WP-21-001

Range Commanders Council
Telemetry Group

ADDITIONAL DATA TO SUPPORT SPECTRUM CERTIFICATION REQUESTS FOR AERONAUTICAL MOBILE TELEMETRY SYSTEMS

ABERDEEN TEST CENTER
DUGWAY PROVING GROUND
ELECTRONIC PROVING GROUND
REAGAN TEST SITE
REDSTONE TEST CENTER
WHITE SANDS TEST CENTER
YUMA PROVING GROUND

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION PATUXENT RIVER
NAVAL AIR WARFARE CENTER WEAPONS DIVISION CHINA LAKE
NAVAL AIR WARFARE CENTER WEAPONS DIVISION POINT MUGU
NAVAL SURFACE WARFARE CENTER DAHLGREN DIVISION
NAVAL UNDERSEA WARFARE CENTER DIVISION KEYPORT
NAVAL UNDERSEA WARFARE CENTER DIVISION NEWPORT
PACIFIC MISSILE RANGE FACILITY

96th TEST WING
412th TEST WING
ARNOLD ENGINEERING DEVELOPMENT COMPLEX

SPACE LAUNCH DELTA 30
SPACE LAUNCH DELTA 45

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Preface

This white paper is intended to describe the dilemma that currently exists between the current spectrum certification process and modern agile and versatile Aeronautical Mobile Telemetry (AMT) transmitters and receivers (aka AMT systems) being produced and fielded on Ranges today. The current spectrum certification process does not adequately capture and document the full capabilities of modern AMT systems. This white paper describes the issue and recommends a methodology for resolving this dilemma. It provides a sound path forward should the Spectrum Management community choose to promote changes to the way spectrum certifications are currently performed for AMT systems. The Telemetry Group of the Range Commanders Council hopes that this happens and that these recommendations will be helpful going forward.

1.0 Executive Summary

The equipment frequency allocation process, more commonly known as the Joint Frequency Allocation (J-12 or J/F-12) process, is the process that enables NTIA and the DOD to evaluate systems for spectrum supportability. A related, but separate process, called the frequency assignment process, documents the approved radio frequency for the emitters for usage at specific locations and under specific conditions. Both of these processes will benefit from the additional technical data for the latest generation of aeronautical mobile telemetry (AMT) links provided in this whitepaper. The spectrum certification process, which is initiated with development of an Equipment Location – Certification Information Database (EL-CID) file for the Navy or a Stepstone Editor, xml file, for the Air Force and Army[1] and form, must include any and all possible equipment modes and modulations possible with the latest generation of AMT systems. The frequency assignment process can then accurately reflect current capabilities used for telemetering data from test articles to ground stations in the Government Master File (GMF) database.

No longer does the latest generation of AMT links operate at the same center frequency with the same modulation at a constant over-the-air (OTA) bit rate. The AMT links now have the capability to be adjusted to meet the test's needs, ensuring the highest quality of data is transmitted to the ground station and delivered to the control rooms. The amount and rate of test data sent, coupled with the addition or subtraction of coding, both change the OTA bit rate. Frequency congestion at some test ranges, or within geographical areas, forces daily changes in operating center frequencies. When the OTA bit rate changes, necessary bandwidth changes and, subsequently, the emission designator changes for the system. In reality, this telemetry (TM) system could be thought of as requiring an "Emission Designator for the Mission", which changes based upon the user's needs.

In order to effectively apply the existing spectrum certification process to AMT links, an understanding of how AMT links can operate is required. This is documented in the *Telemetry Standards*[2] (referred to in this white paper as IRIG 106). With this understanding, the proposed AMT-specific modifications to certain inputs to the AMT system spectrum certification documents will be put into proper context. The proposed changes supported with supplemental information (presented below) allow the local frequency manager to properly document the emission designator(s) for that mission driven by the end TM system user's needs. This flexibility is already in the frequency assignment process and is documented in a GMF record via multiple emission designators (i.e. multiple Spectrum XXI ([SXXI] Standard Frequency Action Format [SFAF] line item 113/114/115 entries) to properly document how AMT links are used today.

