

RECOMMENDATION ITU-R F.1246*, **

**Reference bandwidth of receiving stations in the fixed service to be used
in coordination of frequency assignments with transmitting
space stations in the mobile-satellite service
in the 1-3 GHz range**

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

(1997)

The ITU Radiocommunication Assembly,

considering

- a) that several frequency bands in the 1-3 GHz range are shared between the mobile-satellite (space-to-Earth) service and the fixed service (FS);
- b) that networks in the mobile-satellite service (MSS) will generally use digital modulation and frequency division multiple access (FDMA), time division multiple access (TDMA) or code division multiple access (CDMA) access techniques, which will result in relatively uniform spectral shape in the allocated bandwidth of the MSS carrier;
- c) that most MSS networks, according to Radio Regulations (RR) Appendix 4 data, use narrow-band modulation techniques such that several channels in these networks could be encompassed in a 1 MHz reference bandwidth for systems in the FS and that these channels are also usually subject to voice activated channel loading and active power control in order to reduce the effective power resource requirements on the MSS satellite;
- d) that in order to accommodate the worst potential case for interference to the FS, coordination threshold levels of power flux-density have been specified in Recommendations ITU-R M.1141 and ITU-R M.1142 for 4 kHz reference bandwidth;
- e) that use of a relatively large reference bandwidth for receivers in the FS enables consideration of the actual types of digital modulation and access schemes used for space-to-Earth transmissions from space stations in the MSS, which can reduce the effective level of expected interference;
- f) that digital systems should generally be used as the reference model for interference calculations in the 1-3 GHz range,

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

** Radiocommunication Study Group 9 made editorial amendments to this Recommendation in 2004 in accordance with Resolution ITU-R 44.

recommends

1 that a 1 MHz reference bandwidth should be used for analogue and digital systems in the FS for coordination thresholds of power flux-density and fractional degradation in performance of MSS systems in the MSS space-to-Earth allocations in the 1-3 GHz range (see Notes 1, 2, 3 and 4);

2 that a 4 kHz reference bandwidth should be also used for analogue FDM-FM systems in the FS for coordination thresholds of power flux-density for MSS systems in the MSS space-to-Earth allocations in the 1-3 GHz range (see Notes 1, 3 and 4).

NOTE 1 – The reference bandwidths in § 1 and 2 form a basis of the coordination threshold values of power flux-density and fractional degradation in performance recommended in Recommendations ITU-R M.1141 and ITU-R M.1142.

NOTE 2 – Use of a 1 MHz reference bandwidth is consistent with the protection of digital systems (see Annex 1).

NOTE 3 – In cases where MSS carrier spectrum is uniform across its occupied bandwidth and is not highly concentrated in any narrow spectral range within the reference bandwidth, use of a 1 MHz reference bandwidth is generally consistent with protection of analogue systems (see Annex 1).

NOTE 4 – Use of both a 1 MHz and 4 kHz reference bandwidth would be consistent with the protection of analogue FDM-FM systems, since the use of the 4 kHz reference bandwidth limits the peak power spectral density of narrow-band interfering MSS carriers.

If the coordination threshold applicable to a 1 MHz reference bandwidth is X dB(W/m²), the additional coordination threshold appropriate for a 4 kHz reference bandwidth is $X - 18$ dB(W/m²) (see Annex 1). For analogue systems in the FS carrying television, it is not necessary to apply the coordination threshold employing a 4 kHz reference bandwidth.

This new approach of employing both 1 MHz and 4 kHz reference bandwidths in specifying coordination threshold levels is applicable only to the frequency bands in the 1-3 GHz range shared by the MSS and the FS. This result is based on the fact that the analogue systems in the FS in these bands are generally used for low to medium capacity of 960 channels or less. This new approach is not appropriate for other frequency bands where high-capacity analogue radio-relay systems are employed. (The power flux-density limit for the fixed-satellite service in the 6825-7075 MHz band also adopts both 1 MHz and 4 kHz reference bandwidths (see RR Table 21-4), but it was decided on the basis of a reason which is outside the scope of this Recommendation.)

NOTE 5 – Annex 2 contains information on the characteristics of digital narrow-band MSS carriers and the benefits the use of a 1 MHz reference bandwidth would have in the coordination of MSS satellite networks with fixed networks. Detailed information concerning the spectral characteristics of MSS carriers operating in the space-to-Earth direction in the 1-3 GHz range can be found in RR Appendix 4 data filed with the Radiocommunication Bureau for planned MSS networks.

