SMALL-DIAMETER EARTH TERMINAL TRANSMISSION ISSUES IN SUPPORT OF HIGH DATA RATE MOBILE SATELLITE SERVICE APPLICATIONS

Gary Comparetto
Principal Engineer
The MITRE Corporation
(703) 983-6571
garycomp@mitre.org

James Marshall
Principal Engineer
The MITRE Corporation
(703) 983-5488
jmarshal@mitre.org

ABSTRACT

There is a growing interest in the DoD and in industry to use small-diameter, directional antennas in the Ku- and Ka-band frequency ranges, in order to support peer-to-peer connectivity in the Mbps data rate range. This is normally accompanied by relatively high Earth terminal (ET) transmit powers which, together with the directionality of the antenna system, may result in unacceptable off-axis ET transmission levels relative to national and international criteria. The purpose of this paper is to highlight the challenges involved in designing this type of Earth terminal in the face of evolving ET transmission limits.

INTRODUCTION

There is a continual desire to support high data rate, direct-to-user, mobile services in both the commercial and DoD user communities. This is more readily attainable using a terrestrial-based infrastructure, if available, since the relatively small source/destination ranges can be supported using omni antenna designs and low transmit power levels. Furthermore, adequate ITU mobile service (MS) frequency allocations currently exist to support MS services.

Third generation mobile services are being offered that support 144 kbps and techniques are being proposed to increase this rate up to the 2 Mbps range, and beyond. However, there are situations in which a terrestrial-based infrastructure is not available and cannot be easily implemented. In these cases, a satellite-based solution must be considered. From a satellite standpoint, these rates are not attainable using omni antennas due to the much larger source/destination ranges that must be supported, in addition to other propagation phenomena that may impact link performance. Consequently, small-diameter, directional antennas, capable of rapidly acquiring and tracking the satellite, are needed to support mobile satellite service (MSS) applications and provide direct-to-user data rates in the multiple Mbps range. This is precisely the goal of the Army's next-generation SATCOM terminal that is referred to as the Multi-Band Integrated Satellite Terminal (MIST)[1].

This mode of operations raises a number of interesting and challenging issues that must be addressed; two of which are the topic of this paper. Specifically, this paper addresses the need of the ET system design engineer to ensure that: (1) adequate ITU MSS frequency allocations exist in the desired frequency bands in order to support high data rate, direct-to-user, mobile communications and (2) the ET design meets existing and/or evolving off-axis ET emission criteria, both nationally and internationally.

CURRENT MSS FREQUENCY ALLOCATIONS

The ITU MSS frequency allocations are provided in Figure 1 for the 14 through 74 GHz frequency range. The data is taken from the 1998 ITU Radio Regulations. Four columns are shown in Figure 1. Column one identifies the frequency band. Column two identifies the link direction (I.e., Earth-to-space, E-S, or space-to-Earth, S-E). Column three identifies whether the frequency allocation is primary (users operating with primary allocations are protected from harmful interference by other users in the operational frequency band) or secondary (no protection from harmful interference). Finally, column four identifies the global regions for which the frequency allocations and service assignments are valid. The ITU has divided the world into three regions for the allocation of frequencies - the United States is in Region 2.

The MIST[1] terminal would be adequately supported with a worldwide, primary, DoD-usable, MSS frequency allocation of 75 MHz (Ku-band) and/or 150 MHz (Ka-band), governed by "acceptable" ET transmission criteria. Based on the data shown in Figure 1, it can be concluded that no worldwide MSS allocation at Ku-band exists on a primary basis that meets this criteria. The situation is better, however, with respect to Ka-band operations. As shown, there is a 1.1 GHz worldwide MSS primary allocation for both uplink and downlink operations (29.9 to 31 GHz and 20.1 to 21.2 GHz, respectively). Note that the first 100 MHz of these band segments are *commercial* allocations while the remaining 1 GHz are *Government* allocations. It is allowable for Government agencies and organizations to utilize commercial space assets using DoD-developed Earth terminals; however, these ETs would have to adhere to the applicable national and international ET off-axis emission limits.

Based on the above, it is clear that the DoD should take a more active role in the ITU Worldwide Radio-Communication Council (WRC) and related activities in order to ensure that sufficient MSS frequency allocations are made in support of SATCOM-on-the-move (SOTM) operations at commercial Ku- and Ka-band.

