

REPORT ITU-R M.2118

**Compatibility between proposed systems in the aeronautical mobile service*
and the existing fixed-satellite service in the 5 091-5 250 MHz band**

(2007)

Introduction

This Report is related to Agenda items 1.5 and 1.6 of WRC-07. It proposes a methodology based on Appendix 8 of the Radio Regulations and other ITU-R documents and Recommendations, for the compatibility analyses between possible new systems in the aeronautical mobile service and non-GSO MSS feeder links in the fixed-satellite service in the 5 091-5 250 MHz band.

1 Structure of the Report

This Report sets forth a general methodology for computing the aggregate $\Delta T_s/T_s$ seen by the FSS from new systems, and the $\Delta T/T$ levels seen by any one of the new systems due to the other new systems. The new systems include AM(R)S, systems of Aeronautical Mobile Telemetry (AMT) limited to flight testing, and aeronautical security¹. The methodology is then applied, in detail, in each of three annexes. Annex 1 explores sharing with AM(R)S. Annex 2 discusses sharing by systems of AMT. Annex 3 describes a proposed aviation security system and the resulting sharing scenarios. In addition, the impact of FSS on these new AMS systems is also considered.

2 Methodology

The methodology is based on Appendix 8 of the Radio Regulations (RR), including Document 8B/195, and Recommendations cited above. It is based on a computation of an aggregate $\Delta T_s/T_s$, where T_s is the noise temperature of the satellite (that is, $T_s = T_{space\ station}$), performed using equation (1):

$$\frac{\Delta T_s}{T_s} = \frac{1}{T_s} \sum_{n=1}^{n=N} \frac{p_{e_n} g_{1_n}(\theta_{t_n}) g_{2_n}(\delta_{e'_n})}{k l_{u_n}} \leq C \quad (1)$$

where C is the proposed criterion for sharing assessment.

* Limited to aeronautical mobile telemetry for aircraft flight testing (referred to as AMT) and AMS for aeronautical security, and AM(R)S.

¹ *Terminology:* An aeronautical mobile service that supports aeronautical security transmissions ensure confidential and secure radiocommunications between aircraft and ground intended for systems used in response to interruption of aircraft operations that have not been permitted by the appropriate authorities.

The parameters are defined as follows (see Appendix 8):

- T_s : receiving system noise temperature of the receiver channel under consideration of the space station, referred to the output of the receiving antenna for that channel of the space station (K)
- ΔT_s : apparent increase in the receiving system noise temperature of the satellite S , caused by an aggregate interfering emission, referred to the output of the receiving antenna of this satellite (K)
- $g_2(\delta)$: receiving antenna gain of satellite S in the direction δ (numerical power ratio)
- $g_{1n}(\theta_t)$: transmitting antenna gain of the earth station number n (AM(R)S or AMS) in the direction of satellite S' (numerical power ratio)
- p_{e_n} : maximum power density per Hz delivered to the antenna of the transmitting earth station number n (averaged over the worst 4 kHz band) (W/Hz)
- $\delta_{e'}$: direction, from satellite S , of the transmitting earth station number n
- θ_{tn} : direction, from the earth station number n , of the satellite S
- k : Boltzmann's constant (1.38×10^{-23} J/K)
- l_{un} : free-space transmission loss on the uplink (numerical power ratio), evaluated from the earth station number n , to satellite S
- N : number of earth station (AM(R)S for AI 1.6 and AMS for AI 1.5)
- n : index of the earth station.

In order to perform computations using equation (1), a scenario for the location of the earth stations (AM(R)S or AMS) is needed as well as a worst-case assumption on the maximum number of earth stations operating at the same time in the satellite receiver bandwidth and visibility.

The methodology consists in computing equation (1) for each time step of the above-defined scenario.

