RECOMMENDATION ITU-R M.1314*

# REDUCTION OF SPURIOUS EMISSIONS OF RADAR SYSTEMS OPERATING IN THE 3 GHz AND 5 GHz BANDS

(Question ITU-R 202/8)

(1997)

**Summary**

This Recommendation provides information on the design factors and spurious emission characteristics of some radar output devices to be taken into account when selecting such devices during the design of radars. It also recommends certain types of such devices that should be used when practicable to minimize non-harmonic and harmonic spurious emissions.

The ITU Radiocommunication Assembly,

*considering*

a) that the radio spectrum available for use by the radiodetermination service is limited;

b) that the radionavigation service is a safety service as specified by No. 953 (S4.10) of the Radio Regulations, and in addition that some other types of radar systems such as weather radars may perform safety-of-life functions;

c) that the necessary bandwidth of emissions from radar stations in the radiodetermination service is large in order to effectively perform their function;

d) that new emerging technology systems may use digital or other technologies that are more susceptible to interference from radars' spurious emissions due to their high peak envelope power;

e) that the ITU-R has been studying the question of efficient use of the radio spectrum by radar systems including the study of inherent spurious emission characteristics of various types of output devices;

f) that the ITU-R is also studying the effects of unwanted emissions from radar systems on systems in the fixed service;

g) that interference to fixed radio-relay stations and fixed-satellite earth stations has been attributed to spurious emissions from radar systems operating in the radionavigation, radiolocation and meteorological aids services around 3 GHz and 5 GHz;

h) that spurious emissions from radar systems may in some cases cause interference to systems in other radio services operating in the adjacent and harmonically related bands, especially when the technical and operational characteristics of the other radio service systems are changed in ways that make them more susceptible to interference;

j) that performance (bandwidth, coherency, etc.), expected lifetime, cost, weight, size and mechanical ruggedness are important factors that should be considered in the design-to-performance specifications of radiodetermination systems,

*recommends*

**1** that the information on radar design factors associated with radar output devices and spurious emission characteristics of radar output devices contained in Annex 1 be used in the selection of radar output devices;

**2** that, when practical, linear beam or solid state radar output devices should be used in radars to reduce non-harmonic radar spurious emission levels;

**3** that, when necessary and when possible, radar output filters should be used to reduce radar non-harmonic and harmonic spurious emissions.

* This Recommendation should be brought to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Maritime Radio Committee (CIRM), and the World Meteorological Organization (WMO) and Radiocommunication Study Groups 1 and 9.

ANNEX 1

# Reduction of spurious emissions of radar systems operating in the 3 GHz and 5 GHz bands

## 1 Introduction

In recent years there has been a significant increase in the number of reported cases of radar interference to fixed radio-relay stations operating around 4, 5 and 6 GHz, and fixed-satellite earth stations operating around 4 GHz. The increase in interference has been attributed to: high radar spurious emission levels, the trend of fixed and fixed-satellite services towards digital modulation techniques and a rapid growth in systems operating in bands adjacent to and in harmonic relationship with high power radar systems. This Annex is intended to provide information on inherent spurious emission characteristics of radar output devices, design factors associated with the selection of radar output devices and other methods to reduce radar spurious emissions.

## 2 Radar design factors

The function or mission of a radar largely determines the design of the radar and selection of the radar output device. Radar missions are widely varied (such as: navigation, weather observation, wind velocity determination, surveillance, imagery and mapping, terrain following, altimeter, etc.) and generally require unique performance specifications. These missions determine some parameters that are not under the control of the radar designer such as target cross section which directly impacts upon the required transmitter power, antenna gain and receiver sensitivity.

Therefore, the selection of radar output device affects the design of not only the transmitter, but also the radar receiver and antenna systems. Also, the design of multifunction radar systems can even further complicate the selection of a radar output device.

Other major design factors in selecting an output device include: energy efficiency (conversion of DC energy to RF), instantaneous bandwidth (available tuning bandwidth without adjustments), and pulse-to-pulse coherency (relative phase of each pulse which is important for Doppler processing), weight, size, mechanical ruggedness, life of the device and cost.

Table 1 shows the output device performance for major design factors considered in the design of radar systems. As seen in Table 1, there is a wide variation in the output device characteristics for the major design factors of peak power, instantaneous bandwidth and energy efficiency. It should be noted that the above design factors must be given primary consideration in the selection of the radar output device to ensure that the radar mission(s) can be achieved. Radar output device spurious emission characteristics are considered only after all mission objectives are satisfied.

