with receiver number 1 and the data revealed good correlation with results being symmetric. In other words, it does not matter which side (higher or lower in frequency) the interfering signal sits in relation to the victim. Minimum separation value for this case is approximately 11 MHz.

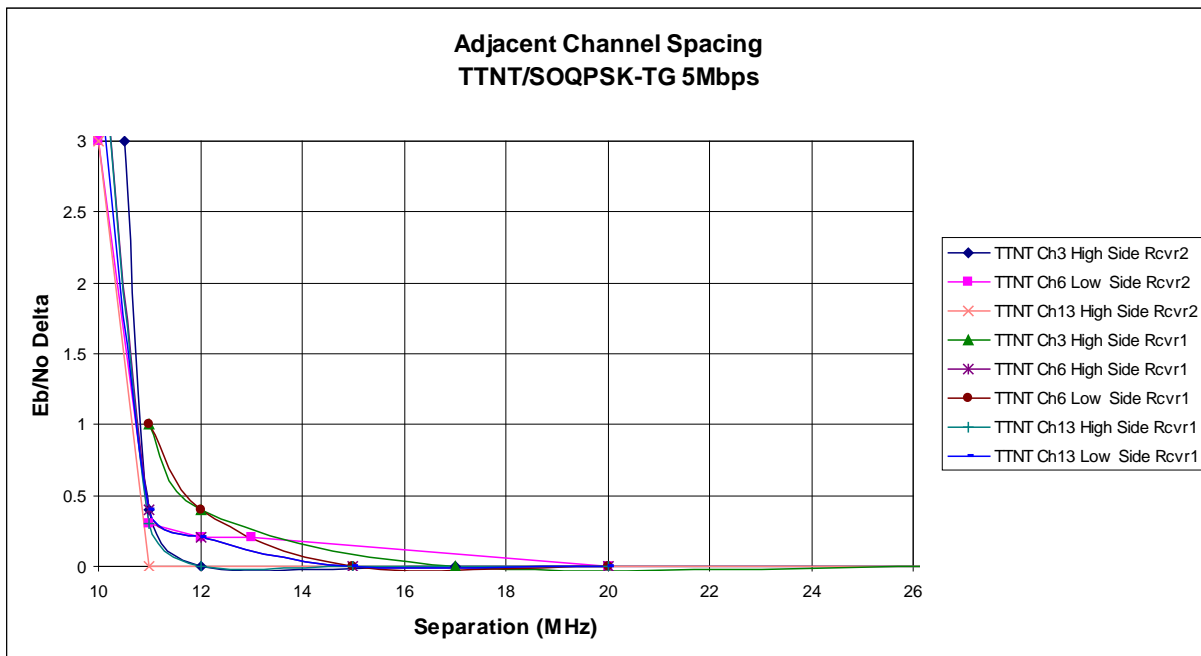


Figure 3-13. Separation versus Delta  $E_b/N_0$ , 5 Mbps SOQPSK-TG.

Next, 10 Mbps SOQPSK-TG was used as the victim signal (see Figure 3-14). Again, there is some variation in required separation when comparing the two TM receivers, but the data for each receiver is well correlated and symmetric (within measurement accuracies) around the victim signal. Minimum separation values ranged between 13 MHz and 14 MHz.

