About the author

Professor Dr.-Ing. Matthias Wuschek was awarded a Dipl.-Ing. degree in Electrical Engineering (RF and communications technology) in 1986. He achieved his PhD in 1998, after several years as a technical trainer for radar and antenna technology. He joined the Deggendorf Institute of Technology (Germany) as professor in 2000, lecturing on the subjects of communication technology, RF measurement technology, and mobile communications. Prof. Wuschek is Head of the Telecommunication Engineering and EMC Test Laboratories.

His main scientific objective is the development and improvement of field strength measurement techniques for EMF exposure determination. Within just the last decade, he has undertaken several hundred EMF measurement projects and some 100 workshops and training courses about aspects of electromagnetic radiation and the determination of EMF exposure, both in Germany and in many other countries around the world.

About the book

This book is intended to provide you with the theoretical and practical background information that is necessary for the correct determination of high frequency EMF immission using a frequency selective device, particularly in the vicinity of broadcast and mobile communications transmitters.

Although this practical guide is aimed at both newcomers and experienced users of the Narda SRM-3006, users of other frequency selective measuring devices for the determination of EMF exposure levels will find much universally applicable information in this book that they can apply in their everyday work.

narda Safety Test Solutions
an L3 Technologies Company

ISBN 978-3-00-061912-0

narda Safety Test Solutions
an L3 Technologies Company

Measuring RF Electromagnetic Fields

at Mobile Communications Base Station and Broadcast Transmitter Sites

A Guide to Good Practice by
Matthias Wuschek

Contents

1 Basic principles ... 12
1.1 Limit values for high frequency electromagnetic fields ... 12
1.2 Task definition and measurement procedure ... 17
1.3 Basic measurement method requirements ... 19
1.4 Measurement implementation and result evaluation ... 22
1.4.1 Basic measurement methods ... 22
1.4.2 Measurement location selection ... 24
1.5 Available measuring devices ... 26
1.5.1 Broadband measuring devices ... 26
1.5.2 Frequency selective measuring devices ... 28
1.5.3 Code selective measuring devices ... 29
1.5.4 Measuring device calibration ... 29
1.5.5 The near field / far field problem ... 30
1.6 Making the measurement ... 35
1.6.1 Setting the measuring devices correctly ... 35
1.6.2 The effects of spatial variations in field strength ... 35
1.7 Processing the measurement results ... 39
1.8 Measurement uncertainty ... 40
1.9 Documentation ... 43
1.10 Quality assurance ... 45

2 The SRM-3006 and its measurement capabilities ... 48
2.1 Brief description of the SRM-3006 ... 48
2.2 Antennas for the SRM-3006 ... 51
2.3 PC software ... 53
2.4 SRM-3006 operating modes ... 54
2.4.1 Spectrum Analysis mode ... 56
2.4.1.1 Introduction and areas of application ... 56
2.4.1.2 Setting the displayed frequency range ... 56
2.4.1.3 Setting the Measurement Range (MR) and Reference Level (RL) . 57
2.4.1.4 Selecting the vertical axis physical units and scaling ... 59
2.4.1.5 Selecting the Resolution Bandwidth (RBW) ... 61
2.4.1.6 Measurement speed and selection of result type ... 64
2.4.1.7 Selecting the Video Bandwidth (VBW) ... 67
2.4.1.8 Saving the selected device settings as a setup ... 72
2.4.1.9 Saving the measurement results ... 74
2.4.2 Level Recorder mode ... 75
2.4.2.1 Fundamentals and areas of application ... 75
2.4.2.2 Setting the center frequency and Resolution Bandwidth (RBW) ... 75
2.4.2.3 Setting the Measurement Range (MR) ... 76
2.4.2.4 Selecting the vertical axis physical units and scaling ... 77
2.4.2.5 Selecting the Result Type ... 77
2.4.2.6 Selecting the Video Bandwidth (VBW) ... 78
2.4.3 Safety Evaluation mode ... 80
2.4.3.1 Fundamentals and areas of application ... 80
2.4.3.2 Setting the frequency band and the standard for measurement ... 82
2.4.3.3 Setting the Result Type ... 85
2.4.3.4 Setting the Resolution Bandwidth (RBW) ... 87
2.4.3.5 Setting the Measurement Range (MR) ... 90
2.4.4 Scope mode ... 95
2.4.4.1 Fundamentals and areas of application ... 95
2.4.4.2 Example measurement: Time domain analysis of a DECT signal.. 96
2.4.5 UMTS mode ... 98
2.4.5.1 Fundamentals and areas of application ... 98
2.4.5.2 Selecting the UMTS signal for measurement ... 99
2.4.5.3 Setting the Measurement Range (MR) ... 101
2.4.6 LTE mode ... 101
2.4.6.2 Selecting the LTE signal for measurement ... 103
2.4.6.3 Setting the Channel Bandwidth (CBW) ... 106
2.4.6.4 Setting the Measurement Range (MR) ... 107
2.4.6.5 Setting the CP Length and Cell Sync. parameters ... 107
2.4.6.6 Particular features of LTE-TDD signal measurements ... 108

3 Determining the immission of important radio systems ... 112
3.1 Introduction ... 112
3.2 FM radio transmitters ... 114

