Applicaton Note

GSM measurements with the Selective Radiation Meter SRM-3000

Determining exposure levels due to mobile phone transmitting equipment in the 900 and 1800 MHz frequency bands

GSM – Global System for Mobile Communication – is the most widely used mobile telephone system. It is therefore often a significant factor in any assessment of the effects of electromagnetic fields on humans and animals. On the one hand this is because of the field emissions, which are quantifiable, and on the other hand because of the impression that results from the proliferation of mobile phone transmitter antennas.
This Application Note describes the use of the SRM-3000 to measure the field emission of GSM transmitting equipment and the evaluation of the results with regard to aspects of human safety.

Typical site with several mobile phone antennas for GSM 900, GSM 1800 and UMTS

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1 Background

GSM combines several techniques for transmitting voice and data signals.

Frequency channels – Timeslots

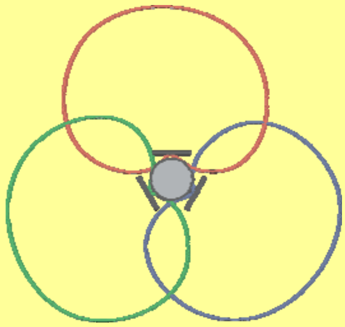
GSM uses several frequency channels (carriers) spaced 200 kHz apart. Each of these frequency channels contains eight timeslots (or time channels). Each timeslot carries just one voice channel, so each carrier can handle up to eight subscribers in one direction – uplink or downlink.

Frequency channels: BCCH and TCH

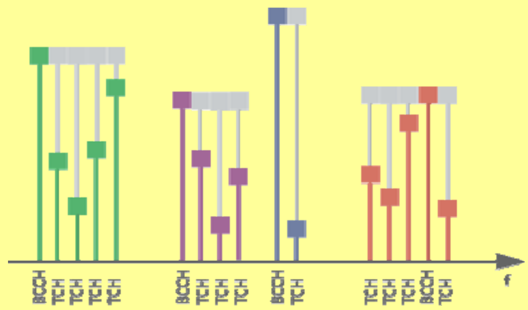
Each base station provides a base channel with information about the network and the base station itself. This channel occupies a specific frequency band and is called the Broadcast Control Channel (BCCH). It is transmitted at practically constant field strength. One or more frequency channels, called traffic channels (TCH) are added to this for transmitting voice and data signals. The field strength of these channels varies with the load, and they can also be switched off completely. Frequency hopping is also possible, where an existing connection is switched to different frequency channels without interruption.

Instantaneous and maximum field strength

Most measurements are generally more concerned with the area close to the transmitter site, and hence with the downlink field strength which predominates in this region. Long-term measurements over a period of 24 hours determine the maximum for the day. The worst case field strength, i.e. the maximum field strength when all TCHs are fully loaded, can be calculated from the practically constant field strength of the BCCH.



Typical arrangement
of mobile phone antennas as seen from above.
These are the most common type of antenna, sector antennas, which each cover an angle of 120 º. Each sector is supplied by just one base station, so it is characterized by a single BCCH.
Several such arrays may be installed at a single location.



Typical mobile phone channel frequency spectrum.
The field strength of the BCCHs stays almost constant, while that of the TCHs varies according to the load.

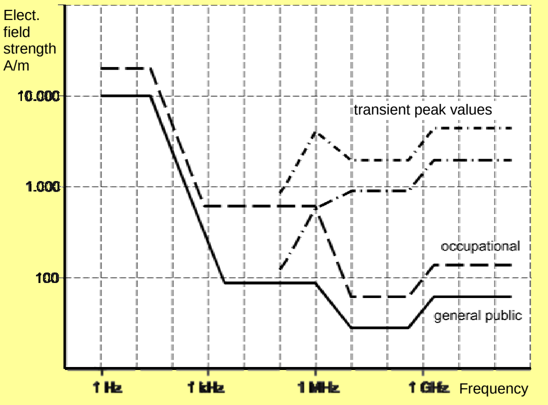
Global System for Mobile Communication	
GSM 850 (America)	824 – 849 MHz (uplink), 869 – 894 MHz (downlink)
GSM 900 incl. GSM-R (Railway)	876 – 915 MHz (uplink), 921 – 960 MHz (downlink)
GSM 1800	1710 – 1785 MHz (uplink), 1805 – 1880 MHz (downlink)
GSM 1900 (PCS 1900; America)	1850 – 1910 MHz (uplink), 1930 – 1990 MHz (downlink)
Carrier spacing	200 kHz
Channels per carrier	8 timeslots (channels) per TDMA frame (4.615 ms)
Modulation	GMSK (Gaussian Minimum Shift Keying)
Access type	TDMA (Time-Division Multiple Access)
Power control	in 2 dB steps over a 30 dB range

