RECOMMENDATION ITU-R F.1335[*]

TECHNICAL AND OPERATIONAL CONSIDERATIONS IN THE PHASED TRANSITIONAL APPROACH FOR BANDS SHARED BETWEEN THE MOBILE-SATELLITE SERVICE AND THE FIXED SERVICE AT 2 GHz[**]

(Question ITU-R 208/9)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that the mobile-satellite service (MSS) (Earth-to-space) and the fixed service (FS) are allocated frequencies on a co-primary basis in the band 1 980-2 010 MHz in all Regions and in the band 2 010-2 025 MHz in Region 2;

b) that the MSS (space-to-Earth) and the FS are allocated frequencies on a co-primary basis in the band 2 170-2 200 MHz in all Regions and in the band 2 160-2 170 MHz in Region 2;

c) that these bands are widely used by the FS in many countries;

d) that for many developing countries, the use of the 2 GHz band offers a substantial advantage for their radiocommunication networks and that it may not be attractive to transfer these systems to higher frequency bands because of the economic consequences that this would entail;

e) that Resolution 716 (WRC-95) concerning the use of the 2 GHz band by the FS and MSS and associated transition arrangements, encouraged administrations where practicable to draw up plans for the gradual transfer of the frequency assignments to their FS stations in the shared 2 GHz MSS bands to non- overlapping bands, giving priority to the transfer of their frequency assignments in the Earth-to-space band 1 980-2 010 MHz in all Regions and 2 010-2 025 MHz in Region 2, considering the technical, operational and economic aspects;

f) that the ITU-R has developed a new channel arrangement in Recommendation ITU-R F.1098 for the FS in the 2 GHz band which will facilitate the introduction of 2 GHz fixed systems in bands not overlapping the 2 GHz MSS band;

g) that Resolution 716 (WRC-95) requests ITU-R to develop planning tools necessary to assist those administrations considering re-planning of their terrestrial networks to accommodate the MSS in the 2 GHz bands,

recommends

1 that administrations may take into account the material in the Annexes 1 to 4 when considering transitional arrangements for the MSS and FS at 2 GHz.

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[*] This Recommendation was developed jointly by Radiocommunication Study Groups 8 and 9, and any further revision should also be undertaken jointly. This Recommendation should be brought to the attention of Radiocommunication Bureau.

[**] In accordance with Resolution 716 (WRC-95) of the World Radiocommunication Conference (Geneva, 1995), the frequency bands dealt with in this Recommendation are mainly in the bands 1 980-2 010 MHz (worldwide) and 2 010-2 025 MHz (Region 2) allocated to the MSS (Earth-to-space) and the bands 2 160-2 170 MHz (Region 2) and 2 170-2 200 MHz (worldwide) allocated to the MSS (space-to-Earth).

ANNEX 1

Technical and operational considerations in the phased transitional approach for bands shared between the MSS and the FS at 2 GHz

1 Introduction

An administration may choose to transition between services to facilitate the introduction of the MSS. In such cases, there is a need to determine the criteria under which it is deemed that interference will be caused or received for a specific MSS system implementation, and the subsequent action or rules. This situation can arise either during a bilateral coordination, or when an administration has decided to implement one or more specific MSS systems. Tools which could be used for this determination, for a single MSS system are currently being addressed in Recommendation ITU-R M.1319. The impact on transition planning due to interference from multiple MSS systems is still under investigation by ITU-R.

The transition time-frame in this context is deemed to be between the time an administration makes spectrum available for MSS and the point at which it requires systems in the FS to move to spectrum outside that which is required for the implementation of the MSS system.

Two aspects are dealt with in this Annex:

– the continued operation of fixed systems within the spectrum identified for MSS implementation for a reasonable period of time; and

– the continued operation of the FS systems in the 2 GHz range beyond this transition period, including the necessary planning and coordination tools to move the system, or a portion of the system, to spectrum outside that which is required for MSS implementation. (See Resolution 716 (WRC-95) *Requests* 1.2.)

2 Co-primary MSS allocations at 2 GHz

Presently, the bands 1 980-2 010 MHz and 2 170-2 200 MHz are allocated for MSSs on a worldwide basis co-primary with the FS and mobile service. In Region 2 the band 2 160-2 170 MHz is also a co-primary allocation. As a result of WRC-95, the band 2 010-2 025 MHz was allocated for MSS on a co-primary basis with the FS and mobile service in Region 2.

3 Background

There are two principal radio-frequency channel arrangements used by the existing fixed systems, Recommendations ITU-R F.283 and ITU-R F.382. Recommendation ITU-R F.283 provides the channel arrangements for the two sub-bands 1 900-2 100 MHz and 2 100-2 300 MHz with six paired channels in each sub-band, each with a bandwidth of 14 MHz. Recommendation ITU-R F.382 provides channel arrangements for the band 1 900-2 300 MHz with six paired channels, each with a bandwidth of 29 MHz, using two 29 MHz channel arrangements overlayed at a 14.5 MHz offset. These arrangements and their relationship with the current MSS allocations are illustrated in Fig. 1.

Recommendation ITU-R F.1098, developed in response to Resolution 113 (WRC-92) as a result of the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum, Malaga-Torremolinos, 1992 (WARC-92) allocations, provides for three channel arrangements for new fixed systems in the band 1 900-2 300 MHz. It focuses on the "core" bands 2 025-2 110 MHz and 2 200-2 290 MHz wherein the FS, mobile and space operations, space research, earth exploration-satellite services (MS, SOS, SRS, EESS) share co-primary allocation space. These channel arrangement descriptions are illustrated in Fig. 2.

FIGURE 1

Recommendations ITU-R F.283 and ITU-R F.382 channel arrangements

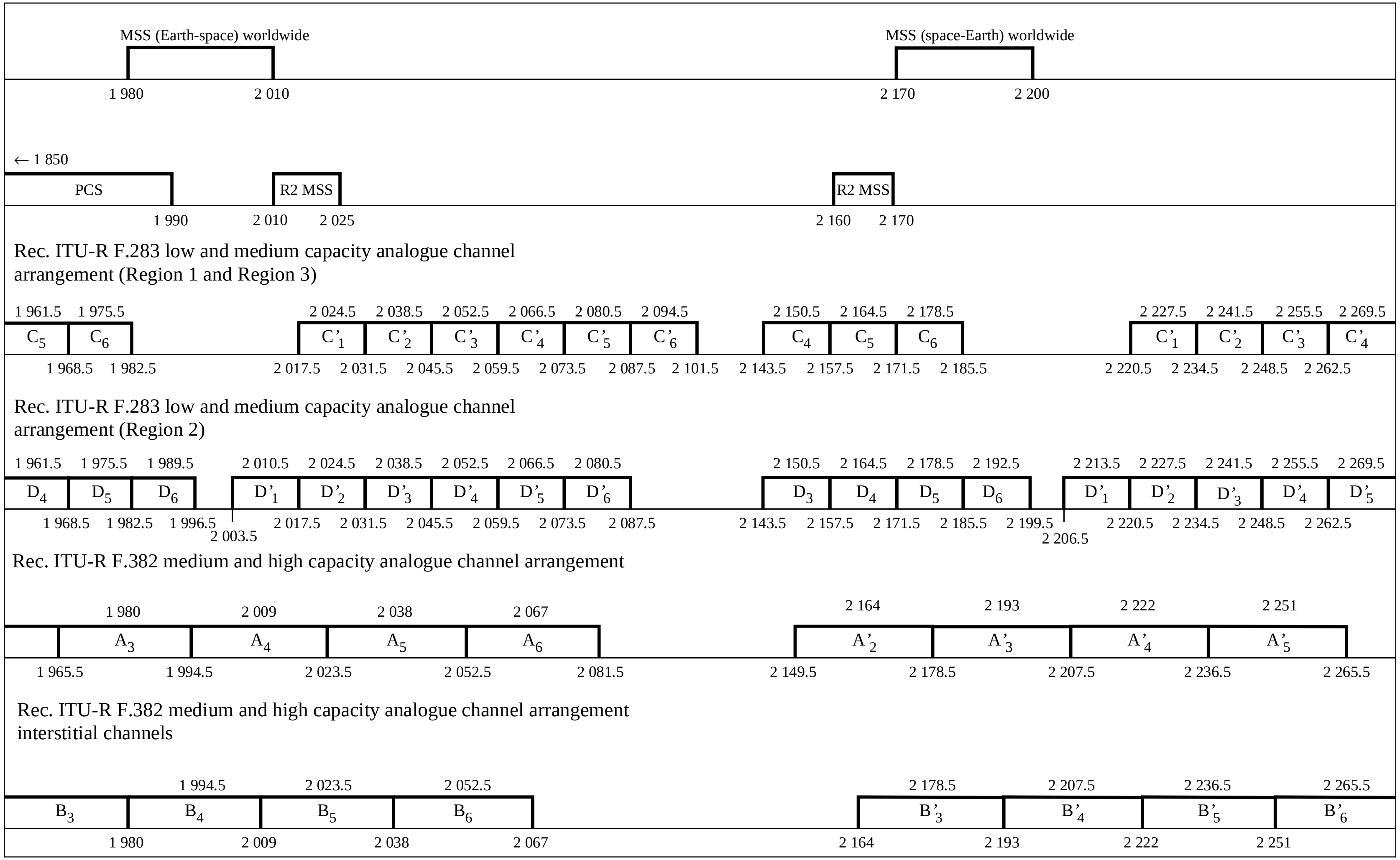

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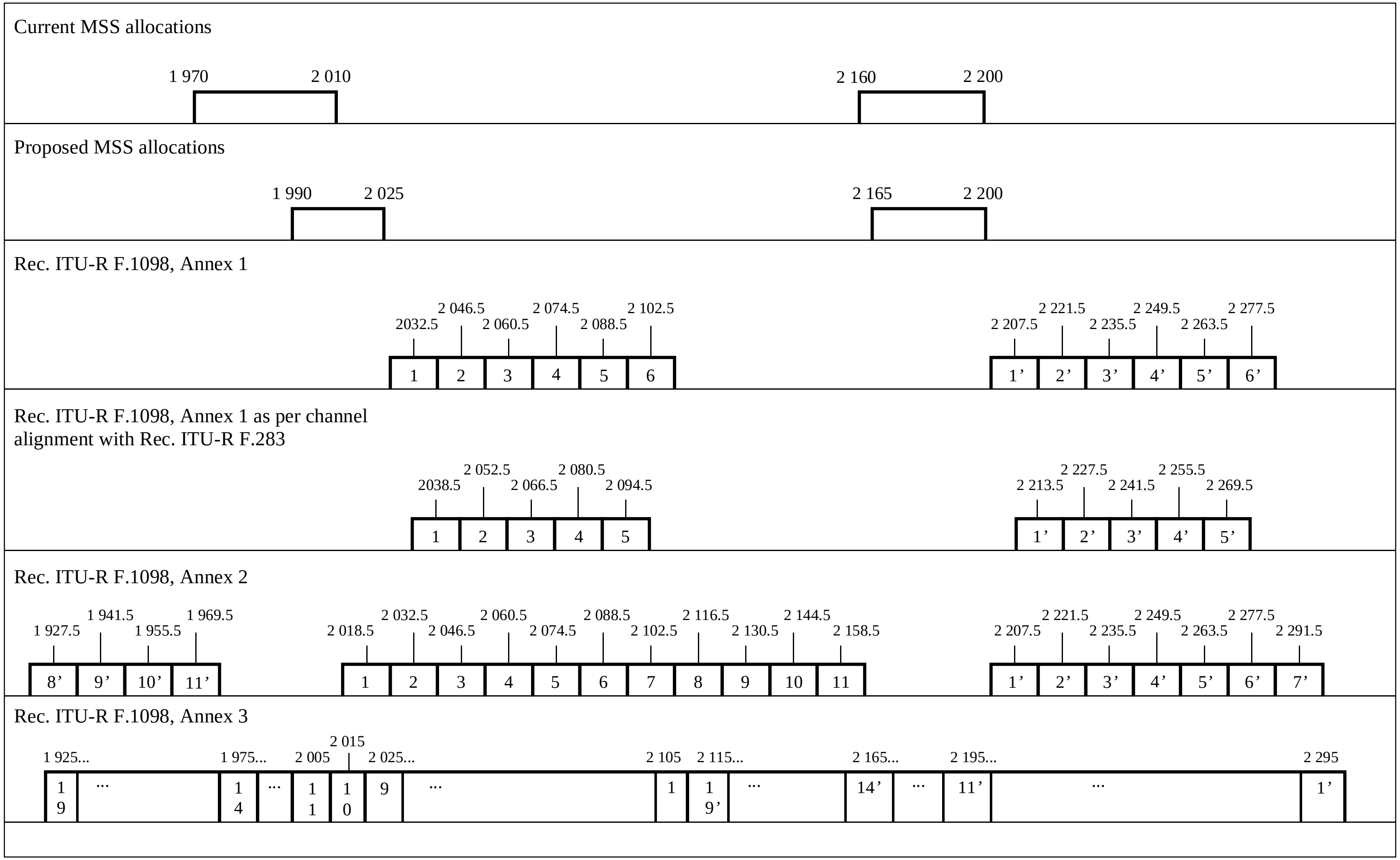
FIGURE 2

Recommendation ITU-R F.1098 channel arrangements



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Annex 1 to Recommendation ITU-R F.1098 describes two channel arrangements which lie entirely within the core bands for up to six go and six return channels with a carrier spacing of 14 MHz. An alternate description provides for up to five go and return channel pairs where the centre frequencies align with the channels given in Recommendation ITU-R F.283.