Annex 1

Reference bandwidth for systems in the fixed service in frequency sharing with the mobile-satellite service

1 Introduction

Recommendations ITU-R M.1141 and ITU-R M.1142 contain coordination thresholds for systems in the fixed service in frequency sharing with the MSS. The World Radiocommunication Conference (Geneva, 1995) (WRC-95) incorporated these coordination thresholds into the revised RR.

This Annex provides some comments on the reference bandwidth adopted in the above ITU-R Recommendations.

2 Reference bandwidth for digital systems in the FS

Recommendation ITU-R M.1141 adopts a 1 MHz reference bandwidth for defining fractional degradation in performance (FDP) of digital systems in the FS with respect to frequency sharing with non-geostationary-satellite orbit (non-GSO)/MSS space stations (except for the band 2483.5-2500 MHz). However, Recommendation ITU-R M.1142 adopts a 4 kHz reference bandwidth for defining the coordination thresholds, in terms of power flux-density, for digital systems in the FS with respect to frequency sharing with GSO/MSS space stations.

The above inconsistency should be resolved. In general, it seems adequate to adopt the 1 MHz reference bandwidth to protect digital FS systems.

In some applications, digital FS systems may employ a relatively small bandwidth and such systems may prefer a smaller reference bandwidth. But attention should be drawn to the fact that MSS systems generally operate in digital modulation (e.g. QPSK) in which spectra are uniform over a certain bandwidth. Therefore, even if a 1 MHz reference bandwidth is adopted, there is little danger in protecting digital FS systems with a smaller bandwidth.

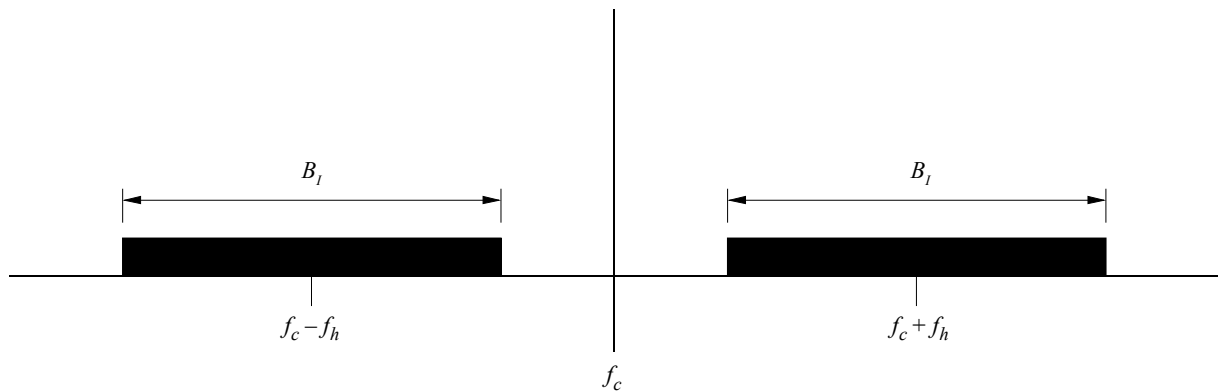
3 Reference bandwidth for analogue systems in the FS

3.1 Interference assessment in case of two interference entries

Traditionally, a 4 kHz reference bandwidth has been adopted for specifying sharing criteria for analogue FS systems. It is particularly appropriate in specifying sharing criteria for high-capacity analogue fixed-wireless systems. However, in the 1-3 GHz range, analogue FS systems are generally of medium or low capacity. In such case, the effect of interference is less than that in case of high-capacity systems, because a greater energy dispersion effect through the FM demodulation process can be expected at a lower capacity.

In order to estimate such effect, calculations were made for a FS radio-relay system carrying 960 channel telephony (baseband: 60-4028 kHz). The 960 channel capacity was chosen for the calculations because it is the highest capacity generally used in the 1-3 GHz range, thus representing a worst case analysis. The interference was assumed to be as shown in Fig. 1, that is, two interference signals (each with bandwidth of B_I) appear with the centre frequencies $f_c + f_h$ and $f_c - f_h$ where f_c is the radio carrier frequency and f_h is the highest baseband frequency. The calculation method is presented in Appendix 1 to Annex 1.

