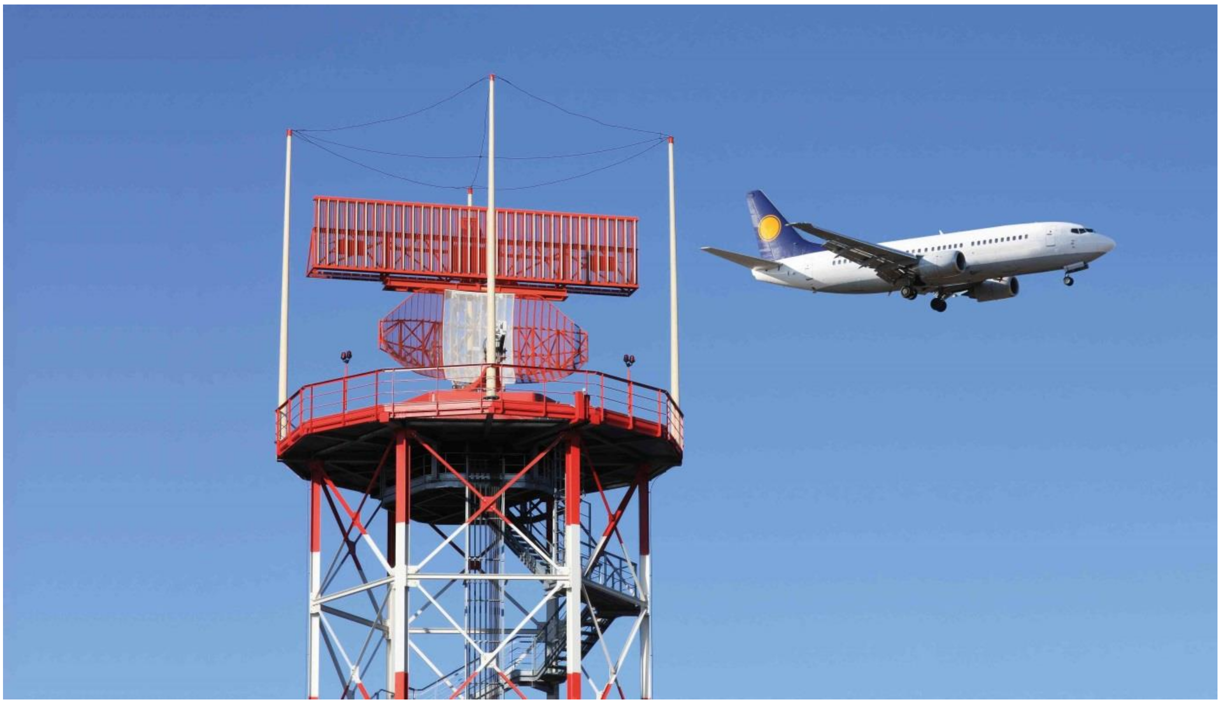
narda Safety Test Solutions® an L3 Communications Company

Technical Note 111

Standards-compliant test of non-ionizing electromagnetic radiation on radar equipment using broadband meters (for example NBM)



1 Introduction

The standards-compliant controlling for personal safety in electromagnetic fields under complex exposure situations requires special know-how in addition to appropriate measuring equipment. Compared with large-scale equipment such as a broadband antenna and a spectrum analyzer, the use of handy, powerful RF radiation meters with isotropic field probes represents a considerable simplification, quite apart from the technical advantages. For example, the electromagnetic field can be sampled independently of polarization and incident direction of the wave without influencing or distorting the field significantly. In some field probes the frequency response shaping according to the standards was integrated before the detector inside the probes. By using such so-called shaped probes, personal safety limit values can be checked without knowing the frequency of the radiation source. The radiation meter displays the exposure level, weighted in accordance with the standard, as a direct percentage of the limit value.

More explicit examination remains a necessity for two reasons in the case of pulsed signals with an extreme ratio between the peak value and RMS value. Such pulsed signals occur in practice in radar equipment. On the one hand, several personal safety standards require that the peak value for pulsed signals be also checked. On the other hand, exact knowledge of the measuring instrument characteristics is also necessary, since the response time of the device becomes a factor where short, pulsed signals are concerned, and the type of detection used can affect the measurement result. This technical Application Note is intended to give equipment users practical assistance in making measurements on radars and to answer some important questions.

