Cell search and cell selection in UMTS LTE

Application Note

Products:

- R&S® SMU200A
- R&S® SMx-K55
- R&S® SMBV100A
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- R&S® FSx
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- R&S® CMW500
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This application note explains the fundamentals of the cell search and cell selection and reselection procedures required for both modes of UMTS Long Term Evolution: FDD and TDD. It describes how to generate and analyze the required signals using Rohde & Schwarz test and measurement solutions. The application note also shows how to perform interoperability tests and terminal conformance tests according to the baseline of the 3GPP specifications for protocol conformance and Radio Resource Management (RRM).

Application Note

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Table of Contents

1 Motivation

Until now ,transmitter and receiver concepts for UMTS LTE have been proven by verifying downlink and uplink transmissions for base stations (enhanced NodeB and eNB) and terminals (User Equipment, UE). Measurements of parameters such as transmission power, modulation quality, or spectrum were performed. The results were then validated against the appropriate limits. Tolerances and measurements are specified in [1] and [2] and in [3] and [4] respectively. This process began with low-level block testing and was further increased to integrate all required functional blocks into the test setup.

After passing the first basic test routines, the next major block of testing was started more or less in parallel. The focus was shifted to Layer 1 testing and especially to validating the physical layer procedures, which are described in [5]. The testing of the physical layer procedures can be categorized into data-path, functional and performance testing. With data-path testing, which is executed in an open-loop fashion, the correct implementation of the individual downlink and uplink channels is validated according to [6] and [7] is validated. In order to facilitate the debugging process, intermediate points within the encoding and decoding chains of the test equipment must be accessible by the test engineer. Once this test step is passed, functional testing begins. Within a controlled and static testing environment, procedures such as reporting the quality of the radio channel (Channel Quality Indicator, CQI) or validating the HARQ process for downlink and uplink data transmission are performed as specified in [5]. The procedures for scheduling can be used to test the HARQ process in both transmission directions.

Performance testing verifies the performance of the device. In the first phase, transmitter and receiver performance are measured, and in the final phase the system performance including closed-loop operation and UE procedures are tested. One example from the performance requirements described and specified in [4] Section 8 is downlink data transmission on the Physical Downlink Shared Channel (PDSCH). The test engineer is interested in how the Block Error Rate (BLER) varies by changing signal power, type and level of interference, the chosen transport format and the fading-channel profiles [8].

Before data-path and functional testing as well as system performance evaluation are performed, two essential physical layer procedures must be validated: cell search and cell selection as well as the random access procedure. Cell search is essential, since it ensures that the UE's receiver is able to synchronize in both time and frequency to an LTE downlink signal. The Device Under Test (DUT) is than enabled to receive important parameters via the broadcasted system information. These parameters are necessary to establish uplink synchronization as well as to perform initial access to network. This procedure has already been used in previous technologies and is commonly known as random access. The random access procedure includes functionality from higher layers, such as the MAC and RRC layer, which increases complexity of this part of the testing.

This application note explains the fundamentals of the cell search and cell selection process for both modes of LTE: FDD and TDD. It describes how to generate and analyze the required signals using Rohde & Schwarz test and measurement solutions for UMTS LTE. It also shows how to perform protocol tests according to the baseline of the required 3GPP specifications for the Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO) scenarios.

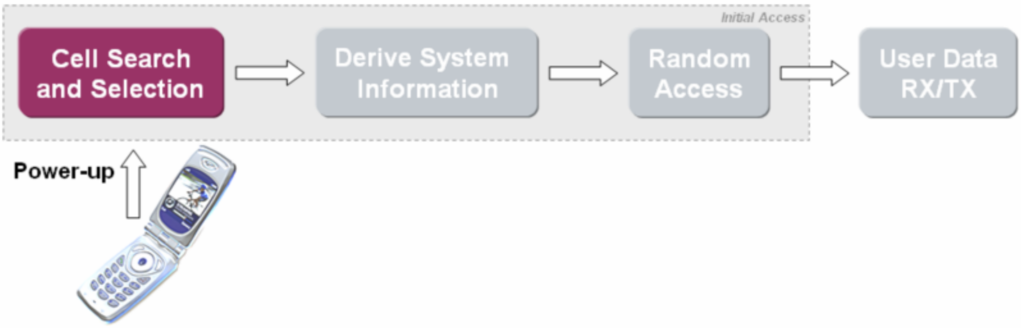
This application note assumes basic knowledge of 3GPP LTE technology as provided in [9].

2 LTE cell search and cell selection procedure

2.1 LTE Initial Access

Like all mobile communication systems, in LTE a terminal must perform certain steps before it can receive or transmit data. These steps can be categorized in cell search and cell selection, derivation of system information, and random access. The complete procedure is known as LTE Initial Access and is shown in Figure 1. After the initial access procedure, the terminal is able to receive and transmit its user data.

Figure 1: LTE Initial Access: cell search and cell selection



2.2 Initial synchronization

Successful execution of the cell search and selection procedure as well as acquiring initial system information is essential for the UE before taking further steps to communicate with the network. For this reason, it is important to take a closer look at this fundamental physical layer procedure. This section focuses on the cell-search scheme defined for LTE and the next chapter describes reception of the essential system information.

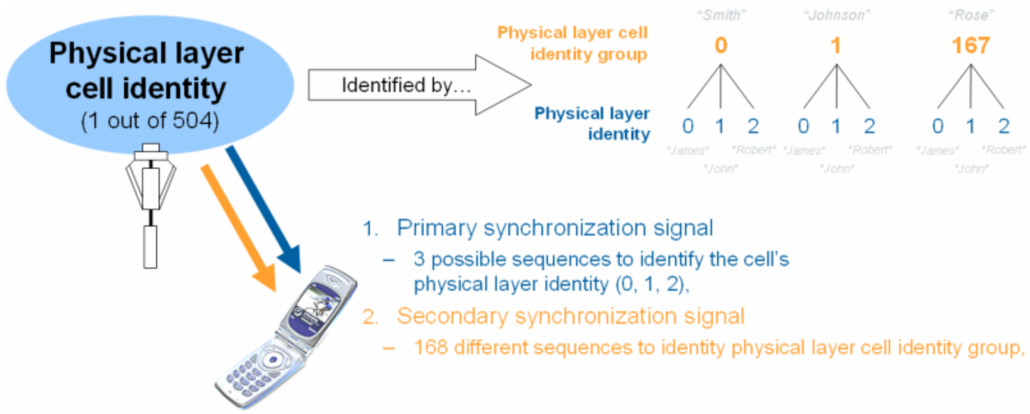
As in 3G (WCDMA), LTE uses a hierarchical cell-search procedure in which an LTE radio cell is identified by a cell identity, which is comparable to the scrambling code that is used to separate base stations and cells in WCDMA. To avoid the need for expensive and complicated network and cell planning, 504 physical layer cell identities of is sufficiently large. With a hierarchical cell search scheme, these identities are divided into 168 unique cell layer identity groups in the physical layer, in which each group consists of three physical layer identities[1]. To remember this hierarchical

[1] $N_{ID}^{(1)}$ = 0…167 and $N_{ID}^{(2)}$ = 0, 1, 2; cell identity $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$

principle, consider the example of first names and surnames. According to statistics[2], the most common English surname is *"Smith"*, which corresponds to physical layer cell identity group 0. The second most common surname is *"Johnson"*, which represents the physical layer cell identity group 1. This example can be extended to the last group, which would be *"Rose"*. The most common male first names are *"James", "John",* or *"Robert"* and female names are *"Mary", "Patricia", and "Linda"*. Each first name represents one of the three physical layer identities.