Left: Overview of common GSM frequencies and other GSM properties.
Uplink: From mobile phone to base station.
Downlink: From base station to mobile phone. This is usually the subject of the measurements.
Many service providers state the channel numbers of the channels they use, rather than the frequencies.
Calculation of the corresponding frequencies from the channel numbers is described in the Annex.

2 Standards and regulations

In 1998 the International Commission for Non-Ionizing Radiation Protection (ICNIRP) published its "Guidelines on Limiting Exposure to Non-Ionizing Radiation" [1, 2]. These guidelines include frequency-dependent limit values in the form of two different limit value curves: a higher one for protection in the work environment (occupational) and a lower one for the general public. The higher values apply in controlled areas where safety measures have been taken and which are only accessible to specially trained personnel. This applies, for example, to mobile phone antenna sites, for which operators have to define safe distances.

The limit values, as well as their division into two parts, are reflected in the European guidelines. Occupational safety is governed by Guideline 2004/40/EC of 29 April 2004 [3], whereas Recommendation 1999/519/EC [4] for protecting the general public was published much earlier, on 12 July 1999. In addition, many countries have their own national standards, most of which are based on the ICNIRP limit values, although some specify lower levels for the limit values.



ICNIRP limit value curve for electric field strength.

3 Preparing for measurement

GSM measurements can generally be made "on the move". The measuring antenna can be mounted directly on the SRM basic unit or connected to it by the 1.5 m long RF cable for this purpose.

The three-axis (isotropic) E-field antenna is recommended for making measurements using the **dot matrix method**, where specific points in the space are measured according to a fixed pattern. The SRM basic unit then determines the isotropic (non-directional) result for each measured point automatically.

Either the three-axis or the single-axis E-field antenna can be used for the **pendulum method**, where the spatial volume is swept continuously. If the antenna is connected to the SRM basic unit using the 1.5 m long RF cable, the instrument can be attached to a belt and the antenna panned through the space by hand. The single-axis antenna should be rotated during panning to take account of the polarization of the field. This is not necessary if the three-axis antenna is used.

A tripod with antenna holder for single- and three-axis antennas is only needed if dot matrix method measurements are to be made using a single-axis antenna. A measurement must be made in all three spatial directions at each point in the space. The SRM basic unit then calculates the isotropic result from the three separate measurements, but this procedure is quite laborious (see "Isotropic measurements with a single-axis antenna" in the SRM Operating Manual).

The measurement equipment
depends on the measurement task.
The full measurement equipment setup comprises

- *SRM mainframe with latest firmware (download from www.narda-sts.de),*
- *Three-axis (isotropic) E-field antenna of the SRM-3000 up to 3 GHz*
  – or –
  Single-axis E-field antenna for the frequency range up to 3 GHz,
- *RF cable, 1.5 m,*
- *AC adapter/charger or spare rechargeable battery if no AC line power available at measurement site,*
- *Writing materials for recording details of measurement setups, local conditions, frequencies, measurement settings and possible sources of interference*
  – or –
  Notebook PC with latest SRM-TS PC software for controlling the SRM, saving measured values, and recording comments (download from www.narda-sts.de)

And, if using the matrix method with single-axis antenna:

- *Tripod*
- *Antenna holder for single- and three-axis measuring antennas*
- *RF cable, 5 m.*

4 Measurement settings for "Spectrum Analysis"

The following descriptions refer to measurements in "Spectrum Analysis" mode, which is most often used for GSM. Measurements in "Safety Evaluation" mode may be advantageous if the mobile phone service providers and the frequency bands they occupy are known. These measurements are described in section 9.

Setting the measurement range (MR)

In most cases, the automatic "MR Search" function will be the quickest way to set the measurement range.

The measurement range *must* be set manually only when field strengths from impulse type sources such as radar located nearby predominate (see Application Note AN_HF_1003 "Radar Measurements").

The setting *can* of course be made individually following the results of an overview measurement.

