RECOMMENDATION ITU-R M.1472*, **

Methodology to evaluate the impact of interference from time division multiple access/frequency division multiple access (TDMA/FDMA) mobile-satellite service (MSS) systems operating in the 2 GHz range on baseband performance in frequency division multiplexing-frequency modulation (FDM-FM) analogue line-of-sight (LoS) fixed service receivers

(Questions ITU-R 201/8 and ITU-R 118/9)

(2000)

The ITU Radiocommunication Assembly,

considering

a) that the frequency bands 2 170-2 200 MHz in all Regions and 2 160-2 170 MHz in Region 2 are allocated to the MSS (space-to-Earth) and the FS on a co-primary basis subject to RR Nos. 5.389A and 5.389C;

b) that transmissions from mobile satellites could cause interference to LoS FS receivers operating in these bands;

c) that such interference involves time-varying phenomena such as interference geometry, propagation conditions, and MSS traffic;

d) that computer simulation usually is the only way to accurately evaluate such interference;

e) that the output of such simulations is typically in the form of C/I, C/N and $C/(N + I)$ statistics into the given FS systems;

f) that the impact and acceptability of such interference in most cases can be assessed in detailed bilateral coordination by studying via computer simulation the radio frequency C/N, C/I and $C/(N + I)$ statistics as described in Recommendation ITU-R M.1319;

g) that, in some critical cases, there may be a need during detailed bilateral coordination to evaluate via computer simulation the interference impact on analogue FDM-FM FS baseband performance objectives,

recommends

1 that the methodology in Annex 1 may be used in detailed bilateral coordination between concerned parties for detailed assessment of the impact of interference from TDMA/FDMA MSS satellites in the 2 GHz MSS allocations on baseband performance in analogue FDM-FM LoS FS receivers, in cases where the results obtained by the methodology described in Recommendation ITU-R M.1319 needs further refinement (see Notes 1, 2 and 3).

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* This Recommendation was jointly prepared by Radiocommunication Study Groups 8 and 9, and any further revision will also be undertaken jointly.

** Radiocommunication Study Group 8 made editorial amendments to this Recommendation in 2004 in accordance with Resolution ITU-R 44.

NOTE 1 – The application of the methodology in this Recommendation will require the development of algorithms or calculation procedures to address the implementation of the considerations described. The use or adaptation of these algorithms or procedures in any bilateral coordination would be subject to agreement by the concerned parties.

NOTE 2 – In countries where a large number of FS systems are in operation, it may be sufficient to apply the analysis to a representative set of existing FS systems, using actual FS parameters, especially taking into account those FS systems that are likely to be most sensitive to interference. The most sensitive FS systems are usually those oriented close to the worst-case azimuth direction; this direction can be established based on the orbital characteristics of the MSS system. However, this is a matter that will require agreement between the concerned parties.

NOTE 3 – In the case of GSO MSS systems the calculations are significantly simplified, since there is no need to simulate the orbital mechanics of the MSS constellation, however the potential of interference from multiple GSO MSS satellites may need to be considered when evaluating the impact of interference.

Annex 1

Methodology to evaluate the impact of interference from TDMA/FDMA MSS systems operating in the 2 GHz range on baseband performance in FDM-FM analogue LoS FS receivers

1 Introduction

Sharing between MSS and FS involves time varying phenomena such as interference geometry, propagation conditions, etc. Simulation is usually the only way to accurately evaluate interference between MSS and FS systems. The output of such simulations is typically in the form of radio-frequency C/I, C/N and $C/(N + I)$ statistics presented usually as a cumulative distribution function.

Recommendation ITU-R M.1319 provides a methodology whereby *inter alia* baseband performance objectives for analogue FDM-FM and TV-FM FS systems provided in Recommendation ITU-R F.393 and Recommendation ITU-R F.555 can be translated into equivalent radio-frequency $C/(N + I)$ requirements for an associated percentage of time, with if necessary appropriate scaling to address actual FS routes of shorter length than the reference circuits. These equivalent radio-frequency performance objectives are plotted on the cumulative distribution plots of $C/(N + I)$ in order to determine if the interference from MSS satellites is acceptable.