This information is now transmitted using two different signals, generated by Layer 1. The two signals, carrying the physical layer identity and the physical layer cell identity group, are the primary and the secondary synchronization signals respectively. This means that the complete cell search procedure consists of two steps to identify the cells' identity. The process is shown graphically in Figure 2.

Figure 2: Physical layer cell identity and synchronization signals



2.2.1 Step I – Primary Synchronization Signal

The UE first looks for the primary synchronization signal (PSS) which is transmitted in the last OFDM symbol of the first time slot of the first subframe (subframe 0) in a radio frame. This enables the UE to acquire the slot boundary independently from the chosen cyclic prefix selected for this cell. Based on the downlink frame structure (Type 1, FDD), which is shown in Figure 6, the primary synchronization signal is transmitted twice per radio frame, so it is repeated in subframe 5 (in time slot 11). This enables the UE to get time synchronized on a 5 ms basis, which was selected to simplify the required inter-frequency and inter-RAT measurements. LTE must accommodate handover to and from other radio access technologies, such as GSM/GPRS/EDGE, WCDMA/HSPA or CDMA®2000 1xRTT/1xEV-DO.

In the frequency domain, six resource blocks (RB) around the DC subcarrier are reserved for transmission of the synchronization signals. In the frequency domain, an RB is formed by 12 subcarriers. With a subcarrier spacing of 15 kHz a bandwidth of 180 kHz (12*15 kHz) is occupied, reserving a frequency range of 1.08 MHz (6*180 kHz) around the center frequency for transmission of synchronization signals (that is, 72 subcarriers). This is independent from the defined channel bandwidth that is

[2] http://names.mongabay.com/data/1000.html (visited in 2009-08)

configured for the cell[3]. The type of signal used for primary synchronization is a Zadoff-Chu (ZC) sequence. ZC sequences are CAZAC sequences, which stands for Constant Amplitude Zero Auto Correlation and describes the characteristic of this type of sequences. With a constant amplitude, a low peak-to-average power ratio is achieved, where zero auto correlation equates with good time domain behavior. Since the primary synchronization signal uses only 62 of the 72 reserved subcarriers, the required length N_{ZC} of the Zadoff-Chu sequence is given as N_{ZC}=63[4]. The reason 62 rather than 72 of the reserved subcarriers are used is because it enables the UE to use a 64 Fast Fourier Transform (FFT) and lower sampling rate. This approach helps to approximate the vendor-specific implementations of an estimation algorithm and simplifies the entire procedure. In the case of TD-LTE, it also avoids correlation with the uplink demodulation reference signals that use the same kind of sequence as the PSS. Equation 1 shows how to generate the ZC sequence used as the primary synchronization signal.

Equation 1: Generating the primary synchronization signal [1]

$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n=0,1,...,30 \\ e^{-j\frac{\pi u (n+1)(n+2)}{63}} & n=31,32,...,61 \end{cases}$$

The root index u in Equation 1 depends on the selected physical layer identity. For $N_{ID}^{(2)}=0$ the root index used is 25, for $N_{ID}^{(2)}=1$ it is 29, and for $N_{ID}^{(2)}=2$ the index is 34. Root indices define a ZC sequence from a set of ZC sequences available with the required sequence length N_{ZC}. The root index u also indicates the maximum number of sequences available with a certain length N_{ZC}. For the PSS, the basis is the two sequences 25 (= n_1) and 29 (= n_2). The third index is derived by subtracting N_{ZC} – n_2 (= 63–29 = 34). The reason for selecting n_1 and n_2 depends on the very good conjugate-complex symmetry of these two sequences in the time domain. This reduces the processing effort required for synchronization and the sequences based on indices n_1 and n_2 show the best auto-correlation and cross correlation properties.

Mapping of the selected sequence to the reserved subcarrier depends on the frame structure type and thus on the LTE mode. For FDD frame structure Type 1 the sequence is mapped according to Equation 2.

Equation 2: Mapping of primary synchronization signal to resource elements (k, l) [1]

$$a_{k,l} = d(n), \qquad n = 0,1,...,61$$
$$k = n - 31 + \left\lfloor \frac{N_{RB}^{DL} N_{SC}^{RB}}{2} \right\rfloor, \qquad l = N_{Symbol}^{DL} - 1$$

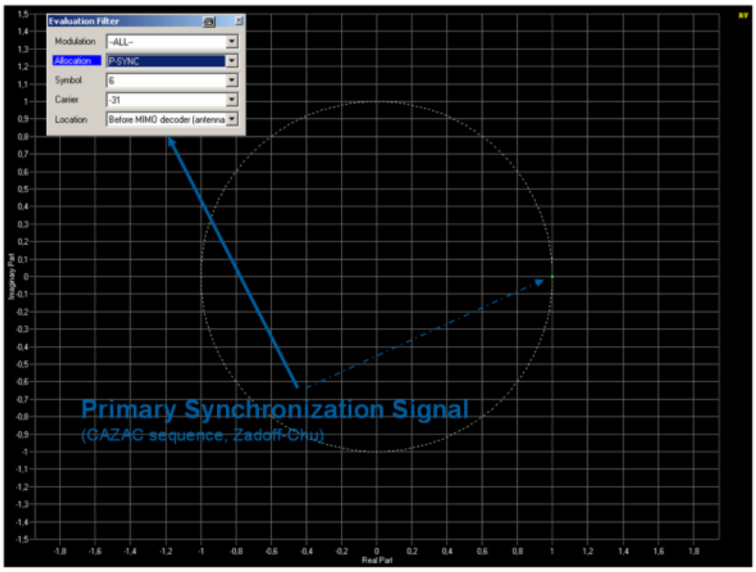
Figure 3 shows the PSS in the constellation diagram using signal analysis performed with R&S® FSQ-K100 software option. With help of the evaluation filter, the constellation diagram can be shown for specific resource elements (k, l) – in this

[3] Channel bandwidths of 1.4, 3, 5, 10, 15 or 20 MHz are supported in 3GPP UMTS LTE.

[4] 62 subcarrier and 1 (un-used) DC subcarrier; which is punctured

example the 31st subcarrier left of the DC subcarrier (k = -31) and in the 6th OFDM symbol (l = 6).

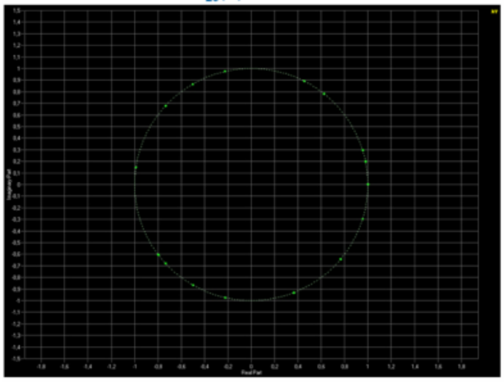
Figure 3: Primary synchronization signal (R&S®FSQ-K100 EUTRA/LTE downlink/BS analysis)



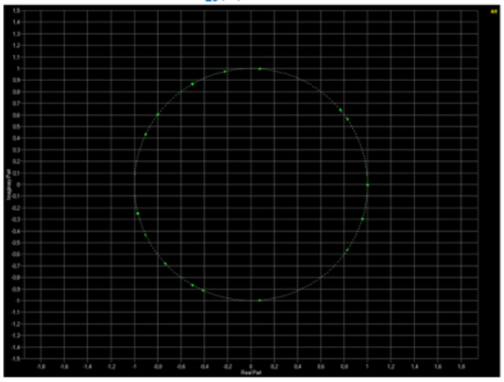
The unit circle represented by the dotted line marks the constant amplitude of the sequence. The excellent auto-correlation properties can be monitored by looking at the different subcarriers, carrying the sequence one-by-one. The dot seems to move randomly on the unit circle when changing the subcarriers, as the distance between the positions is not equidistant. This kind of hopping is unique to each sequence and depends on the root indices u. Figure 4 shows the primary synchronization signal for the three different indices. An LTE downlink signal fully compliant with 3GPP Release 8 can be generated with the R&S® SMU200A vector signal generator.

