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Radiocommunication Sector of ITU

Recommendation ITU-R F.1097-1
(05/2000)

Interference mitigation options to enhance compatibility between radar systems and digital radio-relay systems

F Series
Fixed service

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R F.1097-1[*]

INTERFERENCE MITIGATION OPTIONS TO ENHANCE COMPATIBILITY BETWEEN RADAR SYSTEMS AND DIGITAL RADIO-RELAY SYSTEMS

(1994-2000)

Scope

This Recommendation provides the interference mitigation options which should be taken into consideration in order to enhance compatibility between digital radio-relay systems (DRRSs) and radar systems. The Annex describes technical details for the mitigation options as well as operational experiences of the radar interference to the fixed wireless systems in the bands 4 to 6 GHz.

The ITU Radiocommunication Assembly,

considering

a) that radar systems can produce interference to digital radio-relay systems (DRRSs) in some situations;

b) that there are two coupling mechanisms by which radiated energy from radar stations may be coupled into radio-relay systems:

– radar spurious emission in the radio-relay bands;

– radio-relay system front-end overload (receiver desensitization) caused by the radar fundamental frequency;

c) that the most desirable method of mitigating the interference may be to reduce the spurious emissions at the radar transmitter to a sufficiently low level;

d) that some of the techniques employed by radio-relay system designers to enhance system performance are expected to reduce the susceptibility of these systems to interference from radar transmitters,

recommends

1 that the interference mitigation options for radar systems listed below should be taken into consideration in order to enhance compatibility with DRRSs:

– operational measures, according to agreement with the agency responsible for the radar system;

– selection or adjustment of transmitter frequency;

– replacement of transmitter device;

– RF filter installation in the radar transmitter;

2 that the interference mitigation options listed below should be taken into consideration in the design and implementation of DRRSs in order to enhance compatibility with radar systems:

– microwave RF filters before the front-end of the receiver;

– antenna selection (side-lobe characteristics);

– antenna diversity (space or angle);

– forward error correction (FEC) coding;

– additional bit interleaving technique (BIT);

– alternate channel use, in same band;

– alternate band deployment;

– path re-routing;

– other possible techniques;

3 that Annex 1 should be referred to for additional guidance relating to this Recommendation.

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[*] Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

ANNEX 1

Options to enhance compatibility between radar systems and DRRSs

1 Radar system options

The options listed below all depend on the condition that a particular radar installation has unequivocally been identified as the one causing the interference.

So far, stationary air surveillance radars (ASR) operating near 1.3 GHz and near 3 GHz, and meteorological radars operating near 5.6 GHz have been encountered by DRRS operators.

Furthermore merchant marine (mobile) navigation radars operating near 3 GHz have been encountered by operators with DRRSs in coastal areas.

1.1 Operational measures, sector blanking

When the radar installation and the agency responsible for its operation are known, an agreement with the agency may be made, that the radar is momentarily switched off, when its main beam is pointing in the direction of the DRRS location. This is commonly known as sector blanking.

If sector blanking is agreeable to the radar operating agency, it is simple to implement, either by hardware measures in older radars, or by control software commands in modern installations.

Also, minimal or no expenses are incurred.

This kind of mitigation option has already been implemented in some countries resulting in a successful co-existence of installations of the radiodetermination service and the fixed service (see also Appendix 1).

1.2 Operational measures, selection or adjustment of transmitter frequency

In some types of fixed radar systems it may be possible to select or adjust the fundamental frequency of the radar transmitter within the frequency range allowed for the radar system, so that the second or third harmonic spurious emissions will not be received by the DRRS. In particular, it may be possible to place the radar harmonic in the guardband, between upper and lower radio-relay half band of the frequency plan, or outside the radio-relay band all together.

If this retuning is agreeable to the radar operating agency, for this measure too, minimal or no expenses are incurred.

This kind of mitigation option has already been implemented in some countries resulting in a successful co-existence of installations of the radiodetermination service and the fixed service.

1.3 Replacement of transmitter device

Variations in ground-based radar spurious emission levels have been observed in radars using either conventional or coaxial magnetron power tubes. These variations may be attributed to aging phenomena, resulting in:

- changes in the pulse shaping networks of the modulator;
- changes in anode voltage and current of the power tube; or
- arcing in the tube.

The ground-based radar operators, on a routine basis, may need to perform periodic checks of the radar transmitter to determine whether these transmitters have, because of aging, developed spurious components that were of low level or not present when the transmitter was new.

In some reported cases, interference problems have been corrected by replacing the radar transmitter output device.

1.4 RF filter installation in the radar transmitter

Radio frequency (RF) waveguide filters have been used in several types of radar to reduce interference to radio-relay systems to acceptable, low levels.

Thus RF low pass, absorptive filters have been used in fixed 1.3 GHz ground-based radars to mitigate interference by the third harmonic into the 4 GHz band allocated to the fixed service.

Similarly, 5 GHz ground-based radars had band pass filter (BPF)/low pass filter installed, to suppress spurious components interfering in the lower and upper 6 GHz fixed service bands (see Fig. 1).

Such filters have been known in the radar industry for over 30 years. They will suppress radar spurious emissions by approximately 40 to 50 dB, while having an insertion loss of a few tenths of a dB at the fundamental operating radar frequency. The radar performance (detection range) is reduced by a small amount only by such filters.

When interference into DRRSs is caused by spurious emissions from radars, the installation of an RF filter in the radar transmitter is considered to be the preferred solution, provided that it is technically possible.

The expense incurred by installing filters in radar transmitters should be related to the cost of the entire radar installation.

The measures discussed in § 1.3 and 1.4, in principle also apply to maritime mobile radar systems.

2 Radio-relay system options

When interference from a radar system is observed in a radio-relay system, the first step in attempting to reduce the interference is to determine if the coupling mechanism is:

- front-end overload of the radio-relay receiver caused by the radar fundamental frequency; or
- a radar spurious component occuring at the receiver channel frequency.

In the case of large stationary ASRs with MW peak power output at their fundamental, design frequency, the level of unintentionally generated and inadvertently emitted spurii which may be intercepted by a radio-relay receiver is often higher than the level of the desired radio-relay signal.

In the case of mobile merchant marine navigation radars, the transmitter parameters are significantly different from those of the ASR transmitters. The output levels at the fundamental and thus the spurious levels as well, are lower and the pulse durations are much shorter.

Only if it turns out to be difficult or impossible to suppress at the source (i.e. the radar) the spurious components occurring at the receiver channel frequency, should measures at the victim radio-relay receiver be attempted.

2.1 Microwave RF filters

If front-end overload by the radar signal, of a low-noise preamplifier (LNA) (which is common to all radio-relay channels) is the coupling mechanism, an RF BPF ahead of this pre-amplifier may be used to protect it from radar interference.

Front-end LNA overload from 5 GHz ground-based radars has been encountered by some operators with DRRSs operating in the lower 6 GHz or the upper 6 GHz band. Installation of a BPF solved the problems.

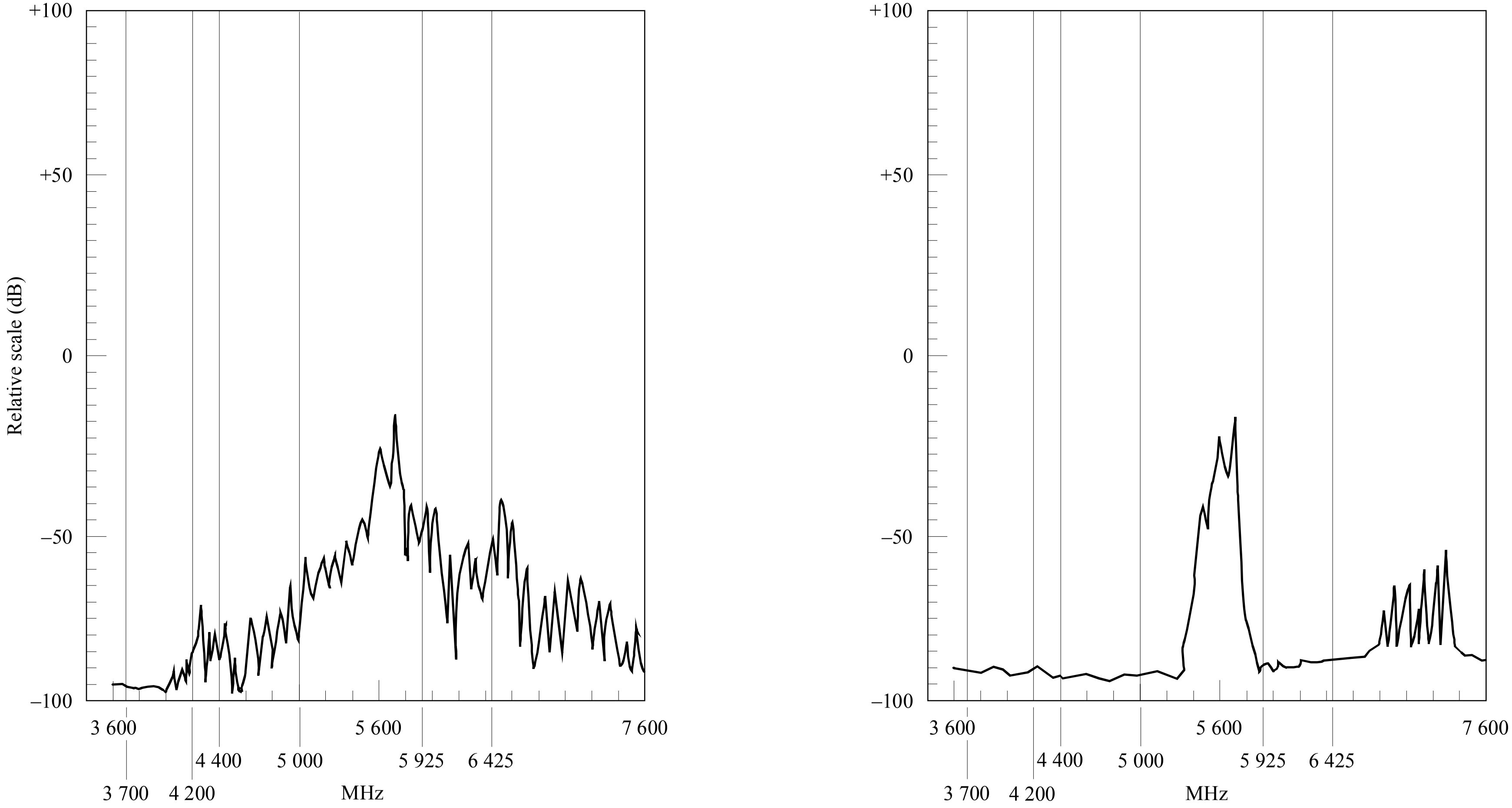
Receiver RF filters will not be effective against interference on, or near to, the radio-relay receiver channel frequencies.

