Electromagnetic Compatibility Between International Mobile Telecommunications System and Aeronautical Telemetry System in the 1429–1518 MHz Frequency Band

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***Abstract*—this paper presents the co-channel compatibility analysis between Aeronautical Mobile Telemetry system (ATS) and International Mobile Telecommunications system (IMT) in the frequency band 1427-1518 MHz. IMT are developing at staggering rates and mobile operators always search for new possible frequency bands to expand their mobile and fixed communication networks (MFCN) and 1427-1518 MHz frequency band is attractive due to the qualified radio propagation conditions. However this band is already operated by other technologies, such as aeronautical networks, radio relay, broadcasting networks, in the neighbouring countries. Co-channel and adjacent channel electromagnetic compatibility have to be evaluated. Electromagnetic compatibility between ATS and IMT is one of the most sensitive issues regarding the decision to identify this band to IMT. This paper was conducted to compare two protection criteria methods, i.e. I/N and C/(I+N).**

Keywords*—*aircraft navigation; 4G mobile communication; electromagnetic compatibility; interchannel interference, UHF propagation; UHF communication

I. INTRODUCTION

In today's world radio frequencies are being increasingly used. There is a growing mobile technology development, thus increasing demand for radio frequencies to mobile services [1], [2]. Mobile operators are often faced with the problem of spectrum scarcity. Companies have the resources to expand their networks, but it becomes increasingly difficult to avoid interference between adjacent stations due to ever growing density of wireless apparatus [3], [4].

At World Radiocommunication Conference in 2015 (WRC-15), the frequency bands 1427-1452 MHz and 1492-1518 MHz were identified globally for IMT in Radio Regulations (RR) in accordance with Resolution 223 (Rev.WRC-15). CEPT has also issued the ECC Decision (17)06 on “the harmonised use of the frequency bands 1427-1452 MHz and 1492-1518 MHz for Mobile/Fixed Communications Networks Supplemental Downlink (MFCN SDL)” and amended ECC Decision 13(03) on “the harmonised use of the frequency band 1452-1492 MHz for Mobile/Fixed Communications Networks Supplemental Downlink (MFCN SDL)”.

All previous studies on this matter have attempted to define the criteria for protection of the ATS and the trigger distances to initiate coordination. However these studies were mainly based on very conservative approaches which would likely lead to overprotection. The purpose of this paper is to determine a protection criterion acceptable for practical purposes [5], [6].

This paper investigates and compares two possible ways to evaluate the electromagnetic compatibility in co-channel operation between MFCN BS transmitter and ATS ground station receiver based on two protection criteria methods – I/N and C/(I+N). In general, when the information is only available about system sensitivity, I/N criteria could be used. In cases where information is also available on the link budgets for telemetry system, appropriate way to define permitted levels of interference would be the C/(I+N) method.

The paper investigates and proposes the more efficient approach (more efficient use and share of spectrum) to evaluate the electromagnetic compatibility in co-channel operation between MFCN BS transmitter and ATS ground station receiver – the resource of frequencies are limited and better understanding of maximum interference limits would lead to more developed radio services in each country.

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II. Technical Characteristics of ATS System

Tracking-type antenna system – main technical implementation of the ground station ATS works only on receiving data from the tested aircraft by slowly tracking the movement of the aircraft. In this case, ATS ground station antenna pattern is according to the Recommendation ITU-R M.1459-0 [7].

Radar-type antenna system – another distinctive feature of the aeronautical mobile telemetry system is the use of pulse-code signals, which allows in some cases to partially combine the functionality of radar and ATS. Therefore, ATS stations can have as a separate functional implementation and be an additional component of radar equipment. In particular, the reflector-type radar antenna and separate components of the radar feeder system are used both by the radar and by the ATS station. In this operating mode the data from the tested aircraft is received by synchronised rotation with radar. In this case, ATS ground station antenna pattern is according to Recommendation ITU-R M.1851-0 [8].

The characteristics of aeronautical mobile telemetry system are provided in Table I.

