RECOMMENDATION ITU-R BO.1293

PROTECTION MASKS AND ASSOCIATED CALCULATION METHODS FOR INTERFERENCE INTO BROADCAST SATELLITE SYSTEMS INVOLVING DIGITAL EMISSIONS

(Question ITU-R 93/11)

(1997)

The ITU Radiocommunication Assembly,

considering

a)   that protection ratios and associated protection masks are essential characteristics for the television signals in the broadcasting-satellite service (BSS) and associated feeder links;

b)   that the Radio Regulations (RR) Appendices 30 and 30A Plans have been developed by using values of protection ratio and interference calculation methods based on fixed frequency offsets and given types of signal;

c)   that new systems submitted to the Radiocommunication Bureau (BR) for implementation in these plans propose to use new types of signals for which no protection masks and only limited interference calculation methods are available;

d)   that the BR has requested radiocommunications Study Group 11 to provide additional methodologies and protection criteria to assess interference from and to these new types of signals;

e)   that the definition of protection masks and associated calculation methods are very useful technical information when revising the RR Appendices 30 and 30A Plans for Regions 1 and 3;

f)   that several studies have now been carried out by various administrations and organizations that validate the proposed interference calculation method,

recognizing

a)   that protection masks extend the usefulness of protection ratios, which are themselves associated with fixed frequency offsets;

b)   that appropriate protection masks for interference calculation between digital emissions can be derived by using the methodology provided in Annex 1,

recommends

1   that the calculation method to generate protection masks provided in Annex 1 for different types of digital phase shift keyed emissions, should be applied as needed in compatibility analyses for RR Appendices 30 and 30A.

2   that the associated interference calculation methods provided in Annex 2, should be used as needed to assess the interference situation in RR Appendices 30 and 30A.

NOTE 1 – Further studies are needed to develop masks for interference between other types of emission (i.e. for analogue into analogue, digital into analogue and analogue into digital interference). Until such time as these masks are available, the method described in Annex 3 should be used when calculating interference between emissions when the interference is digital.

NOTE 2 – Although the method proposed in Annex 1 provides an accurate assessment of the protection mask for interference between two digital signals, based on knowledge of the key signal parameters and assuming a linear channel, in practice most BSS satellite transponders operate in a saturated non-linear mode. The proposed model is expected to underestimate the interference when the channel is non-linear. Further studies are required to quantify these non-linear effects. In the meantime, the (more conservative) method described in Annex 3 should be used when calculating interference between digital emissions.

NOTE 3 – The effects of the application of the method proposed in Annex 1 on the notification of new parameters associated with each digital emission are described in Appendix 1 to Annex 1.

ANNEX 1

Calculation of protection masks for interference between various types of digital carriers

1 Method

It is assumed that the interfering digital carrier can, for interference calculation purposes, be modelled as a white noise source followed by a square-root, raised cosine pulse shaping filter. The roll-off factor, α_i, of this filter may be freely specified in the range $0 \le \alpha_i \le 1$ (0% to 100% roll-off). The filter's 3 dB bandwidth is specified by the transmitted symbol rate, R_i, for the interfering digital signal.

The level of digital interference affecting the wanted digital signal is dependent upon the frequency offset between the wanted and interfering signals, δf, and the characteristics of the receiver's filter. It is assumed that this filter is also a square-root, raised cosine filter with a roll-off factor, α_w, where ($0 \le \alpha_w \le 1$), and a 3 dB bandwidth specified by the wanted signal symbol rate R_w.

The parameters R_i and R_w are expressed in Msymbol/s. The total bandwidths of the wanted and interfering signals are given by $R_w(1 + \alpha_w)$ MHz and $R_i(1 + \alpha_i)$ MHz respectively. The frequency difference parameter δf is expressed in MHz. The interference at the output of the receiver filter is assumed to be noise-like.

The level of interference power $I(\delta f)$, measured at the output of the receiver's filter and expressed relative to the wanted carrier power for a reference link *C/I* of 0 dB (i.e. assuming equal wanted and interfering carrier powers), is calculated as follows (see § 3 for definitions of the terms used below):