2.0 Problem Statement

The one term that uniquely identifies systems operating in the electromagnetic spectrum is the emission designator. For AMT systems in operation today, there is an infinite number of possible emission designators defining that system. Transmitting and receiving hardware

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[1] The reference to EL-CID and Stepstone Editor will be annotated as "spectrum certification request" for the remainder of this document.
[2] Range Commanders Council. *Telemetry Standards*. RCC 106-21. July 2021. May be superseded by update. Retrieved 16 July 2021. Available at https://www.trmc.osd.mil/wiki/x/EoPOBg.

available within the market place today implement all technologies standardized within IRIG 106. The following is a list of capabilities the IRIG 106-compliant AMT links being fielded and in use have today.

- The OTA bit-rate agility, tens of kilobits per second (kbps) to tens of megabits per second (Mbps)
  - 50 kbps to over 40 Mbps
- Modulation agility, IRIG 106 has three modulation modes (waveforms)
  - Pulse code modulation (PCM)/frequency modulation (FM)
  - Shaped offset quadrature phase-shift keying (SOQPSK) modulation– Telemetry Group (TG)
  - Advanced range telemetry (ARTM) continuous phase modulation (CPM)
- Coding selections
  - Low-density parity check (LDPC) forward error correction (FEC)
  - Space-time coding (STC)
- Multiple AMT band capability
  - Lower/Upper L-Band
  - Lower/Upper S-Band
  - Lower/Mid C-Band

With this much capability, users of TM data are implementing these techniques to increase the data quality seen in the control room. This vast combination of capabilities can change the emission designator on a per-mission basis. Given this, there are two questions that need to be answered.

a. How can the AMT community ensure the correct information is included in the spectrum certification process used to allocate, assign, and accurately document the telemeters' capabilities?

b. Can the spectrum certification request form be used for such an agile system?

NOTE	It is understood that an infinite number of possible emission designators defining a specific AMT system cannot be included in either the spectrum certification request, or the GMF assignment, due to limitations of current tools. However, the AMT community will ensure that "worst case" emissions designators (related to necessary bandwidth) are included on all future spectrum certification requests so they can be included on GMF assignments by the local spectrum managers. Further, the additional data and processes described in this whitepaper will assist the spectrum community to determine if additional emission designators that were <u>not included</u> in the original spectrum certification request are required. If additional emission designators are in fact required, the Range Commanders Council Telemetry Group (RCC TG) recognizes that it is the responsibility of the program office or acquisition command that submitted the original spectrum

	certification request to update the spectrum certification request files appropriately and resubmit for approval, and it is not the responsibility of the local spectrum manager nor service spectrum management office(s) to submit a modified spectrum certification request for review and approval.

3.0 Background

Extensive research and development over the last 15 to 20 years has led to very capable TM transmitting and receiving systems that are bit-rate and modulation-mode agile, have multiple coding options, and are able to tune in multiple AMT bands. The TM transmitters exist today in small form factors with an extensive list of options able to tune in all TM bands. Ground-station receivers are available to receive and demodulate all TM signals that may originate from a test article implementing some or all of these options. These options can be used by the TM engineer, program under development, test range, etc., to maximize the data quality seen by the control room or real-time end user.

In the past, the former DD Form 1494 submission for a TM link was straightforward. These links operated within the same TM band with one modulation mode at a fixed bit rate. When filling out the form, the result for this type of TM link was a <u>fixed</u> necessary bandwidth resulting in a <u>fixed</u> emission designator. These links are extensively documented with multiple entries in the GMF.

Today, this is no longer the case. When programs are presented with the option for better data quality, they take it. No longer are TM users flying missions with only one TM link configuration. These links are being tailored per the requirements for the test, which can now take into account the transmitting channel conditions.

The list of available technologies used is endless. Several examples are listed.

- An instrumentation system gets reconfigured resulting in more (or less) data being transmitted for that test.
- Due to spectrum congestion, the program could not fly unless they reduced their occupied bandwidth (OC-BW). One option is to change to a more bandwidth-efficient modulation scheme.
- The mission included a long-range test point, so forward-error correction was required to close the link. The OTA bit rate would again change.
- Perhaps a range-receiving asset was not available requiring a change to a receiving antenna with less gain. Again, forward-error correction could be applied to overcome this link budget deficit.
- A highly dynamic flight profile is planned necessitating a top and bottom transmission antenna. In this case, STC would be applied.
- A high-quality video link is required necessitating near error-free data being sent to the video decoder. In this case, forward-error correction would be applied that changes the OTA data rate.

These scenarios change the necessary bandwidth, emission bandwidths, and ultimately, the emission designator. It should be obvious that the trade space for telemetry link optimization is large.