Overview measurement

An overview measurement of the entire available frequency range setting (Full Span) is always recommended if there are other dominant field sources in the vicinity of the GSM transmitting equipment such as radio transmitters, which can affect control of the measuring instrument (Figure 1). Settings:

- Resolution Bandwidth RBW: **5 MHz**
- Result Type: **MAX**

Starting from a large measurement range **MR** (low sensitivity), the MR is progressively reduced (sensitivity increased) until the spectrum becomes clearly separated from the noise signal. Using the "Highest Peak" marker function, the field strength of the highest spectral line peak is read off and the measurement range set to approximately twice this value.

Setting the frequency range (Span)

It is sensible to restrict the frequency range to the frequencies of interest to achieve good screen resolution and fast measurement speeds. The upper and lower frequency limits can be selected using "Fmin / Fmax" or the zoom functions can be used for this (Figures 2, 3; also refer to the Operating Manual).

Setting the resolution bandwidth (RBW)

Since GSM uses a channel spacing of 200 kHz, a resolution bandwidth of 200 kHz is also sufficient to resolve the spectrum into individual channels. The SRM uses a special algorithm to ensure that the real value is displayed when making evaluations with the Peak Table or using the Highest Peak marker function even if the selection filter is not exactly tuned to the channel center frequency. This does not apply if the marker is positioned using the rotary control.

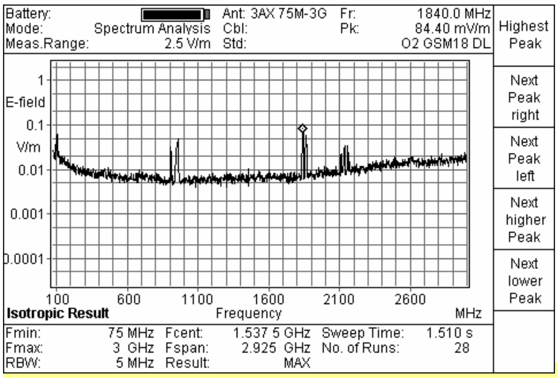


Figure 1: Check measurement shows fields due to GSM-900 and GSM-1800, with UMTS at 2100 MHz.

Measurement settings:

Minimum Frequency	*75 MHz*
Maximum Frequency	*3 GHz*
Resolution Bandwidth	*5 MHz*
MR Range	*Depends on field situation; 2.5 V/m in this case*
Unit	*V/m*
Result Type	*MAX*

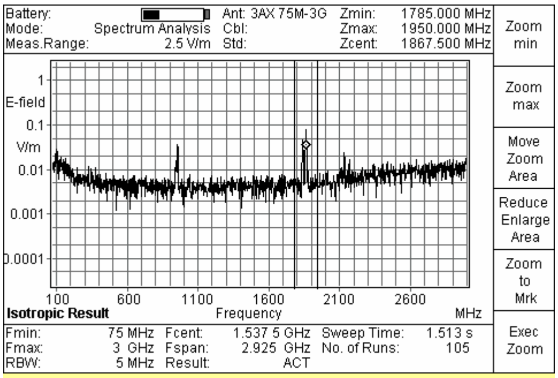


Figure 2: The frequency range can also be set using "Zoom min / Zoom max".

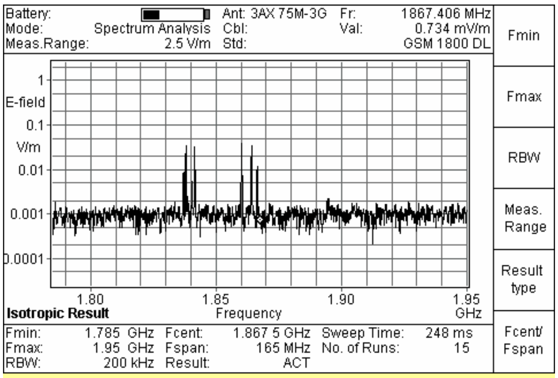


Figure 3: GSM-1800 downlink spectrum.

Measurement settings *as above, except:*

Minimum Frequency	*1.785 GHz*
Maximum Frequency	*1.95 GHz*
Resolution Bandwidth	*200 kHz*

Setting the Result Type
The Result Type depends on the purpose of the measurement and the standard or regulation used to assess the results.

