

RECOMMENDATION ITU-R M.1314-1*

**Reduction of unwanted emissions of radar systems
operating above 400 MHz**

(Question ITU-R 202/8)

(1997-2005)

Scope

This Recommendation provides information on the design factors affecting unwanted emission characteristics of radar transmitters to be taken into account during the design of radars. It also recommends certain types of transmitter output devices that should be used when practicable to minimize unwanted 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 delineated in No. 4.10 of the Radio Regulations (RR), 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' unwanted 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;
- f) that unwanted emissions from radar systems may in some cases cause interference to systems in other radio services operating in the adjacent and harmonically related bands;
- g) that RR Appendix 3 specifies maximum permitted power levels for spurious or spurious domain emissions, and that Recommendation ITU-R SM.1541 specifies out-of-band limits for radiodetermination radars,

recommends

- 1** that the information on radar transmitter design factors affecting unwanted emission characteristics of radars contained in Annex 1 should be used to reduce unwanted emissions;
- 2** that, when practical, the best available output device technology should be used in radars to reduce non-harmonic radar spurious emission levels;

* 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.

3 that, when necessary and when possible, radar output filters should be used to reduce radar unwanted emissions.

Annex 1

Reduction of unwanted emissions of radar systems

1 Introduction

To maximize future efficiency of spectrum use, radar transmitters should be chosen, designed, and constructed such that the emission spectrum falls off as rapidly as possible, given the constraints on radar performance, size, cost, weight, reliability, maintainability, etc. The emission-spectrum skirt fall-off rate (out-of-band emission characteristics), and the emission floor level (spurious emissions) are determined by the transmitter hardware and architecture and by the transmitted waveform. Those influences are discussed below.

2 Radar design factors

The function or mission of a radar largely determines the design of the radar. 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 which directly impacts upon radar design factors such as: required transmitter power, transmitter waveform selection, transmitter output device selection, antenna gain, receiver sensitivity, range and azimuth resolution, and Doppler coverage. The judicious trade-off of radar design factors to improve emission spectrum control is key in enhancing compatibility between radar systems and other services.

3 Waveform selection and shaping

The choice of pulse waveform type and the way in which the waveform is shaped can also have important influences on spectrum control and hence on compatibility. Most radars, especially those using a single power oscillator or power amplifier, are constrained by considerations of energy efficiency and heat dissipation to use pulses having essentially constant-amplitude except during brief transitions between subpulses. That limits the types of waveforms that can be chosen. Even when that constraint applies, however, choices remain that can have a major effect on the emission spectrum.

Radar waveforms can be categorized, at the first level, into plain-pulse, or unmodulated-pulse, waveforms (having the emission designator of “P0”) and intra-pulse-modulated waveforms. Intra-pulse modulation usually serves as a means for implementing pulse compression, although an exception occurs in the case of waveforms used to drive frequency-steered arrays. Intra-pulse modulations can thus be divided further into the following subcategories:

- continuous FM, or “chirp” pulses;
- stepped-chirp pulses;

- stepped-frequency pulses used in frequency-steered radars;
- discretely-coded pulses.

From the standpoint of emission-spectrum control, a guiding principle in selecting and shaping a waveform is to remove discontinuities in as many derivatives of the waveform as possible, since that determines the ultimate spectrum fall-off slope, in dB/decade of frequency offset, that is achieved. The various pulse waveforms are therefore distinguished by the differences among their transitions of amplitude, phase, and frequency within the pulse.

All pulse waveforms, of course, contain rise and fall ramps on the overall envelope. Other things being equal, it is desirable to have gradual and smooth rise and fall ramps. However, other things are not always equal. In particular, pulses generated in crossed-field devices require quick rise ramps to avoid excitation of spurious oscillatory modes that would worsen the spectrum. When amplifiers other than crossed-field devices are used, smooth, gradual rise ramps are helpful to spectrum control when they can be implemented. Such implementation might still be difficult because power-amplifier dissipation is usually high when the amplifiers are not driven close to saturation; that can motivate use of fast rise and fall ramps even when spurious oscillations are not a concern.

Continuous frequency modulation, or chirp, waveforms with high pulse-compression ratio, or bandwidth-pulsewidth product, have very steep spectrum fall-off rates. This applies to both linear FM and nonlinear FM waveforms. The main contribution to undesired spectral components of these waveforms arise from the use of short rise ramps on the pulses.

Stepped-chirp waveforms have piecewise-constant frequencies that increment or decrement monotonically throughout the pulse. They can be considered as a subset of continuous-frequency-modulation chirp. However, stepped-chirp waveforms, as well as non-monotonic stepped-frequency waveforms that are used with frequency-steered antenna arrays, have poorer emission spectra than continuous-FM chirp waveforms have. This is a consequence of discontinuities in the waveform. It might be feasible to remove those discontinuities by implementing the stepped chirp in a way that maintains continuity of phase at the junctions between frequency steps. Even if that is so, however, discontinuities in the first derivative, which do not occur in true continuous-FM waveforms, will remain, so the spectrum will not be as good as that of a continuous-FM pulse with comparable pulse-compression ratio.

There are also certain polyphase-coded waveforms, of which the Frank polyphase-coded waveform is the prototype, that effectively approximate chirp waveforms; i.e., they approximate “continuously-coded” waveforms¹. However, these contain abrupt steps in phase, so their spectra do not fall-off nearly as steeply as those of continuous-FM chirp waveforms.

Herein, discretely-coded radar waveforms refer to those that do not resemble continuous-FM waveforms in any way. Since that excludes the polyphase codes, most discretely-coded radar waveforms can be subdivided into bi-phase-coded and frequency-coded types. Waveforms in either of these categories can use Barker codes and pseudo-random binary sequence codes.

In the absence of refinements, discretely phase-coded waveforms have abrupt transitions between constant-phase “chips”. (The same is true of Frank codes and other polyphase codes.) As a consequence, their spectra fall off at only 20 dB/decade. However, some options are available that can improve the spectra of phase-coded waveforms.

In principle, the spectrum of the RF drive (excitation) waveform can be made to fall-off arbitrarily fast by filtering the modulating waveforms or the modulated low-level drive waveforms (either IF or RF) themselves. However, those gains can be eroded in practice by spectral regrowth that occurs in both the transmitter power amplifier and in receivers in the environment. When premodulation

¹ Chirp waveforms are sometimes referred to as coded waveforms even though their “coding” is not discrete.