3 Proposed criteria for sharing assessment

In the studies of this document, the following criteria² are considered:

- In the band 5 091-5 150 MHz (aggregate $\Delta T_s/T_s$ for all other primary services of 6%):
 - A maximum $\Delta T_s/T_s$ of 3% for the ARNS;
 - A maximum $\Delta T_s/T_s$ of 2% for the AM(R)S or the AMS limited to aeronautical security applications;
 - A maximum $\Delta T_s/T_s$ of 1% for the AMS limited to AMT.
- In the band 5 150-5 250 MHz (aggregate $\Delta T_s/T_s$ of 6%):
 - A maximum $\Delta T_s/T_s$ of 3% for the MS (RLAN);

² In common with other applications using bands allocated to the FSS, in keeping with Recommendation ITU-R S.1432, WP 4A considers it appropriate for MSS feeder up-links to be designed to allow an aggregate of 6% of the total noise to interference from other primary services in the band 5 091-5 150 MHz. Thus on the assumption that there is unlikely to be significant MLS development in this band before 2018, it would seem reasonable to allow 3% of the MSS feeder up-link noise budget to interference from the aeronautical radionavigation service, and the other 3% for all other services.

- A maximum $\Delta T_s/T_s$ of 3% for other services:
 - A maximum $\Delta T_s/T_s$ of 1% for the AMS limited to AMT;
 - A maximum $\Delta T_s/T_s$ of 2% for other services (not precise).

4 List of characteristics used in the compatibility analyses

For an FSS system considered in the analyses that follow, the following criteria have been used:

TABLE 1

Parameter values used in satellite interference calculations

Parameter	HIBLEO-4 FL
Satellite orbit altitude h (km)	1 414
Satellite receiver noise temperature T (K)	550
Interference threshold H (dBm) in 1.23 MHz ($\Delta T_s/T_s = 3\%$)	−125.5
Interference threshold H (dBm) in 1.23 MHz ($\Delta T_s/T_s = 2\%$)	−127.3
Interference threshold H (dBm) in 1.23 MHz ($\Delta T_s/T_s = 1\%$)	−130.3
Polarization discrimination L_p (dB)	1
Feed loss L_{feed} (dB)	2.9
Satellite receiver bandwidth B (MHz)	1.23
Satellite receive antenna gain (dBi)	4

Some of the parameters that have been used for characterization of AMS systems in the analyses:

- N : maximum expected AMS operating at the same time in the satellite receiver bandwidth.
- Worst-case scenario AMS stations' location versus time.
- The antenna gain patterns (ground and airborne).
- The maximum power density per Hz delivered to the antenna of the transmitting earth station (averaged over the worst 4 kHz band) (W/Hz) (Pe).
- AMS typical emitter filter.
- AMS typical modulation.

Specific values for these parameters are given in the Annexes of this Report.

5 Conclusion

5.1 Impact into FSS conclusion

Analyses indicate, for the systems described in the annexes and visible within an FSS satellite antenna footprint, that interference to the FSS from the proposed AMT, AM(R)S, and a future aeronautical security system will represent a $\Delta T_s/T_s$ of less than 2.7% (criterion 3%) accounted by typically:

- 0.7% (criterion 1%) for AMT in the band 5 091-5 250 MHz;
- less than 2% (criterion threshold for AM(R)S plus AMS for security) in the band 5 091-5 150 MHz for:
 - either AM(R)S;
 - or AMS for aeronautical security.

In the band 5 091-5 150 MHz, in order not to exceed a $\Delta T_s/T_s$ of 2% allowable for AM(R)S plus AMS for security, AM(R)S and AMS for security cannot operate co-frequency at the same time (within the field of view of a single non-GSO satellite). The practical means for operating in a time sharing mode would require a very complex coordination procedure. Therefore it is proposed that AM(R)S and AMS for security operate in a non co-frequency basis.

With respect to the band 5 091-5 250 MHz, it should be noted that this band is already used by existing allocations and that the addition of new allocations, such as AMS and AM(R)S, will increase interference to the FSS feeder links unless significant steps are taken. These steps would need to include some kind of regulatory arrangement, where necessary, that would ensure the protection of the FSS, utilizing the 5 091-5 250 MHz band, from unacceptable interference.

5.2 Impact from FSS conclusion

5.2.1 Impact into AMS for telemetry limited to flight testing

The compatibility between the FSS ground transmitter and the AMS for telemetry limited to flight testing ground receiver can be handled at AMS for telemetry application level by ensuring sufficient distance separation between these stations. Due to the limited number of these ground stations this should be manageable.