2.2 Antenna selection

After a radio-relay site survey, where appropriate electronic intelligence has been collected, the approximate location of a radar and the levels of spurii which may cause interference will be known. Thus the path geometry from the radio-relay receiver to the desired radio-relay transmitter and toward the radar may be established.

FIGURE 1

Radiated spectrum measurements of a 5 GHz radar without and with an RF filter



Without filter

With filter

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If it appears that the radar main beam will intercept the radio-relay receiver antenna through its side lobes, then selection of a radio-relay antenna type with sufficiently low side-lobe levels may contribute toward protection of the receiver from spurious interference.

The level of the interference ingressing through the side lobes into the receiver may exceed the thermal background noise by a small amount at most, in order not to compromise the transmission performance of the DRRS.

Well designed, shrouded parabolic antennas are a good choice. If the interference arrives from an angle in the forward field of view of the antenna, between about 20° and 60° from main beam, then an antenna with an offset feed system (shell-type) may yield better suppression than a shrouded parabola; however, it is significantly more expensive.

2.3 DRRS antenna diversity

DRRSs susceptible to radar interference are wideband, high capacity systems for trunk transmission. They are normally employing channels in the 4 GHz, 5 GHz, lower 6 GHz or upper 6 GHz bands allocated to the fixed service. These bands are chosen in order to permit long spans or hops to be bridged.

Because of the propagation phenomena encountered in these bands, on most hops receiver antenna diversity is used, either space diversity or sometimes angle diversity. Thereby the probability of a marginal received signal level is minimized. Only in this manner may the stringent requirements to signal transmission quality (see Recommendation ITU-R F.1189 and ITU-T Recommendation G.826) be met in normal operation.

Thus diversity will also protect against radar spurious interference, provided this is incident on the radio-relay receiving site at a modest level. In such cases, the spurious levels may be well above the receiver background noise; however, the signal-to-total-noise ratio is still sufficient for proper detection/demodulation of the desired signal.

2.4 Antenna site shielding

This mitigation possibility has been suggested; it is sometimes used for satellite ground station antennas, located at ground level. Here the use of radar fences or soil dikes has been useful.

However considering the normal placement of radio-relay antennas, 50 to 100 m above ground level on towers or masts, the shielding of antenna side lobes by nearby devices or means is unrealistic.

2.5 Forward error correction (FEC)

FEC coding is a method used in most digital microwave systems to improve the BER performance. The utilization of FEC coding techniques permits a limited number of random errors to be corrected at the receiver by means of special coding software implemented at both ends of the hop.

Measurements have shown that for a double-error correcting code, the threshold for interference breaking through and causing errors in the desired signal is improved by approximately 10 dB when the interfering pulse duration is 1 Bd interval (i.e. the interference produces a receiver impulse response). Trunk transmission DRRSs operate at rates of about 30 MBd corresponding to baud intervals of the order of $\cong$ 30 ns.

However, spurious pulses from ASRs (being generated mainly during pulse rise and fall time of the intentionally generated radar pulse) have a considerably longer duration, of the order of 100 ns, and thus traditional FEC will not be effective against such interference.

2.6 Additional bit interleaving

The situation is different when the interference originates from a navigation radar, because the intentional pulse duration is much shorter ($\leq$ 100 ns) than in ASRs. Therefore the spurious pulses generated during rise and fall times are exceedingly short (~ 15 ns), but may still be picked up by the wideband radio-relay receivers.

A useful mitigation method has been found for this situation. It consists of additional bit interleaving. Upon reception of a signal which is corrupted by short bursts of errors due to the interference, the errors are spread out in time due to the de-interleaving. Thereafter the individual bit errors may be corrected by the FEC process.

The disadvantage of the BIT is the additional processing time required at the receiver. Therefore the BIT should be available as an add-on option to normal receivers, to be used only on radio-relay hops where interference from navigation radars is encountered.

The BIT mitigation method has been in successful operational use in Japan for several years (see also Appendix 1).

2.7 Radio-relay transmitter power increase

This mitigation possibility has been suggested; however, normally it is not likely to improve the situation for the following reasons:

- a few dB of additional power from the radio-relay transmitter is not likely to improve the signal-to-total-noise ratio significantly, so the transmission performance will remain compromised;
- a significantly more powerful radio-relay transmitter would definitely be uneconomical;
- additional power increases the likelihood of interference with other distant DRRSs which are reusing the particular channel.

2.8 Alternate radio-relay RF channel selection

This mitigation measure might be applied in certain situations only, since it is definitely not viewed as efficient spectrum utilization. The conditions for this measure are:

- the interference is caused by a reasonably well defined harmonic of the radar, so only a particular radio-relay channel is affected;
- for some reason it is not possible to retune the radar, as above, in § 1.2;
- an undisturbed RF channel may be made available by the administration, on the hop under consideration.

2.9 Alternate band employment

This mitigation measure could be considered when planning a new DRRS, and when a site survey has indicated the likelihood of interference problems in bands allocated to the fixed service, which would otherwise be considered first choice.

Also, this would depend on the availability of channels in a suitable alternate band.

However, it is not an economical alternative for an established fixed service operation.

It will usually mean a major expense to re-equip the hop(s) affected with new transceivers.

2.10 Alternate path routing

This possibility would apply only when planning a new DRRS. It consists of circumventing the basic problem and, in most cases, for economic reasons this is not a realistic option.

3 Proactive role of administrations

Administrations may stipulate, through national regulations concerning radio frequency transmitters, specific conditions and requirements for the operation of radio-determination installations (radars), both fixed and mobile, to ensure compatibility with the fixed service in adjacent bands.

The responsibility of radar operators for avoiding emission of unwanted spurious spectral components which may cause harmful interference to other radio services should be part of said requirements.

APPENDIX 1

TO ANNEX 1

Operational experience

1 Introduction

In this Appendix operational experience, as reported by a number of DRRS operating entities in input contributions to the ITU former CCIR and subsequent Radiocommunication Study Group 9, will be summarized.

The material was previously summarized in a number of attachments to the reports of the Radiocommunication Working Party 9A meetings. Also additional information was recently received by WP 9A.

Furthermore, relevant background information found in other sources will be mentioned briefly.

The intent is to give further guidance to DRRS operators about what may be expected in operational practice, and how to handle radar interference problems when they are encountered.

2 Information received from Japan

A summary of past experience from 1985 to 1998 is given below (Doc. 9A/64 – Operational experience of radar interference to digital radio-relay systems, 5 October 1998).

The main parameters of typical systems are given in Table 1.

TABLE 1

Main parameters of long-distance DRRSs in Japan

Frequency band	4 GHz: 3 600-4 200 MHz 5 GHz: 4 400-5 000 MHz 6 GHz: 5 925-6 425 MHz
Modulation scheme	16-QAM (3-carrier)
Transmission capacity	3 × STM-0 (52 Mbit/s per carrier)
Receiver bandwidth	20 MHz per carrier

It had been reported from more than 30 radio switching sections that the error performance of such DRRSs was seriously degraded, so as to produce bit errors even during periods without any fading. Among these, about 20 sections include an over-sea hop, and another 10 sections include stations located near land radar stations.

2.1 Countermeasure for land fixed radar interference

There were two kinds of source for this interference, i.e. meteorological radar and Government-use radar. The location and the characteristics of these kinds of radar could readily be identified. Therefore, the insertion of a BPF in the radar transmitter was accomplished through individual negotiation with the radar operators.

These cases are examples of the mitigation method mentioned in § 1.4, Annex 1.

Table 2 shows examples of the BPF insertion in the land fixed radar transmitters.

The characteristics of such BPF are given in Table 3.

TABLE 2

Examples of BPF insertion to land fixed radar

DRRS route	Interfering radar	Interfered-with system	Date
Fukuoka-Ohita	Meteorological radar	16-QAM, 3 carrier (5 GHz)	09-1985
Nagasaki-Sasebo	Government-use radar	16-QAM, 3 carrier (5/6 GHz)	10-1989
Sendai-Aomori	Government-use radar	16-QAM, 3 carrier (4 GHz)	03-1991
Tokyo-Sendai	Government-use radar	16-QAM, 3 carrier (4 GHz)	03-1991
Tokyo-Nagoya	Government-use radar	16-QAM, 3 carrier (4 GHz)	11-1991

TABLE 3

BPF characteristics for land fixed radar

	Meteorological radar
Centre frequency, f_c (Bandwidth)	5 320 MHz ($f_c \pm 4$ MHz)
Insertion loss	Less than 2 dB at f_c
Attenuation characteristics	3 600-4 200 MHz: more than 70 dB 4 400-5 000 MHz: more than 70 dB 5 925-6 425 MHz: more than 70 dB
Maximum allowable power	Peak: 250 kW

2.2 Countermeasure applied to receiver side

On a route constructed in 1990 which was crossing Tokyo bay, interference from ship radar systems was sometimes observed at the level even higher than the desired receiving wave.

In this case an RF pre-amplifier was placed at the input of the receiver branching network. This pre-amplifier was saturated by the radar fundamental frequency signal.

A BPF was inserted in front of the pre-amplifier in order to suppress this radar interference, resulting in a much smaller occurrence of bit errors.

This was an example of the mitigation method mentioned in § 2.1, Annex 1.

2.3 Countermeasure for maritime mobile radar interference

In the case of ship navigation radar interference into over-sea hops it is usually very difficult to identify the source. Therefore mitigation measures at the DRRS receiver are required.

FEC in conjunction with the BIT has been applied to many of the interfered-with hops since 1993.

The results proved fairly well, however, on account of the substantial processing delay time caused by the BIT, only one hop using BIT within a switching section may be implemented.

In particular a number of examples of successful application of the BIT (Doc. 9A/45 – Performance improvement by bit interleave technique (BIT), 23 September 1998, contains further details presented about this important mitigation method).

Table 4 with results is reproduced here. These are examples of the mitigation method mentioned in § 2.6, Annex 1.