## 3 Spurious emission characteristics of radar output devices

The levels of spurious emissions from radar transmitters are dependent upon the output device used in the radar transmitter. Knowledge of the inherent spurious emission characteristics of the various output devices used in radar transmitters is essential in promoting efficient use of the spectrum and minimizing interference to services operating in adjacent bands.

Table 2 lists the spurious emission characteristics (non-harmonic and harmonic) for output devices used in radar systems operating in the 3 GHz and 5 GHz bands. Radar systems using crossed-field output devices have inherent non-harmonic spurious emission levels that would require filtering if spurious emission limits are greater than about –60 dBc. Both linear-beam tubes and solid-state output devices have inherent non-harmonic spurious that are below –100 dBc. All radar output devices have harmonic spurious emissions in the range of –15 to –55 dBc, and thus require filtering to suppress the harmonic spurious emissions. For radars employing distributed output devices (phased arrays) filtering may not be practical.

TABLE 1

**Radar output device performance for major design factors considered for radar systems operating in the 3 GHz and 5 GHz bands**

| Output device | Peak output power range (kW) | Energy efficiency (%) | Instantaneous 1 dB bandwidth (% of carrier frequency) | Pulse-to-pulse coherency | Weight (kg) | Size | Mechanical ruggedness | Relative life expectancy[1] | Relative cost[2] |
|---|---|---|---|---|---|---|---|---|---|
| *Crossed-field*: | | | | | | | | | |
| Crossed-field amplifiers | 60-5 000 | 40-65 | 5-12 | Yes | 25-65 | | | 1.0 | |
| Magnetrons (unlocked) | 20-1 000 | 35-75 | [3] | No | 1-25 | Small | Good | 1.0 | Low |
| Magnetrons (locked) | 20-1 000 | 35-75 | [3] | Yes | 1-25 | | | 1.0 | |
| Coaxial magnetrons | 10-3 000 | 35-50 | [3] | No | 2-55 | | | 5.4 | |
| *Linear beam*: | | | | | | | | | |
| Coupled cavity travelling wave tube | 25-200 | 20-40 | 10-15 | Yes | 10-135 | | | 7.4 | High |
| Klystron | 20-10 000 | 30-50 | 1-12 | Yes | 25-270 | Large | Good | 13.5 | Medium |
| Twystron | 2 000-5 000 | 30-40 | 1-12 | Yes | 55-65 | | | 10.4 | High |
| *Solid state transistors (Parallel-class C modules)*: | | [5] | | | | | | | |
| Si bipolar | 10-90 | 20-30 | 10-30 | Yes | 0.5-2.5 per module | Small | Excellent | 15 | High |
| GaAs field effect transistor[4] | 0.5-5.0 | 10-25 | 10-30 | | | | | | |

[1] Life expectancy is normalized relative to a conventional magnetron.

[2] Depends on production volume.

[3] Although magnetrons do not have an instantaneous bandwidth capability, tuning frequency ranges up to 10% of the operating frequency can be achieved.

[4] Silicon (Si) bipolar modules are generally used below 3.5 GHz and Gallium Arsenide (GaAs) modules in the 5 GHz band.

[5] Depends on the number of modules combined in the output stage.

TABLE 2

**Radiodetermination pulsed output device spurious emission characteristics for systems in the 3 and 5 GHz bands**

| Output device | Spurious emission level | | | |
|---|---|---|---|---|
| | Non-harmonic (dBc) in 1 MHz | Harmonic [(1), (2)] (dBc) | | |
| | | 2nd | 3rd | 4th |
| *Crossed-field*: | | | | |
| Crossed-field amplifiers | –35 to –50[(4)] | –25 | –30 | –45 |
| Magnetrons (unlocked)[(3)] | –65 to –80[(4)] | –40 | –20 | –45 |
| Magnetrons (locked)[(3)] | –75 to –90[(4)] | –40 | –20 | –45 |
| Coaxial magnetrons[(3)] | –60 to –75[(4)] | –40 | –20 | –45 |
| *Linear beam*: | [(5)] | | | |
| Coupled cavity TWT | –105 to –115 | –20 | –25 | –35 |
| Klystron | –110 to –120 | –20 | –25 | –35 |
| Twystron | –105 to –115 | –20 | –25 | –35 |
| *Solid state transistors (Parallel-class C modules)*: | | | | |
| Si bipolar | –100 to –110 | –45 | –55 | –65 |
| GaAs FET | –100 to –110 | –35 | –45 | –55 |

(1) Harmonic spurious emission levels listed are nominal values. The range of harmonic spurious emissions is typically + 5 to –10 dB of the nominal values.