Step 1: Calculate the wanted signal power, P_w, at the output of the receiver filter:

a) set the interfering signal parameters equal to the wanted signal parameters and the frequency offset to zero ($R_i = R_w$, $\alpha_i = \alpha_w$, $\delta f = 0$);

b) calculate the nine pairs of limits (U_n, L_n, $n = 1, \ldots, 9$);

c) calculate the five power contribution terms (C_m, $m = 1, \ldots, 5$);

d) Calculate the total received power, P_w:

$$P_w = \sum_{m=1}^{5} C_m$$

Step 2: Calculate the interfering signal power, P_i, at the output of the receiver filter:

a) set the interfering signal parameters and the frequency offset to the appropriate values for the interference scenario under consideration;

b) to d) repeat steps b) to d) above using the revised input parameters, leading to the calculation of the interfering signal power:

$$P_i = \sum_{m=1}^{5} C_m$$

Step 3: Calculate the relative interference power for the given signal parameters and frequency offset:

$$I(\delta f) = 10 \log \left(\frac{P_i}{P_w} \right) \qquad \text{dB}$$

2 Example calculation of a protection mask

As an (arbitrary) example, it is assumed that the wanted and interfering signal parameters are as follows:

Wanted digital signal:

symbol rate, $R_w = 22.7$ Msymbol/s

roll-off factor, $\alpha_w = 0.4$ (40% cosine roll-off).

Interfering digital signal:

symbol rate, $R_i = 22.7$ Msymbol/s

roll-off factor, $\alpha_i = 0.4$ (40% cosine roll-off).

The frequency offset between the wanted and interfering signals, δf, is assumed to be 19.18 MHz. The application of the calculation method described in § 1 of this Annex, and detailed in § 3 of this Annex, gives the following:

Step 1: Calculate the wanted signal power, P_w, at the output of the receiver filter ($\delta f = 0$):

$L_1 = -6.81, \quad L_2 = L_3 = L_4 = L_5 = L_6 = L_7 = L_8 = L_9 = 6.81$

$U_1 = U_2 = U_3 = U_4 = U_5 = 6.81, \quad U_6 = U_7 = 15.89, \quad U_8 = U_9 = -6.81$

$C_1 = 0.8, \quad C_2 = C_3 = 0, \quad C_4 = 0.1, \quad C_5 = 0$

$$P_w = \sum_{m=1}^{5} C_m \qquad P_w = 0.90$$

Step 2: Calculate the interfering signal power, P_i, at the output of the receiver filter ($\delta f = 19.18$ MHz):

$L_1 = L_3 = L_4 = 12.37, \quad L_2 = L_5 = L_7 = 6.81, \quad L_6 = L_9 = 25.99, \quad L_8 = -12.37$

$U_1 = 6.81, \quad U_2 = U_5 = -12.37, \quad U_3 = U_4 = U_6 = 15.89, \quad U_7 = -3.29, \quad U_8 = U_9 = -6.81$

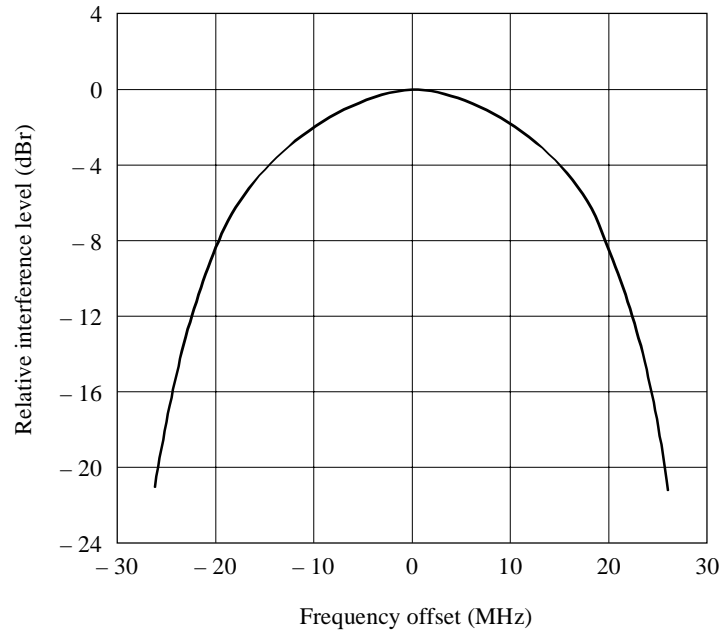$C_1 = 0.216, \quad C_2 = C_3 = -0.030, \quad C_4 = 0, \quad C_5 = 0.004$

$$P_i = \sum_{m=1}^{5} C_m \qquad P_i = 0.16$$

Step 3: Calculate the relative interference power for the given signal parameters and frequency offset:

$$I(\delta f) = 10 \log \left(\frac{P_i}{P_w} \right) \qquad \text{dB} \qquad I(19.18) = -7.5 \, \text{dBr}$$

Following this procedure for a range of frequency offsets results in the example protection mask given in Fig. 1.

