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ERC REPORT ON INTERFERENCE CALCULATIONS FROM MSS SATELLITES INTO RADIO ASTRONOMY OBSERVATIONS

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1 INTRODUCTION

WARC 92 allocated:

- on a primary basis worldwide to the mobile-satellite service (MSS) in the space to earth direction (downlink), the frequency band 2483.5 - 2500 MHz.

- on a secondary basis worldwide to the mobile-satellite service (MSS) in the space to earth direction (downlink), the frequency band 1613.8-1626.5 MHz.

These two allocations were identified by the ERC Working Group Spectrum Engineering (WG SE) as eventually constituting a risk of interference to the radio astronomy primary allocations at 1610.6-1613.8 MHz, adjacent to the MSS secondary downlink allocation at 1.6 GHz, and at 4990-5000 MHz, which is within the frequency range of the second harmonic of the MSS downlink allocation at 2.5 GHz.

Project Team SE28 was mandated by WG SE to investigate this issue.

The interference calculations will be supported by a further report on interference based on actual practical measurements.

2 LEVELS OF INTERFERENCE PRODUCED BY MSS SATELLITES

2.1 Case of the 2.5 GHz band

Concerning the protection of the 5 GHz band, at least one operator, namely Globalstar, has shown that its satellite specification would meet the ITU-R Rec. RA.769 threshold for the protection of the radio astronomy observations by 20 dB. The radio astronomy community has indicated that such specifications are satisfactory to them.

Since the second harmonic can always be suppressed by appropriate RF filtering, the opinion of SE28 is that all other MSS proponents wishing to operate in the band 2483.5-2500 MHz will be able to specify their systems so that they will meet the requirements of the radio astronomy service at 5 GHz.

However, if a great number of compatible systems were to share the 2.5 GHz band then studies of aggregate interference, taking into account the multiplicity of satellites and the sharing between them, should be carried out.

Other studies within SE28 have shown that co-frequency co-coverage sharing between TDMA systems is not possible and that co-frequency co-coverage sharing between CDMA systems would imply sharing of the total capacity between the CDMA operators.

2.2 Case of the 1.6 GHz band

The only operator which has announced that they would use the secondary downlink allocation at 1.6 GHz is Iridium.

Simulations from Motorola (the Iridium system manufacturer) have shown that the level of unwanted emissions in the radio astronomy band from the whole satellite constellation at 1613.8 MHz during the system busy hour could be up to 26 dB above the radio astronomy sensitivity threshold of -238 dBW/(m².Hz) as defined in ITU-R Rec. RA.769 when assuming a worst case Motorola traffic model for Europe and operations limited to frequencies above 1621.35 MHz. At a frequency of 1610.6 MHz, Motorola expects the levels to be 21 dB above the sensitivity threshold as defined in ITU-R Rec. RA.769.

The unwanted emission is not due to the noise floor, which is expected to be low enough, but to the mixing products between all carriers operated at the same time because of the non-linearity of the downlink transmitters.

Some other conclusions could be drawn from this simulation:

- The decrease of the unwanted emissions between 1613.8 MHz and 1610.6 MHz is 5 dB, so that the increase of the frequency separation does not provide much improvement.

- The interference threshold of -238 dBW/(m².Hz) is reached only when assuming very low traffic. There would be only 4 continuous hours in each 24 hour day, during the night, in which traffic, as modelled by Motorola, would be low enough to meet this threshold.

Radio astronomers understand that if assignments were made below 1621.35 MHz there could be increased interference for two reasons; one being potentially more users; and the other increased proximity to the radio astronomy band. ERC decision ERC/DEC(97)03 indicates that the TDMA band extends from 1621.35 to 1626.5 MHz but a footnote says that more frequencies will be needed by 2001 in order to meet commercial objectives. Additional spectrum will only be obtained at the cost of reduction of CDMA spectrum designation and modification of the ERC decision. It should be noted that the existing flight hardware can already support their extension down to 1616 MHz. If this extension was envisaged, a full reassessment of the impact on interference should be carried out.

