RECOMMENDATION ITU-R S.1068*

Fixed-satellite and radiolocation/radionavigation services sharing in the band 13.75-14 GHz

(1994)

The ITU Radiocommunication Assembly,

considering

a) that the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) allocated the frequency band 13.75-14 GHz to the fixed-satellite service (FSS) on a primary basis;

b) that this band is also allocated to the radiolocation and radionavigation services on a primary basis;

c) that the Footnote No. S5.502 of the Radio Regulations (RR) restrictions were placed on the FSS and radiolocation and radionavigation services in order to allow these services to share this band;

d) that WARC-92 in former Resolution No. 112 invited ITU-R to conduct the necessary studies with respect to the values given in RR No. S5.502 and report its outcome;

e) that digital and analogue TV-FM carriers in the FSS are sensitive to interference from radars;

f) that studies have been performed to ascertain the effects of radar interference to these carrier types;

g) that the highest average e.i.r.p.s of known existing radars operating in the band 13.75-14 GHz is 59 dBW,

recommends

1 that the minimum value of any emission from an earth station of 68 dBW e.i.r.p. is appropriate for the protection of carriers in the FSS from existing radars with a maximum average e.i.r.p. of 59 dBW;

2 that the minimum earth station antenna diameter of 4.5 m is consistent with the minimum e.i.r.p. requirement of 68 dBW for FSS networks and also minimizes the possibilities of unacceptable interference to the radionavigation and radiolocation services;

3 that the maximum value of any emission from an earth station of 85 dBW e.i.r.p. is consistent with the maximum values employed in FSS networks;

4 that the methods and criteria given in Annex 1 be used to compute and assess the interference from radars to FSS networks;

5 that the design of new transmitters in the radiolocation/radionavigation services should be consistent with the sharing criteria in Annex 1.

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* Radiocommunication Study Group 4 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44 (RA-2000).

ANNEX 1

Sharing criteria between radiolocation/radionavigation services and the fixed-satellite service

1 Interference from radar into FSS

Measurements reflecting very severe interference from radars in the band were conducted in order to assess its impact on some FSS digital carriers as well as to analogue TV carriers.

1.1 Measurements of interference into digital FSS carriers

The interference was measured into Intelsat intermediate data rate (IDR) digital carriers operating at 2 Mbit/s, 8 Mbit/s and 45 Mbit/s and using FEC rate 3/4. The interfering radars were assumed to operate in a range of the pulse repetition frequencies (PRF) of 1 kHz to 100 kHz. It was also assumed that the interference occurs during the "clear sky" conditions, i.e. that the noise level on the link is very low compared to the interference, and consequently, its impact is insignificant. The results of the measurements of the BER versus the duty cycle δ are shown in Fig. 1 for all the three digital carriers measured and for $PRF = 1$ kHz. The results for other PRFs show similar behaviour.

Having in mind that radar interference is a short time event, a degradation up to $\text{BER} = 10^{-6}$ is acceptable. Using the results of the measurements, the C/I values corresponding to $\text{BER} = 10^{-6}$ were determined and converted into the permissible peak radar e.i.r.p.s (e.i.r.p.s of the FSS carrier of 68 dBW, 74 dBW and 81.5 dBW for 2 Mbit/s, 8 Mbit/s and 45 Mbit/s carriers, respectively). A composite envelope of the results is shown in Fig. 2 together with the $(59 - \log \delta)$ (dBW) limit imposed by the RR.

1.2 Measurements of interference into analogue TV carriers

The C/I ratios for "just perceptible interference" into a NTSC, 20 MHz TV carrier were recorded for PRFs of 1 kHz, 10 kHz and 100 kHz, and for duty cycles up to about 3%. The carrier-to-noise ratio of the TV carrier was set at 18 dB. The results are presented in Fig. 3. Following the same procedure as above for IDR carriers, a composite envelope of the maximum permissible peak radar e.i.r.p.s was then derived for a TV carrier e.i.r.p. of 77 dBW and presented in Fig. 4.

2 Sharing criteria

The following criteria are based on the analysis in § 3 and 4 and are consistent with the expected radar emissions from the radars described in § 3.

2.1 Short-term criterion for FSS digital IDR carriers

The necessary short-term criterion for sharing between the FSS digital carriers and radars was obtained as an envelope of the maximum permissible peak radar e.i.r.p.s towards FSS geostationary satellites determined for various FSS carriers as indicated in § 1. The following expression provides a good approximation of the envelope:

$$e.i.r.p._p\,(\text{dBW}) = 59 + 15 \log [1 + 0.5\, PRF\ (\text{kHz}) / \delta\,(\%)] \qquad (1)$$

Taking into account the peak radar e.i.r.p. limit defined by the RR and the above developed criterion, the short-term sharing criteria can be defined as:

$$e.i.r.p._p\,(\text{dBW}) \leq \begin{cases} 59 - 10 \log [\delta\,(\%) / 100] \\ \text{or} \\ \begin{pmatrix} 59 = 15 \log[1 + 0.5\, PRF\,(kHz) / \delta\,(\%)] \\ \text{for more than 99.98\% of any month} \\ \text{and 99.996\% of any year} \end{pmatrix} \end{cases} \qquad (2)$$

whichever is less. The criteria are shown in Fig. 2.