The method described in Recommendation ITU-R M.1319 although it requires extensive computer simulation is relatively straightforward to implement in software, since all calculations and comparisons are undertaken in the radio-frequency domain. The methodology of Recommendation ITU-R M.1319 should be used in the detailed coordination phase between administrations, when coordination is formally required and triggered in application of the RR, in order to determine if interference is acceptable or not, when considered in the context of actual FS system information and the relevant ITU-R performance and availability objectives.

In some cases during the bilateral coordination phase, it may be necessary for the parties concerned to further examine the impact of MSS interference on the performance objectives of analogue FS systems. This could be the case where the results of the simulation method described in Recommendation ITU-R M.1319 above are not sufficiently definitive to enable the conclusion of frequency coordination.

The objective of this Annex is to present methodologies to evaluate the baseband performance impairments more accurately for FDM-FM analogue FS carriers taking into account the effects of varying frequency separations that would exist for multiple narrow-band interfering carriers, recognizing that the interference reduction factor or *B*-factor and the protection ratio requirements of Recommendation ITU-R SF.766 indicate a strong dependence on frequency separation between the wanted and the interfering carriers.

The methodology presented in this Annex necessarily involves more sophisticated simulation tools than those described in Recommendation ITU-R M.1319 and is expected to require considerably more computer resources to execute.

2 Methodology for FDM-FM FS systems

2.1 Reference FDM-FM FS system for simulation

In the detailed coordination phase, it is expected that actual analogue FS route parameters will be available in order to assess the impact of MSS interference. It is noted that in the 2 GHz range, the intermediate FS stations in a FS modem section are usually equipped with IF repeaters. Demodulation to the baseband takes place at the terminal station. Since demodulation to baseband does not take place at the intermediate repeaters, it is only necessary to calculate the baseband interference at the last/terminal repeater in the modem section or actual FS route.

According to Recommendation ITU-R F.393, the maximum allowable values of noise power at a point of zero relative level in any telephone channel on a 2 500 km hypothetical reference circuit for FDM radio-relay systems should not exceed the values given below, which have been chosen to take account of adverse propagation conditions:

– 7 500 pW0p, psophometrically weighted one minute mean power for more than 20% of any month;

– 47 500 pW0p, psophometrically weighted one minute mean power for more than 0.1% of any month;

– 1 000 000 pW0, unweighted (with an integration time of 5 ms) for more than 0.01% of any month.

2.2 Estimation of statistics of baseband interference and thermal noise

2.2.1 General description

The impact of interference from MSS satellite systems employing narrow-band modulation/access schemes into an FDM-FM baseband telephone channel can be assessed as follows.

Using the simulation methods described in Recommendation ITU-R M.1319, at each time step in the simulation period for each FS receiver in an FS route one can estimate the C/I and C/N values, where now the C/I levels are computed due to each individual TDMA/FDMA MSS carrier within the receiver bandwidth of the FDM-FM FS receiver.

The r.f. interference power at the k-th receiver may be obtained as the k-th term of equation (1) in Annex 1 of Recommendation ITU-R M.1143. The received carrier power at the k-th receiver includes the loss due to multipath fading on the k-th hop of the radio-relay route.

Once the value of C/I is known for each narrow-band MSS carrier at each time step, the next step is to convert the C/I value into the baseband noise power. The method of computation of baseband interference noise power is based on Recommendation ITU-R SF.766. The interference reduction factor B (dB) is expressed as follows:

$$B = 10 \log \frac{2(\delta f)^2 \, p(f / f_m)}{b \, f^2 D(f, f_0)} \tag{1}$$

$$D(f, f_0) = \int_{-\infty}^{+\infty} S(F) P_1(f + f_0 - F) \, \mathrm{d}F + \int_{-\infty}^{+\infty} S(F) P_1(f - f_0 - F) \, \mathrm{d}F + S(f + f_0) P_{10} +$$

$$S(f - f_0) P_{10} + S_0 P_1(f + f_0) + S_0 P_1(f - f_0) + \frac{S_0 P_{10}}{b} \, \delta(f - f_0) \tag{2}$$

$$P_1(f) = P(f) \, A^2(f) \tag{3}$$

$$P_{10} = P_0 \, A^2(0) \tag{4}$$

$$\begin{array}{lll} \delta(f - f_0) = 1 & & \text{when } f = f_0 \\ \delta(f - f_0) = 0 & & \text{when } f \neq f_0 \end{array} \tag{4a}$$

where:

- δf: r.m.s. test tone deviation (without pre-emphasis) of the wanted signal (kHz)
- f: centre-frequency of channel concerned, within the wanted signal baseband (kHz)
- f_m: upper frequency of the wanted signal baseband (kHz)
- $p(f/f_m)$: pre-emphasis factor for centre-frequency of channel concerned, within the wanted carrier baseband
- b: bandwidth of telephone channel (3.1 kHz)
- f_0: separation between carriers of the wanted and interfering signals (kHz)
- $S(f)$: continuous part of the normalized power spectral density of the wanted signal with pre-emphasis (Hz^{-1})
- S_0: normalized vestigial carrier power of the wanted signal
- $P(f)$: continuous part of the normalized power spectral density of the interfering signal (Hz^{-1})
- P_0: normalized vestigial carrier power of the interfering signal
- $A(f)$: amplitude-frequency response of the wanted signal receiving filter, the origin of the frequencies being the centre frequency of the interfering signal carrier.

The power spectral densities are normalized to unity and are assumed to be one-sided (only positive frequencies).

The expression of N_p in terms of the ratio C/I is derived from expressions (5) and (6). In order to determine N_p, it is necessary to determine:

– the wanted signal spectrum (analogue telephony);

– the interfering signal spectrum.

The weighted interference power (N_p) is obtained as unweighted power in 1.75 kHz, which gives:

$$N_p = 10^{0.1(87.5 - B - C/I)} \tag{5}$$

where C/I is the carrier to interference ratio (dB).

The computation of the interference reduction factor involves the convolution of wanted and interfering power spectra. The power spectra of FS radio-relay systems of various channel capacities are given in Recommendation ITU-R SF.766. Once, an expression or a value is obtained for the interference reduction factor, the calculation of noise in baseband is quite straightforward.

The baseband thermal noise levels at each FS receiver can be computed from C/N estimates at each time step and using the standard relationship between the C/N and baseband S/N applicable for FDM-FM FS systems.

The total baseband noise at the end of the radio-relay route of interest at each time step can be determined as:

$$(I + N)_{BB} = \sum_k \left(N_{pk} + N_{Tk} + N_{Ik}\ L_{MPk}\right) + N_{other} \tag{6}$$

where:

$(I + N)_{BB}$:	total baseband noise on the FS route of interest (pW)
N_{pk}:	weighted interference power for the *k*-th receiver, from equation (5)
N_{Tk}:	thermal noise at the input of the *k*-th receiver
N_{Ik}:	estimated baseband intra-service interference noise at the *k*-th receiver
L_{MPk}:	multipath fade loss for the *k*-th hop
N_{other}:	baseband system noise from all other sources. (For analogue FM radio-relay systems used for telephony, factors are needed to account for intermodulation distortion noise and for contributions from such systems components as multiplexers/demultiplexers, and entrance links.)

Note that all three terms in the summation in equation (6) scale with the multipath fade loss on the *k*-th hop although N_{pk} and N_{Tk} already take into account the automatic gain control scaling.

The statistics of total baseband noise can be developed from the estimates of the total baseband noise at each time step.

2.2.2 Specific methodology

The computation of aggregate interference noise and thermal noise power in the given (typically top) telephone channel in the FDM-FM system involves the following steps:

Step 1: Calculation at each time step of C at each receive FS station with multipath fading taken into account on that particular hop. Multipath fading is taken into account using a random fade depth predictor, whose output is consistent with the statistical distribution derived from the Recommendation ITU-R P.530 multipath fading model.

Step 2: Calculation at each time step of I at each receive FS station due to each interfering TDMA/FDMA MSS carrier from each spot beam of each visible MSS satellite, taking into account MSS satellite spot beam and receive FS antenna discrimination and MSS satellite spot beam power/traffic loading and frequency plans.

Step 3: Calculation at each time step of C/I due to each interfering TDMA/FDMA MSS carrier from each spot beam of each visible MSS satellite and C/N at each receive FS station.

Step 4: Calculation at each time step of the aggregate C/I and C/N for the FS system.

Step 5: Calculation at each time step, at the terminal FS receive station, of baseband interference reduction factor or B-factor at various frequency offset intervals with equation (1) and baseband interference noise power with equation (5), based on per carrier C/I estimates taking into account the allocated bandwidth of the interfering TDMA narrow-band MSS carrier. A look-up table can be used for B factor values for various frequency offsets.