3.2.1 Fundamentals 114
3.2.2 Frequency range, modulation method and signal bandwidth 115
3.2.3 Determining FM radio immissions with the SRM-3006 116
3.2.3.1 Measurement in Spectrum Analysis mode 116
3.2.3.2 Measurement in Safety Evaluation mode 117
3.3 DVB-T (DVB-T2) transmitters 119
3.3.1 Fundamentals 119
3.3.2 Frequency ranges, modulation method and signal bandwidths 119
3.3.3 Determining DVB-T (DVB-T2) immissions with the SRM-3006 121
3.3.3.1 Measurement in Spectrum Analysis mode 121
3.3.3.2 Measurement in Level Recorder mode 122
3.3.3.3 Measurement in Safety Evaluation mode 124
3.3.3.4 Measuring the immission of other digital TV systems 127
3.4 DAB (DAB+) transmitters 127
3.4.1 Fundamentals 127
3.4.2 Frequency ranges, modulation method and signal bandwidth 128
3.4.3 Determining DAB (DAB+) immissions with the SRM-3006 128
3.4.3.1 Measurement in Spectrum Analysis mode 128
3.4.3.2 Measurement in Level Recorder mode 129
3.4.3.3 Measurement in Safety Evaluation mode 131
3.5 Simultaneous measurement of FM radio, DAB and DVB-T 133
Original 135
3.6 GSM base stations 136
3.6.1 System parameters relevant to immission measurement 136
3.6.1.1 Frequency ranges 136
3.6.1.2 Modulation method, signal structure and bandwidth 137
3.6.2 Determining GSM immissions with the SRM-3006 140
3.6.2.1 Setting the SRM-3006 correctly 140
3.6.2.2 Extrapolation of measurement results and limit value comparison 144
3.6.2.3 Additional notes on correct measurement and extrapolation for GSM 149
3.7 TETRA base stations 152
3.7.1 System parameters relevant to immission measurement 152

3.7.1.1 Frequency ranges 152
3.7.1.2 Modulation method, signal structure and bandwidth 152
3.7.2 Determining TETRA immissions with the SRM-3006 154
3.7.2.1 Setting the SRM-3006 correctly 154
3.7.2.2 Extrapolation of measurement results and limit value comparison 155
3.8 UMTS base stations 157
3.8.1 System parameters relevant to immission measurements 157
3.8.1.1 Frequency ranges and duplex methods 157
3.8.1.2 Signal structure and bandwidth 159
3.8.2 Determining UMTS immissions with the SRM-3006 164
3.8.2.1 Introduction 164
3.8.2.2 Frequency selective measurement 165
3.8.2.4 Extrapolation of measurement results and limit value comparison 172
3.8.2.5 Comparative evaluation of both methods 177
3.9 LTE base stations 177
3.9.1 System parameters relevant to immission measurements 177
3.9.1.1 Frequency ranges, bandwidths and duplex methods 177
3.9.1.2 Transmission methods, antenna technology, and signal structure 181
3.9.2 Determining LTE immissions with the SRM-3006 189
3.9.2.1 Introduction 189
3.9.2.2 Frequency selective measurement 189
3.9.2.3 Code selective measurement 192
3.9.2.4 Extrapolation of measurement results and comparison with limit values 198
3.9.2.5 Extrapolating LTE TDD signals 208
4 Bibliography 210
5 Annex 216
5.1 Using the ICNIRP summation formulas 216
5.2 Frequency channels used for DAB and DVB-T in Germany 219
5.3 Frequency bands currently used for GSM in Germany 222
5.4 Evaluating high frequency immission measurements 222
Index 231

display during the search. The measurement space can simply be scanned until the device does not emit any more beeps, and it will then have recorded the maximum field strength within the space.
This function is disabled in the factory default setting of the *SRM-3006*. It can be activated in the **Main** menu under the **Settings** softkey (*Beep on new Maximum*).

2.4.3 Safety Evaluation mode

2.4.3.1 Fundamentals and areas of application

The following questions often need to be answered when demonstrating safety in electromagnetic fields:

- How great is the overall exposure in comparison to the permitted limit values?
- How much is each source contributing to the overall exposure?
- If the limit is exceeded, which source needs to be reduced in output power to ensure that safety at the measurement location is restored?

Although the entire spectrum of interest needs to be measured selectively in order to answer these questions, generally only a few of the results will be important: The overall exposure level, and the individual contributions to it made by the sources present in the vicinity. The total exposure level should be expressed either in absolute terms, as a field strength value, or (better) as a relative value as a percentage of the permitted limit values (total exposure quotient, TEQ; see Section 1.7).

Safety Evaluation mode of the *SRM-3006* is provided for this. It has been specially developed for the automatic measurement and evaluation of field strength exposure in a multi-frequency environment. It delivers an overview of the exposure values in units of field strength or as a percentage of a selected human safety standard value for individual frequency bands that can be defined by the user. These frequency bands are called **Services**. A measurement made using **Safety Evaluation** mode can provide direct evidence on site of compliance with defined limit values (and therefore the safety of the location under test), as well as information about the proportion of the overall exposure that is due to each of the frequency bands considered.

However, this fully automatic measurement and summation of individual signals does not yield the correct total exposure value in all situations. There are some restrictions in the use of **Safety Evaluation** mode that must be observed:

