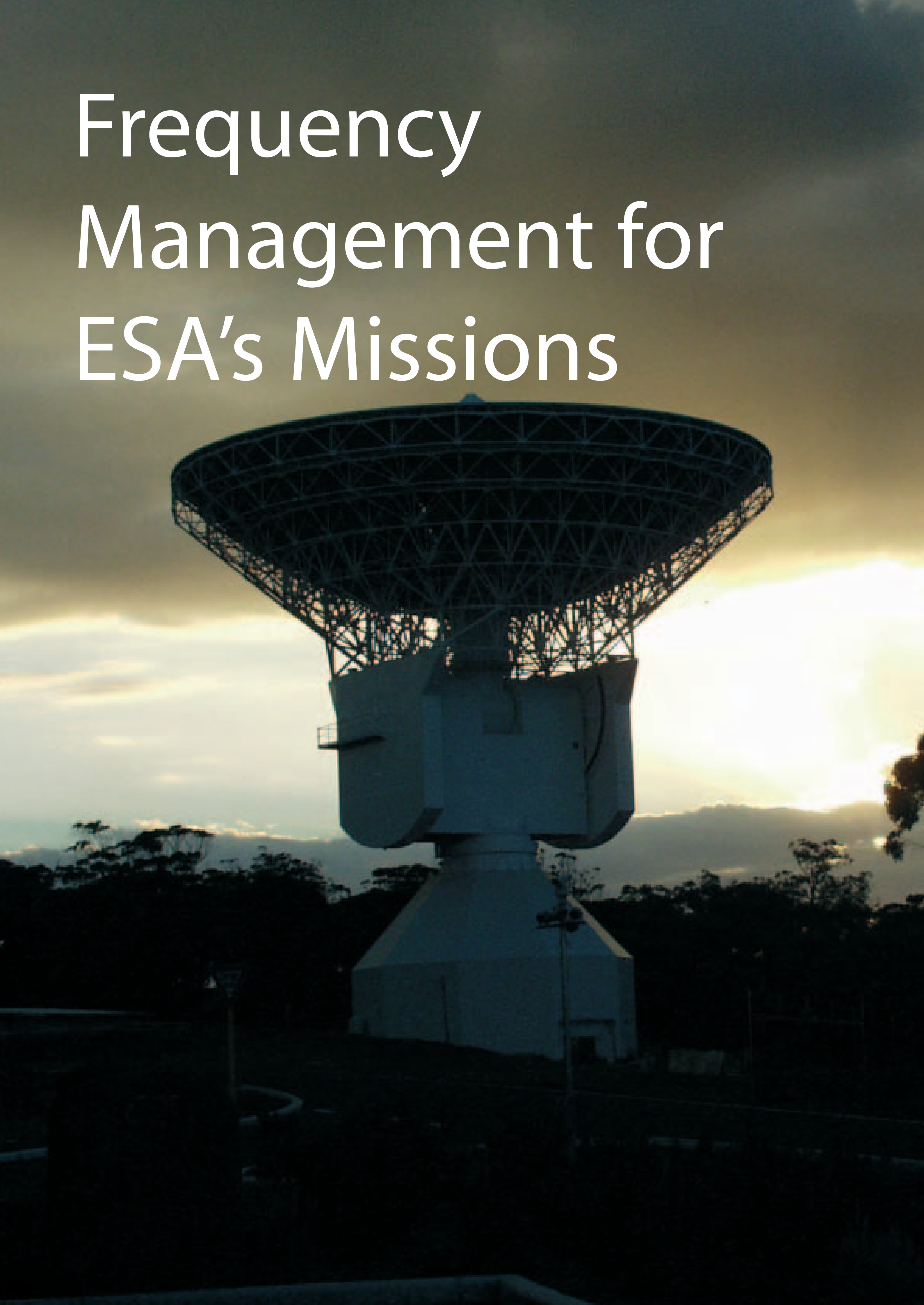
Frequency Management for ESA's Missions



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People not familiar with the subject sometimes see the frequency management for a satellite as an activity whereby the 'good' frequency is selected by applying some mysterious formula. In reality, as this article will try to explain, there is much more to it. Frequency management is a rather broad discipline in which international regulations, technical discussions and negotiations play a key role. The radio-frequency spectrum is becoming an increasingly scarce resource and more and more users of all kinds are competing with each other for their share. In a nutshell, frequency management involves minimising the implications of this problem for the satellite users.

