AN INITIAL LOOK AT ADJACENT BAND INTERFERENCE BETWEEN AERONAUTICAL MOBILE TELEMETRY AND LONG-TERM EVOLUTION WIRELESS SERVICE

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ABSTRACT

With National Telecommunications & Information Administration (NTIA) Advanced Wireless Services (AWS-3) auction of frequencies in the 1695-1710 MHz, 1755-1780MHz, and 2155-2180MHz bands, users of the Aeronautical Mobile Telemetry (AMT) band from 1755-1850MHz, known as Upper L-Band, could be greatly affected. This paper takes an initial look at how the 1755-1780MHz band will be used by the cellular carriers and presents some preliminary testing results of adjacent channel (band) interference that could be experienced by AMT users. This paper should be considered as the stepping off point for future interference discussions, required analysis, and further testing.

KEY WORDS

Adjacent Channel Interference, ACI, LTE-A, LTE, PCM/FM, SOQPSK-TG, ARTM CPM, AWS-3, User Equipment, UE, Evolved Node B, eNodeB, Resource Blocks

INTRODUCTION

"On January 29, 2015, the Federal Communications Commission completed an auction of Advanced Wireless Service licenses in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz bands (collectively, the "AWS-3" bands). This auction, designated as Auction 97, raised in net bids a total of $41,329,673,325, with 31 bidders winning a total of 1,611 licenses. With the reallocation of the 1695-1710 MHz and 1755-1780 MHz bands, most of the federal systems will relocate out of the bands." [1]

Times are changing for users of AMT spectrum as new neighbors will be showing up in the form of cellular carriers. Typically AMT users are only worried about in-band interferers, addressed within IRIG-106 [2] as recommendations for channel spacing of AMT waveforms. Characterizing adjacent band interferers typically has not been done due to various reasons (geographical separation, pointing azimuths for receive antennas, frequency scheduling, etc.). With the proliferation of cellular services coupled with public demand for the service and the AWS-3 auction, AMT ranges will be presented with a new challenge. Figure 1 graphically shows two potential interference scenarios for AMT test ranges given an implementation of a cellular service in the AWS-3 band. The first is the "near-far" scenario, the second is ground station antenna side lobe interference. Will the new commercial neighbors affect AMT operations? If so, what conditions should be avoided? Are there mitigation techniques, such as receive antenna feed filtering, that may mitigate the interference? This work will attempt to provide the basis to start these conversations and hopefully provide the reader with more information on what to look for at ground stations once AWS-3 enable handsets are fielded by the carriers.

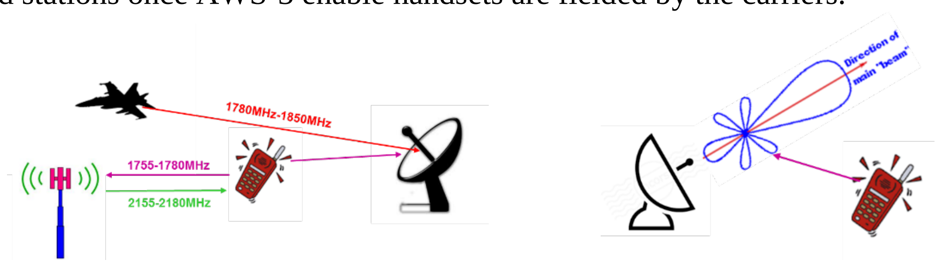

Figure 1 – The Interference Scenarios

AWS-3 CELLULAR SERVICE

In order to characterize any adjacent channel (adjacent band) interference from a neighboring cellular service, an understanding of how the spectrum is allocated and a basic understanding of how the service works is required. Per the guidelines in the AWS-3 auction, portions of the bands were paired with differing bandwidths. Of concern to AMT users, the upper portion of the AWS-3 band is partitioned into a 10MHz channel making this channel (1770-1780MHz) directly adjacent to the lower part of the AMT band Upper L-Band [2]. The AWS-3/AMT boundary is at 1780MHz. Figure 2 shows the channel pairings and the bandwidths in the AWS-3 spectrum. Note that the 10MHz channel at the AMT band edge allocates 1770-1780MHz to what is commonly called the *uplink*, or the user equipment (UE) to base station (Evolved Node B or eNodeB) link. Conversely, the paired *downlink* (eNodeB to UE) operates between 2170-2180MHz. AWS-3 spectrum will only be used for 3GPP 4G applications or what typically is referred to as LTE or LTE-A by the general public [3].