2.2 Long-term criterion for FSS digital IDR carriers

The mask in Fig. 5 provides the long-term criterion for FSS digital IDR carriers for radar duty cycles up to about 10%.

The peak radar e.i.r.p. at point A should be computed using equation (2). The percentage of time at point A is:

$$t(\%) = \frac{36\, T(\%)}{BW\ (\text{MHz})} \qquad (\text{For } BW = 36 \text{ MHz}, \quad t\% = T\%)$$

$T = 0.004\%$ is the overall annual allowance. However, in the case of non-uniform distribution of radar emissions over the year, the worst month percentage should not exceed 0.02% provided that the overall annual allowance is maintained.

2.3 Short-term criterion for FSS analogue TV carriers

The following expression provides a good approximation of the maximum permissible peak radar e.i.r.p.s towards FSS geostationary satellites presented in Fig. 4 for the duty cycle ratios up to about 10%.

$$e.i.r.p._p\,(\text{dBW}) = 52 - (1.25)^{\log PRF\,(\text{kHz})} \left(5 \log [\delta\,(\%) / 100]\right) +$$

$$+ 30 \log \left[1 + 0.001\, PRF\ (\text{kHz}) / \delta\,(\%)\right] \qquad (3)$$

The short-term sharing criteria for analogue TV carriers can be defined as:

$$e.i.r.p._p\,(\text{dBW}) \leq \begin{cases} 59 - 10 \log [\delta\,(\%) / 100] \\ \text{or} \\ \begin{pmatrix} 52 - 1.25^{\log PRF\,(\text{kHz})} \left(5 \log [\delta\,(\%)/100]\right) + \\ 30 \log\left[1 + 0.001\, PRF\ (\text{kHz}) / \delta\,(\%)\right] \\ \text{for more than 99.98\% of any month} \\ \text{and 99.99\% for any year} \end{pmatrix} \end{cases} \qquad (4)$$

whichever is less.