Figure 5: Primary synchronization signal (ID=0, ID=1 and ID=2)

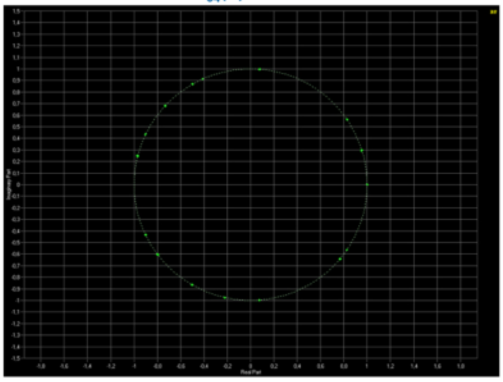
$d_{25}(n)$ ⇨ ID=0



$d_{29}(n)$ ⇨ ID=1



$d_{34}(n)$ ⇨ ID=2



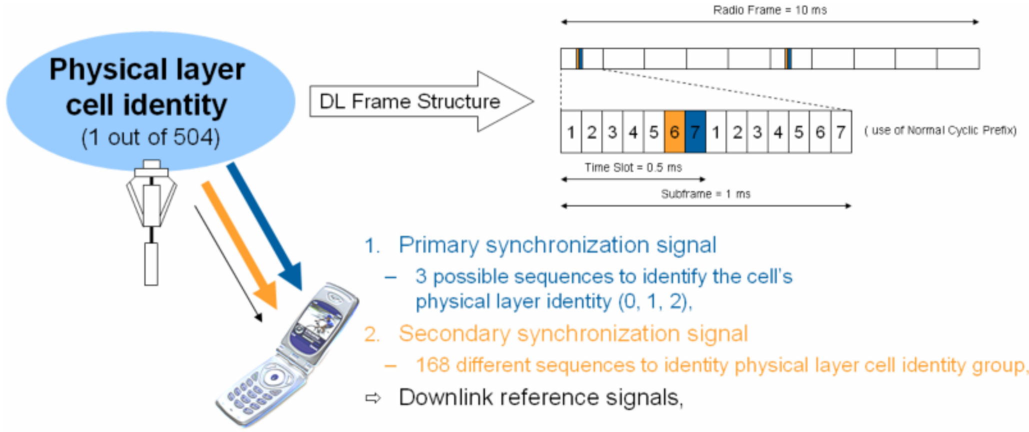
The matched filtering works generally in this way so that the received signal is correlated with the possible sequences for the PSS. This procedure is not executed on the received analog RF signal, but rather in the digital domain. The possible sequence (e.g. *"James"*, ID=0) is multiplied by the received pattern, and the operation must be synchronized to the clock. A subsequent integrator adds up the signal, and if the output agrees with the checked sequence a rising, positive ramp is produced. This indicates that the tested sequence is the sequence used for the PSS. In another example, the next sequences (e.g. *"John",* ID=1; *"Robert"*, ID=2) is multiplied by the pattern.

With successful matched filtering, the device has identified the physical layer identity for this cell as well as 5 ms timing. It can later execute the next step, which is looking for the secondary synchronization signal and the physical layer cell identity group to compute the cells' identity.

2.2.2 Step II – Secondary Synchronization Signal (SSS)

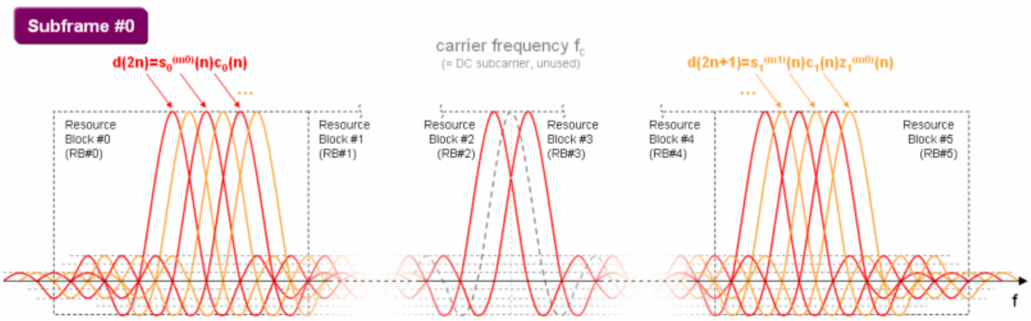
After the mobile has found the 5 ms timing, the second step is to obtain the radio frame timing and the cells' group identity. This information can be found from the SSS. In the xtime domain, the SSS is transmitted in the symbol before the PSS . The SSS also has 5 ms periodicity, which means it is transmitted in the first and sixth subframes (subframes 0 and 5) as shown in Figure 6. Like the PSS, the SSS is transmitted on 62 of the 72 reserved subcarriers around the DC subcarrier.

Figure 6: Downlink frame structure type 1 (LTE FDD) with synchronization signals (P-Synch, S-Synch)



The SSS is represented by an interleaved concatenation of two length-31 binary sequences that are scrambled with a sequence that depends on the physical layer identity ($N_{ID}^{(2)}$)as the PSS . It is always a pair of sequences ($s_0^{(m_0)}, s_1^{(m_1)}$), which is transmitted in a subframe. Sequence $s_0^{(m_0)}$ is mapped in the case of subframe 0 to the even numbered subcarriers ($d(2n)$), whereas sequence $s_1^{(m_1)}$ is mapped to odd numbered subcarriers ($d(2n+1)$). For subframe 5 it is the other way around. Figure 7 shows the sequences used for the secondary synchronization signal and their mapping for subframe 0.

Figure 7: Mapping of secondary synchronization signal to 62 subcarriers for subframe 0



The combination of the indices m_0 and m_1 defines the physical layer cell identity group $N_{ID}^{(1)}$, and the possible combinations of m_0 and m_1 for the 168 groups ("Smith", "Johnson", …) are defined in [6]. Depending on the subcarrier – even or odd – another scrambling sequence is used for sequences $s_0^{(m_0)}, s_1^{(m_1)}$. In case of $d(2n)$, the scrambling sequence employed is $c_0(n)$, for $d(2n+1)$ it is $c_1(n)$. Depending on the subframe in which $d(2n+1)$ is transmitted, an additional scrambling sequence is used. For subframe 0 it is $z_1^{(m_0)}(n)$, and for subframe 5 $z_1^{(m_1)}(n)$ is used. Each of these two scrambling sequences depends on the indices m_0 and m_1, which define the physical layer cell identity group. Scrambling with an additional scrambling sequence optimizes cell search at the cell edge. Here the UE receives signals of several eNBs. At this point differentiation is required, which is achieved using a cell-identity-dependent scrambling sequence such as $z_1^{(m_0)}(n)$ and $z_1^{(m_1)}(n)$.