FIGURE 1

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3 Algorithms: Calculation of the received (wanted or interfering) signal power

3.1 Limits

$$A = (1 - \alpha_w)\frac{R_w}{2} \qquad B = (1 + \alpha_w)\frac{R_w}{2} \qquad C = (1 - \alpha_i)\frac{R_i}{2} \qquad D = (1 + \alpha_i)\frac{R_i}{2}$$

$$L_1 = max\,(-A;\, \delta f - C) \qquad L_4 = max\,(A;\, \delta f - C) \qquad L_7 = max\,(A;\, -\delta f + C)$$

$$U_1 = min\,(A;\, \delta f + C) \qquad U_4 = min\,(B;\, \delta f + C) \qquad U_7 = min\,(B;\, -\delta f + D)$$

$$L_2 = max\,(-A - \delta f;\, C) \qquad L_5 = max\,(A;\, -\delta f - C) \qquad L_8 = max\,(-B;\, -\delta f + C)$$

$$U_2 = min\,(A - \delta f;\, D) \qquad U_5 = min\,(B;\, -\delta f + C) \qquad U_8 = min\,(-A;\, -\delta f + D)$$

$$L_3 = max\,(-A + \delta f;\, C) \qquad L_6 = max\,(A;\, \delta f + C) \qquad L_9 = max\,(-B;\, \delta f + C)$$

$$U_3 = min\,(A + \delta f;\, D) \qquad U_6 = min\,(B;\, \delta f + D) \qquad U_9 = min\,(-A;\, \delta f + D)$$

NOTE 1:

max $(a;\, b)$:   maximum value of *a* and *b*

min $(a;\, b)$:   minimum value of *a* and *b*

δf = frequency of interfering signal − frequency of wanted signal

3.2 Functions

When $1 \le n \le 3$:

$$p_n(a, b) = f_n(a) - f_n(b) \quad \text{for } a > b$$
$$= 0 \quad \text{for } a \le b$$

When $4 \le n \le 5$:

$$p_n(a, b, \delta f) = f_n(a, \delta f) - f_n(b, \delta f) \quad \text{for } a > b$$
$$= 0 \quad \text{for } a \le b$$

$$f_1(x) = \left(\frac{x}{R_i} \right)$$

$$f_2(x) = \frac{\alpha_i}{2\pi} \cos\left(\frac{\pi}{2} \frac{2x - R_i}{\alpha_i R_i} \right)$$

$$f_3(x) = \frac{\alpha_w R_w}{2\pi R_i} \cos\left(\frac{\pi}{2} \frac{2x - R_w}{\alpha_w R_w} \right)$$

$$f_4(x, y) = f_{4a}(x, y) \quad \text{for } \alpha_w R_w = \alpha_i R_i$$
$$= f_{4b}(x, y) \quad \text{for } \alpha_w R_w \ne \alpha_i R_i$$

$$f_5(x, y) = f_{5a}(x, y) \quad \text{for } \alpha_w R_w = \alpha_i R_i$$
$$= f_{5b}(x, y) \quad \text{for } \alpha_w R_w \ne \alpha_i R_i$$

$$f_{4a}(x, y) = \frac{1}{16\pi R_i} \left(2\pi x \cos\left(\frac{\pi}{2} \frac{2y + R_i - R_w}{\alpha_i R_i} \right) - \alpha_i R_i \sin\left(\frac{\pi}{2} \frac{4x - 2y - R_i - R_w}{\alpha_i R_i} \right) \right)$$

$$f_{4b}(x, y) = \frac{\alpha_i \alpha_w R_w}{4\pi(\alpha_i^2 R_i^2 - \alpha_w^2 R_w^2)} \left(\alpha_i R_i \cos\left(\frac{\pi}{2} \frac{2x - R_w}{\alpha_w R_w} \right) \sin\left(\frac{\pi}{2} \frac{2y - 2x + R_i}{\alpha_i R_i} \right) + \alpha_w R_w \sin\left(\frac{\pi}{2} \frac{2x - R_w}{\alpha_w R_w} \right) \cos\left(\frac{\pi}{2} \frac{2y - 2x + R_i}{\alpha_i R_i} \right) \right)$$

$$f_{5a}(x, y) = \frac{1}{16\pi R_i} \left(\alpha_i R_i \sin\left(\frac{\pi}{2} \frac{4x - 2y - R_i + R_w}{\alpha_i R_i} \right) - 2\pi x \cos\left(\frac{\pi}{2} \frac{2y + R_i + R_w}{\alpha_i R_i} \right) \right)$$

$$f_{5b}(x, y) = \frac{\alpha_i \alpha_w R_w}{4\pi(\alpha_i^2 R_i^2 - \alpha_w^2 R_w^2)} \left(\alpha_i R_i \cos\left(\frac{\pi}{2} \frac{2x + R_w}{\alpha_w R_w} \right) \sin\left(\frac{\pi}{2} \frac{2x + 2y - R_i}{\alpha_i R_i} \right) - \alpha_w R_w \sin\left(\frac{\pi}{2} \frac{2x + R_w}{\alpha_w R_w} \right) \cos\left(\frac{\pi}{2} \frac{2x - 2y - R_i}{\alpha_i R_i} \right) \right)$$