Step 6: Calculation at each time step, at the terminal FS receive station, of baseband thermal noise based on C/N estimates using the applicable C/N to S/N translation for the given FDM-FM FS system.

Step 7: Calculation at each time step, at the terminal FS receive station, the sum of aggregate total baseband interference from each multiple TDMA/FDMA MSS interfering carriers and thermal noise power into top baseband channel.

Step 8: The above steps are repeated for each time step over a statistically valid period commensurate with a full or equivalent orbital cycle period of the MSS satellite constellation and a representative period for multipath fading behaviour.

Step 9: Finally the probability distribution of total baseband noise is computed and plotted. This can then be compared with the objectives of Recommendation ITU-R F.393, appropriately apportioned.

3 An example

An example application of the above method is given in Appendix 1.

Appendix 1
to Annex 1

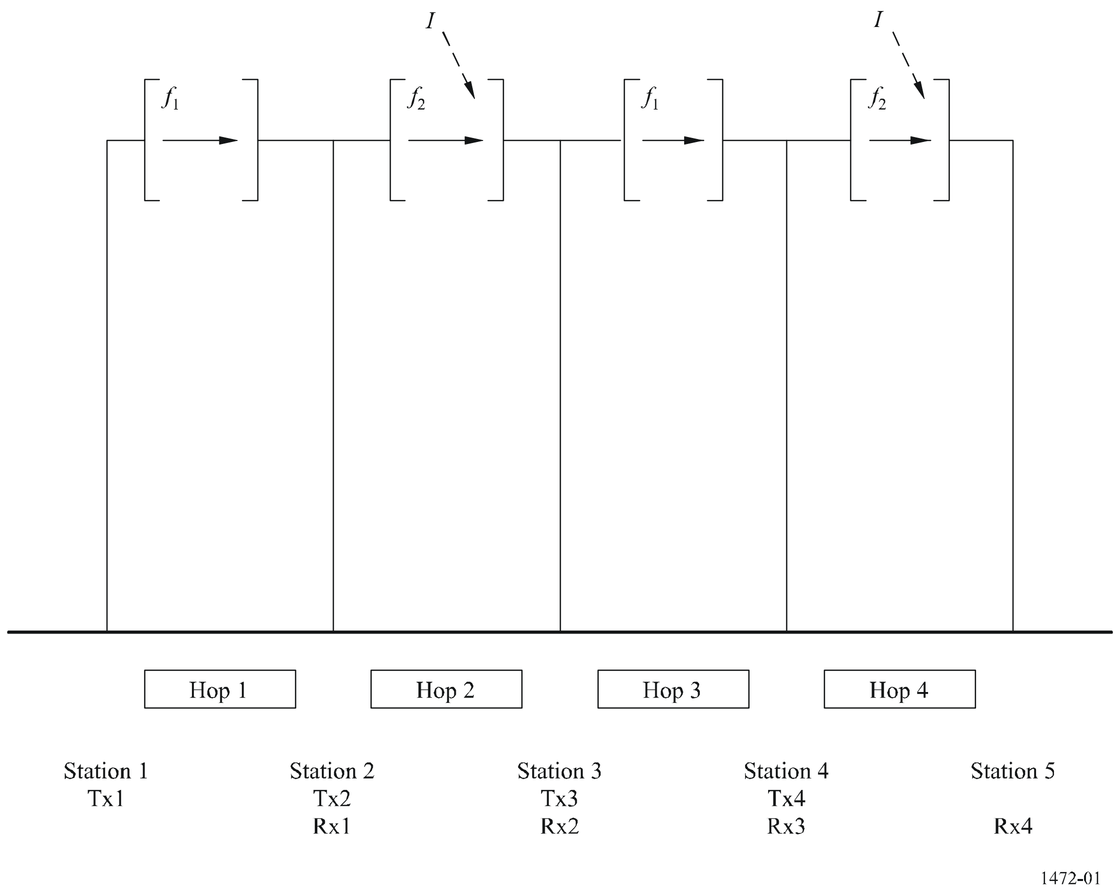
Example application of methodology for the computation of baseband interference from the LEO-F system into 4-hop 960-channel FDM-FM radio-relay systems

1 Introduction

In this Appendix, the methodology explained in Annex 1 is applied to compute the baseband interference plus thermal noise from the LEO-F system into an example 4-hop 960-channel FDM-FM radio-relay system operating at 2 GHz (see Fig. 1).

