Frequency Band Sharing : Utopia or Reality ?

Towards specification of operational scenarios

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ABSTRACT

In order to offer an increasing number of equipment access to the electromagnetic spectrum, ITU increasingly authorises the sharing of bands. This will inevitably result in a risk of unintentional friendly interference.

The electromagnetic compatibility (EMC) of equipment will no longer be based on the sole shape of transmitted spectra. As a result the compatibility has to be previously estimated using realistic scenarios of dynamic electromagnetic environment, the latter forming an essential part of EMC.

1-INTRODUCTION

The increasing numbers of equipment using the electromagnetic spectrum obliges ITU (International Telecommunication Union) to place more constraints on frequency allocation.

The main condition of success of this policy has so far been that the transmitted spectra were confined within limits representing the spectrum extensions just about necessary to fulfil the functions of each piece of equipment, the main objective being to obtain the «best spectrum efficiency».

Nowadays ITU tends to increasingly authorise a greater sharing of bands.

All manufacturers will then be obliged to insist not only on the limits and levels of transmitted spectra according to ITU recommendations but also on a higher risk of unintentional interference.

The previous necessary conditions are no longer sufficient ; in addition it seems difficult to put even more constraints on transmitters : the dynamic aspect of the electromagnetic environment has to be taken into account as well as its consequences on the performance of all equipment.

One has also to remember that radio-astronomy, and other similar radio sensing techniques (i.e. receiving not transmitting) are unique in their use of precious spectrum resources : all that is required is clear access to the frequency spectrum, because radio astronomy and radio sensing techniques are highly vulnerable to environmental pollution.

The increasing number of equipment entails the need to share the same band in the same geographical area between various services. This is contemplated, for example, for the operation of UMTS/IMT 2000 network and Air Traffic Control Radio-Navigation Systems in the 2700-2900 MHz band.

The usual optimal bands for radar (L, S, X, Ku) which are of course the most frequently used for civil and military applications, are now becoming also optimal for new Services. This is for example the case in the S band for mobile phones and the Ku band for TV broadcasting by satellite. This latter example is typical for the extension over a large area.

The compatibility of equipment is important, in particular to ensure the integrity of certain Services (Instrument landing equipment). However this compatibility does not only apply to a few isolated fittings, but to a whole complex environment which comprises a) a large number of fittings and b) a great variety of operations.

In order to meet the challenge resulting from this evolution, it is necessary to proceed in two stages, if necessary in a recurrent way.

First, for each radar equipment review the actual conditions of false alarm (FA) and non-detection/false dismissal (ND), which result from the simultaneous presence of several signals in the receiver.

Radar engineers have been knowing for long that the performance (FA/ND) based on gaussian white noise have only a technical interest for the first tuning of the equipment. Today it is necessary to go further and ensure no-interference from simultaneously operating equipment. It is moreover reasonable to foresee cases of interference which have to be taken into account in the general operation of systems.

Second, for the various kinds of equipment currently using the same band in the same area each one must be tested separately in order to verify that its performance is obtained in a genuine dynamic environment. This will lead **to the need of setting up realistic scenarios of dynamic electromagnetic environment**.

Some techniques do already exist for military applications, but they have now to be completed and applied systematically to all equipment including the civil ones.

Therefore, the real effort has currently to be put on the working out of dynamic electromagnetic models for these scenarios.

2-ITU ORGANISATION

The International Telecommunication Union (ITU) is organized in three sectors,

Radiocommunication

Telecommunication standardization

Telecommunication development.

All ITU work in the field of radiocommunications has been consolidated in the Radiocommunication Sector (ITU-R).The aim of the ITU-R is to ensure rational, equitable, efficient and economical use of radio-frequency spectrum and satellite orbits. The world is divided in three Regions,

Region 1 Africa and Europe,

Region 2 Americas

Region 3 Asia-Pacific.

