Iridium and Radio Astronomy in Europe

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1. Introduction

I describe here how the Iridium mobile satellite system was coordinated with radio astronomy in Europe. It was a difficult episode that we all need to learn from. Negotiations began in 1991, when Motorola approached me about the possibility of a small delegation visiting Jodrell Bank, to discuss the Iridium satellite system and ways of minimizing any possible interference to radio astronomy, in particular in the frequency band 1610.6-1613.8 MHz. Iridium planned to use the frequency band 1616-1626.5 MHz to provide mobile communications anywhere on the globe, via a constellation of 66 satellites. The Iridium system is unique in using the same frequencies for uplinks and downlinks, through time division, with a 90-millisecond duty cycle. Individual messages are transmitted in bursts, in separate time and frequency channels, a combination of TDMA (time division multiple access) and FDMA (frequency division multiple access).

The visit in August 1991 was very friendly and productive. It included a one-day plenary meeting with representatives of British Aerospace and Motorola, as well as smaller meetings. Key issues to emerge from the discussions were possible interference from the Iridium downlink (unwanted emissions into the radio astronomy band), and the possibility of using a beacon transmitter at the radio observatory to inhibit transmissions from Iridium mobile terminals whenever they were close enough to detect the beacon. It was also clear, to the radio astronomers at least, that the downlink issue was pan-European, and would need to be negotiated at European level, simply because of the large area served by each satellite. I suggested that Motorola and Iridium take the matter up with the CEPT (European Conference of Postal and Telecommunications Administrations) and with CRAF (Committee on Radio Astronomy Frequencies of the European Science Foundation). It was many years before these suggestions bore fruit, as summarized in Table 1.

Table 1. Short History of Iridium in Europe

Date	Milestone
1991 August	Visit by Iridium to Jodrell Bank
1991 October	Iridium presentation to ITU-R WP7D in Geneva
1992 November	WARC-92 allocates Iridium downlink (secondary)
1994 June	NRAO sign MOU with Iridium
1995-1997	Iridium tries to reach an MOU in the UK
1995-1997	European discussions in SE28(CEPT)
1998 July	ESF signs a pan-European MOU with Iridium

In October Iridium were back in Europe to present the results of further studies to ITU-R WP7D in Geneva. They said they were confident that they could protect radio astronomy to the levels specified in Recommendation ITU-R RA.769, namely –238 $dBW/m^2/Hz$ (Robinson 1991). On the strength of these and other arguments, WARC-92 allocated the band 1613.8-1626.5 MHz to the mobile satellite service, on a primary basis for the uplink and on a secondary basis for the downlink. At the same time, WARC-92 upgraded the radio astronomy allocation at 1610.6-1613.8 MHz to primary status and modified Footnote **733E** (nowadays Footnote **5.372)** to read:

> "Harmful interference shall not be caused to stations of the radio astronomy service using the band 1610.6-1613.8 MHz by stations of the radio-determination-satellite service and mobile-satellite services (No. **2904** applies)."

Things went quiet in Europe after the frequency band had been allocated. However we were somewhat taken aback to learn in 1995 that Iridium had signed a Memorandum of Understanding (MOU) with NRAO in June of 1994, and more surprised still to learn that the concept of a blanker had been accepted by US radio astronomers as a way of mitigating interference from the pulsed downlink. The existence of this MOU and the technical details it contained were to strongly colour the exercise of coordinating Iridium in Europe. European radio astronomy had a lot to lose at 1612 MHz, yet European radio astronomers were placed in the extraordinary position of having to defend their right to observe up to 100% of time without a blanker.

2. European Radio Astronomy at 1612 MHz

The frequency band 1610.6-1613.8 MHz is used heavily in Europe to observe the spectral line of OH at 1612.231 MHz, which is one of the characteristic emissions of OH-IR sources. The large reflector at Nançay in France has discovered hundreds of OH-IR sources, and is engaged in long-term monitoring of their OH emission. Approximately 30% of the available observing time is devoted to OH monitoring programmes, which became feasible again following the first stages of the GLONASS "clean-up". There have also been extensive OH monitoring programmes at other European observatories, including Dwingeloo, Effelsberg and Jodrell Bank.