5.2.2 Impact into AM(R)S

The compatibility between the FSS ground transmitter and the AM(R)S ground receiver located at airports can be handled by ensuring sufficient distance separation between these stations and/or appropriate frequency separation. Due to the limited number of FSS ground stations and the limited location of AM(R)S ground stations at airports this should be manageable.

5.2.3 Impact into AMS for security

The compatibility between the FSS ground transmitter and the AMS for security ground receiver can be handled at AMS for security application level by ensuring sufficient distance separation between these stations and/or appropriate frequency separation. Due to the limited number of these ground stations this should be manageable.

The compatibility between the FSS ground transmitter and the AMS for security airborne receiver can be handled at AMS for security application level as any interference suffered would not be frequent.

Annex 1

Aeronautical mobile (R) service

1 Introduction

1.1 The very high frequency (VHF) band 117.975-137 MHz is heavily utilized in the for air-ground communications associated with air traffic services and aeronautical operational control supporting safety and regularity of flight and operating in the aeronautical mobile (route) service (AM(R)S). In fact, use of the band is such that in some regions it is very difficult to find channels to meet current requirements. While regional efforts are underway to extend the capacity through measures such as channel splitting and/or functional reassignments, with the expected growth in air service, together with increasing desires for more data to the flight crews, the spectrum shortage issue will become even more challenging. This need was recognized at WRC-03 as evidenced by Agenda item 1.6 for WRC-07. In order to determine requirements for new AM(R)S spectrum, a number of aviation studies were completed.

1.2 Results of the studies provide guidance as to future AM(R)S requirements. In particular more spectrum is needed to support:

- surface applications;
- air-ground/air-air voice and data link applications;
- advanced surveillance/navigation applications;
- unmanned aerial vehicle (UAV) control.

The 5 091-5 150 MHz band has been identified to satisfy the requirements of the first category-surface applications.

1.3 Studies have turned up a number of AM(R)S applications for the airport surface. These range from uploads of routing and electronic flight bag information, to de-icing, and surface mapping to preclude runway incursion and aid in obstacle avoidance. In general those applications share the characteristics of short-range (e.g. 3 km) and high bandwidth per airport. Limitation to ground transmission, and geographic separation of airports would likely ease airport-to-airport channel reuse.

1.4 To accommodate future growth in surface applications, portions of the 5 GHz band have been selected for evaluation as a potential spectrum location for an airport radio local area network (RLAN). Initial studies have indicated that the 5 GHz band is well suited to the type of applications envisioned, and work is being accomplished to determine if IEEE 802.xx technologies – utilized in adjacent bands (i.e. above 5 150 MHz) for commercial, unlicensed terrestrial RLANs – can be leveraged³.

³ This proposed AM(R)S application will be implemented only at airports.

2 System characteristics

2.1 Assumed aviation system

2.1.1 In order to address the mix of aviation applications intended for the airport surface, development of an airport safety-rated RLAN is envisioned for the 5 091-5 150 MHz sub-band. One candidate architecture is the airport network and location equipment (ANLE) system. ANLE is visualized as a high-integrity, safety-rated wireless RLAN for use at airports, combined with an interconnected grid of multilateration sensors. Simple transmitters would be added to surface-moving vehicles, allowing for the development of a high-fidelity, complete picture of the airport surface environment. In order to speed development and reduce the cost of the ANLE, the system would be based on existing Institute of Electrical and Electronics Engineers (IEEE) “802-Family” standards⁴.

2.1.2 While there are several protocols in the IEEE 802 family standards, analysis has focused on two candidates for the ANLE application: 802.11a and 802.16e:

- 802.11a currently operates in the 5 GHz unlicensed band using an orthogonal frequency division multiplexing (OFDM) modulation scheme. It operates using 20 MHz wide channels.
- 802.16e is designed to support non-line-of-sight (NLOS) communications in the 2-11 GHz band. Though below 6 GHz the standard allows various channel bandwidths, a 20 MHz channel has been defined to be compatible with the 802.11a standard, and is the channel bandwidth assumed for this analysis. One desirable feature of 802.16e is that it has been designed to allow for networking between users with relative speeds of up to 150 km/h – suitable for taxing aircraft.

