RECOMMENDATION ITU-R F.698-2*

PREFERRED FREQUENCY BANDS FOR TRANS-HORIZON RADIO-RELAY SYSTEMS

(1990-1992-1994)

Scope

This Recommendation provides factors which should be taken into account when selecting frequency bands for trans-horizon radio-relay systems in the fixed service from the viewpoint of frequency sharing conditions with other services as well as the total noise including thermal and intermodulation noises due to propagation.

The ITU Radiocommunication Assembly,

considering

a) that the World Administrative Radio Conference (Geneva, 1979) (WARC-79), in its Recommendation No. 100 asked the ex-CCIR to prepare a Recommendation concerning the specific frequency bands found preferable for trans-horizon radio-relay systems, taking into account allocations to other services, particularly allocations to space services;

b) that the WARC-79 and the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) made additional allocations of frequency bands for the space services in view of their increasing development;

c) that Recommendation No. 100 of the WRC-95 notes that the proliferation of trans-horizon systems in all frequency bands, and particularly in those shared with the space systems, is bound to aggravate an already difficult situation;

d) that there are optimum frequency ranges for trans-horizon radio-relay systems from the viewpoint of thermal and intermodulation noise due to propagation, depending on the distance of links;

e) that the power limits specified in Article 21 of the Radio Regulations (RR) are applicable to transmitters of trans-horizon radio-relay systems, sharing the frequency bands with space radiocommunication services (Earth-to-space) except for certain frequency bands,

recommends

1. that in selecting frequency bands for trans-horizon radio-relay systems, the following factors should be taken into account from the viewpoint of the total noise including thermal and intermodulation noises due to propagation:

1.1 on links of approximately 400 to 700 km relatively low frequencies below about 1 GHz with large antennas are optimum to provide adequate performance including low intermodulation noise. The transmission capacity will normally be small. Operation above 1 GHz may result in poor performance except for very favourably sited terminals and for very favourable propagation conditions;

1.2 on links of approximately 200 to 400 km the transmission capacity may be somewhat greater. Multipath intermodulation noise may be a major factor; frequencies around 2 GHz may be preferable to lower frequencies in order to reduce intermodulation noise;

1.3 for shorter links (approximately 100 to 200 km) operation at frequencies up to about 5 GHz is possible, resulting in low multipath intermodulation noise even with relatively small antennas. Frequencies between about 2 GHz and 3 GHz may be optimum for high transmission capacities on such links;

2. that in selecting frequency bands for trans-horizon radio-relay systems, priority should be given to bands which are not shared with space radiocommunication services;

3. that, in general, frequency bands shared with space radiocommunication services (Earth-to-space) should not be used for trans-horizon radio-relay systems (see Note 1);

* Radiocommunication Study Group 9 made editorial amendments to this Recommendation in 2007 in accordance with Resolution ITU-R 44.

4. that frequency bands shared with space radiocommunication services (space-to-Earth) may be used for trans-horizon radio-relay systems, provided that due consideration is given, on the basis of Recommendation ITU-R SM.1448, to avoiding interference from trans-horizon radio-relay systems to earth station receivers in space radiocommunication services (see Notes 2 and 3);

5. that in selecting frequency bands for trans-horizon radio-relay systems, due consideration should be given to avoiding interferences to line-of-sight radio-relay systems in accordance with Recommendation ITU-R F.302 (see Note 4);

6. that the additional information given in Annex 1 should be referred to for the application of this Recommendation;

7. that the following Notes should be treated as part of this Recommendation.

Note 1 – Trans-horizon radio-relay systems cannot generally operate under the power limits applicable to all systems in the fixed service shared with space radiocommunication services (Earth-to-space), as specified in RR Article 21 (see also § 3.1 of Annex 1).

Note 2 – When frequency bands shared with space radiocommunication services (space-to-Earth) are used for trans-horizon radio-relay systems, it should be confirmed that space stations in space radiocommunication services complying with Recommendation ITU-R SF.358 (or, with RR Article 21 for 1 525-2 500 MHz bands) do not cause unacceptable interference into trans-horizon systems. It should be taken into account that the space stations may be in geostationary or non-geostationary-satellite orbits.