EARTH TERMINAL EMISSION CRITERIA

Earth terminals must adhere to specific emission criteria when operating in assigned frequency allocations. The criteria are generally characterized by a mathematically defined "form", accompanied by specific operational limits. For example, the ITU ET transmission criteria are stated in terms of a piece-wise linear operational envelope that defines the maximum Effective Isotropic Radiated Power (EIRP) density (i.e., dBW per 40 khz) as a function of off-axis angle relative to the ET antenna.

It is important to note that the ET transmission criteria are quite specific for a given set of operational parameters. These typically include: (1) operational frequency (or band), (2) service type (e.g., fixed satellite service - FSS, mobile satellite service - MSS), (3) orbital type (e.g., Geostationary satellite orbit - GSO, non-Geostationary satellite orbit - NGSO), and (4) D/λ value (where D is the antenna diameter and λ is the operating wavelength).

Normally, the FCC (the US national organization responsible for defining satellite ET emission limits) attempts to ensure that the criteria (described in CFR 47 Part 25) are consistent with ITU criteria; however, this is not always the case. For example, up until a recent FCC-proposed modification, the ET transmission criteria defined in Part 25 included an operational envelope based upon "transmit antenna gain" versus "EIRP density". While this may seem like a minor difference, it turns out that it could have major design implications.

As stated above, the ITU limits are normally in terms of "EIRP density" which takes into account the ET transmit power as well as the gain patter of the transmit antenna. The EIRP density is calculated over a 40 kHz reference bandwidth in order to standardize the calculations. The ITU ET transmission limits for Ku-band operations in the frequency bands 12.75-13.25 GHz and 13.75-14.5 GHz are provided in Figure 2 and are taken from ITU-R S.524-7. As shown, the limits include an operational envelope based upon EIRP density limits as a function the antenna off-axis angle, using a 40 kHz reference bandwidth.

The ITU ET transmission limits for Ka-band operations in the frequency range 29.5-30 GHz are provided in Figure 3 and are also taken from ITU-R S.524-7. Note that these limits are only applicable up to 30 GHz and, as such, would not be applicable to MSS terminals operated by the US Government using satellites operating in the Government-apportioned Ka-band E-S allocation of 30-31 GHz. (e.g., this would be the scenario if MIST terminals were to be used in conjunction with a Gapfiller satellite.) However, the limits in Figure 3 would be applicable for MSS systems, operated by the US Government, using a commercial satellite operating in the commercial Ka-band E-S MSS allocation of 29.9-30.0 GHz. (e.g., this would be the scenario if multi-band MIST terminals, having commercial Ka-band S-E capability in the 29.5-30.0 GHz range, were to be used in conjunction with commercial satellites.) Thus, it is possible that the limits imposed by the ITU and, as we shall see below, the FCC, on ET emissions at E-S Ka-band frequencies may render US Government use of MIST MSS terminals with commercial satellites unfeasible at operationally significant data rates (i.e., 100s of kbps or higher).

As was the case for the Ku-band limits of Figure 2, the Ka-band limits shown in Figure 3 also include an operational envelope based upon EIRP density limits, using a 40 kHz reference bandwidth, as a function of the antenna off-axis angle. However, the Ka-band limits are also a function of *the maximum number, N, of simultaneously transmitting co-frequency Earth terminals in the receive beam of the satellite*. This parameter, "N", is equal to 1 for FDMA and TDMA implementations. Note that, while the form is "similar" to the Ku-band ITU regulations, for FDMA applications (i.e., N=1), the operational envelope is 20 dB more stringent than the Ku-band ITU limits identified previously in Figure 2! Additionally, the emission limits begin at an off-axis angle 2° at Ka-band versus 2.5° at Ku-band. While this seems like a minor difference, the effect can be dramatic depending upon the shape of the main lobe of the transmit antenna beam.

The ITU intent in developing the Ka-band limits of S.524-7 was to account for the aggregate affect of Ka-band networks having large numbers of terminals operating simultaneously. These terminals would generally employ asymmetrical link designs in support of internet connectivity (i.e., a high rate forward link to the ET supported by a much lower rate return link from the ET). From a licensing standpoint, adherence to these limits could then support "blanket" approval of an ET family design, given that the system operator was able to demonstrate that their ET design would meet the ET emission criteria.

Recently, the FCC has proposed a modification to its ET transmission limits that brings it more into line with the "form" of ITU regulations[2]. The revised limits are presented in Figure 4. As shown, these limits are also a function of the maximum number of simultaneously transmitting co-frequency Earth terminals in the receive beam of the satellite and are about .5 dB more stringent that the ITU limits in Figure 3!