Annex 2 to Recommendation ITU-R F.1098 describes a channel arrangement for the core bands as well as an extended channel arrangement for up to eleven “go” and “return” channel pairs with a carrier spacing of 14 MHz. The channel arrangement avoids the existing worldwide MSS allocation between 1 980-2 010 MHz and 2 170-2 200 MHz.

Annex 3 to Recommendation ITU-R F.1098 describes a channel arrangement for the core bands as well as an extended channel arrangement for up to nineteen “go” and “return” channel pairs with a carrier spacing of 10 MHz. The channel arrangements are based on the 190 MHz transmitter-receiver duplex spacing of the current MSS allocation pairing.

Allowance is made in Annexes 2 and 3 to Recommendation ITU-R F.1098 for extended channel arrangements where adequate geographical and/or frequency separation would make sharing possible with MSS or future public land mobile telecommunication systems (FPLMTS).

4 Impact of worldwide MSS allocations on the fixed systems’ Recommendations ITU-R F.283 and ITU-R F.382 channel arrangements

In the Recommendation ITU-R F.283 channel arrangement, the guardband between transmitter/receiver (Tx/Rx) in each of the sub-bands is 35 MHz and 39 MHz in Recommendation ITU-R F.382. The present MSS worldwide allocation takes up 27.5 + 14.5 MHz of this 35 MHz guardband in Regions 1 and 3 and 7 + 0.5 MHz in Region 2.

The following is the impact of the MSS worldwide allocation on each of the Recommendations:

– Recommendation ITU-R F.283	(Regions 1 and 3)	1 980-2 010 MHz	2.5 MHz of C6
	(Region 2)	1 980-2 010 MHz	2.5 MHz of D5
	(Region 2)	1 980-2 010 MHz	14 MHz of D6
	(Region 2)	1 980-2 010 MHz	6.5 MHz of D1'
	(Regions 1 and 3)	2 170-2 200 MHz	1.5 MHz of C5
	(Regions 1 and 3)	2 170-2 200 MHz	14 MHz of C6
	(Region 2)	2 170-2 200 MHz	1.5 MHz of D4
	(Region 2)	2 170-2 200 MHz	14 MHz of D5
	(Region 2)	2 170-2 200 MHz	14 MHz of D6
– Recommendation ITU-R F.382	(Arrangement)	1 980-2 010 MHz	14.5 MHz of A3
	(Arrangement)	1 980-2 010 MHz	15.5 MHz of A4
	(Offset arrangement)	1 980-2 010 MHz	29 MHz of B4
	(Offset arrangement)	1 980-2 010 MHz	1 MHz of B5
	(Arrangement)	2 170-2 200 MHz	8.5 MHz of A2'
	(Arrangement)	2 170-2 200 MHz	21.5 MHz of A3'
	(Offset arrangement)	2 170-2 200 MHz	23 MHz of B3'
	(Offset arrangement)	2 170-2 200 MHz	7 MHz of B4'

5 Impact of Region 2 MSS allocations on the fixed systems' Recommendations ITU-R F.283 and ITU-R F.382 channel arrangements

The following is the impact of the MSS Region 2 allocation on each of the Recommendations:

– Recommendation ITU-R F.283	(Regions 1 and 3)	2 010-2 025 MHz	7.5 MHz of C1'
	(Region 2)	2 010-2 025 MHz	7.5 MHz of D1'
	(Region 2)	2 010-2 025 MHz	7.5 MHz of D2'
	(Regions 1 and 3)	2 160-2 170 MHz	10 MHz of C5
	(Region 2)	2 160-2 170 MHz	10 MHz of D4
– Recommendation ITU-R F.382	(Arrangement)	2 010-2 025 MHz	13.5 MHz of A4
	(Arrangement)	2 010-2 025 MHz	1.5 MHz of A5
	(Offset arrangement)	2 010-2 025 MHz	15 MHz of B5
	(Arrangement)	2 160-2 170 MHz	10 MHz of A2'
	(Offset arrangement)	2 160-2 170 MHz	6 MHz of B3'

6 Impact on Recommendation ITU-R F.1098

The current MSS worldwide allocation affects Recommendation ITU-R F.1098 as follows:

– Annex 1	Not affected
– Annex 2	0.5 MHz go and return channel 11
– Annex 3	10 MHz of go and return channel 11 10 MHz of go and return channel 12 10 MHz of go and return channel 13 10 MHz of go and return channel 14

The current MSS Region 2 allocation affects Recommendation ITU-R F.1098 as follows:

– Annex 1	Not affected
– Annex 2	13.5 MHz of channel 1 5.5 MHz of channel 11
– Annex 3	10 MHz of channel 10 5 MHz of channel 9 10 MHz of channel 14

7 Operational dates for worldwide and Region 2 MSS allocations in the 2 GHz band

Usage of the worldwide MSS allocation bands 1 980-2 010 MHz and 2 170-2 200 MHz shall not commence before 1 January 2000 (see Radio Regulations (RR) No. S5.389A).

Usage of the worldwide MSS allocation band 1 980-1 990 MHz in Region 2 and of Region 2 MSS bands 2 010-2 025 MHz and 2 160-2 170 MHz shall not commence before 1 January 2005 (see RR No. S5.389A and RR No. S5.389C) with the exception that in Canada and the United States of America usage of the latter bands by the MSS shall not commence before 1 January 2000 (see RR No. S5.389D).

8 Transition principles

When an administration decides to implement MSS, the following principles could be observed during the transition period.

To ease implementing MSS, the universe of FS's could be frozen:

– no expansion of existing fixed networks in bands that overlap MSS bands; and

– no new deployment of networks of existing fixed systems.

When MSS is introduced initially into FS bands, every effort should be made to coordinate and share spectrum between existing FS and new MSS service. These coordinating efforts should take into consideration that:

– transition be considered where interference criteria predicts unacceptable interference to incumbent fixed networks or links or into MSS systems;

– transition be prioritized in MSS Earth-to-space bands, given the difficulties of sharing of FS systems with MSS uplinks (see Resolution 716 (WRC-95) *resolves* 4.3);

– in the long term as MSS traffic increases, total relocation may be desirable.

Given that existing FS networks will be transitioned out of spectrum identified for MSS implementation, alternative spectrum (and/or alternative non-radio technology) could be identified to accommodate re-located existing fixed systems:

– alternative spectrum should be bands that do not overlap spectrum identified for MSS (e.g. Recommendation ITU-R F.1098 or in higher frequency FS bands);

– expansion of existing FSs and new deployment of existing FSs should be implemented in alternative spectrum.

Transition of existing fixed systems can occur over a reasonable time period, balancing the interests of existing FS operators and new MSS operators.

– when existing licences expire or when equipment is amortized;

– after a reasonable period, fixed systems could continue to operate in spectrum required for MSS implementation on a no interference no protection basis.

When a point has been reached when the FS systems are required to move outside the spectrum required to implement MSS, the usual planning tools for system implementation can be used (Note 1).

NOTE 1 – For example, fixed systems can be accommodated in the Recommendation ITU-R F.1098 channel arrangement or in channel arrangements in higher bands as indicated in Recommendation ITU-R F.746.

Retuning to channels within the same channel arrangement or moving to new channels within the same frequency range under new channel arrangements which lie outside the spectrum required for MSS implementation provides the benefit of retaining most of the existing infrastructure. This is particularly important for longer links which would be more difficult to achieve in higher frequency ranges.

9 Additional information concerning the transitional arrangements

Annex 2 gives an overview concerning frequency sharing between the MSS and the FS in the 2 GHz range.

Annex 3 offers some techniques for revisiting existing frequency division multiplex-frequency modulation (FDM-FM) systems to improve performance in the presence of interference from MSS and to take advantage of additional system capacity where it is available.

Annex 4 describes an approach for evaluating the impact of replanning existing FS systems in order to avoid overlap with the spectrum identified for MSS. This could be considered in conjunction with current existing Recommendations dealing with coordination methodologies such as Recommendation ITU-R F.1095 dealing with a procedure for determining coordination area between radio-relay stations of the FS.

ANNEX 2

Frequency sharing between the MSS and the FS in the 2 GHz range

1 FS shared with MSS space-to-Earth allocations

Recommendations ITU-R M.1141 and ITU-R M.1142 give coordination threshold levels between non-GSO (geostationary satellite orbit) MSS (space-to-Earth) and GSO MSS (space-to-Earth) on one hand and FS systems on the other hand sharing the same frequency bands in the 1-3 GHz range, respectively.

Recommendation ITU-R M.1143 Annex 2 and Annex 3 gives a system specific methodology for coordination of non-GSO MSS space stations (space-to-Earth) with the FS sharing the same frequency bands.

In addition, ITU-R developed Recommendation ITU-R M.1319 for considering, in detailed coordination, the impact of MSS satellite interference to 2 GHz line-of-sight FS systems. This Recommendation details the basis for a methodology to be used in order to compute the radio-frequency $C/(N+I)$ statistics of FS systems, taking into account MSS interfering carrier, I, and wanted FS carrier, C, levels. The wanted FS carrier levels are estimated taking into account parameters on relevant FS station, carrier, antenna path and intra-FS degradation together with predictions of typical multi-path levels according to the latest version of Recommendation ITU-R P.530-6 (Geneva, 1995) or alternative propagation models as appropriate. The MSS interfering levels are estimated taking into account MSS constellation orbital parameters, MSS spot beam carrier and antenna parameters and if needed MSS spot beam traffic loading and frequency plans.

The $C/(N+I)$ statistics can be compared with applicable ITU-R Recommendations for performance of digital and analogue FS systems in order to assess, for example, if these ITU-R performance objectives are still respected for a given FS system subject to interference from the given MSS system.

The ITU-R is studying the methodology to assess the interference from mobile earth stations to FS systems. This applies Recommendations ITU-R P.452 and ITU-R P.617 propagation models as appropriate.

1.1 Effects on analogue FS systems for telephony

Analogue FS systems for telephony in the 1-3 GHz range are generally used for low to medium capacity of 960 channels or less. There are two approaches to consider the effect of channel capacity on interference from MSS space stations.

