Radiation exposure due to UMTS

Radiation due to individual cells detected by frequency and code selective measurement: Helpful to providers, users, and authorities

The output power level of base stations in modern mobile phone networks is so low that, even in the main beam direction, the permitted limits for occupational exposure are not exceeded at short distances from the transmitting antenna. Calculations these days reliably demonstrate that the public safety limit values in the near field of the antenna are adhered to. Despite this, some members of the public feel threatened by mobile phone transmitters, possibly because of the proximity and increasing numbers of such installations. In actual fact, the reduction in cell size and the correspondingly shorter distance from the antenna directly results in lower immission values, and also to lower transmission power levels from the mobile phone next to your ear. Most people, though, do not appreciate this.

The need for selective measurement

To allay unnecessary fears, mobile phone network providers, authorities, or measurement services acting on their behalf, check the electromagnetic fields in residential areas, even in individual homes. Measurements are made selectively so as to assess the effects of each source separately and with sufficient sensitivity. In practically all cases, the ambient immission values prove to be several orders of magnitude below the limit values prescribed for the general public. However, simulation is not enough to inspire the needed confidence.

The need for extrapolation

The problem when measuring the electromagnetic fields emanating from mobile phone base stations is that the output power level of the traffic channels varies according to traffic load. This means that the field strength also varies. However, at least one channel per base station in GSM and UMTS networks outputs at a constant, known power level. This is the BCCH (broadcast control channel) in GSM and the P-CPICH (primary common pilot channel) in UMTS. Since the provider knows the factor by which the output power of this reference channel is less than the maximum output power, it is possible to extrapolate the exposure level at maximum output power from a measurement of the reference channel. With GSM, the BCCH power level can be measured separately from the traffic channel power levels by using a selective receiver. However, UMTS uses CDMA (code domain multiplex access), which means that the P-CPICH and the other channels share the same spectrum. The channels cannot therefore be distinguished from one another using a conventional spectrum analyzer. To separate the channels, the measuring instrument must be able to distinguish the UMTS channels at code level. This function is provided by the new UMTS option for the SRM-3000. This article describes how the option works and its practical application in more detail.

Peculiarities of UMTS

The signal transmitted in an UMTS frequency channel is very similar to band-limited white noise. The band limiting corresponds to that of an RRC (root raised cosine) filter. The 3 dB bandwidth is 3.84 MHz. The transition on both edges from full power to zero power is only 22 % of the 3 dB bandwidth. The total output power is thus nominally distributed over a 4.6848 MHz frequency band.

The 3 dB bandwidth of 3.84 MHz corresponds to the value given by the so-called chip rate of the system. Spreading techniques are used to multiply the payload signal bit rate – this new bit rate is called the chip rate to distinguish it from the original bit rate – and hence to spread the bandwidth of the signal in the frequency domain.

Frequency ranges

The overall frequency band available in Germany for the downlink (transmissions from the UMTS base station to the UMTS user) ranges from 2110 to 2170 MHz. This is divided into six bands of about 10 MHz, two of which are currently unassigned. Four different providers occupy the four remaining frequency bands (*Table 1*). Each provider can thus operate two UMTS frequency channels of 5 MHz (exactly 4.6848 MHz) in the assigned frequency band. The channel center frequency can be selected as desired, the only provisos being that adjacent channels are not impaired and that the channel frequency is an integer multiple of 200 kHz; in exceptional circumstances, a channel spacing of 100 kHz can also be used. For example, Vodafone transmits on 2112.8 MHz and T-Mobile on 2167.2 MHz in Germany. There are corresponding licences for the uplink, which are exactly 190 MHz lower in each case.

