Satellite Coordination

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1. What is Coordination?

The International Telecommunication Union allocates frequency bands to services at World Radio Conferences. In general, any one frequency band is shared between several different services. Article 5 of the Radio Regulations contains the detailed information for each frequency band. The Radio Regulations also lay out complex procedures to ensure that when new systems start to use the frequency bands allocated to them, there is minimum disruption to existing systems of all services sharing the same frequency bands. Coordination is among these procedures.

Before an administration allows an operator to commence operation of a new system, other administrations likely to be affected must be informed and agree to technical and operational parameters, perhaps with conditions. To this end the ITU maintains a master list of officially registered systems and stations, with their characteristics, in the Master International Frequency Register. Radio telescopes need to be registered there and so do satellite systems and any radio system which affects or is affected by the radio systems of another country. Any officially registered station or system is to be protected from the incoming new system by the process of coordination. Once coordination is completed the new system can be registered on the Master Register. The new system then acquires its own protected status, even if not yet implemented, and further incoming systems must coordinate with it and protect it. Radio telescopes not registered in the Master Register have no official status and cannot claim protection.

Coordination is a critical process for satellite systems. Unless it is sucessful a proposed new system is not guaranteed protection, which may mean that the satellites never fly. But coordination is also critical for radio astronomy. It is our one official chance to protect our science and our facilities against new satellite systems. The decisions we make during coordination will affect not only our own local time and place, but will set the mould for future generations of radio astronomers. We need to be aware of this when entering into satellite coordination. We must also be vigilant, because we normally only get one chance in the coordination game. GLONASS slipped through the safety net of coordination because almost nobody objected to it (on behalf of radio astronomy) at the appropriate time.

The following sections look at the regulatory machinery of satellite coordination and discuss some of the issues for radio astronomy.

2. The Regulatory Process

Chapter III of the Radio Regulations describes "Coordination, notification and recording of frequency assignments and Plan modifications". The relevant articles are the following:

- Article 7	Application of the procedures
- Article 8	Status of frequency assignments recorded in the Master International Frequency Register
- Article 9	Procedures for effecting coordination with or obtaining agreement of other administrations
- Article 10	Not used
- Article 11	Notification and recording of frequency assignments
- Article 12	Seasonal planning of the HF bands allocated to the broadcasting service between 5 900 kHz and 26 100 kHz
- Article 13	Instructions to the Bureau
- Article 14	Procedure for the review of a finding or other decision of the Bureau

Articles 7 and 8 set out the priority gained by coordination: only coordinated systems have priority. Note in particular the strong language of **8.5**: "If harmful interference to the reception of any station whose assignment is in accordance with No. **11.31** is actually caused by the use of a frequency assignment which is not in conformity with No. **11.31**, the station using the latter frequency assignment must, upon receipt of advice thereof, immediately eliminate this harmful interference." Articles 13 and 14 are concerned with the appeal process, if the coordination process fails to reach agreement. Ultimately an administration has the right to raise the matter at a World Radiocommunication Conference.

The details of the coordination process are spelled out in Article 9. The first stage is Advance Publication, in which the general characteristics of the satellite system, such as frequency bands, orbit type and service area are published. The information should be published not earlier than five years and preferably not later than two years before the planned date of bringing it into use. The information to be provided is set out in Appendix 4. This information is published by the ITU in weekly International Frequency Information Circulars. Any admininstration which considers that its existing or planned systems may be affected has four months to register its interest and its concerns with the ITU. If no comments are received within this time it is assumed that the administration has no objections to the planned system.

The next stage is the request for coordination. The date of receipt of this request effectively establishes the priority date for the new system. Using more detailed information on the satellite system the administrations identified in the first stage enter into detailed bilateral discussions, estimate the likely interference and hopefully reach some agreement on how the new system can be brought into operation. During this process the parameters of the new satellite system may be modified so as to mitigate interference, for example by changing the coverage area or sidelobe performance of the satellite antenna, by reducing power levels, by frequency planning or even by changing orbital location.