The MERLIN interferometer and the European VLBI Network (EVN) have unique capabilities for imaging OH-IR sources, through their combination of long baselines and large collecting area. MERLIN provided the first images of the circumstellar shells of OH 1612-MHz masers around OH-IR sources (Booth et al. 1981). The combination of interferometer maps with phase-lags obtained from single-telescope monitoring can be used to estimate accurate distances to OH-IR sources by simple geometry (comparing the angular diameter of the OH shell with the front-to-back light travel time). This technique is potentially of great fundamental importance in astronomy.

The EVN measured the first proper motions of circumstellar OH 1612-MHz masers, showing the stellar mass-loss in real time, while EVN also pioneered the measurements of the circumstellar magnetic field through Zeeman splitting of the 1612-MHz spectral line (Kemball 1992). OH-IR sources were used by Lindqvist et al.(1992) as test particles orbiting in the Galactic nucleus, to measure the mass distribution within 100 pc of the Galactic Centre to estimate the mass of the central black hole. The 1612-MHz line is studied in other regions such as star-forming clouds and comets. And finally the band 1610.6-1613.8 MHz is used for continuum measurements, for example multifrequency synthesis with MERLIN (using measurements at 1612, 1665 and 1720 MHz to synthesise extra interferometer baselines).

In summary, the 1612-MHz frequency band is of great importance in Europe, and is widely used. It was essential to look for an overarching regional agreement with Iridium, since any downlink transmissions accepted over one small European country would impact on radio astronomy in many other European countries. Nevertheless Iridium tried very hard to get bilateral agreements first, particularly in the UK. It also tried many times to get a non-disclosure agreement. Although these are normal in industry and commerce, such an agreement would have effectively isolated Jodrell Bank from the rest of CRAF.

3. Technical Discussions within SE28

Technical discussions on the European sharing issues with Iridium started within the CEPT project team SE28 in late 1995. The matters to be resolved included not only sharing with radio astronomy, but also the protection of GLONASS, the protection of Inmarsat above 1626.5 MHz, and the future sharing between Iridium and other MSS systems such as Geostar which use CDMA (code division multiple access) spread spectrum coding for uplinks from user terminals.

Sharing between the MSS uplink and radio astronomy was a challenging problem that raised a number of new issues. The concept of a beacon at the observatories was eventually abandoned. Instead, direct position measurements of user terminals were to be used to determine whether they were far enough away from observatories to be allowed to transmit without restriction. The method developed by SE28 to determine the coordination zone using Monte Carlo simulations eventually found its way into the ITU-R as Recommendation M.1316. The question of how much data loss is acceptable to the radio astronomy service had not been firmly dealt with hitherto, since the 10% criterion recommended for propagation calculations does not automatically correspond to 10% of data loss. Again the approach developed in SE28 found its way into the ITU-R, this time as Recommendation RA.1513.

Sharing between the MSS downlink and radio astronomy turned out to be the "killer problem", the most difficult to resolve. Unwanted emissions from the Iridium satellites are primarily due to intermodulation between the different frequency channels. The level of unwanted emissions rises very sharply with increasing density of user traffic, in ways that Motorola were able to predict. According to their calculations, emission levels of –238 dBW/m^2/Hz would be achieved for only a few hours per day when most users were asleep. During peak traffic periods the emission levels were expected to be more than 20 dB higher! European radio astronomers faced the prospect of having only about four hours of clear time per day. Could the interference be mitigated?

4. Mitigation Factors

The blanker proposed by Motorola was the first of a long series of mitigation factors that were proposed, considered, weighed, and ultimately rejected. The discussions occupied three years, on the UK front and a similar time within SE28. From our side we suggested that filters might be fitted to future Iridium satellites, but since the Iridium beams are formed using active antennas the number of filters required was declared to be unrealistically large. We suggested that user traffic might be capped at peak hours if radio astronomy observations could be done at no other time, but we were told that was impossible for shareholders to accept. We pointed to the regulatory position, but to no avail.

On their side, Motorola and Iridium took the view that radio astronomy protection criteria were to be closely scrutinized down to the last tenth of a decibel. Each assumption of Recommendation ITU-R RA.769 was argued over, starting with the radio telescope sidelobe pattern, the elevation coverage, actual system noise temperatures, possible polarization discrimination, detector sensitivity factor, and post-detection processing such as baseline subtraction. It was argued that the Iridium unwanted emissions would be so broadband in nature that we would be able to subtract them along with receiver noise.

