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Application Note

Radar measurements with the Selective Radiation Meter SRM-3006

on air traffic control radar as an example

Radar equipment field emission measurements pose special challenges for both the measuring devices and the technicians. On the one hand, the radar signals are usually highly directional, fleeting impulses: the main lobe only impinges on the target and the measuring antenna for a brief moment. On the other hand, frequency selective measuring devices do not record all frequencies simultaneously or they do not measure continuously, so that not every radar impulse will be detected.

This Application Note describes an example of the use of the SRM-3006 to measure and evaluate the field emission of an air traffic control radar from the perspective of human safety using the SRM-3006.

Rotating radar antennas on the outskirts of a residential area. The results in this Application Note, however, were obtained from measurements made in a playground situated approximately 500 m away from the radar mast.

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1 Background

Radar stands for "Radio detecting and ranging" and is essentially the use of radio or electromagnetic waves to locate objects and measure their distance from the transmitter.

Two different types of radar are employed for air traffic control: primary and secondary radar.

A typical antenna array: a parabolic antenna for the primary radar beneath a linear dipole array for the secondary radar. Both antennas rotate together.

The primary radar determines the position of aircraft and other objects as well as weather conditions by transmitting a pulsed, focused beam of electromagnetic waves and receiving the echoes that are reflected back. The distance of the object can be calculated from the elapsed time measurement. The direction is determined from the position of the rotating antenna. The slower the antenna rotation speed, the longer the elapsed times that can be measured and thus the ranges that can be determined. The faster the rotation, the more often the radar information is refreshed.

The secondary radar acts as an interrogator, i.e. it transmits a query that elicits a response from the transponder on board the aircraft. This response includes information about the identity and altitude of the object. Because the transponder transmits actively, the secondary radar can transmit at a much lower power than the primary radar that has to evaluate the passive echo signals. This generally means that the secondary radar is not relevant to safety measurements.

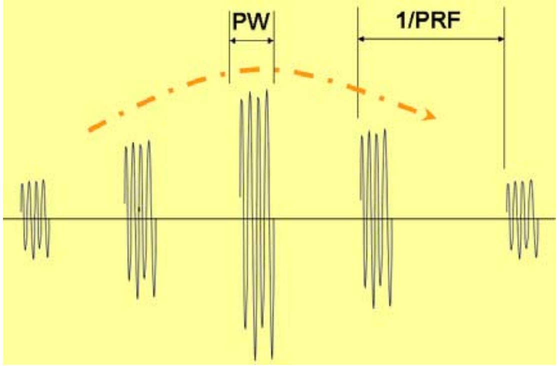
2 Standards and regulations

In 1998, ICNIRP, the International Commission on Non-Ionizing Radiation Protection published "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields" [1, 2]. These Guidelines define frequency-dependent limit values for two different limit value curves: a higher one for occupational safety and a lower one for protection of the general public. The higher values apply within controlled areas that are subject to safety measures and which are only accessible to specially trained personnel. Such values would apply, for example, to the platform of a radar mast or tower.

Primary radar

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

Rotation – *The antenna rotates at typically 12.5 revolutions per minute in order to sweep the surrounding airspace. The directional characteristic corresponds to a narrow lobe. Radar technicians use the terms dwell time (time during which the lobe illuminates the target) and number of hits (number of pulses transmitted during this time).*
A typical target dwell time is 30 ms.



Standard-compliant evaluation

Part of the radiated power of the radar beam is scattered by deflection, diffraction and reflection. Since the directional characteristic is never ideal, side lobes also play a part in the immediate vicinity of the antenna. These signals are just as fleeting as the main signal. Measurement regulations therefore differentiate between

Average power density (P_{avg}), averaged over a 6-minute period, and
Peak power density (P_{peak}).

According to ICNIRP, EU Directive 2013/35/EU [3] and DIN VDE 0848 [5], the peak value may not exceed the permitted average power density value by more than a factor of 1000, i.e. 32 times the field strength value.

