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Safety Test Solutions

Measuring RF Electromagnetic Fields

at Mobile Communications Base Station and Broadcast Transmitter Sites

Second edition including 5G measurements

5G

A Guide to Good Practice by
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Foreword to the second edition

More than three years have passed since this practical guide to measuring electromagnetic fields at mobile communications base stations and broadcasting stations was first published. During this time there have been many technical innovations in connection with the introduction of the fifth generation of mobile radio communications (5G), which have had a considerable influence on the way personal safety in the vicinity of mobile communications equipment is assessed by measurement. The new type of antennas with electronic beam steering (mMIMO antennas) that are now for the first time being widely used only for 5G are just one example of this. Their use means that the field distribution around the 5G antenna is much more variable than was the case with the static characteristic antennas commonly used before.

There have also been developments in the field of international recommendations to limit exposure to electromagnetic fields, with the publication in 2020 of the long-awaited updated ICNIRP guidelines for the high frequency range.

As a result, it seemed timely to update this practical guide, not just to make editorial changes and correct minor errors in typesetting or inaccuracies, but rather to add new sections to the book to deal with these as yet undiscussed topics.

In this new second edition of the guide, section 1.1 now additionally presents the updated reference levels from ICNIRP 2020 and discusses other particularly relevant differences to ICNIRP 1998. Chapter 2.2.2 now additionally contains a brief presentation of the new millimeter wave antennas for the SRM-3006. The new section 2.4.7 presents the newly available “5G NR” operating mode of the *SRM-3006* and an introduction to its operation.

Some of the fundamental technical characteristics of the 5G air interface need to be examined in order to derive and explain suitable strategies for determining the RF fields of 5G equipment. This is covered in the new section 3.10, which also includes a description of the correct procedure for measuring the field strength of 5G signals. To complete this section, the method for extrapolation of the measured field strength values to the maximum operational system load is explained. In addition, Section 5.4 has been supplemented with a practical example for determining the extrapolation factors for 5G systems.

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Foreword to the first edition

Although it is possible to calculate the exposure level to high frequency electromagnetic fields caused by radio frequency applications, in practice this requires excessive effort, particularly within buildings. As a result, it is often more effective to measure the high frequency field in order to evaluate the exposure. Additionally, there will always be situations in the immediate vicinity of RF transmitting antennas where compliance with limit levels for personal safety cannot be determined with certainty by calculation, such as when the exact attenuation factor of a structural wall is unknown. In such cases, only on-site measurements can provide a final evaluation of safety in the area around the installation.

This practical guide is intended to provide you with the necessary theoretical and practical background information that you need to correctly determine high frequency field strength levels using specialist measuring devices, particularly in the vicinity of broadcast and mobile communications transmitters. The experience gained over the past fifteen years by the author from conducting more than 100 training seminars on the subject of determining exposure levels in the high frequency range has been included in this guide.

The first chapter of this guide starts with important basic information. This includes discussion of the current international limit value specifications for high frequency electromagnetic fields for the frequency range above 10 MHz and the consequences of these specifications for the standard-compliant determination of human exposure. The chapter also includes an introduction to the fundamental measurement principles as well as questions regarding performance of the measurements and quality assurance.

To correctly capture the high frequency field strength levels present at the measurement location, the measuring device used must be set up appropriately for each field source (e.g. FM radio transmitter or LTE mobile communications base station) that is to be investigated by measurement to determine its compliance within its locality with limit values. The device settings may vary considerably, depending on the field source and on the measuring device used, even though the theoretical basis for correctly capturing the field strength is the same in every case.

Because this book places particular emphasis on correct operation of the measuring equipment, the second chapter essentially begins with a thorough introduction to the measuring device that is to be used as the reference device for the measurements described. This is the frequency-selective high frequency field strength measuring system *SRM-3006* from Narda Safety Test Solutions, which is currently very widely used worldwide for frequency-selective measurement of high frequency fields. The author of this guide has also used this device for many years in his practical work, and can therefore draw on his long experience in handling the *SRM-3006*. The second chapter of this book first of all describes the important basic features of the measuring device. It then discusses in more detail how these features affect the correct determination of exposure, and gives an in-depth description of the various measurement modes and parameter settings of the *SRM-3006*.

Chapter 3 gives an introduction to the major broadcasting and mobile communications systems in current use worldwide. The important system parameters that are relevant to correct determination of human exposure by measurement are then introduced. This is followed by a detailed description of how the *SRM-3006* can be used to make a correct measurement of field strength for each of the RF systems mentioned. The chapter also shows how the measurement results are evaluated and how to make a correct comparison with the limit values and determine the standard-compliant sum of the individual signal contributions to the exposure. The chapter not only looks at how to operate the measuring device, but also at how to evaluate the measured values properly. This post processing requirement is often underestimated, and is therefore often done incorrectly.