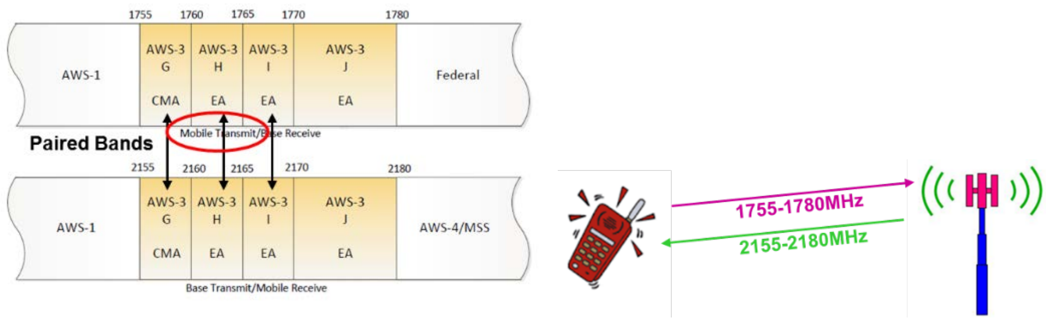

Figure 2 - AWS-3 Band Plan

Understanding how an entire LTE cellular system works is far beyond the scope of this paper. What is of concern is the portion of the LTE system that could potentially interfere with an AMT receive station, the physical layer. The uplink utilizes single carrier-frequency division multiple access SC-FDMA which is a unique OFDM-like multi-carrier scheme that reduces peak-to-average power ratio (PAPR) in the signal. Minimizing PAPR is very important for the UE handset, less PAPR means more battery life [5]. The amount of capacity a user is allocated is typically determined by demand on the channel (total capacity), user demand (current need), and channel condition. The LTE uplink uses a multiple access scheme where each UE uses a pre-allocated set of resource blocks (RB). A resource block is a time-frequency block and is the basis for resource allocation for both the uplink and downlink.

Since SC-FDMA is a multi-carrier scheme, the carriers are modulated with one of three different modulation schemes, the selection being dependent upon a combination of channel condition and user demand. The three schemes are QPSK, 16-QAM, and 64-QAM.

ADJACENT CHANNEL (BAND) INTERFERENCE RATIONALE

For typical "in-band" ACI testing based upon IRIG-106 recommendations, the interfering signal is 20dB above the victim signal. An acceptable degradation level in the victim is assessed in terms of energy per bit to noise power spectral density ratio (Eb/No). *A difference of 1dB of required Eb/No to achieve an error rate of* $1x10^{-5}$ *as the victim is moved closer to the interferer is the threshold interference criteria.* For in-band testing, the interferer can be moved as close as required to attain the 1dB of degradation. For adjacent band testing, this is not the case as there is a fixed boundary between the AMT signal and the interferer.

This testing was to determine if interference could be expected from an adjacent band interferer rather than an adjacent in-band interferer as is the norm in AMT operations. The difference is that in this case there is a fixed frequency boundary at 1780MHz which means the interferer, LTE in a 10MHz bandwidth configured any number of ways, is fixed. The AMT signal is also fixed as band-edge back-off has a fixed center frequency based upon data rate and modulation mode and calculated per recommendations in IRIG-106. So, both victim and interferer are fixed in frequency, the only way to introduce interference into the victim AMT signal is to vary the Carrier to Interference ratio (C/I). This is exactly what was done for this testing.