FIGURE 1

Layout of LOS radio-relay system

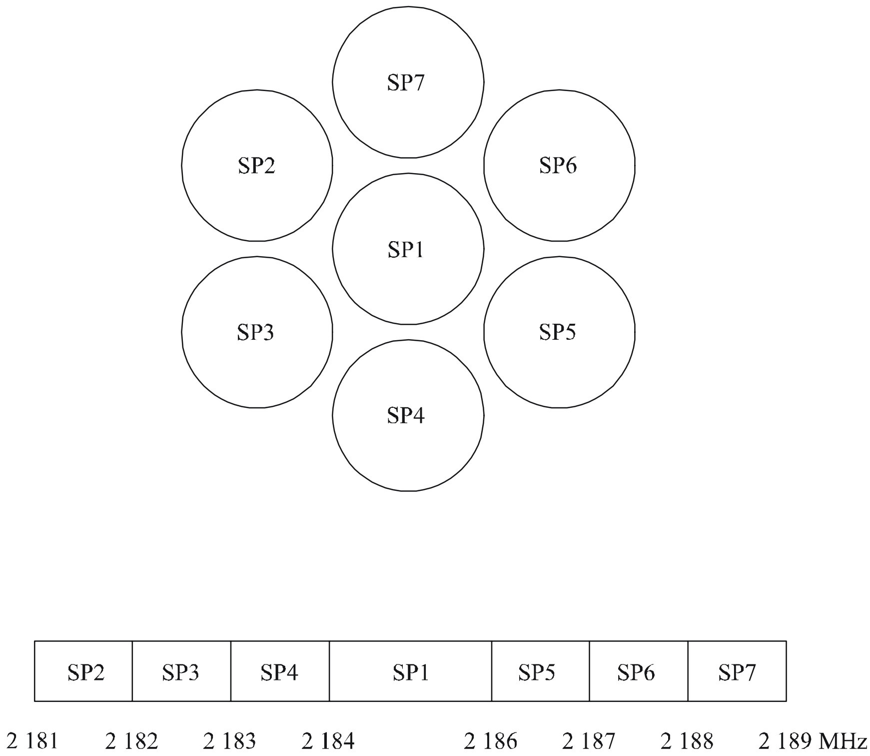


2 Frequency plans of the LEO-F system and the FDM-FM relay system

A seven-cell frequency re-use pattern has been considered. Six spot beams (SP2, SP3, SP4, SP5, SP6 and SP7) each of 1 MHz bandwidth and 1 spot beam (SP1) of 2 MHz bandwidth are assumed. The frequency span of 2 181-2 189 MHz is assumed for the simulation of FDM-FM system (see Fig. 2). The centre frequency of the FDM-FM channel is assumed to be 2 185 MHz with a bandwidth of 20 MHz.

FIGURE 2

Frequency plan of LEO-F system spot beams and 960-channel FDM-FM system



1472-02

3 Transmission parameters of the FDM-FM FS system

The Recommendation ITU-R F.1245 is used for the off-axis gain pattern of the FS antenna. The parameters of the FDM-FM system are given in Table 1. The normalized power spectrum for the 960-channel FS system has been taken from the graphs given in Recommendation ITU-R SF.766 (see Fig. 3a). A (sin x/x)^2 pattern has been assumed for the narrow-band TDMA QPSK carrier (see Fig. 3b). The station particulars and the frequencies of transmission of FDM-FM FS systems used in the simulation are given in Table 2.

TABLE 1

Parameters of FDM-FM system

Parameter	960-channel FS system
RF bandwidth (MHz)	20
Top baseband frequency (kHz)	4 028
Lower baseband frequency (kHz)	60
RMS test tone deviation (kHz)	200
Loading factor	5.5
RMS multichannel deviation (kHz)	1 100
Multichannel modulation index	0.273
Normalized residual carrier (dB)	–9.21
LOS receiver antenna gain (dBi) (3.7 m diameter)	34
Feeder multiplexer loss (dB)	3
Maximum transmitter output power level (dBW)	7
Nominal receiver input power level (dBW)	–64
Receiver noise figure(1) (dB)	10

(1) While this example calculation used a noise figure of 10 dB, a more appropriate representative value for noise figure in this frequency range would be 8 dB.