FIGURE 1

BER versus duty cycle for PRF of 1 kHz

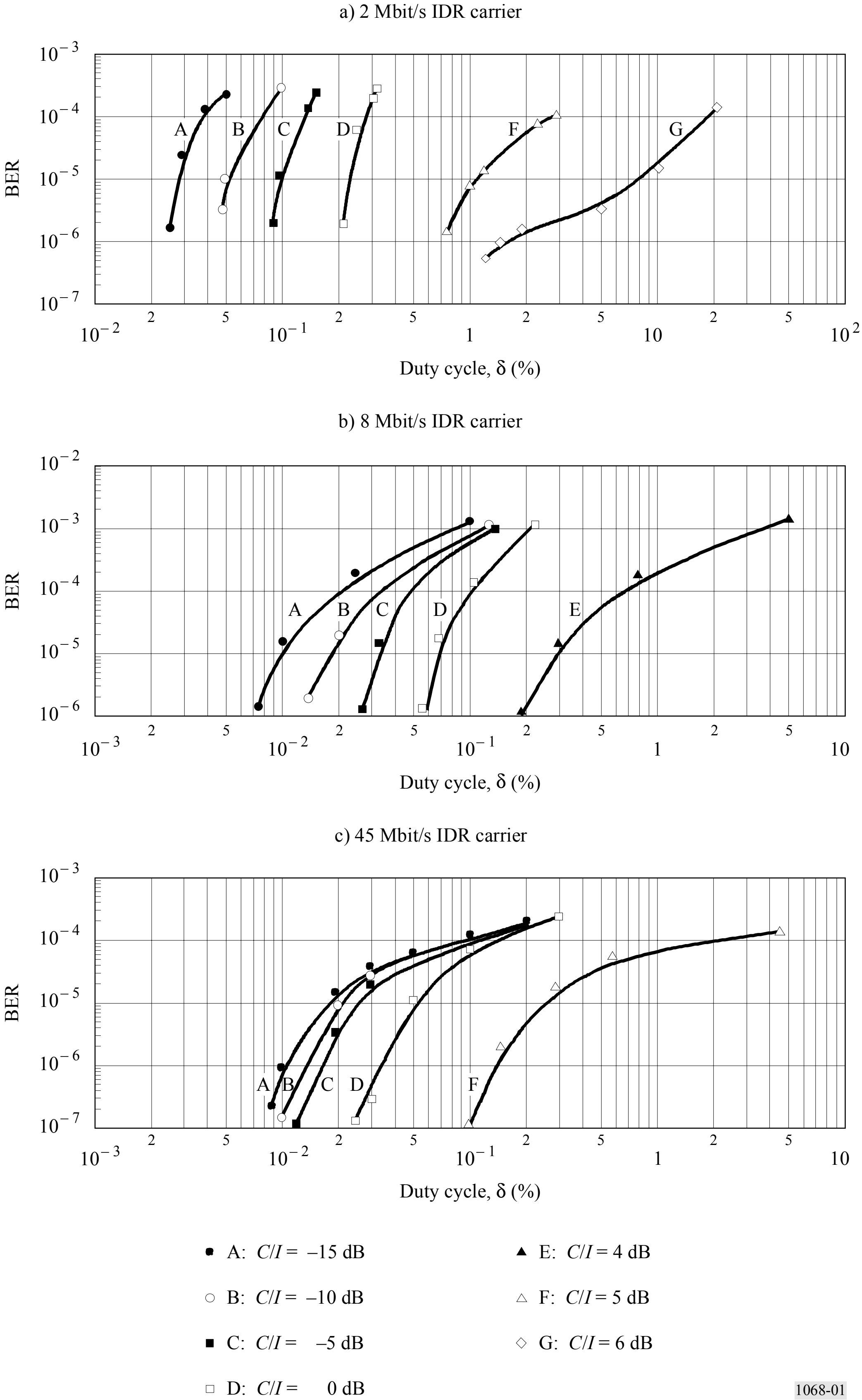
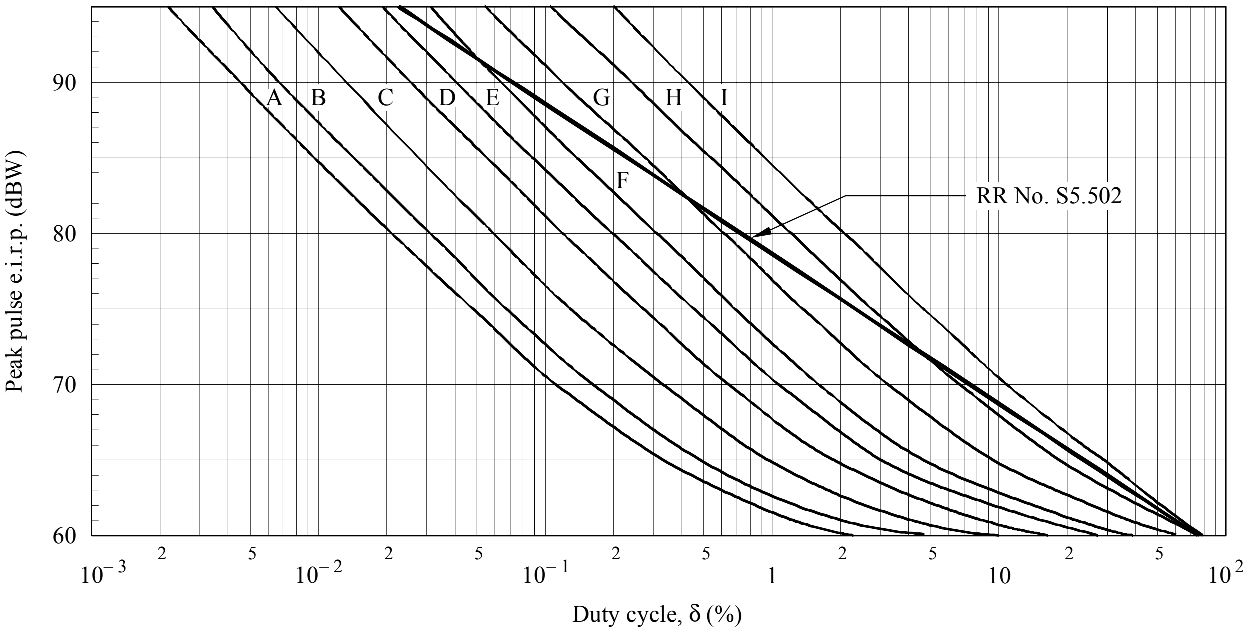


FIGURE 2

Interference criteria for IDR carriers



A: PRF = 1 K
B: PRF = 1.5 K
C: PRF = 3 K
D: PRF = 6 K
E: PRF = 10 K
F: PRF = 115 K
G: PRF = 130 K
H: PRF = 160 K
I: PRF = 100 K

e.i.r.p. ≤ 59 + 15 log [1 + 0.5 *PRF* (kHz)/δ (%)] dBW

For IDR carriers, 2 Mbit/s to 45 Mbit/s,
QPSK, rate 3/4 FEC, BER = 1 × 10^6

e.i.r.p. ≤ 59 – 10 log [δ (%)/100] dBW (RR No. S5.502)

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FIGURE 3

Radar interference into analogue TV

(*C*/*I* for "just perceptible interference" into NTSC, 20 MHz TV)