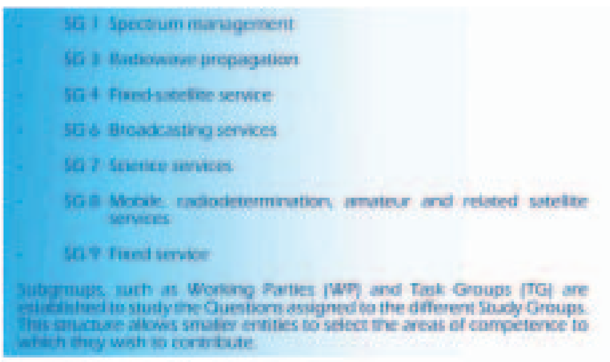
International Regulations

The frequency bands available for use by the different radio-frequency services, the technical/operational conditions under which it is possible to operate, and the relevant protection criteria are specified in the Radio Regulations of the International Telecommunication Union (ITU), a UN international treaty signed by 190 nations. These regulations are particularly important for satellite services, because their radio-frequency emissions go well beyond national boundaries.

The Radio Regulations can be changed only by a Word Radiocommunication Conference (WRC), a formal meeting of the Delegates from all nations participating to the ITU, which typically takes place in Geneva (CH) every three years and lasts a whole month. While decisions are taken at the WRC, during the intervening three years each item on the WRC agenda is assigned to the appropriate Study Group (SG) to carry out the preparatory technical work. This work enables the ITU delegates to take an informed decision on the proposed changes. The structure of the study group (see accompanying panels) follows the ITU definition of radio services, with the space research service, terrestrial service, mobile-satellite service, etc. As a consequence, ESA is mainly active in SG7, where all space-science services belong, in SG8 (radio navigation satellite service and mobile satellite service) and in SG3 (propagation).

The ITU sectors and their roles

The ITU-R study groups



The ITU works to achieve a consensus on all WRC agenda items through intense negotiations and diplomacy. It is normal practice for nations to form common proposals to the Conference via regional agreements prior to the WRC. This is why ESA also participates in the meetings of the European Communication Commission (ECC/CEPT), with the goal of achieving common European proposals for the WRC.

Satellite Network Filing

In order to properly register an ESA satellite and its ground stations with the ITU, a number of steps have to be followed (in accordance with administrative note ESA/ADMIN/IPOL-PROC(2004)2). At the beginning of a satellite mission's design, it is necessary to prepare a so-called 'Request for Frequency Assignment', containing preliminary data on the satellite's telecommunication systems, the preferred frequency bands, the station network to be used, and the orbital characteristics of the mission.

This request is thoroughly checked to assess compliance with the ITU radio regulations and international radio frequency and modulation standards of the Consultative Committee for Space Data Systems (CCSDS) and of the European Cooperation for Space Standardization (ECSS). Compliance is also checked with the interagency agreements of the Space Frequency Coordination Group (SFCG) (see coloured panel). If needed, changes are requested to the project. The amended document then forms the basis for conducting

The Space Frequency Coordination Group (SFCG)

The SFCG was created 24 years ago as an ESA and NASA initiative. It is an informal group composed of frequency managers from all of the main civil space agencies in the World. Its main objectives are to:

- adopt agreements that allow space agencies to make best use of the allocated bands and to avoid interference between members' space systems
- agree common policies and identify long-term targets related to potential changes to the international regulations.

To achieve these objectives, the SFCG members develop and adopt common resolutions and recommendations to be applied within their own organisations. These cover a variety of subjects, including for example: spectrum masks, deep-space channel plans, inter-agency frequency co-ordination procedures, interference criteria, standard transponder turn-around frequency ratios, use of specific bands, common objectives with respect to the next WRC, etc.