- Safety Evaluation mode determines the immissions of the individual signals present at the measurement location at the time, evaluates them against the particular limit value, and adds them together. However, the power output from the transmitter will vary considerably according to the actual loading of the station, particularly in the case of mobile communications base stations. To demonstrate compliance with the specified limit values in the case of cellular communications signals, therefore, the comparison with the limit values must not be made simply using the field strength values present at the time of the measurement. A suitable extrapolation of the fields to their values when the equipment is at maximum load additionally needs to be done (see Section 1.1 and 1.7). The exact procedure for extrapolation to maximum equipment load differs considerably for the various mobile systems (GSM, TETRA, UMTS, LTE) and is described in more detail in Chapter 3 of this guide. Automatic extrapolation of the measured values is not provided for in **Safety Evaluation** mode for the simple reason that it would be too costly to implement in the device (for example, in practice a different extrapolation factor usually needs to be applied for each different RF signal that is measured). In many cases also, the extrapolation factors are often not available before the measurement, as they are determined only after the measurement from the system data provided by the system operator or provider.
- In addition to the above, the immissions due to UMTS and LTE systems cannot be extrapolated to maximum output power with any accuracy based on the results of a purely frequency selective measurement (which is what **Safety Evaluation** mode performs). An extrapolation based on code selective measurement results gives much more accurate results (**UMTS** and **LTE** modes).
- Correct measurement and evaluation of complex signal structures (e.g. radar impulses, or the frequency hopping signals often used in GSM) is also very difficult using **Safety Evaluation** mode. To be certain that the parameter settings on the *SRM-3006* will give the correct results, comprehensive trial measurements, possibly with the aid of signal generators, are necessary before making measurements of this type. Such measurements should therefore only be made by persons with the necessary degree of experience.
- As a general rule, the assumption should be avoided that using **Safety Evaluation** mode in all applications can reliably check whether there is compliance with

limit values, even if the name of the measurement mode might seem to suggest otherwise.

However, **Safety Evaluation** is very suitable for the automatic measurement, limit value evaluation, and summation of signals that emanate from sources that do not vary in output power according to load, such as broadcast radio and TV transmitters. The following therefore uses a simple example measurement to determine the total exposure in the vicinity of FM radio and TV transmitters to illustrate the use of **Safety Evaluation** mode.

Safety Evaluation mode is also activated by a softkey in the *SRM-3006* **Main** menu.

2.4.3.2 Setting the frequency band and the standard for measurement

The frequency ranges in which the *SRM-3006* is to automatically measure and evaluate the signals must be defined first after activating this mode. This is done in the form of a table, called a **Service Table**.

Service Tables, which are the basis of **Safety Evaluation** mode, are usually created using the *SRM-3006 Tools* or *SRM-3006 TS* PC software and transferred to the *SRM-3006*. The online help for the PC software contains details on how to create **Service Tables** using the PC software. It is also possible to create the **Service Tables** directly on the *SRM-3006*, although with a limited range of functions (see the Remarks in the *SRM-3006* operating manual).

A large number of service tables can be stored in the *SRM-3006*. The manufacturer has provided some examples of such tables already stored in the device memory (with no claim that they are suitable for a particular measurement task). The list of Service tables currently stored in the device can be opened from the **Main** menu under **Settings** by pressing the **Service Table** softkey that is displayed. To see which frequency ranges have been defined for the measurement in the **Service Table**, use the jog wheel to select the table and open it by pressing the **View Service Table** softkey. Figure 2.17 shows the contents of the **Service Table** created for the example measurement that is described below.

The **Service Table** specifies the frequency ranges in which the signals are measured and added together. In the example above, the total immission in the FM radio frequency range (87.5 to 108 MHz) is to be determined without individual resolution of the signals within the band. The same applies to the other two frequency ranges defined (DAB from 174 to 230 MHz, and DVB-T from 470 to 790 MHz). Each service can be given a simple name for ease of identification (the names of the individual broadcast services have been used here).

Service Table Broadcast

Service	Fmin	Fmax	RBW
FM Radio	87.500 000 MHz	108.000 000 MHz	200 kHz
DAB Radio	174.000 000 MHz	230.000 000 MHz	10 kHz
DVB-T	470.000 000 MHz	790.000 000 MHz	50 kHz

Main Menu • Settings • Service Tables • View Service Table

Figure 2.17: Example of a simple service table for measuring FM radio, DAB and DVB-T signals.

It is also possible to specify an individual **RBW** for each frequency range (service) defined in the table. This determines the step width used for integration of the measured fields. In the above example, a coarser step width is selected for FM than for DVB-T and than for DAB in particular. The smaller the step width, the more accurate the addition, but the longer the measurement time for the particular frequency band.

The table could be made more detailed if, for example, the measurement was to determine the individual DVB-T channels that were carrying signals, and the strengths of these signals. Up to 500 separate frequency ranges (services) can be defined in one **Service Table**. This example does not require a detailed analysis, however, as it basically only distinguishes between the total immissions for each of the three broadcast services: FM radio, DAB, and DVB-T.

It is not possible to subsequently edit the table in this window, i.e. change frequency ranges or the RBW settings. The editor function in the PC software must be used for this.

To select a particular table for a measurement, select it from the overview list using the jog wheel and then press the **OK** button.

A large number of limit value data sets taken from international standards (e.g. ICNIRP General Public) are stored already in the *SRM-3006* as delivered, so that the results can be displayed relative to a particular standard limit value. Each measured field strength value can thus be compared with the selected (frequency dependent) limit value and the result displayed directly as a percentage of the limit value instead of only the absolute value. It should, however, be remembered that the manufacturer does not guarantee the correctness of the example limit value data stored in the memory of the *SRM-3006*, and that this data is also not automatically updated. Users are therefore themselves responsible for ensuring that the limit value comparison is correct. The PC software can also be used to generate individual limit value standards and save them to the device memory.

The standard (**Stnd**) is selected in the same way as the **Service Table** from the **Main** menu under **Settings** by pressing the **Standard** softkey that is shown on the right. Use the jog wheel to select the required standard and then press the **OK** button.

The **Service Table** and limit value standard that are currently being used by the device for the measurement are shown in the status line top right of the display screen (**SrvTbl** and **Stnd**). Once these initial settings have been made, the measurement can be started by pressing the **Safety Evaluation** softkey in the **Main** menu. The example selected here gives the result display shown in Figure 2.18 below.