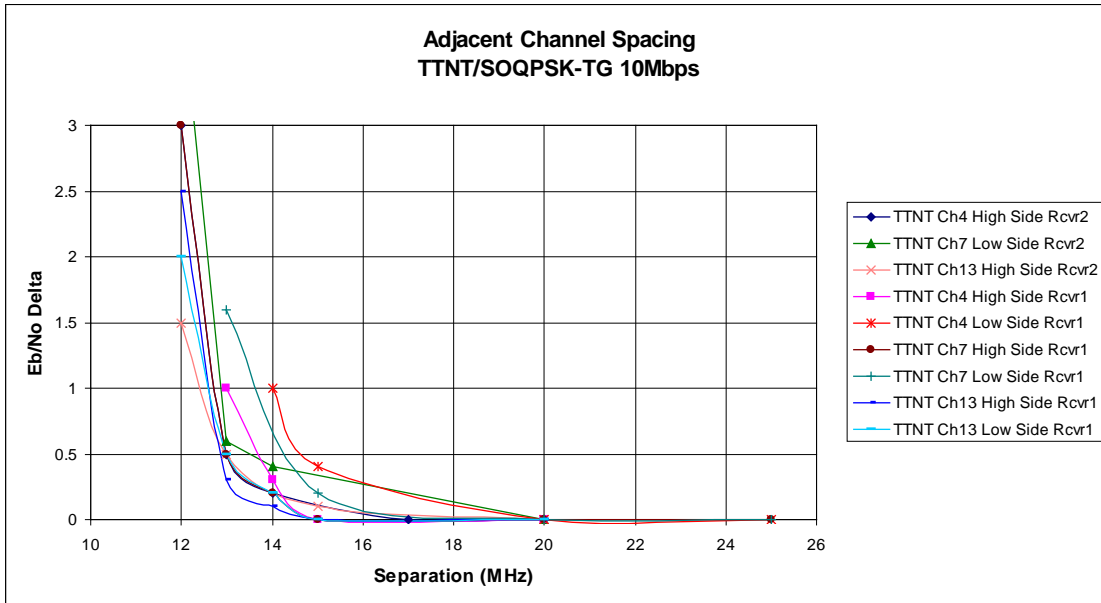


Figure 3-14. Signal separation versus Delta Eb/No, 10 Mbps SOQPSK-TG.

The last data rate tested using SOQPSK-TG modulation was 20 Mbps. Figure 3-15 shows data for one TM receiver operating at 20 Mbps. As with the data in Figure 3-13 and Figure 3-14, Figure 3-15 indicates consistency between spacing numbers with a typical value of 17 MHz of separation required for this test case.

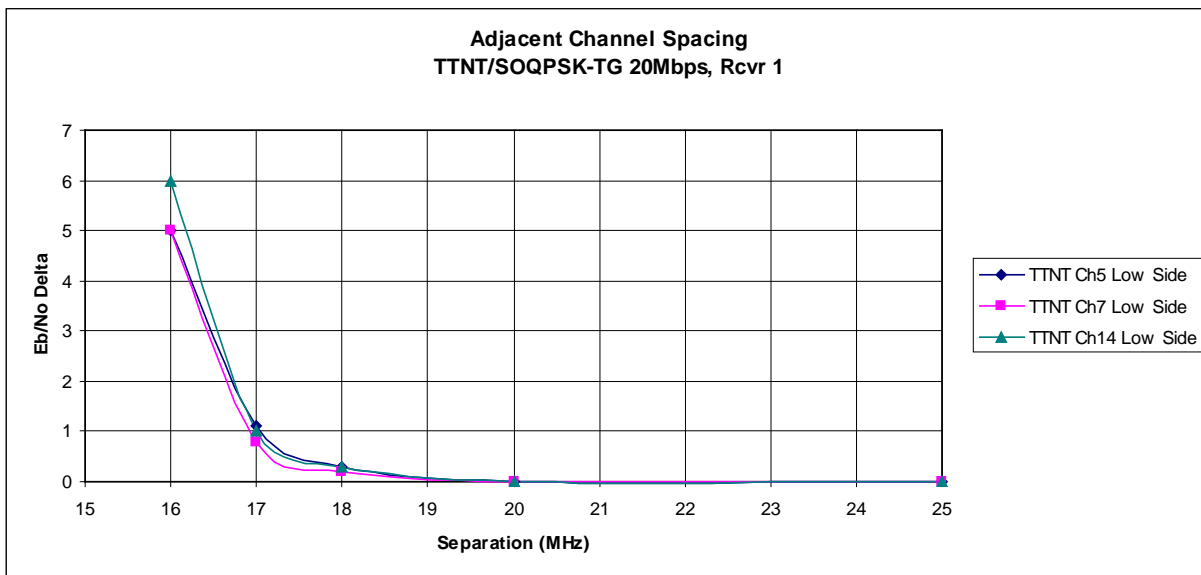


Figure 3-15. Signal separation versus Delta Eb/No, 20Mbps SOQPSK-TG.