TABLE 4

Difference of error performance in the systems with and without BIT

No.	Date	Time	Duration	Errored seconds (ES) count without BIT	With BIT
1	02.07.92	6:55 ~ 7:00	5 min	at BER 10^{-6}: 75 ES	Error free
2	02.07.92	13:15 ~ 13:19	4 min	at BER 10^{-6}: 65 ES	Error free
3	02.07.92	16:03 ~ 16:06	3 min	at BER 10^{-6}: 52 ES	Error free
4	04.07.92	7:55 ~ 7:58	3 min	at BER 10^{-6}: 44 ES	Error free
5	04.07.92	22:03 ~ 22:06	3 min	at BER 10^{-6}: 33 ES	Error free
6	08.07.92	16:38 ~ 16:43	5 min	at BER 10^{-6}: 44 ES	Error free
7	11.07.92	5:57 ~ 6:00	3 min	at BER 10^{-6}: 33 ES	Error free
8	11.07.92	15:10 ~ 19:23	4 h 13 min	at BER 10^{-6}: many times	Error free
9	12.07.92	8:42 ~ 9:22	40 min	at BER 10^{-6}: many times	Error free
10	12.07.92	10:06 ~ 10:14	8 min	at BER 10^{-6}: 30 ES	Error free

Examples Nos. 1-7 are typical of the situation where a ship passes through the line-of-sight (LoS) of a DRRS straddling a shipping lane. The total passage event lasts a few minutes and during this period a considerable number of ES occur.

From some theoretical considerations about the design of the bit interleaver the relationships between the following parameters: FEC block length, FEC correction capability (errors per block), DRRS transmission clock rate (e.g. 140×10^6 Hz), radar interfering pulse width (μs), interleaving depth and interleaver frame length, were obtained.

The maximum permissible processing delay of the DRRS results in an upper limit of interfering pulse width which the BIT can handle. This is briefly mentioned in § 2.6, Annex 1.

Further details of the BIT are given in Appendix 2 to Annex 1.

In one case a ship which was regularly passing just beneath the radio route was identified as the source equipped with the interfering radar transmitter.

Here it was possible to apply the same procedure of BPF insertion at the transmitter as in the case of land fixed radar, i.e. the mitigation method of § 1.4, Annex 1 was used.

The characteristics of the BPF for the navigation radar are given in Table 5.

TABLE 5

BPF characteristics for maritime mobile radar

	Type 1	Type 2
Centre frequency, f_c (Bandwidth)	f_c = 3 050 MHz (f_c ± 10 MHz)	f_c = 3 050 MHz (f_c ± 25 MHz)
Insertion loss	Less than 0.5 dB at f_c	
Attenuation characteristics	3 600-4 200 MHz: more than 60 dB 4 400-5 000 MHz: more than 60 dB 5 925-6 425 MHz: more than 60 dB	
Maximum allowable power	30 kW	90 kW

Attention is drawn to the low insertion loss of these narrow-band filters for the navigation radar.

It implies that the performance of the radar (detection range) is slightly reduced only (see Appendix 2, § 1.8).

3 Information received from Denmark

3.1 Identification of sources of interference

A method for unequivocally identifying merchant marine vessels causing interference normally appears to be a very difficult task. However, by fortuitous circumstances it has been possible to obtain assistance from a vessel traffic service, where operators are on duty around the clock keeping the passage of ships under surveillance (Doc. 9A/15 – Radar interference from moving platforms; identification of individual ships causing error bursts in 4 GHz digital radio links crossing shipping lanes, 23 February 1998). When a radio link was registering error bursts occurring regularly, an automatically generated alert was forwarded to the vessel traffic service operator, who could record which ship caused the alert.

These records have been collated into monthly tables, showing all pertinent details of said vessels: time of passage, ships name and international call sign, ship type and size, and of particular interest: ship owner and home port.

Information from more than 4 years of observation is now on record.

3.2 Examples of mitigation of interference from large fixed radar installations

Interference from a radar with a peculiar operation mode and antenna scan pattern was collected (Doc. 9A/5 – Interference from air surveillance height finder radar into 140 Mbit/s digital radio receiver, 23 January 1996).

This radar, of United States of American origin, has been in use in many countries for many years for air surveillance purposes. The designation is AN/FPS-90 (originally/FPS-6).

The AN/FPS-90 employs a high power coaxial magnetron providing ~3 MW of peak pulsed output power at the fundamental design frequency. It has been established that such a tube, after many thousand hours of continuous operation, may develop a tendency for rather strong spurious output generation.

Since the height finder is an adjunct to a normal ASR, it will operate occasionally only. Thus many weeks could pass where no DRRS interference was encountered.

The interference events would be encountered only when the height finder antenna was aiming in azimuth exactly in the direction of the DRRS station. When this occurred the antenna would scan in elevation over an interval of –5° to +30°, thereby generating regularly spaced groups of error bursts.

This regularity was the clue to what the source of the poor performance of the DRRS was.

Once the location of the height finder and the agency responsible for its operation was known, an agreement on sector blanking was obtained. This solved the interference problem for an interim period. The agency agreed to acquire a suitable filter for insertion in the radar transmitter.

Thus this is an example of the mitigation method in § 1.1, Annex 1.

Interference into 4 GHz DRRS by way of the third harmonic of a transportable air defense surveillance radar was obtained (Doc. 9A/66, which describes "Experience with an L-band defense air surveillance radar", 29 October 1992). This belongs to an IHAWK missile battery, and it is known as the perimeter acquisition radar. The power output stage consists of a crossed field amplifier power tube in conjunction with an external high-Q cavity. This oscillator design is known as a stabilotron. Thus it is inherently a stable generator providing about 1/2 MW at the fundamental frequency near 1.3 GHz. Because of a slight residual non-linearity, this high power microwave tube may generate at low level, a third harmonic which occurs in the 4 GHz fixed service band.

When this was found to be the source of interference, an agreement was reached with the agency responsible for the radar operation, to let the radar operate at a frequency such that the ensuing third harmonic would occur in the guardband of the 4 GHz frequency plan.

Since, as mentioned, the power tube operates in a stable manner, the third harmonic too is rather well defined. Thus when it was tuned to the guardband region, the DRRS interference ceased.

This then is an example of the mitigation method in § 1.2, Annex 1.

Interference into 4 GHz DRRS by way of the third harmonic of a high power civilian ASR was also studied (Doc. 9A/67, which describes "Experience with an L-band civilian air surveillance radar", 29 October 1992). This radar too operates near 1.3 GHz. It employs a solid state Master Oscillator and a final stage high power klystron Power Amplifier. This scheme is known as MOPA. The klystron pulsed output is of the order of 1.3 MW. This tube also has a slight residual nonlinearity, so it may generate a third harmonic.

In this case the agency operating the radar had obtained a fixed frequency assignment from the authority, so re-tuning was not possible.

Furthermore, the operating licence had a stipulation, that the operator would be fully responsible in any case of legitimate complaint about interference. Thus the operator was obliged to acquire at his expense, a suitable low-pass filter for installation in the radar.

This solved the interference problem, and the case illustrates the mitigation method in § 1.4, Annex 1, and also illustrates § 3, Annex 1.

4 Information received from Germany

A summary of information received from Germany is given below (Doc. 9A/90 – An example of suppression of spurious emissions of radar systems by means of filters, 29 March 1999).

4.1 Introduction

The limits for spurious emission due to radiolocation/radionavigation are defined in CEPT-ERC draft Recommendation 74-01, Annex 5, on spurious emissions by:

> "–30 dBm (e.i.r.p.), or –100 dBc, whatever is less stringent ... for fixed stations only".

This definition is based on the corresponding Category B limit in Recommendation ITU-R SM.329 and was introduced to protect radio services located in adjacent frequency bands, in particularly digital radio-relay links.

4.2 Spurious emissions by magnetrons

Transmitters using magnetrons as e.g. applied in high power radar systems generate significant spurious emissions. An example of a measured, unfiltered radar spectrum is given in Fig. 2.

The technical data of the corresponding weather radar system are:

Frequency range:	5.6-5.65 GHz
Antenna gain:	40 dBi
Power (PEP):	360 kW (= 126 dBm e.i.r.p.)
Pulse repetition:	0.8-2 µs
Pulse repetition:	250-1 200 Hz

In Fig. 2, at 6.477 GHz a spurious spike of –24.17 dBm or 49 dBc is marked.

4.3 Suppression of spurious emissions by using a filter

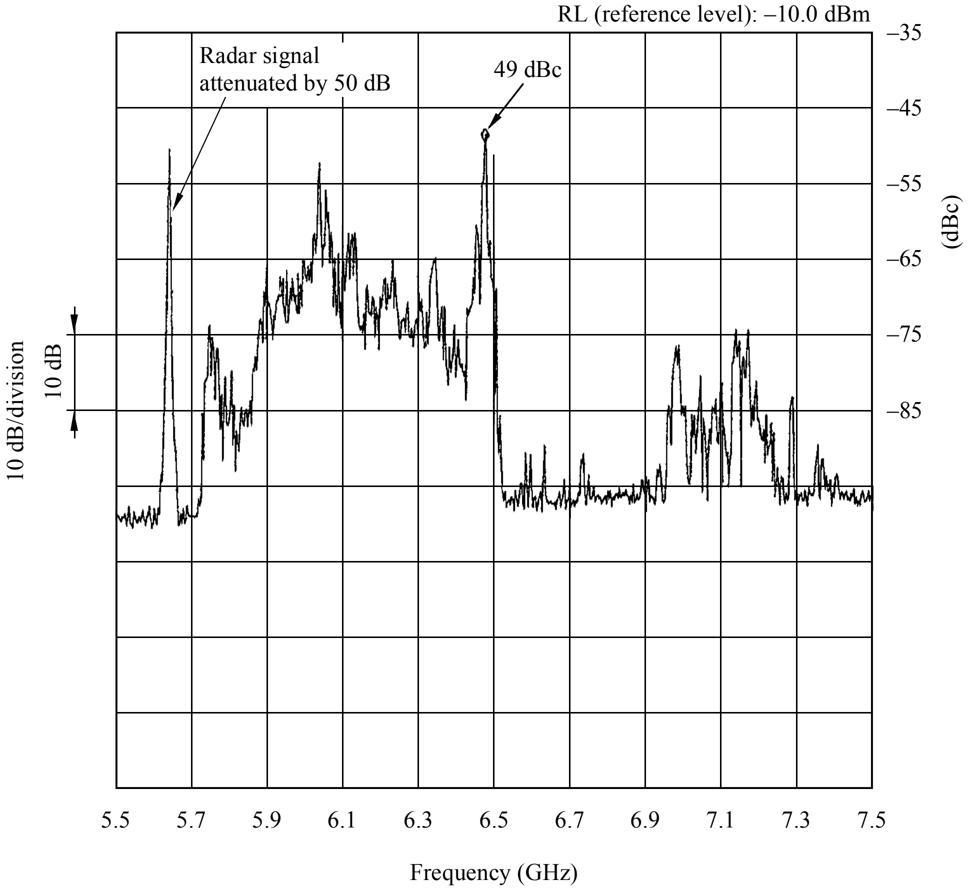
A waveguide filter consisting of a band-stop filter connected in series with a low-pass filter was provided. The filter was filled with compressed air only (to provide power handling capability).