Both the separation into two classes of values as well as the limit values themselves are reflected in the European Directives. EU Directive 2013/35/EU applies to occupational safety. Protection for the general public is outlined in the earlier Recommendation 1999/519/EC [4] that was published on 12 July 1999. Many countries have also published their own national standards that frequently incorporate the ICNIRP limit values, but which sometimes prescribe lower limit values.

3 Measurement preparation

Careful preparation and suitable measuring equipment are needed for successful radar measurements.

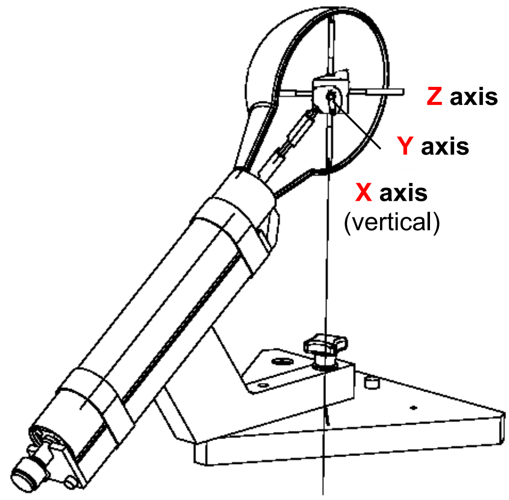
Preparation includes obtaining information about the radar installation, which can often be provided by the system operator. Additionally, information about the location and its surroundings is also important in order that a suitably representative location for the measurement can be found. This may need to be agreed with the client requesting the measurement. Consideration should also be given to the question of whether the operator, authorities or local residents should be informed of the proposed measurement.

The measuring equipment comprises

- SRM basic unit with latest firmware
- Single axis E field antenna for the frequency range up to 3 GHz and an antenna holder for single and three axis measuring antennas
  – or –
  Three axis (isotropic) E field antenna for the SRM-3006 up to 6 GHz and one of the antenna holders available as accessories
- Tripod
- RF cable, 5 m
- AC adapter/charger or a spare rechargeable battery if there is no AC line power available on site
- Writing materials to record the test setup, local conditions, frequencies, measurement settings and possible interference factors
  – or –
  Notebook PC with the latest SRM-TS or SRM-Tools PC software for controlling the SRM, saving measured values, and recording comments.

When setting up the measuring equipment, care should be taken to ensure that the antenna head is as far away from the metal parts of the tripod as possible, i.e. by extending the plastic center post as far as possible, and that the person performing the measurement is a few meters away from the measuring antenna in order that the measurement is not affected.

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



Why is a single axis antenna used in preference?

The SRM-3006 makes isotropic measurements with the three axis E field antenna by successively measuring the field strength in the three spatial directions (scanning) and calculating the resultant field strength. The measurements are thus made at different times over a scan time of around 120 ms. This is short enough to be ignored for the mostly virtually stationary fields encountered in telecommunications, but is too long for the target dwell time of a radar beam which is typically 30 ms.

This problem does not occur with a single axis antenna, which also has a higher measurement sensitivity at radar frequencies. Nevertheless, a three axis antenna can be used if the SRM basic unit is set to Single Axis measurement.

4 Overview measurement

Measure Full Span

Even if precise details about the radar equipment such as the transmission frequencies are known, an initial measurement over the entire settable frequency range (Full Span) in Spectrum Analysis mode is still recommended to obtain an overview. This will show the complete field situation including other sources like UMTS that could affect the result or the modulation level of the measuring device. The following settings are important or recommended for the SRM:

- Resolution bandwidth RBW: **500 kHz**
  in order to obtain results quickly
- Set a large measurement range **MR** (low sensitivity)
  to avoid overmodulation
- Result Type: **MAX**

This measurement requires a **measurement time of several minutes** because the radar beam will only occasionally hit the measuring antenna. This can be seen by the fact that the spectral lines for the radar signal only emerge slowly in the display.