Note that the limits shown in Figures 2 through 4 are only applicable to Fixed Satellite Services (FSS) operations using geo-stationary (GSO) satellites. Currently, there are no ET emission limits specifically identified for MSS operations; however, it is believed that MSS terminals (such as the MIST) would have to abide by these FSS ET emission limits in the absence of MSS-specific limits.

The bottom line is that the ET system design engineer must be cognizant of both FCC and ITU ET emission criteria and should actively participate in the working group meetings supported by both organizations.

IMPACT OF ET EMISSION CRITERIA ON ET DESIGN

Figure 5 provides a *representative* example of how ET transmission limits would be applied to mobile MIST operations. For this example, the Ka-band limits of ITU-R S.524-7 are applied to a *representative* MIST design. The results in Figure 5 were generated using three different antennas having 17 dB, 24.6 dB, and 30 dB first side-lobe roll-off patterns, respectively. As shown in Figure 5, only the 17 dB roll-off pattern (i.e., the design having the narrowest main lobe but the highest side lobes) meets the ITU-R S.524-7 emission limit, with an allowable EIRP density in a 40 kHz bandwidth of approximately 24 dBW/40 kHz.

If we assume 8 simultaneous MIST satellite accesses in an FDMA full-mesh configuration, and representative values for the link parameters, this EIRP density limit of 24 dBW results in a maximum achievable data rate of less than 5 kbps. In contrast to this, the maximum achievable data rate for the same link, without taking into consideration the ITU limits, is on the order of 8.5 Mbps! It is clear that current ITU (and FCC) ET emission limits will have a dramatic effect on the maximum achievable data rate of Earth terminals having small-diameter, directional antennas in the GHz frequency range.

FINAL REMARKS

While the above data is *only representative*, it does highlight the fact that the antenna radiation pattern of the mobile MIST terminal design is significant in terms of whether or not a particular design will be able to meet the ET EIRP density transmission criteria. One way to help meet the ITU ET off-axis emission limits it to lessen the main lobe beamwidth of the ET antenna. For a given transmit frequency, this can be accomplished with a larger diameter antenna; however, this can only be taken so far since SOTM operations are more difficult to support with larger antennas (due to acquisition/tracking,, mechanical steering, and weight/size/power considerations).

Finally, based on these results, it would appear that the US Government should concentrate on operating their small-diameter Ka-band terminals, such as MIST, in the US Government Ka-band E-S allocation of 30-31 GHz or they may be forced to operate at very low data rates (i.e., in the several kbps range) in the commercial band allocation.

REFERENCES

1. *"Multi-Band Integrated Satellite Terminal (MIST) - A Key to Future SOTM for the Army"*, G. Comparetto and W. Hall, Presented at MILCOM 2001, McLean, VA., 28-31 October 2001.
2. *"Redesignation of the 17.7-19.7 GHz Frequency Band, Blanket Licensing of Satellite Earth Stations in the 17.7-20.2 GHz and 27.5-30.0 GHz Frequency Bands, and the Allocation of Additional Spectrum in the 17.3-17.8 GHz and 24.75-25.25 GHz Frequency Bands for Broadcast Satellite-Service Use"*, FCC Report and Order, IB Docket No. 98-172, released 22 June 2000.

	Frequency Band (GHz)	Direction	Primary (P) or Secondary (S)	Regions
Ku-band	14.0 – 14.5	E-S	S	1,2,3
Ka-band	19.7 – 20.1	S-E	S P	1,3 2
Ka-band	20.1 – 21.2	S-E	P	1,2,3
Ka-band	29.5 – 29.9	E-S	S P	1,3 2
Ka-band	29.9 – 31.0	E-S	P	1,2,3
	39.5 – 40.5	S-E	P	1,2,3
	43.5 – 47.0	Undesignated	P	1,2,3
	50.4 – 51.4	E-S	S	1,2,3
	66.0 – 71.0	Undesignated	P	1,2,3
	71.0 – 74.0	E-S	P	1,2,3

Figure 1: ITU MSS Frequency Allocations from 14 - 74 GHz (Based on 1998 ITU Radio Regulations)

39-25Log(*)	2.5deg <= * <= 7deg
18	7deg < * <= 9.2deg
42 - 25Log(*)	9.2deg < * <= 48deg
0	48deg < * <= 180deg