In addition there was the question of whether the radio astronomy observations could wait until periods of low MSS user traffic. On this point the Nançay instrument gave a firm answer: *"Non!"* Being a transit instrument it could only observe each source at a particular time of day that varied through the year at sidereal rate. Monitoring programmes require regular observations, so necessarily in a year there would be at least two months when the source was only available during peak MSS traffic. It was proposed to use the blanker to observe in such cases, but this was rejected as too high a rate of data loss. We also discussed more exotic solutions, such as adaptive cancellation, which were deemed to be too expensive for the radio astronomy community at large. That is probably still the case nowadays. Nobody, to my knowledge, has demonstrated a realistic way to cancel 4 rapidly moving satellites simultaneously!

One reason why the Motorola engineers were so knowledgeable about possible mitigation factors is that they had got hold of my preliminary report on the GLONASS experiment. This was a confidential hand-produced document sent to only a few people in Russia, the USA, and Australia. I will know next time to number the copies.

In view of the lengthy debates we had, it is interesting to note several unforeseen developments. Far from being smooth, the Iridium emission showed spikes due to a "broadcast signal" that had not been included in the simulations or mentioned before we saw them. Transmissions over Europe commenced in July 1998 and occupied the whole band available to the hardware, 1616-1626.5 MHz, although only the band 1621.5-1626.5 MHz had been agreed with CEPT. This was put right after a few quick exchanges, but the hardware can be switched back at any time. Finally, the user traffic predictions turned out to be over-optimistic, given the rapid growth of GSM in Europe.

5. Agreement between Iridium and ESF/CRAF

When a technical solution could not be found in SE28, the debate moved into the political arena. The European Commission wanted to have a coordination agreement despite the technical issues. Direct negotiations between CRAF and Iridium were organized by the European Radiocommunications Committee under the auspices and guidance of the Milestone Review Committee. The CRAF delegation was led by Titus Spoelstra, the CRAF Frequency Manager. CRAF insisted on a pan-European agreement, and after further months of hard debate the so-called Framework Agreement was reached and signed in August 1998. The European Science Foundation, the umbrella organization for CRAF, signed on behalf of European radio astronomy. The full text can be found on the CRAF web pages (at *http://www.astron.nl/craf/framagr.htm*). Half of the agreement describes what is to be done in the case of dispute!

The crucial part of the Framework Agreement is its first clause:

> "§1. From 1 January 2006, European radioastronomers shall be able to collect measurement data consistent with the recommendation ITU-R RA.769-1."

The Framework Agreement also sets out the plan for an interim agreement to cover the period up until 2006. Parameters to be agreed for the interim period were left as variables:

- an interference level of X dBW/m^2/Hz for 24 hours per day;
- an interference level of –238 dBW/m^2/Hz for Y consecutive hours per day;
- an interference level of –238 dBW/m^2/Hz for an additional T hours per year.

The Interim Agreement reached the following year is subtler than the Framework Agreement. The key breakthrough in the second phase of negotiations was the concept of "*le weekend*". The issue of protecting the Nançay monitoring programme was solved by having two quiet weekend days per month, giving the chance to observe for 48 hours at any right ascension. Furthermore it was agreed that every weekend would be moderately quiet, to a level of –224 dBW/m^2/Hz, allowing monitoring observations of bright sources, plus aperture synthesis observations over full tracks. The fully quiet level of –238 dBW/m^2/Hz would be available for 7 hours every day of the week (Y=7). The full text of the Interim Agreement is given in Appendix A.

It is generally accepted that the CRAF agreements are far more favourable to radio astronomy than previous agreements reached with Iridium.

6. Personal Observations

Looking back, there are many lessons for us to learn from these events. I was struck from the beginning by the contrast with the GLONASS-IUCAF negotiations, where leading OH astronomers discussed the issues with the chief GLONASS engineer and the head of GLONASS operations. The top people have more scope to negotiate. In the Iridium case we were never allowed to meet the top people, but were left to the mercy of corporate lawyers.