2 Personal safety standards for high-frequency electromagnetic radiation

The relevant protection guides for personal safety in RF and microwave electromagnetic fields all sets reference levels as limits for electric and magnetic fields derived from the basic limits. These reference levels are frequency dependent. The possibility of a higher specific absorption in the region of the body resonance is thus taken into account by defining lower limit values for the electric and magnetic fields in this frequency range. All relevant standards dictate to measure the electric and magnetic field components without human presence [1]. Neither the electric nor the magnetic field strength may exceed the limit value.

The measuring equipment should display the RMS (root mean square) field strength value. Generally, the RMS value may be averaged over a period of up to 6 minutes, with the maximum permitted averaging time being slightly reduced above 10 GHz. The term "6 minute average" is used here to mean the average taken over the maximum permitted time. The time needed for a measurement can usually be reduced significantly, since most signals occurring in practice can be averaged over a few seconds to obtain a result comparable to the 6-minute average. If someone who is working in an electromagnetic field is to be warned of excessive exposure by a radiation monitor, it is quite likely that the warning will be too late if a 6-minute average is used.

Some safety standards make an exception to the evaluation of the RMS value in the case of pulsed signals. According to the ICNIRP guidelines [1], the peak value of the signal must also be checked. In the sense of the ICNIRP guideline, this is understood as being the maximum value of the RMS value averaged over the pulse width at high frequencies. In addition to the 6-minute average RMS value, this peak field strength value is not allowed to exceed 32 times the limit field strength value (corresponding to 1000 times the limit value for power flux density).

3 Measurements on radar equipment according to standards

Measurements on still-standing radar equipment

Determination of the RMS field strength value is a sufficient measurement for evaluation of maximum permissible exposure (MPE) in the case of many radar applications, e.g. when determining the radiation levels with stopping the radars rotation or searching for leakage in waveguide based high-power systems. Put another way, it is permissible to average the power flux density over several periods of the lowest frequency component of the signal, i.e. over several periods of the pulse repetition frequency.
Evaluations conforming to ICNIRP [1] also require a check of the peak value of the signal. The power flux density averaged over the pulse width is not allowed to exceed 1000 times the 6-minute average value. Consequently, the peak value becomes relevant at duty cycles below 1:1000, and the peak field strength value divided by 32 is not allowed to exceed the derived limit value. If the duty cycle is known, it is possible to calculate the peak value from the RMS value. To refer the result of a RMS measurement to the relevant limit value in ICNIRP, the factor

$$\frac{E_{peak}/32}{E_{rms}} = \sqrt{\frac{S_{peak}/1000}{S_{rms}}} = \frac{1}{\sqrt{Duty\ cycle \cdot 1000}} \qquad (1)$$

must be applied to the measured values of RMS field strength E_{rms} for duty cycles below 1:1000. The $duty\ cycle$ can be calculated from the pulse width PW and the pulse repetition frequency PRF

$$Duty\ cycle = PW \cdot PRF \qquad (2)$$

At duty cycles of greater than 1:1000, the RMS value is relevant because the peak value of the field strength divided by 32 is less than the RMS value.

Measurements on radars in scanning operation

When the radar is scanning, exposure to the pulsed signals only occurs for a fraction of the time. The received signals are pulsed twice. According to ICNIRP, the power flux density averaged over the pulse width is not allowed to exceed 1000 times the 6-minute average value. For practically all radar transmitter RF hazard measurements, this means that the peak value is relevant, even for duty cycles greater than 1:1000. Other standards make no clear statements regarding exposure to pulsed signals. For taking safety precautions, however, it is a good idea even in these instances to check the exposure and the resultant RMS value of the potential still standing radar.

4 Test equipment influence factors

Response time of instrumentation

The radiation meter display is varying when measuring scanning radars. The response time of the instrument is often such that the display cannot settle during the brief illumination of a rotating radar beam. The MAX or MAX HOLD function is useful for determining the maximum display value during scanning. The largest measured value since the function was activated or reset is displayed. It is a good idea in practice to wait a few sweeps of the beam when using the MAX [HOLD] function.