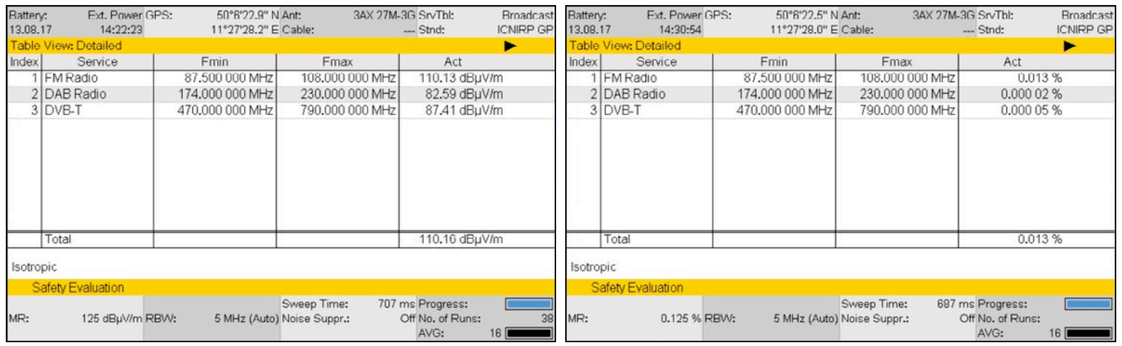

Figure 2.18: Automatic immission measurement of sound radio and TV signals in Safety Evaluation mode (left: absolute display; right: relative display as a percentage of the limit value). Measured in AUTO mode, i.e. the predefined RBW values in the service table are ignored and the device automatically selects a fixed RBW (5 MHz in this case).

The absolute results of the measurement are shown as field strength values (on the left in Figure 2.18). The total field strength generated by all the signals present in each

frequency band can be read off for each of the three frequency ranges. The total is the linear sum of the power, which means that the total field strength is the square root of the sum of the squares of all the field strength components. If power density instead of field strength is selected for the absolute display, the total immission will be the linear sum of all of the power densities present in the frequency band under consideration.

In contrast, the total immission weighted according to the limit value (shown on the right in Figure 2.18) is always determined in terms of power (also see Section 1.7). Each separate signal that is present within the frequency band under investigation is compared with its individual (frequency dependent) limit value as determined by the standard previously selected for the evaluation by the user. The percentages of the limit value that are listed in the right-hand column of the table are always determined from the signal power levels, i.e. they are calculated as the square of the quotient of the measured field strength and the corresponding limit value. This makes it possible to determine the total sum of immissions over all the frequency ranges (i.e. the *total value*) in a second step always as the linear sum of all the individual parts contributed by each frequency range. The value recorded on the right at the bottom of the result table thus corresponds to the total exposure quotient (TEQ) expressed as a percentage. As long as this value is below 100%, the requirements of the standard (e.g. ICNIRP) for immissions in the frequency range producing purely thermal effects (i.e. frequencies above 10 MHz) are met.

⚠ **Note**

It is well known that the biological effects of electromagnetic fields in the frequency range below 10 MHz are not just based on the thermal effect of the field energy, but also on a limiting of this effect by the currents generated in the body by the external fields. For this reason, the applicable specified limit values (e.g. ICNIRP) for frequencies below 10 MHz additionally require a different evaluation that encompasses a linear addition of the individual components referred to the field strength limit value. **Safety Evaluation** mode of the *SRM-3006* cannot be used to make this kind of linear addition of the individual components, however.

2.4.3.3 Setting the Result Type

The *SRM-3006* provides the same result types in **Safety Evaluation** mode as in **Spectrum Analysis** mode. The **Result Type** determines how the results of individual consecutive measurements are processed (see Table 2.3).

3.8.2.5 Comparative evaluation of both methods

It is fundamentally possible to obtain an immission value extrapolated to maximum operational system load using the frequency selective method, but the chance that the immission will be considerably overestimated is relatively high. It is also comparatively tedious to determine the extrapolation factor, as it may be necessary to obtain the values of a large number of separate parameters for different UMTS systems from the system operators. The code selective method delivers much more reliable results, with much less effort needed to obtain data from the network operators.

Code selective measurement is clearly superior to frequency selective measurement and should therefore be the preferred measurement method because of the reliable extrapolation that does not systematically overestimate the immission at maximum system load from the extrapolated field strengths of the P-CPICH signals, and the much lower effort needed to obtain data from the network operator.

Note

A further disadvantage of frequency selective immission measurement of UMTS signals should also be mentioned here: A frequency selective measurement always determines the total field strength in every frequency channel of all the UMTS signals present around the measurement location. When considering the displayed measurement results, it is therefore difficult or impossible to determine if the signal from one antenna is missing or not. A missing signal could be caused by one or more radio cell transmitters (antennas) being deactivated due to technical problems at the time of the measurement, for example. In such cases, the immission values determined by frequency selective measurement will be too low.

In contrast, a missing antenna signal is very easily seen when code selective measurement is used, since in such cases the signal with the scrambling code for the particular cell will also be missing permanently from the result table. Code selective measurement thus effectively prevents an incorrect evaluation of the immission.

3.9 LTE base stations

3.9.1 System parameters relevant to immission measurements

3.9.1.1 Frequency ranges, bandwidths and duplex methods

LTE (*Long Term Evolution*) is a mobile communications standard for high-speed data transmission and can be seen as the successor generation to UMTS (Universal Mobile Telecommunications System). LTE is actually reckoned as part of the third generation of mobile communications and is therefore labeled chronologically as 3.9G. The further development of LTE to *LTE Advanced* is formally termed as the fourth generation, or 4G. Regardless of this distinction, the general public and most official descriptions issued by system operators refer to LTE as 4G.