Only the current internationally most widely distributed (and therefore most relevant) RF systems in the frequency range above 10 MHz are considered in this practical guide in order to keep this first edition within sensible limits. In the field of broadcasting, for example, classic AM broadcast radio in the range from around 0.1 to 30 MHz is not considered in detail, since this is fast disappearing from the global scene. Practically all the federal long and medium wave radio broadcasting transmitters in Germany had been decommissioned by the end of 2015, and a similar trend can be seen in many other countries. The only analog radio broadcast system considered in this guide is FM radio. In the digital broadcasting field, the guide looks at transmitters for DAB (Digital Audio Broadcasting) and DVB-T (Digital Video Broadcasting Terrestrial, i.e. terrestrial digital television).

The field strength values, generated by GSM (2G), UMTS (3G) and LTE (4G) mobile communications base stations are considered in detail in this guide. The human exposure to terminal equipment such as cellphones is not considered.

This practical guide is aimed at both newcomers and experienced users of the *SRM-3006*. It does, however, assume that readers have a basic understanding of high frequency and radio technology as well as of the determination and evaluation of high frequency exposure. Those who use other frequency selective measuring devices to determine exposure levels will also find much universally applicable information in this book that they can apply in their everyday work.

I am very grateful to Narda Safety Test Solutions in Pfullingen, Germany, for their support in the realization of this book. Thanks also to John Nutley, the translator of this book, and to Bernd Brozio for the layout of text, pictures and drawings. Further special thanks are due to Dr.-Ing. Christian Bornkessel of Ilmenau Technical University for his constructive advice and suggestions for improvement.

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2 The SRM-3006 and its measurement capabilities

Before looking in more detail at the correct recording of the field strength values caused by common radio communication systems, this second chapter introduces the device used for the measurements (*SRM-3006*), and describes its measurement capabilities. This chapter does not cover operation of the instrument in detail, as this in-depth information can be found in the *SRM-3006* User Manual when needed. The chapter is primarily concerned with getting to know the important basic features of the instrument, and its various measurement modes and their parameter settings, and with understanding why it is necessary sometimes to make very different parameter selections for the various measurement tasks.

2.1 Brief description of the SRM-3006

The *SRM-3006* (SRM = Selective Radiation Meter) from *Narda Safety Test Solutions* is a portable, frequency selective measuring system for safety analysis and environmental measurements in high frequency electromagnetic fields in the range from 9 kHz to 6 GHz. Since direct digital sampling of such high signal frequencies is hardly possible, the *SRM-3006* uses a combination of analog and digital signal processing. It is suitable for measuring the high frequency electromagnetic fields that are produced by audio broadcast transmitters (AM, FM, DAB), television (analog, digital), cellular communications (GSM, TETRA, UMTS, LTE, 5G NR), radar or local wireless systems (e.g. WLAN, DECT).

In situations where the field environment is unknown, such as on the platform of a radio tower (see Figure 2.1), where several network providers share an antenna site, the

SRM-3006 can display the instantaneous overall field exposure that is present, along with the contributions to it that are made by the individual frequency bands (services), either in absolute terms or as a percentage of the permitted limit value. The *SRM-3006* can resolve the RF signal spectrum down to individual channel level and determine the proportion each channel contributes to the overall field exposure. The field strength can also be integrated over a larger frequency range and the resulting overall value displayed as an absolute value or as a percentage of the limit value selected by the user. The *SRM-3006* has all the typical functions of a spectrum analyzer, so it can also be used for applications other than RF exposure measurements (e.g. in the laboratory).

This battery-operated device incorporates a wide range of functions that are particularly tailored to EMF measurements in a compact design that is comparatively light in weight. This means that it can also be used under conditions that particularly demand high mobility and robust qualities. One major advantage of the *SRM-3006* over conventional laboratory spectrum analyzers is that it can be used in situations where the ambient field strength is very high (up to 200 V/m) thanks to the excellent screening characteristics of its casing.

The wide operating temperature range of -10°C to +50°C allows the instrument to be used outdoors even at temperatures that are well above or below the usual room temperature range.

The main measurement task in the area of exposure measurement is the determination of the electric or magnetic field strength. For this reason, the complete *SRM-3006* measuring system comprises a basic measuring unit and a three-axis antenna. Narda also supplies single axis antennas. All Narda antennas can be directly mounted on the basic unit or connected to it by means of a special high frequency cable.

Measuring antennas from other manufacturers can also be used with the *SRM-3006*, as can standard high frequency cables that are fitted with N connectors.