If the test equipment system integration time, which characterizes the inertia of the instrumentation, and the illumination time of the signal (time on target) are known, the RMS value of the potential still standing radar can be calculated from the value displayed in MAX [HOLD] mode. As long as the time on target is significantly greater than the system integration time, no additional display deviations are to be expected. If, on the other hand, the time on target is much less than the integration time, the instrument's inertia will strike the displayed value too low. A power flux density display correction can be derived from the ratio of the equivalent integration time to the equivalent time on target. The attenuation in dB that must be taken into account is given by

$$a = 5 \cdot \log_{10}\left(1 + \left(\frac{t_{\text{int}}}{t_{oT}}\right)^2\right) \quad \text{[dB]} \qquad (3)$$

In the far distance of rotating radar, the time on target t_{oT} can be estimated from the rotation time and the beam width of the antenna:

$$t_{oT} = \frac{\Delta\varphi}{360^o} \cdot t_{rot} \qquad (4)$$

In near-field situations, however, the illumination time t_{oT} is significantly greater since it is more determined by the antenna geometry (horizontal aperture width a_{hor}) and the distance r of observation:

$$t_{oT} = \frac{\Delta\varphi}{360^o} \cdot t_{rot} = \frac{\arcsin\left(\frac{a_{hor}}{2r}\right)}{180^o} \cdot t_{rot} \qquad (5)$$

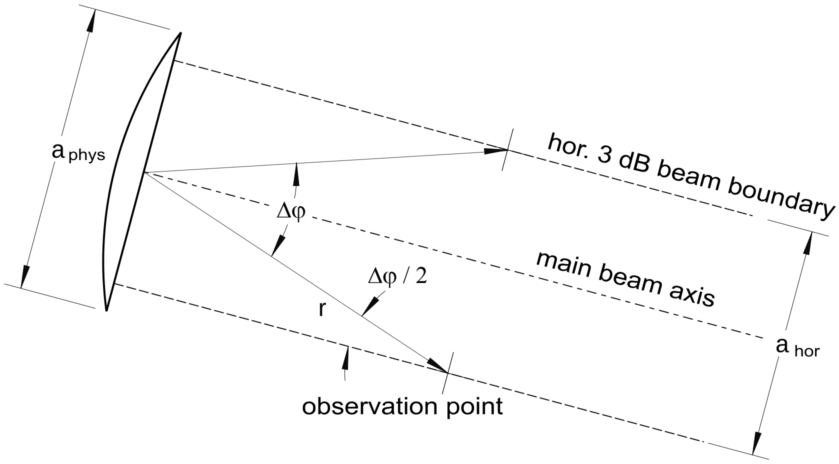


Figure 1: *Near-field observation*

Where

- t_{int} pulse integration time of the measuring instrument
- t_{oT} time on target (illumination time) of signal
- t_{rot} time per revolution of the radar
- $\Delta\varphi$ radiation angle of antenna (3 dB beam width)
- a_{hor} horizontal aperture width
- r observation distance.

An equal-area rectangle of power flux density is relevant here for the radiation angle $\Delta\varphi$; the half-value width of the beam (-3 dB) can be used as a good approximation.

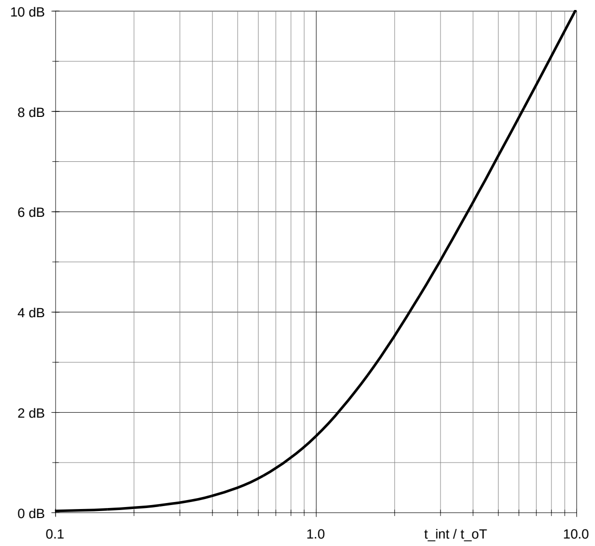


Figure 2: *Attenuation of rotating radar signals due to the response time of the test equipment*

Thermocouple probes

Since these probes employ heat-based detectors and the thermoelectric potential difference between two dissimilar metals is evaluated, thermocouples work as true averaging detectors. The thermocouple yields the average of the power level absorbed by the probe. For this reason, thermocouple probes give a practical true RMS value regardless of signal waveform, even for extremely pulsed RF signals. No correction is therefore necessary for RMS values measured on non-scanning radar equipment.