2.1.3 Because of the “mobility” capabilities built into IEEE 802.16e, it is expected that it will prove to be the most compliant with aviation requirements. As a result, the remainder of Annex 1 will focus on that protocol.

3 Airport LAN characteristics

3.1 As noted above, a key parameter of the sharing study is ANLE transmitter power. Providing connectivity, with conservative margins to account for fading effects, over the assumed 3 km maximum range drives required transmitter power. ANLE transmitter and receiver antenna gain, ANLE receiver sensitivity, and path loss over the 3 km range in turn drive connectivity between the ANLE transmitter and the ANLE receiver.

3.2 The ANLE transmitter antenna gain versus elevation angle pattern considered in the analysis is adopted from International Telecommunication Union (ITU) Radiocommunication Sector, Recommendation ITU-R F.1336-1⁵ and is shown in Fig. 1.

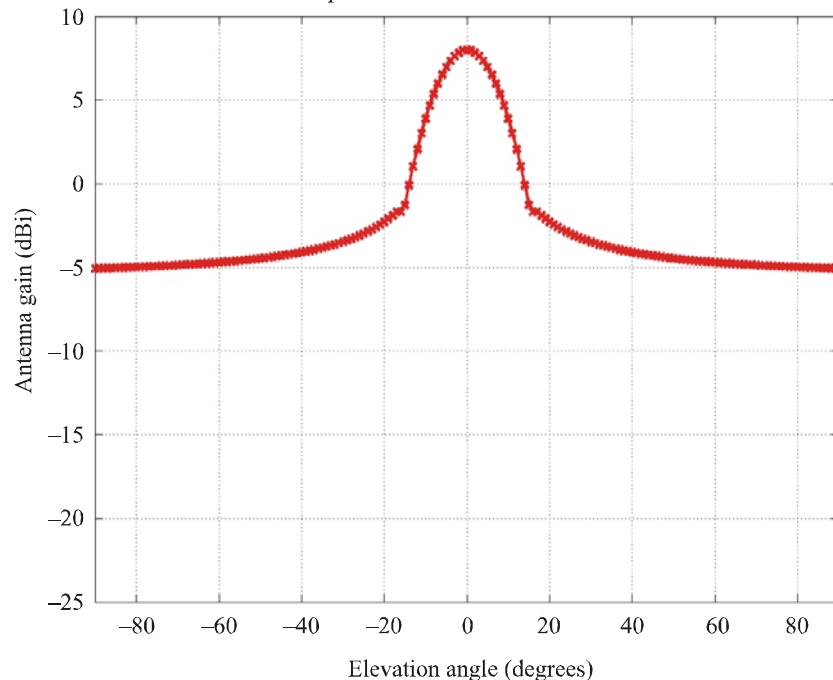
For this initial analysis, the radiation pattern was assumed to be omnidirectional in the horizontal plane. It must be noted that in practice, many if not all installed ANLE antennas are likely to have sectoral rather than omnidirectional horizontal-plane patterns. Sectoral antennas would allow ANLE

⁴ While the system would be based on the IEEE standards, it is expected that system elements would be tailored for the aviation application. Such tailoring might include bandpass filtering to facilitate sharing with adjacent band MLS, improved receiver sensitivities, and sectorized antennas.

⁵ Reference radiation patterns of omnidirectional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to above 70 GHz, Recommendation ITU-R F.1336-1 (1997-2000 version).

transmitters to operate at lower power, thereby enhancing compatibility with FSS and reducing overall interference levels below the values estimated in this Report.

FIGURE 1
Potential ANLE 802.16e transmitter antenna pattern
ITU reference pattern for an omnidirectional 8 dBi antenna



Rap 2118-01

3.3 The ANLE transmitter power required to cover a cell 3 km in radius can be estimated on the basis of a set of nominal parameter values. Based on the receiver minimum performance requirements from the IEEE 802.16e standard, the minimum receiver sensitivity level is -80.1 dBm. Receivers with better sensitivity however are technically feasible for 802.16e, and based on available literature⁶, for the purpose of this analysis the assumed sensitivity level used will be -83.4 dBm.

3.4 The path loss is a function of the path distance d . For an ANLE system the propagation path loss is evaluated on the airport surface where the path loss characteristics – in particular considering multipath effects – could be different (higher attenuation) from simple free-space path loss.