There are seven lasting Study Groups (SG) which draft the technical bases for Radio-communication Conferences, i.e. SG7 "Sciences Services".

The use of electromagnetic spectrum is a sovereign right of State; in order to ensure the best use of the electromagnetic spectrum and avoid interference, States respect world-wide rules**,**

The Radio Regulations (RR).

Their evolution is decided upon by the World Radio-communications Conference (WRC) organised every three to four years (2000, 2003, …) by the International Telecommunication Union (ITU)

The band sharing is established and organized at three levels

- International (ITU). The band sharing is decided upon between Services (Fixed, Satellite, Radio-location,…) : decisions taken by the WRCs are compulsory for States in the same way as international treaties.
- Regional (CEPT, CITEL, APAT and some others). These organisations regroup States following their geographic location in the three Regions of the world determinted by ITU. It is within these three organisations that are :

a) Prepared and harmonised the positions of Governments before the WRCs and,

b) Determined the local conditions of applications after the WRCs

- National (189 members States of ITU with voting rights at WRCs). At national level are :

a) Prepared positions at both International and regional levels

b) Allocated frequencies between various national users.

Although it is always possible to vote, all Working Groups and Conferences of ITU prefer to seek compromises which allow to reach consensus. This explains the importance of the work done in the three Regional organisations (CEPT, CITEL, APAT and some others) although they don't have voting rights at the ITU.

The band sharing is no novelty and was founded until recently in three rather vague rules :

1) Operational conditions of each Service are different,

2) Certain levels of interference are accepted at low level in the long term, at more intensive level in the short term,

3) Certain constraints are compulsory : regions of co-ordination, power limits, types of orbits, etc, …

The applications of these three rules are, for example, illustrated in the domain of territorial sharing as follows :

- If the location of transmitting or receiving stations is known they are co-ordinated station by station
- If the location of stations is unknown Service areas are defined and co-ordinated.

However nowadays the requests for access to the frequency spectrum are such that these rules have become obsolete, which has led to a rearrangement of the spectrum. For example it is roughly estimated that the number of radio-communication sites in France (550 000 km^2) increased from 20 000 in 1995 to 50 000 in 2000.

This new arrangement favors mainly commercial applications but is detrimental to

Security and Defence users at the very moment when it has become necessary to implement high instantaneous bandwidth signals (larger than 10% of the center frequency). The situation is due to the evolution of primary radars toward high resolutions in order to implement non co-operative target recognition (NCTR) methods.

3-AFTER WRC 2000 SITUATION

Following WRC 2000 the main items currently under discussions are as follows :

3.1 Increase of the number of applications in L -band

a) Radio-Navigation satellite Service RNSS

- GPS (USA)
- GLONASS (Russian federation)
- GALILEO (Future European System)

b) IMT 2000 (3rd generation mobile telephone voice and data).

Three bands are allocated in Region1

806 - 960 MHz

1710 -1885 MHz

2500 – 2690 MHz

c) High Density Fixed Service or local Multi-point Distribution System (LMDS)

Example : Bluetooth

Decisions taken at WRC 2000 and items on the Agenda of the next WRC (Caracas, 2003) have a direct bearing on the compatibility of the following equipment :

Ground radar (civil and military)

DME

MIDS

Tactical military communication

SAR on board satellite

Fixed communications

Digital TV (analog and digital TV : band sharing)

Possible extension of IMT 2000.

3.2 Possible sharing of S-band (2.7-2.9 GHz)

The future extensions of IMT 2000 leads to the establishment of rules of compatibility with ATC radars or even their moving to the band 2.9 – 3.1 GHz.

3.3 Re-arrangement of C-band (5 GHz)

The introduction of HIPERLAN (Local Access Network) makes it necessary to rapidly examine the compatibility with radars or even exclude them from this band.

3.4 X and K bands (10-30 GHz)

The opening of these bands to non-geostationnary satellite of the SFS, particularly SKYBRIDGE has an impact on many systems.