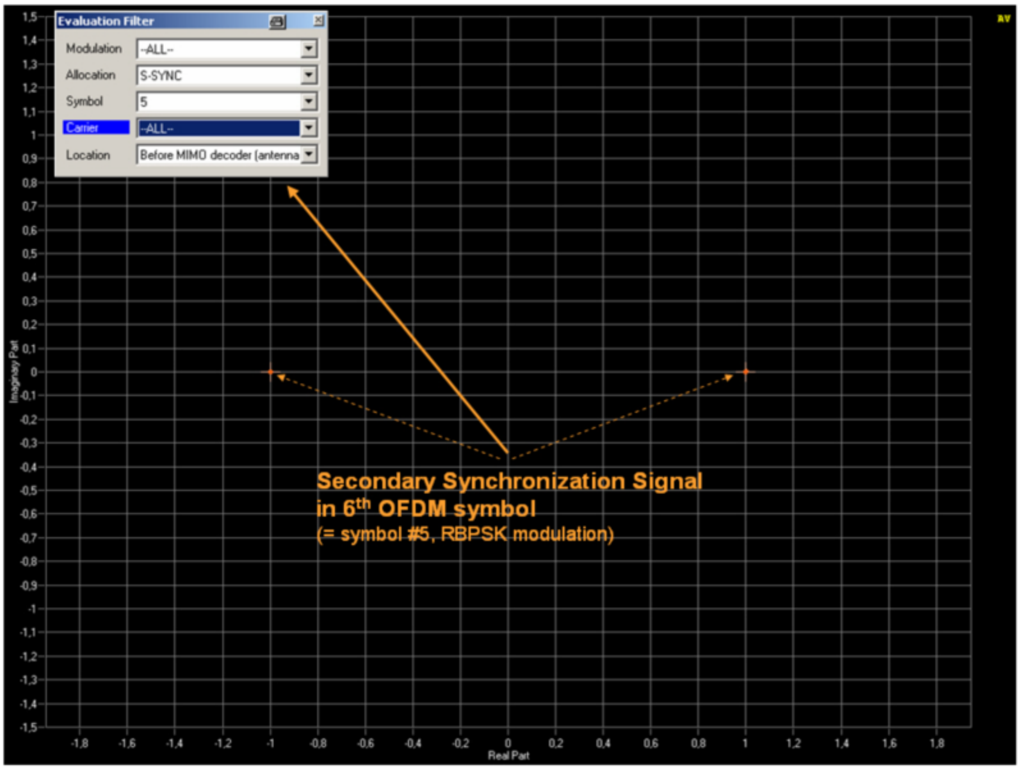
Equation 3: Generation of secondary synchronization signal according to [6]

$$d(2n)=\begin{cases} s_0^{(m0)}(n)c_0(n) & in\,subframe\,0 \\ s_1^{(m1)}(n)c_0(n) & in\,subframe\,5 \end{cases} \quad 0\le n\le 30$$

$$d(2n+1)=\begin{cases} s_1^{(m1)}(n)c_1(n)z_1^{(m0)}(n) & in\,subframe\,0 \\ s_0^{(m0)}(n)c_1(n)z_1^{(m1)}(n) & in\,subframe\,5 \end{cases} \quad 0\le n\le 30$$

Figure 8 shows the SSS in the constellation diagram using the R&S® FSQ-K100 EUTRA/LTE downlink/BS analysis software option.

Figure 8:Secondary synchronization signal in the constellation diagram



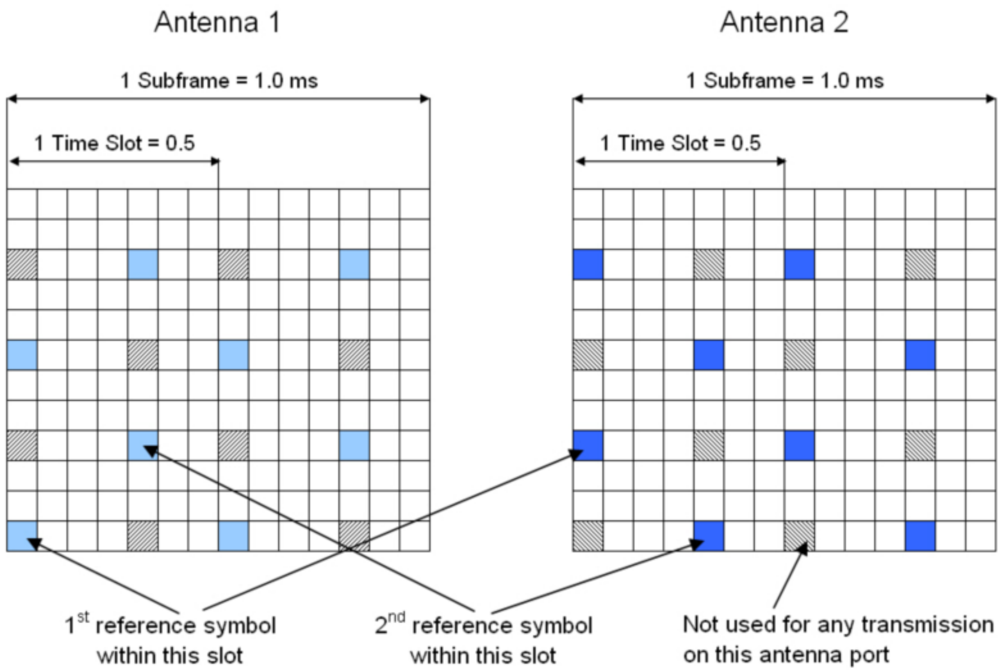
By exploiting the property that the combination of $s_0^{(m_0)}$, $s_1^{(m_1)}$ transmitted in subframes 0 and 5 is an allowable pair representing the SSS, the terminal can resolve the ambiguity resulting from the previous step and determine the frame timing as well as physical layer cell identity group. Knowing this, the UE can determine the cells' unique identity using $N_{ID}^{cell}=3N_{ID}^{(1)}+N_{ID}^{(2)}$, which shows that the calculation of cells identity is based on a modulo-3 operation. The determination of the cells' identity enables the UE to examine the pseudo-random sequence used to generate the cell-specific reference signals as the initialization of the PRS generator based on N_{ID}^{cell} and the used cyclic prefix (CP): normal or extended.

Equation 4: Initialization PRS generator used generating the cell-specific reference signal pattern [1]

$$c_{\text{init}} = 2^{10} \cdot \left(7 \cdot (n_s + 1) + l + 1\right) \cdot \left(2 \cdot N_{ID}^{cell} + 1\right) + 2 \cdot N_{ID}^{cell} + N_{CP} \qquad N_{CP} = \begin{cases} 0 & \textit{for normal CP} \\ 1 & \textit{for extended CP} \end{cases}$$

