

RECOMMENDATION ITU-R F.1097-1

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

(Question ITU-R 159/9)

(1994-2000)

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.

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 occurring 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 spuri 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.

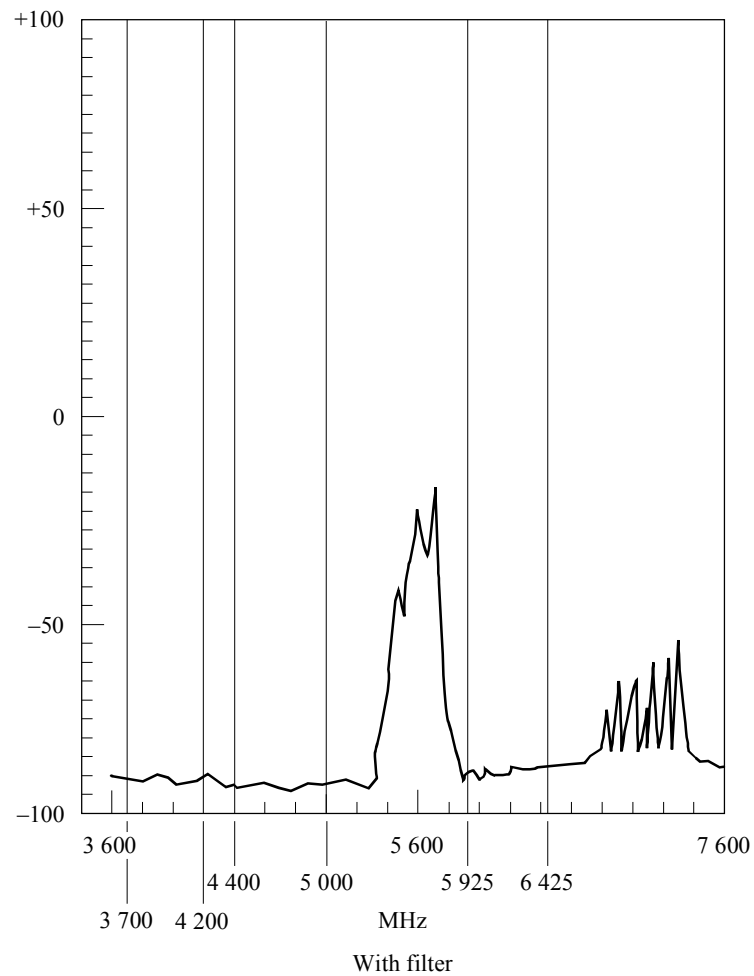
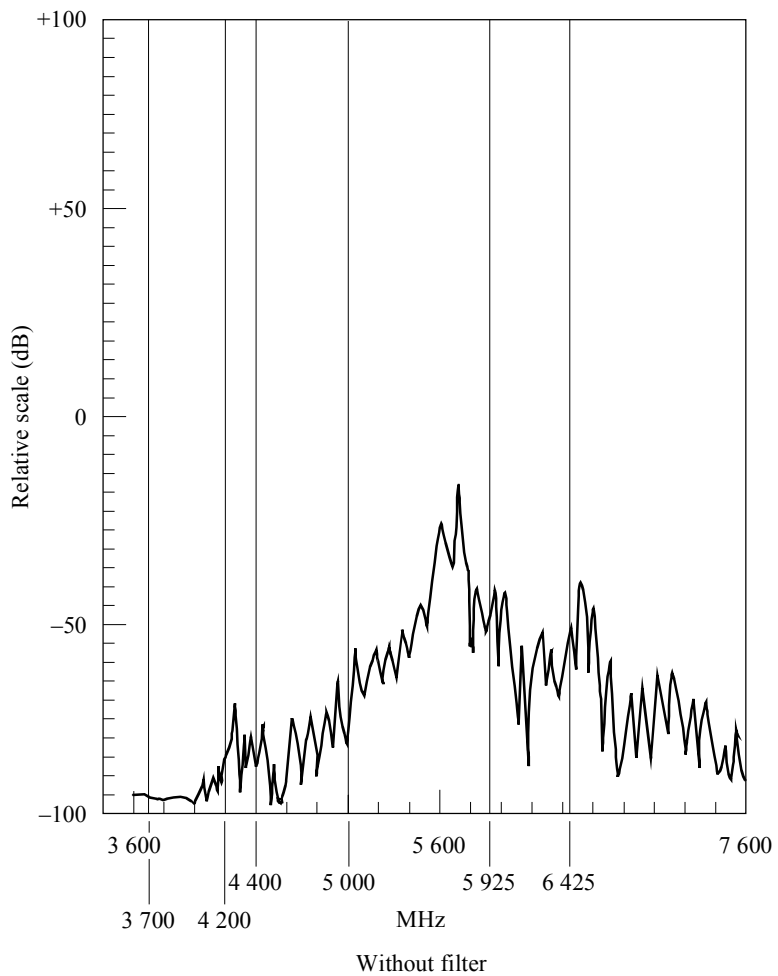
Receiver RF filters will not be effective against interference on, or near to, the radio-relay receiver channel frequencies.

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 spuri 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



1097-01

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 ≈ 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 (≤ 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 (μ s), 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 ($f_c \pm 10$ MHz)	$f_c = 3\,050$ MHz ($f_c \pm 25$ 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