2.3 Mitigating Factors

Motorola has proposed several areas where mitigation factors may apply, which have been answered by the radio astronomers. These are:

2.3.1 Radio Astronomy sidelobe levels

ITU-R Rec. RA.769 assumes a 0 dBi sidelobe level and a static interference case. Motorola argues that this is pessimistic, especially since satellites will move through the sidelobes during an observation. Motorola has proposed that radio astronomers could exclude observation periods when a satellite passes close to the main beam of the radio telescope, and calculates that for the case of the Lovell telescope, the average sidelobe level for the remaining observation time (over 95 %) will be between -9.3 and -12 dBi depending on elevation angle. This calculation is based on the measured antenna pattern of the Lovell Telescope and the orbital parameters of the Iridium system.

Motorola further proposes that the loss of radio astronomy observation time using this technique could be halved to about 2.5 % if the radio astronomy stations could be synchronised on the satellite transmissions (called "blanking" see section 4 for further discussions) in order to enable observations during roughly half of the time of the 5 % or so when a satellite is close to the main beam of the radio astronomy antenna.

The radio astronomers dispute that the Lovell telescope case alone should be considered because this telescope has particularly good sidelobe levels. The radio astronomers have estimated antenna sidelobe levels based on measurements of interference power from the partial GLONASS constellation during 1993 and comparisons with calculated power levels assuming a single GLONASS satellite and a 0 dBi sidelobe. It is estimated for the Lovell telescope that the average sidelobe level during the integration time is lower than - 5 dBi for 90 % of the time.

The two analyses of the GLONASS interference and the mean sidelobe levels of the Jodrell Bank 76m antenna contain factors which might lead to an underestimate or an overestimate of the mean sidelobe level. The analysis is specific to that particular antenna. One key difference between the analyses is that Motorola considers that radio astronomers will have to exclude data when a satellite passes within the main beam of the telescope, and that data could also be excluded for a few percent of the time when the satellites are just outside the main beam of the radio telescope. The case of the Nancay antenna is acknowledged to be much more difficult to analyse in this way. Indeed, due to its particular structure (a tiltable plane reflector and a spherical fixed mirror), the sidelobes from the diffracting surfaces have 4 different origins and solid angles and lie in the range -13.5 dBi to + 3.5 dBi. The mean sidelobe level is about -8.8 dBi in good agreement with the Lovell telescope. However the Nancay antenna has high sidelobes at low elevations which makes it more vulnerable to LEO systems like Iridium because satellites tend to dwell at the horizon.

Nevertheless, the Nancay antenna also presents the most difficult sharing situation, so some specific analysis is highly desirable (see section 4).

Further work involving measurements from Iridium satellites is required before this item can be fully answered. Such tests should be carried out with fully loaded satellite transmitters simulating maximum to minimum traffic conditions.

2.3.2 Thermal Noise

Motorola stated that for low elevation measurements, the system temperature experienced by the radio astronomers is a few dB's above that experienced for high elevation measurements (up to 3.7 dB). Motorola also mentioned that this is significant for a LEO system because satellites tend to dwell at the horizon. The noise factor would tend to balance the fact that for low elevation measurements, more satellites would be close to the main beam.

Radio astronomers point out that observations at such low elevation angles are in the minority. Radio astronomers disputed Motorola's statement as the sensitivity value given in ITU-R Rec. RA.769 is already a "typical" value and that in fact a typical noise level at high elevation angles will typically be 1.4 dB better than that assumed by the current version of ITU-R Rec. RA.769. The likely Tsys values of radio astronomy receivers which will be achieved by radio astronomy in the next years, typically reach 22 K (ITU-R Handbook on radio astronomy), instead of the 30 K used to define the ITU-R Rec. RA.769 limit. This will result in a negative mitigation factor of -1.4 dB.

Radio astronomers point out that observations of high sensitivity made in the 1980's already exceeded the sensitivity assumed in ITU-R Rec. RA.769 by approximately10 dB through the use of longer integration times and wider bandwidths than the canonical 2000s and 20 kHz.