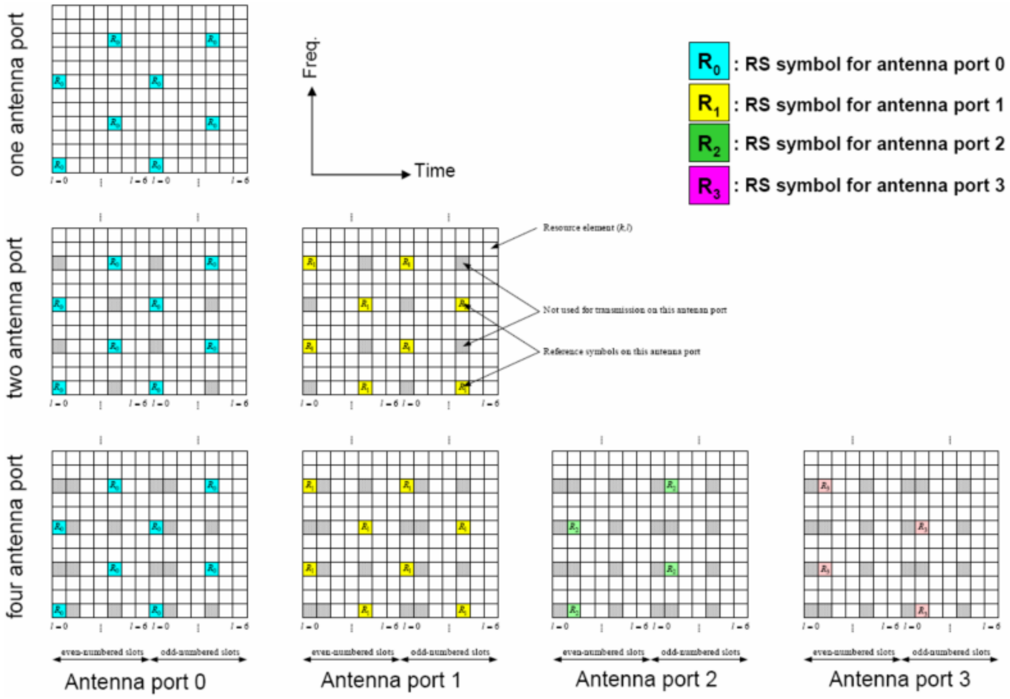
The UE is thus able to become fully synchronized with the radio cell because the reference signals are transmitted in well-defined resource elements. In every sixth subcarrier in the frequency domain a reference symbol from the generated reference signal pattern is transmitted. In the time domain, every fourth OFDM symbol transmits a reference symbol . A resource block contains four reference symbols. Figure 9 shows reference signal pattern for two antennas.

Figure 9: LTE downlink reference signals



With increasing numbers of antennas the number of unused resource elements increases as well, and the signaling overhead is increased. Nevertheless, when using four transmitting antennas the number of reference symbols is reduced for antenna ports 2 and 3. This is a trade-off between MIMO performance and the overhead generated by the required reference signal pattern per antenna. Figure 10 shows the reference signal pattern for up to four antennas.

Figure 10: Reference signal pattern for up to four transmitting antennas



The downlink reference signals help the terminal distinguish between the different transmission antennas. Where one antenna is transmitting the reference pattern the other antennas are transmitting nothing. These physical signals are also used to estimate the quality of the radio channel. The network submits the power level to the device that reference signals transmit, and the terminal measures this power level. The difference corresponds to a Channel Quality Indicator (CQI) that is given to the network. This CQI value provides transport format and modulation scheme information to the base station, at which the transport block error probability at the terminal side would not exceed 10%.

Figure 11 shows power over time, displaying the averaged power level for reference signals and synchronization signals.

Figure 11: Power vs. time LTE FDD downlink signal showing P-, S-Synch and reference signals

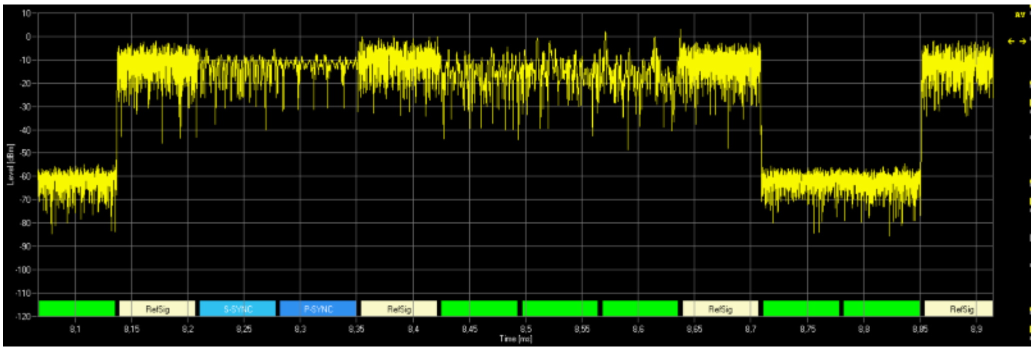
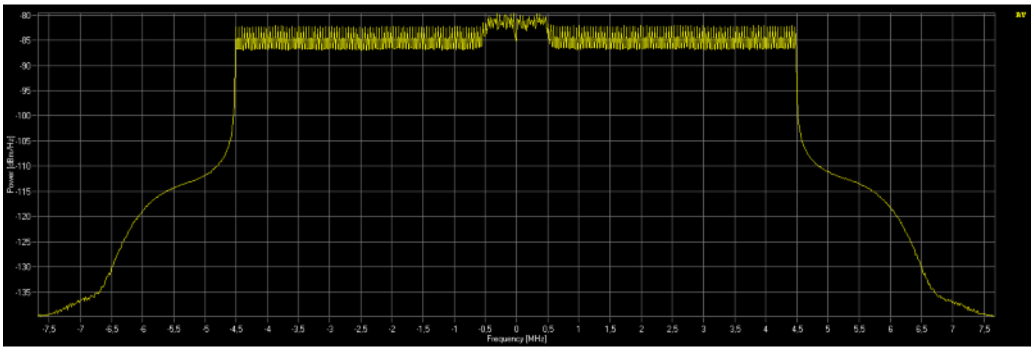


Figure 12 shows the power spectrum of a 20 MHz LTE downlink signal with PSS and SSS signals as well as reference signals transmitted on certain resource elements as described above.

Figure 12: Power spectrum LTE FDD downlink signal, 20 MHz with P-, S-Synch and reference signals



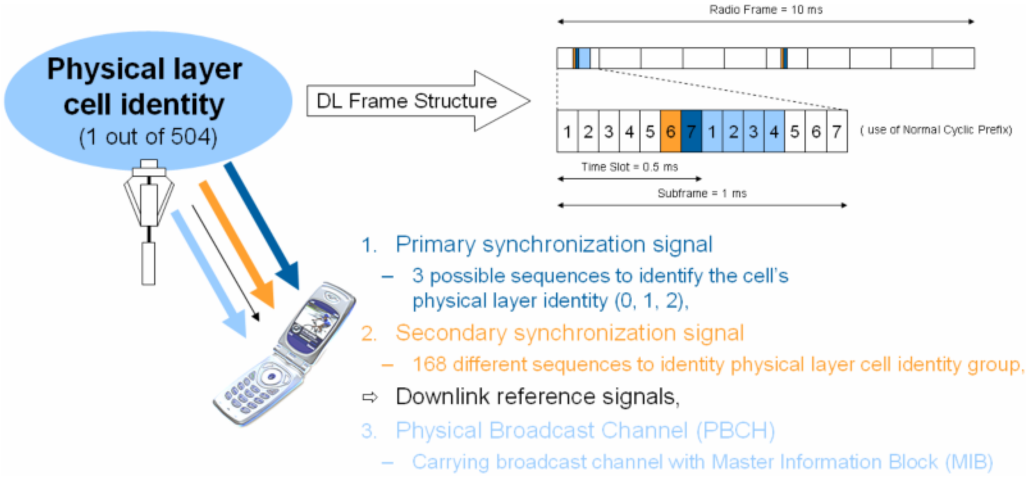
But from what does the UE determine the bandwidth of, for example, 20 MHz?