TABLE I. ATS SYSTEM CHARACTERISTICS

Parameter	**Value**
Characteristics of ATS on-board transmitter	
Maximum e.i.r.p., dBW	38
Occupied bandwidth of emission, MHz	1/3/5
Operation frequencies, MHz	1429-1518
Maximum antenna height, m	10000
Maximum antenna gain, dBi	6
Antenna pattern on -3 dB level, º	Non-directional or low directional
Main lobe direction	Low hemisphere
Transmission path length, km	up to 320
Characteristics of ATS ground (terrestrial) receiver	
Antenna height, m	10
Polarisation	linear
Thermal noise floor (kTB), dBW/5 MHz	−135.98
Noise figure, dB	7
Maximum antenna gain, dBi	30
Feeder losses, dB	3
Antenna pattern on -3 dB level (average), º	Vertical pattern: 10º; Horizon pattern: 4
Main lobe direction, °	Azimuth: 0-360
C/N ratio, dB	13

According to the RR footnote No. 5.342, the service area of ATS stations operating in 1429–1535 MHz frequency band is limited to the national territory. As the service area is determined by the maximum radius of the system, which in turn is limited by the power budget of the link from the aircraft to the ground level, hence the possibility of data receiving from the aircraft is determined by the flight path of the aircraft within the national territory. Thus, in the course of research, the scenario of the interference from the IMT BS should take into account the effect of interference towards both the main and side lobes of the antenna pattern of the ATS station.

III. Technical Characteristics of Mobile System

The characteristics of mobile service systems are according to Report ITU-R M.2292-0 [9] and are extracted in Table II.

For the analysis in this paper the channel bandwidth of 5 MHz will be considered, however other channel bandwidth values also may be under consideration.

TABLE II. MFCN SYSTEM CHARACTERISTICS

IMT base station (BS) characteristics	
Cell radius	4.75 km
Antenna height	30 m
Sectorisation	3 sectors
Downtilt	3 degrees
Frequency reuse	1
Antenna pattern (see Annex 1)	Recommendation ITU-R F.1336 [10] (recommends 3.1) $k_a = 0.7$, $k_p = 0.7$, $k_h = 0.7$, $k_v = 0.3$ Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336
Antenna polarisation	Linear / ±45 degrees
Feeder loss	3 dB
Channel bandwidth	5 MHz
Maximum base station output power (5 MHz)	43 dBm
Maximum base station antenna gain	18 dBi
Maximum base station output power/sector (e.i.r.p.)	58 dBm

IV. ATS System Operation

A. Protection Criteria

The maximum permitted interference power level at the receiver input may be specified according to one of the two criteria [11], [12]:

- "I/N" criterion – where the maximum permitted interference is defined in relation to the thermal noise level (I is interfering signal and N is system thermal noise power);
- "C/(I+N)" criterion – where the value of the maximum permitted interference is defined in relation to a target reduction in the receiver's signal-to-interference-plus-noise ratio (C is wanted signal, I is interfering signal, N is thermal noise). This criterion might be appropriate if the receiver operates at some margin above its minimum sensitivity and in cases where information on the link

budgets is available.

B. Coordination Trigger

The main goal of international cross-border coordination is to allow each of the countries a mutual and optimal use of the radio spectrum. Different countries may wish to adopt different approaches to cross-border coordination.

In order to calculate the effect of possible harmful interference a parameter for permissible interference impact on the receiving station needs to be determined. Coordination triggers could be defined as [13]:

a) maximum permitted field strength levels (land mobile and broadcasting services),
b) coordination distances (broadcasting and fixed services, radars),
c) coordination area (broadcasting and space services), triggering power flux density (fixed service).

This paper will analyse the field strength level method.

The required maximum permitted field strength level for the protection of ATS ground stations from interference could be calculated in one of two following ways:

- at the location of ATS station. This should be seen as the primary method since the main objective is to protect the station in the place where it is located. The information on the location of these stations can be obtained from the Master International Frequency Register (MIFR) or from the administrations concerned;
- at the borderline. This should be agreed between neighbouring countries concerned. In such situation the requirements for the protection of ATS ground stations should not impose higher levels comparing to the case of known location. This provides implementation flexibility for the country using ATS without creating additional constraints to the mobile service in the neighbouring countries.