When using a NBM shaped probe, it is important to know that they include both diode and thermocouple sensors. However, in the frequency range above 1.5 GHz, which is the relevant range for radar applications, the probe behaves like a thermocouple probe.

The dynamic range of thermocouple probes is limited to about 30 dB to 40 dB. When the sensitivity is insufficient at low electric field strengths, field probes with diode detectors can be used, as these generally have higher sensitivity.

Field probes with diode detectors

Compared with thermocouple probes, E-field probes with detector diodes deviate from the ideal RMS meter because the diode rectifier only gives a good approximation to the RMS value for small signal levels. The diode detector no longer behaves as an ideal RMS rectifier at high levels, and the waveform of the field source affects the measurement result. The behavior of such detectors in the presence of multi-frequency or modulated signals is described in detail in [1], for example. The shaped probes (RadMan Personal Monitor) have specially designed sensors to ensure that the detector diodes operate in the square-range region within the whole dynamic range of interest. This keeps the deviations from the RMS value negligible for many types of signals, e.g. in broadcasting and telecommunications.

However, significant deviations from the true RMS value can be expected at high field strengths with pulsed signals having high crest factors, i.e. an extreme relationship between the peak value and the RMS value. Values above or below the RMS value may be displayed, depending on the pulse repetition frequency. Extensive measurements with numerous radar signal parameters were carried out to qualify various E-field probes. The raster of pulse repetition frequencies and duty cycles was chosen to cover the practically relevant radar applications. The results for three different duty cycles between 1:316 and 1:3162 and pulse repetition frequencies (PRF) between 316 Hz and 3.16 kHz are summarized in Annex 1.

5 Selection guide for field probes

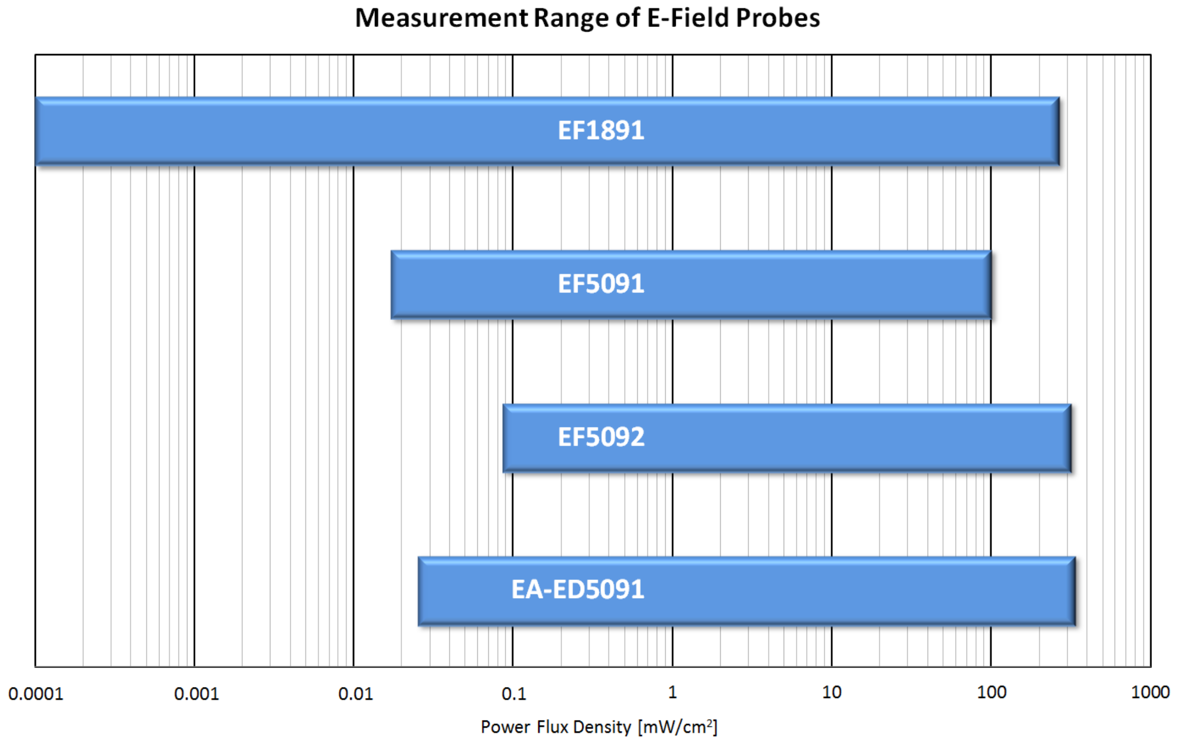


Figure 3: Dynamic ranges of thermocouple and diode probes

Figure 3 gives an overview of the dynamic ranges of various E-field probes for the frequency range above 2 GHz. For medium to high levels of RF exposure thermocouple probes have the advantage of providing an ideal RMS measurement. Probe model EF5092 offers a dynamic range of 35 dB and the model EF5091 extents measurement range up to 37 dB.

