Application Note

Radar measurements with the Selective Radiation Meter SRM-3000

using air traffic control radar as an example

Measuring the field emissions of radar equipment sets particular challenges for both the test equipment and the technician performing the measurement. On the one hand, radar signals are usually pulsed, highly directional and spatially labile, with the main lobe only illuminating the target as well as the measuring antenna for a brief moment. On the other hand, frequency selective test equipment does not measure all frequencies simultaneously or does not measure continuously in the time domain, so not every radar impulse will be detected.
This Application Note uses air traffic control radar as an example to describe the use of the SRM-3000 for measurement and evaluation of field emissions with regard to human safety issues.

Rotating radar antennas adjacent to a residential area. The results used in this Application Note were actually obtained by measurements made in a playground about 500 m from the radar tower.

Contents

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1 Background

The term “radar” stands for radio detecting and ranging, describing a method of using electromagnetic waves to detect objects and determine their distance from the transmitter.

Two types of radar, known as primary and secondary radar, are used in air traffic control.

Typical antenna setup: The parabolic antenna for the primary radar is below the linear dipole array used for the secondary radar. Both rotate together.

The primary radar determines the position of aircraft or other objects including weather systems by transmitting a focused beam of electromagnetic waves and receiving the reflected signal (echo). The distance to the object can be calculated from the measured delay time. The direction can be determined from the position of the rotating antenna. The slower the rotation speed, the higher the delay times and hence ranges that can be detected. The faster the rotation, the more frequently the radar information is refreshed.

The secondary radar acts as an interrogator, in that it transmits a query to which the transponder on board the aircraft responds with information about the identity and height of the object, for example. Since the transponder is also an active transmitter, the secondary radar can operate at a much lower power level than the primary radar, which has to evaluate the passive echo signals. For this reason, the secondary radar is usually irrelevant to human safety measurements.

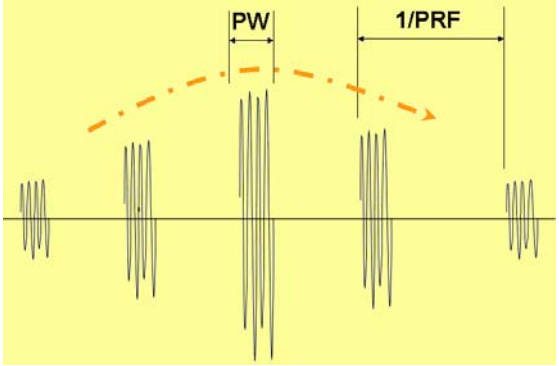
2 Standards and regulations

In 1998, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) published “Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields” [1, 2]. These guidelines include frequency-dependent limit values in the form of two different limit value curves: one with higher values for occupational safety and another with lower values for the general public. The higher values apply in controlled areas for which specific safety measures have been applied and which are only accessible to appropriately trained personnel. This applies to the radar tower platform, for example.

Primary radar

Pulse *– Air traffic control radar is pulsed rather than continuous wave radar. Typical pulse width (PW) is 1 µs with a pulse repetition frequency (PRF) of 1 kHz, corresponding to a period duration (T) of 1 ms.*
This corresponds to a duty cycle (DC) of 1:1000.

Rotation *– Sweeping the airspace evenly, the antenna typically rotates at 12.5 revolutions per minute. The directional characteristic corresponds to a narrow lobe. Radar technicians refer to the target dwell time (time during which the target is illuminated by the beam) and the number of strikes (number of pulses transmitted during this time).*
A typical target dwell time is 30 ms.