V. ATS System Operation

A. Interference Analysis for Different Protection Methods

The following analysis investigates interference from MFCN BS to ATS ground station based on protection criterion by methods I/N and C/(I+N).

For the I/N method ATS receiver's sensitivity threshold according to Table I is −135.98 dBW (when the interference to noise ratio (interference criterion) at 1 dB sensitivity degradation is −6 dB).

For the C/(I+N) method, according to the same table, the transmission path length of the ATS system is up to 320 kilometres and the required C/N is 13 dB.

In order to obtain field strength level at the ATS receiver, the transmission loss from aircraft transmitter should be calculated by the formula from Recommendation ITU-R P.525-2 [14] for the frequency under consideration (1474 MHz is used in this paper) and for isotropically received power involving no feeder loss. To obtain the level at the reference point of the receiver, antenna gain and feeder losses should be taken into account.

B. Single and Aggregate Interference Simulations

Due to variety of border shapes, two possible simplified borderline cases could be analysed: straight line type and a ring type (see Figure 1). For the first case (straight line), the ATS system (ground station and aircraft station) could be placed either perpendicular (scenario 1) or parallel (scenario 2) to the borderline. These two cases could assess the interference from MFCN into main lobe and side lobes of the ATS antenna pattern. This paper will analyse in details Case 2 and Scenario 2 (parallel) of Case 1. Scenario 1 of Case 1 will be investigated separately.

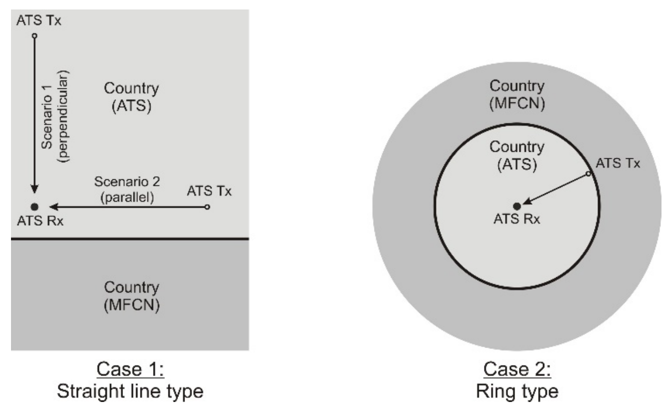

Fig. 1. Borderline cases.

C. Scenario 2 (parallel) of Case 1

In scenario 2, see Fig. 2, five network clusters are placed along the borderline: simulations for 1 cell or BS (3 sectors) as interferer and 19 cells or BSs (57 sectors) as interferers (the maximum number of cells or BSs in SEAMCAT cluster, version 5.3.0) are performed. Since the cell radius is 4.75 km, then the radius of one cluster will be 38 km, consequently, this would cover an area of 4536 km^2. The interference from each of the network is calculated at ATS ground station location. ATS ground station distance from the borderline is 10 km, antenna height is 10 m, ATS aircraft station is 320 km from ATS ground station alongside the borderline, aircraft altitude is 10000 m. The ATS aircraft distance was chosen to account the lowest wanted signal which also corresponds to the lowest C/(I+N).

The propagation model for the interfering Received Signal Strength (iRSS) path from MFCN BSs to ATS ground station is in accordance with Recommendation ITU-R P.1546-5 [15] and Recommendation ITU-R P.525-2 [14] is used for wanted signal path from ATS on-board transmitter. Three different antenna patterns used: according to recommendation M.1459 and M.1851 with cos and sin cos antenna distribution pattern types.

The results from each clustered network and aggregated from all networks are provided in Table III for both type of ATS systems (radar-type antenna and tracking-type antenna).