Provider	FDD mode, uplink	FDD mode, downlink	Bandwidth, ca.
Vodafone	1 920.3 to 1 930.2 MHz	2 110.3 to 2 120.2 MHz	2 x 5 MHz
–	1 930.2 to 1 940.1 MHz	2 120.2 to 2 130.1 MHz	2 x 5 MHz
E-Plus	1 940.1 to 1 950.0 MHz	2 130.1 to 2 140.0 MHz	2 x 5 MHz
–	1 950.0 to 1 959.9 MHz	2 140.0 to 2,149.9 MHz	2 x 5 MHz
O_2	1 959.9 to 1 969.8 MHz	2 149.9 to 2 159.8 MHz	2 x 5 MHz
T-Mobile	1 969.8 to 1 979.7 MHz	2 159.8 to 2 169.7 MHz	2 x 5 MHz

Table 1: Frequency bands used in Germany for UMTS FDD

In the UK, five providers share the 2 110 to 2 170 MHz downlink band, two of them assigning three UMTS frequency channels of 5 MHz each. The corresponding uplink frequencies are a little lower, ranging from 1 920 to 1 980 MHz.

Apart from these so-called FDD (frequency division duplex) licences, TDD (time division duplex) licences are also generally available. In the UK, four of five providers bought licences for 5 MHz “unpaired spectrum” each. Here, the same spectrum is used for the uplink and the downlink, which are separated in time. This method is intended for applications where the uplink and downlink are unequally loaded. It has no practical significance at present.

Provider	FDD mode, uplink	FDD mode, downlink	Bandwidth, ca.
Hutchinson 3G	1 920.3 to 1 934.9 MHz	2 110.3 to 2 124.9 MHz	3 x 5 MHz
BT Cellnet	1 934.9 to 1 944.9 MHz	2 124.9 to 2 134.9 MHz	2 x 5 MHz
Vodafone	1 944.9 to 1 959.7 MHz	2 134.9 to 2 149.7 MHz	3 x 5 MHz
One2One (T-Mobile)	1 959.7 to 1 969.7 MHz	2 149.7 to 2 159.7 MHz	2 x 5 MHz
Orange	1 969.7 to 1 979.7 MHz	2 159.7 to 2 169.7 MHz	2 x 5 MHz

Table 2: Frequency bands used in the UK for UMTS FDD

In Hungary, three providers – Pannon, T-Mobile and Vodafone – bought licences for UMTS channels in the end of year 2004. Pannon, for example, will run three FDD (paired) channels and one TDD (unpaired) channel.

In Poland, Netia Mobile Sp. z o.o. recently (May 2005) acquired the licence for running three FDD (paired) channels in the 1964.9 to 1979.7 MHz and 2154.9 to 2169.7 frequency ranges and one TDD (unpaired) channel.

Sectors (cells) and how scrambling codes are used to distinguish between them

There are usually six antennas arranged in pairs on three masts at a FDD station. The three masts are arranged in a triangle with sides several meters long. The radiation pattern forms three sectors (cells) with a spread of about 120° each. Two antennas on different masts can be used per sector to give better reception or transmission characteristics as a result of diversity.