Substantially higher data rates are specified for LTE when compared to UMTS (3G) and the HSPA/HSPA+ (3.5G, *High Speed Packet Access*) data accelerators. LTE can achieve maximum downlink rates of 100 Mbit/s and maximum uplink rates of 50 Mbit/s (both at a bandwidth of 20 MHz). These data rates can be further increased significantly if higher value modulation techniques (64-QAM) and multiple antenna technology (2 antenna or 4 antenna MIMO) are used. Data rates of several hundred Mbit/s up to more than one Gbit/s are possible with LTE Advanced.

The spectral efficiency is thus much higher than for UMTS. As a result, this technology is primarily used for mobile broadband access to telecommunications services. Conversations can be transmitted using the *Voice over Internet Protocol* (VoIP), but data services are the primary application.

Duplex methods

The LTE standard recognizes two duplex methods that are used to separate the uplink from the downlink.

- In frequency division duplex mode (FDD), the signals for the uplink and downlink are transmitted in different frequency channels that have a fixed duplex separation.
- In time division duplex mode (TDD), the uplink and downlink are both handled by the same frequency channel. The uplink and downlink signals are transmitted at different times.

The term “uplink” refers to the communication link from the subscriber to the base station; “downlink” refers to the reverse direction.

One advantage of TDD is that asymmetric data transfer is possible (i.e. different data rates for the two directions of communication). TDD-LTE supports seven different configurations that determine how much time is allocated to the uplink and the downlink. Four of these seven configurations allocate more time to the downlink; one configuration gives the uplink and downlink equal shares. Most of the LTE networks in operation around the world use FDD mode, although in some countries, FDD and TDD networks exist side by side, particularly in Asia.

Figure 3.30 clearly shows the subframes where the LTE system is or is not transmitting a signal. Such an overview measurement can thus be used to determine which of the seven possible uplink/downlink configurations has been selected by the system operator.

Summary

The following characteristics of the signals from LTE base stations are of particular importance for the correct measurement of exposure levels:

- LTE signals can have six different signal (transmission) bandwidths between 1.08 and 18 MHz, unlike GSM and UMTS.
- LTE networks are operated as Single Frequency Networks (SFN).
- The instantaneous power of an LTE signal varies strongly over time because of the modulation method that is used; the power can vary considerably within the space of a few microseconds.
- The radiated average power varies slowly compared to the variation caused by the modulation. The variation is dependent on the system load at the time. The typical load dependent variation has a maximum depth of from 6 to 10 dB.
- Depending on the selected uplink/downlink configuration there is an additional effect on the average power emitted by the antenna for LTE TDD signals, because the base station does not transmit in all ten subframes of a radio frame.
- The Reference Signal (RS) that is distributed across the entire signal spectrum is of particular importance for exposure measurements. This signal is output by each base station at a constant, clearly defined power. A measuring device that is capable of separating this signal – like the P-CIPCH for UMTS – and determining its individual receive level at the measurement location (code selective measurement) makes it possible, regardless of the actual load, to extrapolate the measured exposure level to maximum system load if the power ratio between the RS and the maximum system load is known.

The next Section gives more information about the various measurement methods for LTE base stations.

3.9.2 Determining LTE immissions with the SRM-3006

3.9.2.1 Introduction

There are two basic ways to determine the immissions of individual LTE signals:

- Frequency selective measurement of the signals in the individual LTE frequency channels.
- Code selective measurement of the RS signals present in one LTE channel.

As the following will show, the frequency selective measurement only allows a very imprecise extrapolation to the immission that would be present at maximum system load, whereas the code selective measurement ensures the best possible determination of the immission.

The code selective measurement is therefore the preferred method.

3.9.2.2 Frequency selective measurement

A measurement of LTE immissions resolved into individual frequencies can of course be made using **Level Recorder** in a similar way to the immission measurement for UMTS systems described in Section 3.8.2.2, for example. A frequency selective measurement using **Spectrum Analysis** mode or **Safety Evaluation** mode is not recommended because the signals to be captured with the frequency selective measurement method are only very briefly present during a radio frame, so the signal to be measured must be captured without any gaps if possible. This is ensured if **Level Recorder** mode is used.

A frequency selective measurement over the entire bandwidth of an LTE signal would give a result that was strongly dependent on the actual loading of the system, due to the load dependent power radiation that is typical of LTE, similar to UMTS. An extrapolation to maximum power would only be very approximate – again, similar to UMTS base stations – since the actual load state at the time of the measurement is unknown.

For this reason, only the immissions generated by signals that are not load dependent are measured to form the basis for an extrapolation that is as accurate as possible for LTE. In particular, the primary and secondary synchronization signals (P-SS and S-SS) as well as the physical broadcast channel (PBCH) are suitable for this. These signals are transmitted at constant power every 5 or 10 ms and occupy the central part of the LTE signal spectrum with a bandwidth of about 1 MHz [BOR 12].

Figure 3.31 shows a typical LTE spectrum (signal bandwidth: 9 MHz), which will be used to explain the fundamental procedure for frequency selective measurement. It can be clearly seen that the central part of the spectrum has a stable, non-load dependent, and often slightly higher level than the rest of the spectrum due to the regularly transmitted signaling signals. This is easily seen in Figure 3.31, as there was little traffic being transmitted at the time of the measurement. At full load, the areas of the spectrum outside this central part would assume greater values so that they would at most have the same level as the central part of the spectrum.