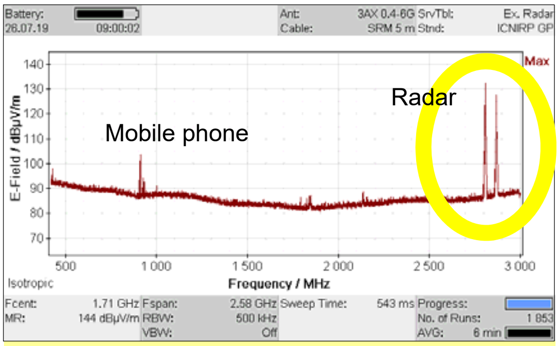


Figure 1: Determining the radar frequency
In this case, the primary radar uses two channels at 2.808 GHz and 2.868 GHz. The channels transmit pulses alternately in order to achieve higher resolution without one channel saturating the receiver of the other channel in each case.

Measurement settings:

Dataset Type	*SPEC*
Store Mode	*MAN*
Minimum Frequency	*420 MHz*
Maximum Frequency	*3 GHz*
Resolution Bandwidth	*500 kHz*
Measurement Range	*dependent on the field situation*
Unit	*dBµV/m*
Result Type	*MAX*
Axis	*Isotropic*
Cable Name	*SRM 5 m*

Determine the radar frequencies

If the radar frequencies are unknown, they can be determined by narrowing down the frequency range (figures 1, 2) and selecting lower resolution bandwidths RBW (the examples in figures 1 and 2 use 500 kHz and 200 kHz respectively). If the frequencies are known, the measurement frequency can be entered directly.

Set the measurement range MR

This is most easily done in Level Recorder mode. Settings:

- Center frequency **Fcent**
  corresponding to the known or measured **radar frequency**. If there are two radar channels, one of these must be selected.
- Resolution bandwidth RBW: **32 MHz**
- Result Type: **Peak & RMS**

The field strengths in the three spatial axis directions can now be measured. In Level Recorder mode, two or three revolutions of the radar antenna will be enough to obtain a result, unlike Spectrum Analysis mode.

A suitable measurement range for the radar signals can now be set manually from the results of this initial field strength measurement. However, any higher field strengths emanating from other sources that may have been captured during the Full Span measurement still need to be considered, so the measurement range chosen must not be less than the measurement range determined by the Full Span measurement, for example.

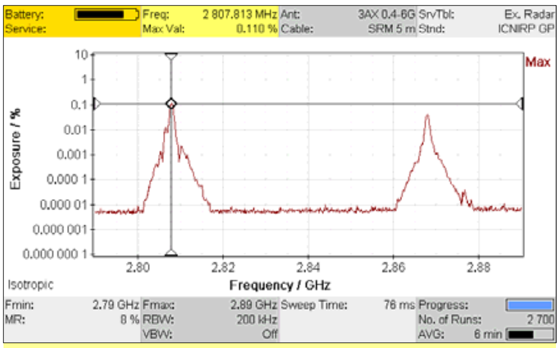


Figure 2: Zoom for more precise determination of the radar frequencies

***Measurement settings,** different from above:*

Minimum Frequency	*2.79 GHz*
Maximum Frequency	*2.89 GHz*
Resolution Bandwidth	*200 kHz*

The automatic measurement range search function MR Search can also be used for the overview measurement. However, use of the MR Search function is not recommended for the actual measurement due to the pulsed nature of the radar signal. Where there are several spectral lines of approximately the same amplitude (as in figure 2), an appropriate reserve should be included. For example, if there are two peak values of 10 V/m each, the MR should be set to 20 V/m. If the display is in dBµV/m, the measurement range should correspondingly be set 6 dB higher than the individual peak value.



The antenna holder allows the single axis antenna to be positioned in the three spatial directions easily.

The antenna is simply fixed to the specially designed holder and turned from Position 1 to Position 2 and finally Position 3. While doing this, it is important that the position of the overall measurement setup (tripod, antenna, SRM, antenna holder, cable, person measuring) is not changed.