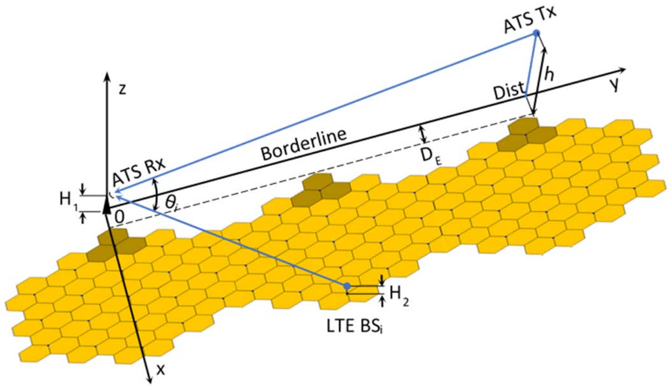

Fig. 2. Aggregate interference from MFCN clusters (Scenario 2).

TABLE III. INTERFERENCE LEVELS FOR SCENARIO 2

iRSS, dBm	**Antenna pattern**		
	M.1459	**M.1851_cos**	**M.1851_sinc**
iRSS1	−105.64 dBm	−118.13 dBm	−98.13 dBm
iRSS2	−114.71 dBm	−138.18 dBm	−118.17 dBm
iRSS3	−117.08 dBm	−154.31 dBm	−135.02 dBm
iRSS4	−120.79 dBm	−158.74 dBm	−142.79 dBm
iRSS5	−123.23 dBm	−161.17 dBm	−148.34 dBm
iRSS6	−126.22 dBm	−161.42 dBm	−153.10 dBm
iRSS total	−104.66 dBm	−118.09 dBm	−98.09 dBm

It could be noted that for this type of scenario the highest interference is from the first network which is placed closest to the ATS. The results also indicate that protection requirement of I/N = −6 dB for ATS with antenna ITU-R M.1459 is exceeded only by 0.36 dB and for the ITU-R M.1851_sinc antenna type by 7.87 dB. But for the ITU-R M.1851_cos antenna type iRSS is below the protection requirement by 12.3 dB.

D. Surrounding Network (ring) Case

In addition to the above analysis there could be some cases when mobile networks could possibly surround ATS ground station therefore the ATS receiver could experience the interference not only from main lobe and side lobes but also from back lobes.

The geographical separation of the victim receiver and interferer LTE network was modelled by specifying the modelled cellular cell as centred "infinite" network. This is illustrated in the Figure 3, where DE is ATS Rx distance from the network edge, DC is the distance from the hexagonal cluster centre, RC is the cluster maximum range, and α is the central (network visibility) angle. The ATS aircraft is considered to be above the edge of the network, i.e. at DE, this corresponds to the borderline.

It is obvious that in case of any surrounding network, iRSS will depend on the BS arrangement inside the LTE cluster (especially in near distances, DE, from the cluster), therefore, and for getting the more even distribution of interfering BS over the cluster area, the LTE-C cluster was rotated around its centre and iRSS was calculated every 5 degrees. It is equivalent to the ATS antenna rotation around the cluster keeping the unchanging distance and antenna pointing direction to the cluster centre. A set of simulations were done using ATS Rx antenna (in accordance with Recommendations ITU-R M.1459 and M.1851) and aggregated iRSS were calculated. Then the averaged value of iRSS were evaluated for each antenna. It depends on the distance DE and aircraft altitude. The results of such simulations are presented in Table IV.

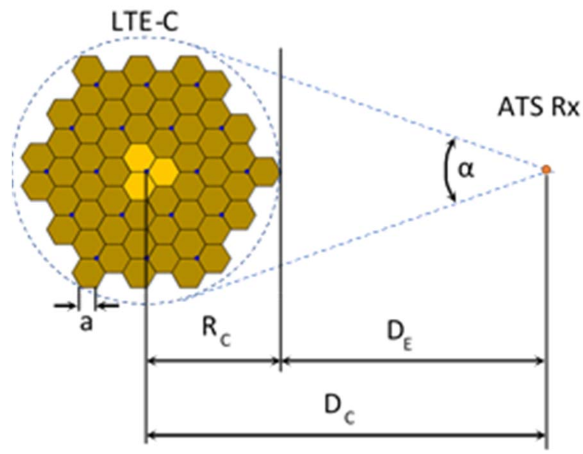

Fig. 3. Layout used in SEAMCAT simulation.