Figure 2: ITU Ku-band ET Transmission Limits as Defined in ITU-R S.524-7 (Allowable EIRP in a 40kHz Bandwidth)

19 - 25Log(*) - 10Log(N)	2deg <= * <= 7deg	where "N" represents the maximum number of simultaneously transmitting co-frequency earth stations in the receive beam of the satellite (N=1 for FDMA and TDMA; N=8 for our MIST calculations)
-2 - 10Log(N)	7deg < * <= 9.2deg	
22 - 25Log(*) - 10Log(N)	9.2deg < * <= 48deg	
-10 - 10Log(N)	48deg < * <= 180deg	

Figure 3: ITU Ka-band ET Transmission Limits as Defined in ITU-R S.524-7 (Allowable EIRP in a 40kHz Bandwidth)

18.5 - 25Log(*) - 10Log(N)	2deg <= * <= 7deg
-2.63 - 10Log(N)	7deg < * <= 9.23deg
21.5 - 25Log(*) - 10Log(N)	9.23deg < * <= 48deg
-10.5 - 10Log(N)	48deg < * <= 180deg

Figure 4: Revised FCC Part 25 ET Transmission Limits for Ka-Band FSS Operations (Allowable EIRP in a 40kHz Bandwidth)

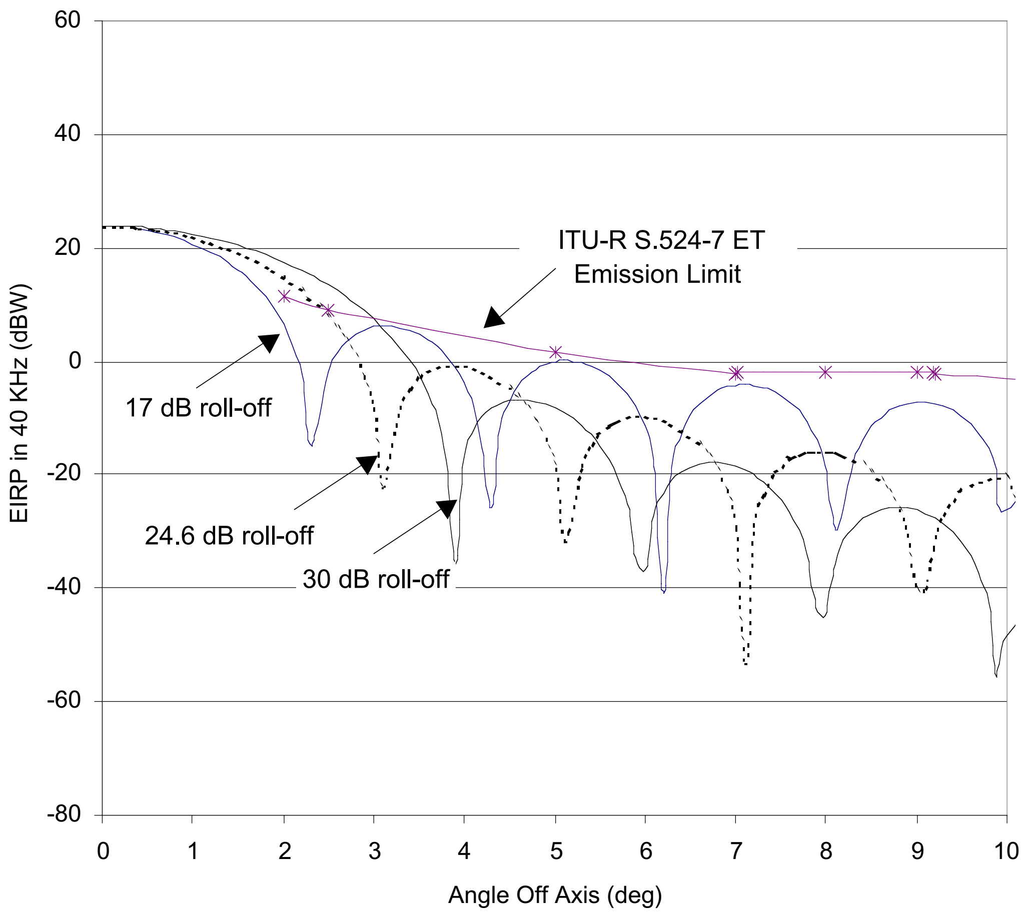

Figure 5: Representative MIST ET Performance Using the ET Transmission Limits of ITU-R S.524-7