FIGURE 1
Interference situation

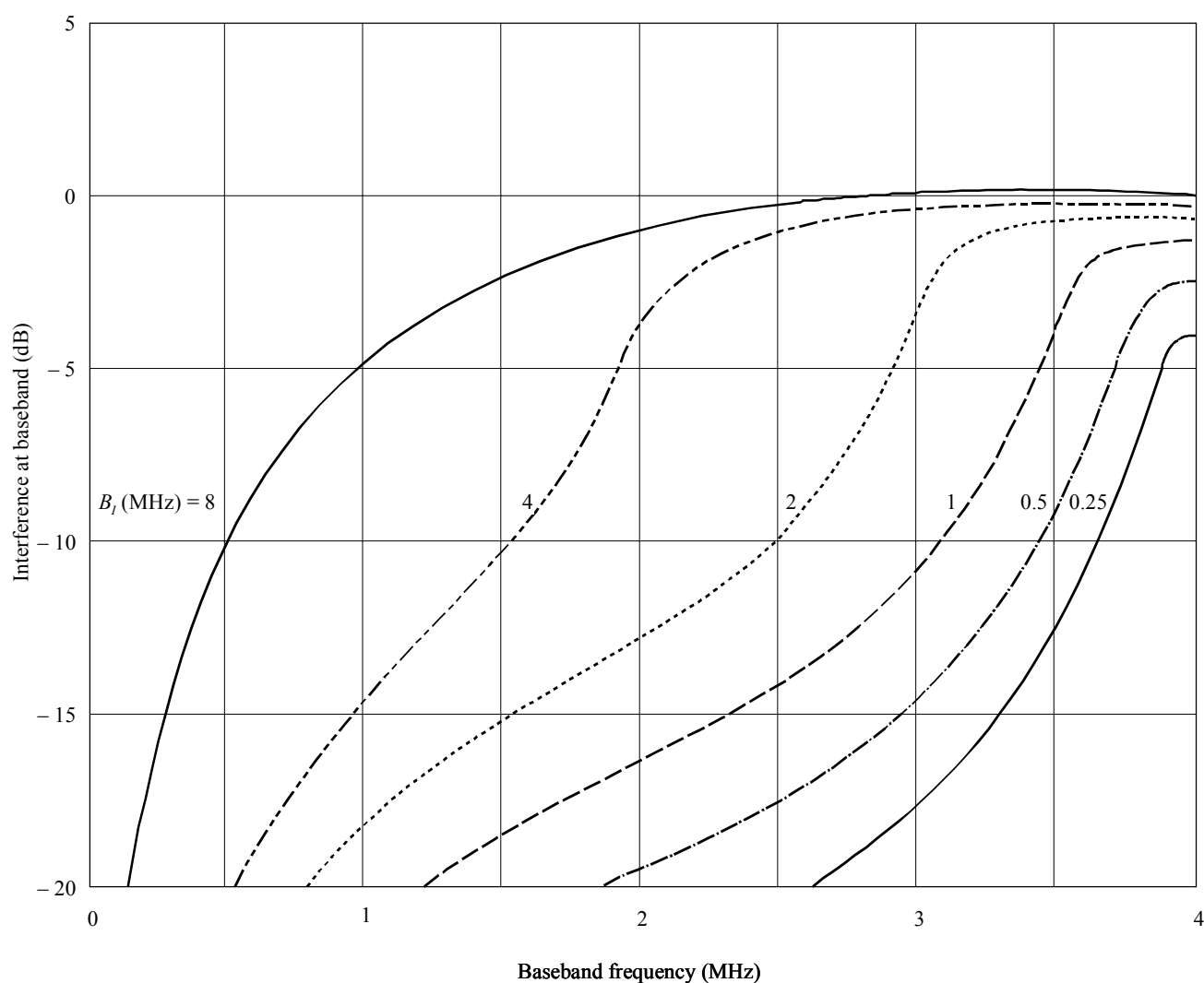


f_c : carrier frequency of the FS system
 f_h : highest baseband frequency of the FS system
 B_I : bandwidth of the interference signal

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The results are shown in Fig. 2. $B_I = 8$ MHz corresponds to the case of an interfering signal of very wide bandwidth (similar to thermal noise). The baseband interference level at f_h ($= 4028$ kHz) for $B_I = 8$ MHz is taken as 0 dB. The baseband interference in the range of 2-4 MHz is almost constant due to pre-emphasis effect.