For the AMT victim signal, all three IRIG-106 modulation schemes (PCMFM/SOQPSK-TG/ARTM CPM) were used at various data rates (1/5/10/15Mbps). The pairing of modulation mode and data rates is shown in Table 1. For the LTE interfering signal, the generation matrix is considerably more complicated. Controllable parameters are the number of user (UE) handsets (1, 2, 3, 4), the resource block allocation for each UE (50 total RBs for a 10MHz channel), addition of control channels, and the modulation scheme for each UE.

Victim (AMT)	
Bit Rate, Modulation Mode	1/5Mbps (PCM/FM) 1/5/10Mbps (SOQPSK) 5/10/15Mbps (ARTM CPM)
Telemetry Receiver	8 IF SAW filters, selected per data rate and modulation mode
Interferer (LTE)	
Number of User Equipment (UE)	1, 2
Resource Blocks	50 Total, Random Allocation
Control Channels	2 or 4
Modulation	QPSK, 16-QAM, 64-QAM

Table 1 – ACI Test Parameters

In order to achieve a realizable test matrix for the LTE signal, several assumptions were made:

- Only QPSK and 16-QAM were the chosen modulations for the LTE signal. The reasoning is that for AMT interference the UE's will be near AMT ground stations. AMT ground stations are typically geographically remote which translates to long link distances from UEs to eNodeBs. Given this longer link distance, the assumption was made that the transmission channel would not support 64-QAM modulation.
- No more than two UE's would be in close proximity to the AMT ground station.
- Control channels were assumed to be at edges of the spectrum, i.e. RB 1/2 and RB 49/50, so these were not allocated during the testing.

# of UEs	RBs	RB/UE	Modulation	OBW (MHz)
1	46	46	QPSK	9
1	46	46	16-QAM	9
1	23	23	QPSK	4.5
1	23	23	16-QAM	4.5
1	10	10	QPSK	1.8
2	46	23	QPSK (both)	9
2	46	23	16-QAM (both)	9
2	20	10	16-QAM (both)	9

Table 2 – LTE Parameters

AMT Band Edge Back-Off

When scheduling center frequencies near the band edge of AMT bands, IRIG-106 (Chapter 2, Section 2.4.7) [4] provides the frequency manager a recommendation. Once the modulation mode and data rate is known, the calculation can be made. Table 3 shows the modulation mode, data rate, amount of back off required, and resulting center frequency. For an example, band-edge is known to be located at 1780MHz, for SOQPSKTG at 10Mbps the center frequency would be tuned to 1780MHz + 9MHz = 1789MHz. Also included is the bandwidth of the IF filter chosen by the telemetry receiver given the modulation mode and data rate. This filter plays a key role in the amount of interference encountered by the received signal.

Modulation	Data Rate	Back-Off (MHz)	Center Frequency	Receiver IFBW
PCM/FM	1Mbps	2.5MHz	1782.5MHz	2MHz
PCM/FM	5Mbps	10MHz	1790MHz	10MHz
SOQPSK-TG	1Mbps	1.5MHz	1781.5MHz	1MHz
SOQPSK-TG	5Mbps	5MHz	1785MHz	10MHz
SOQPSK-TG	10Mbps	9MHz	1789MHz	20MHz
ARTM CPM	5Mbps	4MHz	1784MHz	10MHz
ARTM CPM	10Mbps	7MHz	1787MHz	20MHz
ARTM CPM	15Mbps	10MHz	1790MHz	20MHz

Table 3 – Band Edge Back-Off for AMT Waveforms

Resource Blocks

A resource block is the smallest unit of resource that can be allocated to a user and is the fundamental scheduling unit in an LTE system. The total number of resource blocks available in a 10MHz LTE channel is 50. These 50 blocks are allocated to the UE(s) to support the uplink data requirements of each user in the system. The location of the allocated RBs have a direct relationship to where the UE will transmit within the 10MHz of spectrum. RB 1 is located at the bottom of the 10MHz, RB 50 is located at the top of the 10MHz. In order to keep the test matrix relatively simple with an attempt toward a real-world allocation, only a couple of RB/UE allocations where used. Figure 3 illustrates the UE to RB relationships that were tested.