Standardized evaluation

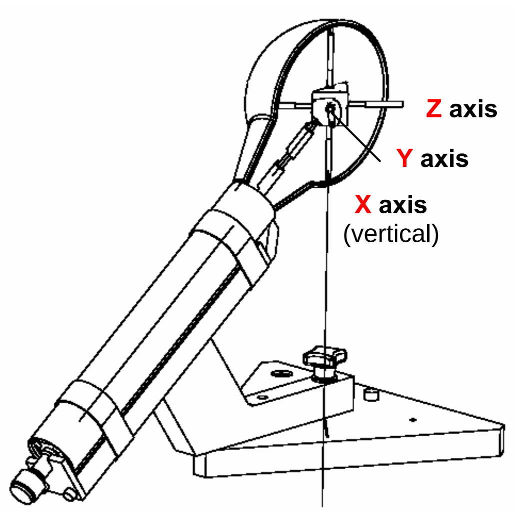
Deflection, refraction, and reflection of the radar beam results in part of the radiated power being scattered in all directions. Since the directional characteristic is also never perfect, side lobes also play a role in close proximity to the source. These signals are just as transient as the main signal. Because of this, measurement regulations make a distinction between

average power density (P_{avg})
taken over a 6 minute period, and
peak power density (P_{peak}).

According to ICNIRP, EU Directive 2004/40/EC and DIN VDE 0848, the peak value must not exceed the permitted average power density value by a factor of more than 1000, i.e. it must not be more than 32 times the field strength value.

These limit values as well as the distinction between occupational and general public are also reflected in the European Directives. Directive 2004/40/EC of 29th April 2004 [3] applies to occupational safety. Recommendation 1999/519/EC [4] dealing with protection of the general public was published as early as 12th July 1999. Many countries have additional national standards that frequently use the ICNIRP limits, although some specify even lower values.

Single-axis E-field antenna on antenna holder for single- and three-axis measuring antennas (above). The three-axis E-field antenna can also be used as a single axis antenna when fitted on the holder.



3 Preparing for measurement

Careful preparation along with suitable test equipment and a relatively large amount of time are needed for radar measurements to be successful.

Preparation includes obtaining information about the radar installation, which can often be obtained from the operator. Information about the site and its surroundings is also important for determining a suitable, representative location for the measurements; this may also require consultation with the client requesting the measurements. Consideration must also be given as to whether the radar operator, authorities, or local residents should be informed about the intended measurements.

The measuring equipment comprises:

- SRM basic unit with latest firmware
- Single-axis E-Field antenna for the frequency range up to 3 GHz together with antenna holder for single- and three-axis measuring antennas, or
  three-axis (isotropic) E-field antenna for SRM-3000 up to 3 GHz and one of the two antenna holders offered as accessories
- Tripod
- RF cable, 5 m
- AC adapter / charger (or spare battery if AC power is not available on site)
  Writing materials for recording details of test setups, local conditions, frequencies, measurement settings, and possible interference factors, or
  a notebook PC with the latest SRM-TS or SRM-Tools PC software for controlling the SRM, storing measured values, and recording comments.

When setting up the test equipment, you must make sure that the antenna head is as far as possible from any metal parts of the tripod by fully extending the plastic center rod, and that the person making the measurements is a few meters away from the measuring antenna so as not to affect the measurement.

Why is a single-axis antenna preferable?

When isotropic (non-directional) measurements are made using the three-axis E-field antenna, the SRM-3000 successively measures the field strength in the three directions (scanning) and calculates the resulting field strength from these values. The measurements thus take place at different times, with a spatial scan taking around 120 ms. This is short enough to be ignored for most quasi-stationary fields encountered in telecommunications, but too long for the typical target dwell time of 30 ms for the radar beam.

This problem does not occur with the single-axis E-field antenna, which also provides better measurement sensitivity in the radar frequency range. The three-axis antenna can still be used, however, if the SRM basic unit is set to measure a Single Axis.

4 Overview measurement

"Full Span" measurement

Even if precise information about the radar equipment such as the transmitting frequency is known, it is still a good idea to make an overview measurement in "Spectrum Analysis" mode covering the entire settable frequency range (full span). This indicates the overall field situation, including other sources, e.g. UMTS, which might affect the results or the test equipment operating level. The following settings on the SRM are important or recommended for this purpose:

- Resolution bandwidth RBW: **5 MHz**
  for rapid results.
- Large measurement range **MR** (low sensitivity) setting
  to avoid overdriving the measuring set
- Result Type: **MAX**

This measurement requires **several minutes** to perform, since the measuring antenna is only occasionally illuminated by the radar beam. This can be seen from the fact that the spectral lines of the radar signal build up only slowly on the display.