2.3 Broadcast of essential system information in LTE

2.3.1 PBCH and MIB

After the successful execution of the cell-search procedure described in the previous section, the device is able to decode the *Physical Broadcast Channel* (PBCH) and read out the *Master Information Block* (MIB). As shown in Figure 13, the PBCH is transmitted in the first four OFDM symbols of the second time slot of the first subframe. The periodicity is 40 ms, which means that the MIB is transmitted every fourth radio frame. The PBCH is scrambled prior to modulation with a cell-specific sequence that depends on the cells' identity N_{ID}^{cell}. In contrast to the synchronization signals, the PBCH is transmitted on the 72 reserved subcarriers, which are QPSK-modulated.

Figure 13: Synchronization signals, broadcast channel and downlink frame structure (Type 1, FDD)



As in 3G networks, system information in LTE is separated into the MIB and a number of System Information Blocks (SIBs). This classification as well as a high-level description of the carried information is shown in Figure 14. The color code highlights as an example the system information with relevance for the random access procedure (SIB Type 2, purple-colored) respectively which is a prerequisite (MIB and SIB Type 1, blue-colored) before the required parameter for this procedure can be extracted.

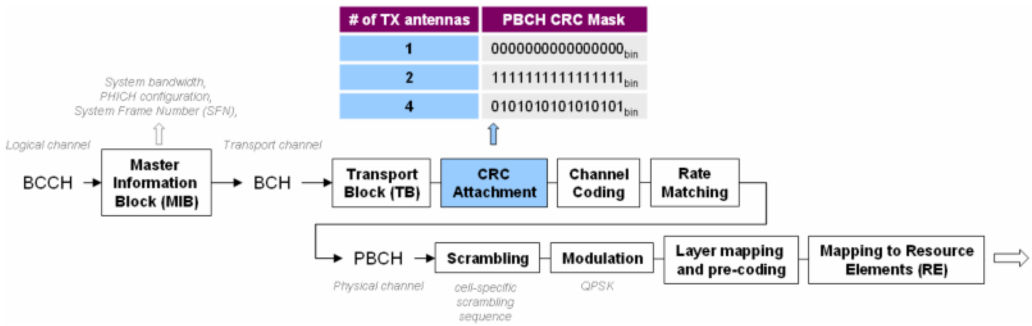
Figure 14: Classification of system information in LTE

MIB Physical Layer Information	**SIB Type 1** Access restrictions, SIB scheduling information	**SIB Type 2** Common and shared channel information
SIB Type 3 Cell re-selection information	**SIB Type 4** Cell re-selection information, intra-frequency neighbor information	**SIB Type 5** Cell re-selection information, intra-frequency neighbor information
SIB Type 6 Cell re-selection information for UTRA	**SIB Type 7** Cell re-selection information for GERAN	**SIB Type 8** Cell re-selection information for CDMA2000
SIB Type 9 Home eNB identifier (HNBID)	**SIB Type 10** ETWS[1)] primary notification	**SIB Type 11** ETWS[1)] secondary notification

[1)] ETWS = Earthquake and Tsunami Warning System

For cell search and selection the UE reads the PBCH and extracts the information from the MIB. The MIB carries the most essential system information, which is submitted by the logical *Broadcast Control Channel* (BCCH) via the *Broadcast Channel* (BCH) mapped onto the PBCH. The device is informed about the transmission bandwidth by transmitting the number of available resource blocks. This indicates the overall channel bandwidth, which for this radio cell is configured as 100 RB that corresponds to 20 MHz [1]. The configuration of *Physical HARQ Indicator Channel* (PHICH) and the *System Frame Number* (SFN) are the other types information carried by the MIB. Other essential information is the number of used transmission antennas on the eNB side, of which the terminal is not directly informed . In fact, this information is derived from the sequence in which one of the CRC bits is scrambled and is added to each transport block. The generation of the PBCH as well as the bit sequence indicating the number of transmit antennas is shown in Figure 15.

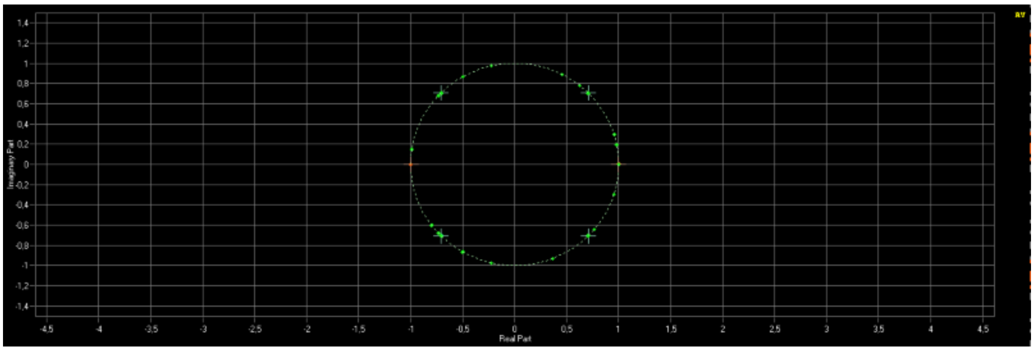
Figure 15: Generation of Physical Broadcast Channel (PBCH); number of TX antennas



Based on the bandwidth information, the terminal is able to calculate the position of the reference symbols frequency-wise as they are transmitted every fourth OFDM symbol (from a time-domain perspective) . That enables the UE to get fully synchronized to the time and frequency domain.

Figure 16 shows the constellation diagram for a downlink signal with just the PSS and SSS and reference signals present as well as the PBCH.

Figure 16: Constellation diagram LTE FDD DL signal with P-, S-Synch, reference signal and PBCH



2.4 Difference between LTE FDD and TD-LTE

The essential LTE TDD parameters are given in [9]. In the case of cell search, the position of the synchronization signals is different than in LTE FDD. The primary synchronization signal is always transmitted in the second subframe (subframe 1) in the third OFDM symbol (symbol 2). As the repetition rate for synchronization signals is in TD-LTE the same as for LTD FDD (i.e., 5 ms), the PSS is again transmitted in subframe 6, which is a special subframe with Downlink Pilot Time Slot (DwPTS), Guard Period and Uplink Pilot Time Slot (UpPTS), or a subframe directly assigned for downlink transmission. The secondary synchronization is instead transmitted in the first subframe in time slot 1, OFDM symbol 13 when a normal cyclic prefix is used. The Physical Broadcast Channel is the as LTE FDD as well. This one is transmitted in the first four OFDM symbols of the second time slot in the first subframe.

Figure 17 assumes UL-DL Configuration 1 and shows the position of PSS and SSS signals as well as PBCH using the TDD time plan available in the R&S® SMU200A vector signal generator.