3.3 Power contributions

$$C_1 = p_1(U_1, L_1) + \frac{1}{2} \sum_{n=2}^{5} p_1(U_n, L_n) + \frac{1}{4} \sum_{n=6}^{9} p_1(U_n, L_n)$$

$$C_2 = p_2(U_2, L_2) + p_2(U_3, L_3) + \frac{1}{2} \left[p_2(U_6 - \delta f, L_6 - \delta f) + p_2(U_7 + \delta f, L_7 + \delta f) + p_2(U_8 + \delta f, L_8 + \delta f) + p_2(U_9 - \delta f, L_9 - \delta f) \right]$$

$$C_3 = p_3(U_4, L_4) + p_3(U_5, L_5) + \frac{1}{2} \left[p_3(U_6, L_6) + p_3(U_7, L_7) + p_3(-L_8, -U_8) + p_3(-L_9, -U_9) \right]$$

$$C_4 = p_4(U_6, L_6, \delta f) + p_4(U_7, L_7, -\delta f)$$

$$C_5 = p_5(U_8, L_8, -\delta f) + p_5(U_9, L_9, \delta f)$$

3.4 Total received signal power

$$\text{Power} = \sum_{m=1}^{5} C_m$$

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APPENDIX 1

TO ANNEX 1

Notification of parameters associated to digital emissions

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Application of the method described in Annex 1 for calculation of protection masks for interference between digital emissions requires the notification of new parameters associated with each digital emission. These parameters are:

–   the digital modulation type (the method is applicable only to phase shift keyed signals);

–   the transmitted symbol rate (Msymbol/s);

–   the roll-off factor of the digital pulse shaping filter (assumed to be a cosine roll-off filter or an approximation thereof), a value in the range 0 to 1.

Pending the results of further studies as indicated in this Recommendation, additional parameters may need to be defined (e.g. indication of linear or non-linear channel operation).

The necessary parameters should be submitted explicitly for each digital emission.

It is recommended to update Annex 2 of RR Appendices 30 and 30A accordingly at a competent Radio Conference once the results of the study become available.

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ANNEX 2

Interference calculation methods associated with Annexes 1 and 3[*]

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1   Introduction

The purpose of this Annex is to define a generic method to calculate the interference situation in the BSS Plans, taking into account different categories of interference (e.g. co-channel, adjacent-channel, ...).

The generic interference calculation method defined below, associated with the appropriate protection mask calculation methods, should be applied to establish the values necessary to assess the interference situation between different emissions of the BSS Plans.

2   Terminology, symbols and operators

In order to simplify this Annex and to facilitate its understanding, the following terminology, symbols and operators are defined:

Single entry, se: a single interfering carrier is considered

Aggregate, ag: all interfering carriers are considered

Equivalent, eq: combination of co-frequency and frequency offset interference

Overall, ov: combination of feeder-link, up, and downlink, dn, interference

fo: frequency offset: difference between the centre frequencies of two carriers

c/i: carrier to interference ratio

C/I: carrier to interference ratio (dB)

PR: protection ratio (dB)

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[*]   This method has been developed to carry out the compatibility analysis of assignments, submitted to the BR under the provision of RR Appendices 30 and 30A, with parameters different from those used in the establishment of the Plans (channel bandwidth, centre frequency, type of emission, etc.).

EPM: equivalent protection margin (dB)

OEPM: overall equivalent protection margin (dB)

X: reduction of the overall C/I due to interference in the feeder link (dB)

Operator $\oplus$: $A \oplus B = -10 \log \left(10^{-A/10} + 10^{-B/10} \right)$

Operator $\copyright$: $A \copyright B = -10 \log \left(10^{-A/10} - 10^{-B/10} \right)$

Operator $\Sigma\oplus$: $\displaystyle\sum_{n=1}^{N} \oplus A_n = -10 \log \left(10^{-A_1/10} + 10^{-A_2/10} + \ldots + 10^{-A_n/10} \right)$

3   Interference calculation methods

In order to calculate the interference situation of an assignment, two major elements are needed:

–   the equivalent aggregate carrier to interference ratio, $C/I_{eq, ag}$, on both up and downlinks, $C/I_{eq, ag, up}$, $C/I_{eq, ag, dn}$, respectively,

–   the overall co-channel (or co-frequency) protection ratios of the wanted carrier, PR_{ov}.