If the measurement is restricted to just the central part of the spectrum occupied by the P-SS and S-SS (these occupy 62 RE per symbol, i.e. 930 kHz) or the PBCH (72 RE per symbol, i.e. 1.08 MHz), the result displayed will be the maximum of the P-SS, S-SS and PBCH.

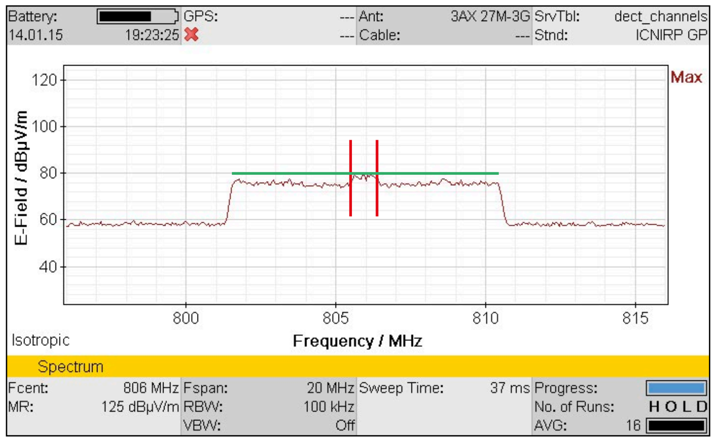

Figure 3.31: Spectrum of an LTE signal with low traffic load. The two vertical red lines in the center mark the area of the spectrum for which the power is measured in a frequency selective measurement.

The values to be set for the **RBW** and **VBW** for the measurement have been investigated in detail in [KEL 10], [KEL 11]. According to these works, 800 kHz is the optimum value for the **RBW**, as this gives the best selection of the central part of the spectrum containing the constant power level components P-SS, S-SS and PBCH. In practice, the measurement result is often dominated by the P-SS and S-SS synchronization signals, because these signals are frequently transmitted at a somewhat higher power level than the PBCH (so-called *synch boost*).

[KEL 10], [KEL 11] also recommend a **VBW** of 2 kHz for smoothing the variable envelope in the time domain, since no additional corrections to the result are needed at this value, and the measurement uncertainty is close to optimal.

The *SRM-3006* in **Level Recorder** mode should be set as follows in order to determine the field strength generated by the signals in the central part of the spectrum shown in Figure 3.31:

Mode	**Level Recorder**
Result Type	**Peak**
Fcent	Signal center frequency of the LTE signal to be measured.
MR	Depending on the strength of the signals to be measured.
RBW	**800 kHz**; the selection filters do not have an ideal rectangular frequency response, so a somewhat smaller RBW must be selected to ensure that no signal power outside the central 1 MHz of the signal spectrum passes through the filter.
VBW	**2 kHz** (RBW/400); serves to smooth out the rapid power variations in the signal.
Unit	Absolute (dBµV/m) result display.

The **Peak** result type should be chosen in preference to **RMS** because the determination of the correct, smoothed RMS immission value using the video filter is set so that any areas with lower power between two synchronization signals within a radio frame (i.e. at low traffic load, see Figure 3.29) will not affect the measurement result. The **RMS** result type would totally include these areas in the formation of the average, which could lead to an underestimation of the immission.

Figure 3.32 shows a typical result for a correct measurement of the central part of the spectrum of an LTE signal using **Level Recorder** mode of the *SRM-3006*.

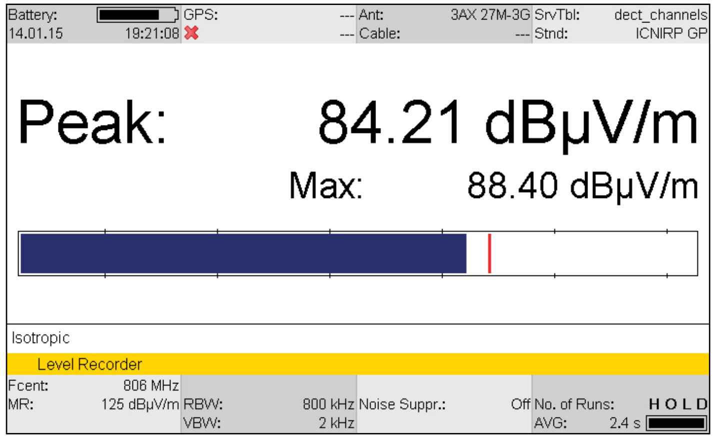

Figure 3.32: Result of the measurement of the central portion of the spectrum of an LTE signal (center frequency 806 MHz) using Level Recorder mode of the SRM-3006.

Where several LTE signals are present, the measurement can be repeated in the next relevant channel simply by altering the center frequency **Fcent**. All other parameters can be left unchanged (the **MR** may also need adjustment).

The results of mobile communications immission measurements should be displayed by the device as absolute level values (i.e. in dBµV/m) and not as a percentage of the limit value. The extrapolation and subsequent comparison with the limit value for LTE mobile communications immissions is also performed apart from the *SRM-3006* (e.g. using an Excel table), as is explained in more detail in Section 3.9.2.4.

3.9.2.3 Code selective measurement

In practice, the determination of the immission of an LTE system by extrapolation of the central portion of an LTE spectrum is quite inaccurate. Since LTE operates in a single frequency network, the same problems occur as with frequency selective measurement of UMTS signals (e.g. no separation of signals from individual antennas). A determination of the immission based on the RS (Reference Signals) is much more satisfactory, because these signals have the following two properties:

- RS signals are radiated by every MIMO antenna path at constant output power.
- The RS signals are also coded cell-specifically just like the P-CHPICH for UMTS, so that a code selective receiver can be used to determine the field strength caused by each individual RS. In addition to this cell-specific coding, it is also possible to measure the RS of each MIMO channel separately and display the result.