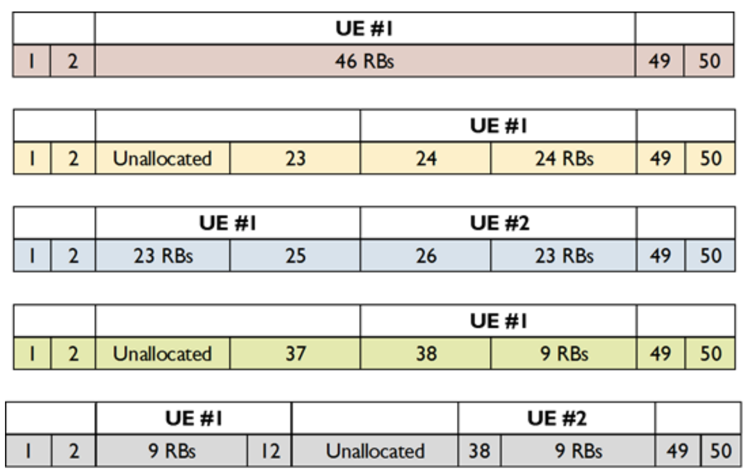

Figure 3 – Resolution Block per User Equipment Allocations

LAB TEST CONFIGURATION

The lab test configuration consisted of the generation of the LTE and AMT signals, isolating and combining them, and then splitting the combined signal for observation, measurement, detection, and finally interference analysis. For signal generation, a Rohde & Schwarz SMW200A Vector Signal Generator (VSG) was used. This specific VSG was optioned with the Beyond 3G Standards option for EUTRA/LTE A configuration and signal generation. Reference AMT waveforms (PCM/FM, SOQPSK-TG, ARTM CPM) were loaded into VSG and selected via the Arbitrary Waveform Generator. This VSG has two individual RF modulators allowing one box to generate both test signals. For this testing, RF path 1 (I/Q modulator #1) was dedicated to generating the LTE signal, RF path 2 (I/Q modulator #2) was dedicated to generating the AMT signal. Both signals where then isolated with 20dB of reverse isolation to insure no intermodulation products were created that could bias the testing results. After isolation the signals were combined then split again. One path went to the AMT reference receiver, in this case a Quasonix RDMS, the other path went to the Rohde & Schwarz FSW Spectrum and Signal Analyzer with the Multi-Standard Radio Analysis (LTE) package. (Note: Though not used in this testing, this analysis package will be useful for any future AMT to LTE interference testing).The reference receiver was configured for the AMT waveform under test and connected to a bit error rate tester (HP3784A). Figure 4 shows a block diagram of the lab test configuration.

Care had to be taken setting the levels of the LTE and AMT waveforms. At higher amplitude levels of the LTE signal, out of band distortion was present. This distortion fell into the AMT band and initially biased the test results. To mitigate this effect, the amplitude of the LTE signal was then adjusted based upon the required C/I referenced to the level of the AMT waveform. Since a reduced amplitude in the LTE waveform reduced the distortion, the level of the AMT signal was minimized. The AMT waveform level was set approximately 20dB above where additive system noise was causing a bit error rate of 1e-5. This was done for each AMT waveform. C/I was precisely set by removing the modulation, verifying the ratio on the spectrum analyzer, then double checking that ratio by verifying the amplitude of each signal path in the VSG.