Note 3 – Further study is required concerning frequency sharing between trans-horizon radio-relay systems and receiving earth stations in the broadcasting-satellite service.

Note 4 – It should be also confirmed that interference into trans-horizon radio-relay systems caused by line-of-sight radio-relay systems is within acceptable limits.

ANNEX 1

Factors affecting the choice of frequency bands for trans-horizon radio-relay systems

1. Introduction

This Annex identifies various factors affecting the choice of frequency bands for trans-horizon radio-relay systems. At first the optimum frequency range of a trans-horizon radio-relay link system is determined from propagation considerations, taking into account the antenna diameter and the transmitting power. Then, interference problems relating to frequency sharing with other systems, including line-of-sight radio-relay systems and space radiocommunication systems, are discussed.

2. Optimum frequency range of a trans-horizon system

2.1 As a function of received level (considering thermal noise only)

Existing trans-horizon radio-relay systems normally use transmitter powers which are of the same order of magnitude for different frequency ranges. The sensitivity of modern receivers is, to a large extent, independent of the frequency band used.

Long-term variations in received power levels, as a function of carrier frequency, depend essentially on three phenomena:

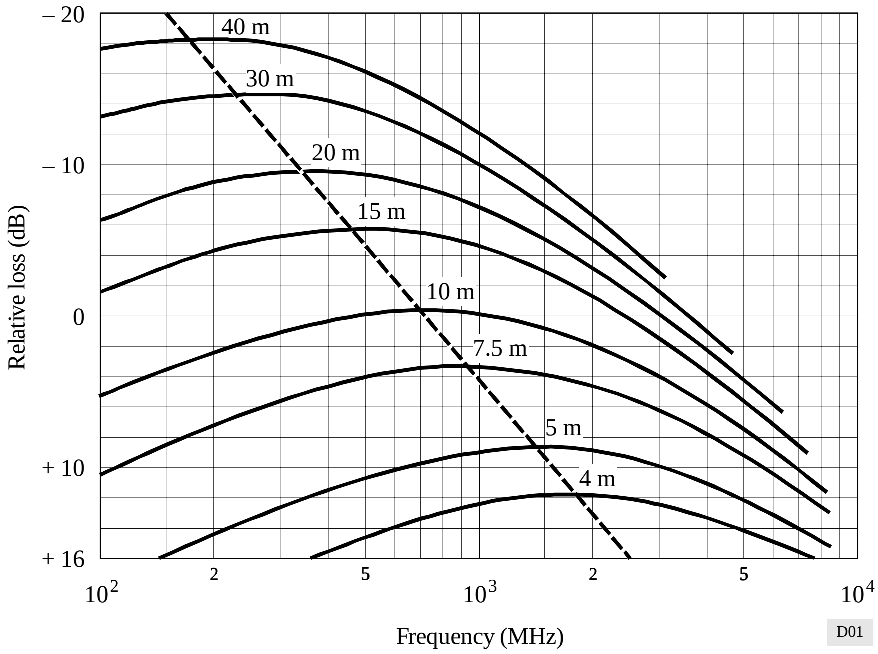
– the loss between isotropic antennas; it is usually assumed that this loss is proportional to the cube of the frequency;
– the free-space gain of the antennas used; for an antenna of a given diameter this gain is proportional to the square of the frequency;
– the drop in antenna gain; for an antenna of a given diameter this drop depends on the frequency and can be calculated from Fig. 1 of Recommendation ITU-R F.1106.

The effect of variations of all these three parameters, as a function of the frequency for antenna diameters between 4 and 40 m, is shown in Fig. 1.

Figure 1 represents the relative loss between the terminals of two antennas of the same diameter, located at the two ends of a trans-horizon radio-relay system; the reference loss (0 dB) is taken as that which exists under the same conditions between two antennas 10 m in diameter at 1 000 MHz. As regards the length of the connection, the validity of Fig. 1 is the same as that giving the loss in antenna gain, i.e. the link under consideration is assumed to be between about 150 and 500 km in length.