4.0 Solution

The pages in the spectrum certification request form and the data fields in those pages that are affected by the AMT link's configuration are shown in Table 1. If another method of inputting link characteristics is used instead of the either of the two data collection tools provided by the service spectrum management offices (i.e., Stepstone or EL-CID application), this solution is still valid as the information required is consistent throughout all methods. In reality only two definitions are affected: emission designator and emission bandwidth.

Table 1. Spectrum Certification Request Pages of Interest

Page Title	Block	Block Title
DoD General Information	4.b.	Emission Designator
Transmitting Equipment Characteristics	8	Emission Designator
Transmitting Equipment Characteristics	12	Emission Bandwidth
Receiving Equipment Characteristics	8	Emission Designator
NTIA General Information	4.b.	Emission Designator

Key:
DoD – Department of Defense
NTIA – National Telecommunications and Information Administration

4.1 Emission Designator

a. The data in blocks 4.b. and 8 change depending upon input data rate, modulation mode, and coding selection, which are variable. The emission designator consists of the necessary bandwidth (first part of the designator) and the emission classification symbols (second part of the designator) as illustrated in Figure 1. (NOTE: The block numbers are not defined in the spectrum certification request programs.)

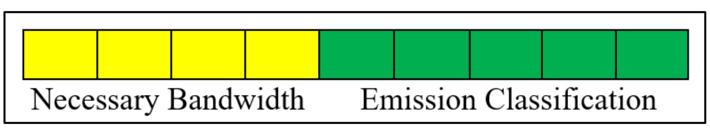


Figure 1. Emission Designator Format

There are five symbols in the emission classification field.

NOTE	Per the NTIA Red Book the fourth and fifth symbols are optional and thus may or may not be used. They are included and explained here for completeness.

1) The first symbol indicates the main carrier's type of 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 telemetry is directly mentioned in the chart in the National Telecommunications and Information Administration (NTIA) Redbook.

4) The fourth symbol indicates the signal's details. This will be modulation mode-specific; "B" (indicating a two-condition modulation scheme) is used for PCM/FM and "D" (indicating a four-condition modulation scheme) is used 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, several examples of emission designators for various AMT links are shown in Table 2.

Table 2. 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 bandwidth, the last five emission designator symbols are consistent for each modulation scheme.

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

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

b. A definition of necessary bandwidth can be found in Annex J of the NTIA Redbook.[3] Subsection A.5a(3)b of IRIG 106-20 Chapter 2[4] also addresses necessary bandwidth for TM waveforms. This section defines the necessary bandwidth used in the spectrum certification request for each TM waveform and shown in Table 3 in terms of modulation mode and OTA bit rate.

Table 3. Necessary Bandwidth Calculation for AMT Waveforms

Modulation	Necessary Bandwidth (DD Form 1494)
PCM/FM	1.16*(OTA bit rate)

[3] National Telecommunications and Information Administration. Manual of Regulations & Procedures for Federal Radio Frequency Management. NTIA Redbook, September 2017 Revision. May be superseded by update. Retrieved 16 June 2021. Available at https://www.ntia.doc.gov/page/2011/manual-regulations-and-procedures-federal-radio-frequency-management-redbook.

[4] Range Commanders Council. "Transmitter and Receiver Systems." In *Telemetry Standards*, Chapter 2. RCC 106-20. July 2020. May be superseded by update. Retrieved 17 June 2021. Available at https://www.trmc.osd.mil/wiki/x/EoPOBg.

SOQPSK	0.78*(OTA bit rate)
ARTM CPM	0.56*(OTA bit rate)

c. Five numbers and one letter can be used to express the necessary bandwidth portion of the emission designator. For AMT waveforms, three numbers and one letter are sufficient. The letter occupies the decimal point position and represents the unit of bandwidth. Use "**H**" for hertz, "**K**" for kilohertz, "**M**" for megahertz, and "**G**" for gigahertz.

For AMT systems, the emission designator for Block 4.b and 8 in the spectrum certification request for each modulation scheme will be specified at a 1-Mbps reference bit rate.

d. The necessary bandwidth for each 1-Mbps waveform is found using Table 3. The following are the resulting emission designators.

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

If the input bit rate changes from 1 Mbps, the OTA bit rate and necessary bandwidth change accordingly, requiring a new calculation per Table 3 and Figure 2.