The equivalent time on target for a typical scanning radar (rotation time 5 s, radiation angle 1.8°) is around 25 ms. This gives a correction due to the measuring system inertia of 10.7 dB and 11.5 dB when taken with the equivalent system integration time for the radiation meters NBM-520 or NBM-550 in combination with a thermocouple probe (EF5091, EF5091: 295 ms; EA-ED5091: 350 ms). This is already a considerable attenuation, which restricts measurement sensitivity and dynamic range. The probes should be selected to match the application, keeping in mind the reduced dynamic range and the maximum permissible peak overload during the pulse period.
The NBM field strength meters have a pulse integration time of 270 ms, regardless of the probe used. When used together with the sensitive EF1891 diode probe with flat frequency response, the high sensitivity results in advantages compared with thermocouple probes. Here too, correction of the RMS characteristic can be ignored at low field strengths. At higher field strengths, deviations from true RMS behavior are to be expected, with a tendency to underestimate signals with high crest factors. The curves shown in annex 1 (figures A1 to A3) can be used to correct the measured values. Correction values for very high field strengths are not available, since the detector diodes are operating close to their physical limits.

The NBM shaped E-field probes EA… ED5091 allow the derived personal safety limits to be checked without the signal frequency of the radiation source being known. Even multi-frequency signals are correctly weighted. The special design ensures that deviations from the true RMS value remain relatively small, even for pulsed RF signals. The personal radiation monitors RadMan (ESM-20) and RadMan XT (ESM-30) can be used to check electric and magnetic field strengths simultaneously in the frequency range from 1 MHz to 40 GHz (H field up to 1 GHz). In these instruments two isotropic, shaped sensors are integrated. The exact RMS response for a fixed radar is shown for two of the available standards in figures A7 to A12. The deviations from the RMS value are small across the board. At small duty cycles, the tendency is to slightly overestimate the RMS value. However, this is considered desirable for ICNIRP.

Compared with the shaped E-field probes for the NBM-500 series of instruments, the RadMan monitor has the additional advantage of a fast signal processing (integration time 30 ms for the “fast response” models). There is thus no noticeable device inertia even when measuring scanning radars. In practice, then, no correction for measurement deviation is required for either still standing or rotating radars. This is a particular advantage, since the RadMan monitor is also intended for warning untrained personnel of hazardous RF exposure levels.

6 Summary

This Application Note shows how measurements that conform to the relevant standards are performed on radar equipment. The response of the NBM radiation meters with isotropic probes and the RadMan monitor to the kind of pulsed signals that occur in radar applications is described. The measurement deviations cannot be ignored in many cases, but it is possible to take them into account if the radar parameters are known or can be roughly estimated. Various advantages are offered by the use of thermocouple probes as true RMS detectors, sensitive probes with diode detectors, or shaped probes, depending on the application. The RadMan monitor can even provide a correct assessment, over a range of a few dB, of RF exposure in common radar installations, including in scanning radars, without the need to correct for measurement deviations.

References

[1] International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz). Health Physics, Vol. 74, No.4, pp. 494-522, April 1998.