FIGURE 1

Relative loss between antennas of a given diameter



It can be seen that, for an antenna of given diameter, the relative loss passes through a minimum at a particular frequency and increases on either side; at the lower frequencies, because the relative dimensions of the antenna measured in wavelengths decrease (with a consequent decrease in free-space gain) and at the upper frequencies, because the drop in antenna gain increases as the free-space gain increases. The optimum operating frequency lies between 200 MHz for an antenna with a diameter of 40 m and 2 GHz for an antenna 4 m in diameter. However, the minimum is very flat and a frequency departure on either side in the ratio of 2/1 is possible without substantially increasing the relative loss.

2.2 As a function of total noise (including thermal and intermodulation) for analogue systems

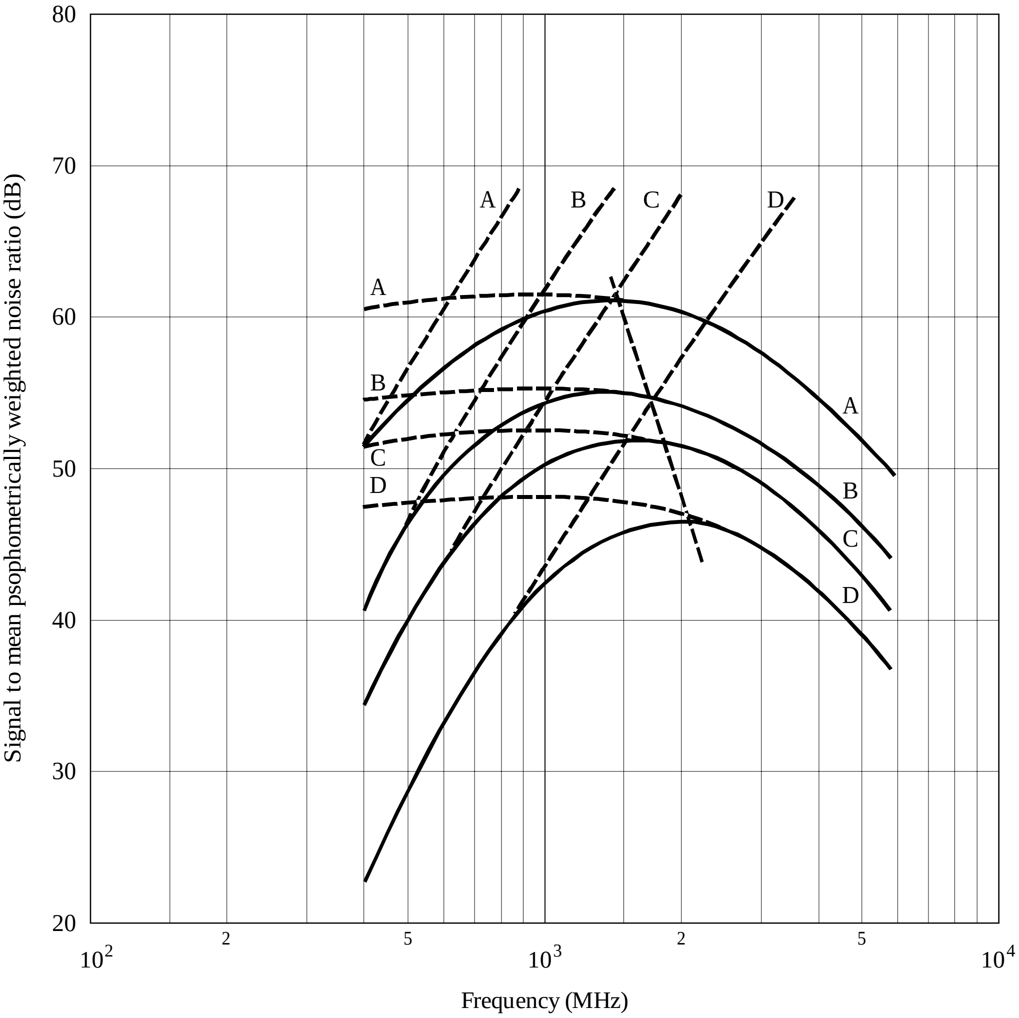
The reduction of intermodulation noise due to propagation may demand higher antenna gains than would be strictly necessary for the reduction of thermal noise. For a given antenna gain, the dimensions of the antennas are obviously smaller at high frequencies. The choice of frequency does not depend essentially on the intermodulation noise if the antenna gain is fixed, but this is not true if the antenna diameter is fixed.