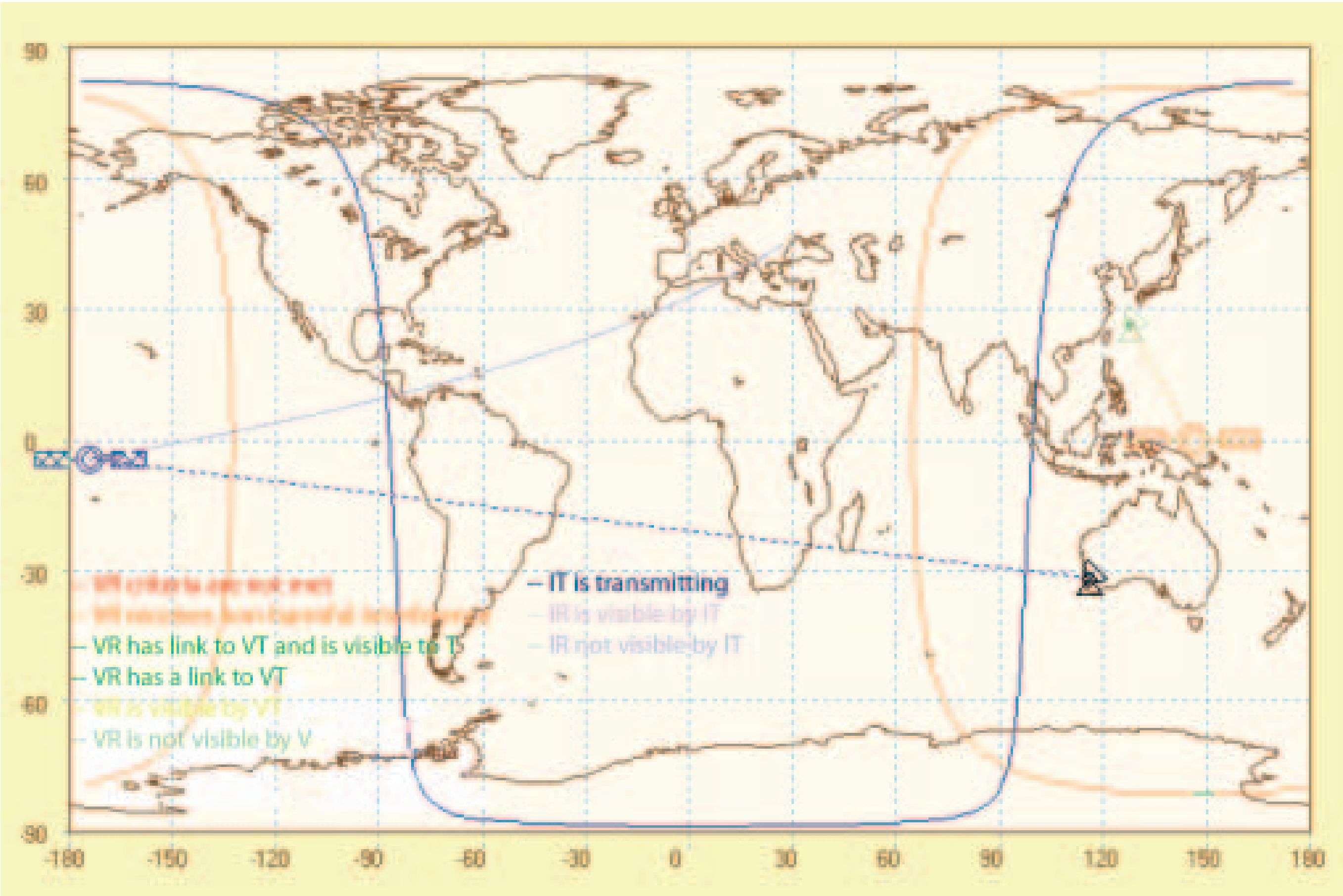
The current SFCG member agencies are: ASI (Italy), BNSC (UK), CAST (China), CMA (China), CNES (France), CONAE (Argentina), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA, EUMETSAT, INPE (Brazil), INSA (Spain), ISRO (India), JAXA (Japan), KARI (Korea), NASA (USA), NIVR (Netherlands), NOAA (USA), NSA (Malaysia), NSAU (Ukraine), NSPO (Taiwan), SSC (Sweden), RFSA (Russia). WMO, IUCAF, ITWG, CCSDS and ITU-R are observers.