5 Measuring the instantaneous field exposure level

- Result Type setting: **ACT**

The SRM displays the instantaneous field exposure level at the measurement site. This setting is useful for finding hot spots (points of highest field strength in the space) or for detecting BCCHs and TCHs (see section 8).

Spatial Averaging with the SRM-3000 and an isotropic E-field antenna.

6 Measuring the average field exposure level

- Result Type setting: **AVG**

The SRM displays the time-averaged field exposure value at the measurement site. An averaging time of 6 minutes, which is required by many standards and regulations, can be set using CONF and the “Configuration Spectrum Analysis Mode” menu.
The SRM permits spatial averaging over several measurement locations using the “Spatial Averaging” function, which is accessed from the “Result Type” softkey. This does not affect the time average setting (ACT, AVG, or MAX).

Save and evaluate the results as described in section 10.

7 Measuring the maximum field exposure level by the pendulum method

- Result Type setting: **MAX**

The SRM records the maximum value that occurred for each frequency while the antenna was panned through the space being tested. This method is therefore a “worst case” investigation, since the maxima do not have to occur at one and the same place or even at the same time. Frequency hopping alone simulates a field exposure level when this method is used that does not correspond to reality, because just one switched channel will “leave behind” a number of spectral lines. Nevertheless, this method is used to be sure that limit values have definitely not been exceeded.

Save and evaluate the results as described in section 10.

8 Determining the maximum field exposure level by BCCH measurement

The measurement is simple if the frequencies of the BCCHs of interest are known, e.g. those of a particular provider. The frequencies can be requested from the service providers. However, even when they are not known, they can be determined with a little patience:

- Result Type setting: **ACT**

just as for the measurement of instantaneous field exposure. The BCCHs are recognizable by the fact that their field strength hardly varies at all, in contrast with that of the TCHs.
Read off the frequencies from the spectrum using the marker or determine and record them using the Peak Table (Figure 4).

The actual measurement can now be performed, this time using

- Result Type setting: **MAX** or **AVG**
  depending on the standard or regulation that applies.

Extrapolation using the formula below is initially necessary if the cell is not operated at its maximum permitted power level P_{max}:

$$E_{BCCH\,\max} = E_{BCCH} \bullet \sqrt{\frac{P_{\max}}{P_{BCCH}}}$$

Information given by the service provider is needed to determine the ratio of the permitted output power level P_{max} to the actual power level P_{BCCH}.

The total field strength $E_{\max}$ of a cell that would occur if all TCHs were fully loaded is extrapolated from the field strength of the BCCH, $E_{BCCH\,max}$, using the following formula:

$$E_{\max} = E_{BCCH\,\max} \bullet \sqrt{n}$$

where n is the *total* number of traffic channels, *including* the BCCH. The possible number of traffic channels depends on the hardware installation, and must be obtained from the service provider.

Typically, there will be three BCCHs from one provider and possibly further BCCHs from other providers to be measured at a given site. The total field exposure level will then be

$$E_{total} = \sqrt{E^2_{\max 1} + E^2_{\max 2} + \ldots + E^2_{\max m}}$$

where m is the number of BCCHs.

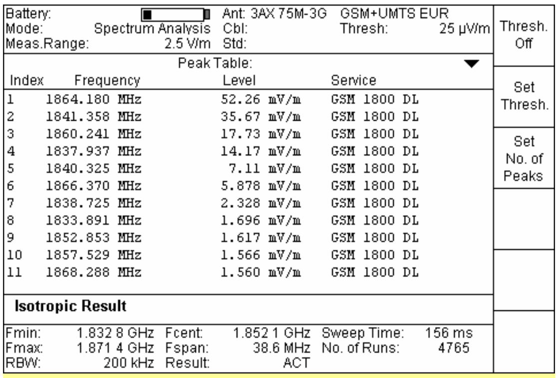


Figure 4: The Peak Table shows the spectral lines with the highest field strengths automatically. Since the values vary only slightly with time, they are most likely the values for the BCCHs.

9 Measurements in “Safety Evaluation” mode

The SRM 3000 “Safety Evaluation” mode can be useful if a quick assessment of the overall field situation is required, since the results can be displayed directly as a percentage of the permitted limit value. The limit values for various standards are stored in the instrument. This does however require that corresponding Service Tables are stored in the instrument. These define the frequency ranges of GSM bands or different partial bands according to service providers or groups of cells, for example.