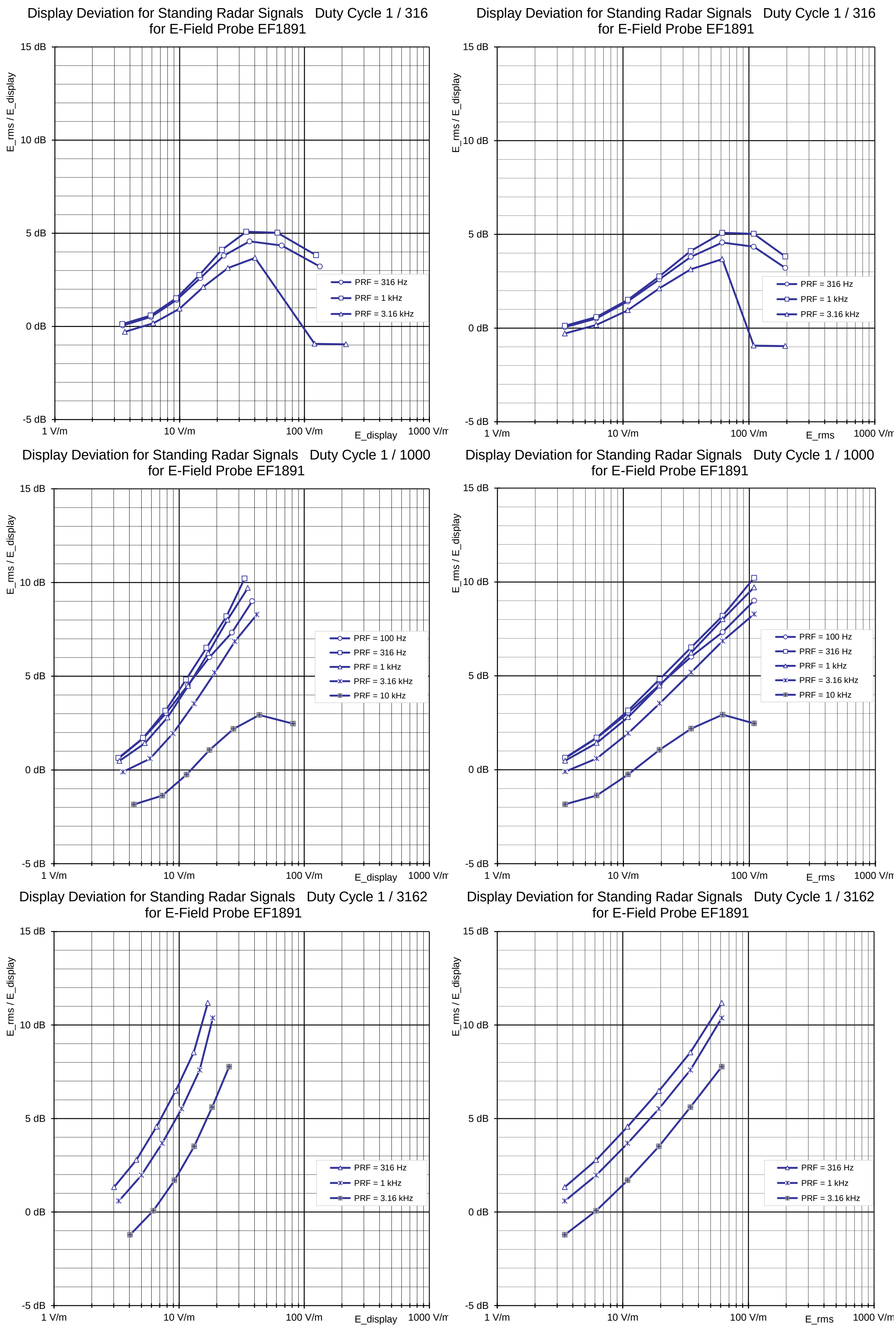
[2] Datasheets NBM-520, NBM-550 and Field-Probes EF1891, EF5091, EF5092, EA-ED5091, Narda Safety Test Solutions, 2016.

Annex 1: RMS response of E-field probes with diode detectors to pulsed RF signals