FIGURE 2
Baseband interference distribution for interference signals of various bandwidth
(960 channel analogue radio-relay system)



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Calculations were made for $B_I = 8, 4, 2, 1, 0.5$ and 0.25 MHz. The interference level at f_h becomes lower at smaller B_I . This is because of dispersion effect of the analogue radio-relay system. If there is no such dispersion effect, the baseband interference level should be as follows:

- no interference for the band from 0 to $f_h - B_I/2$;
- almost 0 dB interference for the band from $f_h - B_I/2$ to f_h .

This situation will apply only to high-capacity radio-relay systems employing a very small modulation index. However, in the case of 960 channel systems, the situation is different.

For example, in case of $B_I = 500$ kHz, the interference level at f_h is -2.5 dB.

In some sense, the situation in Fig. 1 is of a worst case. This is because it is assumed that two interfering signals appear symmetrically in two sides of the FS carrier frequency. If the interfering signal in one side disappears, the baseband interference level will be 3 dB lower.

Interpretation of the calculation results in Fig. 2 is not simple. However, at least, the following may be concluded:

- the reference bandwidth of 4 kHz is too small. A larger bandwidth may reasonably be chosen;
- even if the reference bandwidth of 1 MHz was chosen, the actual risk may be negligible, because in case of $B_I = 500$ kHz, the baseband interference is -2.5 dB (for two sided interference signals) or -5.5 dB (for one sided interference signal). If this is converted to a spectral density in 1 MHz, the interfering signal is only 0.5 dB higher or still 2.5 dB lower than a uniform interfering signal over a wide bandwidth (i.e. $B_I = 8$ MHz).

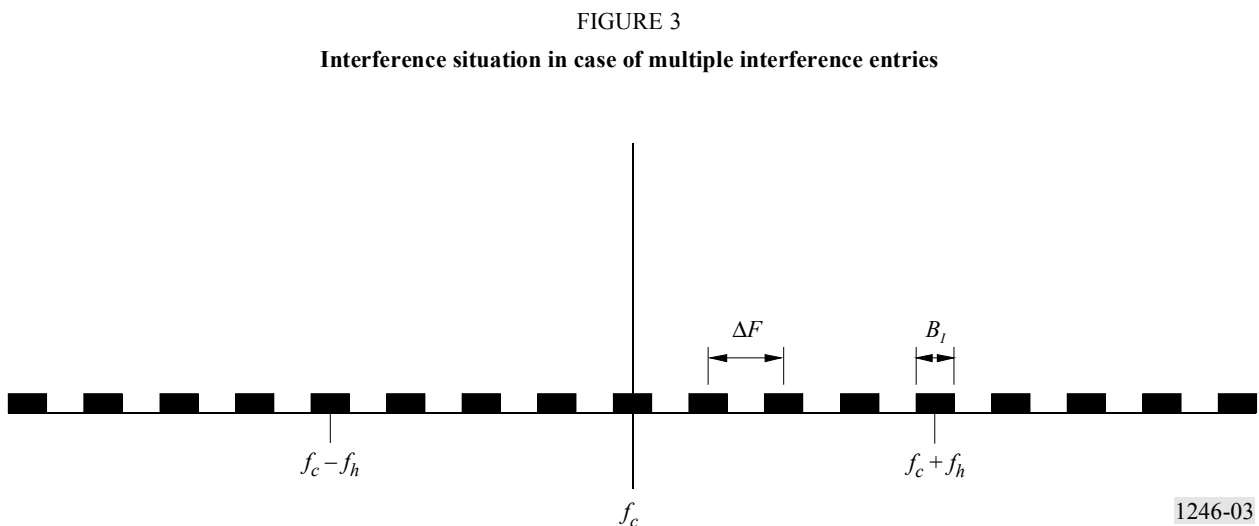
The above statement may imply that the reference bandwidth of 1 MHz may be adopted without risk in the frequency range of 1 to 3 GHz.

This conclusion could be acceptable when the nature of the interfering signal is known (see Annex 2).

It is assumed that radio signals emitted from MSS space stations have a uniform spectrum over a certain bandwidth. In such case, the 1 MHz reference bandwidth is generally acceptable.