Knowing the iRSS average from the LTE cluster, the interference of any surrounding network can be estimated. This can be achieved by introducing the interfering angular power flux density of interfering network which directly follows from the calculated by means of SEAMCAT average value of the iRSS.

Thus, having defined the power flux density value ρ, the whole interfering signal strength iRSS produced by a ring-shaped network of the width of 2RC in the range of φ varying from 0 to 360 degrees with one degree angle increment (Figure 4) can be calculated using equation:

$$iRSS[\delta B\mu] = 10\, log\left(\rho \cdot \sum_{i=0}^{359} G(\phi_i, \theta_i)\right) \qquad (1)$$

where $G(\varphi_i, \theta_i)$ denotes the linear antenna gain factor, and φi and θ_i are antenna pattern azimuth and elevation angles, respectively.

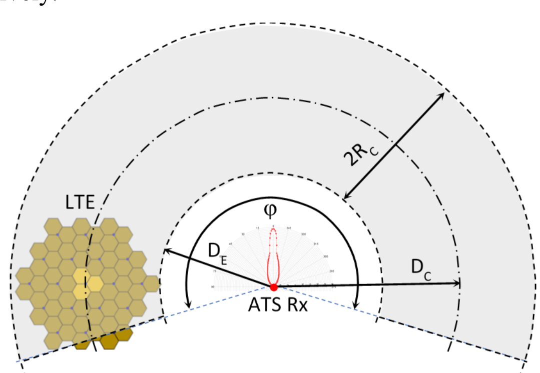

Fig. 4. Effective ring-shaped LTE network.

The results of interference from surrounding network when ATS ground station uses antenna patterns according to Recommendation ITU-R M.1459 (tracking-type antenna system) and Recommendation ITU-R M.1851 (radar-type antenna system) are provided in Table IV when ATS ground receiver antenna height is 10 m and MFCN BS antenna height is 30 m. Three radius DE (10, 40 and 80 km) of surrounding networks are studied. This corresponds to the area of 314 km2, 5026 km2, 20106 km2 and could be compared to the territory of Riga city, twice as country of Luxembourg and Slovenia respectively, surrounded by MFCN. The comparison of ring-type network results with the clustered network case is also provided in Table IV. Since for the clustered network case simulations were performed when the nearest base station (reference cell) one of three sectors was looking directly to ATS, therefore to compare the results with ring type network the averaged value of iRSS for clustered network at these three radius DE under investigation has been extracted.