Determining the radar frequencies

The radar frequencies can be determined if they are unknown, simply by restricting the frequency range (figures 1 and 2) and selecting narrower resolution bandwidths RBW (300 kHz and 200 kHz are used respectively in the examples of figures 1 and 2). If the frequencies are known, you can enter the measurement frequency directly.

Setting the measurement range MR

This setting is most easily made in "Time Analysis" mode. Settings:

- **Center frequency Fcent**
  corresponding to the known or determined radar frequency.
  If there are two radar channels, one channel must be chosen for measurement.
- Resolution bandwidth RBW: **6 MHz**
- Detector: **Peak**
- Result Type: **MAX**

The field strengths in the three axis directions can now be measured one after the other. Each measurement in "Time Analysis" mode only requires two or three rotations of the radar antenna for completion, in contrast with "Spectrum Analysis" mode.

A suitable measurement range for the radar signals can now be set manually from the results of this preliminary field strength measurement. However, the field strengths of other sources detected by the "full span" measurement which may have higher levels may also need to be taken

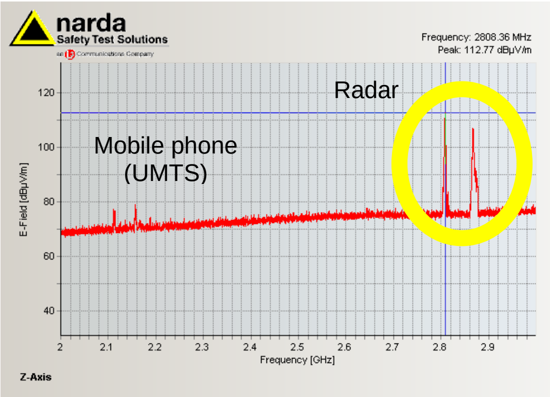


Figure 1: Determining the radar frequency

In this example, the primary radar uses two channels with frequencies of 2.808 GHz and 2.868 GHz. The channels transmit pulses alternately to achieve higher resolution without overloading the receiver for the other channel in each case.

Measurement settings:	
Dataset type	*SPEC*
Store mode	*MAN*
Minimum frequency	*2 GHz*
Maximum frequency	*3 GHz*
Resolution bandwidth	*300 kHz*
Measurement range	*Dependent on field situation*
Unit	*dBµV/m*
Result type	*MAX*
Axis	*Z*
Cable name	*SRM 5 m*

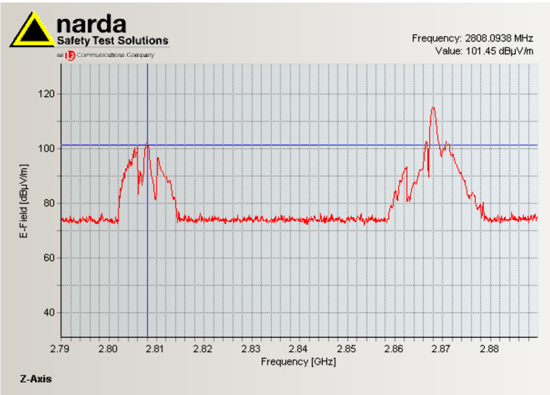


Figure 2: Zoom for exact determination of the radar frequencies

***Measurement settings** differing from the above:*	
Minimum frequency	*2.79 GHz*
Maximum frequency	*2.89 GHz*
Resolution bandwidth	*200 kHz*

into account. The measurement range should not be set to a more sensitive setting than that determined for the "full span" measurement, for example.