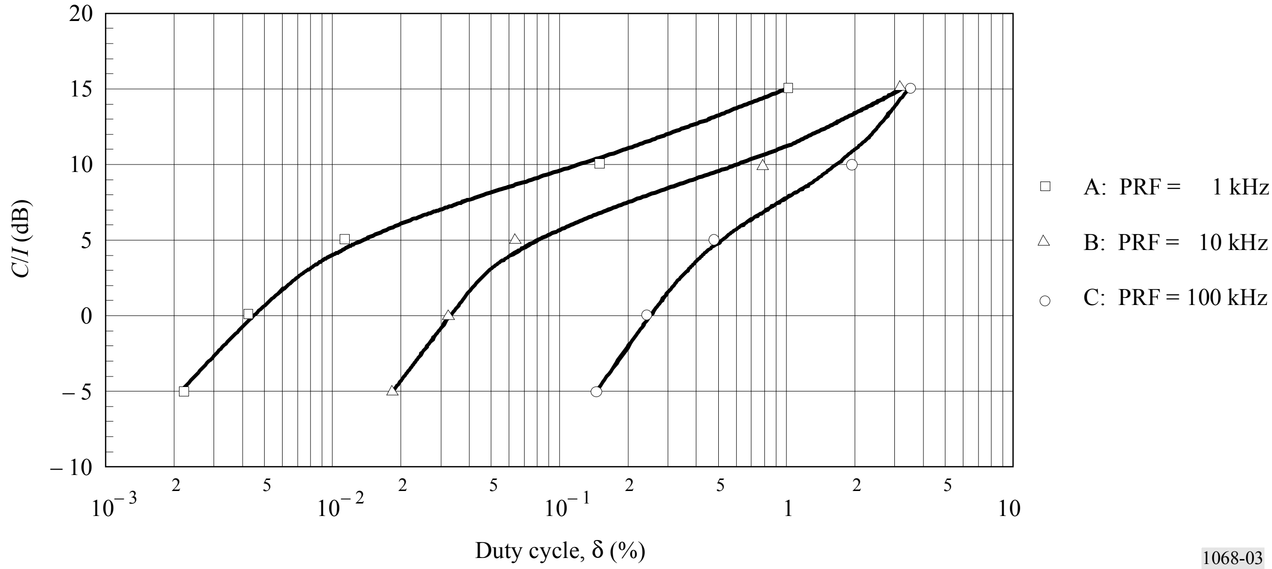

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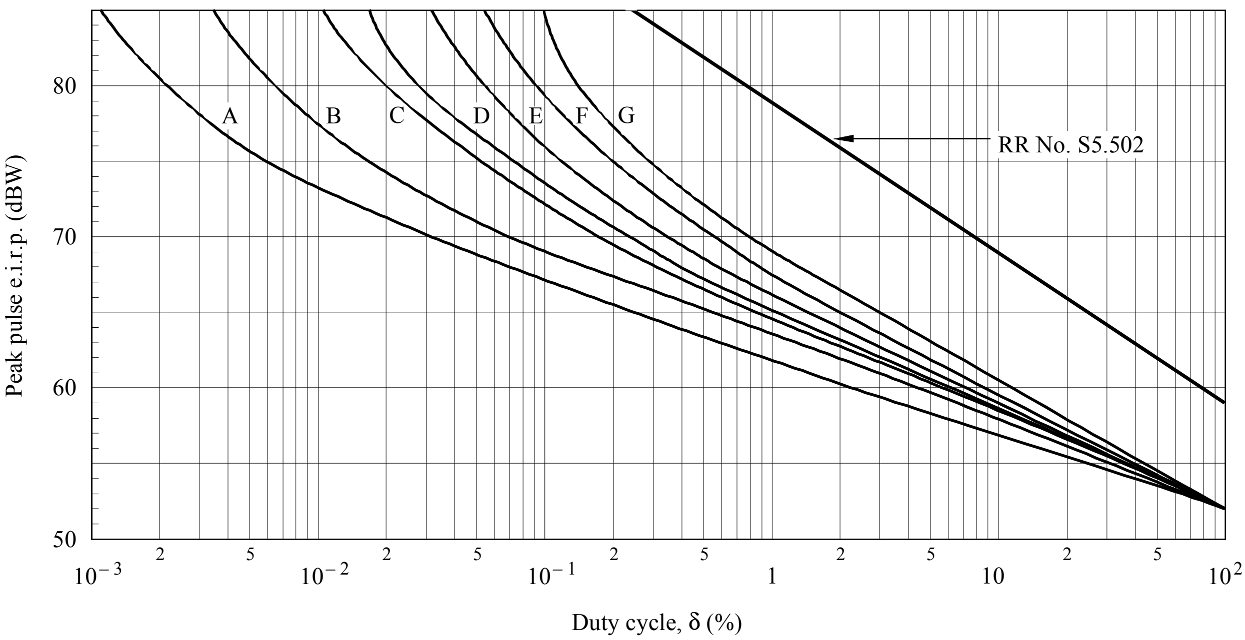
FIGURE 4

Interference criteria for analogue FM-TV carriers



A: PRF = 1 K
B: PRF = 3 K
C: PRF = 10 K
D: PRF = 15 K
E: PRF = 130 K
F: PRF = 160 K
G: PRF = 100 K

e.i.r.p. $\leq 52 - (1.25)^{\log PRF\,(\text{kHz})}\{5 \log [\delta\,(\%)/100]\} + 30 \log [1 + 0.001\, PRF\,(\text{kHz})/\delta\,(\%)]$ dBW

For just perceptible interference to analogue FM-TV carriers

e.i.r.p. $\leq 59 - 10 \log [\delta\,(\%)/100]$ dBW (RR No. S5.502)

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2.4 Long-term criterion for FSS analogue TV carriers

The mask in Fig. 5 should also be used as a long-term criterion for FSS analogue TV carriers.