Users can select different operating modes on the *SRM-3006*, which are described in more detail below. In the simplest case, the complete field strength measuring setup comprises the basic unit with an antenna connected to it (see Figure 2.1).

Figure 2.1: Using the *SRM-3006* on an antenna roof.

Depending on the measurement method used, it may be more useful to have the antenna separate from the basic unit rather than directly mounted on it, and to connect the two together using a coaxial cable. A 1.5-meter cable with N connectors is provided in the basic *SRM-3006* kit for this purpose. As accessories, Narda also offers a 5-meter cable for special applications, and a suitable tripod with a special antenna holder for separate positioning of the antenna (see Figure 2.2).

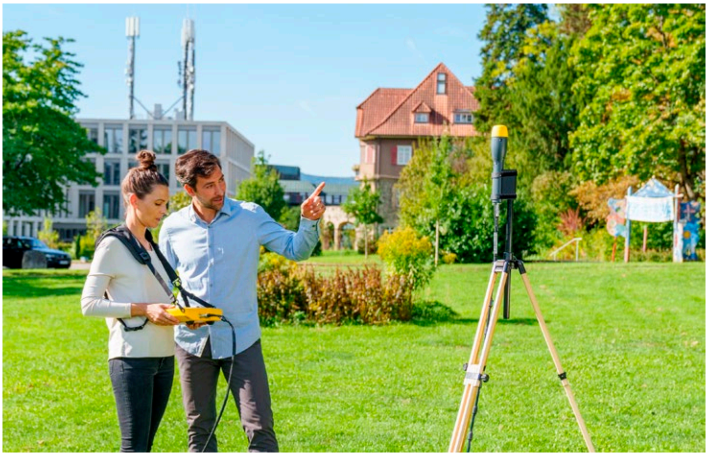

Figure 2.2: Field strength measurement using a separate antenna mounted on a tripod.

2.2 Antennas for the SRM-3006

2.2.1 Antennas for the frequency range from 9 kHz to 6 GHz

A three-axis antenna (Type 3502/01) is included in the standard *SRM-3006* set. This three-axis antenna allows quick and simple isotropic measurements up to 6 GHz by automatically determining the three spatial components of the field to be measured using three orthogonally arranged dipoles.

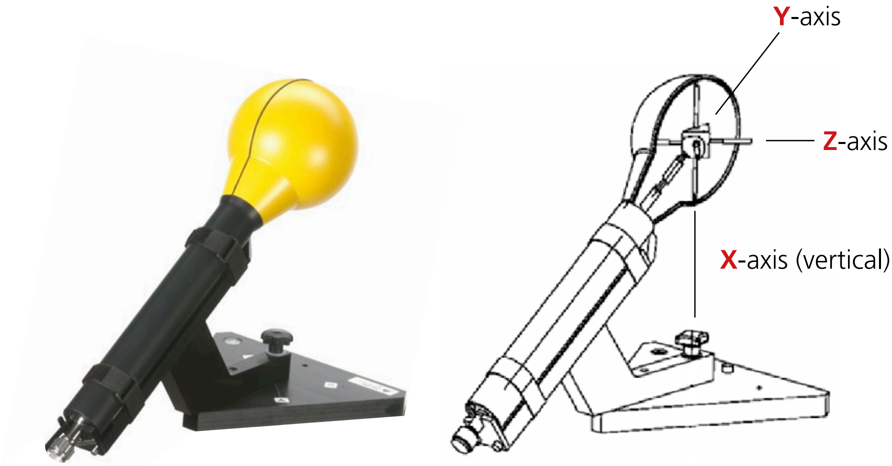

Figure 2.3: Three-axis antenna consisting of three orthogonally arranged dipoles.

The manufacturer *Narda Safety Test Solutions* offers single-axis antennas in addition to the three different thee-axis antennas (one for measuring low frequency magnetic fields and two for measuring electric fields in the higher frequency range).

Each of these antennas is equipped with a control cable in addition to the high frequency connection, which is connected to the basic unit via a multi-pin connector. This cable is used to transfer the antenna parameters stored in an EEPROM (type, serial number, calibration date, list of antenna factors). This enables the *SRM-3006* to automatically recognize this data and directly calculate the on-site field strength from the signal level detected by the measuring device.

The following Table lists the Narda antenna types that can be used to determine field exposure:

Type No.	Field type	Sensor type	Frequency range	Max. field strength
3501/03	E	Three-axis	27 MHz – 3 GHz	200 V/m
3502/01	E	Three-axis	420 MHz – 6 GHz	160 V/m
3581/02	H	Three-axis	9 kHz – 250 MHz	0.56 A/m
3531/01	E	Single-axis	27 MHz – 3 GHz	160 V/m
3531/04	E	Single-axis	9 kHz – 300 MHz	36 V/m (f > 10 MHz)
3551/04	H	Single-axis	9 kHz – 300 MHz	0.071 A/m

Table 2.1: Antennas available for the *SRM-3006*.