2.3.3 Interference spectrum

Motorola suggested that radio astronomers could take profit of the smoothness of the interfering power as suggested by simulations through the radio astronomy band, because it is the fluctuations in the spectrum due to interference which is important rather than the interference level itself. Motorola calculated that a mitigation factor of about 6 dB could result, and in Motorola's opinion, this factor could increase for longer integration times and wider bandwidths.

The 6 dB mitigating factor claimed by Motorola is strongly disputed by the radio astronomy community. Radio astronomers foresee problems with the Iridium baseline (5 dB slope across the whole band) in certain cases, in particular for wideband measurements. Furthermore, only simulated results are known about the noise statistics and stability of the Iridium spurious emissions: thus, one cannot guarantee that the noise fluctuation will decrease as the square root of time.

The mitigation factor, if any, cannot be ascertained without full scale tests. Motorola and the radio astronomers agree that measurements from satellites are required to investigate this further. Such tests should be carried out with fully loaded satellite transmitters simulating maximum to minimum traffic conditions.

2.3.4 Polarisation

The emission levels quoted by Motorola are the total power on both polarisations and the analysis of ITU-R Rec. RA.769 does not take this into account explicitly.

The Motorola analysis shows that as a result, in the case of single polarisation measurements, the analysis of ITU-R Rec. RA.769 is 4.5 dB too severe. Radio astronomers accept a value of 3 dB mitigation factor but have reservations on the additional 1.5 dB. They further note that a single channel operation is atypical of normal radio astronomy observations.

In general radio astronomy measures dual polarisation. For total intensity I, the mitigation factor will be 3 dB. For the other Stokes parameters, Motorola's analysis shows that the mitigation factor will also be 3 dB, but radio astronomers believe that this factor would be only 1.5 dB in the case of polarised signals.

2.3.5 Summary of mitigation techniques and factors according to Motorola and the radio astronomy community

	Motorola	Radio astronomers
Original excess of interference (at peak time)		
at 1613.8 MHz	26 dB	26 dB
at 1610.6 MHz	21 dB	21 dB
Mitigation technique and factors		
Sidelobe levels (loss of 5 % of measurements or 2.5 % if the blanker is employed)	9.3 dB (low elevation) 12 dB (high elevation)	5 dB
Thermal noise	3.7 dB (low elevation) 0 dB (high elevation)	< 0 dB (high elevation)
Interference spectrum	6 dB	0 dB
Polarisation	3 (dual polarisation) 4.5 dB (single polarisation)	3 dB (Intensity) < 3 dB (other Stokes parameters)
Total mitigation technique and factors (depending on polarisation and elevation))	21-23.5 dB	< 8 dB
Excess of interference with all mitigation technique and factors taken into account (depending on polarisation and elevation)		
at 1613.8 MHz	+2.5 to +5 dB	> 18 dB
at 1610.6 MHz	-2.5 to 0 dB	> 13 dB

3 IMPACT OF THE INTERFERENCE

Radio astronomers have explained within SE28 the difficulties they have to face with satellites from the GLONASS, GPS, and ASTRA networks. For GPS, all new satellites will have sufficient filtering. Concerning ASTRA, the recent problem of interference in the 10 GHz band has not yet been resolved.

For GLONASS, there is a step by step plan described in the MoU between IUCAF and the GLONASS Administration to reduce GLONASS interference and the first step (GLONASS frequency reconfiguration) in of this plan is being implemented. The GLONASS Administration has agreed to investigate the ways of reducing out-of-band emissions in the frequency band 1610.6 - 1613.8 MHz to the levels of -238 dBW/(m²Hz). Radio astronomers are expecting that such improvement will be implemented on the GLONASS system, the IUCAF/GLONASS MoU stating that "the GLONASS Administration agrees to investigate the ways of reducing out-of-band emissions in the frequency band 1610.6-1613.8 MHz to the levels indicated in Rec.769 and to communicate their proposed solution of this problem at a future meeting" (between IUCAF and GLONASS).