5 Measurement using Level Recorder mode

The peak and RMS values of the field strength can be measured in Level Recorder mode, just as is required by the standards.

Settings for measuring the **peak and RMS values**:

- Center frequency **Fcent** corresponding to the **radar frequency**.
- Resolution bandwidth RBW: **32 MHz**
- Result Type: **Peak & RMS**

The measurement time is sufficient when the result does not change any more. The value will be static after a few revolutions of the radar antenna.

The measurement should be performed for each of the three spatial axes for the **measurement using a single axis antenna**. The SRM automatically calculates the isotropic result from the individual results (see the Operating Manual under: Isotropic measurement using a single axis antenna).

Each axis should be measured separately for the **measurement using a three axis antenna**, i.e. the SRM should be set to Manual Isotropic operation.

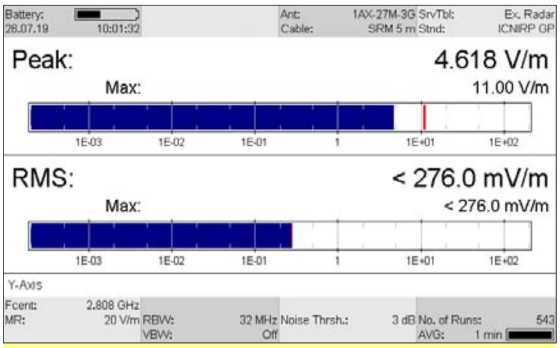


Figure 3: Level Recorder, result for one axis.

Measurement settings:

Center Frequency	*2.808 GHz*
Resolution Bandwidth	*32 MHz*
Measurement Range	*20 V/m*
Result Type	*Actual & MAX*
Detector	*PEAK & RMS*
Time Interval [s]	*60*

6 Measurement using Scope mode

The SRM can display the changes in the level of a signal over time frequency selectively. The maximum sweep time can be up to 24 hours. Conversely, the smallest resolution at an RBW of 32 MHz is 31.25 nsec. This means that the SRM-3006 is capable of resolving even events that are as brief as radar impulses so that they can be measured using markers. The SRM can therefore be of great help in determining these values when information about the system is missing. The built in trigger function also means that the SRM can record one-off events as well.

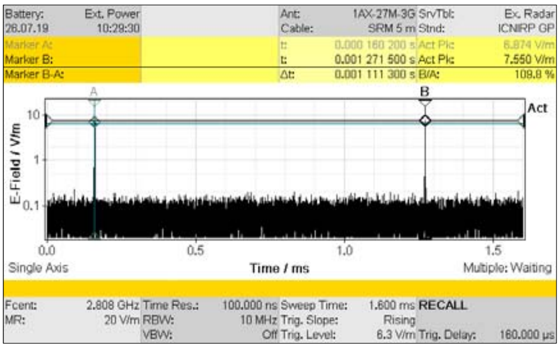


Figure 4: Scope Mode, determining the pulse repetition frequency PRF

Center Frequency	*2.808 GHz*
Resolution Bandwidth	*10 MHz*
Measurement Range	*20 V/m*
Result Type	*Actual*
Sweep Time	*1.6 ms*
Time difference between markers	*1.111 ms*

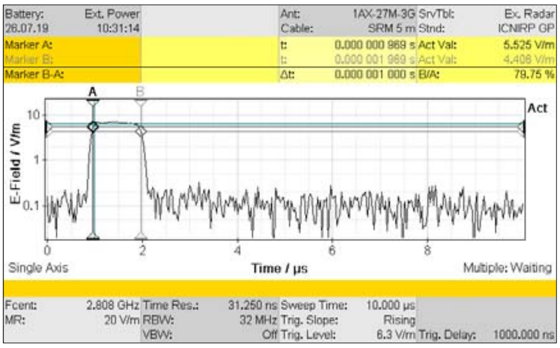


Figure 5: Scope Mode, determining the pulse length

Center Frequency	*2.808 GHz*
Resolution Bandwidth	*32 MHz*
Measurement Range	*20 V/m*
Result Type	*Actual*
Sweep Time	*10 µs*
Pulse length	1 µs

7 Measurement using Spectrum Analysis mode

Spectrum analysis is the traditional method used to measure electromagnetic waves. It has the advantage that it provides detailed information about the nature of the radar signal. The disadvantage is that it can only determine the peak value, and this only indirectly after the application of correction values. The measurement also takes quite a long time. Both these disadvantages are inherent in the way that a spectrum analyzer operates. The measurement using Level Recorder mode described in section 5 avoids these difficulties, giving much faster direct results but without the additional information provided by spectrum analysis.