- b. PCM/FM ACI Results. The PCM/FM waveform was tested with the interfering TTNT signal at baseband rates of 1 Mbps and 5 Mbps. Again, the center frequency of the victim signal was started at a lower frequency and then higher in frequency than the interfering signal to verify spacing symmetry. The spacing results were found to be symmetric; therefore, the test data presented is valid regardless of the side in which the interferer approached the victim.

For 1 Mbps, Figure 3-16 shows the minimum spacing requirements are between 9 MHz and 10 MHz. There is also good correlation of the data regardless of the TTNT channel selected.

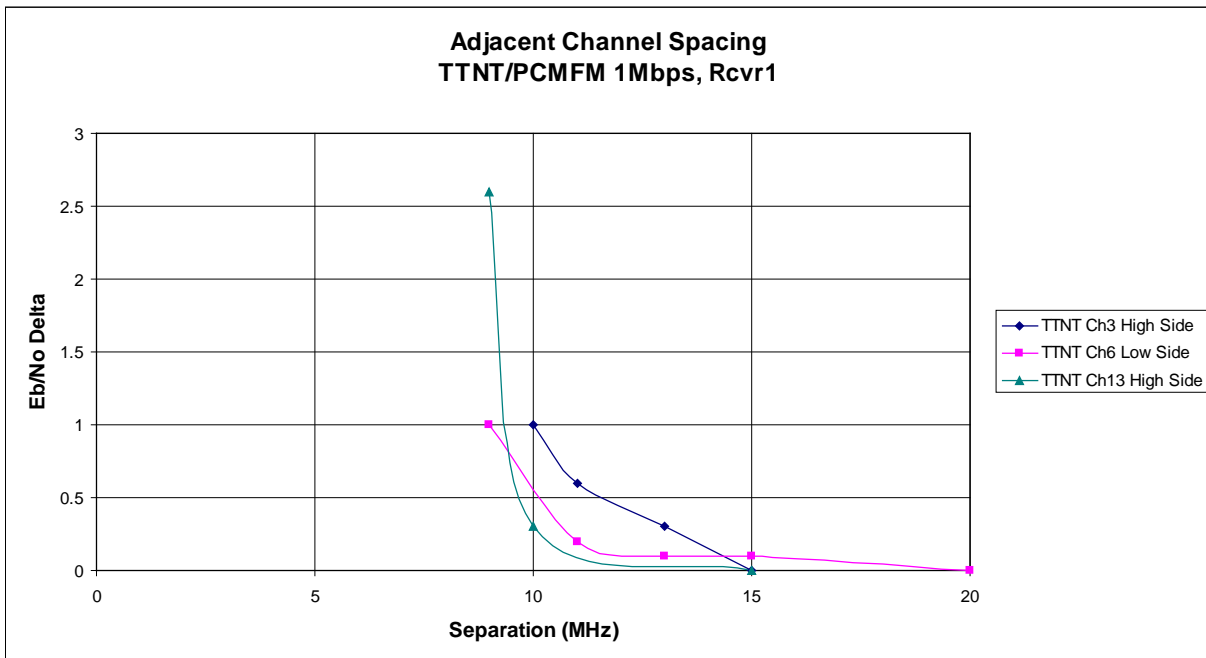


Figure 3-16. Signal separation versus Delta Eb/No, 1 Mbps PCM/FM.



The results of the testing at 5 Mbps, this time with two TM receivers, are shown at Figure 3-17. Correlation of this test data is also good with the resulting minimum separation being 11-12 MHz.