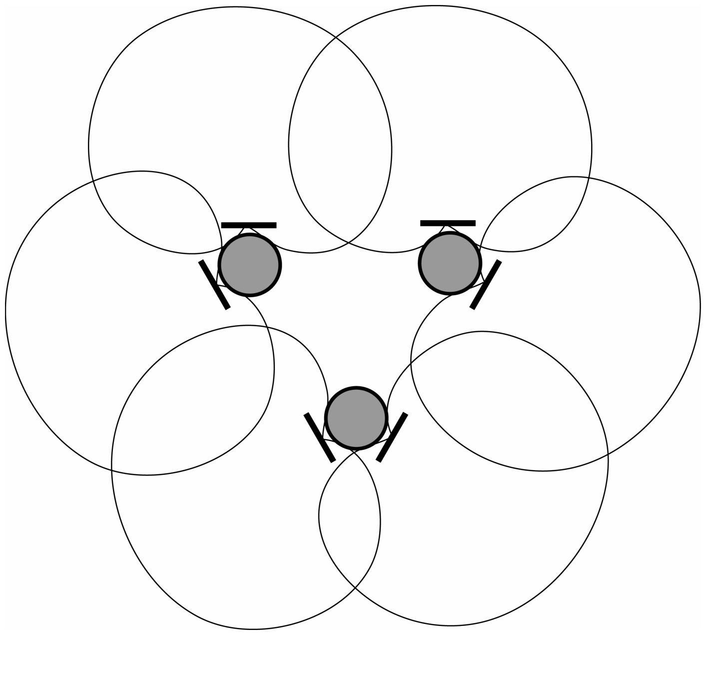

Fig. 1: Typical arrangement of UMTS antennas

The signals from different stations as well as those from different sectors are transmitted in one UMTS frequency channel. To enable the UMTS mobile phone to distinguish between the signals from different sectors (cells), the signals are scrambled using different codes, known as scrambling codes. Each cell uses just one scrambling code. Thus, signals with up to three different scrambling codes will be received in close proximity to the antenna station, corresponding to the three cells at the station. It is possible that a much greater number of scrambling codes may even be present at greater distances from the station.

Signals that have not been scrambled are also always transmitted so that synchronization is possible and information can be received about the code group that is used. The P-SCH (primary synchronization channel) always transmits the same, unscrambled signal. The S-SCH (secondary synchronization channel) transmits an unscrambled sequence from which the start of frame and the code group used can be determined. Both synchronization channels are transmitted simultaneously in a pulse of length 256 chips. This is followed by a pause of 2304 chips. Taken together, this results in a slot length of 2560 chips. A radio frame consists of 15 slots and thus has a duration of exactly 10 ms.

The scrambled signal consists of up to 512 different channels. These are differentiated from one another by the channelization codes, which also accomplish the spreading of the bandwidth. The P-CPICH (primary common pilot channel) that we are interested in is one of these channels. It always transmits the same symbol and is easily decoded as soon as synchronization and unscrambling have been achieved successfully.

P-CPICH demodulation in a portable unit

The Selective Radiation Meter SRM-3000 uses an analog superheterodyne receiver for preselection in the frequency domain. The final IF is at 36 MHz; the IF filter has a bandwidth of more than 6.4 MHz, which is wide enough to fully record a UMTS frequency channel. A 12-bit ADC with a sampling rate of 48 MHz is used to convert the IF signal. In theory, these data could be saved and the demodulation performed using them. However, the hardware structure of the SRM-3000 offers the facilities for digital down conversion using freely programmable filters. Therefore, the down conversion is accomplished by the digital hardware in real time using UMTS channel filters (the same RRC filter as is used in the transmission path). The sampling rate for these complex output values is twice the chip rate, i.e. 7.68 MHz. From these sampled values, a little more than one radio frame is stored each time in an internal transient recorder. The micro controller in the SRM-3000 reads out this memory and performs the rest of the demodulation process. The micro controller used includes a high-performance floating point computing unit, which is ideal for this purpose.

Determining the scrambling codes by correlation

The sampled values are initially interpolated to give quadruple the chip rate to ensure that significant level errors due to time offsets can be eliminated in subsequent steps in the process. To determine the exact position of the P-SCH impulses, the recorded signal is correlated with the known transmission sequence. Local maxima in the correlation function indicate the possible time points. The higher the maximum, the more likely is the presence of a P-SCH at this point in time. Up to twelve such local maxima are traced further. Each of them could originate from a separate transmitter, or they might be due to multipath reception of one and the same transmitter. The code group and position of the first slot in the frame must now be determined for each of the local maxima that are traced. All the possibilities are checked, and up to three variants from the best matches are traced further. This is because it is possible that the synchronization patterns from several transmitters may coincide in time. There are still eight possible primary scrambling codes that can be selected for each code group and position variant. All eight possibilities are checked in each case, and the power level of the respective P-CPICH is determined. Under certain circumstances, not one but two P-CPICH may be selected from one code group and position variant. Again, the reason for this is that the synchronization patterns of several transmitters may coincide. Mechanisms are built into each stage of the process, however, to prevent the instrument from “chasing” down hopeless paths or from “detecting” a P-CPICH that in reality is not present.