In addition, definitions for the equivalent protection margins (EPM) (see Note 1) and Overall Equivalent Protection Margin (OEPM) are required.

NOTE 1 – EPM is not needed in case of application of this method to the Region 2 BSS Plan.

3.1   The first elements, i.e. the equivalent aggregate carrier to interference ratios, are calculated as follows for both the up and downlinks

$$C/I_{eq, ag, up} = \sum_{i=1}^{m} \oplus \left(C/I_{i, se, up} + D_i(fo_i) \right)$$

$$C/I_{eq, ag, dn} = \sum_{i=1}^{m} \oplus \left(C/I_{i, se, dn} + D_i(fo_i) \right)$$

where:

   m :   number of interfering carriers on the feeder-link

   n :   number of interfering carriers on the downlink

   fo :   frequency offset between the centre frequencies of the wanted carrier and one interfering carrier; a positive or negative value (MHz)

   $D(fo)$:   difference (dB) between the appropriate protection mask's value with no frequency offset (i.e. the centre value at 0 MHz) and the protection mask's value with a frequency offset of fo MHz.

For the case of a digital wanted carrier and a digital interfering carrier, the value $D(fo) = -I(fo)$, where $I(fo)$ $(\equiv I(\delta f))$ is defined in Annex 1 assuming a linear channel. However, pending further studies to quantify the effects of the non-linear channel, the model given in Annex 3 should be applied to evaluate $D(fo)$.

For other combinations of wanted and interfering carrier types (digital into analogue interference) appropriate masks remain to be defined. Until such time as these masks are available, the model given in Annex 3 should be applied to evaluate $D(fo)$.

From these first elements the overall equivalent aggregate carrier to interference ratio (denoted $C/I_{ov, eq, ag}$) can be calculated as follows:

$$C/I_{ov, eq, ag} = C/I_{eq, ag, up} \oplus C/I_{eq, ag, dn}$$

3.2 **The second major element, i.e. the overall protection ratio, PR_{ov}, is associated to the type of the wanted carriers**

In addition to this second element, a feeder-link protection ratio and a downlink protection ratio, PR_{up} and PR_{dn} respectively, can be defined. Assuming a given increase, X, in the downlink protection ratio to allow for interference in the feeder-link, PR_{up} and PR_{dn} are defined as follows:

$$PR_{dn}^2 = PR_{ov} + X$$

$$PR_{up}^2 = PR_{ov} \ \copyright \ PR_{dn}$$

3.3 **EPM_{up}, EPM_{dn} and OEPM definitions**

$$OEPM = C/I_{ov, eq, ag} - PR_{ov}$$

$$EPM_{up}^2 = C/I_{eq, ag, up} - PR_{up}$$

$$EPM_{dn}^2 = C/I_{eq, ag, dn} - PR_{dn}$$

ANNEX 3

Calculation of digital interference in the absence of appropriate protection masks

When applying the calculation method of Annex 2, it is desirable to apply the most appropriate protection mask for the digital interference situation under consideration (i.e. the most appropriate value for $D_i(fo_i)$ in Annex 2). For example, for digital interference into a digital emission, this mask can be derived using the calculation method given in Annex 1, subject to further studies to quantify the effects of channel non-linearities.

Further studies are also required to derive suitable generic protection masks for the case of digital into analogue interference.

Until such time as these masks are available, the method given below should be used to calculate the interference between two emissions, where the interferer is a digital emission.

The value for $D(fo)$ is calculated as follows:

$$D(fo) = 10 \log_{10}\big(B/b(fo)\big) + K$$

where:

   $b(fo)$: overlapping bandwidth between the interfering carrier and the wanted carrier (MHz)

   B: necessary bandwidth of the interfering digital carrier (MHz)

   K: positive weighting coefficient.

In general, a protection mask calculation method such as that given in Annex 1 quantifies the value K which may vary depending upon the wanted and interfering signal parameters and the frequency offset between the two signals (in fact, the method of Annex 1 does not explicitly calculate the factor K but rather calculates directly the value $-D(fo)$).

In the absence of suitable protection masks which quantify the factor K, either directly or indirectly, it should be assumed that $K = 0$ which corresponds to the worst case.