1.1.1 First approach

In the first approach, it is assumed that at any channel capacity, the radio-relay route is so designed that the overall noise performance will just meet the maximum allowable noise objectives of a real link specified in Recommendation ITU-R F.395 (Volume IX-1 (Düsseldorf 1990)). In this case, the received power level at a receiving station for a system with lower capacity will be correspondingly low. Therefore, under this assumption, roughly speaking, the effect of MSS interference will be almost the same regardless of channel capacity.

However, even in this case, the energy dispersion effect of interference through the FM demodulation process is greater at a lower capacity (see Annex 1 to Recommendation ITU-R F.1246). Therefore, the overall effect of MSS interference will be somewhat smaller at FS systems with lower capacity.

1.1.2 Second approach

The above first approach may not be realistic, because in general it is more difficult for a radio-relay system with higher capacity to select repeater stations which satisfy the required noise performance objectives specified in Recommendation ITU-R F.395.

As an extreme case, it is assumed that the received power level at a receiving station for a radio-relay system is constant regardless of channel capacity. In this case, the effect of interference is roughly proportional to the square of the highest baseband frequency. For example, the interference to a 600 channel system is 4 dB lower than that to a 960 channel system. To this should be added an additional amount due to energy dispersion effect referred to in the § 1.1.1.

1.1.3 Summary

The actual effect of MSS interference on analogue FS systems will depend on the parameters of each radio-relay system. But generally speaking, it will be somewhere between the first and second approaches, and the effect of MSS interference will be smaller at analogue FS systems with lower channel capacity.

1.2 Effects on digital FS systems

Digital FS systems in the 1-3 GHz range are generally used for low to medium capacity of 2 Mbit/s to 45 Mbit/s or less. Most of the comments in the preceding sections (except for that relating to the energy dispersion effect which is unique to analogue FS systems) also apply to digital FS systems. Therefore, the effect of MSS interference will generally be smaller at digital FS systems with lower capacity.

In the detailed coordination process, the impact of MSS systems on actual FS systems can be determined. This will allow for the identification of any need for transitional arrangements.

2 FS shared with MSS Earth-to-space allocations

Recommendations ITU-R M.1141 and ITU-R M.1142 deal with sharing in the frequency bands in the 1-3 GHz range between non-GSO and GSO space stations operating in the MSS and the FS, respectively.

Annex 2 to Recommendation ITU-R M.1141 states that sharing studies have shown that co-channel operation of the transmitting stations of the new FS and receivers of non-GSO MSS space stations in the 1 980-2 010 MHz band would not in general be possible.

Annex 2 to Recommendation ITU-R M.1142 states that co-channel sharing in the 1-3 GHz range is not feasible for GSO mobile-satellite space stations employing global beam antennas and impractical for GSO space stations employing spot beams (e.g., for subregional or domestic coverage or for multiple beam spacecraft providing global coverage) due to the low e.i.r.p. density restrictions, the requirement for future fixed stations to avoid the GSO by 5° and the impracticality in developing regulatory controls on the total number of FSs.

The above finding led to *resolves* 4.3 of Resolution 716 (WRC-95), in which administrations are encouraged, where practicable, to draw up plans for gradual transfer of the frequency assignments to their FS stations in the bands shared with the MSS in the 2 GHz range to non-overlapping bands, considering the technical, operational and economical aspects.

ANNEX 3

Some transitional arrangements for analogue radio-relay systems for telephony in the 2 GHz range

1 Review of optimum frequency deviation

Preferred frequency deviation for analogue radio-relay systems for telephony using FDM-FM is given in Recommendation ITU-R F.404-2 (Volume IX-1 ((Düsseldorf, 1990)). The values applicable to capacities of 960 channels or less are reproduced in Table 1.

TABLE 1

Frequency deviation without pre-emphasis

Maximum number of channels	Root mean square (r.m.s.) deviation per channel(1) (kHz)
12	35
24	35
60	50, 100, 200
120	50, 100, 200
300	200
600	200
960	200

(1) For 1 mW, 800 Hz tone at a point of zero reference level.

Where pre-emphasis is used, the pre-emphasis characteristic should preferably be such that the effective (r.m.s.) deviation due to the multichannel signal is the same with and without pre-emphasis.

The reason for choosing the preferred values in Table 1 is considered as follows.

The performance of FDM-FM analogue radio-relay system is usually measured using a continuous uniform spectrum signal (see Recommendation ITU-R F.399-3 (Volume IX-1 ((Düsseldorf, 1990)). Generally the baseband signal-to-noise (S/N) ratio shows the characteristic of Fig. 3 as a function of r.m.s. frequency deviation per channel (loading level).

The solid curve in Fig. 3 corresponds to the S/N curve measured under normal propagation conditions. If the loading level is much lower than the nominal value, S/N is degraded mainly due to higher thermal noise. On the other hand, if the loading level is much higher than the nominal value, S/N is again degraded mainly due to higher intermodulation noise. S/N reaches a highest value at a certain loading level which is generally a couple of decibels below the nominal value. This is because it is necessary to take into account some degradation of thermal noise due to fading.

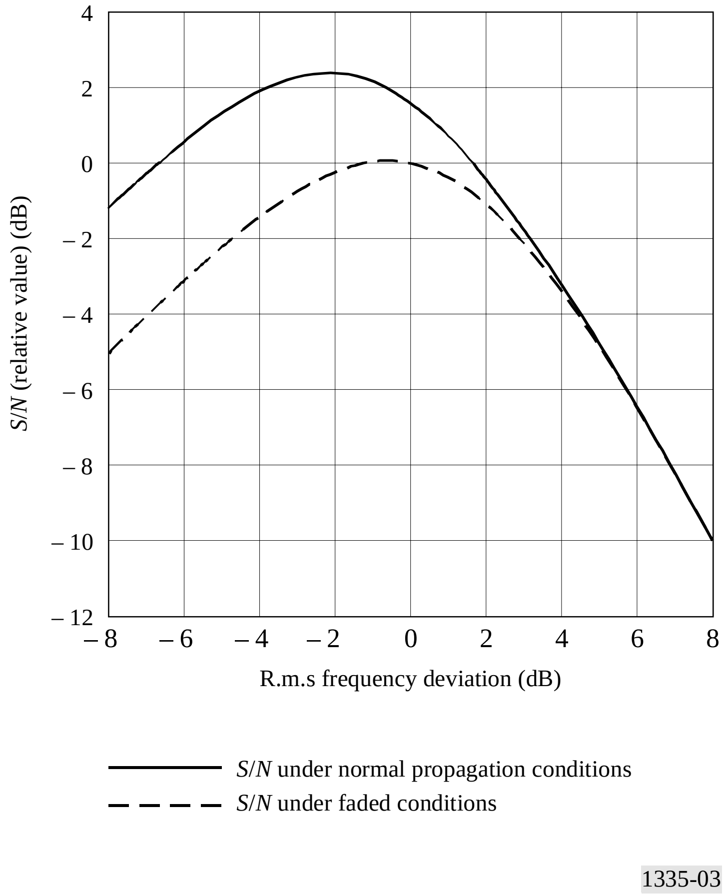
Therefore, ideally S/N reaches its maximum value at the nominal loading level under faded conditions (see the dashed curve). The preferred values of r.m.s. frequency deviation per channel as given in Table 1 were determined from this consideration.

However, the following factors may be pointed out:

- the preferred values of Table 1 were determined many years ago, when the intermodulation noise due to equipment imperfections was a serious constraint. More recent analogue radio-relay systems may show better performance with respect to intermodulation noise. This may allow increasing r.m.s. frequency deviation per channel;
- the preferred values of Table 1 were determined without taking account of interference from the MSS.

FIGURE 3

S/N of an analogue FDM-FM radio-relay system as a function of frequency deviation



Interference from space stations in the MSS behaves like an added thermal noise. Therefore, if the r.m.s. frequency deviation per channel is increased, the effect of both thermal noise and interference noise will be decreased, while the effect of intermodulation noise will become more significant.

For example, if the r.m.s. frequency deviation is increased by 3 dB (280 kHz instead of 200 kHz in case of 300, 600 and 960 channels), the effect on interference from space stations in the MSS will be as follows:

– the interference will be decreased by at least 3 dB;

– in addition, the dispersion effect of the spectrum of the analogue radio-relay system will become larger at a larger r.m.s. frequency deviation per channel; in case of the MSS which emits signals as a burst in a number of narrow-bands, the dispersion effect will result in an additional reduction of interference noise by about 1 or 2 dB, this value being dependent on the spectrum of the MSS.

Therefore, administrations operating FDM-FM analogue radio-relay systems are invited to re-examine the optimum value of frequency deviation. If the equipment design allows, 3 dB increase of the r.m.s. frequency deviation per channel may lead to the reduction of interference noise from the MSS at the expense of slight increase of intermodulation noise. (Needless to say, at the receiving end, the signal level should be attenuated by 3 dB in order to return to the original level.) However, an increase of the r.m.s. frequency deviation more than 3 dB is generally not recommended because:

– a larger increase of frequency deviation will generally bring about an excessive increase of intermodulation noise;

– if the adjacent channel spacing is not wide enough, a larger increase of frequency deviation will result in a wide spread of the spectrum of the radio-relay system which may give a larger interference to an adjacent channel of the same radio-relay route.

2 Possible reduction of the system capacity

In some situations, the actual traffic carried by a radio-relay system may be smaller than its nominal capacity. For example, a radio-relay system designed for the maximum capacity of 960 channels may carry signals with a capacity lower than 600 channels.

In such case, if the multiplex terminal is rearranged so that the highest baseband frequency (4 028 kHz for 960 channels) is changed to a lower one (2 540 kHz for 600 channels), the effect of interference from the MSS will be ameliorated.

In this case, there are two choices according to whether the pre-emphasis circuit is also rearranged or not.

2.1 New pre-emphasis circuit

Pre-emphasis characteristic for FDM-FM radio-relay systems for telephony is given in Recommendation ITU-R F.275-3 (Volume IX-1 (Düsseldorf, 1990)).

If practicable, a new pre-emphasis circuit and a new de-emphasis circuit applicable to the lower capacity should be adopted. In case of a change from 960 to 600 channels, the interference from the MSS will be reduced by at least 20 log (4 028/2 540) = 4 dB due to the change of the highest baseband frequency.

In addition, the increase of the r.m.s. frequency deviation should be also introduced. In this case, if the equipment design so allows, up to 5 dB increase (360 kHz instead of 200 kHz per channel) will be acceptable. This will contribute a great deal to reduction of the effect of interference (additional improvement of about 7 dB resulting in the total improvement of 11 dB).

2.2 No change of pre-emphasis circuit

In some cases, it may not be practicable to adopt a new pre-emphasis circuit appropriate for a lower capacity.

In such case, if the equipment design so allows, the r.m.s. frequency deviation per channel should be increased. In case of a change from 960 to 600 channels, 5 to 6 dB increase is preferred. If it is practicable, the effect of interference from the MSS will be significantly reduced (by approximately 7 to 8 dB).

ANNEX 4

Algorithms and methodologies for simulation of interference between FS networks

1 Introduction

This Annex describes algorithms and methods required to simulate interference between networks operating in the terrestrial FS.

The motivation for this type of simulation is two fold:

– to respond to Resolution 716 (WRC-95) § 1.2, where the ITU-R is requested to develop tools to assist Administrations in possible re-planning of 2 GHz FS systems to avoid overlap with the 2 GHz MSS allocations;

– to allow Administrations to investigate the feasibility of replanning existing 2 GHz FS systems using for example Recommendation ITU-R F.382 or ITU-R F.283 to replace FS channels presently overlapping with the 2 GHz MSS allocations, in particular in the MSS Earth-to-space direction, with other available FS channels. Such a simulation tool would be able to assist in determining whether or not in the replanned FS system the network performance objectives would continue to be respected.