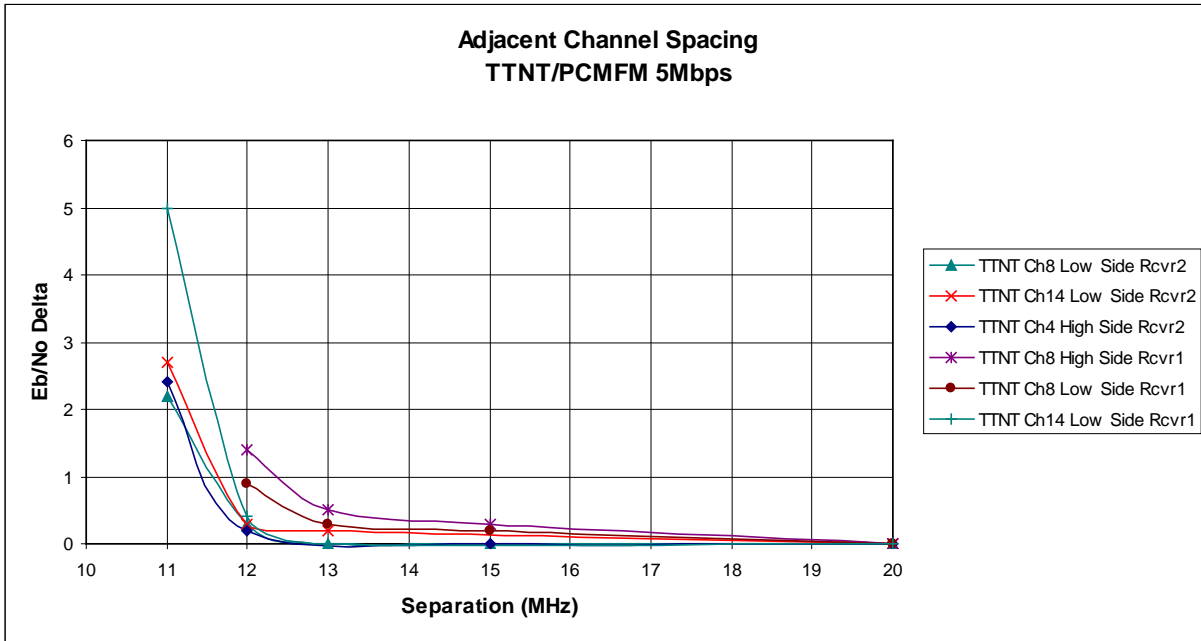


Figure 3-17. Signal separation versus Delta Eb/No, 5 Mbps PCM/FM.

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## CHAPTER 4

### SPACING RECOMMENDATIONS

Recommendations for minimum frequency separations are contained in paragraph 4.1 and paragraph [4.2](#).

#### 4.1 SOQPSK-TG, TTNT Minimum Frequency Separation

Testing with the SOQPSK-TG waveform showed consistent results between TM receivers and that the results were symmetric. Table 4-1 presents the minimum separation required for each data rate and modulation mode.

<b>TABLE 4-1. SOQPSK-TG MINIMUM SPACING VARIATION</b>			
<b>Data Rate (Mbps)</b>	<b>TTNT Channel (CH)</b>	<b>Low Side Separation (MHz)</b>	<b>High Side Separation (MHz)</b>
5	3		11
5	6	11	11
5	13	11	11
10	4	13	
10	7	14	
10	13	13-14	13-14
20	5	17	
20	7	17	
20	14	17	

There seems to be a good correlation between high and low side values with the only curious value occurring at TTNT channel 6. However, this test was run again using both receivers and the results were identical to the previous results. The conclusion is that one of the TM receivers may have a problem because the results of the other receivers are consistent with the data shown in the rest of the table.

In order to schedule spectrum efficiently, frequency management agencies require a simple formula in order to calculate minimum spacing requirements. Such a formula is given in IRIG-106 for minimum spacing requirements for TM signals (Reference [4](#)). In order to provide a like formula, minimum separation numbers per data rate will have to be assumed. Table [4-2](#) contains a summary of these numbers.