Recommended settings:

- Resolution Bandwidth RBW: **Automatic**
- Measurement Range MR: as described in section 4
- Result Type as specified by the standard or regulation to be applied to the result evaluation.

Example: Factory-defined Service Table “GSM + UMTS Europe” and Result Type ACT (Figure 5). Here, the SRM shows the instantaneous field strength values in power density units, split up according to uplink (UL) and downlink (DL) for GSM 900, Extended GSM 900, GSM 1800 and UMTS. “Others” records the field strengths that lie between the defined frequency bands.

Example: Service Table specially created for the measurement location and Result Type ACT (Figure 6). Here, the instantaneous field strength values are shown directly as percentages of the permitted limit values, split up according to service providers. Only the downlink (DL) is of interest for this measurement. Very low measured values may be distorted by ambient noise so a threshold value (Noise Threshold) can be set. The SRM displays results below this threshold as “below threshold” (e.g. <0.0000011 %). Such values can be ignored anyway when calculating the overall exposure level.

With Result Type MAX, the SRM retains the maximum value that occurred in each case during the measurement duration (Figure 7).

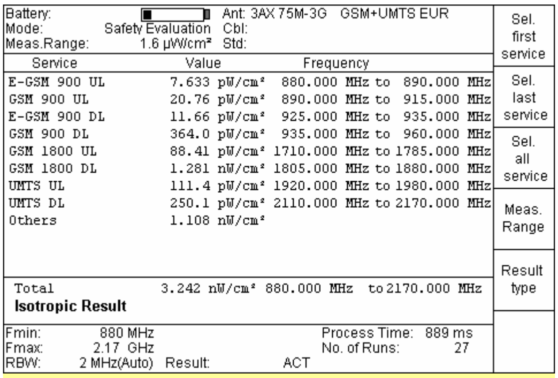


Figure 5: Safety Evaluation using the factory defined “GSM + UMTS Europe” Service Table and Result Type ACT. Results are displayed in units of power density.

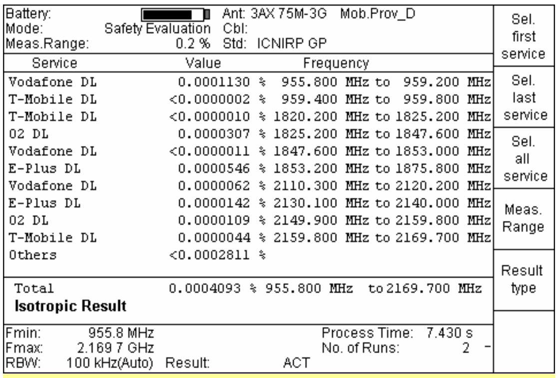


Figure 6: Safety Evaluation using a Service Table specially created for the location, and Result Type ACT. Results are displayed as a percentage of the limit values specified by ICNIRP GP (general public).

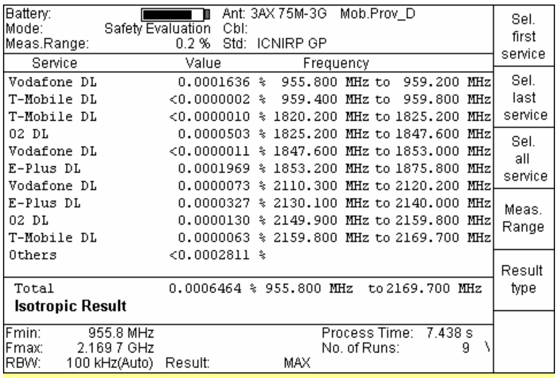


Figure 7: Safety Evaluation as above but using Result Type MAX.

10 Evaluating results and creating a test report

The client requesting measurements of field emissions is ultimately interested in knowing whether field strengths are within the permitted limit values, or which service provider is exceeding the limits (and by how much) and who therefore needs to reduce output power. Hence, an assessment of the results relative to the limit values is part of the evaluation.

Spectrum evaluation using Integration over Frequency Band

This function of the SRM or the SRM-TS PC software allows automatic integration of several spectral lines or regions of the spectrum (Figures 8, 9). For example, results can be integrated over the frequencies occupied by a service provider. The field exposure caused by the antennas of this provider can then be read off directly in figures. The display can be subsequently switched between field strength and power density units. This simplifies comparison with the permitted limit values.