(2) Harmonic emission levels can be reduced below –100 dBc with a harmonic (low pass) filter.

(3) Magnetron output devices have inherent $\pi - 1$ modes which may be only 40 dB below the carrier. These modes are intermittent and of short duration occurring during the start-up of oscillations.

(4) Non-harmonic emissions levels in crossed-field devices can be reduced below –100 dBc with a waveguide bandpass filter. These filters generally have a few tenths of a dB in insertion loss.

(5) Linear beam output devices may have non-harmonic spurious emissions close to the carrier in the order of –80 to –90 dBc depending on the characteristics of the overall cavity selectivity.

## 4 Radar output filters

As shown in Table 2, the selection of the radar output device has a major effect on the requirement for filtering non-harmonic spurious emissions. However, as mentioned earlier, the selection of the radar output device can not be made entirely on spurious emission characteristics. Because of the inherently high levels of harmonic spurious emissions of all output devices, the suppression of harmonic spurious emissions by the use of harmonic (low pass) filters is generally performed when practical. To mitigate radar non-harmonic spurious emissions bands from some moderate and high-power radars in bands adjacent to radiodetermination, bandpass filters after the radar transmitter would also be required for some radar output devices. These would typically have to be separate from the harmonic filter, since the wide-stop-band characteristics of harmonic-suppression filters can not ordinarily be achieved along with the sharp cutoff characteristic of adjacent-band-suppression filters. The number of filters required can be much greater than two, however; in active-array radars, one or two filters would need to be interposed between each power-output device and the antenna element or subarray that it feeds. Tens of filters would be required altogether.

The monetary cost of these filters can be significant, since unconventional filter types, sometimes requiring pressurization or evacuation, are required to handle the high powers and maintain the desired suppression over a wide stopband. Use of such filters also imposes trade-offs in radar system performance. The insertion loss of transmitter harmonic filters and bandpass filters for radars in these bands ranges from 0.1 to 0.7 dB. If both harmonic and bandpass filters are required, the insertion loss would be roughly double. Due to the many variables in radar operation, the attendant decrement in detection and tracking performance usually goes unnoticed, but the fact is that even 0.2 dB represents a major loss of RF power (for example, 47 kW of peak power in the case of a 1 MW radar). The transmitter would need to be that much more powerful to recover the performance loss, since it must be assumed that more cost effective means of improving the performance would already have been exploited. A loss of 0.4 dB, for example, corresponds to a 2.3% reduction of detection range, which is inconsequential for most radars but significant for some. The voltage standing wave ratio of both types of filters is in the range of 1.1 to 1.3.

Also, power handling, size, and weight of the filter are factors to be considered in the feasibility of using an output filter on the radar, particularly in mobile radars. Size and weight can be overriding considerations in the case of mobile, active-array radars. Filtering bands close to the radar operating band requires steep selectivity skirts and hence high energy storage, which raises the risk of breakdown (or lowers the power-handling capacity) and can also introduce phase distortion in the passband – another major consideration for active-array radars. The higher the radar power, the more attenuation is needed to suppress spurious outputs to a given level, so the more sections the filters will need, and hence the higher their insertion loss, size, and weight will tend to be.

Transmitter filtering is best implemented during the original design of the radar. The addition of transmitter filters to existing radars has been achieved with minimal impact on system performance in many cases, but there have been other cases in which breakdown problems have occurred when a bandpass filter was added to suppress adjacent-band emissions.

## 5 Radar trends

Two major areas of advance driving the direction of the selection of radar output devices are:

– digital radar signal processing which is leading to rapid growth in Doppler radars which require high pulse-to-pulse coherency (linear beam and solid state output devices),

– the development of higher power solid-state transmitter devices (modular/bottled and distributed (phased array) configurations).

These trends will have an influence on reducing the spurious emission levels of the newer generation of radars.