The measured attenuation versus frequency is plotted in Fig. 3. Except for a small frequency range the desired attenuation is larger than 115 dB in the range of interest above 5.9 GHz.

The insertion loss of the combined filter in the pass band is about 0.7 dB.

FIGURE 2

Frequency spectrum of unfiltered magnetron radar system, radio measurement path length: 600 m



Resolution bandwidth:	2.0 MHz
Video bandwidth:	3.0 MHz
Sweep time:	50 ms
Count at 6.03470 GHz:	–24.17 dBm
Mark at 6.477 GHz:	–24.17 dBm
Attenuation:	0 dB

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If the stop-band-attenuation of the two overlapping filters is optimized, the spike at 6.477 GHz in Fig. 2 can be reduced by 115 dB due to the combined filter. This results in 164 dBc or –38 dBm in absolute scale referred to e.i.r.p.

In Fig. 4 the corresponding filtered radar spectrum is plotted.

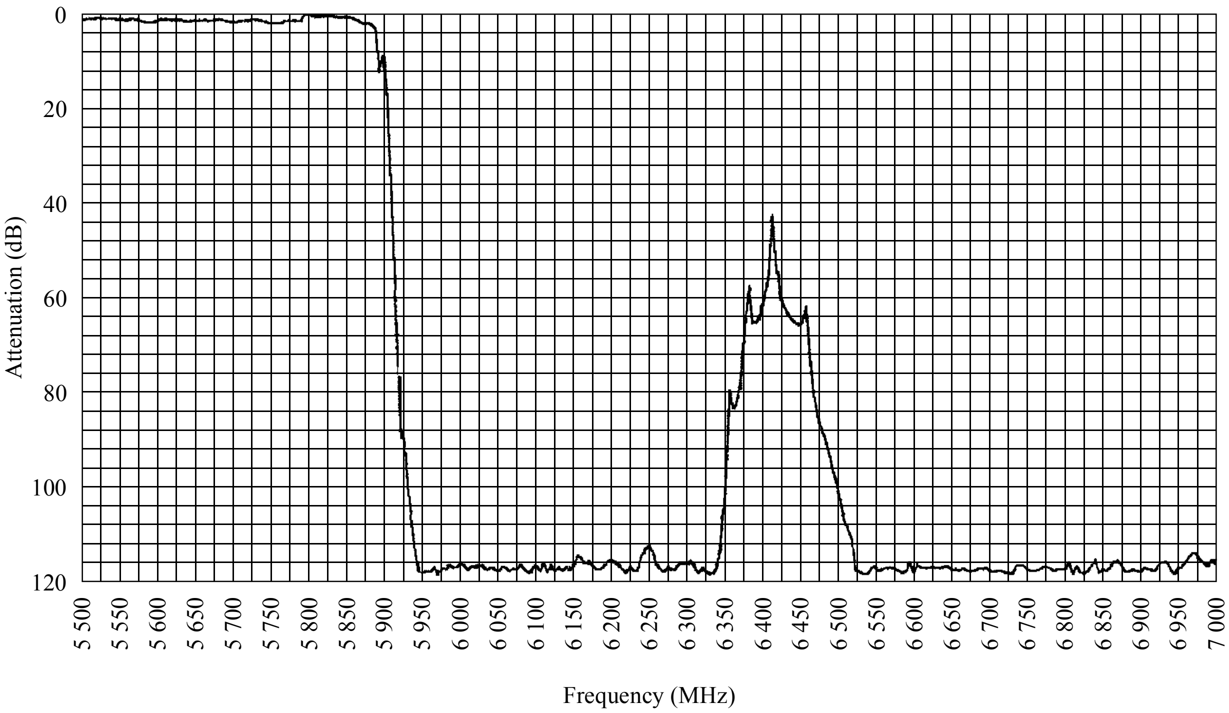
4.4 Conclusion

It was shown that it is feasible technically to achieve the limits –30 dBm (e.i.r.p.) or –100 dBc for fixed high power radar stations by using a relatively simple waveguide filter.

Also the expenditure is affordable (for example eight USD 8 000 for a single part production from one manufacturer).

FIGURE 3

Transfer function of the waveguide filter



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5 Information received from Sweden

In the late 1980s new radio-relay channels in the upper 6 GHz band were put into operation on a radio-relay link crossing Arlanda Airport near Stockholm (Doc. 9A/107 – Interference into a radio-relay link from radar spurious emissions, 12 April 1999).

At the airport a weather-radar was operating at 5.6 GHz. Spurious emissions from the radar reduced the effective fade margin of the hop to about 5 dB where bit errors started to occur.

The solution to this problem was to install a low-pass wave-guide filter to the radar transmitter, which eliminated the interference problem.

5.1 Radio-relay system and path data

Some technical data for the radio-relay system are given below:

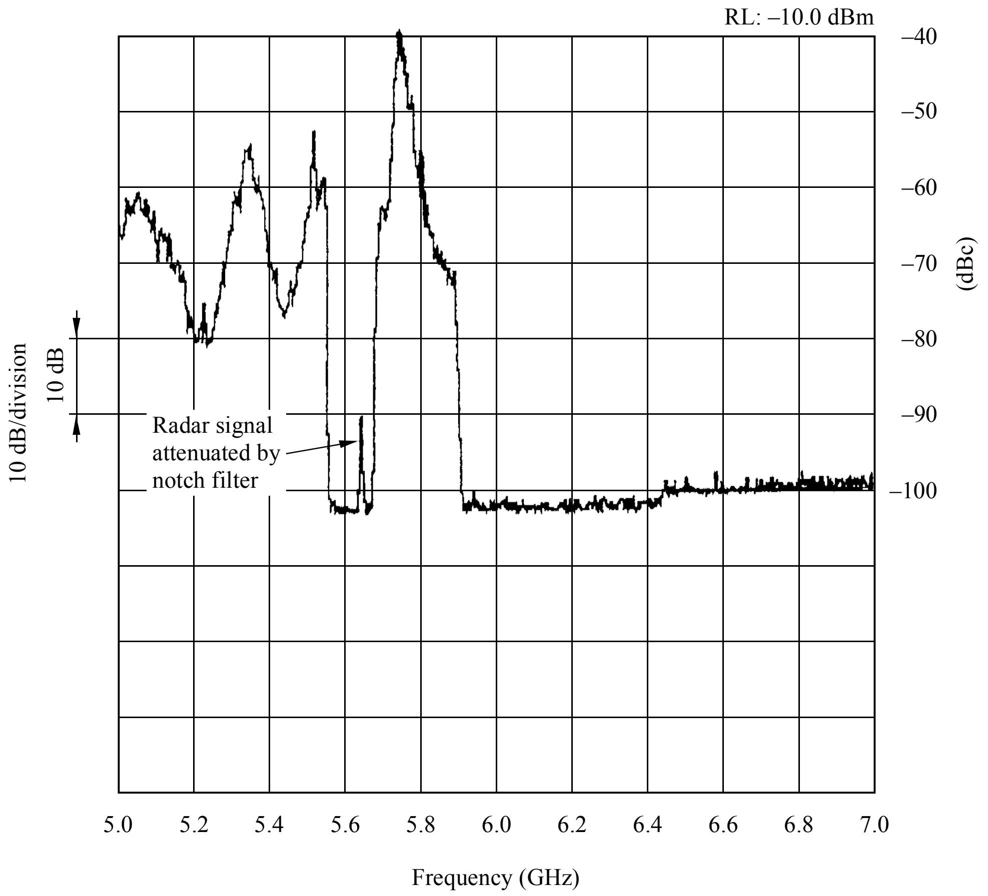
Receiver bandwidth:	40 MHz
Bit rate:	140 Mbit/s
Modulation:	16-QAM
Antennas:	3 m, dual-polarized
Hop length:	32 km
Nominal received level:	–35 dBm

The radar is situated in the middle of the hop, 900 m offset from the line between the two stations.

This gives a discrimination angle of 3.2° from boresight, which should give, for a 3 m antenna, some 20 dB of antenna pattern discrimination for the spurious emission from the radar.

FIGURE 4

Frequency spectrum of the filtered magnetron radar system, radio measurement path length: 838 m (far field)



Resolution bandwidth:	2.0 MHz
Video bandwidth:	3.0 MHz
Sweep time:	60 s
Count at 5.86477 GHz:	–57.50 dBm
Mark at 6.477 GHz:	–24.17 dBm
Attenuation:	0 dB

1097-04

5.2 Weather-radar system data

The technical data of the corresponding weather radar system:

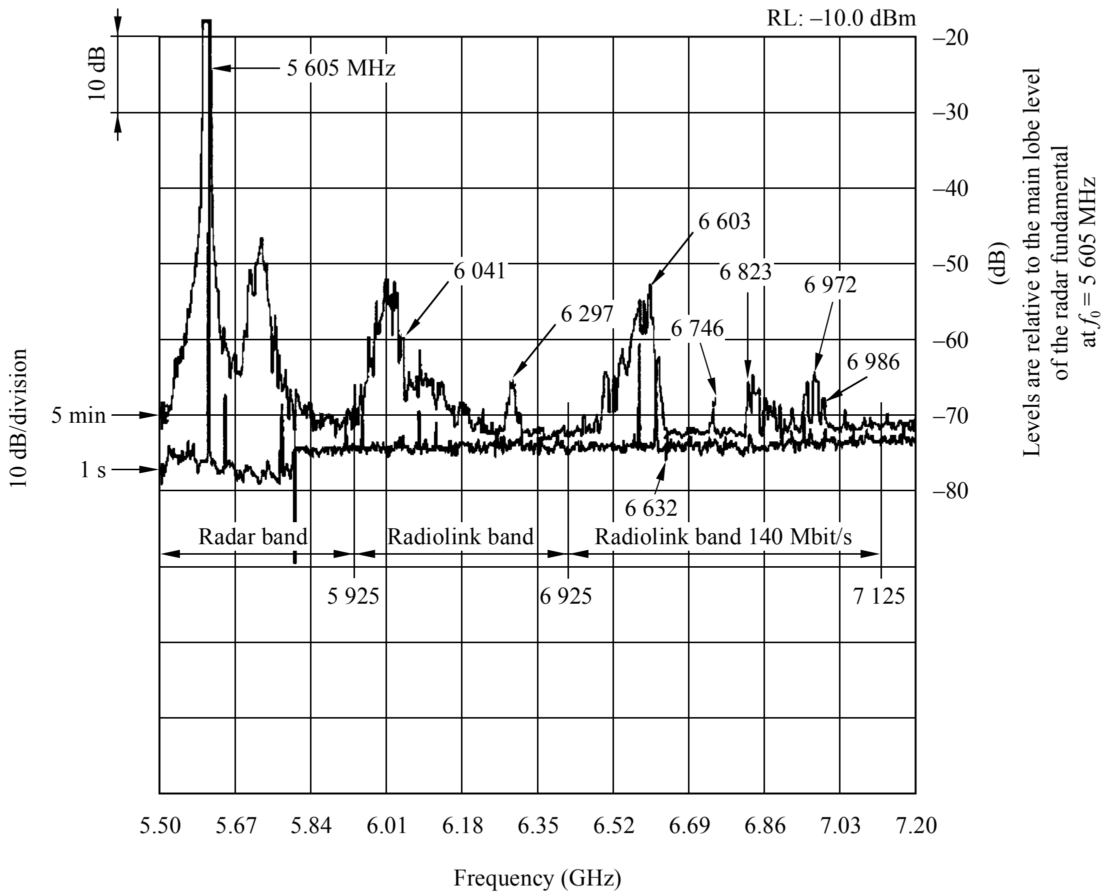
Frequency:	5.605 GHz
Transmitter peak power:	270 kW (⇒ 129 dBm e.i.r.p.)
Antenna gain:	44.8 dBi (pencil beam)
Polarization:	horizontal
Pulse length:	0.5 or 2 µs
Pulse repetition:	250, 900 or 1 200 Hz
Antenna rotation rate:	2 or 6 rpm
Elevation angle range:	0°-20°

5.3 Radar spurious emissions

Transmitters using magnetrons as applied in high power radar systems normally generate significant spurious emissions. An example of a measured unfiltered radar spectrum from the Arlanda radar is shown in Fig. 5. As can seen from the Figure there are spurious both in the lower and upper 6 GHz band, at a level approximately 50 dB below the peak power of the radar.

FIGURE 5

Frequency spectrum of unfiltered weather-radar system



Resolution bandwidth:	3.0 MHz
Video bandwidth:	3.0 MHz
Sweep time:	42.5 ms
Attenuation:	0 dB
HP analyser input attenuator:	0 dB
External pad:	6 dB
Front-end LNA:	20 dB gain

1097-05

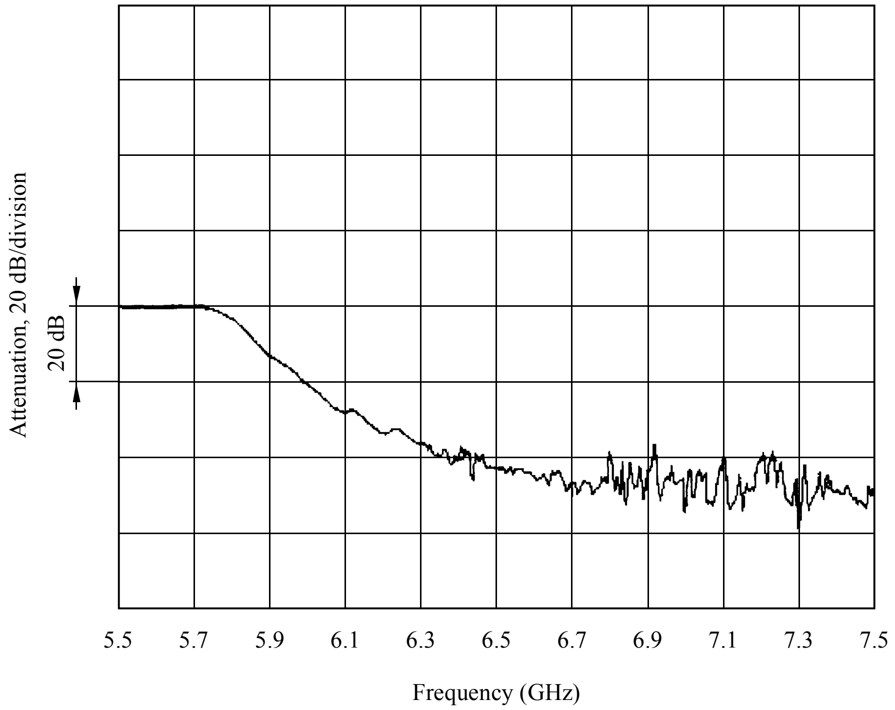
5.4 Suppression of spurious emissions by using a filter

In order to suppress spurious emissions from the radar in the upper 6 GHz band a wave-guide filter consisting of low-pass filter was installed. The filter attenuation above 6.4 GHz is ≥ 40 dB.

The measured attenuation versus frequency is plotted in Fig. 6.

FIGURE 6

Transfer function of the wave-guide filter



1097-06

5.5 Result from measurements

A lot of measurements were made in order to investigate the influence of radar spurious emissions on transmission performance for DRRSs. These measurements included signal level measurements, spectrum measurements and bit error measurements in different configurations. Some of these measurements which were made before the filter was installed in the radar are reported below.

5.6 BER versus received signal level

In Fig. 7 two BER curves as a function of received signal level are shown. The dashed curve characterizes the receiver under normal conditions without any interference. The solid line is measured on the hop by stepwise reducing the transmit power. The great difference between the two curves is due to spurious emission from the weather-radar. The flat fade margin for BER = 1×10^{-10} (when bit errors start to occur) is reduced from 28 dB to 5 dB.

When the radar operated at zero elevation angle and the wanted signal was 5 dB or more below the nominal value of –35 dBm, one or two ES occurred per revolution. ES did not occur when the radar pointed away more than ±1.5° from the radio-relay station or when the elevation angle exceeded 1.5°.

After inserting the low-pass filter in the radar the difference between the two curves was negligible.

5.7 Conclusion

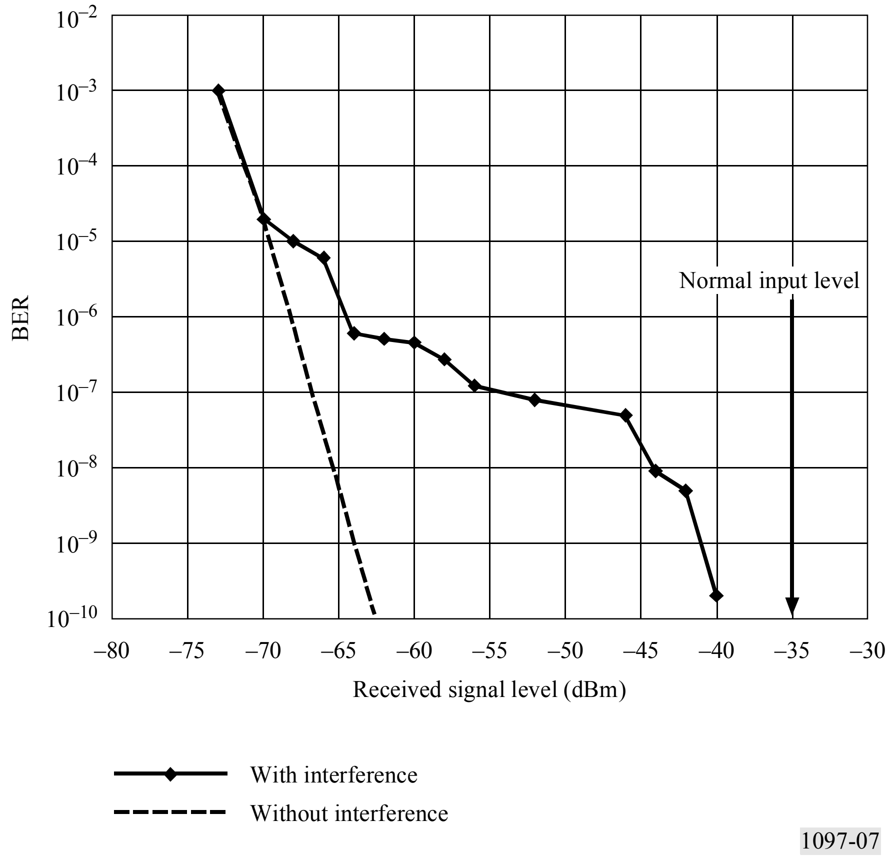
It has been shown that spurious emissions from radar systems can easily cause harmful interference in DRRSs.

By using relatively simple counter-measure techniques, such as low-pass wave-guide filters in the radar, the interference to radio-relay receivers can be reduce to negligible values.

This is also illustrated in § 1.4, Annex 1.

FIGURE 7

Measured BER versus received signal level



6 Information found in other published sources

Radar interference into radio-relay receivers is not a recent phenomenon. Presumably R.D. Campbell from AT&T who published an account of field experience in 1958 was the first to do so. Some years later, D.E. Cridlan, of the United Kingdom Post Office reported on a similar experience.

At that time the influence on the FDM analogue transmission was not so serious as the impact upon digital transmission in later years. The earliest account known is an internal Bell Telephone Laboratories (BTL) (United States of America)) memorandum from 1980, reporting on interference by a United States of America weather radar installation into 64-QAM radio carrying 135 Mbit/s plesiochronous digital hierarchy signals. This was mentioned subsequently in a fairly detailed report by the United States of America National Telecommunications and Information Agency (NTIA).

Shortly before this report was issued, evidence of radar interference encountered in Europe was presented at the 2nd European Conference on Radio Relays (ECRR) in 1989.

As a consequence, Radiocommunication Study Group 9 in 1991 adopted a new task, Question ITU-R 159/9.

Since then, operational evidence has been presented to Radiocommunication Working Party 9A and also at the 4th ECRR.