Spectrum evaluation using the Peak Table

Evaluation using the Peak Table (Figure 10) is most convenient when it comes to assessing the field strengths of individual channels belonging to a given provider. Here too, the units can be subsequently switched to allow easy comparison of the results with the limit values. Extrapolation of the instantaneous field strength to the maximum possible field strengths is described in section 8 above.

Accounting for measurement uncertainty

Measurement uncertainty must be taken into account in all results. Please refer to our Application Note "Accounting for Measurement Uncertainty in the SRM-3000" (AN_HF_1004).

A measurement report is usually prepared to record the evaluation and assessment. The SRM-TS PC software is very useful for this. The measurement data can be copied directly into the measurement report using simple copy and paste functions, or the measurement data sets can be exported to standard spreadsheet applications.

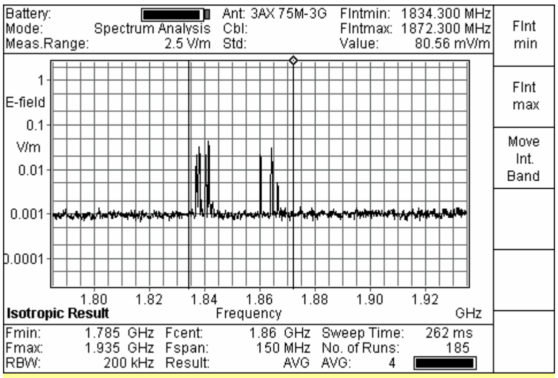


Figure 8: Spectrum evaluation using Integration over Frequency Band. All the spectral lines in the GSM 1800 downlink range are included.

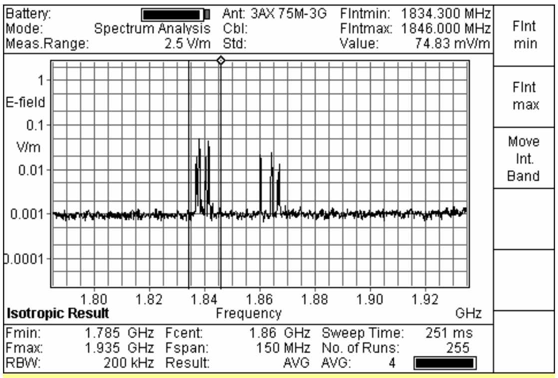
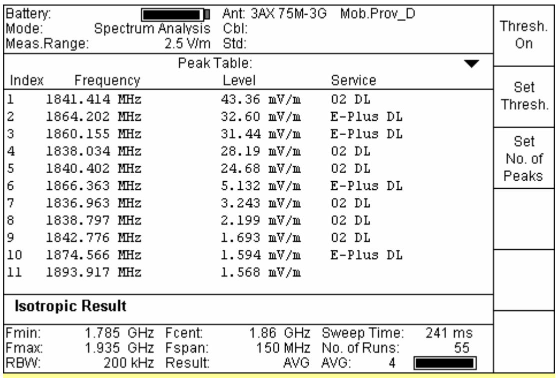


Figure 9: As Figure 8, but with restriction of the integration range to the spectral lines from one operator. The result (Value) can be read of directly as a numerical value.



Index	Frequency	Level	Service
1	1841.414 MHz	43.36 mV/m	O2 DL
2	1864.202 MHz	32.60 mV/m	E-Plus DL
3	1860.155 MHz	31.44 mV/m	E-Plus DL
4	1838.034 MHz	28.19 mV/m	O2 DL
5	1840.402 MHz	24.68 mV/m	O2 DL
6	1866.363 MHz	5.132 mV/m	E-Plus DL
7	1836.963 MHz	3.243 mV/m	O2 DL
8	1838.797 MHz	2.199 mV/m	O2 DL
9	1842.776 MHz	1.693 mV/m	O2 DL
10	1874.566 MHz	1.594 mV/m	E-Plus DL
11	1893.917 MHz	1.568 mV/m	

Figure 10: Using the Peak Table to evaluate the spectrum.

Annex: Calculating the frequency from the channel number

Service operators often only quote the numbers of the occupied channels for their base stations. These numbers are so-called ARFCNs (Absolute Frequency Channel Numbers). The frequencies that correspond to these channels are easily calculated if the following values are known:

Using the SRM-TS and SRM-Tools PC software, you can simply enter the channel numbers for the major systems GSM 900 (Primary) and GSM 1800. The software automatically calculates the corresponding frequencies.