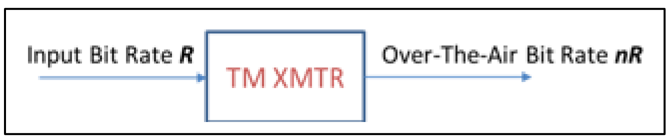


Figure 2. OTA Bit Rate Determination

As an example: if the input data rate changed to 5 Mbps (***R***=5 Mbps), then the OTA bit rate ***nR*** would equal 5 Mbps (in this case the multiplier ***n*** in Table 4 is **1**), resulting in the necessary bandwidth of 5M80, 3M90, and 2M80, respectively, for each modulation mode. These new numbers are then coupled with the emission classification for the appropriate waveform arriving at the new emission designator.

Table 4. Modulation/Coding Multiplier

Modulation/Coding	Multiplier *n*
PCMFM/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

e. 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 OTA bit rate as shown in Figure 2. This new OTA bit rate is then used with Table 3 for the appropriate modulation mode to calculate the new necessary bandwidth.

   Table 4 specifies the multiplier ***n*** to be used based upon all of the available coding combinations. This new necessary bandwidth is then used with the emission classification for the waveform to arrive at the new emission designator.

4.2 Emission Bandwidth

a. Block 12 in the Transmitting Equipment Characteristics page is for providing the modulated waveform's emission bandwidth, which is defined as that emission appearing at the antenna terminals. Measurements or calculations are made at the modulated waveform's −3 dB, −20 dB, −40 dB, and −60 dB points.

   For AMT applications, these measurements are referenced to the peak of the modulated waveform using the resolution bandwidth (RBW) and the video bandwidth (VBW) settings for the spectrum analyzer as recommended within IRIG 106 (RBW=30 kHz, VBW=300 Hz).

   Figure 3 is an example of the measurement points for the three AMT waveforms.

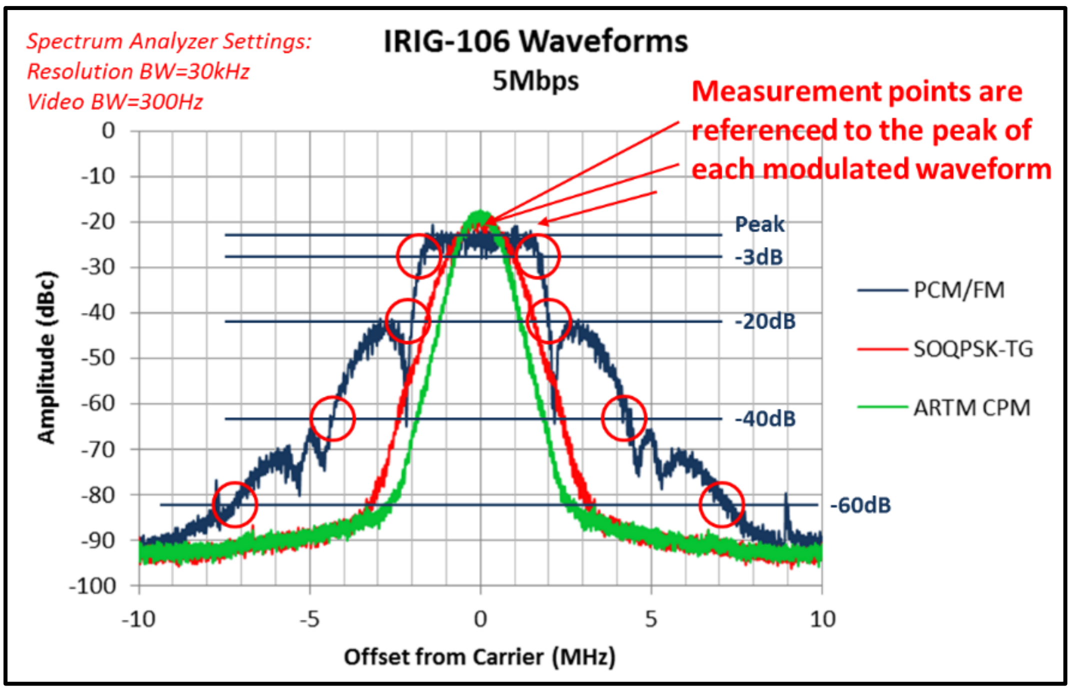
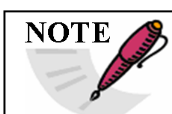


Figure 3. Emission Bandwidth Example for AMT Waveforms

b. Block 12 also requires the OC-BW for each waveform. The OC-BW for TM waveforms is directly addressed in IRIG 106 Chapter 2 and Appendix 2-A.