Figure 17: P-, S-Synch and PBCH position for TD-LTE

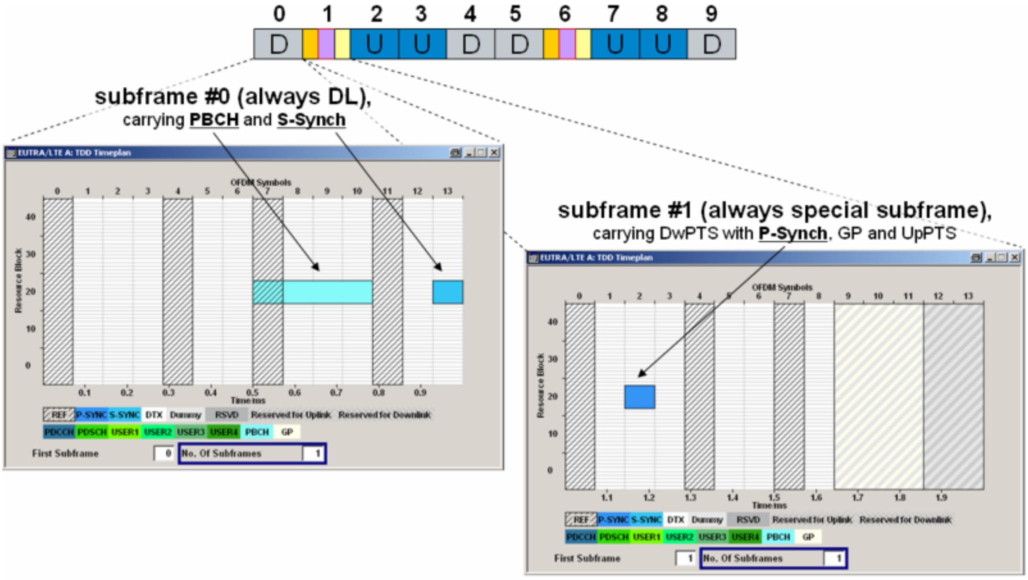
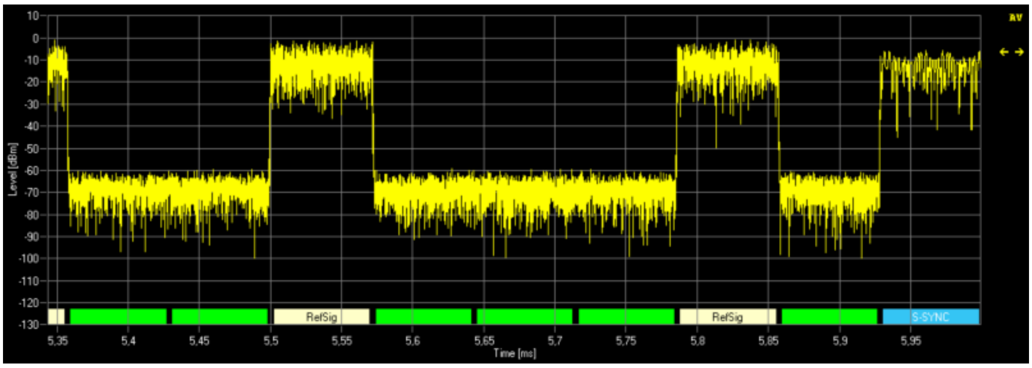


Figure 18 shows power over time for TD-LTE for the first subframe. The differences between it and FDD (Figure 11) for the position of the signal components can be extracted directly in the measurement results.

Figure 18: Power versus time; TD-LTE, subframe 0



2.5 Cell selection and reselection criteria

The previous section described how initial cell selection will work and the difference between LTE FDD and TD-LTE. However, only when specific criteria are fulfilled is the UE allowed to camp on that cell. These criteria for cell selection as well as cell reselection for LTE are specified in [10].

It is further illustrated by a description of the two procedures: In the initial cell selection procedure, as described in the previous sections, no knowledge about RF channels carrying an E-UTRA signal is available at the UE. In that case the UE scans the supported E-UTRA frequency bands to find a suitable cell. Only the cell with the strongest signal per carrier will be selected by the UE. The second procedure relies on information about carrier frequencies and optionally cell parameters received and stored from previously-detected cells. If no suitable cell is found using the stored information the UE starts with the initial cell selection procedure.

S is the criterion defined to decide if the cell is still suitable . This criterion is fulfilled when the cell selection receive level is $S_{rxlev} > 0$. S_{rxlev} is computed based on Equation 5.

Equation 5: S_{rxlev}, $P_{Compensation}$ ***estimation [10]***

$$S_{rxlev} = Q_{rxlevmeas} - (Q_{rxlevmin} + Q_{rxlevminoffset}) - P_{Compensation} \quad [dB]$$
$$\text{where} \quad P_{Compensation} = \max(P_{EMAX} - P_{UMAX}, 0) \quad [dB]$$

- $\mathbf{Q_{rxlevmeas}}$ is the measured receive level value for this cell, i.e. the *Reference Signal Received Power* (RSRP) as defined in [11]. This measured value is the linear average over the power of the resource elements that carry the cell-specific reference signals over the considered measurement bandwidth. Consequently, it depends on the configured signal bandwidth. In the case of receiver diversity configured for the UE, the reported value will be equivalent to the linear average of the power values of all diversity branches.
- $\mathbf{Q_{rxlevmin}}$ is the minimum required receive level in this cell, given in dBm. This value is signaled as *Q-RxLevMin* by higher layers as part of the *System Information Block Type 1* (SIB Type 1). $Q_{rxlevmin}$ is calculated based on the value provided within the information element (-70 and -22) multiplied with factor 2 in dBm.
- $\mathbf{Q_{rxlevminoffset}}$, is an offset to $Q_{rxlevmin}$ that is only taken into account as a result of a periodic search for a higher priority PLMN while camped normally in a Visitor PLMN (VPLMN). This offset is based on the information element provided within the SIB Type 1, taking integer values between (1…8) also multiplied by a factor of 2 in dB. This gives a wider range by keeping the number of bit transmitting this information. The offset is defined to avoid “ping-pong” between different PLMNs. If it is not available then $Q_{rxlevminoffset}$ is assumed to be 0 dB.

- $\mathbf{P_{Compensation}}$ is a maximum function as shown in Equation 5. Whatever parameter is higher, P_{EMAX}-P_{UMAX} or 0, is the value used for $P_{Compensation}$. P_{EMAX} [dBm] is the maximum power a UE is allowed to use in this cell, whereas P_{UMAX} [dBm] is the maximum transmit power of an UE according to the power class the UE belongs too. At the moment only one power class is defined for LTE, which corresponds to Power Class 3 in WCDMA that specifies +23 dBm. P_{EMAX} is defined by higher layers and corresponds to the parameter P-MAX defined in [11]. Based on this relationship, P_{EMAX} can take values between -30 to +33 dBm. Only when P_{EMAX} > +23 dBm $P_{Compensation}$ is it considered when calculating S_{rxlev}. The P-MAX information element (IE) is part of SIB Type 1 as well as in the *RadioResourceConfigCommon* IE, which is part of the SIB Type 2.

As explained above, all parameters except for $Q_{rxlevmeas}$ are provided via system information. In a real network a UE will receive several cells perhaps from different network operators. The UE only knows after reading the SIB Type 1 if this cell belongs to its operator's network (PLMN[5] Identity). First the UE will look for the strongest cell per carrier, then for the PLMN identity by decoding the SIB Type 1 to decide if this PLMN is a suitable identity. Afterwards it will compute the S criterion and decide for a suitable cell or not.