Information about spurious generation by radar high power output devices, especially magnetrons has been published periodically in technical journals and books ever since 1945, when this was first encountered.

Also, information about the design and performance of filters to be inserted into high power radar transmitters has been published in professional journals at least since 1965.

APPENDIX 2

TO ANNEX 1

Derivation of equations, and numerical examples

In this Appendix information conveyed in the various input documents received since 1991 is collated, and some numerical examples are provided to further illustrate the general guidance given in Annex 1.

1.1 Frequency-dependent rejection (FDR)

The FDR is the rejection provided by a receiver to an input signal as a result of the bandwidth of the receiver, and the frequency separation between the receiver and the transmitter. The FDR of radio-relay systems can be obtained from the spurious emission levels as measured at the source (radar) with 1 MHz resolution bandwidth plus a bandwidth correction factor.

The radio-relay systems in the 4 GHz and 6 GHz bands have a receiver intermediate frequency (IF) bandwidth of approximately 40 MHz and 30 MHz respectively. Since the measurements are often made with a spectrum analyser bandwidth of 1 MHz (standard spectrum analyser resolution bandwidth), a correction must be applied to the measured spurious emission levels to reflect the peak power received with a 40 MHz or 30 MHz system.

This bandwidth correction factor is 20 log (receiver IF bandwidth in MHz/1 MHz) for receiver IF bandwidths less than the reciprocal of the radar pulse rise/fall-times.

The nominal spurious emission levels given in Recommendation ITU-R M.1314, Annex 1, Table 2 may be used to determine the FDR of radio-relay systems to radar spurious emissions.

For example, for coupling from a radar using a coaxial magnetron (spurii: –60 to –75 dBc, according to Recommendation ITU-R M.1314), the FDR of a radio-relay system in the lower 6 GHz band (IF BW = 30 MHz) would be:

$$\begin{aligned} FDR &= 20 \log (30) - (60 \text{ to } 75) \quad \text{dBc} \\ &= +15 - (60 \text{ to } 75) \quad \text{dBc} \\ &= -45 \text{ to } -60 \quad \text{dBc} \end{aligned} \tag{1}$$

Thus for a radar with a 250 kW peak fundamental output power (+84 dBm), the equivalent in-band generated power ($= P_T - FDR$) would be: +24 to +39 dBm.

This is of the same magnitude or even larger than the output power generated by radio-relay transmitter output stages operating at 6 GHz.

1.2 Time waveform response

In order to determine the effect of spurious emissions from many radar stations on digital radio-relay system performance, it is necessary to characterize the pulse time waveform responses in the receiver IF passband. Measurements of the time waveforms indicate that the responses of radio-relay receivers to radar spurious emissions in the radio-relay bands may consist of two components:

- responses produced by the radar pulse modulation leading and trailing edges;
- responses produced by the radar output tube inherent noise during the pulse interval.

The spurious emissions occurring during the leading and trailing edges of the pulse are broadband in nature thus producing an impulse response in the radio-relay receiver IF output.

The width of these impulse responses are equal to the reciprocal of the receiver IF bandwidth. That is the leading and trailing edge impulse responses are approximately 25 ns and 33 ns for a 4 GHz and a lower 6 GHz radio-relay receiver, respectively.

Therefore, the leading and trailing edge impulse responses appear as short IF output pulses, approximately equal to a baud interval of a DRRS.

It should be noted that the leading and trailing edge impulse or trailing edge frequency responses may not necessarily be equal; they increase at 20 log (receiver IF bandwidth) for receiver IF bandwidths less than the reciprocal of the radar pulse rise/fall times.

The spurious emissions occurring during the entire pulse interval are noise-like in nature and are produced by the radar output tube.

The receiver amplitude responses to these noise-like emissions are also a function of the tuned frequency of the receiver and are more predominant at spurious modes of the output tube.

The amplitude of the non-coherent noise during the pulse interval increases at 10 log of the receiver IF bandwidth.

In summary, the radar spurious emissions produce two types of time waveform responses at a radio-relay receiver IF output:

– impulse responses due to the radar pulse modulation leading and/or trailing edge;

– non-coherent noise during the pulse interval.

Observed interference cases have shown that interference from radars to radio-relay receivers mainly occurs from pulses emitted from the antenna main beam of the radar.

A search radar antenna scanning continuously through 360° will briefly illuminate a radio-relay site during each scan interval. Thus the radio-relay antenna will intercept a number of radar pulses during each scan interval, either through its side lobes, or in the worst case by its main beam.

The total number of radar pulses intercepted per illumination pass may be estimated from:

$$N = \frac{1}{RPM} \cdot 60 \cdot \frac{BW}{360} \cdot PRF \tag{2}$$

where:

N: number of pulses intercepted per pass emanating from the main beam of the radar

RPM: antenna rotation rate (rpm)

BW: width of the main beam of radar (degrees)

PRF: pulse repetition rate (pps).

The total duration of the pulse train intercepted from the radar main beam during one pass is given by:

$$PTD = N \cdot PRI \tag{3}$$

where:

N: number of pulses intercepted per pass emanating from the main beam of the radar

PRI: pulse repetition interval, (s) = 1/*PRF*

According to typical ground-based radar characteristics, the number of pulses, *N*, intercepted per azimuth scan (pass) of radar antennas, range between 10 to 70 pulses.

The pulse train duration (exposure duration) is approximately 0.01 s to 0.12 s per pass.

The observed effects of pulsed emissions from radar into digital radio-relay facilities generally have fallen into the following four performance degradation categories:

– time-dependent increased background error ratios (dribble),

– BER momentarily above errored second ratio (ESR) threshold: initiating spurious failure reports and protection channel switching, or initiating service failure alarms on multiple channels,

– events of severely errored seconds (SES) on one or multiple channel,

– out-of-frame (OoF) events alarm indication signal (AIS) and loss of service (LoS).

Each of these four categories is discussed below. The first three categories are caused by coupling mechanism of spurious responses, the fourth by both front-end overload and spurious emissions.

1.3 Background or residual dribbling error ratios

Radar spurious emissions that appear as impulse responses or low level full duration pulses in the digital radio-relay receiving system can cause background or residual dribbling error ratios. Receiver impulse responses can be generated by the radar pulse leading and trailing edges.

The width of these impulse responses are equal to the reciprocal of the receiver IF bandwidth. For example, for the 4 GHz and 6 GHz common carrier bands, the typical values of the impulse response are 25 ns and 33 ns, respectively. These values are approximately equal to a baud interval of the DRRS.

For this specific case, the effect of radar leading and trailing edge impulse responses on system performance for a train of pulses emanating from the radar main beam may be estimated by the following equation:

$$BER = \frac{0.5\, p\, N\, m}{R\, t} \tag{4}$$

where:

BER: bit error ratio

p: number of leading/trailing edge impulses per radar pulse (number of baud intervals affected per pulse) (0, 1, or 2)

N: number of pulses intercepted from the main beam of the radar per pass

m: number of bits/Bd (6 for 64-QAM)

R: rate of baseband signals (140 Mbit/s)

t: period of time over which errors are calculated (0.1 s for 140 Mbit/s).

Sample calculation:

$$\text{BER resulting from a typical radar} = \frac{0.5 \times 2 \times 15 \times 6}{140 \times 10^6 \times 0.1} \cong 6.4 \times 10^{-6}$$

Thus, depending on the amplitude and number of impulse responses during the radar main beam pass, the BER may exceed 1×10^{-6} causing an alarm to be issued.

In addition, for this case of impulse response interference, the digital radio FEC may be able to correct errors occurring in a single baud interval.

1.4 Error ratios momentarily above the threshold

Error ratios momentarily above threshold (BER > 10^{-6}) can occur when radar spurious emissions produce a noise pulse width of full duration, above the radio-relay receiver *C*/*I* protection threshold. For this case, the duration of the operational surveillance radar pulses are typically in the order of 1-4 µs.

When the full pulse duration interference exceeds the required *C*/*I* protection threshold of the radio-relay receiver, it will defeat the error correction function and result in blocks of errors which occur for each incoming pulse.

When this situation occurs, a block of errors will typically range between 100 bits and 5 000 bits, depending on the duration of the pulse.

The estimate of the BER resulting from receiving a train of pulses each of full pulse width duration is given by:

$$BER = \frac{0.5\, N\left(PW / BI\right) m}{R\, t} \tag{5}$$

where:

BER: bit error ratio

N: number of pulses per radar main beam intercept

PW: radar pulse width (1 µs, 3 µs or 4 µs)

BI: baud interval (140 Mbit/s ≅ 43 ns)

m: number of bits per baud (6 for 64-QAM)

R: rate of baseband signals (140 Mbit/s)

t: period of time over which errors are calculated (0.1 s for 140 Mbit/s).

Sample calculation:

$$BER \text{ for typical radar: } \frac{0.5 \times 18 \ (4 \times 10^{-6}/43 \times 10^{-9}) \ 6}{140 \times 10^{6} \times 0.1} \cong 3.5 \times 10^{-4}$$

1.5 Severely error seconds (SES) events

SES in a digital radio-relay receiver can occur due to radar spurious emissions with high levels, or due to front-end overload.

For spurious emission coupling, SES also can occur as a result of multiple scattering reflections of a radar pulse. These multiple scattering reflections are usually due to reflections caused by terrain (hills and mountains) or buildings. The major effect of multiple scattering is to cause some stretching of the received pulse width, and additional received pulses when the difference in distance between the direct and reflected path exceeds the distance that the radio-relay signal can travel during one pulse width.

Thus multiple scattering propagation may add to the severity of the interference caused by pulsed radars. When multipath scattering occurs (pulse stretching) the BER may exceed 1×10^{-3}.

1.6 Out-of-frame (OoF) and loss of service (LoS)

If the response to a radar pulse at the receiver IF output exceeds five consecutive framing pulses (approximately 10 µs for 140 Mbit/s), system OoF will occur. OoF will result in the receiving system causing all downstream systems to reformat as well.

The reformat interval will last for tens of ms and inevitably cause a SES to all payloads carried by the radio channel. Also, error correction provides no advantage when OoF occurs.

OoF can occur by the coupling mechanisms of spurious responses or front-end over-load (receivers sharing a common pre-amplifier). In the case where front-end saturation causes OoF, the radar signal level at the receiver input will typically be greater than 2.5 dBm at the radar fundamental frequency, and the pulse duration greater than 4 µs. Due to the recovery time of the shared radio-relay low-noise preamplifier, an intercepted 4 µs radar pulse is stretched to greater than 10 µs.