Particularly important is Footnote **9.50.1** "In the absence of specific provisions in these Regulations relating to the evaluation of interference, the computational methods and the criteria should be based on the relevant ITU-R Recommendations agreed by the administrations concerned. In the event of disagreement on a Recommendation or in the absence of such a Recommendation, the methods and criteria shall be agreed between the administrations concerned. Such agreement shall be concluded without prejudice to other administrations." The first sentence of this footnote shows that if both parties agree then Rec.RA.769 can form the basis of the interference evaluation. I have had this happy experience myself several times. In more difficult cases a private deal may be needed. The last sentence indicates that such a deal applies only to the affected parties, and has no wider implications for other coordination parties and other bilateral coordination discussions. In practice this is not so easy to achieve. The deal struck between Iridium and US radio astronomers at the NRAO was carried abroad and used in a strong way to try to force similar deals with radio astronomers around the world.

Once coordination is completed the final details of the new system, and the fact that coordination has been agreed with the relevant adminstrations, are officially notified to the ITU and the system is entered in the Master Register, which establishes its priority over any subsequent systems. Details of this are in Article 11. If the coordination process is not concluded within five years (plus a possible extension of two years) then the ITU will cancel the provisional entry and terminate the coordination process.

3. More Regulatory Details

Some of the detailed information that the ITU requires for coordination purposes is set out in Appendix 4 "Consolidated list and table of characteristics for use in the application of the procedures of Chapter III", which has four annexes:

- Annex 1A: Lists of characteristics of stations in the terrestrial services
- Annex 1B: Table of characteristics to be submitted for stations in the terrestrial services
- Annex 2A: Characteristics of satellite networks or earth or radio astronomy stations
- Annex 2B: Table of characteristics to be submitted for space and radio astronomy services

Radio telescopes need to be registered in this way in order to be protected by the ITU machinery. The process is cumbersome and not well suited to the flexible use we make of radio telescopes in our research, but it must be respected or we lose any priority over incoming satellite systems.

Within Annex 2A, A.17 "Compliance with aggregate power flux-density limits", we find a group of power flux density limits that trigger coordination. Three of these concern the protection of radio astronomy from satellite systems:

(a) NGSO satellites in the RNSS operating in the band 5010 - 5030 MHz, aggregate pfd into the band 4990 - 5000 MHz (**5.443B**);

(b) NGSO satellites in the FSS operating in the band 41.5 - 42.5 GHz, aggregate pfd into the band 42.5 - 43.5 GHz (**5.551G**); and

(c) NGSO satellites operating in the FSS in the band 15.34 - 15.63 GHz, aggregate pfd into the band 15.35 - 15.4 GHz (**5.511A**).

What is most surprising and significant about these three triggers is that they trigger coordination between systems that operate in *different* frequency bands: satellites in one band and radio telescopes in a different band. Normally coordination is between systems that operate in the *same* frequency band. The issue here is how to protect the sensitive radio astronomy service against unwanted emissions from the satellite transmitters that spread into nearby frequency bands.

Further triggers for coordination are spelled out in Appendix 5 "Identification of administrations with which coordination is to be effected or agreement sought under the provisions of Article 9". The very extensive Table 5-1 lists technical conditions for coordination, such as bandwidth overlap, orbital position relative to existing system, pfd into a certain frequency band and coordination area of earth station covers the territory of another administration. The coordination area around an earth station is to be calculated according to the methods set out in Appendix 7, which runs to 96 pages and includes models of antenna gain and propagation models. In principle, something similar could be used to set out coordination areas around radio observatories, if administrations agreed.

Article 21, concerning sharing between terrestrial and space services in frequency bands above 1 GHz, gives limits of power flux density from space stations (in Section V, and Table 21-4). Here we see that higher pdf is allowed at higher elevation angles! This is appropriate for protection of most terrestrial services, which transmit and receive horizontally, but it is not so good for radio astronomy, with telescopes looking up into the heavens.