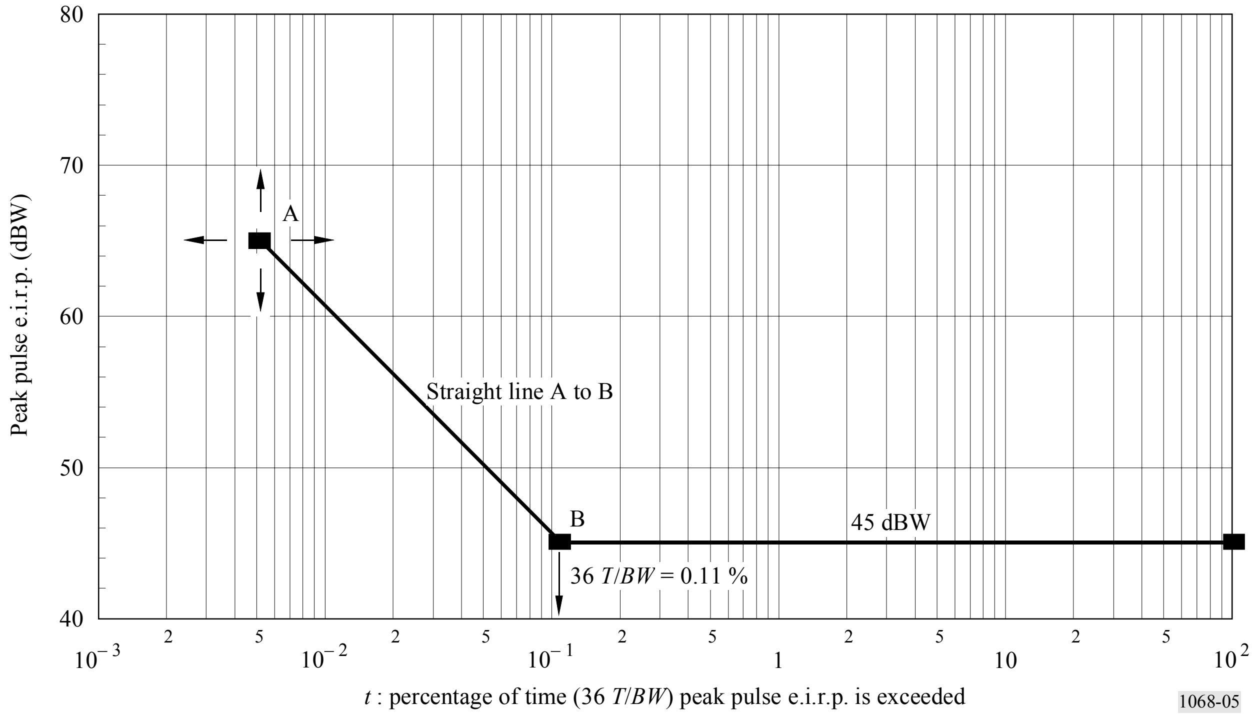
The peak radar e.i.r.p. at point A should be computed using equation (4). The percentage of time at point A is:

$$t(\%) = \frac{36\, T(\%)}{BW\ (\text{MHz})} \qquad (\text{For } BW = 36 \text{ MHz}, \quad t\% = T\%)$$

$T = 0.01\%$ is the overall annual allowance. In the case of non-uniform distribution of radar emissions over the year, the worst month percentage should not exceed 0.02% provided that the overall annual percentage allowance is maintained.

FIGURE 5

Long-term radar peak e.i.r.p. mask for protection of FSS analogue TV carriers and for FSS digital IDR carriers



3 Characteristics of radars operating in the band

3.1 General comments

It appears that the class of radars which represents the most potential up-path interference to FSS networks is surface based; most of which are mounted on ships. These radars have a number of operating modes which include both scanning and tracking modes. Various duty cycles (δ), pulse repetition frequencies (PRF) and peak e.i.r.p.s are used.

The higher levels of interference to an FSS satellite will be intermittent and will be present a very small percentage of time. Analyses of the per cent of time versus peak e.i.r.p. levels have been made and are described in the following paragraphs. Two models are analysed, a global situation and a quasi-stationary situation.

3.2 The global situation

The peak e.i.r.p. as a function of time is determined by the following factors:

a) *Antenna main-lobe patterns*

$$e.i.r.p. = e.i.r.p._{max} - 20 \log \left((\sin K\,\theta) / K\,\theta \right) \qquad \text{dBW} \qquad (5)$$

where:

θ: angle from peak gain, and

K: appropriate constant for each antenna pattern.