The RS signals are therefore ideally suitable for cell-specific measurement and extrapolation of LTE signals. It is true that the synchronization signals (P-SS and S-SS) are also coded cell specifically, but separation according to MIMO paths is not possible with these signals, which is a distinct disadvantage when compared with analysis using the RS signals.

Two different modes are provided in the *SRM-3006* for code selective measurement of LTE signals (**LTE FDD** and **LTE TDD**). The main functions of these two modes are identical and are described in more detail in Section 2.4.6. Operation of this mode is very simple: After activating the mode from the **Main** menu, it is only necessary to set the correct center frequency of the LTE signal. This setting must be made to the nearest 0.1 MHz, otherwise the instrument will not demodulate the signal correctly and the result table will remain empty or will deliver comparatively low and unstable results. As with UMTS, the actual LTE signal center frequencies set by the system provider do not have to correspond exactly to the channel center frequencies (center frequency setting can be varied in 0.1 MHz steps).The system operator should therefore be asked for this information, although the signal center frequencies can be determined quite easily on site by trial and error because the deviation from the channel center frequency can only be a few 100 kHz at most.

Unlike UMTS, the individual radio cells are not differentiated by means of scrambling code numbers but by the so-called *Physical Cell ID* (a value between 0 and 503) for each radio cell. These do not need to be known, as the *SRM-3006* decodes them automatically. The display on the measuring device will typically look like Figure 3.33. The result type **Max** should be selected so that the sweeping method can be used to determine the spatial field strength maximum. It is also possible to observe the results of the current measurement run by additionally selecting the result type **Act**.

Clearly, two transmission paths per radio cell are used for the signals detected in the example above because **RS 0** and **RS 1** are always detected. The *SRM-3006* can measure up to four MIMO paths individually (**RS 0** through **RS 3**). The instrument also determines how many MIMO paths are being used to radiate the signals of a radio cell and displays this in the third column of the table from the left (**No. Ant.**).

Either the **Max** values of the individual RS signals (**RS 0** through **RS 3**) or just the value of the largest of these (**RS Max**) can be used as the basis for the extrapolation to maximum output power. Details on how to evaluate the measurement results are given in the next Section.

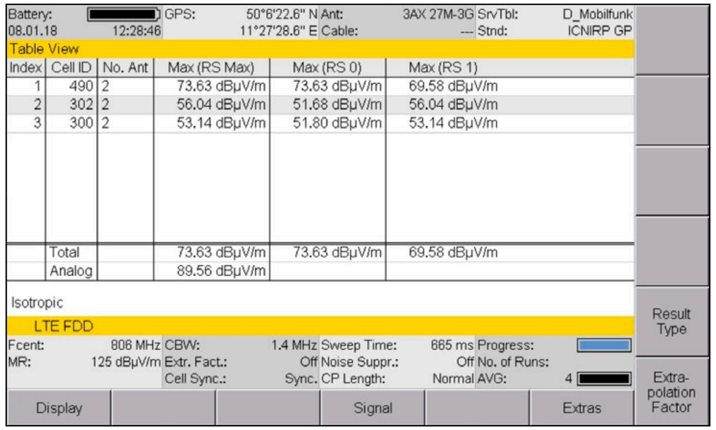

Figure 3.33: Typical result display of a code selective LTE measurement. In this example, an isotropic measurement has found the RS signals of three radio cells in the frequency channel under investigation (signal center frequency: 806 MHz).

Note

When using the **RS Max** values as the basis for the extrapolation to maximum system load, it is a good idea to also always display the individual values of all the MIMO channels in the radio cell, as shown in Figure 3.33 (**RS 0** and **RS 1** in this example). This makes it easier to see if, for example, a MIMO channel with an unexplained low level is present (individual MIMO channels are usually transmitted each at the same power), or if a channel has been completely deactivated, which would not be easy or even impossible to recognize if only the maximum value of all RS signals for a radio cell is considered (**RS Max**). Such irregularities could be caused by a technical fault in the transmitter. Nevertheless, some LTE system technology gives the provider the option of completely deactivating individual MIMO channels for a time when the traffic volume is low in order to save energy. If immission measurements using **RS Max** as the basis for extrapolation are made during such a period, this could in some cases result in an underestimation of the immission as one of the currently deactivated MIMO channels at the measurement location can easily have a greater immission value than can be generated by those channels that are currently active. As can also be seen from Figure 3.33, the measurement results for the individual MIMO channels of one antenna can in practice be significantly different from one another even if the radiated power is the same, because the antennas used to transmit the individual MIMO signals will never have completely identical radiation characteristics. However, this kind of incorrect evaluation can be prevented if the measurement results for the individual MIMO channels are also observed.

Some measurement recommendations (e.g. [PYT 12]) suggest always using the measured value for **RS 0** as the basis for the extrapolation, regardless of the number of actual MIMO channels, because the signal for this antenna path cannot be switched off. However, a certain underestimation of the immission cannot be completely excluded if this method is used.

As already explained in detail in the introduction to the **LTE FDD** and **LTE TDD** measurement modes of the *SRM-3006* (Section 2.4.6.3), the instrument provides the facility for adjusting the bandwidth for RS capture to the actual signal bandwidth. However, in practice it is usually enough to always leave the measurement bandwidth set to the smallest possible value (**CBW** = 1.4 MHz) to keep the measurement time as short as possible. If an isotropic probe is used, the measurement time will then be about around 0.7 seconds, which means that the antenna must purposely be moved slowly within the measurement space if the sweeping method is used, to allow measurement with all three orthogonal antennas to be made at the same position each time. The time taken for each measurement is reduced to about 0.4 seconds if a single-axis antenna is used.