1.1 Features of an intra-FS analysis model

The top level requirements can be summarized as follows:

- one FS system must be defined as the wanted system;
- define all stations of all other FS systems as potentially interfering;
- aggregate interference from all interfering links into each wanted link is calculated;
- wanted propagation model based on Recommendation ITU-R P.530-6 (Geneva, 1995);
- interfering propagation model based on Recommendation ITU-R P.452-7 (Geneva, 1995), including terrain based diffraction model and digital terrain data;
- computation of C/I, C/N and $C/(N+I)$ PDF (probability distribution function) and CDF (cumulative distribution function) for each station of the wanted system;
- end-to-end statistics calculated, making a distinction between digital and analogue systems;
- inclusion of polarization discrimination for orthogonal linearly polarized carriers.

1.2 Antennas and polarization discrimination

Antenna modelling involves the specification of a gain roll-off pattern, where the relative gain of the antenna is given as a function of the off-axis angle and the half power beamwidth. Circular symmetry is assumed.

A typical pattern for the FS is given in Recommendation ITU-R F.699 which gives curves defining co- and cross-polar response.

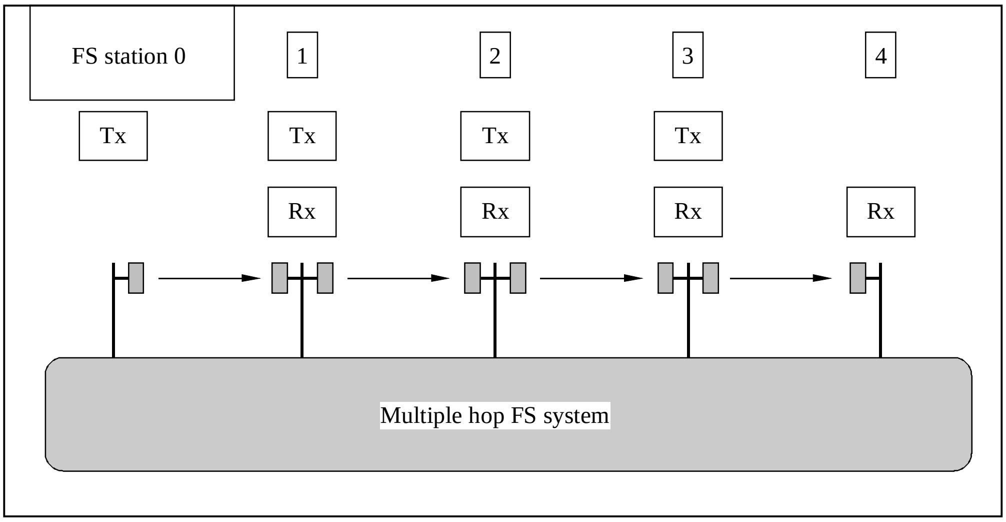
The method proposed for modelling purposes involves switching between the co- and cross functions depending on the type of polarization on the wanted and interfering link; either horizontal or vertical.

2 FS system representation

An FS system comprises a series of n FS stations with (n – 1) FS hops in between as shown in Fig. 4.

FIGURE 4

FS system



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For the purpose of this description, the stations in the FS system are numbered starting at zero, with the link starting at station 0 and the last transmitting (Tx) station being station n – 2. The first receiving station is station 1, and the last receiving (Rx) station is station n – 1.

2.1 FS systems

Information required for FS systems:

- station,
- carrier,
- link,

as described in the sections below. It is assumed that the FS system is point to point that can be modelled using axially symmetric antenna gain patterns, and that each antenna points at the receiving/transmitting station.

2.1.1 Station data

To specify the stations of an FS system the following information is required:

- number of stations,
- station characteristics,

where each station is specified by:

- *station position*
    - latitude (degrees North),
    - longitude (degrees East),
    - height ((m) above mean sea level and local terrain);
- *station antenna characteristics*

    Antennas are specified using the following data:

    - peak gain (dBi) and beams size (half power beamwidth or semi-major axis) (degrees),
    - dish size (m) and efficiency.

The beam pattern can be defined using one of the following, and can be given in both co- and cross-polar cases through:

- one of the standard equations given in the relevant ITU-R Recommendation;
- tables specifying relative gain versus off axis angle.

ITU-R Recommendation 699 is used typically as the gain pattern for FS.

In addition the following are required to calculate the system temperature:

- receiver noise figure,
- antenna temperature (K),
- feeder loss (dB),
- feeder temperature (K).

2.1.2 Carrier data

The carrier either digital or analogue, describes how the radio frequency (RF) signal carries information. It is defined through:

- the occupied bandwidth (Hz or kHz or MHz),
- the polarization (left-hand circular (LHC), right-hand circular (RHC), linear horizontal, linear vertical).

2.1.3 Link data

The link defines how the carrier described above travels from the Tx to the Rx station. The following parameters are required:

- transmit frequency (GHz),
- nominal transmit power (dBW),
- propagation model and corresponding input parameters,
- operating criteria required (such as C/I or $C/(N+I)$) (dB),
- percentage of time for which operating criteria should be met.

If a system is using power control then the following is required:

- minimum transmit power (dBW),
- maximum transmit power (dBW),
- target receive signal level (dBW).

3 The interference calculation

The key functions in the interference calculation are:

- the power calculation of the received wanted and interfering power levels including terrain, atmospheric and multipath effects;
- the bandwidth adjustment factor including where necessary the effect of multiple carriers in the wanted bandwidth or the spectral power density;
- loop aggregate interference from multiple sources.

The interference calculation is based upon *C*, *I*, and *N*. For multiple interferers, the aggregate interfering signal, I_{agg}, is taken as the sum of all single entry interferers. *N* is calculated based upon the noise temperature *T*.

$$I_{agg} = 10 \log \sum 10^{I_i/10} \qquad \text{dBW}$$

$$N_0 = K_{abs}\, T_{abs} \text{ (absolute value) or } N_0 = K_{dB} + T_{dB} \qquad \text{dB(W/Hz)}$$

where *K* is Boltzmann’s constant.

By defining the following as:

BWC: bandwidth of the signal carrier *C* (dB)

FTC: bandwidth factor for the wanted signal (dB)

FTI: bandwidth factor for the interfering signal (dB),

one can calculate:

$$N = N_0 + BWC$$

$$I' = I - FTI + FTC$$

So:

$$C/I = C - I'$$

$$C/N = C - N$$

$$C/(N + I) = C - dB[UndB(N) + UndB(I')]$$

$$= dB\big(1/[1/UndB(C/I) + 1/UndB(C/N)]\big)$$

$$I/N = UndB(I' - N)$$

$$= 10^{(I' - N)/10}$$

where:

$$dB(x) = 10 \log_{10} x$$

and

$$UndB(x) = 10^{x/10}$$

The total values of C/I, C/N and $C/(N+I)$ for analogue systems are calculated as follows:

$$(C/I)_{total} = dB\left(\frac{1}{\sum^{n}\left(\frac{1}{UndB(C/I)}\right)i = 1}\right)$$

$$(C/N)_{total} = dB\left(\frac{1}{\sum^{n}\left(\frac{1}{UndB(C/N)}\right)i = 1}\right)$$

$$\left(C/(N + I)\right)_{total} = dB\left(\frac{1}{\left(\frac{1}{UndB(C/I)_{total}}\right) + \left(\frac{1}{UndB(C/N)_{total}}\right)}\right)$$

For digital carrier systems there may be bit regeneration at each hop. Bit regeneration is taken into consideration by:

- calculating C/X using thermal noise addition for hops without regeneration;
- taking the worst C/X of those segments with regeneration.

The FDP over a run duration is calculated as:

$$\frac{I_{avg}}{N} = \frac{\sum_{i}\frac{I_i}{N} \cdot t_{step}}{Total\ time}$$

For multiple hop systems, the FDP is calculated using the same process as C/X.

3.1 Power calculation

The power calculation is based on the following equation:

$$Power_{Rx} = e.i.r.p._{Tx} + RelativeGain_{Tx} - Propagation\ Losses + PeakGain_{Rx} + RelativeGain_{Rx}$$

The received power level could be either the wanted signal or the interfering signal.

Details of the relevant propagation models are described in § 5. Special care must be taken with the antenna gains, which vary for different terrain path types. Two different terrain paths have been identified.

3.1.1 Beyond Radio Horizon

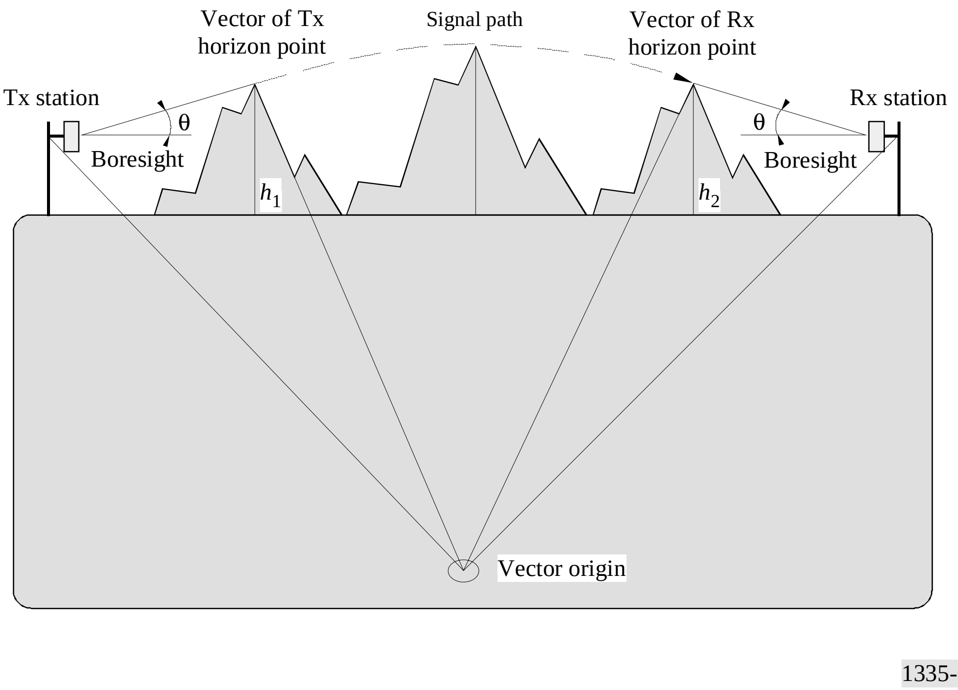
In this case the line-of-sight (LOS) relative gain towards to horizon in the direction of the radio path must be calculated at both the transmitter (Tx) and receiver (Rx). The propagation model handles the loss between the stations. This is shown in Fig. 5.

3.1.2 Radio line-of-sight (LOS)

In this case the relative gains are based upon a straight line between transmitter and receiver stations.

FIGURE 5

Off-axis gain towards horizon for beyond radio horizon paths



3.2 Propagation modelling

This subsection gives an overview of the applicable propagation models. Detailed descriptions of these models are given in § 5.

A distinction is made between interfering signals and wanted signals in performing the interference analysis. For LOS losses, Recommendation ITU-R P.530-6 (Geneva, 1995) is applicable to wanted signals and Recommendation ITU-R P.452 to interfering signals.

These Recommendations (i.e. Recommendations ITU-R P.530-6 and ITU-R P.452) are being revised and the intent of this section is to specify the algorithm. Relevant algorithms are included in this Recommendation for completeness based on existing equations in Recommendations ITU-R P.530-6 and ITU-R P.452. These algorithms would be however generally applicable within the context of new revisions to Recommendations ITU-R P.530-6 and ITU-R P.452, although the specific form of the equations contained herein may change.

LOS fixed links can be modelled using the Recommendation ITU-R P.530-6 initial planning method, combined with free space path loss. This method gives a distribution of fade and multipath enhancement as a function of link length, frequency antenna heights and meteorological parameters.

Recommendation ITU-R P.452 describes how to apply propagation models of several modes to general links. Interfering paths can be characterized into three types for the purpose of terrain based propagation loss computations.