3.5 40 GHz band

The 41 GHz band will require co-ordination between interactive multimedia applications and telecommunications.

3.6 Radiated spectra

The conformity of transmitted spectra with ITU recommendations will be reinforced in 2003. (Appendix APS 3 to the RR).

4-ITU APPROACH

The electromagnetic compatibility (EMC) has three general aspects

- Fundamental EMC (lightning)
- Functional EMC (detection, EW, RL, RN, …)
- Safety EMC (personal, ammunition)

In the following presentation we will only speak about functional EMC directly linked to the operation of a given equipment, namely radar among other equipment of different nature. The functional EMC applies to all equipment, however since ITU can not foresee either all equipment nor their detailed operating conditions, it limits its role to specify the intrinsic characteristics of radiating mask to prevent unwanted emissions. This is why the Appendix APS3 of the RR is so important («Table of maximum permitted spurious emission power levels»).

Unwanted emissions (RR – Article S1.146) consist of spurious emissions and out-of-band (OOB) emissions.

Spurious emissions (RR-Article S1.145)

Emissions on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, inter-modulation products and frequency conversion products, but exclude out-of-band emissions.

Out-of-band (OOB) emission (RR-Article S1-144)

Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions.

Necessary bandwidth (Bn) (RR- Article S1-152)

For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information required under specified conditions.

In accordance with Appendix APS3 to the RR any emission outside the necessary bandwidth, Bn, which occur in the frequency range separated from the assigned frequency of the emission by less than 250 % of Bn of the emission will generally be considered an OOB emission. Likewise all emissions, including inter-modulation products, conversion products and parasitic emissions which fall at frequencies separated from the centre frequency of the emission by 250 % or more of the Bn of the emission will generally be considered spurious emissions.

In principle the ITU approach is simple :

1st calculate the spectrum extension of the necessary bandwidth Bn, for example for radars see formulae in ITU Rec. SM 853-1.

2nd the spurious emissions are those outside the spectral domain equal to + or - 2.5 Bn centered on Bn.

3rd verify that the level of spurious emissions is in conformity with table of Appendix APS 3.

What is above all important is the arbitrary border line between OOB and spurious emissions ; the latter must have a level of – 60 dB, in relation to the maximum of the spectrum for radars. (It is a little more complex than that, it is just to give an order of magnitude).

5-TOWARDS SPECIFICATION OF OPERATIONAL SCENARIOS

The ITU approach which could seem very arbitrary offers the advantage to provide a common basis for all transmitters, it would appear that for many transmitters the specified levels and frequency limits are already difficult to satisfy.

However in order to evaluate the capability of an equipment to function in a shared band there are still two steps to be cleared :

1st the evaluation of the interference potential between a radar and an equipment of a different nature both in static situation

2nd the evaluation of the dynamic performance of the radar operating according to a likely scenario.

Defence equipment is usually evaluated in a jammed electromagnetic environment (EW). At present the evaluation has to be enlarged to all equipment within or near its band of operation before designing it.

It is recalled that apart from the security aspects the objective of imposing spectral emission masks to transmitters is not only to facilitate the compatibility between systems but also to forecast it .

In order to optimise the choice of these masks one has to take into account both the inherent specifics of each type of transmitter and the operating conditions of these systems. Indeed the spectrum is not the sole dimension of compatibility ; compatibility must be resolved when systems are radiating and therefore depends mainly on characteristics of the antennae and their spatial and temporal modes of operation.

The modes of functioning of radars are the opposite of those of many other Services which aim at communicating with the largest possible number of customers at any time. Consequently these other Services have to spread out their emissions in both space and time.

By contrast the radar, in order to fulfil its role of detecting /resolving/spotting/ identifying concentrates its emitted energy toward the target during a short duration compared to the time of reception (a few percent).

This stresses the fact that the amount of information to be obtained from an observation is closely related to the accuracy of the experimental set-up [1].