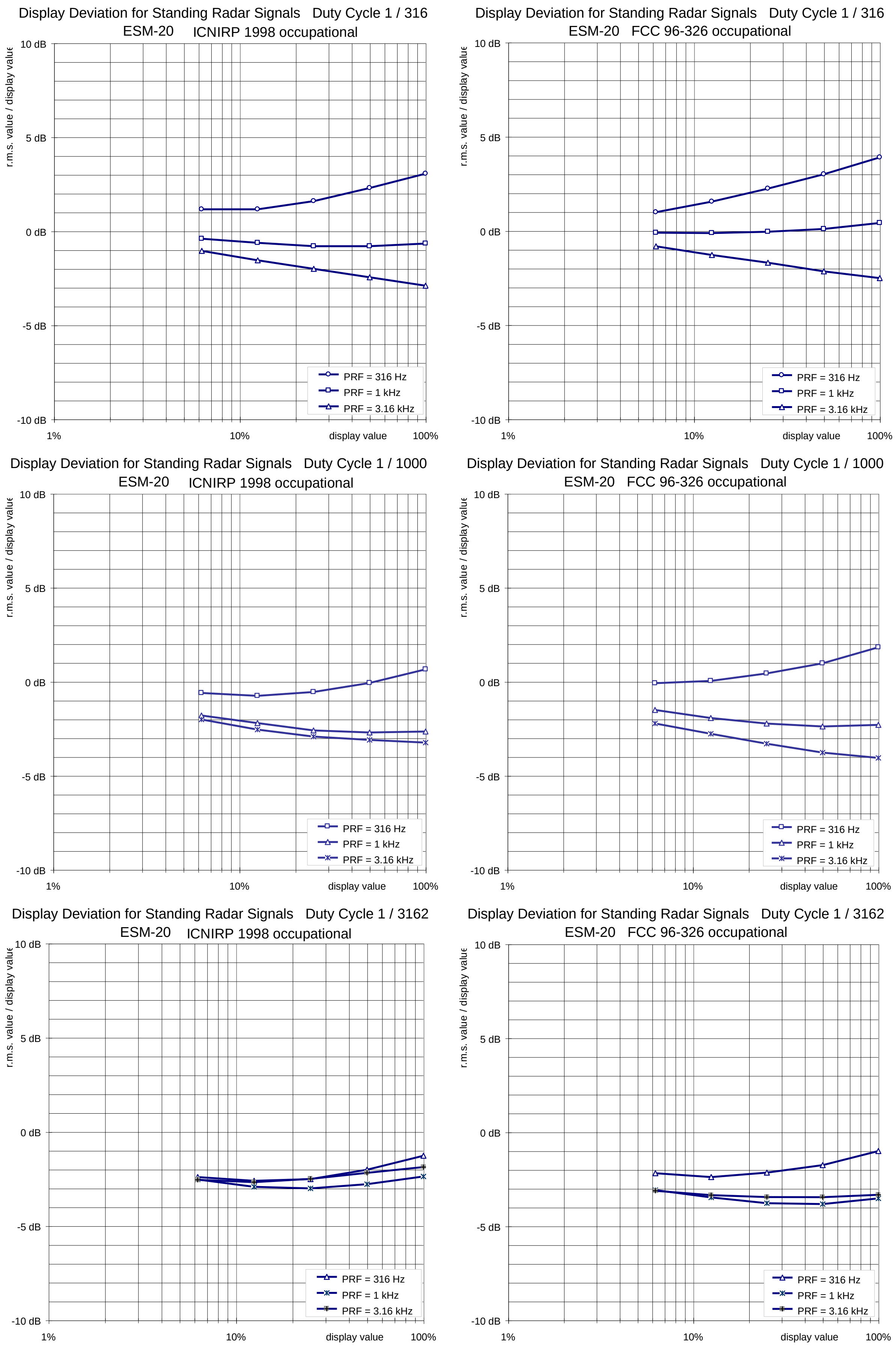
Measuring various diode detector E-field probes and determining the deviation from the RMS value for pulsed RF signals derived the characteristics. The results are shown as graphs on the following pages for three different duty cycles between 1:316 and 1:3162 and pulse repetition frequencies (PRF) between 316 Hz and 3.16 kHz.
For ease of evaluation, adjacent diagrams show the same information to some extent. The curves are plotted against different x-axes. The left-hand diagrams have the display value as the x-axis, allowing correction of the indicated measurement value. The right-hand diagrams, in contrast, show the RMS response versus the RMS value (E_rms) or the relative limit value (1 % to 1000 % referred to the power flux density). The y-axis in all diagrams is the ratio of the RMS value to the display value in decibels. The logarithmic scale is interpreted as follows: A positive value of +3.01 dB means that the display value (in %) referred to the power flux density is less than the RMS value by a factor of 2. The displayed field strength measurement value would therefore be less than the effective field strength by a factor of root 2. Conversely, a negative y value of –3.01 dB indicates overestimation of the power flux density by a factor of 2.
The curves can be applied practically for the ranges shown in the table below, which cover all relevant radar applications. The accuracy of the correction values is normally better than 2 dB. Interpolation between curves can be used to estimate closer values.