The path loss exponent n , is used to characterize the environment. The path loss equation is defined as:

$$L_{path}(d) = L_{free}(d_0) + 10n \log_{10}(d / d_0) \quad (2)$$

where:

L_{free} : free-space path loss

d_0 : distance up to which path loss can be modelled using the free-space equation

n : path loss exponent

⁶ IEEE 802.16 Broadband Wireless Access Working Group. Interference scenarios in 2.4 GHz and 5.8 GHz UNII bands – reviewed document. IEEE C802.16-04/14. June 28, 2004.

and

$$L_{free}(d_0) = 32.44 + 20 \log_{10}(f_{\text{MHz}}) + 20 \log_{10}(d_{0\text{km}}) \quad (3)$$

with

f_{MHz} : operating frequency (MHz)

$d_{0\text{km}}$: propagation distance (km) up to which path loss can be described by free-space loss.

3.5 If $n = 2$, equation (2) reduces to the case where the entire path distance is treated as a free-space path. To determine required ANLE power, however, the values of 2.3 for n and 462 m for d_0 were assumed. It must be noted that the assumption that $n = 2.3$ is considerably more conservative than a free-space loss assumption; and, consequently it results in higher estimated values of necessary ANLE transmitter power.

3.6 Terrestrial communications systems traditionally implement link margins (L_m) to account for fading, such as that due to multipath effects, and line loss (the latter losses should be very small in the ANLE configuration, due to short, low-loss cable runs). In regard to the link margin L_m for the ANLE-like system, the available information is very sketchy and indirect. For this analysis, a conservative value of 11 dB is estimated, however measurements are on-going in airport environments to try to develop a better estimate.

3.7 Using the information above, the required ANLE transmitter power P_t , dB, referred to one milliwatt dBm, is computed using the following expression:

$$P_t = R_{xs} + L_{path}(d) + L_m - G_t - G_r \quad (4)$$

where:

R_{xs} : receiver sensitivity (dBm)

d : distance between transmitter and receiver (3 km)

G_t : transmitter antenna gain (dBi) referred to lossless isotropic gain (dBi)

G_r : receiver antenna gain (dBi).

3.8 The ANLE transmitter power level required to establish a 3-km direct link in the system as determined using equation (4) is 32.2 dBm. Table 1 summarizes the ANLE system parameters and the transmitter power required.

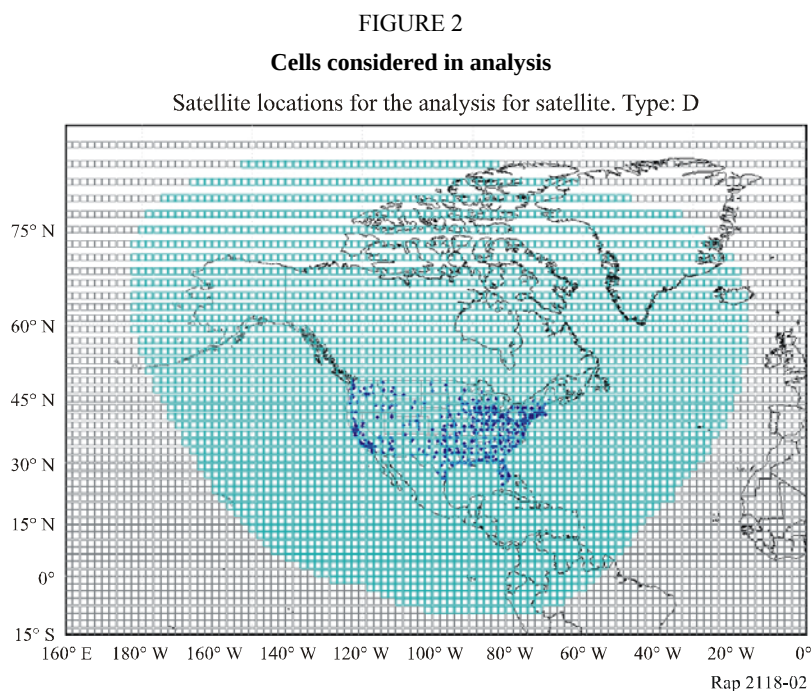
TABLE 1

Estimated ANLE transmitter power needed for 3-km range

Parameter	ANLE (IEEE 802.16e)
Receiver sensitivity R_{xs} (dBm)	−83.4
Transmitter antenna gain G_t (dBi)	8.0
Receiver antenna gain G_r (dBi)	6.0
Assumed link margin L_m (dB)	11.0
Assumed path-loss exponent n	2.3
Transmitter power required P_t (dBm)	32.2