The Head of the ESA Frequency Management Office has the task of permanent SFCG Executive Secretary.

Further information on the SFCG can be found at:

http://www.sfcgonline.org/.

inter-agency coordination and an evaluation of potential radio-frequency interference between the ESA mission and missions by other space agencies (NASA, JAXA, etc). These bilateral negotiations are supported by an ESA-developed software tool, which assesses the potential publication (API) filing and notification (Article 11) filing. This is carried out by using an ITU software suite. Such a filing is first circulated among ESA's Member States for association and then submitted to the ITU via ESA's notifying national administration (France). the informal coordination with other space agencies beforehand, no major problems are usually encountered at ITU level. The procedure at ITU level is much more complex in the case of geostationary satellites, but luckily very few ESA satellites fall into this category.



The radio-frequency interference scenario for ESA's Cluster and JAXA's ETS-VII satellites

mutual radio-frequency interference (RFI) by taking into account orbital characteristics, Doppler shifts, modulation formats and operating modes.

Examples of the capabilities of such a tool can be seen in the accompanying figure, which depicts the RFI scenario for the case of the Cluster satellite interfering with JAXA's ETS-VIII spacecraft.

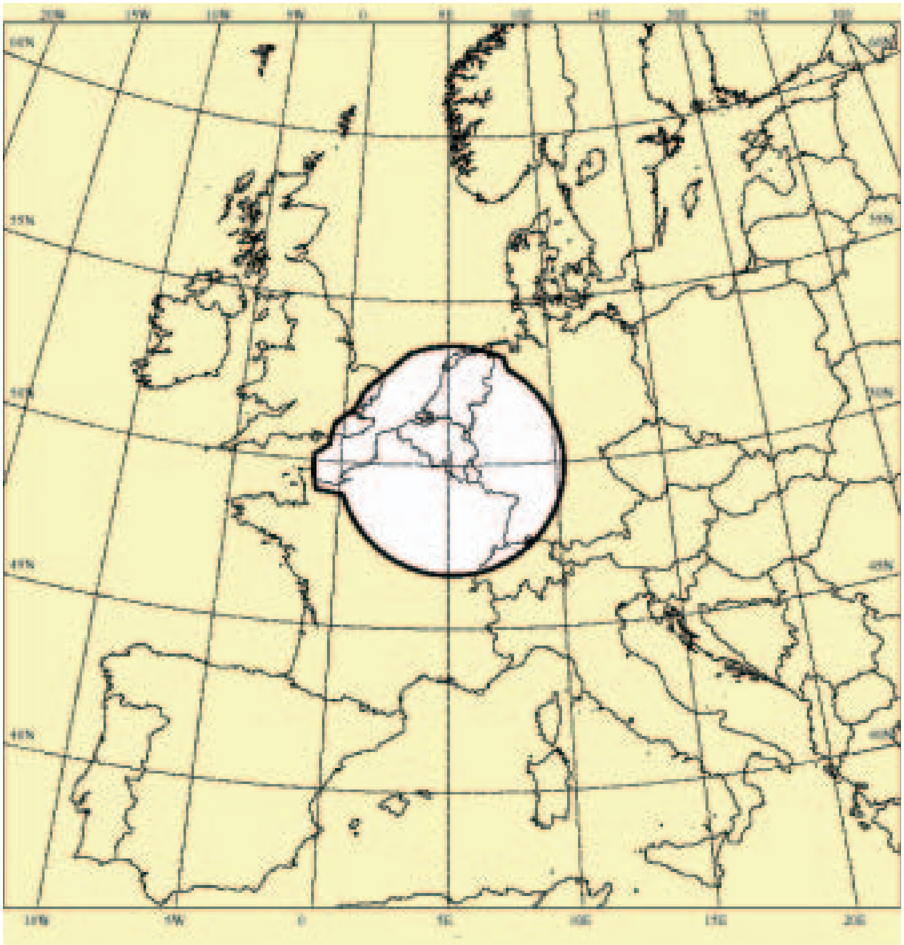
The final goal of such pre-ITU coordination is to find a reasonable frequency assignment that avoids the need for operational coordination in the future.