The automatic measurement range search function "MR Search" can also be used for the overview measurement. The "MR Search" function is, however, unsuitable for the actual measurement because of the pulsed nature of the radar signals. Sufficient reserve is also required when there are several spectral lines that are approximately equal in height (as in figure 2). For example, the MR should be set to 20 V/m if there are two peak values of 10 V/m each. If the display is in dBµV/m, the measurement range should accordingly be set 6 dB higher than the individual measurement value.

The single-axis antenna can easily be rotated and adjusted to all three spatial axes using the antenna holder. Simply fit the antenna in the fixing provided and move it from position 1 to position 2 and finally to position 3. You only need to make sure that the position of the entire setup (tripod, antenna, SRM, antenna holder, person measuring) is not altered.

5 Measuring with "Time Analysis"

The peak and average field strength values required by the various standards can be measured in "Time Analysis" mode.

Settings for measuring the **peak values**:
- Center frequency **Fcent** corresponding to the **radar frequency**
- Resolution bandwidth RBW: **6 MHz**
- Detector: **Peak**
- Result Type: **MAX**

The measurement time is adequate once the result remains stable. The value should remain constant after a few rotations of the radar antenna.

Settings for measuring the **average values**
- Center frequency **Fcent** corresponding to the **radar frequency**
- Resolution bandwidth RBW: **6 MHz**
- Detector: **RMS**
- Result Type: **AVG**
- **Average Time: e.g. 6 min,** set using the Configuration menu in Time Analysis Mode.

The necessary measurement time is the same as the averaging time.

The measurement is performed in each of the three spatial directions separately when **measuring with a single-axis antenna**. The SRM automatically calculates the isotropic result from the three separate results (also refer to the operating manual section "Isotropic measurement with a single-axis antenna")

Each axis must also be measured separately when **measuring with a three-axis antenna**, i.e. the SRM must be set to single-axis operation. The isotropic result is then calculated manually (see Annex 2).

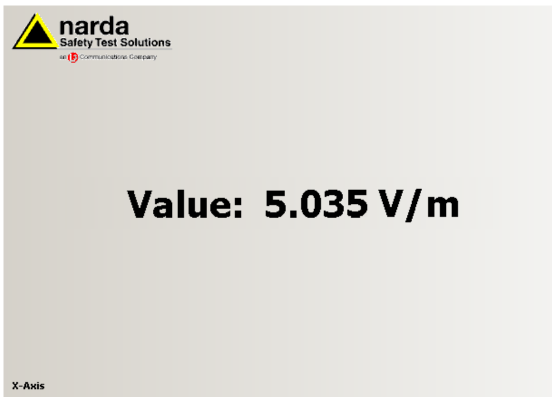


Figure 3: Time Analysis, result for one axis.

Measurement settings:

Dataset type	*VAL*
Store mode	*MAN*
Center frequency	*2.808 GHz*
Resolution bandwidth	*6 MHz*
Measurement range	*10 V/m*
Result type	*MAX*
Detector	*PEAK*
Time interval [s]	*2.4*
Observation time [s]	*300*

6 Measuring with “Spectrum Analysis”

Spectrum analysis is the traditional method of measuring electromagnetic waves. It has the advantage of supplying detailed information about the type of radar signal. The disadvantage is that it can only determine the peak value indirectly, since calculation is necessary to apply correction factors to obtain the result. The measurement also takes quite a long time. This is due to the way that a spectrum analyzer works. A brief summary of this is given in Annex 1. The measurement using “Time Analysis” mode described in the previous section overcomes this difficulty and produces direct results much faster, but without the additional information that spectrum analysis can provide.