3.2 Interference assessment in case of multiple interference entries

In order to examine the effects of interfering power concentration on analogue radio-relay systems, calculations were made under the condition that, as shown in Fig. 3, there exist many interfering carriers with uniform spectral density over bandwidth B_I and with a uniform frequency spacing ΔF .



Baseband interference is calculated for different values of B_I under the condition that the total power of each interfering carrier is constant, that is, the power flux-density increase, ΔPFD (dB), of the interfering carrier is given by:

$$\Delta PFD = 10 \log (\Delta F / B_I)$$

The case of $B_I = \Delta F$ is taken as a reference. In this case, the interfering power spectrum is uniform over a wideband, like thermal noise.

When B_I becomes smaller, the baseband interference concentrates at certain frequencies. Figure 4 shows a fine structure of the baseband interference variation for an example of $\Delta F = 500$ kHz and $\Delta PFD = 4$ or 6 dB. The maximum values of baseband interference increase have been calculated for various cases. The results are shown in Table 1 for a 960 channel analogue radio-relay system (r.m.s. frequency deviation is 200 kHz per channel) and $\Delta F = 1$ MHz, 500 kHz, 200 kHz and 100 kHz.

Table 1 shows that, due to energy dispersion effect of the analogue radio-relay system, the baseband interference increase is much smaller than the value of ΔPFD . The dependence of the baseband interference increase on ΔF and ΔPFD is complicated, but generally speaking it seems that ΔPFD of up to 6 dB is acceptable.

FIGURE 4
 Baseband interference distribution (fine structure) for multiple interference entries ($\Delta F = 500$ kHz, $\Delta PFD = 4$ or 6 dB) (960 channel analogue radio-relay system)