Regarding intermodulation noise, theoretical considerations have shown that intermodulation noise increases in proportion to the fourth power of multipath delay in the radio path.

The multipath delay on the path is proportional to the beamwidths of the antennas employed, and the antenna beamwidth is inversely proportional to the radio frequency, therefore the intermodulation noise decreases in inverse-proportion to the fourth power of the radio frequency when the antenna diameter employed is constant. An estimate of the intermodulation noise for each radio-frequency band and channel capacity is shown in Fig. 2 for a path length of 200 km and an antenna diameter of 10 m.

FIGURE 2

Signal to mean psophometrically weighted noise (thermal and intermodulation noise) ratio



Curves A: 24 channels
B: 60 channels
C: 120 channels
D: 300 channels

Link length: 200 km
Antenna diameter: 10 m
Output power: 1 kW

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As shown in Fig. 2, no conspicuous differences appear in total noise in the 900 MHz, 2 GHz and 2.6 GHz bands for the transmission capacity of 24 channels. These bands have more advantages over bands higher than 3 GHz. It appears that when the transmission capacity is increased to 300 channels, frequency bands of about 2 GHz are more suitable than other bands.

An example of how path intermodulation noise or thermal noise can determine the minimum antenna size is shown in Fig. 3. There are two groups of curves as follows:

– the first group of curves (which decrease from left to right) show antenna size versus frequency for a signal-to-path intermodulation noise ratio of 60 dB. Each curve corresponds to given values of path length and channel capacity;

– the second group of curves (which dip to a minimum value) show antenna size versus frequency for a signal-to-thermal noise ratio of 50 dB (assuming a received signal level of 20 dB above threshold and a signal-to-thermal noise ratio of 30 dB at threshold). Each curve corresponds to given values of transmitter power and distance.

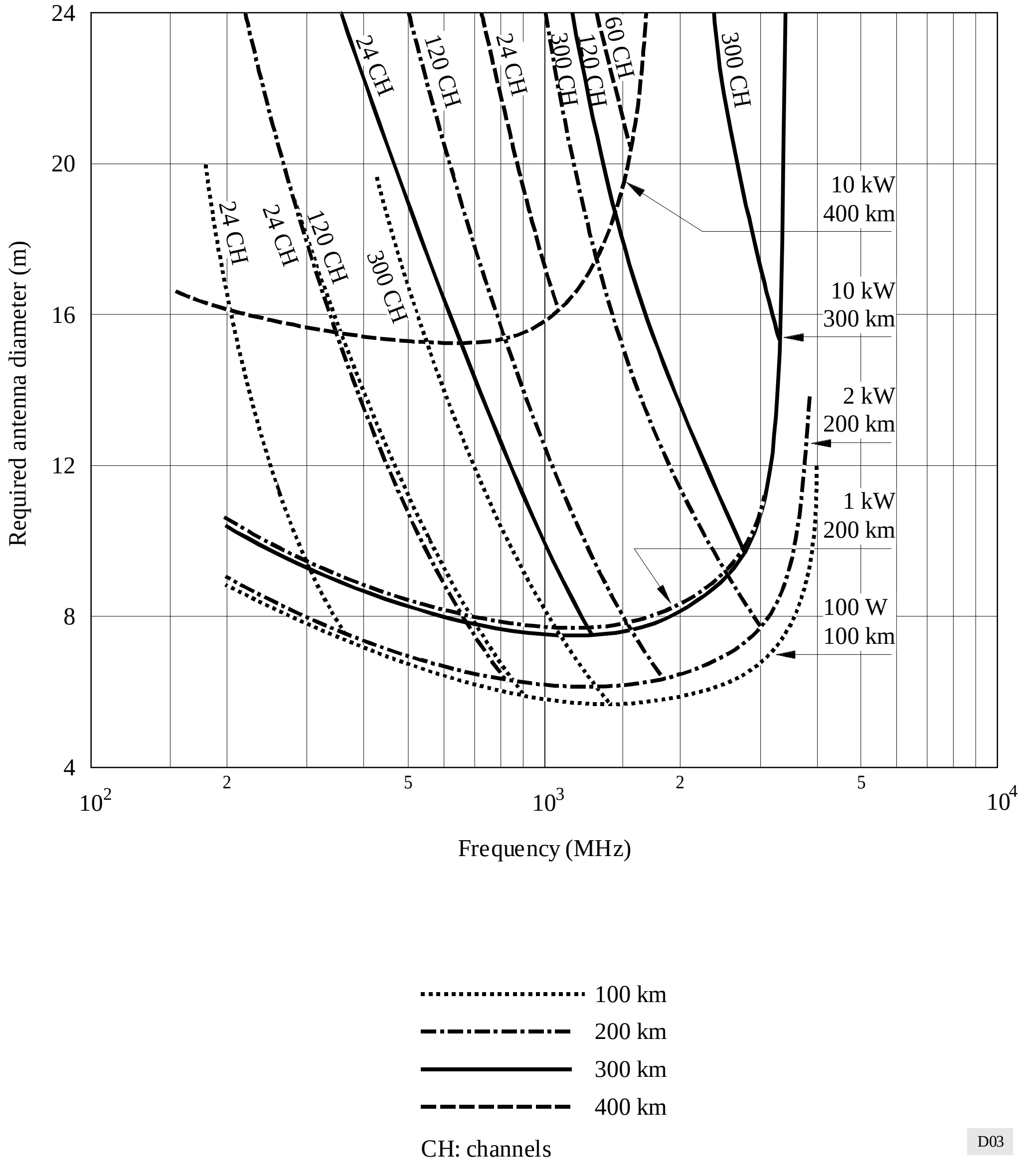
The two groups of curves must be used together to determine the limiting parameter on antenna size (or frequency). For example, with a transmitter power of 1 kW, a frequency of 1 GHz and a distance of 200 km, the minimum antenna diameter would be about 8 m for 24 telephone channels (due to thermal noise), 13 m for 120 telephone channels and 24 m for 300 telephone channels (the last two being due to path intermodulation noise).