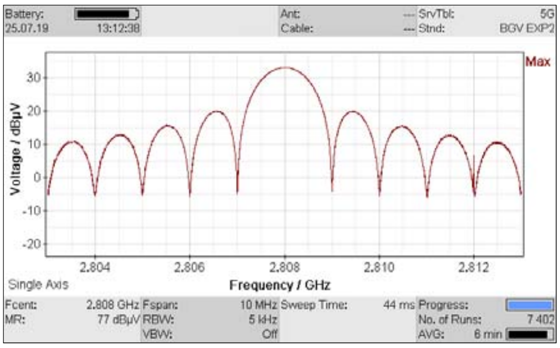


Figure 6: The ideal spectrum
has the form of a sinc-function: sin(x)/x
The spectrum shown here was produced by a generator in the lab. The pulse width can be determined from the distance between the zeros:
PW = 1 / 1 MHz = 1 µs

The SRM settings for a measurement in Spectrum Analysis mode are as follows:

- Result Type: **MAX**
  as for the overview measurement
- Measurement Range **MR**
  stays the same as the range set for the overview measurement
- Unit: Logarithmic, i.e.
  dBµV/m, dBmV/m, dBV/m or **dBA/m**
  to allow simple application of correction factors after the measurement
- Center frequency **Fcent**
  to correspond with the known or measured **radar frequency**. If there are two radar channels, one of these must be selected.
- Frequency range **Span**
  set so that it covers 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 rule
  2 PRF ≤ RBW << 1/PW
  Example: Pulse repetition frequency PRF = 1 kHz, RBW = 2 kHz or a little more. The RBW will then be small enough to resolve the power spectrum of the individual impulses, yet large enough to separate consecutive impulses from one another in time.

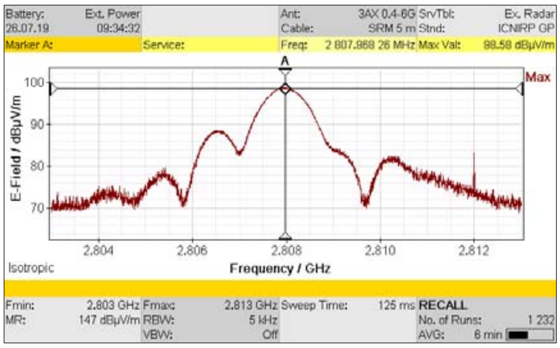


Figure 7: Real spectrum of a radar signal.
Deviations from the ideal are explained by noise and variations in the amplitude and frequency during the pulse duration. Despite this, the pulse width (PW) can be determined from the distance between zeros.

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*

If the frequency range and resolution bandwidth have been correctly chosen, the result displayed will be a spectrum that is similar to a sinc-function (compare figures 6 and 7). the distance of the zeroes from the maximum value of the radar frequency corresponds to the inverse of the pulse width PW. The PW can therefore be calculated from this if it is unknown.

In theory the pulse repetition frequency PRF can also be calculated if it is unknown. If the resolution bandwidth was extremely small, the measurement trace would appear as a line spectrum with a distance between the lines equal to the inverse of the PRF. However, using such a high resolution would lead to unnecessarily long measurement times.

Even if the PRF is not known exactly, the following practical rule can be applied: The resolution bandwidth is set correctly when the main maximum of the radar signal shows only slight ripple when shown in a zoomed in view (figure 8).
It is much easier though to determine the PRF using Scope mode, as described in section 6.