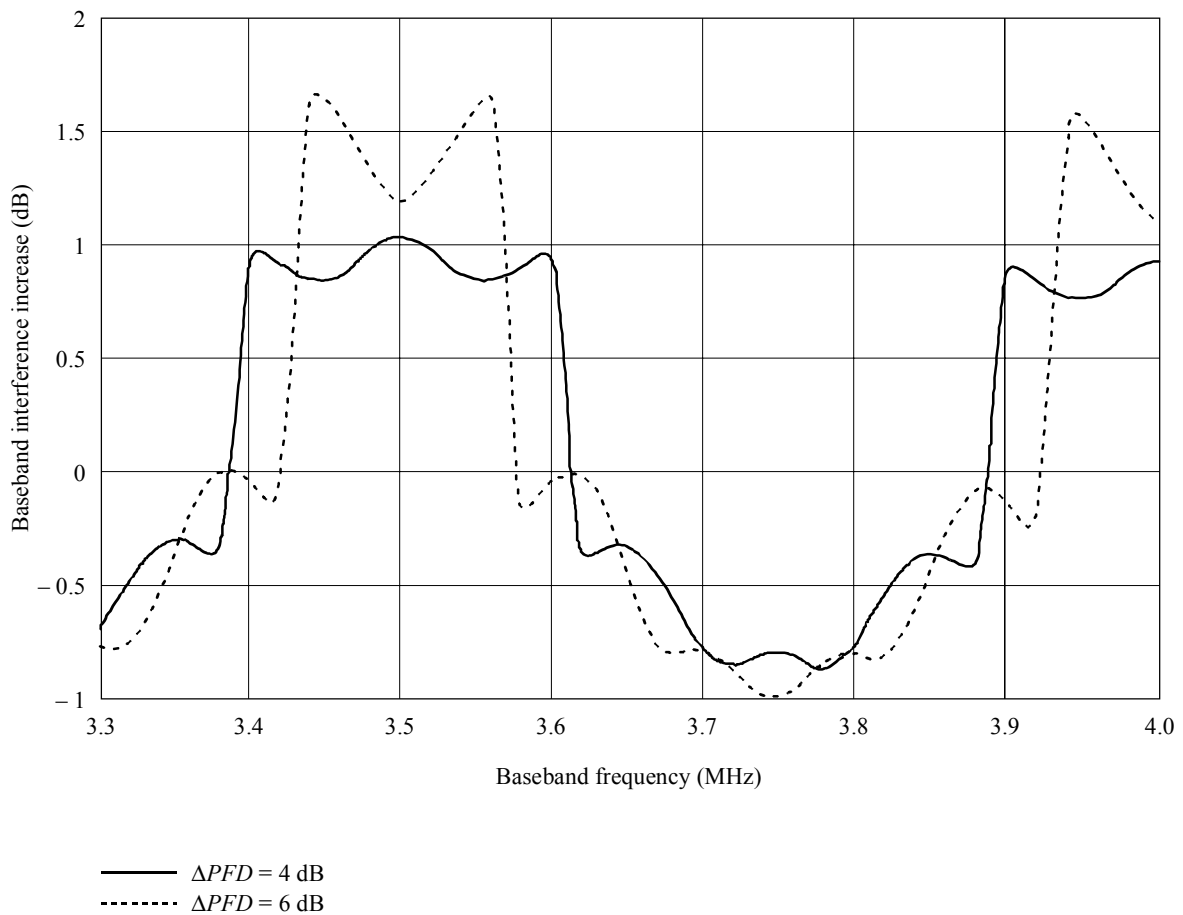


TABLE 1

Maximum values of baseband interference increase (dB) for various values of ΔF and ΔPFD
(960 channel analogue radio-relay system)

ΔF (kHz)	ΔPFD (dB)					
	0	2	4	6	8	10
1 000	0	1.0	1.8	2.5	3.0	3.9
500	0	0.5	1.0	1.6	2.0	3.0
200	0	0.4	0.6	1.1	2.0	3.1
100	0	0.4	0.8	1.4	2.2	3.3

It may be also noted that the above calculations assume that there exist many interfering signals with the same frequency spacing and the same spectral density. This is a kind of worst case assumption.

A similar calculation was carried out to evaluate the impacts of interfering carrier power concentration on the baseband interference noise of a 960 channel FDM-FM analogue radio-relay system. The spectrum shape for the 960 channel FDM-FM carrier was taken from Recommendation ITU-R SF.766. The interfering MSS carrier with a 25 kHz bandwidth had been characterized as a $(\sin X/X)^2$ function.

A numerical convolution technique has been used in the calculations to evaluate the baseband interference. After convolving the desired and the interfering power spectra, the baseband interference noise power into any baseband channel of the desired radio-relay system for the various frequency offsets was obtained through the following expression:

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

where:

B : interference reduction factor (dB)

N_p : weighted interference power (pW0p)

C/I : carrier-to-interference ratio (dB) due to a single interfering carrier.

From the analysis it was found that a baseband channel near the highest baseband frequency receives the worst interference noise for a carrier separation of 4000 kHz. Then, the effect of multiple interfering carriers was evaluated by assuming 40, 20, 10 and 5 interfering carriers at spacing of 25 kHz, 50 kHz, 100 kHz and 200 kHz, respectively. The power of each carrier was adjusted so that the total power in 1 MHz bandwidth was kept constant.

From the analysis, it was found that the baseband effect of 40 contiguously placed interfering carriers with an interference power level of X dBW per carrier and placed 4 MHz away from the centre frequency of the radio-relay carrier into the most vulnerable baseband channel was almost the same as those of 20 carriers (50 kHz spacing), 10 carriers (100 kHz spacing) and 5 carriers (200 kHz spacing), with interference power levels of $X + 3$ dBW, $X + 6$ dBW and $X + 9$ dBW per

carrier, respectively. It was found from the analysis that the maximum relative increase in the baseband due to 5 carriers each with an interference power level of $X + 9$ dBW with 200 kHz spacing is about 0.9 dB with respect to 40 carriers each with an interference power level of X dBW.

The calculation has demonstrated that the power concentration in a small bandwidth will not bring about a significant increase of baseband interference noise of the 960 channel FDM-FM radio-relay system. Further study is required on this analysis.

4 Conclusion

4.1 For protection of digital FS systems, it is appropriate to adopt the 1 MHz reference bandwidth.

4.2 It is appropriate to adopt the 1 MHz reference bandwidth for protection of analogue FS systems, but at the same time, it is appropriate to adopt an additional coordination threshold employing 4 kHz reference bandwidth in order to limit the peak power spectral density of narrow-band interfering MSS carriers.