Parameter		Valid range
Tastverhältnis	$Duty\ cycle = 1/316$	1 / 562 bis 1 / 177
	$Duty\ cycle = 1/1000$	1 / 1778 bis 1/562
	$Duty\ cycle = 1/3162$	1 / 5620 bis 1 / 1778
Pulswiederholfrequenz	$PRF = 316\,\text{Hz}$	177 Hz bis 562 Hz
	$PRF = 1\,\text{kHz}$	562 Hz bis 1,78 kHz
	$PRF = 3{,}16\,\text{kHz}$	1,77 kHz bis 5,62 kHz

Table A1 Valid ranges of parameters

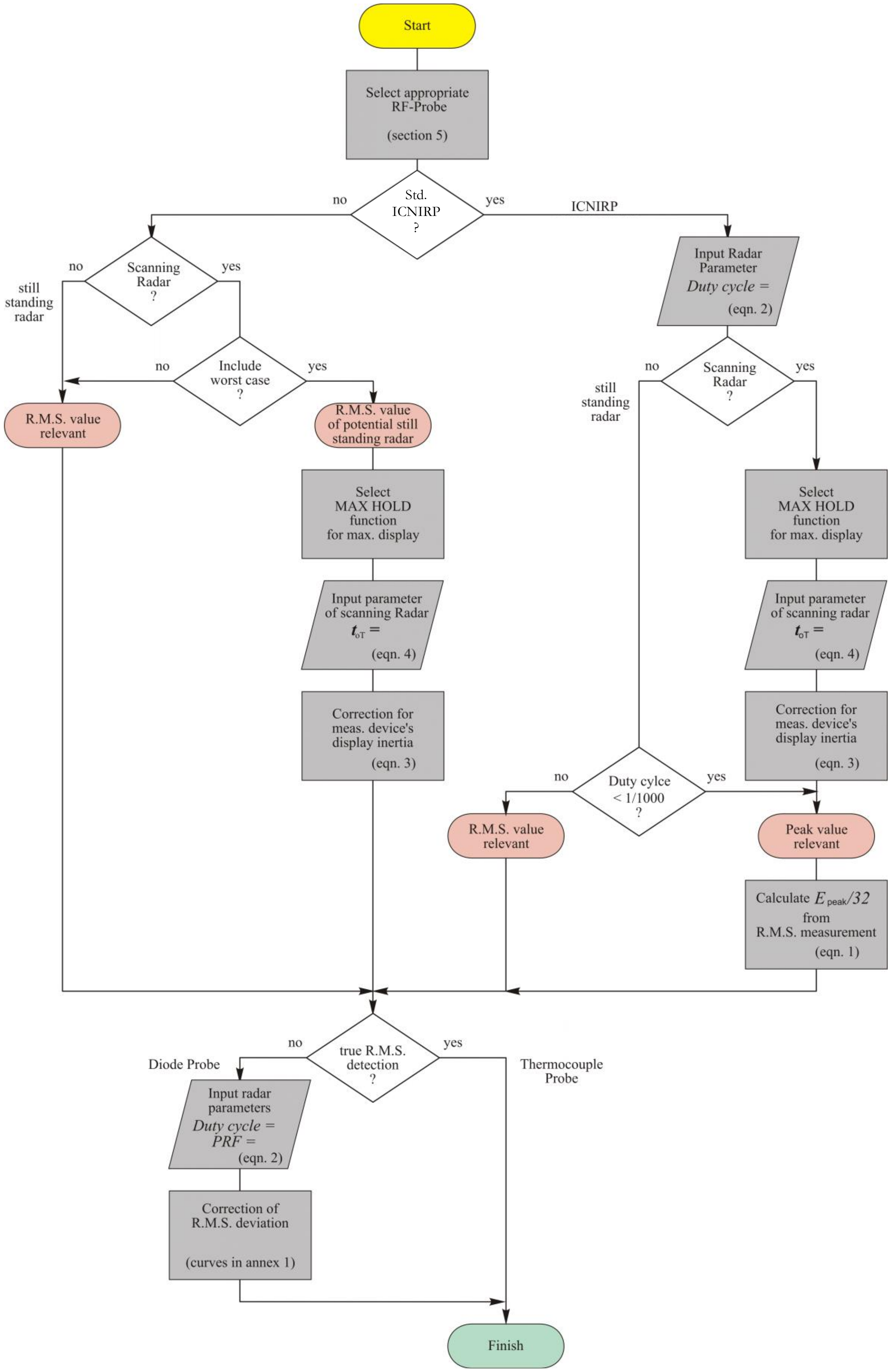


Figures A1-A6: Deviation of RMS value from display value E-field probe EF1891



Figures A7-A12: Deviation of RMS value from display value for RadMan (ESM-20)

Annex 2: Flow diagram for radar signal measurements



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