The first side-lobe levels are at least 17 dB below the peak gain. The maximum e.i.r.p. in the scanning mode is 74 dBW and in the tracking mode is 79 dBW. There are several antenna patterns on these radars.

b) *Operational modes*

For the scanning modes, the operation with respect to azimuth and elevation angles is defined. The radars scan in azimuth by elevation segments. The time per radar in each segment is summed at each e.i.r.p. level to arrive at a total time in which the satellite is within a given e.i.r.p. contour. For the tracking mode the azimuth and elevation angles are assumed to be random.

c) *Radar operating times*

The purpose and use of these radars is such that the per cent of time that the radar is operating is very small as compared to total time. The average time per radar is less than 1% for the scanning mode and less than 0.1% for the tracking mode. This applies to both land-based and ship-based radars.

d) *Co-frequency operation*

The radar frequency assignments are nearly uniform over the 600 MHz of allocated bandwidth.

Thus, the probability of co-frequency operation per radar (P_c) is taken as:

$$P_c = BW / 600 \tag{6}$$

where BW is the interfered-with bandwidth (MHz) and is greater than 2 MHz.

e) *Number and distribution of operational radars*

It is assumed that the radars are uniformly distributed on the Earth's surface and that one-third are visible to a satellite; approximately 200.

The results of combining the above factors for the global situation, including both scanning and tracking mode, are shown in Fig. 6 for peak e.i.r.p. values from 57 dBW to 79 dBW and for a 36 MHz interfered-with bandwidth. Since the overall probability is dominated by time factors, the probability is expressed as per cent of time. The per cent of time can be considered to be proportional to bandwidth.

3.3 Quasi-stationary situation

For the ship-based radars it is fairly common to have a cluster of ships. Because of mutual radar interference problems the frequencies are widely separated, i.e. only one frequency in a 72 MHz transponder. It is assumed that the radar is co-frequency in the interfered-with bandwidth and that the radar location has a very low elevation angle with respect to the satellite. This is the condition for the highest e.i.r.p.s from the radars. The results of the analysis of this situation are also shown in Fig. 6 for values of e.i.r.p. from 57 dBW to 79 dBW. This case is also applicable to a land-based radar.

3.4 Peak e.i.r.p. versus time beyond first side-lobe

The following rationale is used to estimate the peak e.i.r.p. versus time function beyond the first side-lobe. The portion of time that a satellite is within an antenna gain contour is proportional to θ^2.

The side-lobe envelope gain is assumed to be proportional to $1/\theta^{2.5}$ which is also proportional to the e.i.r.p. Thus the e.i.r.p. versus time function is proportional to $1/t^{1.25}$ or –12.5 log t (dB) where t is time. The lowest e.i.r.p. value is based on the smallest D/λ.

3.5 Overall envelope function

Overall envelope functions can be developed which cover the cases shown in Fig. 6 as follows:

$$e.i.r.p._p \begin{cases} \leq 79 & \text{dBW} & & (7a) \\ \geq 79 - 50\,000\,(36\,T/BW) & \text{dBW} & \text{for} \quad 0 < (36\,T/BW) \leq 0.0001\% & (7b) \\ \geq 74.14 - 1428\,(36\,T/BW) & \text{dBW} & \text{for} \quad 0.0001\% < (36\,T/BW) \leq 0.012\% & (7c) \\ \geq 33 - 12.5 \log (36\,T/BW) & \text{dBW} & \text{for} \quad 0.012\% < (36\,T/BW) \leq 0.11\% & (7d) \\ \geq 45 & \text{dBW} & \text{for} \quad 0.11\% < (36\,T/BW) \leq 100\% & (7e) \end{cases}$$

where:

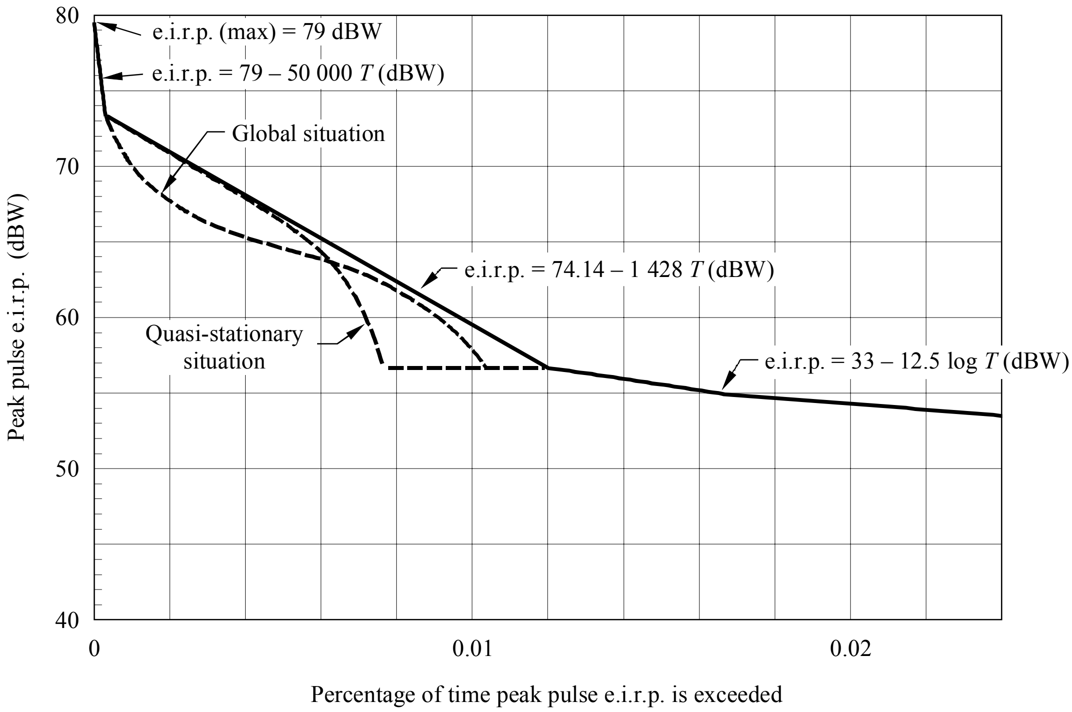
BW: interfered-with bandwidth (MHz) ≥ 2 MHz

