PROTECTION OF OMNIWAVELENGTH RADIO ASTRONOMY AND PREVENTING RADIO POLLUTION OF SPACE

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INTRODUCTION

Radio pollution of space is connected with general ecological conditions resulting from world development. A practical aspect of the problem is related to the possibility of making radioastronomy observations of cosmic emissions and searching for signals from extraterrestrial civilizations over almost all of the entire radio spectrum. For this purpose, it was decided at WACR-79 to keep a quiet zone on the shielded side of the moon. Here we shall discuss the problem as it relates to an observatory in orbit [1]. The vicinity of the L_2 Lagrangian point of the earth-sun system is of particular interest as a location for such an observatory.

The most important source of radio interference from the earth is radio telecommunication systems. Let us estimate the potential spectral power flux density (s.p.f.d.) of the total emission from the numerous terrestrial and space telecommunication transmitters. We consider only the frequency range where absorption and reflection effects of the earth's atmosphere are negligible. The region of space considered here is that at distances from the earth sufficiently large that there are line-of-sight paths to almost all transmitters in one complete hemisphere.

INTERFERENCE FROM TERRESTRIAL TRANSMITTERS

To estimate an upper limit of the s.p.f.d. from the earth we can divide the earth's surface into zones, each of which is served at any instant by only one telecommunication transmitter in any particular band under consideration. We now estimate the number of such zones. The distance over which a telecommunication system in such a zone will operate is

$$R_i = \left[\frac{P_i \, G_{ti} \, A_{ri}}{4\pi \, F_i \, k \, T_{si} \, \delta f_i} \right]^{1/2} \qquad (1)$$

where

P_i = output power of the i^{th} transmitter
G_{ti} = gain of transmitting antenna in the i^{th} zone
A_{ri} = effective collecting area of receiving antenna
δf_i = bandwidth of the signal
F_i = minimum ratio of received power to system noise power in bandwidth δf required for operation of the radio communication system
T_{si} = system noise temperature of the radio communication receivers
k = Boltzmann's constant

The volume of space that can be served by the i^{th} radio communication system is

$$V_i = (4/3)\pi R_i^3 G_{ti}^{-1} \alpha G_{ti}^{1/2} (A_{ri})^{3/2} \qquad (2)$$

For simplicity it has been assumed that the transmitting antenna radiates with gain G_{ti} within a beam of solid angle $4\pi G_{ti}^{-1}$, and has zero emission in other directions. The purpose of eq. (2) is to show that V_i is a *minimum* when the transmitting and receiving antennas are isotropic.

Now let σ_e be the area of the earth's surface, and suppose that 40% of this surface is covered by radio communication zones. Then the number of transmitters can be determined from the following equation:

$$0.4\ \sigma_e = \pi N_m \langle R_i^2 \rangle \qquad (3)$$

where $\langle R_i^2 \rangle$ = mean square value of R_i over all zones and N_m = upper limit on number of transmitters, i.e., the number corresponding to isotropic antennas: $G_{ti} = 1$ and $A_{ri} = \lambda^2/4\pi$ where λ is the wavelength. Let us now assume that the value of $(P_i/\delta f_i)$ is statistically unrelated to other parameters in the right hand side of eq. (1). Then we can rewrite (3):

$$N_m = \frac{6.4\ \pi\ \sigma_e\ k \langle F_i \rangle \langle T_{si} \rangle}{\langle P_i/\delta f_i \rangle \lambda^2} \qquad (4)$$

The value of the potential mean spectral power density isotropically emitted by all terrestrial radio communication transmitters, as seen from any point in space, is estimated to be

$$P_e = \tfrac{1}{2} N_m \langle P_i/\delta f_i \rangle = 3.2\pi\ \sigma_e\ k \langle T_{si} \rangle \langle F_i \rangle / \lambda^2 ,$$
$$= 2.1 \times 10^{-3}\ \lambda^{-2}\ (\mathrm{W\ Hz^{-1}}) \qquad (5)$$

for representative practical values of $\langle F_i \rangle = 100$ and $\langle T_{si} \rangle = 300^{o}$ K

($\lambda < 2$ m). The factor 1/2 is included because only one hemisphere of the earth contributes to radiation in any given direction in space. The mean spectral power surface density is

$$S_e = 2P_e/\sigma_e = 6.4\pi\ k <F_i> <T_{si}>/ \lambda^2$$
$$= 8.3 \times 10^{-18} / \lambda^2 \quad (W\ m^{-2}\ Hz^{-1}) \qquad (6)$$

Note that the potential spectral power surface density does not depend upon the number and power of transmitters, but does depend on the sensitivity of the receivers.

The estimated upper limit for the total spectral power flux density, for example at the Lagrangian point L_2, is:

$$S_e = P_e/4\pi\ R_L^2 = 7.5 \times 10^{-23} / \lambda^2 \qquad (7)$$

where R_L is the distance of the L_2 point, 1.5 x 10^6 km. The value of S_L has a similar spectral variation and order of magnitude to the spectral power flux density from the quiet sun. One may suppose that the total effect of the many terrestrial signals in any particular band will result in interference that is very similar to quasi-stationary random noise modulated periodically by earth rotation. The effect of such interference on a radioastronomy system would, if the integration time were a multiple of the modulation period, be similar to a tolerable increase in the system noise temperature. This point, however, requires further study.