The SRM is set as follows for measurements in “Spectrum Analysis” mode:

- **Result Type: MAX**
  as for the overview measurement
- **Measurement range MR**
  remains set as for the overview measurement
- Units: logarithmic, i.e.
  dBµV/m, dBmV/m, dBV/m or dBA/m
  so that correction factors can be applied easily after the measurement
- **Center frequency Fcent**
  corresponding to the known or detected radar frequency.
  One radar channel must be selected for measurement of dual channel radar.
- **Frequency range Span**
  should be selected to be a multiple of the inverse of the pulse width;
  Example: Pulse width PW = 1 µs, span = 10 x 1 / 1 µs = 10 MHz.
- Resolution bandwidth **RBW** according to the formula
  2 PRF ≤ RBW << 1/PW
  Example: Pulse repetition frequency PRF = 1 kHz, RBW = 2 kHz or slightly more. This makes the RBW narrow enough to resolve the power spectrum of the individual pulse, yet wide enough to separate consecutive pulses from each other in the time domain.

If the frequency range and resolution bandwidth have been selected correctly, a spectrum similar to a sinc-function appears as the result (see figures 4 and 5). The difference between the zero points and the maximum radar frequency value corresponds to the inverse of the pulse width PW. The PW can therefore be determined in this way if it is not already known.

In theory, it is also possible to determine the pulse repetition frequency PRF if it is not known. If the resolution bandwidth were extremely narrow, the measurement trace would appear as a line spectrum, with

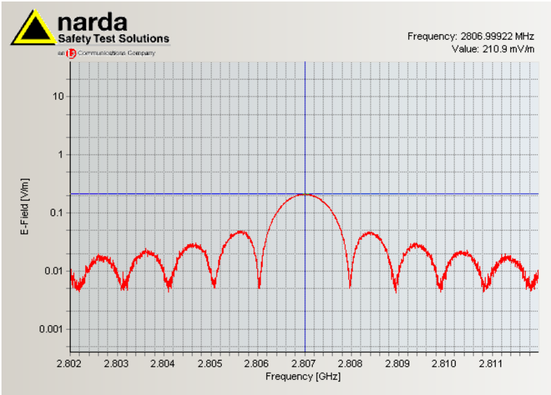


Figure 4: The ideal spectrum
has the form of a sinc-function: sin(x)/x The spectrum shown here was produced by a generator in a laboratory. The pulse width can be calculated from the distance between the zero points:
PW = 1 / 1 MHz = 1 µs

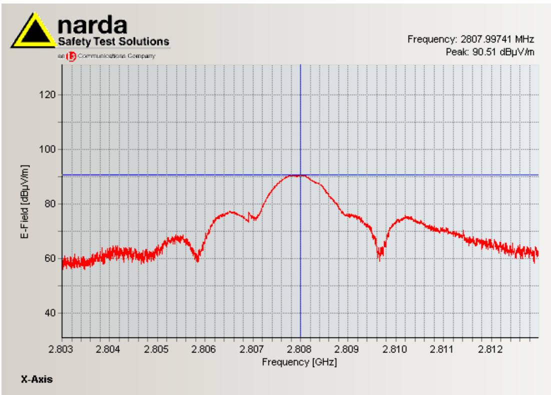


Figure 5: Actual spectrum of a radar signal.
The deviations from the ideal shape are due to noise as well as to amplitude and frequency changes during the pulse duration. Despite this, the pulse width (PW) can still be determined from the distance between the zero points.

Measurement settings:

Dataset type	*SPEC*
Store mode	*MAN*
Minimum frequency	*2.803 GHz*
Maximum frequency	*2.813 GHz*
Resolution bandwidth	*5 kHz*
Measurement range	*dependent on the field situation*
Unit	*dBµV/m*
Result type	*MAX*
Axis	*X*

the lines spacing corresponding to the inverse of the PRF. Such a high resolution would, however, lead to unnecessarily long measurement times. There is a rule of thumb that can be used even if the PRF is not known precisely: The resolution bandwidth is correctly set when the main maximum of the radar signals shows only slight ripple when magnified by zooming (figure 6).