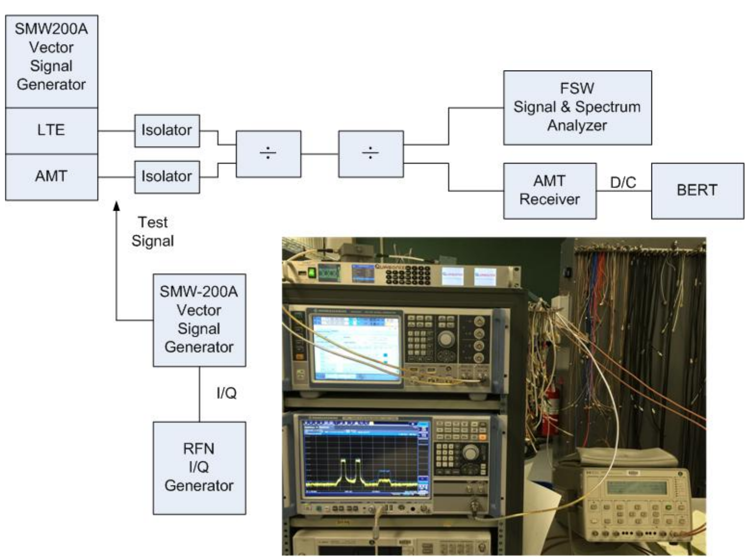

Figure 4 – Lab Test Block Diagram

RESULTS

Adjacent band testing revealed some interesting results. Generally speaking, the configuration of the interfering LTE signal in terms of the number of users, resolution blocks, and modulation mode really didn't make much of a difference as long as there were resolution blocks allocated at the upper part of the bandwidth adjacent to 1780MHz. Slightly greater degradation was observed when the modulation was 16-QAM, possibly due to the greater amplitude variation of the signal. But for the most part, if the spectrum next to 1780MHz was illuminated the interference test results were very consistent.

In all, 45 test scenarios using a combination of the parameters in Tables 1 and 2 were tested. Figures 5 through 7 show spectra of some of the test cases for each AMT waveform.