TABLE IV. SIMULATION RESULTS

Antenna pattern	**h, km**	**DE, km**	**±φfront, deg**	**iRSSfront, dBm**	**iRSSback, dBm**	**Diff1, dB**	**iRSSring, dBm**	**iRSSclust_max, dBm**	**iRSSclust_av, dBm**	**Diff2, dB**
tracking-type antenna system (M.1459)	2	10	46	−95.69	−101.21	5.51	−94.62	−91.98	−96.13	1.51
		40	47	−90.95	−108.62	17.67	−90.88	−86.29	−91.05	0.17
		80	47	−93.81	−113.76	19.95	−93.77	−91.13	−93.94	0.17
	10	10	19	−109.25	−100.57	−8.67	−100.02	−105.07	−107.47	7.45
		40	46	−104.90	−108.93	4.02	−103.46	−104.39	−106.13	2.67
		80	47	−105.82	−113.78	7.96	−105.18	−105.29	−107.04	1.86
radar-type antenna system (M.1851_cos)	–	10	22	−108.00	−112.22	4.22	−106.60	−97.75	−107.95	1.35
		40	22	−117.84	−121.88	4.05	−116.39	−112.11	−117.95	1.56
		80	22	−123.05	−127.00	3.95	−121.58	−119.38	−123.36	1.78
radar-type antenna system (M.1851_sinc)	–	10	29	−107.33	−101.16	−6.17	−100.22	−97.72	−107.29	7.07
		40	29	−115.57	−109.35	−6.22	−108.42	−111.97	−117.44	9.02
		80	29	−119.18	−112.93	−6.24	−112.01	−119.16	−122.97	10.96
radar-type antenna system (M.1851_cos), ant_downtilt_2 degree	–	10	23	−91.20	−110.68	19.48	−91.15	−81.14	−91.21	0.06
		40	23	−100.66	−120.10	19.45	−100.61	−94.83	−100.68	0.07
		80	23	−105.91	−125.34	19.43	−105.87	−101.95	−105.96	0.09
radar-type antenna system (M.1851_sin), ant_downtilt_2 degree	–	10	29	−90.94	−92.59	1.66	−88.68	−81.14	−90.97	2.29
		40	29	−100.04	−101.68	1.63	−97.77	−94.77	−100.40	2.63
		80	29	−105.01	−106.63	1.62	−102.74	−101.81	−105.69	2.95
radar-type antenna system (M.1851_cos), ant_downtilt_5 degree	–	10	23	−83.43	−110.35	26.91	−83.43	−73.40	−83.44	0.01
		40	23	−92.81	119.71	26.90	−92.80	−87.00	−92.82	0.02
		80	23	−98.06	−124.95	26.89	−98.05	−94.10	−98.09	0.04
radar-type antenna system (M.1851_sinc), ant_downtilt_5 degree	–	10	29	−83.21	−91.03	7.82	−82.54	−73.39	−83.23	0.69
		40	29	−92.46	−100.27	7.81	−91.79	−86.94	−92.57	0.78
		80	29	−97.61	−105.41	7.80	−96.94	−93.96	−97.83	0.89

Where h is ATS aircraft altitude, φfront is antenna pattern angle covering main lobe and side lobes, iRSSfront is received interference level for φfront, iRSSback is received interference level for the rest of antenna pattern, Diff1 is the difference between interference level of iRSSfront and iRSSback, iRSSring is overall interference level from ring type network, iRSSclust_max is maximum interference level from clustered network, iRSSclust_av is average interference level from clustered network, Diff2 is the difference between iRSSclust_av and iRSSring.

From the Table IV it is observed that for tracking-type antenna ATS system (i.e. ITU-R M.1459 antenna pattern) when surrounding network radius, DE, is 10 km and altitude of aircraft is 10000 m and also for radar-type antenna system with sinc antenna distribution pattern type for horizontal antenna pattern the main interference is received by back lobes of ATS antenna. For all other cases in the Table IV the main interference is received by main lobe and side lobes of ATS antenna and the interference from back lobes is lower from 4 dB up to 20 dB. For the radar-type antenna system antenna if antenna is downtilted by 2 and 5 degrees the interference will increase. We can also observe that the interference from surrounding network is higher by 0.17–10.96 dB. It should be highlighted that at the same time the protection requirement of $I/N = -6$ dB for radar-type antenna systems (both antenna distribution pattern types for horizontal antenna pattern) is not exceeded for the case of no downtilt.

VI. Conclusions

Methods I/N or C/(I+N) could be considered for the evaluation of interference from MFCN BSs to ATS stations. In case of C/(I+N) method a proper attention should be drawn to margin of wanted signal from aircraft in order to account signal losses related with aircraft maneuverer, propagation conditions, etc.

According to the RR No. 5.342 the ATS service area is restricted by the national territory only. This allows to consider the impact of MFCN BSs to the ATS station on the side and back lobes of the ATS station antenna as the main scenario. Consequently, there is an opportunity to relax the requirements for the maximum permissible interference field strength level at the antenna input of the ATS station.

Due to random nature of the MFCN interference and due to the rotation of the antenna of the ATS station the measurements conducting at the locations of ATS stations could be complicated or even impossible, therefore calculation should be treated as the main instrument to assess possible interference signal.

The results of interference from surrounding network could be applied in case of possible aggregate interference from more than one neighbouring country, and all concerned parties have to conduct a work to minimise possible harmful interference. In this case it is recommended that all affected countries take all necessary measures to avoid harmful interference while providing possibility to use the frequency band for other countries with less possible restrictions.

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