The power levels shown in Fig. 3 cover the range of transmitter powers actually available. For practical reasons, the maximum transmitter power considered is 10 kW, but lower powers are desirable to achieve system economy and practical maintainability.

Using a large aperture antenna is preferable to using large transmit power, but the cost of the antenna and support tower increases significantly, and therefore, for large capacities, lower frequency bands are less economical.

FIGURE 3

Required minimum antenna diameter for frequency bands



2.3 Summary

Considering all the relevant factors, including the mechanical aspects, the maximum useful physical diameter of antennas is approximately 40/*f* m (where *f* is in GHz) for frequencies above 1 GHz. This corresponds to a plane wave gain of about 50 dB and an antenna-to-medium coupling loss of about 15 dB for two identical antennas. The higher antenna-to-medium coupling loss and higher thermal noise may be partially offset by an increase in deviation; for example, thermal and intermodulation noise contributions could be approximately equal.

3. Frequency sharing with space radiocommunication systems

3.1 Frequency bands shared with space services (Earth-to-space)

Recommendation ITU-R SF.406 specifies the maximum e.i.r.p. of radio-relay system transmitters operating in frequency bands shared with the fixed-satellite service. On the other hand, RR Article 21 gives the power limits for a station in the fixed or mobile service sharing frequency bands with any space radiocommunication services.

It is noted that Recommendation ITU-R SF.406 and RR Article 21 are applicable not only to line-of-sight radio-relay systems but also to trans-horizon radio-relay systems. The most important provisions of the RR are No. 21.3, which stipulates that the maximum e.i.r.p. of a station in the fixed or mobile service shall not exceed +55 dBW, and No. 21.5 which stipulates that the power delivered by a transmitter to the antenna of a station in the fixed or mobile service in frequency bands between 1 GHz and 10 GHz shall not exceed +13 dBW.

Most trans-horizon radio-relay systems exceed both of these limits, and therefore cannot generally operate in the frequency bands shared with space services (Earth-to-space). According to Table 21-2 of RR Article 21, such frequency bands used for both fixed service and up links of space services below 5 GHz are as follows:

1 610-1 645.5 MHz (for certain countries)

1 646.5-1 660 MHz (for certain countries)

1 670-1675 MHz

1 980-2 010 MHz

2 010-2025 MHz (for Region 2)

2 025-2 110 MHz

2 655-2 670 MHz (for Regions 2 and 3)

2 670-2 690 MHz.