T: percentage of time.

These functions are also shown in Fig. 6. Figure 7 shows the same functions as Fig. 6 extended to 100% of time. The per cent of time that a radar is operating in a 36 MHz bandwidth within the field of view of a satellite is about 10%.

FIGURE 6

Peak pulse e.i.r.p. versus percentage of time



Interfered-with bandwidth = 36 MHz

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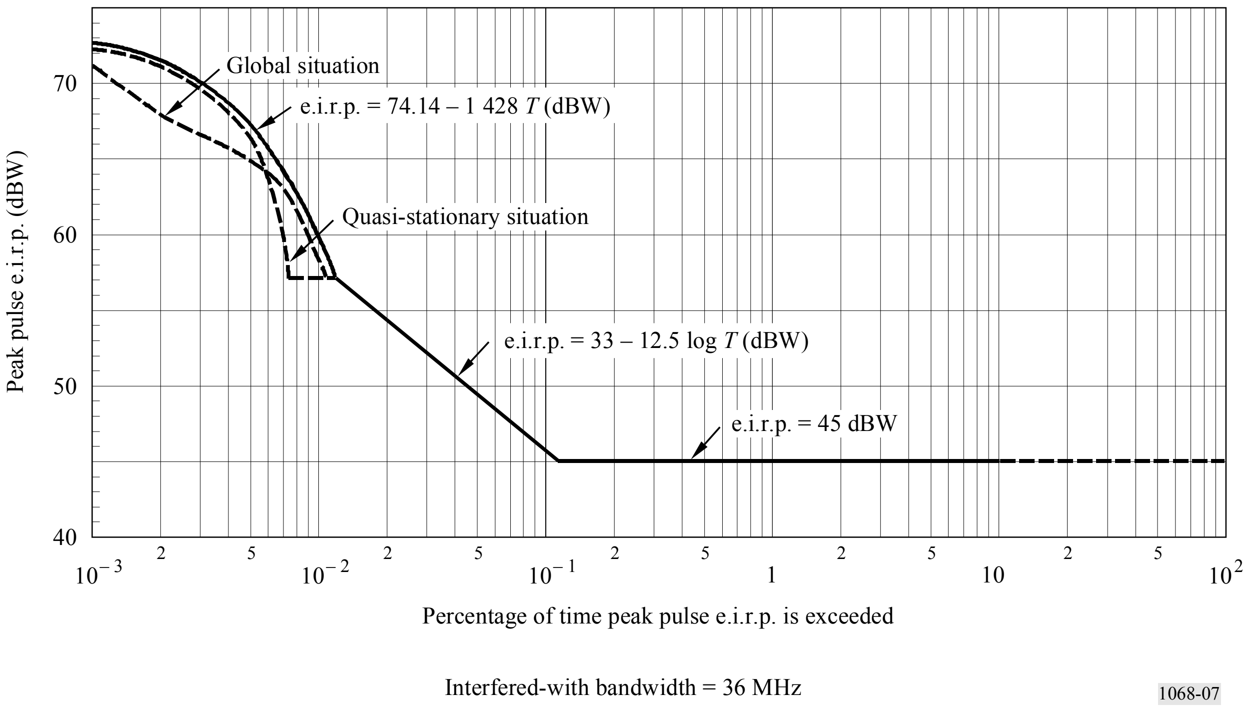
FIGURE 7

Peak pulse e.i.r.p. versus percentage of time



4 Interference to FSS satellites

4.1 General

Measurements have been made as described in § 1.1 and 1.2 of the effects of pulsed radars on IDR and FM-TV carriers and short-term criteria have been developed for these cases. These short-term criteria are shown in Figs. 2 and 4. Short-term is taken as implying values in the order of 0.01 to 0.04% or less. Another factor to be considered is transponder saturation due to the peak radar e.i.r.p. Interference to IDR carriers, FM-TV carriers and transponder saturation is addressed in the following paragraphs.