– Type 1 paths are LOS with first Fresnel Zone clearance,

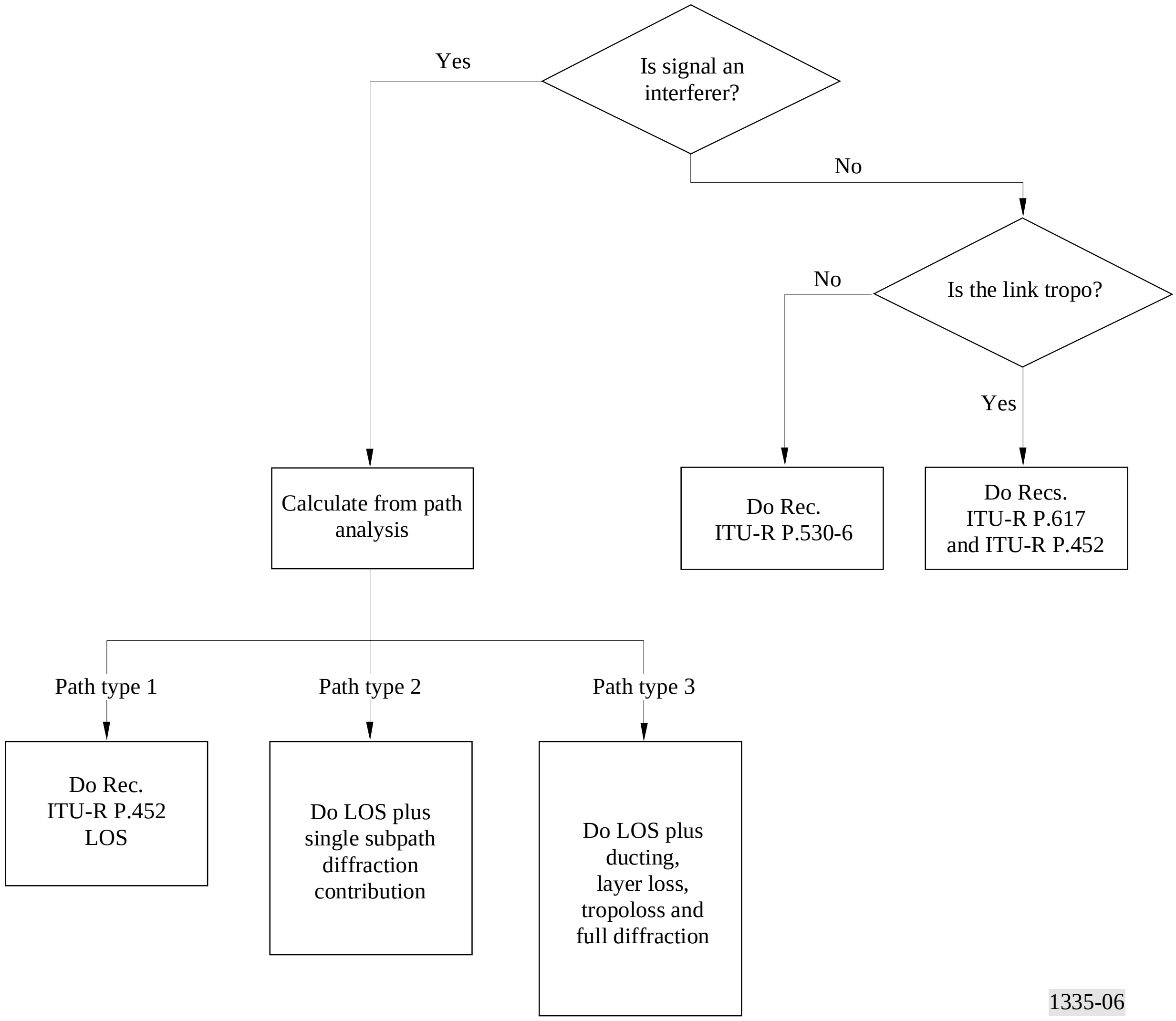
– Type 2 paths are LOS without first Fresnel Zone clearance of all terrain points,

– Type 3 paths are transhorizon with one or more obstacles between the transmitter and receiver.

The path type is then used to determine which loss models are applicable, according to Fig. 6.

FIGURE 6

Propagation modelling overview



Losses due to different mechanisms are combined according to Table 5 of Recommendation ITU-R P.452.

4 Intra-FS analysis results

The results can take numerous forms, primarily:

- statistical: such as probability of interference, or,
- time evolution form.

Statistics can be gathered for each of:

- C,
- I,
- N,
- C/I,
- C/N,
- $(N + I)$,
- I/N.

Where appropriate the following statistics can be calculated:

- single entry interference,
- aggregate interference,
- interference into a single hop,
- interference into an end to end system.

In general, these values are of interest when they exceed specified levels (protection ratios, or trigger levels). When a protection ratio is violated, this is referred to as an interference event. Useful statistics about interference events include:

- percentages of time interference occurs,
- number of interference events,
- average duration of interference events,
- longest interference event,
- time of longest interference event,
- worst interference event,
- time of worst interference event,
- average value: FDP for I/N,
- distribution of values.

The distribution can then be plotted as either:

- PDF, or,
- CDF.

It can also be useful to have multiple criteria levels, to generate multiple statistics.

This could be for:

- interference levels for 20% of the time, or,
- interference levels for 0.01% of the time.

5 Loss models

This section describes the details of propagation loss models applicable to terrestrial interference paths based on ITU-R Recommendations.

5.1 Recommendation ITU-R P.530-6 fading and enhancement model

Recommendation ITU-R P.530-6 gives an FS LOS model specifying the relationship between the depth of a fade and the probability that a fade depth is exceeded, and the degree of enhancement and percentage of time enhancement is not exceeded.

Recommendation ITU-R P.530-6 fade model contains four parts:

- standard equations, for fade depth > 25 dB,
- extrapolation, for fade depth < 25 dB,
- equations for propagation enhancement for enhancements > 10 dB,
- equations for propagation enhancement for enhancements between 0 and 10 dB.

Two methods are proposed in Recommendation 530-6 to assess the fading model. Method 1 is intended for link planning and design and is described below.

Wherever the multipath fade model is used, the enhancement model must also be taken into account. The long and short term fades together with the enhancement define a cumulative distribution function which can be used in a Monte-Carlo simulation of the fade depth. A random number is generated and used to define a % time for which the CDF must be inverted. This inversion of the CDF is a standard method for sampling non-standard distributions, and can always be performed to the required accuracy using a binary chop algorithm.

The equations for calculating the probability of a given fade and a given enhancement are detailed below.

The percentage of time, p_w, that the fade depth, A (dB) is exceeded in the average worst month is given by (valid for small percentages of time):

$$p_w = K\,Q\,f^{B} d^{C} 10^{-A/10}$$

where:

K, Q, B, C are defined as follows:

$B = 0.89$

$C = 3.6$

$Q = \left(1 + \left|\varepsilon_p\right|\right)^{-1.4}$

where:

ε_p: path inclination (mrad) given by $\left|\varepsilon_p\right| = \left|h_1 - h_2\right| / d$

h_1, h_2: antenna heights (m) above sea level

d: path length (km)

f: frequency (GHz)

K: geoclimatic factor for the average worst month from fading.

If the parameters to estimate *K*, the geoclimatic factor are not available, then *K* can be found using an alternative means such as the contour maps of Figs. 7 to 10 of Recommendation ITU-R P.453 for the percentage of time p_L that the average refracting gradient in the lowest 100 m of the atmosphere is less than –100 N units/km along with the empirical relations for *K* given in Table 2.

TABLE 2

Path Type	*K* (Method 1)
Overland non-mountainous	$10^{-(6.5 - C_{Lat} - C_{Lon})} p_L^{\,1.5}$
Overland mountainous	$10^{-(7.1 - C_{Lat} - C_{Lon})} p_L^{\,1.5}$
Over medium bodies of water	$10^{-(5.9 - C_{Lat} - C_{Lon})} p_L^{\,1.5}$
Over large bodies of water	$10^{-(5.5 - C_{Lat} - C_{Lon})} p_L^{\,1.5}$

In Table 2, p_L is the percentage of time probability that the refractivity gradient $\delta M / \delta h$, measured in the first 100 m above ground is less than –100 N units/km. The coefficients C_{lat} at latitude ς are given by:

$C_{Lat} = 0$ for $|\varsigma| \leq 53$

$C_{Lat} = -5.3 + \varsigma / 10$ for $53 < |\varsigma| < 60$

$C_{Lat} = 0.7$ for $|\varsigma| \geq 60$

The coefficients C_{lon}, for longitudes are given by:

$C_{Lon} = 0.3$ for longitudes of Europe and Africa

$C_{Lon} = -0.3$ for longitudes of North and South America

$C_{Lon} = 0$ for all other longitudes.

The percentage of time, p_w, that the fade depth, A (dB), is exceeded for large percentages of time i.e., $A < 25$ dB or $A < 35$ dB, is given by:

$$p_w = 100\left[1 - \exp\left(-10^{-q_a A/20}\right)\right] \qquad \%$$

where:

$$q_a = 2 + 10^{-0.016A}\left[1 + 0.3 \times 10^{-A/20}\right]\left[q_t + 4.3\left(10^{-A/20} + A/800\right)\right]$$

Calculate the value of q'_a for the fade depth $A = 35$ dB with the corresponding value of p_w:

$$q'_a = \frac{-20\log_{10}\left[-\ln\left(\frac{100 - p_w}{100}\right)\right]}{A}$$

then compute the value of the parameter q_t:

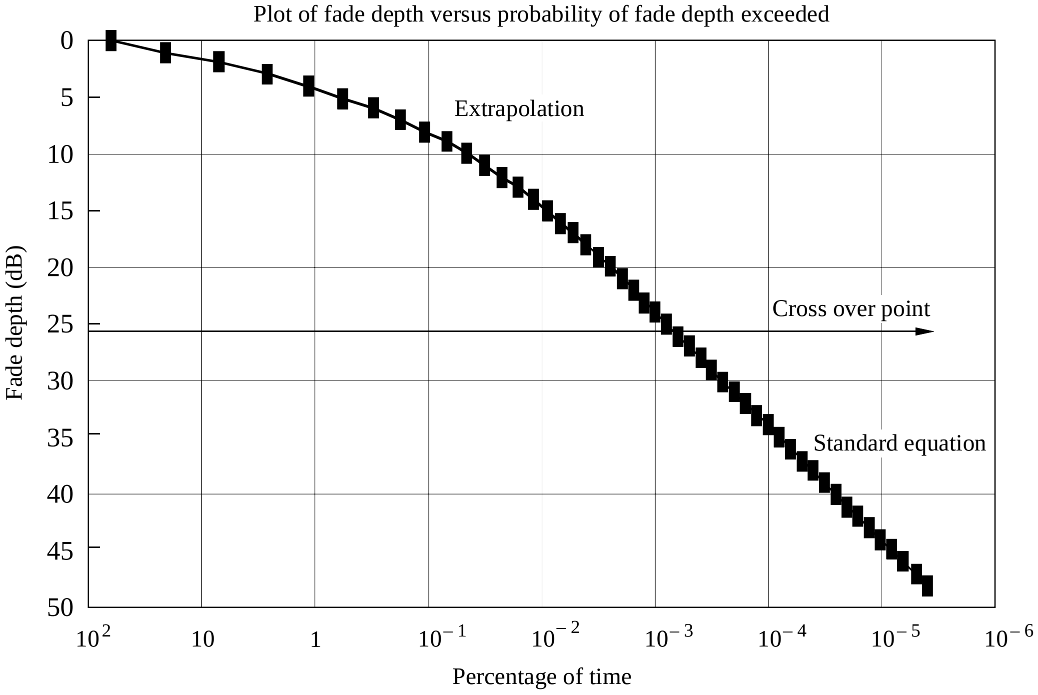
$$q_t = \frac{\left(q'_a - 2\right)}{10^{-0.016A}\left[1 + 0.3 \times 10^{-A/20}\right]} - 4.3\left(10^{-A/20} + A/800\right)$$

If $q_t > 0$ then the above equations should be re-evaluated for $A = 25$ dB.