Article 22 concerning space services introduces the concept of equivalent power flux density (epfd) as a tool for controlling interference from NGSO satellite systems into GSO satellite systems. This tool is one that the satellite operators developed for use when coordinating with each other, and that is why they are keen to bring it into their discussions with radio astronomers.

In passing, Section V of Article 22 concerns Radio astronomy in the shielded zone of the Moon. Footnote **22.22.1** gives the ITU definition of the shielded zone, while **22.22**, **22.23**, **22.24** and **22.25** spell out the agreed protection. According to Footnote **22.22.2** the level of harmful interference is to be determined by agreement between the administrations concerned, with the guidance of the relevant ITU-R Recommendations.

4. Reaching Agreement

Interference issues may be resolved in coordination discussions by one or both parties accepting technical or operational conditions or restrictions. Technical conditions could include limiting transmitter power or power flux density, limiting power in certain sensitive frequency channels, limiting satellite coverage (e.g. beam shaping), or adding filters to transmitters. Operational conditions could include frequency planning of a satellite network, restricting the pointing directions of an earth station (or a radio telescope), or some form of time sharing or time coordination. For example the cloud radar at 94 GHz is planned to operate with time-sharing, to avoid the situation where the radar transmits directly into the main beam of a working mm-wave radio telescope.

In general, coordination discussions start from pessimistic assumptions about interference generation and reception. These are needed to trigger the coordination process. Then the analysis is gradually refined, using actual parameters rather than generic or envelope (worst case) parameters. This is the perspective from which a satellite operator will approach radio astronomy. Our coordination triggers are not worst case, but the satellite people don't know that.

Recall that satellite operators have a lot of experience of trying to coordinate with each other, where there are realistic possibilities for doing deals, trading, and reaching win-win compromises. They are used to beating each other down. Radio astronomers need to defend each of their requirements robustly in such a discussion. It may not be accepted that Rec. RA.769 automatically applies to your radio astronomy station. You may have to explain how the different assumptions concerning system noise temperature, integration time, resolution bandwidth and sidelobe levels apply to your station. You may be called on to consider all kinds of possible mitigation factors, such as polarization discrimination, site shielding, digitization loss, etc. And it is a one-way discussion. You will never get agreement for better protection than the levels of Rec.RA.769, even if you show that you need it.

5. Computerising the Process

Coordinating with a constellation of satellites is a complex problem for which we now have complex methods of solution. The aggregate power flux density (units of W m^{-2} Hz^{-1}) produced at a radio telescope by a constellation of satellites is the flux density averaged over all possible directions of arrival equally. This corresponds to the case of an isotropic antenna.

The equivalent power flux density (epfd) from a constellation of satellites is defined mathematically in Article **22.5C1**. It is a direction-weighted average, taking into account the off-axis discrimination of each transmitter and a reference victim antenna, each assumed to be pointing in its nominal operational direction(s). Epfd was developed for GSO-NGSO sharing studies. It is now the favoured approach for treating radio telescopes, using a Monte Carlo method to simulate a range of observing situations. The epfd cannot usually be measured directly, but must be calculated (estimated) using complex computer software.

The philosophy behind the Monte Carlo approach is that worst-case situations are rare. Most of the time one or other of the sharing requirements may be relaxed. Hence this approach finds favour with people wanting to bring new systems into operation as it eases their coordination burden. The Monte-Carlo approach is now widely used for dealing with moving and intermittent interferers (such as mobile transmitters on the ground, in aircraft, or in orbit) and also for dealing with interference produced by unwanted emissions. A great many input parameters need to be agreed by all parties before the work can commence (emission masks, antenna patterns, sometimes operational details, etc.). Some of the parameters are commercially sensitive, since so much depends in the business world on being first with a new type of product. So it is hard to get the input parameters needed in the simulation. Furthermore the software to calculate epfd is expensive and complicated.