At present, the estimated pfd level is -201 dBW/(m².Hz) from one GLONASS satellite and some -198 dBW/(m².Hz) from the whole constellation i.e. 40 dB above the ITU Interference threshold. In practice, the measured interference temperature is mitigated by about 7 dB due to radio astronomy far side lobe levels and up to 3 dB due to the nature of interference spectrum. These factors have not been put in the table because of the concern from the radio astronomers that these factors might not apply to the case of Iridium. Radio astronomers indicated that it is still possible to make low sensitivity observations in a narrow band but that high sensitivity or wide bandwidth measurements still show strong interference.

The estimated levels of interference from Iridium satellites are well below the current GLONASS levels experienced by radio astronomers in the band. If the existing GLONASS satellites were simply moved to centre frequencies below 1604.8 MHz as indicated for the GLONASS configuration after a date between 2005 and 2008, the Iridium levels would be a few dB below the levels of GLONASS.

Radio astronomers stress that, before the full application of the IUCAF/GLONASS agreement, interference from GLONASS and Iridium constellations will be cumulative and would lead to an increase in the number of observations lost. Motorola state that in the final frequency configuration, Iridium levels are expected to be 7 dB below those of GLONASS in the middle of the band and would only be a small fraction of the interference power. Furthermore, since the two systems operate on either side of the RAS band, the interference maximal do not coincide and therefore it is by no means clear that the effect will be cumulative in this way.

Radioastronomy is protected by ITU-R Radio Regulations Footnote S5.372 which states that " 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 RDSS and MSS services", and by the fact that interference is caused by unwanted emissions. The radio astronomers further stressed the secondary status of the downlink MSS compared to their own primary status. This last argument was questioned by Iridium, which stated that primary/secondary status refers to in-band rather than adjacent band coexistence.

4 POSSIBLE WAYS OF SHARING

As mentioned in section 2.3, radio astronomers have to exclude data when a satellite passes within the main beam of the telescope, and Motorola proposes that, during busy hours, data could also be excluded for a few additional percent of the time when the satellites are just outside the main beam of the radio telescope. Motorola further proposes that the loss of radio astronomy observation time using this technique could be halved (to about 2.5 %) if the Radio Astronomy stations could be synchronised on the satellite transmissions in order to enable observations during roughly half of the time when a satellite is not transmitting. In addition, ITU-R Rec. RA.769 levels will be met during 4 hours per 24 hours day, when the traffic level is down.

Motorola stressed the fact that some observatories are observing in the frequency band 1610.6-1613.8 MHz only during a few percent of time and that a MoU had been signed between NRAO (National Radio Astronomy Observatory in US) and Motorola Satellite Corporation Inc. where radio astronomers state that they accept to evaluate the "blanking" solution.

Motorola further states that with this scheme (blanking, main beam avoidance and all other mitigation factors), only a few additional percent of observation time would be lost, which is not significant, and the remaining observations could be carried out with an interfering level down to 2.5 dB below ITU-R Rec. RA.769 level at 1610.6 MHz and up to 5 dB above the ITU-R Rec. RA.769 level at 1613.8 MHz.

Since radio astronomers doubt these mitigation factors, the proposal to restrict observations to a 4 hour slot per night is strongly opposed by European radio astronomers. The reasons given by the radio astronomy community is the impossibility of making periodic observations of time-varying phenomena (on the scale of hours and days) and the smaller time available for other programmes. The threat is most serious for single dish instruments with limited sky coverage like Arecibo, in US (not a co-signatory of the NRAO MoU) and Nancay, in France. This is a particular concern for Nancay, where almost half of the time is dedicated to the OH bands near 1613 MHz and near 1660 MHz.

The blanking proposal is also strongly opposed by European radio astronomers because it prevents observations of short period time-varying phenomena.

The radio astronomers are concerned that another operator, despite the fact that, for the time being, only Iridium has declared that they will use this allocation, might also use this downlink allocation without being synchronised with Iridium satellites, which would further reduce the available time for radio astronomy observations. Motorola recognises the validity of this argument for the blanking technique but states that, if the main beam avoidance technique is applied, the lost observation time due to Iridium would remain small even without the blanker.