However, No. 21.7 of RR Article 21 recognizes that trans-horizon systems in the 1 700-1 710 MHz, 1 970-2 010 MHz, 2 025-2 110 MHz and 2 200-2 290 MHz bands may exceed the e.i.r.p. limit of RR No. 21.3 (+55 dBW) and the power limit of No. 21.5 (+13 dBW), but at the same time, it states that the provisions of RR Nos. 21.2 and 21.4 (avoidance of the geostationary-satellite orbit) should be observed and that, considering the difficult sharing conditions with other services, administrations are urged to keep the number of trans-horizon systems in these bands to a minimum.

The ex-CCIR Report to WARC-92 based its conclusion as to the feasibility of sharing between the space systems and trans-horizon systems in the 2 025-2 100 MHz and 2 200-2 290 MHz bands on the assumption that there would be a limited number of trans-horizon systems operating in the bands. Severe interference was anticipated if the number of systems was significantly increased. Additional study, as called for in Recommendation 100 (Rev.WRC-03), is required to determine the possibilities and criteria for sharing between trans-horizon and space systems.

3.2 Frequency bands shared with space services (space-to-Earth)

Frequency bands of main interest lie in the ranges 1 525-2 500 MHz, 2 500-2 690 MHz and 3 400-7 750 MHz. According to RR Article 21, the relevant frequency bands below 5 GHz are more specifically:

– between 1 525 MHz and 2 500 MHz:

1 525-1 530 MHz (for Regions 1 and 3)

1 670-1 690 MHz

1 690-1 700 MHz (for certain countries)

1 700-1 710 MHz

2 200-2 300 MHz

– between 2 500 MHz and 2 690 MHz:

2 500-2 670 MHz

2 670-2 690 MHz (for Region 2)

– above 3 400 MHz:

3 400-4 200 MHz

4 500-4 800 MHz.

The relevant space radiocommunication services are the fixed-satellite, broadcasting-satellite, meteorological-satellite, space operation and space research services. It is necessary to consider both interference to trans-horizon radio-relay systems caused by space stations in space services and interference to earth stations in space services caused by trans-horizon radio-relay systems. It should also be taken into account that not all satellites are in the geostationary-satellite orbit.

It should be further noted, that according to RR Article 5, the bands 1 525-1 559 MHz, 1 626.5-1 660.5 MHz, 2 160-2 200 MHz, 2 483.5-2 500 MHz and 2 500-2 520 MHz are allocated to the mobile-satellite services (space-to-Earth) and the coordination and notification procedures for these bands are laid down, but the absolute maximum limits of power flux-density produced by space stations are not defined.

3.2.1 Interference from space stations to trans-horizon systems

Recommendation ITU-R SF.358 specifies the maximum values of the power flux-density at the surface of the Earth produced by satellites in the fixed-satellite service sharing the same frequency bands with line-of-sight radio-relay systems, including the frequency bands 2 500-2 690 MHz and 3 400-7 750 MHz.

In Table 21-4 of RR Article 21, limits are also stipulated for the frequency bands between 1 525 MHz and 2 500 MHz which are allocated to meteorological-satellite, space research and space operation services. According to Table 21-4 of RR Article 21, the power flux-density limit in Recommendation ITU-R SF.358 is also applicable to the broadcasting-satellite service in the band 2 500-2 690 MHz in addition to the fixed-satellite service.

The power flux-density values given in Recommendation ITU-R SF.358 were derived on the basis of protecting line-of-sight radio-relay systems. In this connection, No. 21.16.3 of the RR notes that "where a fixed service using tropospheric scatter operates … and where there is insufficient frequency separation, there must be sufficient angular separation between the direction to the space station and the direction of maximum radiation of the antenna of the receiving station of the fixed service using tropospheric scatter to ensure that the interference power at the receiver input of the station of the fixed service does not exceed –168 dBW in any 4 kHz band".

The interference power of –168 dB(W/4 kHz) is equivalent to a thermal noise temperature of 290 K. This seems to be a reasonable limit in the case of a single interference entry. However, when it is necessary to assume multiple interference entries from space stations to a trans-horizon radio-relay system, a lower value may be appropriate.