Having completed this task, the next step is the preparation of the ITU advance

In compliance with ITU regulations, the submission of API and Article 11 files is typically done three years prior to the nominal satellite launch date. This ensures that stable satellite and station performance figures are already available and that a normal launch delay would not invalidate the ITU filing. The maximum time allowed by ITU regulations between the API submission and the launch is 7 years.

Comments on the filing by any National Administration with the ITU will have to be answered to achieve the satellite notification. Having conducted

In order to operate the ESA ground stations (or a third-party station supporting an ESA mission), it is mandatory to have a transmit-and-receive licence issued by the Administration on whose territory the station is located. To ease this procedure, ESA has concluded agreements on radio-frequency use and protection requirements with all of the nations on whose territory an ESA station is located. Such agreements are based on simulations of RFI between the ESA station(s) and domestic terrestrial stations in its area of influence. These simulations, aimed at demonstrating that the protection criteria



A typical coordination contour, in this case for SMART-1 mission support from ESA's Redu station in Belgium

for both terrestrial and space services are met, utilise ITU software that takes due account of line-of-sight propagation, diffraction, anomalous propagation and rain scatter.

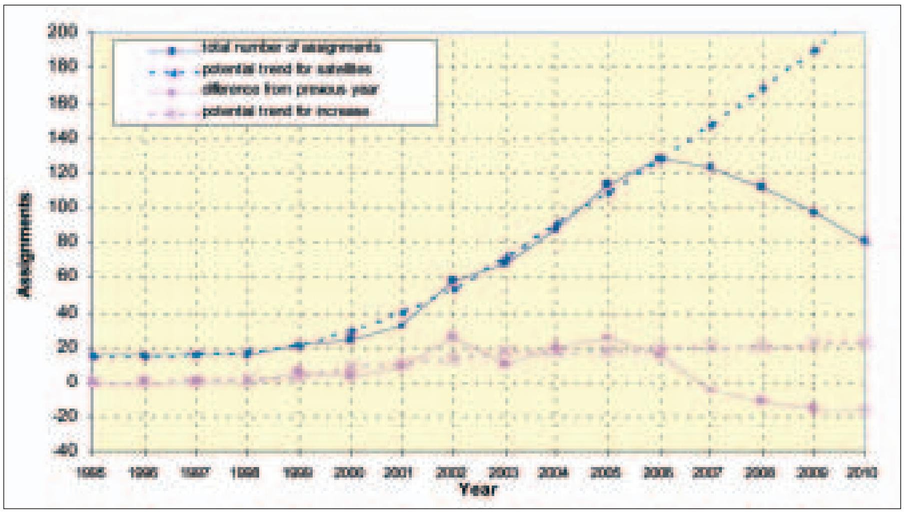
Having concluded such agreements does not absolve ESA from requesting individual licences for each satellite that has to be supported by the station. For European stations where cross-boundary coordination may be an issue, and therefore ITU notification of the station is also needed, the request for station licences has to be accompanied by the station coordination contours and the associated data file computed with the prescribed ITU software. The accompanying figure is an example of the coordination area for the Agency's Redu station in Belgium, in case it would need to support the SMART-1 mission in the 8.4 GHz band. It shows that international coordination with the Netherlands, Luxembourg, Germany, France, Switzerland and the United Kingdom would be required.