Table 2.1 highlights a problem that is faced by all manufacturers of field strength measuring systems: Currently, it is not technically possible without excessive effort to build antennas capable of capturing the electric or the magnetic field over the entire high frequency range, i.e., from 9 kHz to way above 1 GHz. Magnetic field antennas for the lower frequency range from 9 kHz up to a few 100 MHz are straightforward to make. Antennas for higher frequencies are much more problematic. The reverse is true for the electric field: The upper frequency range is no problem, but the low frequency range is difficult.

A consideration of the ICNIRP 1998 limit values for electric and magnetic fields in the frequency range above 10 MHz given in Tables 1.2 and 1.3 makes it clear that two of the three single-axis antennas are not useful for making measurements if the field present at the measurement location is of the same order of magnitude as the ICNIRP limit values (up to 137 V/m or 0.36 A/m). They can, however, still resolve comparatively low field strength levels reliably.

In contrast, the three isotropic antennas can be used even if the field strength values are of the order of the limit values. For this reason, only these antennas are particularly suitable for use, almost without any restrictions, for determining exposure levels, and not just because of their isotropic field coverage.

Note

The ICNIRP limit values for magnetic fields in the frequency range below 10 MHz are to some extent higher than the maximum permitted field strength for the isotropic magnetic field antenna.

There is a further restriction: The three-axis antennas can also reach their limits when measuring short high frequency impulses, such as are radiated by radar installations. This is because the impulse field strength at the relevant measurement points can easily exceed 200 V/m even though the specified ICNIRP limit values are not exceeded, due to the typical pause times between impulses from such radar systems (and, as already explained, the average field strength value over time is relevant here because of the thermal effects of high frequency radiation).

The three orthogonally-arranged dipoles within the antenna casing (see Figure 2.3, right) are sampled sequentially (i.e. one after the other) during the measurement, which can mean that very short RF impulses are no longer captured correctly when the time taken by the *SRM-3006* to (sequentially) sample the three measuring dipoles (120 ms) is greater than the duration of the RF impulse. This is another factor that needs to be considered. Before making measurements on high frequency impulses, therefore, a thorough check must be made to ascertain whether an isotropic antenna is at all suitable for the measurement, or whether it should be operated in single-axis mode, or even if a conventional passive, single-axis antenna from another manufacturer must be used instead.

2.2.2 Antennas for the frequency range from 24.25 to 29.5 GHz

Antennas for the SRM-3006 that can measure the electric field strength in the frequency range between 24.25 and 29.5 GHz have also been available since 2022. A down-converter integrated in the antenna converts signals in the above-mentioned frequency range to a lower frequency range so that they are below 6 GHz and can therefore be measured by the SRM-3006.

These antennas can be used, for example, to measure 5G signals in the designated FR2 frequency range between 24.25 and 29.5 GHz in a frequency-selective manner.

However, only two different types of single-axis downconverter antenna and no isotropic antennas are available (see Figure 2.4):

- Horn antenna with strong directional characteristic (Type 3591/101). Due to its gain (approx. 10 dBi), this antenna is particularly suitable for measuring comparatively weak signals (e.g. indoors). However, the horn must be aligned in the direction of the transmitter and optimally adjusted to the polarization of the incoming electromagnetic wave. Field strengths of up to 100 V/m can be measured with this antenna.

- Dipole antenna with omnidirectional characteristic in one plane (Type 3591/102). Field strengths of up to 200 V/m can be measured with this antenna. If this antenna is mounted vertically (see Figure 2.4), it has an approximately direction-independent reception characteristic in the horizontal plane. This means that it receives horizontally incoming and vertically polarized signals with constant characteristics and maximum gain, regardless of direction. However, if the signals have a different linear polarization (e.g. ±45° relative to the horizontal plane), the existing field strength will be underestimated. If the incoming wave is horizontally polarized, there is (theoretically) no reception at all. This fact should be taken into account if this antenna is to be used in a setup that has the purpose of capturing all signals arriving at the measurement point. The vertical reception characteristic of this antenna is not constant, as is usual with a vertically oriented dipole. The vertical 3 dB aperture angle of the antenna is about ±22.5°. The antenna (theoretically) does not receive at all in the direction of the dipole axis. In other words: Wave fields that are incident from a (nearly) vertical direction or which are (nearly) horizontally polarized are massively underestimated by the antenna.

Figure 2.4: SRM-antennas for the millimeter wave range (left: Horn antenna for directional reception; right: dipole antenna for omnidirectional detection). The angle-dependent reception characteristic of the antennas is visualized by a color representation.