INTERFERENCE FROM SPACE-TO-EARTH TRANSMISSIONS

Assume that the potential distribution of space transmitters working in the same frequency band is uniform over a geocentric solid angle 4π. Each of the transmitters has a corresponding zone on the earth's surface at distance R_i. The total s.p.f.d. emitted by the space transmitters in the vicinity of the L_2 point (S_{LS}) is obviously less than an estimate made without taking into account the shielding effect of the earth, i.e.,

$$S_{LS} < \sum_{i=1}^{N} P_i\ G_{ti}\ F_{ti}/4\pi\ R_{Li}^2\ \delta f_i \qquad (8)$$

where F_{ti} = value of the normalized antenna radiation pattern of the i^{th} transmitter in the direction of the L_2 point, and N = number of transmitters. The mean equivalent isotropically radiated spectral power density (e.i.r.s.p.d.) over all the transmitters is

$$<P_i\ G_{ti}\ /\delta f_i> = 4\pi <R_i^2> S_{es} \qquad (9)$$

where S_{es} is the value of s.p.f.d. of radiation at the earth's surface. The sum of the F_{ti} magnitudes can be estimated from the following equation:

$$(4\pi/N) \sum_{i=1}^{N} F_{ti} = \sigma_e/N \langle R_i^2 \rangle \qquad (10)$$

Note that σ_e/N is the mean area of the earth illuminated by one transmitter, and eq. (10) represents the corresponding solid angle of the beam. Substitution of (9) and (10) into (8) leads to the resulting estimation of S_{LS}:

$$S_{LS} < S_{es}\, \sigma_e/4\pi R_L^2 \qquad (11)$$

Here $\langle R_{Li}^2 \rangle \simeq R_L^2$ is assumed. Let us again assume that the combined interfering signals have a structure resembling random noise. Then we can conclude that S_{LS} would be tolerable if $S_{es} \simeq S_e$, where S_e is estimated from eq. (6).

For the bands which are shared between space and terrestrial services, the radio regulations [2] provide limits on S_{es}. These limits vary from -194 dB W m^{-2} Hz^{-1} at a wavelength of 0.18 m to -165 dB W m^{-2} Hz^{-1} at 0.0075 m. These levels are 37 ± 1 dB less than S_e indicated in eq. (6). Therefore, it might be possible to limit the value S_{es} to the level given by (6) in the other frequency bands used by space transmitters only. In such a manner it might be possible to guarantee frequency sharing between space transmitters and radioastronomy observations in the vicinity of the L_2 point. Satellite transmitters for which $R_{iL} << R_L$ and deep space transmitters would be exceptions. However, there are not many such transmitters and corresponding frequency bands, so coordination with them seems practicable.

INTERFERENCE FROM EARTH-TO-SPACE TRANSMISSIONS

In accordance with the manner used above, let us suppose that the e.i.r.p.d. of an earth-to-space transmitter would be tolerable for radioastronomy observations in the vicinity of the L_2 point if it were no higher than the value of P_e indicated by eq. (5). This means that transmissions for earth-to-space communication distances up to 6.8 x 10^3 km could not disturb the observations. This distance limit was obtained with the help of eq. (1) and representative parameters of space receivers given by CCIR Report No. 1001 [3]:

$$\langle T_{si} \rangle = 3 \times 10^3\,^\circ K, \quad \langle F_i \rangle = 10^2, \quad A_{ri} = 14\,\lambda^2/4\pi.$$

Transmissions to higher orbits could exceed this level of e.i.r.s.p.d. by more than four orders of magnitude. Therefore, coordination in the corresponding frequency bands is needed.

The most densely populated high orbit is the geostationary orbit (GSO). Fortunately, the coordination for this case is provided naturally because the transmitter beams directed to the GSO occupy a circular band, or ring, on the sky. The width of this ring is determined by the earth transmitter spacing angle (± 8°), the GSO receiver spacing angle (± 3°) and the off-axis radiation angle (± 4°). The last was calculated using a relation given in CCIR Recommendation No. 524 [3] and under the condition of decreasing radiation to the level estimated by eq. (5). So the total potential width of the interference ring is about 30°, or one month in time scale. This means that radioastronomy observations in the vicinity of the L_2 point could share frequency bands with Earth-to-GSO transmitters almost always except during equinoctial periods, each lasting about one month, when the radio telescope falls within the ring of transmitter beams.

Other earth-to-space radiation for high orbit satellites and for deep space probes require special coordination. There are not many frequency bands allocated for such spacecraft.

SPACE-TO-SPACE TRANSMISSIONS

In this case the situation is probably similar to that for space-to-earth transmissions. There are no special limitations in the ITU radio regulations for space-to-space transmissions at this time.

CONCLUSIONS

Tentative estimations made above lead to the following points:

1. The potential s.p.f.d. resulting from reasonable estimates of radio communication emissions, at distances comparable to that of the Lagrangian L_2 point, may be tolerable for radioastronomy observations over much of the radio spectrum.
2. Additional regulations based mainly on existing ITU limits are needed to guarantee omniwavelength radioastronomy observations in the vicinity of the L_2 point. At the same time, these regulations would prevent unreasonable radio illumination (pollution) of space.
3. Further consideration of a method of calculation of the effects of large numbers of communication signals in the vicinity of the L_2 point is needed.

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REFERENCES

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[2] ITU. Radio Regulations, 1982. Article 28, Sec. 4.
[3] Recommendations and Reports of the CCIR, 1986, v. 4, part. 1.