From the four possible combinations of high and low accuracy and high and low probability there is only one that applies to the radar, high accuracy /high probability.

By contrast high accuracy of observations is irrelevant for most services, high probability being their main objective.

Spectrum efficiency : a mythical expression.

Plenty of papers including documents of ITU are studded with the expression «spectrum efficiency". For decades spectrum efficiency has been discussed, but there is no generally accepted definition of it or measure of spectrum efficiency covering all Services including radars.

It is generally, but not universally, agreed that the components of spectrum efficiency should be frequency bandwidth, physical space (such as area or volume), time and eventually polarisation [2,3].

In the domain of communications a measure of spectrum efficiency, the general formula

$$\frac{\text{Communication achieved}}{\text{Spectrum space used}}$$

is quite acceptable.

But to accommodate radar or radio-navigation systems the general formula

$$\frac{\text{Information delivered}}{\text{Spectrum space used}}$$

is certainly much more difficult to handle : it remains a theoretical difficulty until now.

6-EXAMPLES

MIDS is probably one of the very few examples to be designed from the start to be operational with other equipment of different nature.

The MIDS was designed and built for operating within the frequency band 960 – 1215 MHz already filled up with several systems : DME, TACAN, IFF, Mode S, TCAS, transponders. MIDS is compatible with all these systems thanks to the fact that main features were defined from the very beginning of the project. This was however very expensive. This is not always possible.

6.1 Interference potential between IMT –2000 and ATC radars

Air traffic control (ATC) services are facing serious saturation problems, especially in en-route control. Major changes will have to be implemented to maintain a sufficient level of safety ; of course improvements can be expected from each step of the control process, but to obtain , overall understanding of the whole system, a few traffic simulators covering several steps of traffic management process have been developed. They can be used to determine a statistical model of the number of conflicts and to propose some conflict resolution methods working with different time horizons, i.e. to evaluate the probability to decrease significantly the separation between aircraft [4].

Various systems (GPS, FMS, DL, …) will provide pilots and controllers with more and more information, but radars are the only device likely to provide controllers with self contained information ; contemplating the possibility for radars to share the 2700-2900 MHz band with IMT 2000 network is taking the risk of deteriorating or even LOOSING this independent source of information which could be vital in case of events that would not have been anticipated such as intruders. Before deciding the sharing of the band it would be necessary to take all useful steps to evaluate the probability of running a great risk of disturbances.

It happens that the above mentioned traffic simulators are capable to furnish not only statistical data gathering algorithm test and validation, but also scenarios assessments. That is exactly what is needed, in three steps :

- To test the radiating characteristics of equipment (emitted spectrum density, antenna diagram…) according to ITU Radio-communications,
- To evaluate the sensitivity of receivers in relation to transmitters and the consequences on false alarm and probability of no-detection,
- To apply the gathered data to selected scenarios in order to evaluate the impact on the operational aspect.

6.2 Sharing the L-band

The decisions at WRC 2000, held in Istanbul (May 8 -June 2, 2000) clearly showed that representatives from countries around the world valued radio-navigation satellite Services (RNSS) ; as a result, mobile satellite Service (MSS) will need to look elsewhere to accommodate their future spectrum needs. The band 1559 to 1610 MHz is currently used for RNSS : US Global Positioning System (GPS) and Europe's proposed GALILEO.

Another key GPS issue was a space–to-space allocation given by conferees for the 1559-1610 MHz band, along with the band 1215 to 1260 MHz. These allocations will allow satellite to use GPS and the Russian GLONASS system to navigate in space. A third important development for GPS was an additional allocution to support a third GPS civil signal. The band 1164 –-1215 MHz was allocated to down-links for this service. The GPS signal will be centred at 1176 MHz. GALILEO plans to use the band 1191 – 1215 MHz in addition to other RNSS allocations, that is to say :

1260-1300 MHz for space-to-space down-links

1300-1350 MHz for Earth-to-space up-links

In a fourth GPS issue it was agreed to phase out the use of the 1559-1610 MHz band by other communication system in order to avoid interference with RNSS : this change will force fixed microwave links to vacate the band by 2015.