<b>TABLE 4-2. SUMMARY OF SOQPSK-TG RESULTS</b>	
<b>SOQPSK-TG (Mbps)</b>	<b>Min Freq Separation (MHz)</b>
5	11
10	13
20	17

The minimum frequency separation data exhibits a linear relationship dependent upon victim data rate that can be expressed with the following equation:

$$F_S = R_S * 0.3 + 11MHz \quad (\text{Eq. 4-1})$$

where:  $F_S$  = the frequency separation (MHz)  
 $R_S$  = the bit rate (Mbps) of the SOQPSK-TG waveform

#### 4.2 TTNT Pulse Code Modulation/Frequency Modulation (PCM/FM) Minimum Frequency Separation

Testing with the PCM/FM waveform gave consistent spacing results regardless of TTNT channel. Table 4-3 contains a summary of the results.

<b>TABLE 4-3. SUMMARY OF PCM/FM RESULTS</b>	
<b>PCM/FM (Mbps)</b>	<b>Minimum Frequency Separation (MHz)</b>
1	10
5	13
10	15

The above data also exhibits a linear relationship between minimum spacing and PCM/FM data rate that can be expressed by the following equation:

$$F_S = R_S * 0.5 + 10MHz \quad (\text{Eq. 4-2})$$

where:  $F_S$  = the frequency separation (MHz)  
 $R_S$  = the bit rate (Mbps) of the PCM/FM waveform

In order to make these equations easier to use, a more generalized form is given as:

$$F_S = R_S * a_S + \Delta f \quad (\text{Eq. 4-3})$$

where:

- $F_S$  = the minimum frequency separation (MHz)
- $R_S$  = the bit rate (Mbps) of the victim signal
- $a_S$  = the spacing factor based upon victim modulation type
- $\Delta f$  = the waveform offset (MHz) based upon modulation type

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## CHAPTER 5

### CONCLUSIONS

Adjacent channel interference (ACI) testing was completed for TTNT and telemetry (TM) signals operating in the same frequency band. Telemetry signals of differing data rates and modulation schemes were used as the victim signal, and a TTNT terminal was used as the interferer. During testing, an acceptable degradation level that is consistent with other published work on this topic was used (see Reference 3 through Reference 6). Results of this testing were evaluated and, based upon this limited data, the following general equation is presented for calculating the required separation between TM and TTNT signals.

$$F_S = R_S * a_S + \Delta f \quad (\text{Eq. 5-1})$$

where:

- $F_S$  = the minimum frequency separation (MHz)
- $R_S$  = the data rate (Mbps) of the victim signal
- $a_S$  = the spacing factor based upon victim modulation type
- $\Delta f$  = the waveform offset (MHz) based upon modulation type

The spacing factors and waveform offset values for use in Equation 5-1 are shown in Table 5-1.

<b>TABLE 5-1. COEFFICIENTS FOR MINIMUM SEPARATION CALCULATION</b>		
<b>Modulation</b>	<b>Spacing Factor (<math>a_S</math>)</b>	<b>Waveform Offset (<math>\Delta f</math>)</b>
PCM/FM	0.5	10
SOQPSK-TG	0.4	9

It should be noted that this test report gives an initial look at minimum spacing requirements for the coexistence of TTNT and TM signals in the same frequency band. Single channel operation with a resident program on the terminal to excite the channel was used in order to ease testing and gather test results. This condition is assumed “worst case.” Further testing may be warranted to assess the impact of the TTNT waveform on TM signals when using multiple TTNT channels (i.e. the intended mode of operation); however, quantifying these effects will be difficult due to the burst nature of the network traffic and the amount of time the terminals spend on one channel. In addition to the two TM receivers tested, other receivers should be tested to investigate their performance for comparison to the recommended spacing calculation.