- Start frequency: Lower limit of frequency band used
- Channel offset: Defined calculated value
- Frequency offset: Frequency difference between uplink and downlink

The values for the most common systems are given in the table below. The following equations are used to calculate the frequencies:

$$f_{uplink} = f_{start} + (ARFCN - N) \bullet 0.2MHz$$

$$f_{downlink} = f_{uplink} + f_{offset}$$

Example for GSM 900 P (Primary):

$$f_{uplink} = f_{start} + (ARFCN - N) \bullet 0.2MHz = 890MHz + ARFCN \bullet 0.2MHz$$

$$f_{downlink} = f_{uplink} + f_{offset} = 890\,MHz + ARFCN \bullet 0.2\,MHz + 45\,MHz$$

Example for GSM-R (Railway)

$$f_{uplink} = f_{start} + (ARFCN - N) \bullet 0.2\,MHz = 890\,MHz + (ARFCN - 1024) \bullet 0.2\,MHz$$

$$f_{downlink} = f_{uplink} + f_{offset} = 890\,MHz + (ARFCN - 1024) \bullet 0.2\,MHz + 45\,MHz$$

	ARFCN	Start frequency f_{start}	Channel offset *N*	Frequency offset f_{offset}	Uplink frequency range	Downlink frequency range
GSM 850 (America)	128 – 251	824.2 MHz	128	45 MHz	824.2 – 848.8 MHz	869.2 – 893.8 MHz
GSM 900 P (Primary)	1 – 124	890 MHz	0	45 MHz	890.2 – 914.8 MHz	935.2 – 959.8 MHz
GSM 900 E (Extended)	0 – 124 975 – 1023	890 MHz	0 1024	45 MHz	880.3 – 914.8 MHz	925.2 – 959.8 MHz
GSM-R (Railway)	0 – 124 955 – 1023	890 MHz	0 1024	45 MHz	876.2 – 914.8 MHz	921.2 -959.8 MHz
GSM 1800	512 – 885	1710.2 MHz	512	95 MHz	1710.2 – 1784.8 MHz	1805.2 – 1879.8 MHz
GSM 1900 (America)	512 – 810	1850.2 MHz	512	80 MHz	1850.2 – 1909.8 MHz	1930.2 – 1989.8 MHz

GSM 900 P (Primary) covers the frequencies originally intended for GSM with channel numbers 1 to 124.

GSM 900 E (Extended) covers a range extended down to lower frequencies. However, the 49 additional channels have higher numbers, i.e. channel numbers 955 to 1023 (channel offset N = 1024) as well as channel number 0.

GSM-R (Railway), the European standard for railway mobile telephone traffic, is similar.

Abbreviations

BCCH	Broadcast Control Channel
E-Field	Electric field
FFT	Fast Fourier Transform
MR	Measurement Range
RBW	Resolution Bandwidth
RMS	Root Mean Square
SRM	Selective Radiation Meter
TCH	Traffic Channel
TDMA	Time-Division Multiple Access

References

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

[2] Directive 2004/40/EC of the European Parliament and the Council of Europe on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18^{th} separate directive according to Article 16 Paragraph 1 of Directive 89/391/EEC) of 29 April 2004.

[3] 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.

[4] BGV B11: Unfallverhütungsvorschrift Elektromagnetische Felder (Berufsgenossenschaftliche Vorschrift für Sicherheit und Gesundheit bei der Arbeit). 1 June 2001.

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[6] prEN 50413:2005: Basic standard for measurement and calculation methods for the exposure of persons to electric, magnetic and electromagnetic fields (0 Hz to 300 GHz).

[7] DIN VDE 0848-1 (VDE 0848 Teil 1):2000-08: Sicherheit in elektrischen, magnetischen und elektromagnetischen Feldern. Teil 1: Definitionen, Mess- und Berechnungsverfahren.

[8] Revised ECC Recommendation (02)04: Measuring non-ionizing electromagnetic radiation (9 kHz – 300 GHz). Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT). Edition October, 2003.

[9] Mobilfunk-Basisstationen (GSM), Messempfehlung. Schweizerisches Bundesamt für Umwelt, Wald und Landschaft BUWAL und Bundesamt für Metrologie und Akkreditierung METAS, Bern, 2002.

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