The RS signals can of course be measured using a greater **CBW** but this will also lead to a considerable increase in the time needed for a measurement run, so that the sweeping method can no longer be sensibly used. However, current research has shown that the results for the RS field strength are not significantly different if the smallest possible measurement bandwidth (**CBW** = 1.4 MHz) is used rather than measurement over the entire signal bandwidth [BOR 18].

What must be avoided at all costs is a measurement using a **CBW** setting on the instrument that is greater than the bandwidth of the LTE channel currently being measured, e.g. measuring in a 10 MHz channel with a **CBW** of 20 MHz. In such cases, the *SRM-3006* will also measure outside the actual LTE spectrum that is present, which would include the results from outside the spectrum (i.e. generally only noise with a comparatively low power level) in the formation of the average, leading to an incorrect (too low) end result.

Note

Code selective measurements have a comparatively limited relative sensitivity, regardless of the measuring device that is used. This means that RS signals present at the measurement location that are much weaker than the strongest RS signal received will not be decoded and so will not appear in the Table. When all the LTE signals in the channel under investigation are roughly the same strength, the *SRM-3006* will usually produce a very comprehensive result table. If, however, there is one dominant signal and several comparatively weak signals present at the measurement point, only the dominant signal may be shown in the table in the extreme case.

The relative sensitivity is at least about 15 dB, which means that RS signals that are more than 15 dB weaker than the strongest RS signal measured in the frequency channel may no longer be displayed. Thus, it is possible that only two of the three signals will be shown in the table for some measurement points when

making a measurement in the vicinity of an LTE site having three radiating antennas arranged horizontally at 120° to each other, and the weakest signal will be missing.
It can, however, be assumed that the signal that is not displayed is at least about 15 dB weaker than the strongest signal measured, so that its contribution to the total immission in terms of power is only about 3% and is therefore negligible in comparison to the typical measurement uncertainty for such high frequency exposure measurements.

In summary, here are the correct parameter settings for the *SRM-3006* for a code selective measurement of the RS signals in an LTE channel:

Mode	**LTE**
Result Type	**Max** (possibly also **Act**).
Center Frequency	Signal center frequency of the LTE to be measured
CBW	**1.4 MHz** (this achieves the highest measurement speed)
Signal to be measured	**RS Max** (additionally **RS 0** … **RS 3**)
Cell synchronization	"Synchronized" (**Sync.**); default setting (see Section 2.4.6.5)
CP	CP length **Normal**; default setting (see Section 2.4.6.5)
MR	Depending on the strength of the signals to be measured (**MR** should be set to at least 30 dB more than the strongest reference signal currently recorded in the result table).
Unit	Absolute (dBµV/m) result display

The results of mobile communications immission measurements should be displayed by the device as absolute level values (i.e. in dBµV/m) and not as a percentage of the limit value. The extrapolation and subsequent comparison with the limit value for LTE mobile communications immissions is also performed apart from the *SRM-3006* (e.g. using an Excel table), as is explained in more detail in Section 3.9.2.4.

Code selective measurement of LTE TDD signals

Code selective measurement of LTE TDD signals is basically the same as for FDD signals, i.e. with the same settings of the *SRM-3006* as listed above, except for the measurement mode which must be set to **LTE TDD**. This is a special device option that must be activated before it can be used.

The only difference from LTE FDD in the result display screen is the additional **Up /Downlink Configuration** softkey and the corresponding display of the uplink/downlink configuration setting used by the device to decode the LTE TDD signal (outlined red in Figure 3.34).

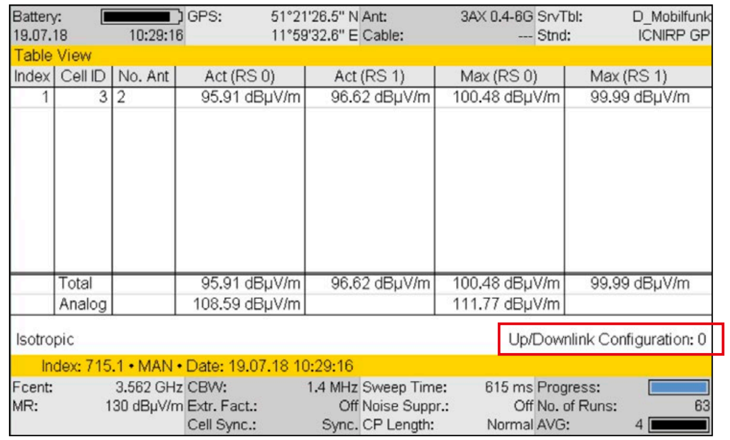

Figure 3.34: Result display for an LTE TDD measurement.

Regardless of the uplink/downlink configuration setting used for the LTE signal by the service provider, it is always best to select **Up/Downlink Configuration 0** for the measurement using the **Up/Downlink Configuration** softkey. This is also the factory default setting. In this setting, the *SRM-3006* only measures in subframes 0 and 5, which are used exclusively for the downlink in all seven configurations, thus avoiding the possibility that the measurement will be made in subframes in which the base station is not transmitting at the time (see Table 3.11).

If the configuration selected by the service provider is known and is the same for all radio cells, then it is of course possible to explicitly select this configuration from the Configuration menu of the measuring device. In such cases, the measurement time periods will be adjusted to coincide with the subframes occupied by downlink