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## REFERENCES

1. *Host Interface Control Document (ICD), Tactical Targeting Network Technology Program, Phase 3*, 31 March 2008
2. *Waveform Specification for Tactical Targeting Network Technology (TTNT), DRAFT Rev 7.0*, 13 February 2006
3. *Telemetry Standard, Range Commanders Council Document IRIG 106-07, Chapter 2*, September 2007
4. *Telemetry Standard, Range Commanders Council Document IRIG 106-07, Appendix A*, September 2007
5. Law, G., Proceedings of the International Telemetry Conference, October 2003. *Recommended Minimum Telemetry Frequency Spacing with CPFSK, CPM, SOQPSK, and FQPSK Signals.*
6. Law, G., Proceedings of the International Telemetry Conference, October 2002, *Adjacent Channel Interference Measurements with CPFSK, CPM, and FQPSK-B Signals.*

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## APPENDIX A

### ADJACENT CHANNEL INTERFERENCE (ACI) TEST RESULTS

#### 1.1 ACI Characterization for $C/I = 0$ dB

Given the power level of the TTNT terminal, ACI testing at  $C/I = 0$  dB has real-world applications. This  $C/I$  ratio is meant to simulate the case of the Tactical Targeting Network Technology (TTNT) signals being within the side lobe of a ground station receiving antenna. A typical number for side lobe attenuation is approximately 15-20 dB. With a test article flying with a 10 W telemetry (TM) transmitter in proximity to a test article with TTNT seeing a 15-20 dB signal attenuation due to antenna side lobes, this  $C/I$  seems a reasonable test point.

#### 2.1 ACI Test Results

Total power levels of both signals must be determined to set the  $C/I$  level to 0 dB. This was accomplished by the same methods used set  $C/I = -20$  dB. See Figure A-1 for the resulting spectrum to set  $C/I = 0$  dB between the TTNT and TM signals using this method.

Once the proper level of  $C/I$  was set, a few tests were run to understand how this new  $C/I$  setting affected the results. For this case, representative data rates were chosen for PCM/FM (5 Mbps) and SOQPSK-TG (5 Mbps and 10 Mbps). See Figure [A-2](#) for the required channel separation for these test conditions.