In other words, the algorithm used is capable of registering all the reflections of a single transmitter separately if they are separated by more than one chip width. If the same pilot channel is detected more than once, all the partial power levels of this channel will be added together to give the total power level for the channel. If the reflections are closer together, it is neither possible nor necessary to separate them. In such cases, the total power level of these reflections that cannot be separated in time is determined by the system anyway. Even two transmitters, which happen to coincide in their time structures, can be distinguished from each other and detected separately. This “luxury” naturally has its price – processor time. A facility is therefore provided for switching between two sets of parameters that control the algorithm, so that measurements can also be made as quickly as possible if needed. In “fast” mode, the instrument reliably detects pilot channels having a power level down to 10 dB below the total power level in the frequency channel. In “sensitive” mode, the instrument will also reliably detect pilot channels with power levels as much as 15 dB below the total power level in the frequency channel.

AFC for high measurement accuracy

The frequency accuracy of the SRM-3000 is 2.6 ppm. It is the result of three partial measurement uncertainties: adjustment offset, thermal response, and aging. At the highest UMTS downlink frequency of 2170 MHz, this translates into a maximum frequency offset of 5.6 kHz. The demodulation algorithm described above functions reliably with a frequency offset of slightly over 6kHz, but as the frequency offset increases, the power level detected will be smaller than the actual power level. The difference can be significantly more than 1 dB. To eliminate this source of error, the frequency offset is determined from the phase characteristic of the strongest P-CPICH. The SRM-3000 then corrects the tuning frequency accordingly on the next sweep. This automatic frequency control (AFC) ensures that the SRM-3000 is locked to within a few hertz of the transmission frequency of the strongest base station (the UMTS system specifies a deviation of less than 0.1 ppm from the nominal frequency for base stations). This reduces the possible power level error due to frequency offset to negligible values. Of course, the already excellent frequency accuracy of the SRM is essential for this AFC to work. Without it, P-CPICH demodulation would not even be possible under certain circumstances, and the frequency offset could not then be determined either.

User interface

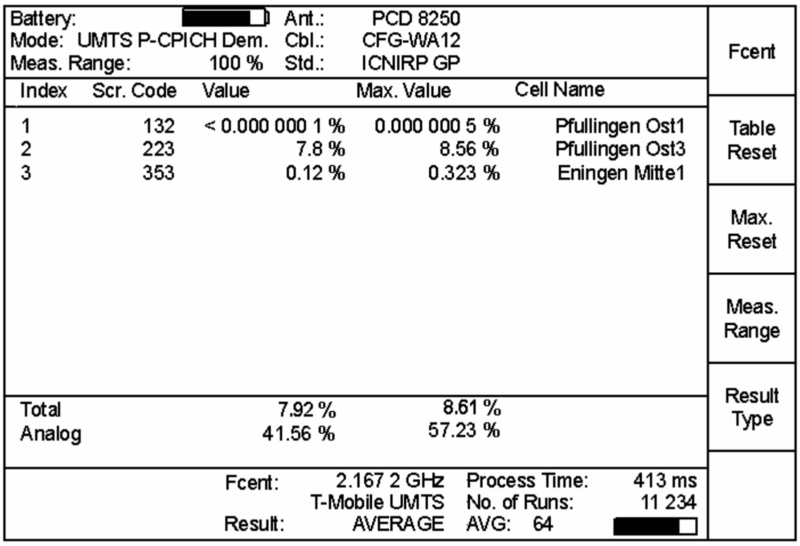

Fig. 2: User interface with table display

UMTS P-CPICH Demodulation is a separate operating mode that is available as a firmware option for the SRM-3000. The additional functions are available as soon as the corresponding enabling code has been entered in the instrument.