The first application of the Monte Carlo approach to radio astronomy was in the case of frequency sharing around 1.6 GHz between radio astronomy stations and mobile earth stations (Earth-space transmitters). A new ITU-R Rec.M.1316 was developed based on the Monte Carlo methodology, and endorsed by Resolution 125 (WRC-97) as a way to facilitate coordination. Res. 125 also invites ITU-R to submit a report to a future competent conference on the effectiveness of using Rec.M.1316. As yet, nobody has provided experimental data to confirm or deny the value of the Monte Carlo approach to sharing with radio astronomy.

6. Paper Satellites

One of the issues that provides an unspoken background to many satellite coordination discussions is that of paper satellites. Until the 1980s most satellite systems filed with the ITU had been designed and would fly. In 1988 a Pacific-based company Tongasat began applying for orbital slots in the GSO that it could not possibly use in the foreseeable future. An amusing account is available on the internet at *http://www.mendosa.com/tongasat.html.* A fully coordinated satellite system is an asset that might be sold. Soon others got the same idea to stake claims cheaply and get rich quickly. Nowadays there is a massive over-filing at the ITU, and not only at the longitude of Tonga. Unfortunately each filed system has to be processed by the ITU and coordinated by administrations. The coordination burden increases as the square of the number of satellite systems. A tenfold increase in filings leads to a hundredfold increase in the coordination burden. This is one reason why satellite operators spend so much time in coordination discussions with each other.

The issue of paper satellites is politically very sensitive. Developing countries want to claim and defend their share of the geostationary orbit for future use. Some are also concerned that the developed countries will use up or pollute radio spectrum resources before the developing nations can bring their orbital slots into use.

Despite attempts at reform, no means has been found to reach a consensus, and the ITU backlog is still increasing.

7. Adjacent-band problems

Satellite coordination matters loom large at WRC-03, through the issue of adjacent band coordination that was mentioned earlier (Section 3). Resolution 128 "Protection of the radio astronomy service in the 42.5-43.5 GHz band" applies to WRC-03 agenda item 1.32, which is one of the most complex of the whole WRC. The fixed satellite service achieved a worldwide allocation in the band 41.5-42.5 GHz at WRC-2000, but under the conditions set out in footnote **5.551G**, which include a limit on the aggregate pfd produced in the adjacent radio astronomy band 42.5-43.5 GHz, that contains astrophysically important spectral lines of SiO. The provisional pfd limit is to be reviewed at WRC-03, and mitigation techniques are to be identified by the ITU–R, including measures that may be implemented at the satellite transmitters to reduce unwanted emissions into the radio astronomy band, and measures that may be implemented at the radio astronomy stations to reduce the susceptibility to such interference.

In addition there is the issue of priority. Radio astronomers are not unreasonable to ask that future radio telescopes be protected against satellites operating in an adjacent, i.e. different, frequency band. Yet satellite operators with their background claim that such a demand places an undue burden on the future development of *their* service in their own band. They do not accept the obligation to keep the adjacent band free of interference. In preparation for WRC-03 there are moves within ITU to extend the concept of priority to this adjacent band situation, so that only radio telescopes notified to the ITU before the end of WRC-03 will be protected in future. This is a disturbing move that we are strongly resisting.

Agenda item 1.15 presents similar problems. It concerns the radio navigation satellite service, which achieved a new allocation (space-Earth) at 5010-5030 MHz at WRC-2000, at the expense of a similar footnote **5.443B** which protects the radio astronomy service against unwanted emissions into the nearby band 4990-5000 MHz, to a certain aggregate pfd level. Res.604 calls for the provisional pfd limit to be reviewed at WRC-03, and interestingly suggests that calculated aggregate pfd values should be provided when filing new systems in the band 5010-5030 MHz. The administration sponsoring the new RNSS system (Galileo) is arguing strongly that only those radio astronomy stations notified to ITU before the end of WRC-03 should receive protection. This would seriously compromise the future development of radio astronomy.