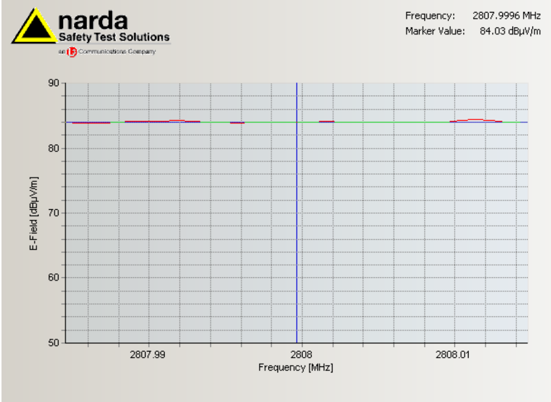


Figure 6: The zoom view of the main maximum of the radar signal shows only minimal ripple when the resolution bandwidth is set correctly.

Measuring

The measurement for the selected axis is complete when the measured values do not increase further.

This can take from 10 to 15 minutes.

Reading the result

Find the highest peak using the marker function and read off the numerical value. The value in this example is 90.51 dBµV/m.

Result correction

The short duration of the radar pulses means that the response characteristic of the selection filter affects the result. The maximum value reading therefore needs to be corrected by an amount which is dependent on the resolution bandwidth RBW and the pulse width PW. The correction values in dB that are typical for the SRM are summarized in the table opposite.

RBW [kHz]	PW = 0.5 µs	PW = 1 µs	PW = 2 µs
1	62.69	56.67	50.65
2	56.67	50.65	44.63
3	53.15	47.13	41.11
5	48.71	42.69	36.67
10	42.69	36.67	30.65
20	36.67	30.65	24.64
30	33.15	27.13	21.14
50	28.72	22.71	16.76
100	22.71	16.76	11.01
200	16.76	11.01	5.91
300	13.35	7.90	3.60
500	9.26	4.56	1.66
1000	4.56	1.66	0.48
2000	1.66	0.48	0.12
3000	0.81	0.22	0.06
5000	0.31	0.08	0.02

Table 1: Correction values in dB for various SRM resolution bandwidths (RBW) and different radar signal pulse widths (PW).

Result correction example

Spectrum analysis with a 5 kHz RBW (figure 5) gave a maximum value of 90.51 dBµV/m; the pulse width was 1 µs. The correction value from Table 1 is therefore 42.69 dB. The peak value is therefore calculated as:

90.51 + 42.69 = 133.20 [dBµV/m].

When converted to field strength using the formula

$$E\,[\mu V/m] = 10^{\frac{L\,[dB\mu V/m]}{20}}$$

this corresponds to a value of

4.571 V/m

Measurement with “Time Analysis” (figure 3) led to a result of 5.035 V/m. The deviation by a factor of 1.1 or 0.84 dB can be explained by the fact that the measurement time for the spectrum analysis was not long enough to record the actual peak value. The relatively small difference does however show that the results from “Spectrum Analysis” and “Time Analysis” are comparable.

7 Evaluating results and preparing a test report

In the end, the client requesting measurements of field emissions is only interested in whether the permitted limit values have been adhered to or by how much they have been exceeded or not. Any evaluation must therefore include an assessment of the results with reference to the limit values.

The SRM-3000 can display the results directly as a percentage of the permitted limit value. The limit values for various standards are stored in the instrument. In “Time Analysis” mode, this assessment is made at the same time as the measurement.

Automatic assessment is also possible in “Spectrum Analysis” mode, but in this case the correction values in table 1 on page 7 must be converted into factors that can then be applied to the results as percentages of the permitted limit values.

The results of “Spectrum Analysis” mode can also be evaluated by measuring in logarithmic units as described, applying the correction values, and then converting the results to field strength or power density values. These values can then be compared “manually” with the permitted limit values.

Comparable results are delivered by all these methods if measurements are made carefully. Differences in the results from “Spectrum Analysis” and “Time Analysis” modes can have the following causes:

- Measurement time in spectrum analysis too short
- Incorrect instrument settings (RBW, Result Type, etc.)
- Saturation if the selected measurement range MR is too sensitive, or corruption of the result due to noise if the measurement range is not sensitive enough.

The inherent measurement uncertainty should be taken into account in all results. Refer to the Application Note “Accounting for measurement uncertainty in the SRM-3000” for more information about this.