NOTE 	For AMT waveforms the terms "occupied bandwidth" and "necessary bandwidth" are interchangeable.

As is the case with the emission designator, emission bandwidth and OC-BW vary with input bit rate, modulation mode, and coding selections. This results in endless combinations of the required waveform measurements. To account for this, the same strategy is employed as the emission designator. The emission bandwidth at each measurement point (−3 dB, −20 dB, −40 dB, −60 dB, and OC-BW) is given for each AMT waveform at a reference bit rate of 1 Mbps. These numbers for ideally generated AMT waveforms are given in Table 5.

Table 5. Emission Bandwidths for AMT Waveforms

Waveform	−3 dB	−20 dB	−40 dB	−60 dB	OC-BW
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

Should the emission bandwidths need to be determined for the TM link setup of the day, it can be recalculated at each point for the appropriate waveform. Determine R and n, then use n*R to determine the new emission bandwidth for each appropriate waveform's point. The OC-BW can also be determined by using n*R and applying that to Table 3.

Add a note in the Remarks block for each affected page explaining the emission designators for AMT links and how to implement the multiplier to arrive at a new necessary bandwidth and thus a new emission designator. Also add an attachment showing Table 3, Table 4, and Figure 2.

5.0 Conclusion

The AMT community requires a method of submitting spectrum certification requests (or the application of choice) that accurately describes the capability and many modes in which an AMT link can operate. The recommendation from the Range Commanders Council Telemetry Group is to document the TM system for each modulation mode at an OTA rate of 1 Mbps. As mission demands change the link requirements, a new OTA bit rate will have to be determined to fully and accurately document the necessary bandwidth, emission designator, and emission bandwidths (if required). Having this information readily available embedded in the approved certification of spectrum support for modern-day AMT links will assist anyone that needs to make modifications to an existing spectrum certification document and add a new emission designator to the certification and/or assignment in the GMF. To summarize, the following is proposed for the AMT community to include on all spectrum certification requests and/or submissions for modern-day generation AMT links:

5.1 For the Emission Designator

a. Specify the emission designator for each modulation mode at a 1-Mbps reference bit rate.

b. Add a note in the Remarks block explaining the how to determine a new emission designator.

- Determine the OTA bit rate. This is calculated using the correct multiplier based upon the link configuration.

- Determine necessary bandwidth. Apply the appropriate scaling factor per modulation mode to the OTA bit rate.
- Determine emission designator. Replace the 1-Mbps necessary bandwidth with the new calculated value of necessary bandwidth, leaving the emission classification as is.

c. Add an attachment to the spectrum certification request that specifies the multiplier required to determine the OTA bit rate given the input bit rate, modulation scheme, and code selected.

5.2 For the Emission Bandwidth

a. Specify the emission bandwidth at each measurement point (−3 dB, −20 dB, −40 dB, −60 dB, and OC-BW) for each modulation scheme at a 1-Mbps reference bit rate.

b. Add a note in the Remarks block explaining that the emission bandwidths at the measurement points and the OC-BW scale are proportionally using the procedure previously discussed.

c. Add an attachment showing the IRIG-106 necessary bandwidth (OC-BW) factor for each modulation scheme.

NOTE	If required by the Service spectrum management office or by the submitting organization, this white paper can be included with the submission for clarification.

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APPENDIX A

Citations

National Telecommunications and Information Administration. Manual of Regulations & Procedures for Federal Radio Frequency Management. NTIA Redbook, September 2017 Revision. May be superseded by update. Retrieved 16 June 2021. Available at https://www.ntia.doc.gov/page/2011/manual-regulations-and-procedures-federal-radio-frequency-management-redbook.

Range Commanders Council. *Telemetry Standards*. RCC 106-21. July 2021. May be superseded by update. Retrieved 16 July 2021. Available at https://www.trmc.osd.mil/wiki/x/EoPOBg.

———. "Transmitter and Receiver Systems." In *Telemetry Standards*, Chapter 2. RCC 106-21. July 2021. May be superseded by update. Retrieved 14 July 2021. Available at https://www.trmc.osd.mil/wiki/x/EoPOBg.

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