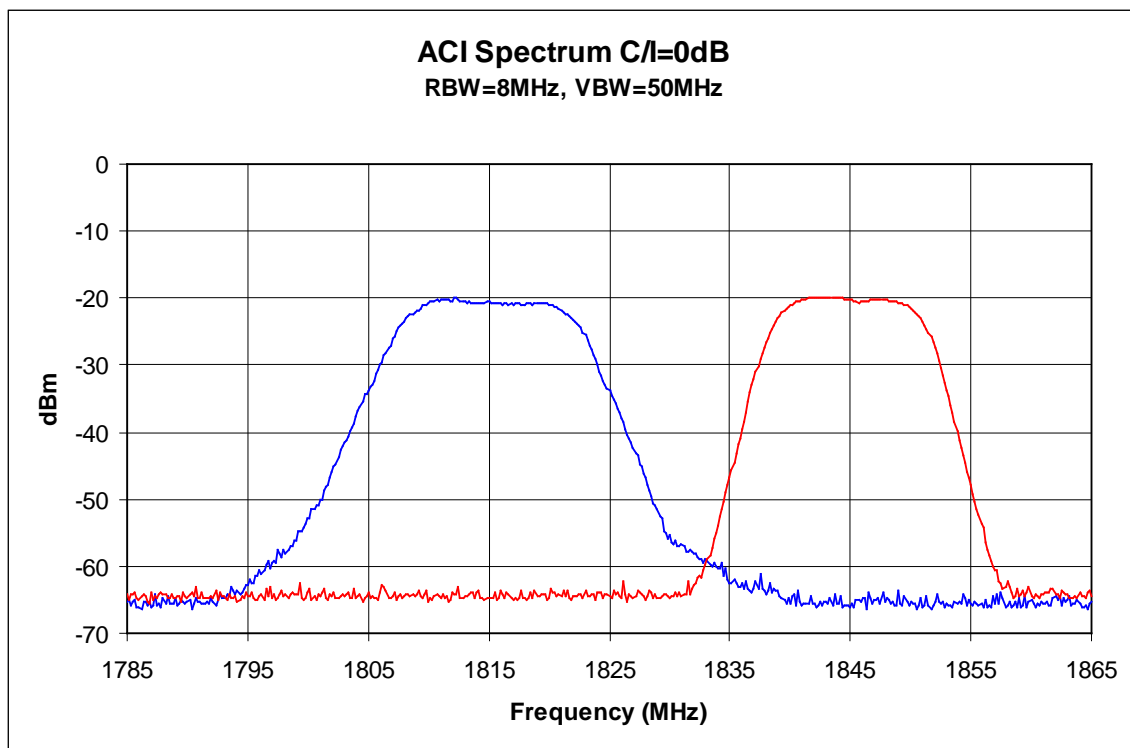


Figure A-1. ACI total power measurement.

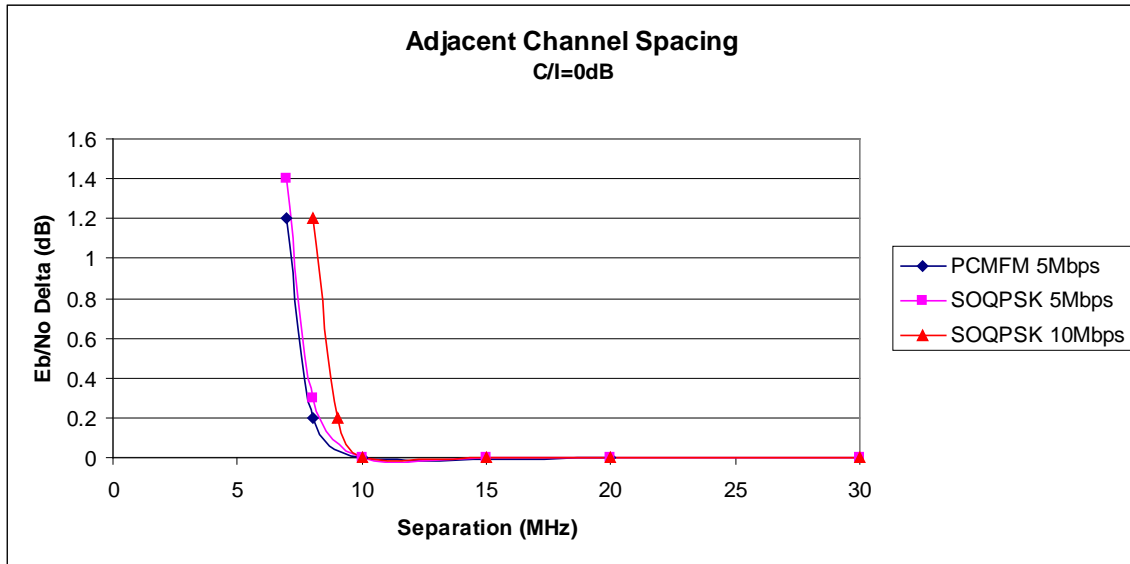


Figure A-2. Signal separation versus Delta Eb/No.

As would be expected, less separation between the signals is required given the less amount of relative power in the interfering signal. Table A-1 presents a comparison of separation values for C/I = 0 dB and C/I = -20 dB.

TABLE A-1. CHANNEL SEPARATION COMPARISON		
Modulation and Data Rate (Mbps)	C/I = 0 dB (MHz) <sup>1</sup>	C/I = -20 dB (MHz) <sup>2</sup>
PCM/FM 5	7	12.5
SOQPSK-TG 5	7.5	12.5
SOQPSK-TG 10	8	14

<sup>1</sup> Measured values.  
<sup>2</sup> Calculated values using Equation 5-1 (repeated below) with C/I = -20 dB.

$$F_S = R_S * a_s + \Delta f$$

where:

- $F_S$  = the minimum frequency separation (MHz)
- $R_S$  = the data rate (Mbps) of the victim signal
- $a_s$  = the spacing factor based upon victim modulation type
- $\Delta f$  = the waveform offset (MHz) based upon modulation type