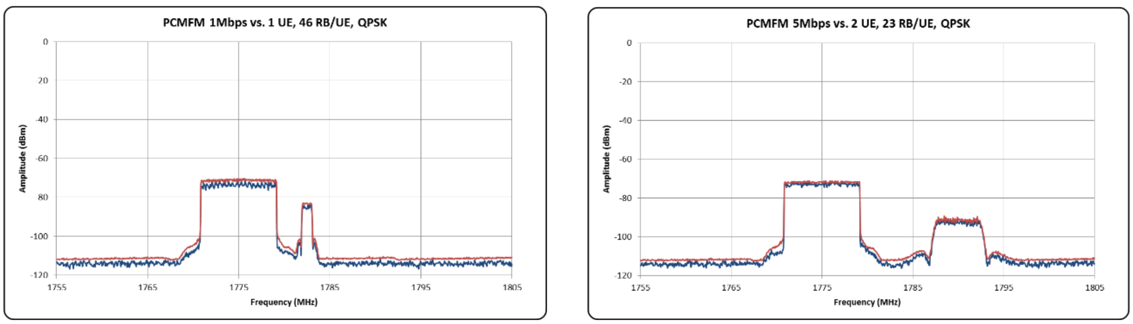

Figure 5 – PCMFM vs. LTE

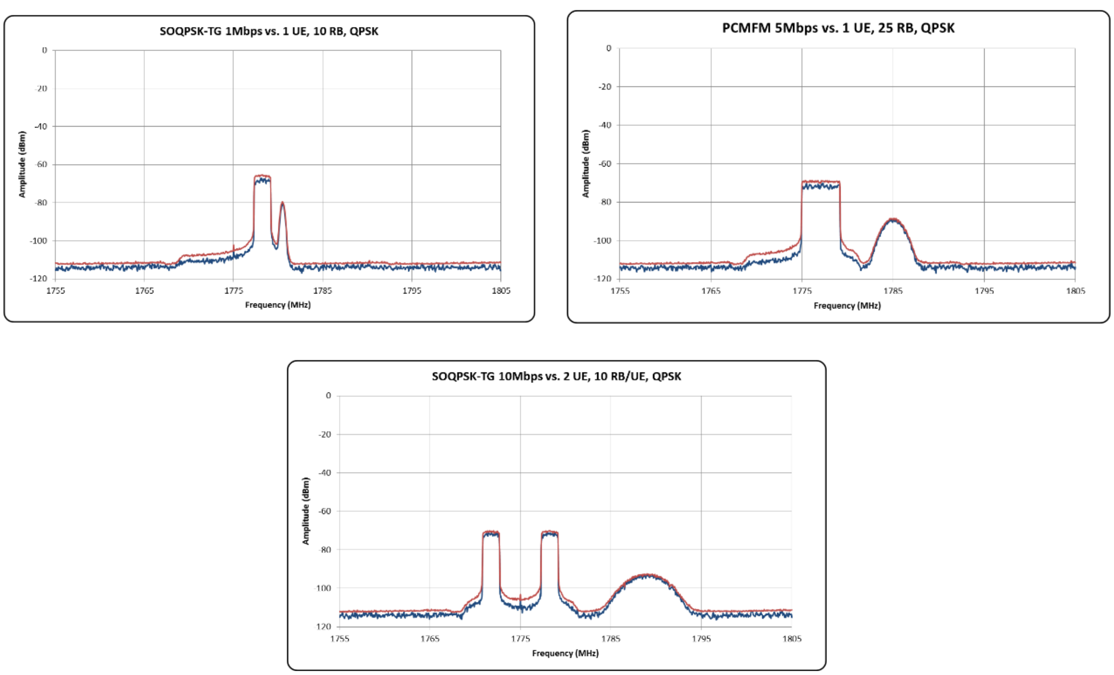

Figure 6 – SOQPSK-TG vs. LTE

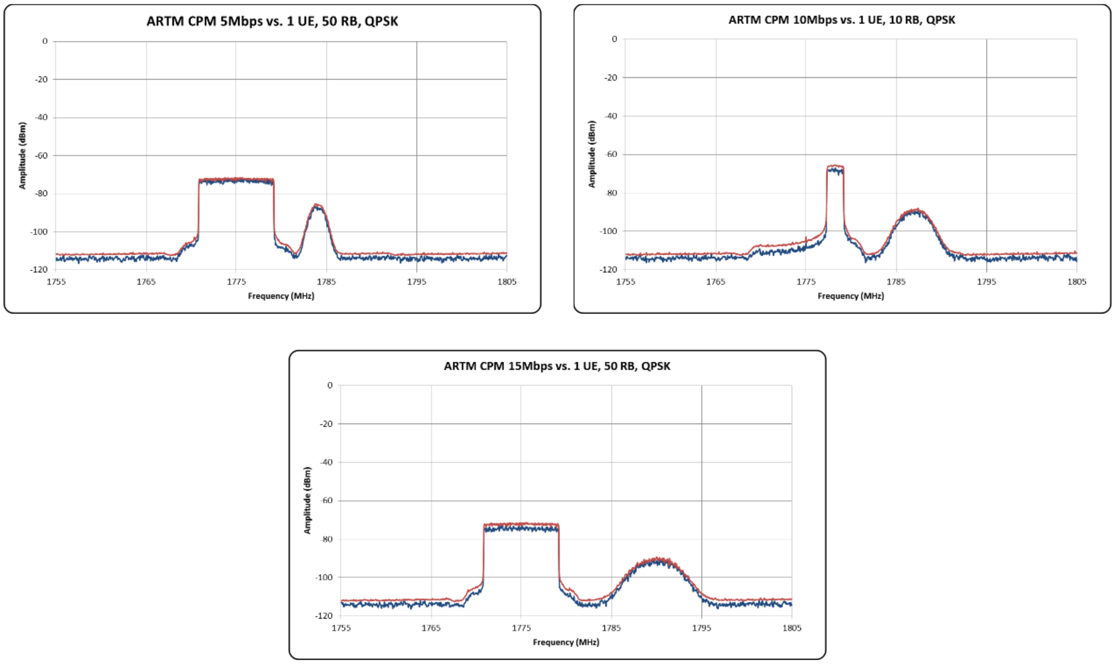

Figure 7 – ARTM CPM vs. LTE

The results of the 45 test scenarios are summarized in Table 4. For PCMFM at 5Mbps, the calculated band-edge back-off of 10MHz from 1780MHz was enough separation where no interference was encountered with a C/I up to -50dB (the interferer being 50dB higher than the victim). For 1Mbps, no interference was observed up to C/I=-35dB. Because the levels were so low to mitigate out of band distortion from the LTE signal generation (mentioned above), higher C/I values in this case were not possible, lowering the victim level brought the amplitude to a point where additive system noise was affecting the results.