Appendix 1 to Annex 1

Interference calculations

1 Case of two interference entries

Assuming that the wanted carrier power is unity, the signal, $Z(t)$, accompanied by an interfering signal can be expressed as follows:

$$Z(t) = \sqrt{2} \cos[2\pi f_c t + s(t)] + I(t) \quad (1)$$

where:

f_c : carrier frequency

$s(t)$: phase angle due to frequency modulation

$$I(t) = \sqrt{2} \sum b_k \cos 2\pi(f_c + \Delta f_k)t \quad (\text{interfering signal}) \quad (2)$$

Assuming that the carrier-to-interference ratio is sufficiently large (that is, $|b_k| \ll 1$), equation (1) can be converted to the following:

$$Z(t) = \sqrt{2} \cos \left[2\pi f_c t + s(t) + \sum b_k \sin (2\pi \Delta f_k t - s(t)) \right] \quad (3)$$

Thus, the phase angle $\varphi_I(t)$ due to interference is given by:

$$\varphi_I(t) = \sum b_k \sin (2\pi \Delta f_k t - s(t)) \quad (4)$$

In order to calculate the power spectrum of $\varphi_I(t)$, first we calculate the autocorrelation function $R_\varphi(\tau)$ of $\varphi_I(t)$. After some complicated calculations, the following relationship can be derived:

$$R_\varphi(\tau) = E[\varphi_I(t) \cdot \varphi_I(t - \tau)] = R_I(\tau) \cdot \exp[-R_S(\tau)] \quad (5)$$

where $E[\]$: expected value.

$$R_I(\tau) = R_I(0) \frac{\sin(2\pi f_{I2} \tau) - \sin(2\pi f_{I1} \tau)}{2\pi(f_{I2} - f_{I1}) \tau} \quad (6)$$

(autocorrelation function of the interfering signal)

$$R_s(\tau) = 2m^2 \int_{\varepsilon}^1 \frac{\sin^2(\pi f_h \tau u)}{u^2} p(u) du \quad (7)$$

(autocorrelation function of the modulation phase signal)

where:

$$f_{I1} = f_h - B_I/2 \text{ (lower end of interference)}$$

$$f_{I2} = f_h + B_I/2 \text{ (higher end of interference)}$$

m : modulation index ($m = 0.276$ for 960 channels corresponding to r.m.s. frequency deviation of 200 kHz per channel)

f_h : highest baseband modulating frequency

f_l : lowest baseband modulating frequency

$$\varepsilon = f_l/f_h$$

$$p(f/f_h) = C_0 + C_2 (f/f_h)^2 + C_4 (f/f_h)^4 \quad (8)$$

where:

$$C_0 = 0.4, C_2 = 1.35 \text{ and } C_4 = 0.75 \text{ (see Recommendation ITU-R SF.675)}$$

Under the above situation, the power spectrum $W(f)$ of the interference phase $\varphi_I(t)$ can be calculated as follows by the Fourier transform:

$$W(f) = 4 \int_0^{\infty} R_\varphi(\tau) \cos(2\pi f \tau) d\tau \quad (9)$$

However, attention should be drawn to the fact that there is a residual discrete carrier power component in the wanted FM signal. The value of $R_s(\tau)$ at $\tau = \infty$ corresponds to the residual carrier (see Recommendation ITU-R SF.675). $R_s(\tau)$ at $\tau = \infty$ is given as follows:

$$R_s(\infty) = \frac{m^2 (1 - \varepsilon)}{\varepsilon} \left[C_0 + \varepsilon C_2 + \frac{C_4}{3} (\varepsilon + \varepsilon^2 + \varepsilon^3) \right] \quad (10)$$

In this case, $R_\varphi(\tau)$ consists of two parts, one due to the residual discrete FM carrier component and another due to continuous sideband components of the FM signal. The autocorrelation function $R_d(\tau)$ due to the residual discrete FM carrier component is given by:

$$R_d(\tau) = R_I(\tau) \cdot \exp[-R_s(\infty)] \quad (11)$$

Therefore, it is appropriate to calculate $W(f)$ as follows:

$$W(f) = 4 \int_0^{\infty} [R_\varphi(\tau) - R_d(\tau)] \cos(2\pi f \tau) d\tau + 4 \int_0^{\infty} R_d(\tau) \cdot \cos(2\pi f \tau) d\tau \quad (12)$$

The first integral in the right-hand side corresponds to the interference due to convolution of the interfering signal and the continuous sideband components of the FM signal and the second integral corresponds to that due to coupling of the interfering signal with the residual discrete FM carrier.