Measurement

The measurement for the selected axis is complete when the measured values stop increasing.
This can take from 10 to 15 minutes!

Read the result

Use the marker to locate the spectral line with the highest amplitude (Highest Peak) and read off the numerical value. This is 98.58 dBµV/m in our example.

Correct the result

The result is affected by the transient response of the selection filter due to the brevity of the radar pulse. The maximum value reading must therefore be corrected by an amount that depends on the resolution bandwidth RBW and the pulse width PW. Table 1 summarizes the correction values in dB that are typical for the SRM.

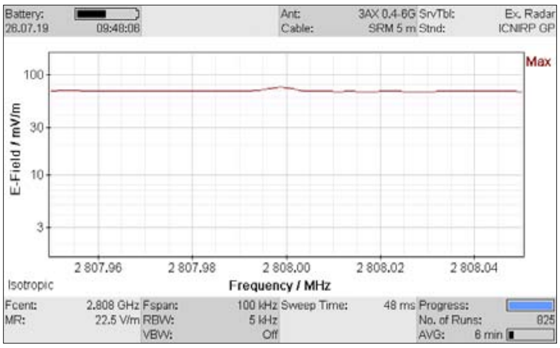


***Figure 8**: A zoom view of the main peak of the radar signal shows only a slight ripple if the resolution bandwidth is set correctly.*

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
10.000	0.08	0.02	0.01
20.000	0.02	0.01	0.00

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

Result correction example

Spectrum analysis with an RBW of 5 kHz (figure 5) resulted in a maximum value of 98.58 dBµV/m. The pulse duration was 1 µs. The correction value from Table 1 is therefore 42.69 dB. From this, the Peak value is calculated as:

98.58 + 42.69 = 141.27 [dBµV/m].

After conversion to field strength using the formula

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

this corresponds to a value of 11.57 V/m.

The measurement using Level Recorder mode (figure 3) leads to a result of 11.00 V/m. The relatively small difference indicates that the results obtained in Spectrum Analysis and Level Recorder modes are comparable.

8 Result evaluation and reporting

Clients that commission filed emission measurements are ultimately interested in whether the permitted limit values have been exceeded and by how much, or how far below the limit the readings are. The evaluation must therefore assess the results in relation to the limit values.

The SRM-3006 can display the results directly as a percentage of the permitted limit value. The limit values specified by various standards are stored in the device. The evaluation is already completed when the measurement is made in Level Recorder mode.

Automatic evaluation is also possible in Spectrum Analysis mode. In this case, however, the correction values listed in Table 1 on page 8 must be converted to factors that can be applied to the results expressed as percentages of the permitted limit values.

The results from Spectrum Analysis mode can also be evaluated by making the measurement using logarithmic units as described, applying the correction values, and then converting the results to field strength or power density values which can then be compared with the permitted limit values.

Careful measurements made using all these methods lead to comparable results. Differences between measurements made using Spectrum Analysis and Time Analysis can be caused by the following:

- Measurement time too short in spectrum analysis
- Incorrect device settings (RBW, Result Type, …)
- Overmodulation due to too sensitive a setting of the MR, or distortion of the results by noise because the MR is not sensitive enough

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

Annex 1: Isotropic result calculation from individual measurements

For successive measurements of the field strength or power density values in three orthogonal spatial directions x, y, z, the isotropic result is calculated using the following expressions:

Field strength values:

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

Power density values:

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

Logarithmic values referred to field strength:

$$L_{isotrop} = 10\lg(10^{\frac{Lx}{10}} + 10^{\frac{Ly}{10}} + 10^{\frac{Lz}{10}})$$

Abbreviations

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

References

[1] Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz). International Commission on Non-Ionizing Radiation Protection (ICNIRP). Published in Health Physics, Vol. 74, No. 4, pp. 436-522, April 1998

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

[3] Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC

[4] Council Recommendation of 12 July on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC). Official Journal of the European Communities L 199/59, 30.7.1999

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