4 Compatibility assessment results

4.1 With the ANLE parameters outlined above, the compatibility assessment can be performed. Figure 2 shows (in light blue), for HIBLEO-4 FL, the full set of “relevant” $2^\circ \times 2^\circ$ latitude/longitude cells such that a satellite directly above the centre of a given cell would be in view of at least one of the 497 towered airports in one administration (shown in dark blue in Fig. 2).



Relevant cells for HIBLEO-4 FL

4.2 The next condition to be determined was how many of the ANLE airport networks would be operating on a given ANLE channel at any instant of time. This parameter – termed transmitter duty cycle – directly affects the aggregate power. A range of values from 1% to 15% was proposed by different parties in a HIPERLAN study for an adjacent band, and a compromise value of 5% was suggested⁷. Detailed design studies (beyond the scope of the present study) will be needed to ascertain a reasonable duty-cycle value for an ANLE network. In order to over-bound expected effects, however, a duty cycle of 50% is assumed for this analysis.

4.3 The final parameter, the bandwidth factor, B_f , is the ratio of the victim satellite receiver bandwidth (B_{LEO}) to the interfering ANLE transmitter bandwidth (B_{ANLE}), if $B_{LEO} < B_{ANLE}$; otherwise, $B_f = 1$. It determines the amount of interfering power falling into the victim’s “filtered” bandwidth. As discussed above, the assumed channel bandwidth for ANLE is 20 MHz. This value is larger than the receiver bandwidth of HIBLEO-4 FL (1.23 MHz). Therefore, the bandwidth factor is much less than unity for this type of LEO receiver. Table 2 lists the computed bandwidth factor.

⁷ European Radiocommunications Committee (ERC). Study of the Frequency Sharing between HIPERLANs and MSS feeder links in the 5 GHz band. ERC Report 67. February 1999, Marbella, European Conference of Postal and Telecommunications Administrations (CEPT).

TABLE 2
Bandwidth factor (dB)

	IEEE 802.16e
HIBLEO-4 FL	−12.1

5 Conclusion

For a given combination of ANLE system and satellite type, the aggregate interference power was computed at each orbit grid point. The maximum value of that aggregate interference power was then identified as the “hot point”. On the basis of the assumed worst-case ANLE transmitter power (32.2 dBm/20 MHz), the results are listed in Table 3.

TABLE 3
Aggregate interference from ANLE (802.16e)

Satellite	Interference Threshold (dBm)	Aggregate interference power at hot point (dBm)	Aggregate interference margin below interference threshold (dB)
HIBLEO-4 FL	−125.5 (3%) −127.3 (2%)	−129.4 at 67° N 104° W	3.9 2.1

Annex 2

Aeronautical mobile telemetry

1 Introduction

To accommodate future growth in AMT applications, the 5 091-5 250 MHz band has been selected for evaluation as a candidate band for air-to-ground flight test telemetry operations. This band currently is allocated to the aeronautical radionavigation service (ARNS) and aeronautical mobile satellite (route) service (AMS(R)S) (reference RR footnote No. 5.367). It is also allocated to the FSS (Ref. RR No. 5.444A), limited to feeder links of non-geostationary mobile-satellite systems (non-GSO/MSS). Initial studies have indicated that this band is suited for the type of AMT applications envisioned. ITU-R has determined that the need for additional AMT spectrum is between 100 MHz and 1 GHz, with at least 650 MHz required specifically for air-to-ground flight test telemetry in designated areas. Aeronautical telecommand functions, which require relatively little spectrum, can continue to be accommodated below 3 GHz. Due to technical constraints, spectrum for AMT use must be below 7 GHz. In the following sections, compatibility is demonstrated with existing FSS feeder links.