When the chips were down regulatory arguments did not help us, nor did technical arguments: Iridium was always going to fly. In practice the secondary service was able to dictate to the primary service when we could operate without interference. It is fortunate for us that the expected levels of user traffic did not materialize.

The media took a strong interest in the David vs. Goliath aspect of the situation, from the most respected scientific journals (e.g. Feder 1996; Abbot 1999) down to daily newspapers, radio and television. In my view, the publicity did radio astronomy no harm.

In practice, non-disclosure agreements were used for gagging people. Our US colleagues did not feel able to tell us about the MOU until we learned of it from Iridium/Motorola. So whereas GLONASS united astronomers, Iridium divided them.

In practice the MOUs with Iridium have been of limited use to us. I can see no direct scientific benefit. This is in contrast with the GLONASS case, where things have changed for the better as a direct result of the GLONASS-IUCAF agreement.

Finally, I keep asking myself, where was IUCAF? Iridium sidestepped IUCAF. We must try very hard to avoid that situation in future.

7. References

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Feder T., 1996, "Iridium Satellite System Poses Threat to Radio Astronomy", *Physics Today*, Vol. 49, No. 11, pp.71-73.

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Appendix A: The ESF/CRAF- Iridium Interim Agreement

Agreement for the Period 1st May 1999 to 1st January 2006
between Iridium LLC and ESF/CRAF
to co-ordinate the operations of
the Iridium System and Radio Astronomy Sites
that are Parties to the Framework Agreement,
in order to temporarily accommodate unwanted emissions
from the Iridium satellites into the band
1610.6-1613.8 MHz

Iridium LLC (hereafter "Iridium") and the European Science Foundation, acting for itself and in the name and on behalf of the ESF Associated Committee for Radio Astronomy Frequencies ("CRAF") (collectively, the "Parties"), hereby enter into this Agreement to govern the operations of the Iridium System and various radio astronomy sites in Europe for the period from 1st May 1999 to 1st January 2006.

CRAF represents the entities which operate radio telescopes that observe in the 1610.6-1613.8 MHz band in the following countries: France, Germany, Italy, Netherlands, Poland, Spain, Sweden and U.K.;

PREAMBLE

1. WHEREAS, the Iridium® System is composed of a constellation of 66 non-geostationary satellites, plus orbiting spares, which have been launched and are in orbit and operational;

2. WHEREAS, Iridium LLC and its European Gateway Operators have been authorised to use the Iridium® System to provide mobile telecommunications services in Europe using the 1621.35-1626.5 MHz band, according to CEPT ERC Decision 97(03), CEPT ECTRA Decision 97(02), MRC Recommendations and any decisions of administrations,

3. WHEREAS, the Iridium® System operates near the band in which the radio astronomy service observes signals from various sources, including signals produced by interstellar clouds of the hydroxyl radical, i.e. from 1610.6-1613.8 MHz;

4. WHEREAS, the status of allocations to services are given by the ITU Radio Regulations, including its provisions and footnotes;

5. WHEREAS, the Parties entered into an Agreement on 11th August 1998 (hereafter the "Framework Agreement"), which specified that the Parties would negotiate before 1st March 1999 an Agreement for the interim period 1st March 1999 to 1st January 2006;

6. WHEREAS, the Parties have agreed to extend the 1st March 1999 date to 1st May 1999;

7. WHEREAS, the term "Observatories" will mean all radio astronomy stations operating at 1610.6-1613.8 MHz that are parties to this agreement;

8. WHEREAS, the Parties anticipate that the current uses of the band 1610.6-1613.8 MHz by the Observatories, and the current uses of the band from 1621.35-1626.5 MHz by Iridium are not static and may change over time;

AGREEMENT

NOW, THEREFORE, the Parties agree to the following:

(1) The Parties agree that Iridium will provide protection to the Observatories as described below. Iridium agrees to meet spectral power flux density levels ("Interference Levels") for the Iridium® System downlink signals within the 1610.6-1613.8 MHz band during the periods specified below:

(a) A level of -238 dB(W/m^2/Hz) for:

(i) 7 contiguous hours per day, 7 days a week, for the following radio astronomy sites: Nançay, France; Effelsberg, Germany; Westerbork, The Netherlands; and Jodrell Bank, UK;