The host country Administration starts coordination on behalf of ESA, which however is required to answer questions from the interested Administrations and conduct ad-hoc RFI assessments with the tools described previously. As soon as the coordination is positively concluded (not all such coordinations to date have been successful), an ITU form similar to the satellite notification has to be prepared and submitted to the ITU. If the station coordination area is entirely within one Administration's territory, a domestic licence is sufficient. This lengthy process is concluded as soon as all stations licences (or notifications) are available.

It goes without saying that the terms and conditions of the satellite and station notifications cannot be violated during the mission operations.

Interference Events and Operational Coordination

Sometimes, the early coordination effort with other agencies like NASA and JAXA reveals a frequency-sharing problem between two missions, but programmatic considerations do not allow the selection of a different frequency. At other times, a non-coordinated satellite interfering with an ESA flying mission is suddenly detected. In these cases, the solution to minimise data loss is operational coordination between these two satellites. This coordination starts by using the



Number of satellites filed with the ITU for operation in the 8025-8400 MHz band satellite RFI prediction tool to assess the level and percentage of interference at both reception ends and results in a set of constraints on both missions to try and reduce the data loss to a minimum whilst not creating a huge operational burden on either mission. Such sets of constraints (typically a no-transmission cone angle) become part of an inter-agency agreement signed by both parties and are enforced by adding them to the mission rules.

To date, fewer than 20 operational coordination procedures have been established, mainly in the 2 GHz bands where there are 1600 ITU notifications. The only coordination procedure established in the 8 GHz bands concerns the Mars-Express and Mars Global Surveyor missions.

Data loss has so far only been experienced with two ESA missions: Integral being interfered with by a military satellite at Goldstone, and SOHO being interfered with by Meteosat Second Generation. While the first incident was due to a change in domestic priorities in the USA, the second is a seasonal problem due to the selection of frequencies that did not take into account an extended lifetime for the SOHO project; it is being resolved by three-party operational coordination, involving ESA, NASA and Eumetsat.

Given the fact that most ESA missions operate in the 2 GHz bands, which are already heavily congested, the very small loss of data experienced so far would indicate that the Agency's internal procedures for frequency management are sound. Nevertheless, as they say in the booklets promoting investment funds, past performance does not constitute a guarantee for the future!

Potential Problems Ahead

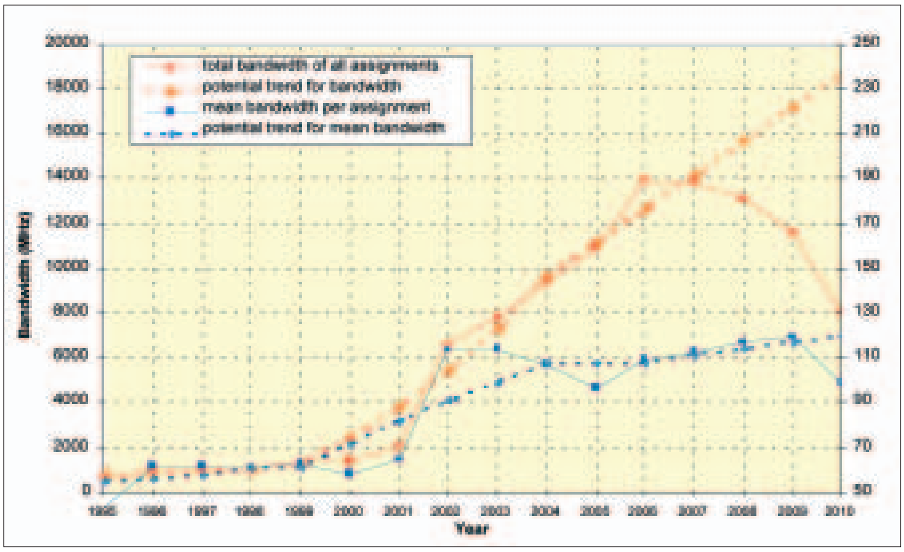
The growing difficulties in frequency management fall into two categories: competition for spectrum within the space-science services, and competition for spectrum from other services.