There were varied results for SOQPSK-TG based upon bit rate. For 5Mbps the calculated back off of 5MHz was enough for C/I=-30dB to attain an error rate of 1e-5. The calculated back-off for 1Mbps and 10Mbps resulted in C/I values of -20dB and -24dB respectively. It is curious that a C/I difference of 10dB between 1Mbps and 5Mbps was observed.

The band-edge back-off calculation of 7MHz for ARTM CPM at 10Mbps does not meet the initial IRIG-106 ACI criteria of -20dB. Again, a C/I difference of 10dB was observed between data rates of 10Mbps and 15Mbps.

The wide range in C/I values is curious. Two potential mechanisms may be in play here. The first is band-edge back-off. The band-edge back-off numbers in Table 3 are rounded to the nearest 500kHz but not channelized on 500kHz steps as is normal Range practice. Increasing (or decreasing) spacing another 500kHz may have brought the C/I results closer together. The second mechanism is the IF filter. Only 8 SAW filters are available in the telemetry receiver and selecting which one is a compromised between ACI and BER performance. It is possible, based upon data rate, that one filter was more selective resulting in a greater (more negative value) C/I.

Modulation/Data Rate	C/I (dB)	BER
PCMFM/1Mbps	-35	0
PCMFM/5Mbps	-50	0
SOQPSK/1Mbps	-20	1e-5
SOQPSK/5Mbps	-30	1e-5
SOQPSK/10Mbps	-24	1e-5
ARTM CPM/5Mbps	-22	1e-5
ARTM CPM/10Mbps	-18	1e-5
ARTM CPM/15Mbps	-28	1e-5

Table 4 – Summary of Test Results

What do the C/I values in Table 4 mean in the real-world? Referring back to the first interference scenario in Figure 1, the near-far interference scenario, we can make some assumptions about both the AMT and LTE links and calculate the distance required from UE to AMT receive antenna for that C/I. For the AMT link, assume an EIRP of 5W (+37dBm) and a link range of 80NM (~150km). For the LTE link, assume the UE requires a worst case EIRP of 25dBm in order to close the UE to eNobeB link and that the UE is within the main beam of the AMT receive antenna. With these assumptions, the distance the UE is from the AMT receive station given a C/I value can be calculated.

C/I	UE to AMT Receive Antenna	
-50dB	120m	390ft
-25dB	2.1km	1.1NM
-20dB	3.8km	2.0NM

Table 5 – Sample Interference Calculation

CONCLUSIONS

This paper has identified a question that needs to get answered by the Telemetry Group standards committees and the telemetry community in general: *"Is a C/I value of -20dB a realistic interference value for adjacent <u>band</u> interference knowing that the adjacent band occupant is LTE"*. Many interference scenarios will have to be considered in order to determine an applicable interference ratio. Once a value is agreed upon, with additional testing the required band-edge back-off at the boundary of 1780MHz can be determined.

<u>What You Should Get Out Of This Paper</u>

- If IRIG-106 is used to schedule AMT operations near the 1780MHz band-edge and the cellular carriers illuminate the upper part of the AWS-3 spectrum by allocating resource blocks in the 40-50 range, there are scenarios where interference to AMT ground stations could exist

- The parameters of the LTE signal did not have a lot of effect on AMT interference, the important part was that resolution blocks near the 1780MHz boundary were allocated

- A very important analysis that was NOT done in this paper was UE aggregation. Multiple UEs in/around an AMT receive station will only magnify the interference potential

- One sample calculation was made showing what could be termed "UE Keep Out Zone" around an AMT receive station for several C/I values

- More analysis and interference scenarios need to be investigated

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