TABLE 2

Station and carrier frequency details for FDM-FM system

Station (STN)	Latitude	Longitude	Hop length (km)	Tx frequency (MHz)	Rx frequency (MHz)
STN 1	29.66° N	122.50° E	48.5	2 166	–
STN 2	29.94° N	122.12° E	48.4	2 185	2 166
STN 3	30.22° N	121.73° E	48.4	2 166	2 185
STN 4	30.50° N	121.35° E	48.3	2 185	2 166
STN 5	30.78° N	120.96° E	–	–	2 185

Worst azimuth pointing: 49.9° of receiver 4.

FIGURE 3a

Normalized power spectrum of 960-channel FDM-FM carrier

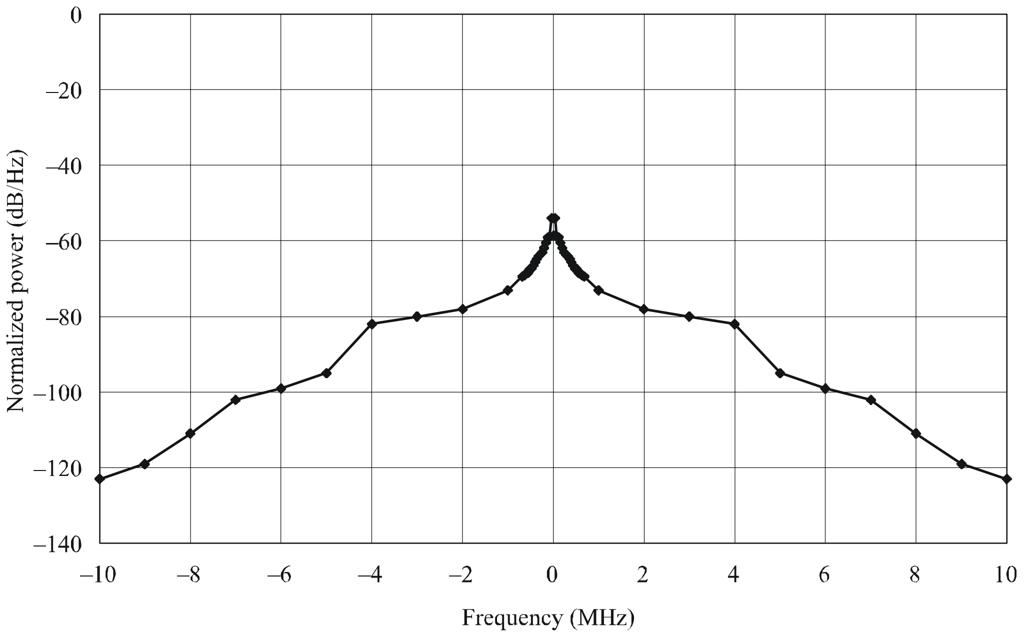
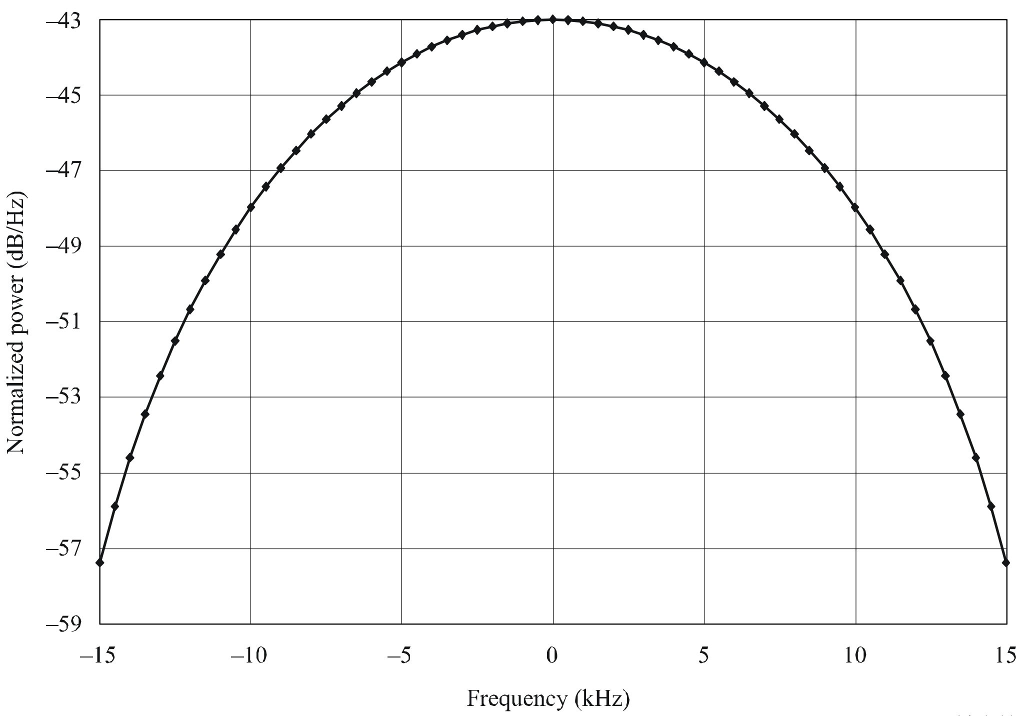