The sharing between RNSS radio-beacons and radars operating in the radio-location and radio-navigation Services requires detailed analysis, the more so since the radars in L-band (ATC or Air Surveillance) are powerful and some of them on board of ships. Fortunately they are sparse on the surface of the Globe. Nevertheless the results are that on the Earth separation distances of up to 30 km might be required to preclude interference depending upon characteristics and geographical placement. In addition on board satellite the receivers might be partially desensitised if their current design is not improved. This is typically a case which requires a world-wide scenario.

6.3 UAV

Radars on board UAVs are particularly subject to functional EM compatibility with other systems.

Indeed most of them operate either on low band (UHF-band) in order to detect targets underneath vegetation or in high bands (Ku or Ka) so as to obtain a high resolution for target imagery (SAR technique) ; in both cases they are in competition with civil systems of radio-communications or direct broadcasting.

The three steps already mentioned are very important if one wants to understand the phenomena of interference :

- Spectral power density of emitted signals vs. space
- Sensitivity of receivers with respect to surrounding transmitters
- Scenarios

Be it for UAVs themselves or surrounding transmitters there are scenarios which already exist both of UAV trajectories and radio-mobiles cellular network [5].

7-CONCLUSION

Radars designers when conceiving a new equipment must take into account right from the start the spectrum congestion.

Although the radar designers are well aware of the EW techniques it is difficult to apply them to an electromagnetic environment which is becoming more and more dense and changing.

Indeed the development cycle and life of equipment are frequently very different. In particular big radars have a higher life duration than several generations of radio-communication equipment. By contrast the technical specifications of the latter are generally well known because they have to satisfy international standards.

Radar designers must therefore focus their efforts on observing the electromagnetic environment, analysing its characteristics and developing techniques of interference elimination. They have to participate in particular in deepening the knowledge of both ends of this process : models of scenarios and specification of spectral density masks.

The main objective of the RR is to determine for each Service *the degree of protection that it requires but not more.*

In order to avoid interference, the solution could be a splitting up of the spectrum between an ever increasing number of systems. Such an extreme fragmentation has two major disadvantages :

-The management of the spectrum becomes more and more difficult,

-The performance of certain systems such as radars will tend to decrease significantly as the bandwidth will be more and more reduced.

In a distant future, an other solution could be a dynamic handling of frequency spectrum; this concept is however far from being ripe; the latter approach would be a real revolution with respect to current practice.

Band sharing will increasingly become a reality because we are compelled to do so, necessity knows no law ; what so far still remains an utopia is a systematic setting up of scenarios in order to evaluate equipment in a realistic electromagnetic environment.

Therefore, the best investment to be made from now on is building realistic scenario models on which all parties can agree.

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9-GLOSSARY

APAT: Asia-Pacific Telecommunity(Region 3)
BLUETOOTH uses radio chips over the 2.4 GHz band to unify communication between different types of electronic devices without the use of cable connections
CEPT: Conférence Européenne des Postes et Télécommunications (Region1)
CITEL: Comision Interamericana de Telecommunicationes (Region 2)
DME: Distance Measuring Equipment
EW: Electronic Warfare
MIDS: Multifunctional Information Distribution System
RL: Radio-Location
RN: Radio-Navigation
UHF: 0.3-3 GHz; paragraph 6.3 points at the lower part of the band.
UMTS: Universal Mobile Telecommunications System, UMTS 2000 is the third generation mobile telephone, also known as IMT 2000.

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Jean J.Isnard spent most of his professional life at ITT and Thalès (former Thomson-Csf) Group. Presently he is collaborating with URSI (International Union of Radio Science) in its F

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