(ii) Up to 7 contiguous hours per day, 7 days a week subject to notification of need for the following radio astronomy sites: Medicina, Noto and Sardinia, Italy; Torun, Poland; Yebes and Robledo, Spain; and Onsala, Sweden;

(iii) 2 weekend days per month, for radio astronomy sites referred to in (i);

(iv) Up to 2 weekend days per month subject to notification of need for radio astronomy sites referred to in (ii);

(v) Up to a total of 30 additional hours per year subject to notification of need for the radio astronomy stations referred to in (i) and (ii);

(b) A level of –224 dB(W/m^2/Hz) every weekend for the radio astronomy stations referred to in (a)(i) and (a)(ii);

(c) Iridium will choose the contiguous 7 hours per day referred to in (a)(i) and (a)(ii) above upon at least 90 days notice. Iridium will also choose the 2 weekend days each month referred to in (a)(iii) and (a)(iv) above upon at least 90 days notice. Under exceptional circumstances notice may be given 2 weeks in advance. The chosen hours and weekend days will be the same for all the Observatories.

(d) The Parties agree that CRAF will notify Iridium LLC, pursuant to (1)(a)(ii), (iv) and (v), in writing at which dates and times the Iridium out-of-band emissions shall not exceed certain levels specified in (1)(a)(ii), (1)(a)(iv) and (1)(a)(v) above. This notification shall be provided no more than once a month and at least 30 days in advance of the date when protection is needed, except that up to two times per calendar year, two weeks notice will be sufficient. The notification document shall be properly certified through the signature of a CRAF designated responsible person. CRAF may send copies of the notifications to FCC and CEPT (ECTRA/ERC) for information.

(e) The Parties agree to evaluate the effectiveness of the agreed upon procedures and may share the appropriate information in this regard with the other party.

(f) The Parties further agree to a workplan to explore existing factors, new techniques and system improvements which will remove the need for operational restraints from the Iridium system as of 1st January 2006. These will include, but are not limited to (1) development of an understanding of actual interference effects from Iridium to radio astronomy observations, (2) changes which could be made to the future generation Iridium spacecraft to reduce unwanted emissions into the radio astronomy band 1610.6-1613.8 MHz, and (3) changes which could be made to reduce the susceptibility of radio astronomy observations to interference. The details of the technical areas which will be investigated, and a schedule for these investigations, are described in Annex 1 hereto.

(2)(a) In accordance with the Framework Agreement, each of the Parties may communicate to the other party the desire to enter into negotiations with a view to amend, to revise, and to adapt this Agreement or its update, including the addition of European radio astronomy stations who also wish to accede to this agreement. Any such request shall include an explanation of the reasons for further negotiations, details of specific changes sought, and a proposed date for beginning negotiations. Such a request shall be sent to the other party no earlier than one year after the entering into force of this Agreement or its update. If a request is made, the Parties shall meet in order to negotiate in good faith the requested amendments, revisions and adaptations. The negotiation process will start at a date, which must be agreed within 2 months after the request has been received by the other party.

(b) This Agreement shall remain effective until the Parties have reached agreement on an update.

(c) Representatives from the CEPT (ECTRA/ERC) may be invited to attend negotiations.

(3) In case of dispute, §§ 7-9 of the Framework Agreement shall apply.

(4) This Agreement shall be binding on successors in interest to the Parties.

The persons executing this Agreement hereby certify that they are authorised to sign this document on behalf of their respective organizations, including the organizations that operate the radio astronomy sites mentioned in WHEREAS (7) of this document.

ACCEPTED AND AGREED:

Iridium LLC	**European Science Foundation**
Name: James G. Ennis	Name: ____________________
Title: Deputy General Counsel	Title: ______________________
Signature: ______________	Signature: __________________
Date: __________________	Date: ______________________

Annex 1

Initial Workplan for
Investigation of Iridium/Radio Astronomy Interference Compatibility Improvement

This document is not meant to be exhaustive or restrictive and may be added to in the future as necessary and agreed between the parties.