This is shown in Fig. 7:

FIGURE 7

Recommandation ITU-R P.530-6 fade depth distribution



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5.1.1 Enhancement model

The enhancement distribution is also given in Recommendation ITU-R P.530-6. Average worst month enhancement above 10 dB are predicted using:

$$p_w = 100 - 10^{(-1.7 + 0.2 A_{0.01} - E)/3.5} \qquad \% \qquad \text{for } E > 10 \text{ dB} \tag{1}$$

where:

E: enhancement (dB) not exceeded for p% of the time

$A_{0.01}$: fade depth exceeded for p_w = 0,01% of the time:

$$A_{0.01} = 10 \log \left(\frac{0.01}{K \, Q \, f^{B} d^{C}} \right)$$

where values of Q, B and C depend on the whether Method 1 or Method 2 is being used for the fade model.

The percentage of time that the enhancement E is not exceeded or is between 0 and 10 dB is given by:

$$p_w = 100 - 58.21 \left[1 - \exp \left(-10^{-q'_e E/20} \right) \right]$$

where the parameter q_e is calculated as follows:

Step 1: Calculate the percentage of time p'_w with enhancement less than or equal to 10 dB (E' = 10 dB) using equation (1)

Step 2: Calculate q'_e:

$$q'_e = -2 \left[\log_{10} \left(-\ln \left(1 - \frac{100 - p'_w}{58.21} \right) \right) \right]$$

Step 3: Calculate q_s:

$$q_s = 2{,}05 \; q'_e - 20.3$$

Step 4: Calculate q_e:

$$q_e = 8 + \left(1 + 0.3 \times 10^{-E/20} \right) \left(10^{-0.7E/20} \right) \left[q_s + 12 \left[10^{-E/20} + E/800 \right] \right]$$

5.2 Recommendation ITU-R P.452 based losses

Recommendation ITU-R P.452 contains a prescription for calculating general loss based on an analysis of the radio path profile.

5.3 Terrain based diffraction loss model

For the interfering links, the diffraction loss calculation should be based on Recommendation ITU-R P.526.

For Type 2 paths only the subpath contribution will be calculated. This contribution is assumed to be from the terrain point with the largest intrusion into the first Fresnel Zone. This point will be modelled as a knife edge obstacle. For Type 3 paths, an array of obstacle parameters will be calculated. Each obstacle will be modelled as a cylinder, and the total loss calculated using the general method given in Recommendation ITU-R P.526.

Given the obstacle array for the path, the total diffraction loss (dB) can be calculated from

$$L_d = \sum_{obstacles} L_c + \sum_{subpaths} L_{ds} - 20 \log \left[\frac{\left(s_1 s_2 \ldots s_{n+1}\right)\left(s_1 + s_2 + s_3 + \ldots + s_{N+1}\right)}{\left(s_1 + s_2\right)\left(s_2 + s_3\right)\ldots\left(s_N + s_{N+1}\right) s_1 s_{N+1}} \right]^{1/2}$$

where the L_c terms are contributions from the individual cylindrical obstacles, L_{ds} are the maximum subpath contribution from between each pair of cylindrical obstacles, and s_i are distances to the centres of each obstacle along the great circle path of the average terrain.

If the path is Type 2 or Type 3, a term due to diffraction will be added to the overall propagation loss. If the path is Type 2, only the subpath term is included.

The term L_c is equal to the knife edge term plus the attenuation due to curvature of the obstacle defined in Recommendation ITU-R P.526, and is given by the following:

$$L_c = 0.0316 \, h \left[\frac{2\left(d_1 + d_2\right)}{\lambda \, d_1 \, d_2} \right]^{1/2} + k \, m^b$$

where:

$$k = 8.2 + 12 \, n$$

$$b = 0.73 + 0.27\left[1 - \exp(-1.43 \, n)\right]$$

and

$$m = R \left[\frac{d_1 + d_2}{d_1 \, d_2} \right] \left[\frac{\pi R}{\lambda} \right]^{-\frac{1}{3}}$$

$$n = h \left[\frac{\pi R}{\lambda} \right]^{\frac{2}{3}} R^{-1}$$

where:

h: height of the top of the obstacle above the straight line joining the two ends of the path. If the height is below this line, h is negative

d_1, d_2: distances of the 2 ends of the path from the top of the obstacle

d: length of the path.

5.3.1 Knife edge diffraction loss

Diffraction over a knife edge can produce a loss or an enhancement, depending on the value of the dimensionless Fresnel-Kirkhoff parameter n. Calculation of n is detailed in the terrain modules design document.

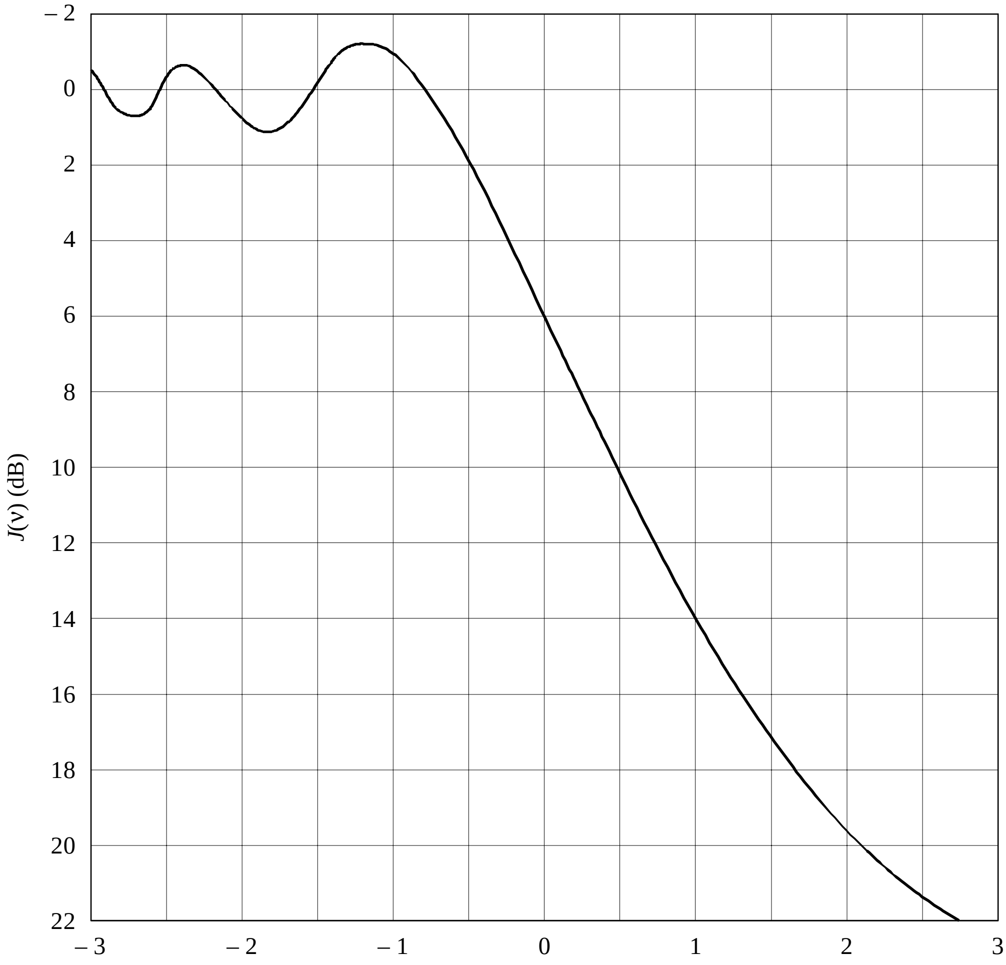
Once n is known, the loss can be calculated. For n values greater than –0.7, the knife edge loss (dB) is obtained from the expression:

$$J(v) = 6.9 + 20 \log \left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1 \right)$$

For values less than –0.7, the loss can be extracted from Fig. 8 taken from Recommendation ITU-R P.526.

FIGURE 8

Knife edge diffraction loss



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5.4 Stretched string analysis and obstacle modelling

5.4.1 Path characterization

This paragraph describes how the path parameters required to classify the path according to Recommendation ITU-R P.452 are extracted from the path profile. The parameters calculated are given in Table 3. Additional parameters required for the calculation of the diffraction loss are described in § 5.3. Before characterizing the path a term for the curvature of the Earth will be added to each point in the path profile. This is a function of length along the path and the earth radius factor. Note that if path characterization is performed using a median value for the earth curvature according to § 3.2.2 of Recommendation ITU-R P.452 and then the obstacle analysis is performed using a different earth curvature factor the classification of the path may change.

Other parameters given in Table 3 of Recommendation ITU-R P.452 relate to over water paths and antenna heights above sea level. These are user inputs in this simulation.

These parameters are then used to classify the path into one of the following types.

Type 1: LOS with first Fresnel Zone clearance;

Type 2: LOS without first Fresnel Zone clearance of all terrain points;

Type 3: transhorizon with one or more obstacles between the transmitter and receiver.

TABLE 3

Path characterization parameters

Parameter	Description
d	Great-circle, path distance (km)
d_{lt}, d_{lr}	Distance from the transmit and receive stations to their respective median horizons (km)
q_{ht}, q_{hr}	Transmit and receive horizon elevation angles (i.e. angle to the highest intervening terrain points) (mrad)
q_{ft}	Angle to the first Fresnel Zone ellipse of terrain point with maximum elevation
q_{rt}	Elevation angle of the receive station from the transmit station (path inclination)
q	Path angular distance (mrad)
h_{te}, h_{re}	Antenna effective heights above terrain, derived by least squares fit to the path profile (m)

A path is:

– Type 1 if $q_{rt} > q_{ft}$

– Type 2 if $q_{ht} < q_{rt} \leq q_{ft}$

– Type 3 if $q_{rt} \leq q_{ht}$.

The calculation of each parameter is given below.

5.4.2 Path classification

The path will be classified into one of three types based on whether the path is LOS or has first Fresnel Zone clearance or is transhorizon. With Type 3 obstacles will be found by the stretched string analysis and characterized as cylinders. Between each pair of cylinders, a single sub path diffraction point will be modelled as a knife edge (see § 5.3.1). For LOS paths with no Fresnel Zone clearance, the terrain point with the largest intrusion into the Fresnel Zone (see § 5.3.1) will be treated as a knife edge.

The input to the calculations described here is the path structure with heights above sea level and number of path points already known. All terrain heights should have a curvature term added assuming a median earth radius for the path data. The median earth radius is defined from the geoclimatic data during run set up.

To find the horizon angle for the transmitter, loop through all the path vectors and get the elevation angle (mrad) to each point from the formula:

$$\theta = \frac{h_n - h_t}{d_n}$$

where:

h_n : height of the nth terrain point in m above mean sea level (amsl)

h_t : interferer antenna height (m) amsl

d_n : distance from the interferer to the nth terrain element (km).

Retain the largest value and the path point which produced this value. This value is q_{ht} and the distance to this point is d_{lt}.

Also for each point, the value of the angle to the first Fresnel Zone ellipse, q_{ft} is calculated by replacing h_n by:

$$h_n \rightarrow h_n + 17.392 \sqrt{\frac{d_n (d - d_n)}{d \ f}}$$

where:

d : total path length (km)

f : frequency (GHz).

The elevation angle to the receive station q_{ft} is calculated by replacing h_n and d_n by h_r and d in the equation for q above.