FIGURE 3b

Normalized power spectrum of LEO-F system of 25 kHz TDMA/QPSK carrier



4 LEO-F system parameters

The spot beam with an e.i.r.p. of 32.2 dBW, a 3 dB beamwidth of 3.4° and an off-axis pattern of $-12\ (\theta/\theta_0)^2$ (dB) is assumed for simulation purposes. The other parameters of the LEO-F system are summarized in Table 3.

TABLE 3

LEO-F parameters

a) Constellation details

Number of satellites	10
Altitude (km)	10 355
Number of planes	2
Orbital inclination (degrees)	45
Number of satellites per plane	5
Inter-plane phasing (degrees)	0
Intra-plane phasing (degrees)	72

b) Frequency bands (service links)

Earth-to-space (MHz)	1 980-2 010
Space-to-Earth (MHz)	2 170-2 200

c) Satellites beam/carrier traffic

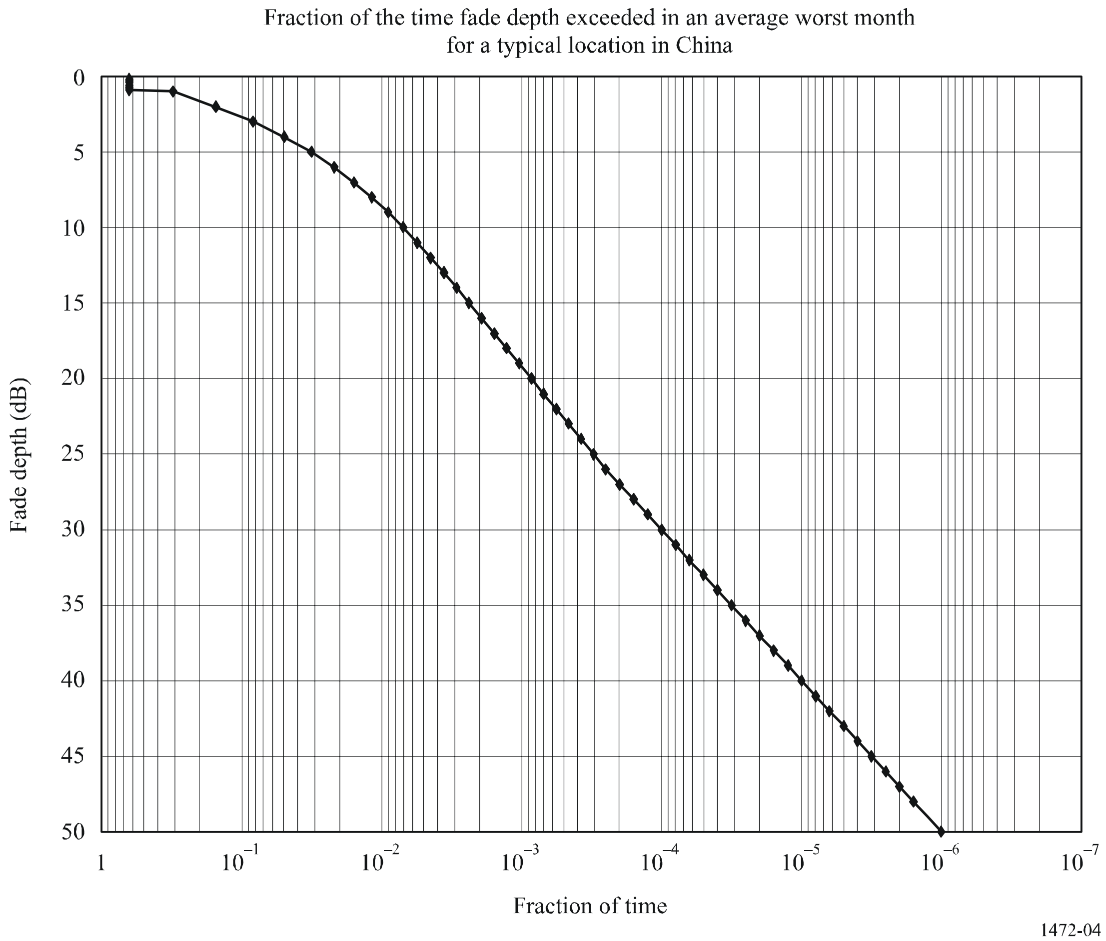
Number of spot beams	163
Carrier type	TDMA/FDMA
Carrier symbol rate (ksymbol/s)	18
Carrier allocated bandwidth (kHz)	25
Beam e.i.r.p./carrier (dBW)	32.2
Number of voice slots/TDMA burst	6
Maximum satellite capacity	4 500 voice channels
Maximum traffic load per beam	1 MHz/2 MHz