In conclusion, it is necessary to evaluate the interference to a trans-horizon radio-relay system caused by space stations in the geostationary-satellite orbit having the maximum power flux-density in accordance with Recommendation ITU-R SF.358 (or, with the RR for 1 525-2 500 MHz bands), and to ensure that they are within the acceptable limits.

Interference from space stations in non-geostationary satellite orbits should be evaluated on a statistical basis. However, no information is available on this subject, except that the power flux-density limits in RR Article 21 apply also to space stations in non-geostationary satellite orbits. Therefore, system planners of a trans-horizon radio-relay system have to develop a model in order to evaluate the interference from space stations in non-geostationary satellite orbits. This matter requires further study.

3.2.2 Interference from trans-horizon systems to earth stations

Annex 1 to Recommendation ITU-R SM.1448, describes the methods for the determination of coordination areas for earth stations in the fixed-satellite, space research, meteorological-satellite and space operation services. Table 2 of Annex 1 to Recommendation ITU-R SM.1448 presents parameters required for the determination of the coordination area for a receiving earth station. This table contains parameters of trans-horizon radio-relay stations.

Therefore, when a trans-horizon radio-relay system shares a frequency band with the above-mentioned space services (space-to-Earth), as the first step, the coordination area for a receiving earth station should be determined using the method described in Annex 1 to Recommendation ITU-R SM.1448. Then the interference potential from trans-horizon stations to earth stations can be determined on the basis of Annex 1 to Recommendation ITU-R SF.1006. Such calculations should ensure that the interference to earth stations is within the acceptable limits.

4. Frequency sharing with line-of-sight radio-relay systems

It may almost be inevitable in many cases that there are nearby line-of-sight radio-relay systems operating in the frequency bands shared with trans-horizon radio-relay systems. Therefore, it is necessary to consider interference from line-of-sight systems to trans-horizon systems and *vice versa*.

4.1 Interference from line-of-sight systems to trans-horizon systems

Where there is insufficient frequency separation between line-of-sight systems and trans-horizon systems, the aggregate level of interfering signals from line-of-sight radio-relay systems should be within acceptable limits. An important point to be taken into account is that the interfering signals may be time variant due to fading. In general, the variation of the interfering signal level is independent of that of the interfered-with signal level.

A possible candidate for the interference criteria may be that the aggregate interference power at the receiver input of the station of the trans-horizon radio-relay system should be lower than $-168 + 10 \log (B/4)$ dBW over the receiver bandwidth B (kHz) for most of the time, e.g., for more than 90% of the time. Since a trans-horizon system generally employs a wide deviation, it seems more appropriate to evaluate the interference in terms of the overall receiver bandwidth rather than any 4 kHz band.

4.2 Interference from trans-horizon systems to line-of-sight systems

In general, a line-of-sight radio-relay system is subject to interference from other line-of-sight radio-relay systems. Interference to line-of-sight systems from trans-horizon systems should be treated as a portion of the aggregate interference from other radio-relay systems. The maximum allowable limits for such interference are given in Recommendations ITU-R F.1094 and ITU-R F.1565.

Interference to line-of-sight systems from trans-horizon systems is in some way similar to that from earth stations in space radiocommunication services. One important difference is that the e.i.r.p. of an earth station towards the horizon is less than +40 dBW in any 4 kHz band in the frequency bands shared with the fixed service, at the elevation angle of 0°. (See No. 21.8 of RR Article 21 or Recommendation ITU-R SF.1004.)

On the other hand, the e.i.r.p. in the direction of the main beam of a trans-horizon radio-relay system is generally much higher. Therefore, for the range of angles for which the e.i.r.p. of the trans-horizon system exceeds +40 dBW in any 4 kHz band, the required separation distance is greater than that between a line-of-sight radio-relay station and an earth station.

5. Conclusion

In view of the increasing development of satellite communications, it cannot be denied that the importance of trans-horizon radio-relay systems is decreasing. Nevertheless, they are still playing an essential role in various parts of the world. At the same time, because of large e.i.r.p. and high receiver sensitivity, trans-horizon radio-relay systems may aggravate a difficult situation in frequency sharing with other radio services, particularly space services.