Other technical solutions have been suggested within SE28, like the improvement of satellite linearity and traffic limitations. But Motorola stated that considerable efforts have already been made to minimise the emissions and considered that further improvement would bring unacceptable economic and technical burdens.

5 CONCLUSIONS

SE28 examined many technical aspects of the issue of interference from MSS satellites into radio astronomy.

The findings of SE28 are that:

- The MSS satellites transmitting at 2.5 GHz should be able to provide sufficient filtering so that the power of the second harmonic is below the interference threshold of the radio astronomy observatories. Globalstar states that they will meet the ITU-R Rec. RA.769 level by 20 dB.

- The unwanted emissions of the Iridium MSS satellite constellation, operating at 1.6 GHz (estimated from simulation up to -215 dBW/(m².Hz) at peak time in the middle of the radio astronomy band, source Motorola) will be 26 dB (21 dB) at 1613.8 MHz (respectively 1610.6 MHz) above the interference threshold (-238 dBW/(m².Hz) as defined by ITU-R Rec. RA.769 for spectrum line measurement) for about 20 hours per day.

- These estimated levels are well below the current GLONASS levels experienced by radio astronomers in the band. If the existing GLONASS satellites were simply moved to centre frequencies below 1604.8 MHz as indicated for the GLONASS configuration after a date between 2005 and 2008, the Iridium levels would be a few dB below the levels of GLONASS. However, the GLONASS Administration has agreed to investigate ways of reducing out-of-band emissions in the frequency band 1610.6 - 1613.8 MHz to the levels of -238 dBW/(m².Hz). Radio astronomers are expecting that such an improvement will be implemented on the GLONASS system, the IUCAF/GLONASS MoU stating that "the GLONASS Administration agrees to investigate the ways of reducing out-of-band emissions in the frequency band 1610.6-1613.8 MHz to the levels indicated in Rec.769 and to communicate their proposed solution of this problem at a future meeting" (between IUCAF and GLONASS). Radio astronomers also stress that the interference from both GLONASS and Iridium are above the ITU-R Rec. RA.769 levels and that the time cumulative effect will reduce the amount of time available for observation. Motorola stresses that fewer satellites of Iridium will be in view than for GLONASS and therefore, together with the lower level of Iridium interference, that the incremental effect of Iridium over GLONASS will be very small.

- Motorola has indicated several mitigating factors and proposed one mitigation technique which they believe will allow radio astronomy observations to proceed at the sensitivity assumed by ITU-R Rec. RA.769 assuming a total mitigation factor of up to 23.5 dB with only a small loss in observation time. This is disputed by radio astronomers who consider that Motorola's proposals will not apply to all radio telescopes and in all circumstances and could result in a total mitigation factor of less than 8 dB. Real measurements from orbiting Iridium satellites are needed to confirm or deny the conflicting claims. Such tests should be carried out with fully loaded satellite transmitters simulating maximum to minimum traffic conditions.

Therefore, SE28's opinion is that no further work is possible before real measurements are made to properly assess the impact of unwanted emissions from Iridium downlinks on the radio astronomy service in the 1610.6 to 1613.8 MHz band. Such measurements are planned at the US Greenbank Observatory.

CEPT should encourage ESF/CRAF and Motorola to collaborate in investigating the feasibility of such measurements in Europe.

The launch of the first Iridium satellites with full simulation of maximum and minimum traffic loads will make it possible to accurately determine the various mitigation factors discussed above. When the measured data are made available to CEPT, WG SE should review the applicability of the mitigation techniques and determine the actual interference levels into radio astronomy observations and forward its conclusion to WG FM and ERC. In the light of these conclusions, the Milestones Review Committee, which was established by Decisions of ERC and ECTRA, will then be able to take a final decision in accordance with the principles laid down in clause 3.2.6, paragraph 4 in the minutes of the 20th ERC meeting.