Competition for spectrum within the space-science services

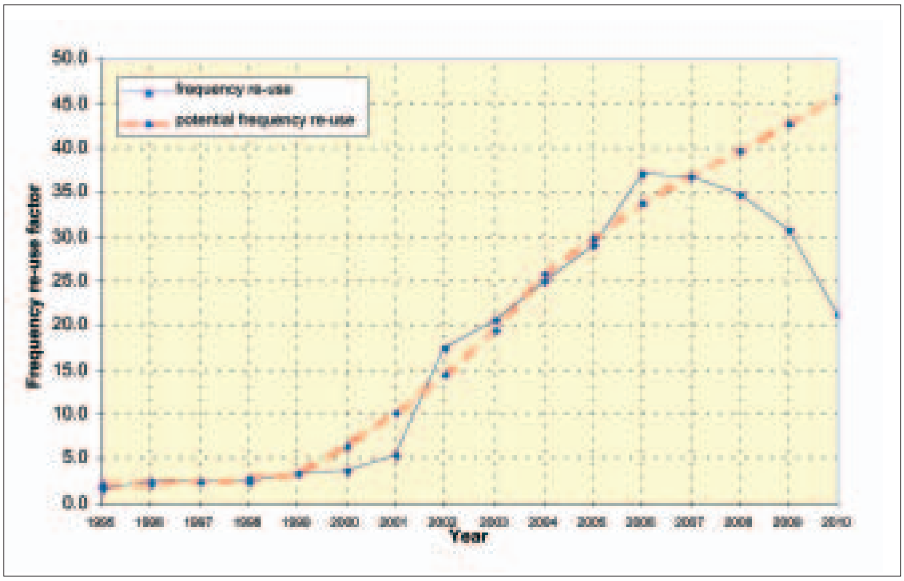
As already mentioned above, the spectrum demand in the bands typically used by ESA satellites for tracking, telemetry and command (TTC) and for payload data transmission is increasing rapidly. New players are joining, mainly from Asian countries and commercial entities, while simultaneously new satellite projects need to transmit ever-increasing volumes of data.

To provide a feeling for the situation, we can take the results of a study made by ESA for the SFCG on the situation with the ITU filings in the 8 GHz band for Earth Exploration satellite downlinks. The three accompanying graphs show the historical evolution in the use of this band, and the expected trend for the coming years. The apparent reduction in the problem after 2006 is an artefact due to the fact that many satellites to be flown after 2006 have not yet been filed with the ITU, and the more meaningful curves are the dotted ones giving the trends. Even discounting the fact that some of the planned satellites will not be flown or will fail, the idea that we already have a mean frequency reuse factor larger than 10 and that this may double within a few years is rather scary!

There is obviously no room for choosing 'free' frequencies. The probability of having interference occur on the



Total bandwidth used by all satellites, and the mean bandwidth per satellite, for the 8025-8400 MHz spectrum range



Estimated frequency re-use for the 8025-8400 MHz band downlinks will increase exponentially, especially around the high-latitude stations. Suitable orbit selection, downlink strategies, ground-station selection, spectrum-efficient coding and modulation, and error-correction coding may alleviate the problem. They may not, however, be sufficient to make it disappear, even if we find a way to have everybody agreeing to some strict self-imposed regulations in these areas. The space-science community may even end up one day having to migrate the more bandwidth-hungry missions to higher frequency bands, with the associated cost of designing and developing new onboard equipment and ground infrastructures.

This is just one example. The S-band at 2 GHz is, in terms of users, even worse.

In other words, space agencies have to prepare themselves for a future when more and more missions will have to coordinate their operations with others and accept the associated costs in terms of extra manpower and intermittent data losses or delays. Not a comforting thought!

Competition for spectrum from other services

In addition to the 'internal problem' outlined above, space-science services have to face another, even more severe challenge. Other spectrum users, particularly those from the commercial terrestrial telecommunication sector, are putting an increasing amount of pressure on the bands used by our satellites. This may take the form of proposing that regulations less favourable to our services be introduced in the bands that we share with them, or proposing that new commercial systems be allowed to operate in these bands. ESA and the other space agencies have fought in all international forums against these attempts, so far with success. The SFCG has been very instrumental in winning these battles, but the pressure is on.