Front-end overload has been observed in 6 GHz radio-relay systems from 5 GHz radars.

If LoS occurs in the microwave receiver, the total transmission outage time of the downstream facilities ranges between 2.5 s to 10 s.

This LoS event occurs when the microwave low-noise preamplifier becomes overloaded by the energy of the radar fundamental frequency, or when the radar antenna main beam is continuously pointed, for whatever reason, at the radio-relay station.

Typical radar signal levels greater than –2 dBm at the low-noise preamplifier input will cause front-end overload. When this occurs, the amplifier may be blocked for considerably more than the pulse duration and SES usually occur.

Prolonged events involving total LoS have only been seen very rarely.

This effect may be corrected by inserting a filter in the receiving waveguide ahead of the low-noise amplifier. Alternatively, individual low-noise amplifiers may be used following the branch network channel filters.

1.7 Far sidebands of the radar fundamental signal

The radar fundamental wave modulated by pulses has significant far sideband contents.

The derivation of spectral components resulting from the pulse modulation of an idealized RF transmitter power device is summarized below.

The modulation pulse shape is assumed to be trapezoidal, of total duration, D, and with rise and fall time, Δ. These pulses occur periodically with a repetition interval T_r.

The detailed steps of the derivation are omitted here. The resulting formulae are:

a) The entire amplitude spectrum is given by:

$$S(t) = K \cdot \cos(\omega t) \cdot f\,(t) \tag{6}$$

$$S(t) = \frac{K\ D}{T_r}\left[\cos\omega_0 t + \sum_{n=1}^{\infty}\frac{\sin\frac{\pi n D}{T_r}}{\frac{\pi n D}{T_r}}\cdot\frac{\sin\frac{\pi n \Delta}{T_r}}{\frac{\pi n \Delta}{T_r}}\cdot\sin\,(\omega_0 + n\,\omega_r)\,t\right.$$

$$\left. - \sum_{n=1}^{\infty}\frac{\sin\frac{\pi\, n\, D}{T_r}}{\frac{\pi\, n\, D}{T_r}}\cdot\frac{\sin\frac{\pi\, n\, \Delta}{T_r}}{\frac{\pi\, n\, \Delta}{T_r}}\cdot\sin\,(\omega_0 - n\,\omega_r)\,t\right] \tag{7}$$

where:

$\omega_0 = 2\,\pi f_0$, radar fundamental frequency

$\omega_r = \frac{2\pi}{T_r} = 2\,\pi f_r$, PRF

K: half-peak amplitude of each trapezoidal pulse.

b) The portion hereof which appears in the bandwidth, B, of a receiver (e.g. radio-relay) which is tuned to a channel centre frequency, f_m, will contain a spectral power given by:

$$I = \frac{K^2\ B\ f_r}{\left[\pi^2\ \Delta\,(f_m - f_0)^2\right]^2} \tag{8}$$

This is the out-of-band power from the transmitter interfering in the radio-relay receiver.

The interfering power may be expressed in familiar terms, (dBm):

$$I_{\text{dBm}} = K^2_{\text{dBm}} - 20\log\left[\pi^2\Delta(f_m - f_0)^2\right] + 10\log\,(B\ f_r) \tag{9}$$

Numerical example:

Consider an L-band (1.32 GHz) ASR with 3.5 MW pulsed output.

It may interfere into an FS receiver operating near 1.47 GHz carrying an 8 Mbit/s, QPSK signal fitting into the channel plan of Recommendation ITU-R F.1242, with 7 MHz channel spacing.

Assume the following detailed radar parameters:

K^2 = 3.5 MW peak ⇒ +95.4 dBm

Δ = 0.1 µs rise time

$f_m - f_0$: 150 MHz separation between radio-relay channel and radar fundamental

B: radio-relay channel bandwidth (≅ 7 MHz)

f_r: pulse repetition rate, 770 pps.

Using these parameters, the portion of the output power which will be generated near 1.47 GHz within 7 MHz bandwidth is computed to be about –13.4 dBm.

Assume further:

$G = 34.5$ dB, radar main beam gain.

Thus the e.i.r.p. will be ≅+21 dBm.

This gives an indication of the level of unwanted emission which may be encountered.

Note that the assumption was: An ideal 3.5 MW transmitter device (no unintentional emissions).

1.8 Consideration of the amount of radar range reduction caused by the introduction of spurious suppression filters

In past discussions it has been claimed that any modification of an existing radar design, i.e. the introduction of suppression filters in the transmission line between the output power tube and the antenna, would compromise the performance. In particular the Merchant Marine radar representatives claimed that this would have adverse effects on the safety at sea.

In the following, a brief analysis of the amount of performance reduction will be presented.

The point of departure is the radar range equation as commonly presented in textbooks [Barton, 1979]:

$$R^4 = \frac{P_t \cdot G^2 \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot k\,T_0 \cdot B \cdot \overline{NF_0} \cdot L_{tot}} \tag{10}$$

where:

R: maximum range for a given radar target size and a given probability of detection

P_t: radar transmitter peak power

G: radar antenna gain

λ: radar operating wavelength

σ: target equivalent cross section

$k\,T_0$: Boltzmann's constant and reference temperature

B: receiver equivalent noise bandwidth

NF_0: receiver noise figure

L_{tot}: system loss factor.

Consider a radar installation having no spurious filter yet.

With a given system loss factor, L_{tot}, it has a nominal range R_0.

Now let a filter be installed, with a measured one-way insertion loss, L_f.

This will contribute twice to the system loss factor, because it attenuates the emitted power, and once again attenuates the received echo signal before it enters the receiver.

One gets an increased system loss factor, L'_{tot}, the received power now is lower, and the result is a somewhat reduced radar range, R'.

Assuming everything else is kept constant, take the ratio on either side:

$$\left(\frac{R_0}{R'_0}\right)^4 = \frac{L'_{tot}}{L_{tot}}$$

$$\left(\frac{R_0}{R'_0}\right) = \sqrt[4]{\frac{L'_{tot}}{L_{tot}}}$$

Now use logarithmic form: $R_0\ (\text{dB}) - R'_0\ (\text{dB}) = 1/4\ [L'_{tot}\ (\text{dB}) - L_{tot}\ (\text{dB})]$

Since $L'_{tot}\ (\text{dB}) - L_{tot}\ (\text{dB})$ is just $2\,L_f\ (\text{dB})$, $R_0\ (\text{dB}) - R'_0\ (\text{dB}) = 1/4\left[2\,L_f\ (\text{dB})\right]$

The range reduction, ΔR, in logarithmic form is just one half of the filter insertion loss, L_f(dB).

Therefore it is easy to give some numerical examples in tabular form, assuming a range of likely values of L_f. Furthermore, the range reduction is expressed in per cent of the nominal R_0, and finally it may be converted into absolute terms, using a typical example of radar range.

L_f (dB)	0.2	0.3	0.4	0.5	0.7
ΔR (dB)	0.1	0.15	0.2	0.25	0.35
ΔR (%)	2.33	3.5	4.7	5.9	8.4

As an example, assume a Merchant Marine navigation radar, with a nominal range of R_0 = 10 nautical miles (≅ 18 km), for the detection of a small object (shipping lane marker, buoy).

The absolute reduction from R_0 ≅ 18 km according to the above will be:

L_f (dB)	0.2	0.3	0.4	0.5	0.7
ΔR (m)	≅ 419	≅ 630	≅ 846	≅ 1 062	≅ 1 512

It is a matter of opinion if these reductions in range for the detection of a small target at about 18 km range is reason for concern.

However, the above also brings out the general importance of keeping the insertion loss of the spurious suppression filters as low as possible.

Looking into the background information mentioned in Appendix 1, § 6, there is general consensus that high power suppression filters may be designed to have 0.15-0.5 dB of insertion loss at the fundamental radar operating frequency.

Also these values of insertion loss were mentioned in the contributions from Japan referred to in Appendix 1.

1.9 Bit interleave technique (BIT)

Figure 8 illustrates the principle and the configuration of the BIT. An FEC circuit using BIT disperses clustered bit errors by changing the order of baseband signal. In the interleaver at the modulator side, the random access memory (RAM) memorizes the data in one interleaving frame which contains F_I binary bits given by the following:

$$F_I = n\,d \tag{11}$$

where:

n: FEC block length

d: bit interleaving depth.

When the RAM outputs the data, the order of the signal is changed so that $(n - 1)$ bits can be inserted in between adjacent bits. In the de-interleaver at the demodulator side, the order is rearranged through the reverse procedure to the interleaver. Thus, burst errors due to the radar interference are transformed into random-wise errors which subsequently can be corrected by the FEC.

If the FEC can correct t bit errors in one block with n bits, contiguous dt bit burst errors will be corrected.

The bit interleaving depth, d, is designed to satisfy the following relation:

$$d = \frac{\tau f_c}{t} \tag{12}$$

where:

d: bit interleaving depth

τ: burst error length (radar pulse width) (s)

f_c: clock rate of the DRRS (Hz)

t: FEC ability (bits)

[*]: nearest integer rounded up from *.

For the BIT operation, the carrier synchronization has to be maintained during burst error period. Therefore the time constant of the carrier synchronization loop should be longer than burst error length τ. It should be noted that the BIT affects the throughput delay of the DRRS.