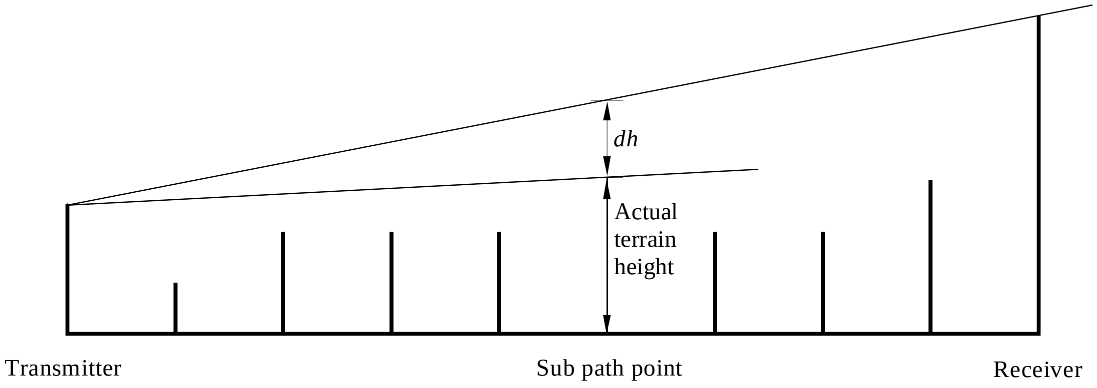
If $q_{rt} \leq q_{ht}$, then the path is Type 3 and the horizon parameters for the receive station must be calculated.

If $q_{ht} < q_{rt} \leq q_{ft}$, then the path is Type 2.

If the path is either Type 2 or 3, the angles and distances are needed for the loss calculation and will be stored with the path profile, i.e. horizon angles, distances and terrain points which may contribute to sub-path losses.

FIGURE 9

Example path profile for Type 1 and Type 2 paths



Terrain with path Type 2
dh + actual terrain height < first Fresnel Zone radius

Terrain with path Type 1
dh + actual terrain height > first Fresnel Zone radius

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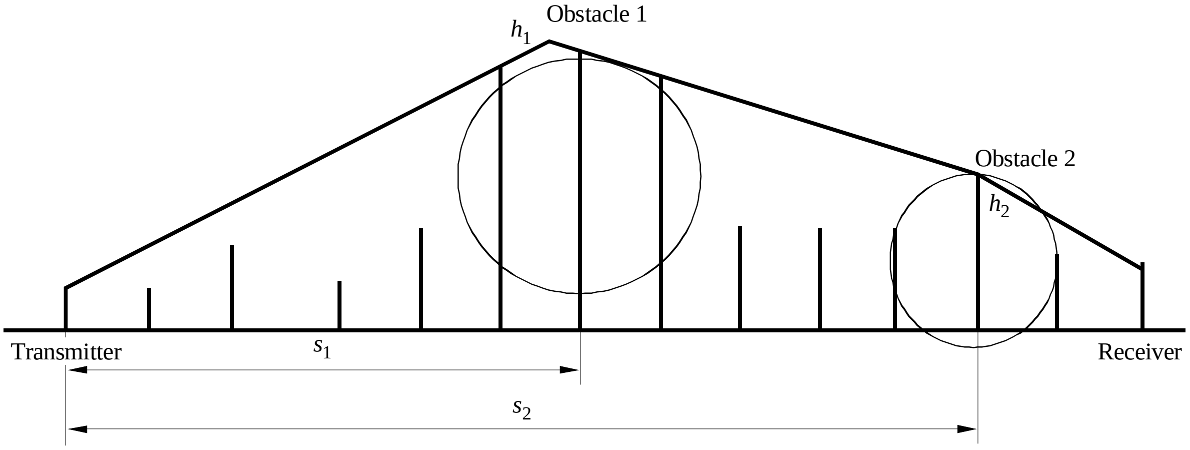
FIGURE 10

Example path profile for path type 3



Terrain profile with two cylindrical obstacles

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5.4.3 Diffraction obstacle characterization

Diffraction calculations require that obstacle positions, heights and radii be calculated from the path profile. Diffraction must be included if the path is Type 2 or Type 3. If the path is Type 2, only the subpath diffraction element from the dominant subpath point needs to be accounted for.

The extraction of obstacle characteristic is described in the following paragraphs.

5.4.3.1 Identification and classification of diffraction obstacles

Obstacles locations will be identified using the stretched string analysis suggested in the Annex 1 of Recommendation ITU-R P.452.

The first obstacle begins at the horizon point seen along a great circle path from the transmit station to the receive station. The obstacle ends at the horizon point looking backwards along the path from the peak of the next obstacle or the receiver. The second obstacle begins at the horizon point seen from the end of the first obstacle along the path to the receive station. The process of identifying obstacles continues until there is LOS from the last obstacle found to the receive station.

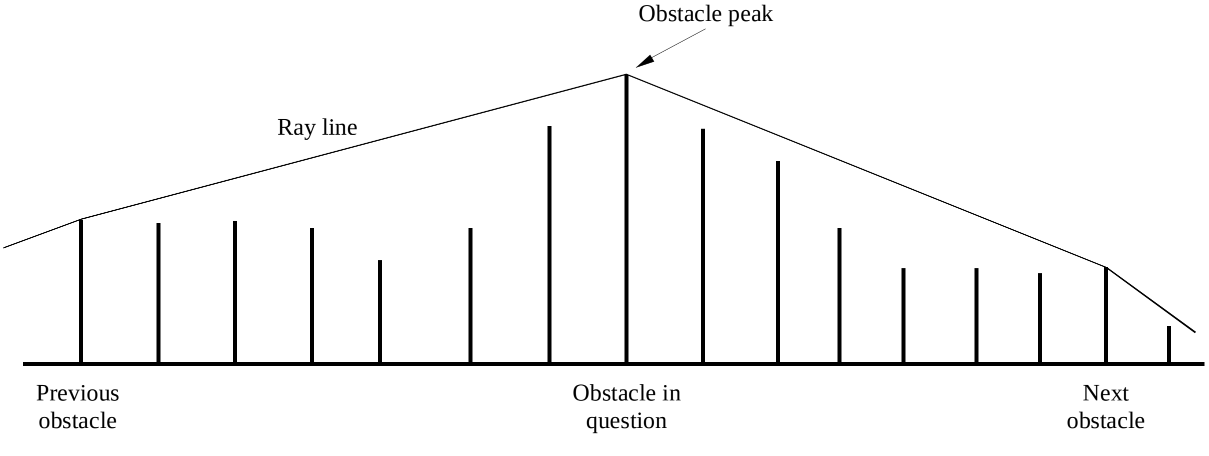
Once all the obstacle have been identified the classification will locate all the obstacle peaks from which the characteristics can be calculated.

If the horizon point from the previous obstacle (or transmitter) and the horizon point from the next obstacle (or receiver) are the same point the obstacle is called a single point obstacle. This can be seen in Fig. 11. The alternative is a multi-point obstacle where there is a gap between the afore-mentioned horizon points as shown in Fig. 12. The peak of the obstacle is defined as the intersection of the imaginary ray paths from the adjacent obstacles. Fig. 11 shows the peak location for a single point obstacle and Fig. 12 for a multi point obstacle.

Single point obstacle

FIGURE 11

Single point obstacle

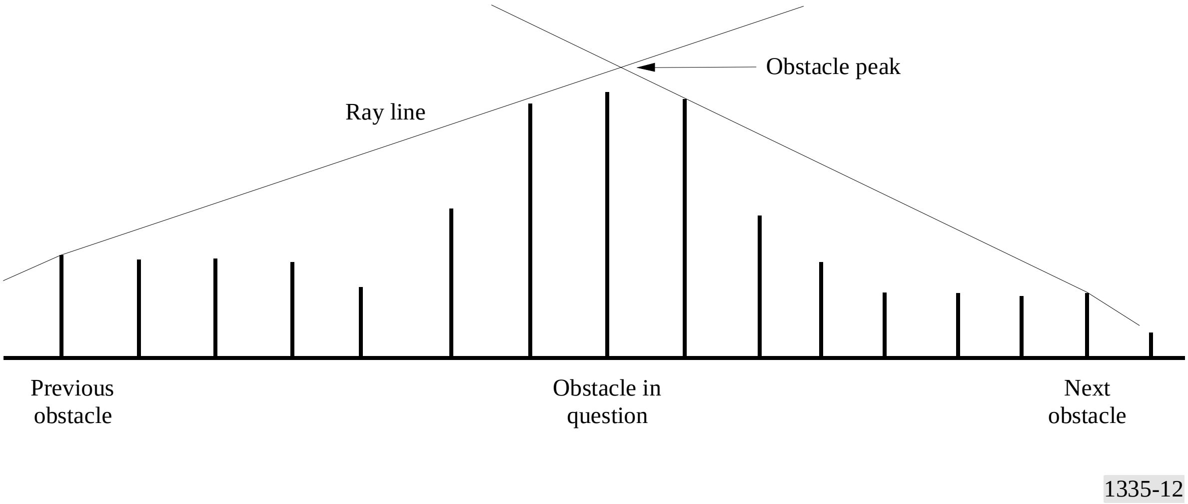


Multiple point obstacle

Where the ray line from the previous obstacle and the ray line from the next obstacle do not cross on a single path point as shown in Fig. 12.

FIGURE 12

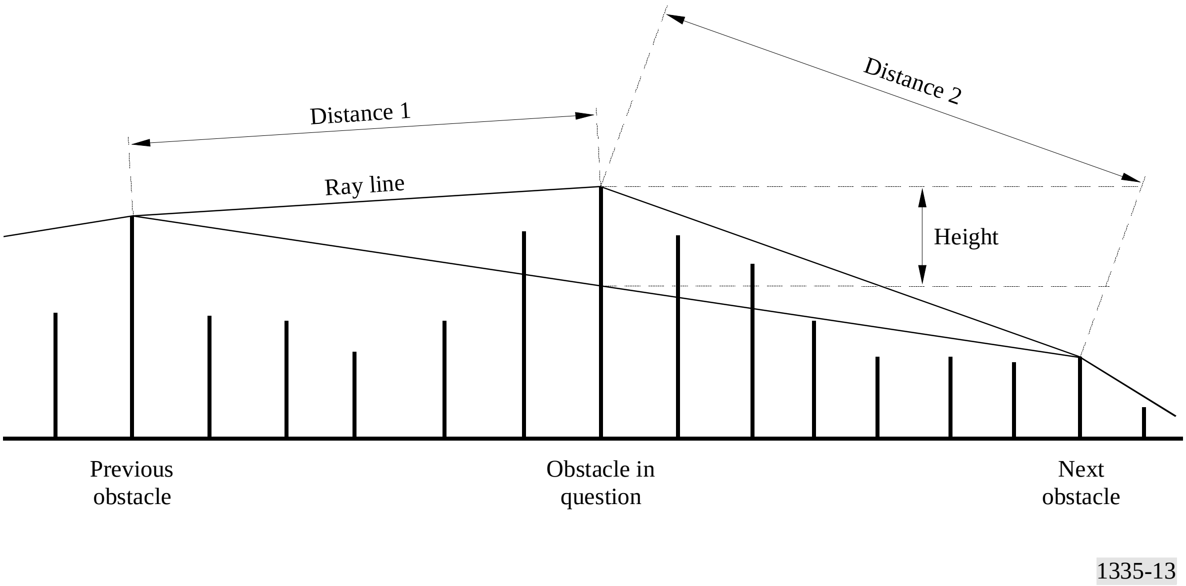
Multi-point obstacle



Once obstacle peaks have been determined the height, distance from previous obstacle and distance to next obstacle will be calculated as shown in Fig. 13.

FIGURE 13

Obstacle parameters



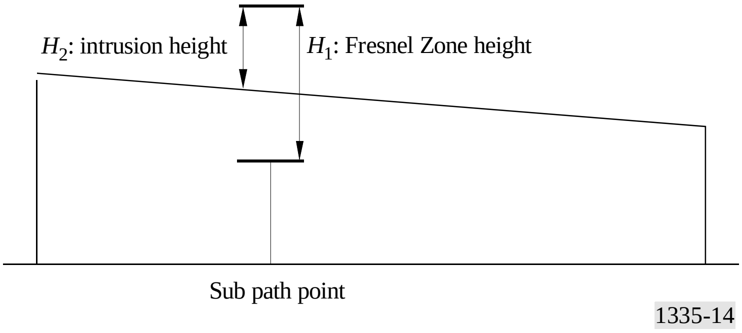
Each obstacle will have a radius calculated from the difference in slope of the path immediately before the obstacle start and after the obstacle end.