Below are just a couple of examples of problems faced in recent the past and the associated consequences:

Example 1: 3rd generation mobile telephones

Most of the 2 GHz range used by our satellites for TTC was targeted in the late 1990's for allocation to the terrestrial mobile service systems implementing the new 3rd-generation mobile telephones (UMTS) that are now appearing on the market. Luckily they were kept out of the larger portions of the TTC bands, which can still be used for space science after in-depth negotiations lasting for two conferences (WRC-95 and WRC-97). The only band assigned to UMTS within the space-science bands is 2110-2120 MHz, which overlaps with the space research deep-space uplink band and was assigned to the predecessor of UMTS in 1992.

In 1992, the first-generation mobile-phone system had only a few thousand subscribers in the World and was not

ESA's new ground station at New Norcia, photographed from the 35-metre antenna considered a threat to space science. In this band, satellite ground stations transmit signals that can have powers of up to a 400 kW in order to reach the most distant satellites. Consequently, UMTS telephones within a few hundreds kilometres of the antenna could be interfered with. If one thinks of the huge amount of money that the telecommunications companies have spent at auctions to 'buy' these UMTS frequencies, it is clear that they are not happy at the idea of suffering interference over large geographical areas. From this has come the pressure on our stations to relocate to the most remote locations. It started in Australia, where ESA had to build a new station in the outback at New Norcia, because the existing one at Gnangara was deemed to be too close to the city of Perth. Later, our Villafranca station in Spain came under similar pressure and the decision was taken to build the new deep-space antenna at the more remote location of Cebreros. Every time ESA reaches the phase of renewing a ground-station agreement with the relevant national authority, this problem is raised and has to be renegotiated.

Example 2. Wi-Fi systems
The next-generation Wi-Fi systems for terrestrial broadband wireless local networks will operate in a band overlapping with the one used by the C-band SAR imager on ESA's Envisat satellite. In Europe ESA was instrumental in defining regulations limiting the use to indoor Wi-Fi systems only, as the building's shielding effect will avoid any interference with SAR measurements. National regulations in North America, however, do not include this limitation, and so there is the possibility that in a few years time Envisat SAR images over its urban areas may experience some degradation.

Example 3. Car collision-avoidance radars
From next year, the car industry will offer the possibility of mounting short-range collision-avoidance radars on new cars. Unfortunately, these radars will initially operate around 24 GHz for a number of years, before moving to their nominal higher frequency at 79 GHz, for which the technology is still under development. Studies made by ESA and other meteorological agencies have demonstrated that a certain density of cars equipped with these devices would interfere with atmospheric water-vapour measurements made by microwave sounders like the one on the MetOp satellites. This resulted in the decision to limit the use of the 24 GHz band by these car radars to just the first few years, during which it is assumed the market penetration of these new devices will still be limited. This compromise was reached after more than two years of difficult discussions with representatives of the car industry.

The mobile-phone industry, the Wi-Fi industry, and the car industry – clearly the economic and political weight of some of our competitors for spectrum is already impressive, and there are more of them lining up! So far, ESA has managed to balance that through some well-coordinated international actions, accurate technical studies to support the space-science position, participation in all the key meetings at which decisions are taken, a good working relationship with all national and international authorities, and a responsible and reasoned approach. Will that be sufficient also for the future?

Conclusions

This article has hopefully provided an interesting overview of the work associated with frequency management for the ESA missions. It has identified the various steps in the process, the tools used and the final result. It has also described the growing complexity in coordinating the use of the bands with space missions from other agencies, as well as the risks stemming from the presence of new radio-frequency systems competing for the use of the scarce spectrum resource available. These challenges can be met only by reinforcing international coordination and by exploiting structures like the SFCG to define common long-term strategies among all the space agencies. Nevertheless, it is not unlikely that the increasing competition for spectrum may result in some limitations on the design and operation of future ESA missions!

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