Introduction

The following document is meant to serve as the starting point for a collaborative work effort between CRAF and Iridium, as called for in the ESF/Iridium Framework Agreement. It is understood between both ESF/CRAF and Iridium that ITU-R Recommendation 769-1, which was used as a basis for establishing the protection for radio astronomy in that Framework Agreement, was not developed with a consideration to non-GSO satellite systems. As such, the Framework Agreement acknowledged that there may be certain existing factors beyond those of Recommendation 769-1, or other additional ways for reducing the susceptibility of radio astronomy observations to interference, or ways to reduce the unwanted emission levels from Iridium satellites that would help to eliminate the effect of Iridium unwanted emissions to radio astronomy. The Framework Agreement calls for the parties to work together to quantify the merit of possibilities before 1 January 2006 and the following document outlines a program for this work. This document is not meant to be exhaustive or restrictive and may be added to in the future as necessary and agreed between the parties.

Initial Areas to be Examined:

a. Existing factors

- Antenna pattern considerations (effect of sidelobe levels below 0 dBi, polarisation effects, main beam, etc.)
- Spectral and statistical nature of the interference (noise-like properties; effect of integration, etc.)

b. Further interference susceptibility reduction techniques

- Possible applications of the blanker (including possible selective use)

- Interference characterisation and subtraction based on Iridium duty cycle and/or measured Iridium intended emissions
- Other techniques as agreed upon by the parties

c. Satellite unwanted emission reduction

- Possible improvements that could be made to next generation Iridium satellites to reduce level of unwanted emissions.

<u>**Technical Approach**</u>**:**

a. Existing factors

Objective – to determine the extent to which, and manner in which, real-world Iridium interference manifests itself in radio astronomy observation data

Antenna Pattern Considerations

- assess relationship between actual interference SPFD and increase in ΔT (as defined in ITU-R Rec. 769-1) as a function of antenna main beam off-axis angle
- assess overall effects of polarisation discrimination between Iridium and radio astronomy antennas

Spectral and Statistical Nature of the Interference

- assess the extent to which Iridium out-of-band emissions exhibit noise-like characteristics
- determine the effectiveness of existing radio astronomy integration techniques at removing fluctuations caused by Iridium unwanted emissions

b. Further interference susceptibility reduction techniques

Objective – to investigate the possible development of practical techniques that could reduce the impact of Iridium unwanted emissions and be deployed at radio astronomy sites

- conduct overall assessment of prior state of the art in order to determine possible applicability to current interference situation
- create models of interference in order to establish thorough understanding of the nature of the interference signal
- using the interference models as a basis, derive and evaluate potential interference subtraction or reduction methods
- estimate the potential effectiveness of all techniques through simulation and practical measurement programs

c. Satellite unwanted emission reduction

Objective - to investigate practical possible improvements that could be made to next generation Iridium satellites to reduce level of unwanted emissions.

- Iridium/Motorola investigate different areas of potential improvement to Iridium next generation satellites and report the result of this investigation.

d. Implementation of Results:

For each of the existing factors, additional techniques or satellite improvements that are deemed to be practical and effective, agreement must be reached on:

- how to apportion the benefit of the solution (i.e. what portion of the benefit is to be applied to the case of Iridium interference)

For each additional technique that is deemed to be practical and effective, agreement must be reached on:

- how the solution would be implemented in practice ;
- who will pay for any such implementation including any hardware or software development costs, system hardware modifications at particular sites, manpower for implementing any solution at particular sites, etc.

e. Annual Planning Exercise

Objective - to provide a periodic review of the forecasted radio astronomy observation requirements in order to assess the extent to which those requirements are addressed by the current flexible time sharing agreement and the extent to which those requirements could be addressed by any agreed interference susceptibility reduction techniques or existing factors relative to ITU-R Rec. 769-1.

Timeframes and milestones:

Feb.22, 1999: strawman workplan agreed

Jan. 1, 2000: detailed workplan for work elements pertaining to existing factors relative to ITU-R Rec. 769-1

Aug. 1, 2000: quantification of possible reduction of unwanted emission levels of next generation of Iridium satellites

Jan. 1, 2001: detailed workplan for work elements pertaining to further interference susceptibility reduction techniques

Jan. 1, 2002: preliminary conclusions on existing factors relative to ITU-R Rec. 769-1 based on practical measurements.

Jan. 1, 2004: preliminary conclusions on further interference susceptibility reduction techniques based on analysis and simulation.

Jan. 1, 2006: final conclusions based on practical measurements.