The evaluation and assessment should normally be recorded in a measurement report. The SRM-TS PC software is very useful for this. The measurement data and graphics can be directly inserted into the measurement report using copy and paste functions, and sets of measurement data can be exported easily to standard spreadsheet applications.

Annex 1: Special features of spectrum analysis

There are basically two types of frequency-selective measuring equipment: classical spectrum analyzers, which operate as (analog) superheterodyne receivers (superhets), and FFT analyzers, which determine the spectrum from the (digitized) time response of the signal.

Superhets sweep through the set frequency range (span) in a set period of time. The analyzer is therefore tuned to only one frequency at any given moment. As a result, even when the measuring antenna is illuminated by a pulse in the main lobe of the radar signal, the analyzer will record only a part of the spectrum.

FFT analyzers record the time response of the signal within a fixed “time window” and calculate the frequency spectrum from the recorded data set. Depending on the frequency span, the spectrum may be made up from several FFTs combined together. Here too, it is possible that not every radar pulse will occur exactly within a time window or that every data set will include a radar pulse.

The Selective Radiation Meter SRM-3000 combines both methods. It uses a superhet to make a coarse pre-selection, and a FFT for fine frequency selection. The superhet remains tuned to a fixed frequency for the narrow measurement frequency spans that are usual for radar measurements. Depending on the frequency span setting, the result may be produced by combining several FFTs (figure 7). The narrower the span, the fewer the number of FFTs that the instrument needs to perform and the higher the probability that the time window will record a radar pulse at the center of the dwell time. The measurement time is thus reduced when a narrow span is used. A maximum hold function and a sufficiently long recording period are necessary in every case.

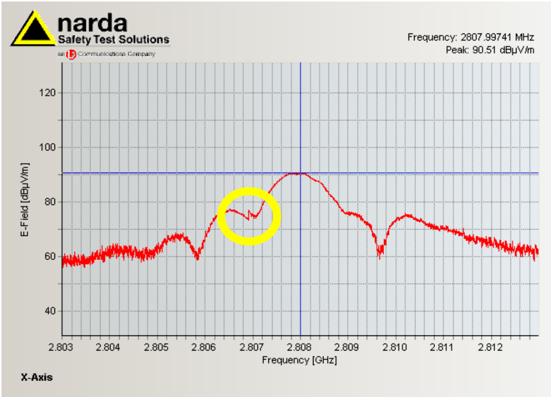


Figure 7: Spectrum generated from several fast Fourier transformations. Despite a measurement time of several minutes, the jump in the curve indicates that, as yet, no radar pulse has been detected in the center of its dwell time by the time window for the lower part of the spectrum.

Annex 2: Calculating the isotropic result from individual measurements

The isotropic result can be calculated from successive measurements of field strength or power density values in the three orthogonal spatial axes x, y, and z using the following formulas:

Field strength values:

$$E_{isotropic} = \sqrt{E_x^{\ 2} + E_y^{\ 2} + E_z^{\ 2}} \quad \text{or} \quad H_{isotropic} = \sqrt{H_x^{\ 2} + H_y^{\ 2} + H_z^{\ 2}}$$

Power density values:

$$P_{isotropic} = P_x + P_y + P_z$$

Logarithmic values referred to field strengths:

$$L_{isotropic} = 10\log(10^{\frac{Lx}{10}} + 10^{\frac{Ly}{10}} + 10^{\frac{Lz}{10}})$$

Abbreviations

DC	Duty cycle
E-field	Electric field
FFT	Fast Fourier transformation
MR	Measurement range
PW	Pulse width
PRF	Pulse repetition frequency
RBW	Resolution bandwidth
RMS value	Root mean square value
SRM	Selective Radiation Meter
T	Period duration

References

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[2] Guidelines on Limiting Exposure to Non-Ionizing Radiation. International Commission on Non-Ionizing Radiation Protection (ICNIRP), July 1999; ISBN 3-9804789-6-3

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