4.2 Interference to IDR carriers

The worst known case scanning mode for these radars with respect to the IDR carrier criterion in Fig. 2 is characterized by a maximum (δ) of 3%, a minimum (PRF) of 60 kHz, a maximum pulse duration of 0.5 μs and a peak e.i.r.p. of 74 dBW. Using these values in the equations shown in Fig. 2 results in an e.i.r.p. criterion value of 74.6 dBW and a maximum allowable peak e.i.r.p. of 74.2 dBW in accordance with RR No. S5.502. It is noted that the e.i.r.p. criterion is only a function of the pulse duration.

The worst known case tracking mode is characterized by a maximum (δ) of 1%, a minimum (PRF) of 45 kHz and a peak e.i.r.p. of 79 dBW. Again using these values in the Fig. 2 equations results in an e.i.r.p. criterion of 79.6 dBW and a maximum allowable peak e.i.r.p. of 79 dBW in accordance with RR No. S5.502. Thus the RR No. S5.502 limits are satisfied and the sharing criteria (e.g. Fig. 2) are met for IDR carriers and for radar emissions from radars described in § 3.

4.3 Interference to FM-TV carriers

The worst known case scanning mode for these radars with respect to the FM-TV carrier criterion in Fig. 4 is characterized by a maximum (δ) of 3%, a minimum (PRF) of 15 kHz, and a maximum pulse duration of 2 μs. The reason that this case is different than for the IDR carriers is that the 2 μs pulse is PSK modulated such that the pulse duration is effectively about 0.2 μs and as noted above, the IDR criterion is a function of pulse duration. However, in the FM-TV criterion equation (Fig. 4) only one term involves pulse duration. For the case considered here an order of magnitude change in the pulse duration has a negligible effect on the criterion value. From the criterion equation of Fig. 4, the criterion value is 62 dBW. For the tracking mode the value is 67 dBW. The per cent of time is determined by the 62 dBW value in equation (7c). For a 30 MHz carrier, 62 dBW is exceeded 0.0071% of the time; for a 20 MHz carrier, 62 dBW is exceed 0.0047% of the time; and for a 17 MHz carrier, 0.004% of the time. Thus, for the FM-TV case the criterion is met for 99.99% of the time for radars described in § 3.

4.4 Transponder saturation

If the peak radar e.i.r.p. plus the desired carriers e.i.r.p. cause transponder saturation, suppression of the desired carriers and other deleterious effects take place. From Fig. 6, it would appear that the transponder saturation e.i.r.p. should be set to accommodate a 74 dBW pulse with acceptable degradation so that transponder saturation would occur a very small percentage of the time; an operating time of 0.0001% for a 36 MHz transponder or 0.0002% for a 72 MHz which are 0.000001% and 0.000002% for actual emissions.

4.5 Long-term interference to IDR carriers

From Fig. 7, values of peak e.i.r.p. of 57 dBW or less might be considered long-term interference. From § 4.2, the allowable short-term peak e.i.r.p. is 74.6 dBW. Thus the long-term C/I will be at least 17.6 dB and up to 29.6 dB higher than the short-term criteria which are more than adequate to account for the additional factors involved in a long-term criteria, e.g. internal system noise, aggregate interference allowances and fade margins.

4.6 Long-term interference to FM-TV carriers

From § 4.3, the allowable short-term peak e.i.r.p. is 62 dBW. Thus the long-term C/I will be at least 5 dB and up to 17 dB higher than the short-term criteria. The FM-TV carrier e.i.r.p. used for the criteria is 77 dBW so that the C/I will be at least 20 dB and up to 32 dB.

4.7 Long-term interference to transponders

Since the e.i.r.p. required for transponder saturation probably needs to be greater than 74 dBW, a radar peak e.i.r.p. of less than 57 dBW should not cause any significant interference problem.

5 Conclusions

Based on the interference criteria of § 1 and 2, the operational characteristics of the radars described in § 3 and the interference analyses given in § 4, the following conclusions are made.

– The limitations imposed by RR No. S5.502 are met by all known operational modes of existing radars in the band. However, new developments of radars may have different operational modes and should be designed to be consistent with the sharing criteria described in § 2 of this Annex.

– The short-term and long-term criteria for IDR carriers are met for all operational modes of the radars described in § 3.

– The short-term and long-term criteria for FM-TV carriers are met for all operational modes of the radars described in § 3 for 99.99% of the time.

– The minimum earth station e.i.r.p. of 68 dBW is necessary for the protection of FSS carriers from radar interference.

– A minimum earth station antenna diameter of 4.5 m is consistent with a minimum e.i.r.p. of 68 dBW and also minimizes the possibilities of unacceptable interference to the radiolocation and radionavigation services.

– The maximum earth station e.i.r.p. of 85 dBW is consistent with the maximum values that might be used in FSS networks.

– The constraints given in RR No. S5.502 are appropriate and should not be modified at this time.