5.4.3.2 Determination of dominant sub-path diffraction contribution

Where there is no first Fresnel Zone clearance, the effects of sub-path diffraction can still be quantified. Recommendation ITU-R P.526 calls for the calculation of a single contribution between each pair of obstacles. The contribution will be taken from the terrain point with the largest intrusion into the first Fresnel Zone. The intrusion will be measured as the ratio of H_1 and H_2 shown in Fig. 14. The point with the largest value of H_1/H_2 will be the subpath point.

FIGURE 14

Measure of intrusion into first Fresnel Zone



The sub-path point will be modelled as a knife edge. The value used for *h* (knife edge height) is the distance between the stretched string and the top of knife edge (this should be negative).

For Type 2 paths a single contribution due to sub path diffraction should be included.

For Type 3 paths, a sub path contribution must be included between each pair of cylinders touched by the stretched string. The maximum sub path contribution will be calculated as for Type 2 paths.

5.5 Transhorizon pathloss model

Transhorizon propagation for frequencies above 30 MHz can occur by diffraction, or by scatter from atmospheric irregularities. Due to the rapid attenuation of the diffracted wave with range and frequency, the principal mechanism for establishing transhorizon links is tropospheric scatter (troposcatter).

These models are applicable to the interfering paths which are transhorizon and do not have first Fresnel Zone clearance.

5.5.1 Method 1 – Average annual median transmission loss distribution for time percentages greater than 50%

The average annual transmission loss not exceeded for *q* % of the time is given by:

$$L(q) = M + 30\log f + 10\log d + 30\log\theta + L_N - Y(q) - G_t - G_r$$

where:

M: meteorological parameter (dB)

f: frequency (MHz)

d: pathlength (km)

θ: scatter angle

L_N: loss depending on the height of the common volume

$Y(q)$: conversion factor for non-exceedance percentages q other than 50%

G_t, G_r: antenna gains.

Table 4 gives meteorological values of M (dB) for the climate zones as defined in Recommendation ITU-R P.617.

TABLE 4

Climate	1	2	3	4	6	7a	7b
M (dB)	39.60	29.73	19.30	38.50	29.73	33.2	26.00

The scatter angle is calculated from:

$$\theta = \theta_e + \theta_t + \theta_r \qquad \text{mrad}$$

where:

θ_t, θ_r: are transmitter and receiver horizon angles

$$\theta_e = d \times 10^3 / k\,a \qquad \text{mrad}$$

where:

k: effective earth radius factor for median refractivity conditions (4/3)

a: radius of the earth (6 370 km).

L_N is a loss depending on the height of the common volume and is given by:

$$L_N = 20 \log \left(5 + \gamma\, 10^{-3}\, \theta\, d / 4\right) + 4.34\, \gamma\, 10^{-6}\, \theta^2\, k\, a / 8 \qquad \text{dB}$$

γ is again climate zone dependent, and is given in Table 5.

TABLE 5

Climate	1	2	3	4	6	7a	7b
γ (km^{-1})	0.33	0.27	0.32	0.27	0.27	0.27	0.27

$Y(q)$ is a conversion factor for non-exceedance percentages q other than 50% and is calculated from:

$$Y(q) = C(q)\, Y(90)$$

$Y(90)$ is the conversion factor for $q = 90\%$ and is climate dependent:

$$Y(90) = -2.2 - (8.1 - 2.3 \times 10^{-4} f) \exp(-0.137\, h) \qquad \text{dB} \qquad \text{for climates 2, 6 and 7a}$$

$$Y(90) \; -9.5 - 3 \exp(-0.137\, h) \qquad \text{dB} \qquad \text{for climate 7b}$$

For other climates the value of $Y(90)$ can be extrapolated graphically from Fig. 1 in Recommendation ITU-R P.617.

$C(q)$ is the conversion factor for other percentages of time. Recommendation ITU-R 617 gives some values, shown in Table 6.

TABLE 6

q	50	90	99	99.9	99.99
$C(q)$	0	1	1.82	2.41	2.90

For values above 50% not given in the table, can be extracted using linear interpolation.

For values below 50% the loss is obtained by assuming a symmetry about the 50% line. This is recommended in Recommendation ITU-R P.617 for percentages down to 20% in all cases and down to 1% in some cases. In the software, it is assumed valid for all p values, in the absence of a better model.

5.5.2 Method 2 – Average worst month median transmission loss distribution for time percentages greater than 50%

This distribution is best determined from the average annual distribution by means of a conversion factor.

By using Method 1, one can obtain the average annual distribution for the non-exceedance percentages (50, 90, 99, 99.9) and climate(s) of interest. The basic transmission loss is calculated by finding the difference between the average annual and average worst month distribution from the curves of Fig. 2 in Recommendation ITU-R P.617. Note that curves for climate 3 should be used for climate 2 since there are no curves available for that climate.

Taking the difference of basic transmission loss and adding it to the corresponding average annual values you can obtain the average worst month transmission losses for the non-exceedance percentages (50, 90, 99, 99.9). The average worst month transmission losses not exceeded for 99.99% of the time can be estimated from the values obtained through logarithmic extrapolation.

5.5.3 Method 3 – Ducting loss

The prediction of the basic transmission loss $L_{ba}(p)$ (dB) occurring during periods of anomalous propagation (ducting and layer reflection) is based on the following function:

$$L_{ba}(p) = A_f + A_d(p) + A_g \qquad \text{dB} \qquad (2)$$

where:

A_f: total of fixed coupling losses (except for local clutter losses) between the antennas and the anomalous propagation structure within the atmosphere:

$$A_f = 102.45 + 20 \log f + 20 \log (d_{lt} + d_{lr}) + A_{st} + A_{sr} + A_{ct} + A_{cr} \qquad \text{dB} \qquad (3)$$

A_{st}, A_{sr}: site-shielding diffraction losses for the interfering and interfered-with stations respectively:

$$A_{st,sr} = \begin{cases} 20 \log \left[1 + 0.361\, \theta''_{t,r} \left(f \cdot d_{lt,lr} \right)^{1/2} \right] + 0.264\, \theta''_{t,r}\, f^{1/3} & \text{dB} \quad \text{for } \theta''_{t,r} > 0 \text{ mrad} \\ 0 & \text{dB} \quad \text{for } \theta''_{t,r} \leq 0 \text{ mrad} \end{cases} \qquad (4)$$

where:

$$\theta''_{t,r} = \theta_{t,r} - 0{,}1\, d_{lt,lr} \qquad \text{mrad} \qquad (4a)$$

A_{ct}, A_{cr}: over-sea surface duct coupling corrections for the interfering and interfered-with stations respectively:

$$A_{ct,cr} = -3\, e^{-0.25\, d_{ct,cr}^2} \left[1 + \tanh \left(0.07 \left(50 - h_{ts,rs} \right) \right) \right] \qquad \text{dB} \qquad \text{for} \quad \omega \geq 0.75, \quad d_{ct,cr} \leq d_{lt,lr}, \quad d_{ct,cr} \leq 5 \text{ km} \qquad (5)$$

$$A_{ct,cr} = 0 \qquad \text{dB} \qquad \text{for all other conditions} \qquad (5a)$$

It is useful to note the limited set of conditions under which equation (5) is needed.

$A_d(p)$: time percentage and angular-distance dependent losses within the anomalous propagation mechanism:

$$A_d(p) = \gamma_d \cdot \theta' + A(p) \qquad \text{dB} \tag{6}$$

where:

γ_d: specific attenuation:

$$\gamma_d = 5 \times 10^{-5}\, a_e\, f^{1/3} \qquad \text{dB/mrad} \tag{7}$$

θ': angular distance (corrected where appropriate (via equation (8)) to allow for the application of the site shielding model in equation (4)):

$$\theta' = \frac{10^3 d}{a_e} + \theta'_t + \theta'_r \qquad \text{mrad} \tag{8}$$

$$\theta'_{t,r} = \begin{cases} \theta_{t,r} & \text{mrad} \qquad \text{for } \theta_{t,r} \le 0.1\, d_{lt,lr} \\ 0.1\, d_{lt,lr} & \text{mrad} \qquad \text{for } \theta_{t,r} > 0.1\, d_{lt,lr} \end{cases} \tag{8a}$$

$A(p)$: time percentage variability (cumulative distribution):

$$A(p) = A_0(p) + 12\,(p/\beta)^{\Gamma} \qquad \text{dB} \tag{9}$$

where:

$$A_0(p) = -12 + \left(1.2 + 4 \times 10^{-3}\, d\right)\, \log\,(p/\beta) \qquad \text{dB} \tag{9a}$$

$$\Gamma = 0.17\, \exp\left[\, 0.027\,\beta + 0.15\, (\log \beta + 4)^{1,4} \right] \tag{9b}$$

In equation (9b), note that evaluation of $(\log \beta + 4)$ should be set to zero if it would otherwise be less than zero.

$$\beta = \beta_0 \cdot \mu_2 \cdot \mu_3 \qquad \% \tag{10}$$

where:

μ_2: correction for path geometry:

$$\mu_2 = \left[\frac{500}{a_e} \, \frac{d^2}{\left(\sqrt{h_{te}} + \sqrt{h_{re}}\right)^2} \right]^{\alpha} \tag{11}$$

The value of μ_2 shall not exceed 1.

$$\alpha = -0.6 - d \times 10^{-3}\, \left(1 - e^{-s}\right) \tag{11a}$$

$$s = 6.7 \times 10^{-3} \left[d\,(1 - \omega) \right]^{1.6} \tag{11b}$$

μ_3: correction for terrain roughness:

$$\mu_3 = \begin{cases} 1 & \text{for } h_m \le 10 \text{ m} \\ \exp\left[-4.6 \times 10^{-5}\, (h_m - 10)\, (43 + 6\, d_i) \right] & \text{for } h_m > 10 \text{ m} \end{cases} \tag{12}$$

$$d_i = \min\,(d - d_{lt} - d_{lr},\ 40) \qquad \text{km} \tag{12a}$$

A_g : total gaseous absorption determined from:

$$A_g = [\gamma_o + \gamma_w(\rho)]\, d \qquad \text{dB}$$

where:

γ_o, $\gamma_w(\rho)$: specific attenuation due to dry air and water vapour, respectively, and are found from the equations in Recommendation ITU-R P.676

ρ: water vapour density:

$$\rho = 7.5 + 2.5\,\omega \qquad \text{g/m}^3$$

where ω is the fraction of the total path over water.

5.5.4 Method 4 – Tropospheric scatter loss

The basic transmission loss due to troposcatter not exceeded for any percentage, p, below 50% is given by:

$$L_{bs}(p) = 190 + L_f + L_c + 20 \log d + 0.573\,\theta - 0.15\,N_0 + A_g - 10.1\,[-\log(p/50)]^{0.7} \qquad \text{dB}$$

where:

L_f: frequency dependent loss computed with:

$$L_f = 25 \log f - 2.5\,[\log(f/2)]^2 \qquad \text{dB}$$

L_c : aperture medium coupling loss computed with:

$$L_c = 0{,}051 \cdot e^{0.055(G_t + G_r)} \qquad \text{dB}$$

N_0 : surface refractivity at the path centre, derived from Fig. 7 in Recommendation ITU-R P.452.

A_g : gaseous absorption derived from:

$$A_g = [\gamma_o + \gamma_w(\rho)]\, d \qquad \text{dB}$$

where:

γ_o, $\gamma_w(\rho)$: specific attenuation due to dry air and water vapour, respectively found in Recommendation ITU-R P.676

ρ : water vapour density

where $\rho = 3$g/m^3 for the whole path length.