The SRM-3000 lists all the pilot channels detected. The number of the scrambling code used, the momentary power level, the maximum power level, and the cell name are each shown in separate columns in a table. The “cell name” is a character string assigned to a scrambling code in selectable, user-defined lists. If regionally specific lists are used, it is easy to correlate the detected scrambling codes with specific cells or sectors using plain text names. These cell name tables can be compiled on a PC by the user and transferred to the measuring set with the aid of the configuration software that is supplied free of charge with the instrument.

The total power level of all the pilot channels detected is shown in the “Total” line on the SRM-3000. The total power level in the frequency channel is shown in the “Analog” line.

All measured values can be displayed in the various appropriate units. In particular, the different field strength and power density units as well as evaluations in terms of human safety standards are available for measurements made using antennas. The antenna factors of Narda antennas are automatically read out from an EEPROM. Antennas from other manufacturers can be used just as easily with the aid of selectable, user-definable calibration tables.

The channel frequency is entered as F_{CENT}. It is also possible to enter the channel number. If the exact channel frequency is not yet known, it can be easily determined in Spectrum Analysis mode. This is done using F_{SPAN} of 5 MHz and RBW of 2 kHz and a rough setting of F_{CENT}. F_{CENT} is then adjusted in steps of 100 kHz until the spectrum appears to be centered on the display screen. The F_{CENT} thus determined is the channel frequency of the UMTS channel under consideration.

The “Table Reset” softkey is used to reset the displayed table. After a reset, the pilot channels detected each time a measurement sweep is made will be entered in the table. Pilot channels that have been detected once will be retained in the table, even if they are not present in the latest sweep results. The power level will be assumed to be zero for this sweep. The maximum value that did occur for the pilot channel will be saved and will continue to be displayed. The list can expand until 16 pilot channels have been detected, after which no new pilot channels will be included.

If a new search for maximum values is to be started, the display of maximum values can be reset using the “Max Reset” softkey. The “Meas.Range” softkey provides access to the instrument’s measurement range setting at all times. Power averaging can be activated using the “Result Type” softkey.

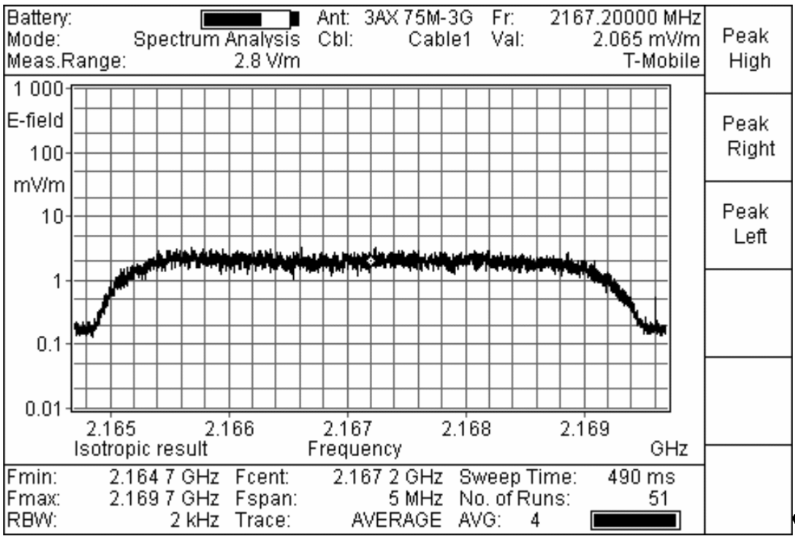

Fig. 3: Typical UMTS channel spectrum

Application

The SRM-3000 fitted with an isotropic antenna only weighs about 2.3 kg, and it has been designed so that measurements can be made comfortably with the instrument held in the hands. A special neck strap with four-point attachment to the instrument even allows one-handed operation. No additional hardware is needed to make isotropic measurements or to perform P-CPICH demodulation.

Fig. 4: The Selective Radiation Meter SRM-3000 fitted with an isotropic antenna

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