In order to take account of the effect of frequency discriminator and de-emphasis at the analogue radio-relay receiver, the finally derived baseband interference is proportional to:

$$\frac{f^2}{p(f/f_h)} W(f) \quad (13)$$

The calculation result is presented in Fig. 2.

2 Case of multiple interference entries

In case of multiple interference entries shown in Fig. 3, the only change necessary for interference calculations is to use the following autocorrelation function of the aggregate interfering signal instead of equation (6):

$$R_I(\tau) = R_I(0) \frac{\sin(\pi B_I \tau) \cdot \sin[(4n+1)\pi \Delta F \tau]}{(4n+1)\pi B_I \tau \cdot \sin(\pi \Delta F \tau)} \quad (14)$$

where $n = f_h/\Delta F$. The calculation assumes that there are $(4n+1)$ interfering carriers.

Annex 2

Example relevant MSS characteristics to be considered in relation to reference bandwidths of receiving fixed stations to be used for coordination of frequency assignments of transmitting space stations in the mobile-satellite service in the 1-3 GHz range

1 Introduction

The spectral power density of downlink transmissions from satellites in the MSS generally is non-uniform over a 1 MHz bandwidth, such that the ratio of the total power in a 1 MHz bandwidth to that in a 4 kHz bandwidth is significantly less than the ratio of those bandwidths. As a result, MSS networks can more readily avoid exceeding a coordination threshold level of power flux-density (pfd) that is specified for a 1 MHz reference bandwidth than one specified for a 4 kHz reference bandwidth. Moreover, in cases where coordination is warranted for MSS downlinks using narrow-band modulation techniques, use of a wide reference bandwidth enables consideration of MSS channel activity and limits on channel assignment and loading as means for limiting interference to acceptable levels.

2 Benefit in preventing unnecessary coordination

FS systems using digital modulation and multiplexing techniques generally can use a reference bandwidth of at least 1 MHz for interference calculations, in which case several narrow-band MSS downlink channels would be encompassed in the reference bandwidth. The pfd across a 1 MHz reference bandwidth would not be uniform at the peak pfd, generated in one narrow-band typical MSS satellite downlink signal because there are guardbands between adjacent MSS signals. Further, transmissions will not occur concurrently on all possible MSS downlink channels that are contiguous across the reference bandwidth. For example, there are 200 MSS channels of 5 kHz bandwidth within a 1 MHz reference bandwidth, yet the occupied bandwidth of the downlink signal in each channel may be of the order of 3.3 kHz, which yields a 2 dB advantage with respect to a 4 kHz reference bandwidth. Furthermore, given the large number of narrow-band MSS channels within the 1 MHz reference bandwidth for the FS, it is possible to consider the effect of MSS channel loading, which can yield an additional 4 dB advantage. Thus, this example MSS network could exceed a pfd threshold specified for a 4 kHz reference bandwidth by up to 6 dB without exceeding the bandwidth-scaled pfd threshold specified for a 1 MHz reference bandwidth.

3 Benefit in the coordination process

MSS network control systems can govern the quantity and frequency-location of MSS channels assigned in any given reference bandwidth. This control enables consideration of limits on the number of narrow-band MSS channels that will be assigned in a reference bandwidth in order to limit the total interfering signal power density.

Further considering the above example for 5 kHz MSS channels and a 1 MHz reference bandwidth, limiting the number of assigned MSS channels per MHz to one-seventh of the maximum potential number of channels per MHz would reduce the potential interfering signal power by 8 dB. This limitation may not for example affect the capacity of an MSS satellite employing TDMA/FDMA access schemes that uses seven or more beams in a seven-cell frequency re-use pattern assuming a uniform distribution of offered traffic among the beams.

4 Conclusion

In light of the above benefits, a 1 MHz reference bandwidth should be used where possible in determining whether coordination is necessary between frequency assignments for service downlinks from MSS satellites and fixed stations. Specifically, use of a 1 MHz reference bandwidth (in lieu of a 4 kHz bandwidth) for coordination thresholds may preclude the need for coordination in some cases and may facilitate coordination in other cases. In addition, the widest possible reference bandwidth (up to the channel bandwidth of representative fixed systems) should be considered during the actual coordination of frequency assignments.