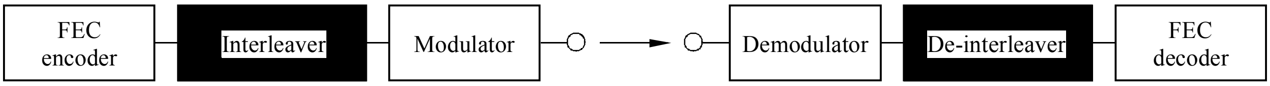
Throughput delay, D (s), expressed by the following should be designed to be shorter than the allowable delay time.

$$D = 2F_I/f_c = 2\,n\,d/f_c \tag{13}$$

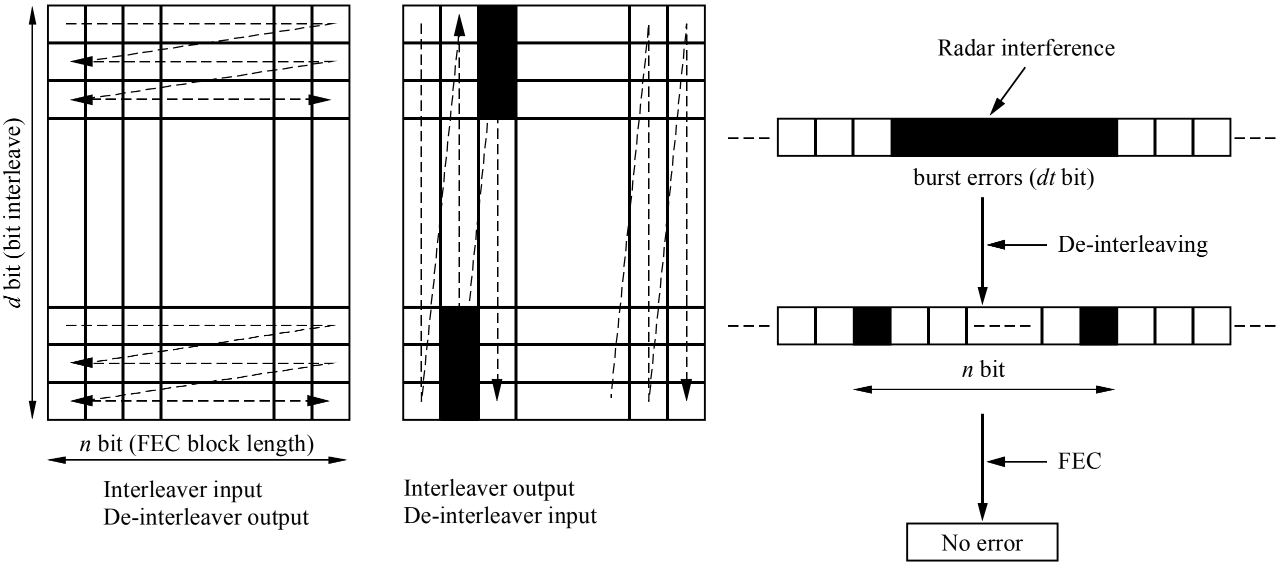
FIGURE 8

Principle and configuration of bit interleaving technique (BIT)

a) Configuration of BIT



b) Frame format and principle



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Provided that DRRS could allow the delay time, *D*, in formula (13), BIT will theoretically realize error free state. However, under an extremely large interference wave, unwanted emissions spread over the specified radar pulse width will cause additional interference. This effect requires further study.

BIT installation is easily realized by adding the baseband circuits to the modem, however, considering the above delay time effect, it may be practical to employ BIT only in hops exposed to continual radar interference.

1.10 Interference ramifications

The error performance objectives for DRRSs operating in conformance with ITU-T Recommendation G.826 are stated in Recommendation ITU-R F.1092 and in Recommendation ITU-R F.1189.

The performance objectives of a 2 500 km multihop system operating at 155 Mbit/s are provided below (for block allowance $B_L = 0$):

$$\text{ESR} = 0.16 \times 0.05 \times 8 \times 10\text{–}3 \text{ or } 20\ 736/\text{month}$$

$$\text{SESR} = 2 \times 10\text{–}3 \times 0.05 \times 1 \times 10\text{–}4 \text{ or } 259/\text{month}$$

$$\text{BBER} = 2 \times 10^{-4} \times 0.05 = 1 \times 10^{-5}$$

ESR: errored second ratio

SESR: severely errored second ratio

BBER: background block error ratio.

Assuming a 50 hop, 2 500 km radio-relay network (RRN), the monthly SES allowance per hop is 5.2.

1.11 Fixed radar interference

Fixed radar interference sources are expected to be persistent (operating around the clock) but fairly rare; therefore it will be assumed that they will affect a single hop in an RRN. This is probably a reasonable assumption since a single interfering radar signal would experience up to 34 dB additional path loss (assuming a hop length of 50 km) beyond the first exposed hop, before encountering another site of the system.

The end result is that one hop in the RRN will operate with a reduced fade margin due to the radar interference. Therefore the performance of that hop (being designed from propagation considerations) would be affected.

The salient question now is: How much degradation in performance can be tolerated on this single hop when the degradation is apportioned over the entire multihop network?

The derivation in § 1.2, of duration an intercepted pulse train, suggests that main-beam interference to a fixed service station could occur for percentages of time near 1%, or accumulated: approximately 14 min/day (24 h). Thus, it will not be appropriate to adopt a fixed service protection requirement based on short-term objectives (i.e. < 0.005%) where a significant portion of the fixed service hop fade margin would be lost for very short periods of time.

In addition, other primary services sharing the band with the fixed service should not cause a degradation in fixed service performance of more than 10% as required by Recommendation ITU-R F.1094.

This interference allowance equates to an I/N floor criterion at the fixed service receiver input of –13 dB for fixed service systems employing diversity. However, in the case of unwanted emissions from services in other bands, it is desirable that this I/N value be much less than –13 dB so as not to significantly affect fixed service band planning.

Recognizing that it may not always be practical to implement cost effectively, very high suppression of out-of-band emissions from fixed radars to achieve this level of I/N, it may be reasonable as a hardship to accept an intermediate level equivalent to a maximum 3 dB degradation in the fixed service hop fade margin.

A minimum protection requirement of 0 dB I/N is needed to ensure that the ESR performance objective of DRRs is not severely impacted. For fixed service systems employing diversity, the I/N should not exceed approximately –4 dB. However, to account for the variety of radar systems and considering that the number of systems is expected to be few, (hence their interference impacts on fixed service networks can be reasonably managed), a maximum I/N of 0 dB may be acceptable (see also Recommendation ITU-R F.1190). A 0 dB I/N will cause an increase by a factor of approximately four in the propagation SES ($BER > 10^{-5}$) performance. Over a 50 hop RRN this will translate to a 6% increase in the SES performance.

1.12 Mobile radar interference

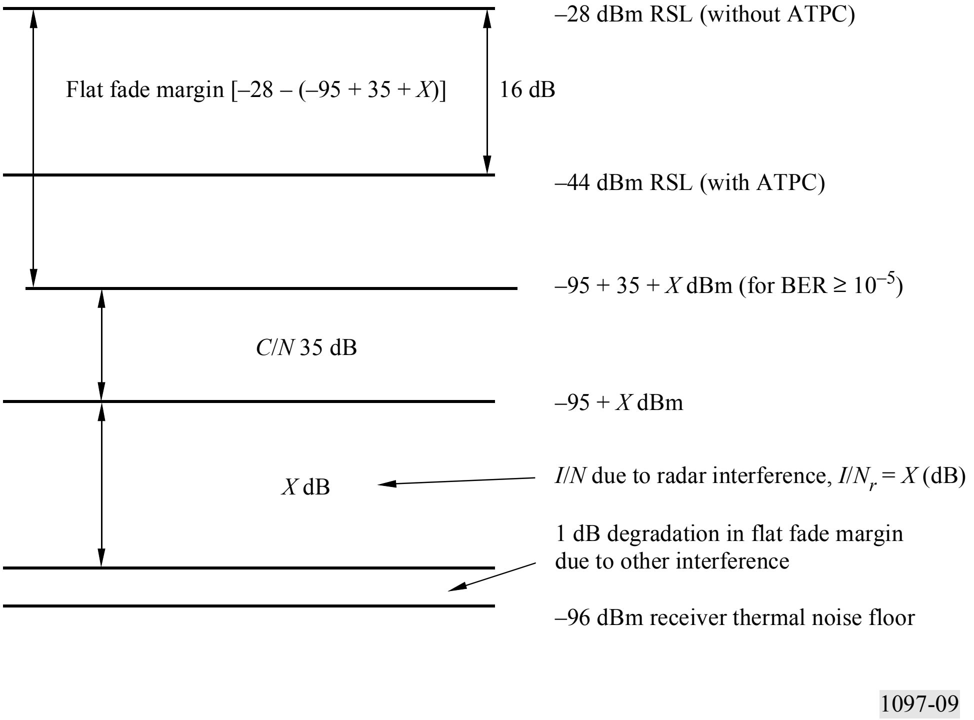
Examples of these interference sources are maritime mobile and land transportable (not operating on the move) systems. It is assumed, as it was above, that only one hop of a 2 500 km radio-relay system will be affected. These interference sources are difficult to control and, as a consequence, may have a severe impact on the victim digital radio system (generally causing SESs).

As an example, the impact of I/N upon a 4 GHz radio-relay system employing 512-QAM modulation is considered below:

Modulation:	512-QAM
Frequency:	4 GHz
IF bandwidth (B):	40 MHz
Automatic transmit-power control (ATPC) backoff:	16 dB
Transmit power:	37 dBm
Hop length (D):	46 km
Net path loss:	65 dB
Nominal receive signal level:	–28 dBm
Noise figure (F):	2 dB
Receiver front end noise:	–96 dBm (–114 + 10 log B (MHz) + F)
Path attenuation:	92.4 + 20 log (frequency (GHz)) + 20 log D (km)

FIGURE 9

Received signal level (RSL) diagram



The X (dB) I/N_r indicated must be less than 16 dB (see below) in order that radar interference does not cause an SES (BER > 10^{-5}) event, and subsequently causes violation of the ITU-T Recommendation G.826 performance requirements.

$$-95 + 35 + X < -44$$

$$X < 95 - 35 - 44$$

$$X < 16$$

An interference level just below receiver threshold will not have a direct impact on the SES performance; however, the ESR and BBER performance objectives will be impacted.

Studies have shown that the requirement for residual BER (RBER) of digital radio-relay systems corresponding to the ESR performance objectives is tighter than that based on the BBER performance objective.

As an example, required RBER corresponding to the ESR interference objectives is of the order of 1×10^{-13} per hop for a system operating at 155.52 Mbit/s. This indicates that approximately 1 to 2 orders of magnitude better RBER should be exhibited under ITU-T Recommendation G.826 than as was required by ITU-T Recommendation G.821.

To allow for this operating environment, a minimum of 6 dB margin is recommended which results in a maximum I/N of 10 dB for the case of mobile radar sources (see also Recommendation ITU-R F.1190).

2 Summary

In summary, radar system characteristics, radio-relay systems characteristics and environmental factors influence the effects of pulsed radar emissions on digital radio-relay receiver systems.

These effects are very complex to determine analytically.

Because of these complexities, every efforts should be made to ensure compatibility by maintaining a sufficient protection threshold (C/I) of the radio-relay receiver.

REFERENCES

BARTON, D. K. [1979] Radar systems analysis. *Artech House Inc.*