5 FS fading distribution

Recommendation ITU-R P.530 is used to assess the fading distribution for various percentages of time. The typical fading distribution for the location in China with 30.78° N latitude and 129.96° E longitude for various percentages of times is given in Fig. 4.

FIGURE 4

Fade depth as a function of time



6 *B*-factor values

The *B*-factor values at different frequency offsets obtained by convolving the 960-channel FDM-FM power spectrum with a 25 kHz QPSK/TDMA carrier are given in Fig. 5.

7 Simulation results

The simulation is performed for the worst-case azimuth angle with a time step of 50 s. The total duration of the simulation is 50 days. The distribution of interference plus thermal noise power values for various percentages of time is plotted in Fig. 6.

The interference noise values in FDM-FM are compared with the Recommendation ITU-R F.393 objectives which have been linearly apportioned in this example. It can be seen that both the long-term and the short-term performance objectives are comfortably met. The assumption of linear apportionment needs further study.

FIGURE 5

_B_ factor values as a function of frequency separation for the FDM-FM system

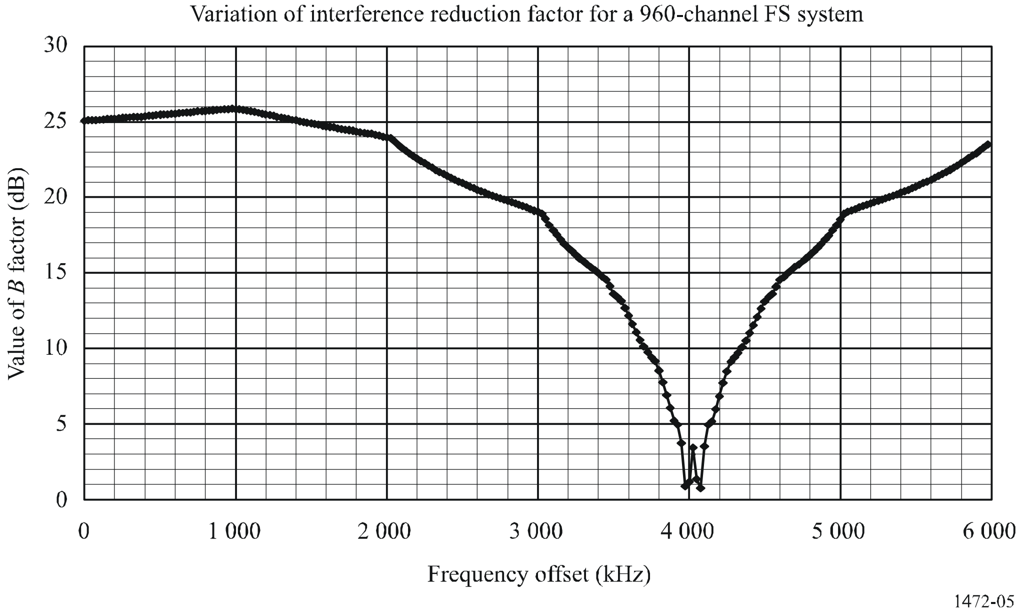


FIGURE 6

Baseband interference and thermal noise distribution for FDM-FM system