Figure 19: Cell selection example

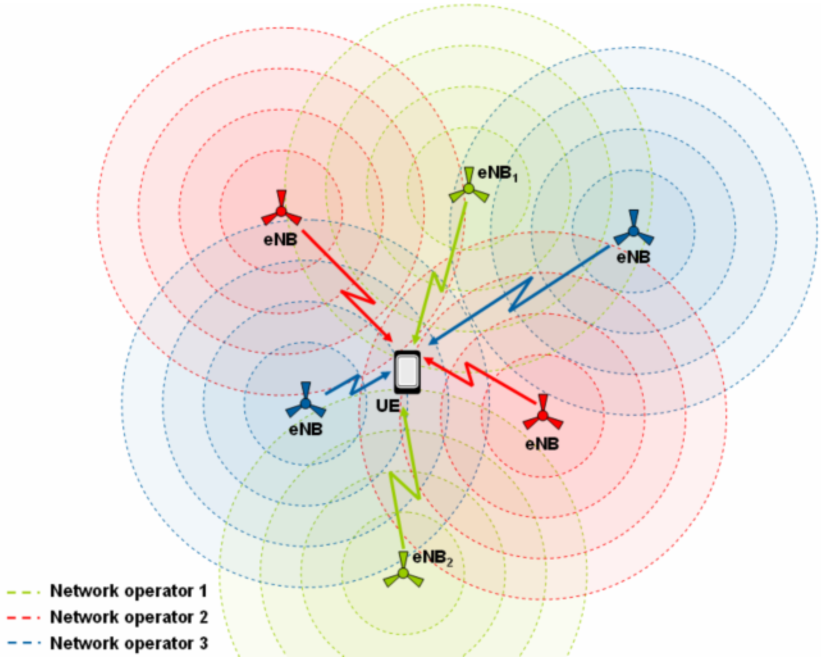


Figure 19 shows one possible scenario in a real network. Assume that the UE belongs to network operator 1 (green). There are two other carriers also operating an LTE network but of course at different frequencies. The terminal receives all base stations but at different power levels. Based on the above definition the UE will select the strong cell for each carrier . Using this the UE will start with network operator 3 and figure out after decoding the SIB Type 1 that the PLMN saved on the USIM does not match to the transmitted one. From this information it will stop with its attempt and

[5] PLMN – Public Mobile Network Identity

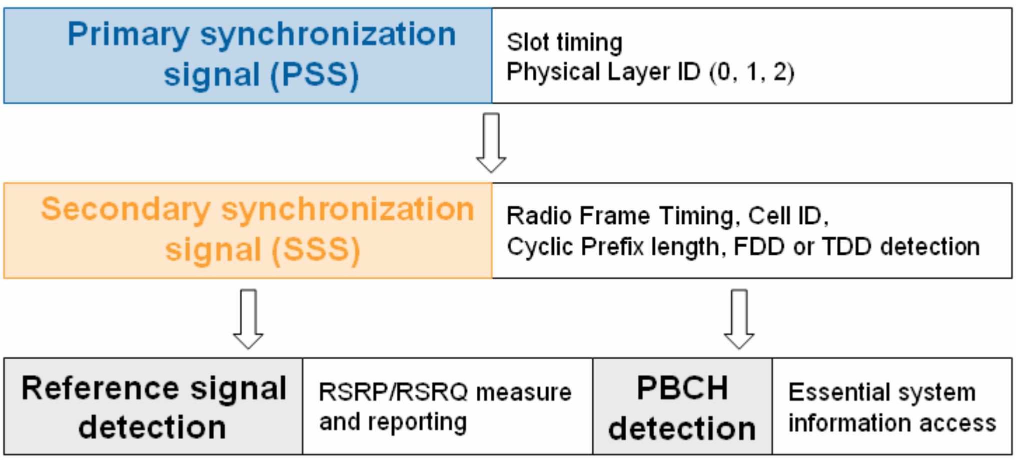
proceed to the next strongest signal, which is operator 2 (red). Now the PLMN does not correspond so the UE will continue with signal 3 (green) – and the PLMN will match. The UE continues to use the information in SIB Type 1 and Type 2 to compute the cell selection criteria. In this example, the parameters transferred and belonging to eNB_1 do not fulfill $S > 0$ where the UE will move along with demodulating and decoding the information provided by eNB_2. $S > 0$ is fulfilled and the UE starts camping on this cell.

3 R&S test solutions for LTE, focus cell search and selection

3.1 Why test cell search and selection performance?

Cell search and selection is an essential procedure and the basis of every interaction between terminal and network. Beside detecting and selecting a cell during initial access, cell search is used for LTE mobility purposes. It is a key requirement that the UE not exceed a defined threshold when a new cell is being detected and report this to the serving eNB. In terms of reporting, the UE measures the Reference Signal Received Power (RSRP) as well as Reference Signal Reported Quality (RSRQ).

Figure 20: Cell search procedure



The RSRP is comparable to the CPICH RSCP measurement in WCDMA. This measurement of the signal strength of an LTE cell helps to rank between the different cells as input for handover and cell reselection decisions. The RSRP is the average of the power of all resource elements which carry cell-specific reference signals over the entire bandwidth. It can therefore only be measured in the OFDM symbols carrying reference symbols.

The RSRQ measurement provides additional information when RSRP is not sufficient to make a reliable handover or cell reselection decision. RSRQ is the ratio between the RSRP and the Received Signal Strength Indicator (RSSI), and depending on the measurement bandwidth, means the number of resource blocks. RSSI is the total received wideband power including all interference and thermal noise. As RSRQ combines signal strength as well as interference level, this measurement value provides additional help for mobility decisions.

Formula 6: Reference signal receive quality

$$RSRQ = N\frac{RSRP}{RSSI} \qquad [dB]$$

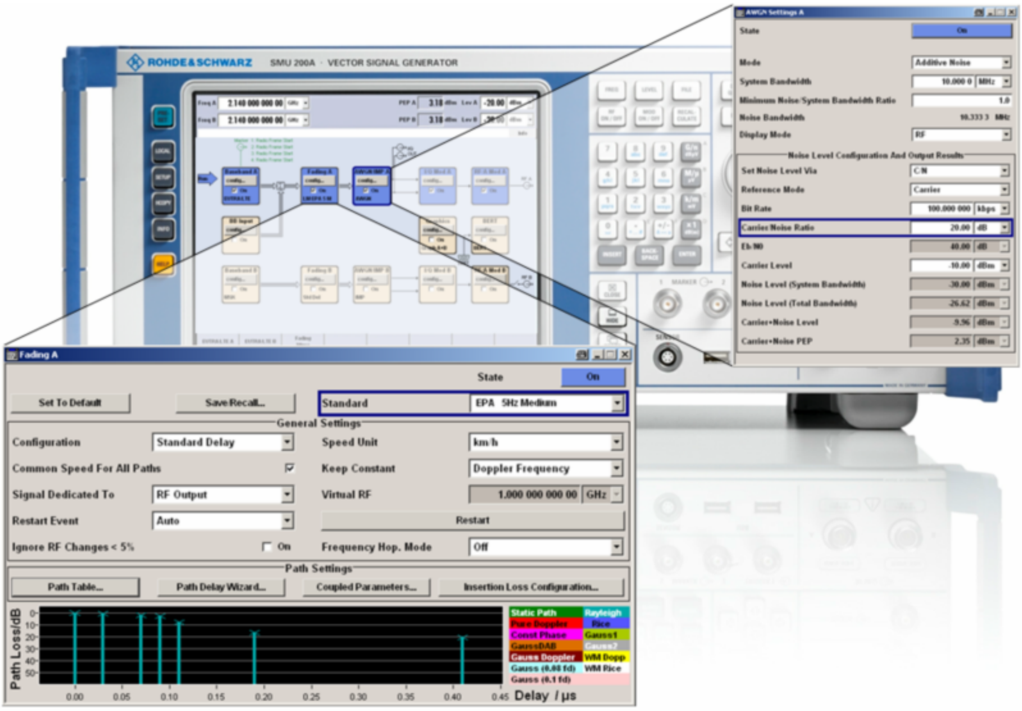
N: Number of Resource Blocks

Assume that only reference signals are transmitted in a resource block, and that data and noise and interference are not considered. In this case RSRQ is equal to -3 dB. If reference signals and subcarriers carrying data are equally powered, the ratio corresponds to 1/12 or -10.79 dB. At this point it is now important to prove that the UE is capable of detecting and decoding the downlink signal under bad channel conditions, including a high noise floor and different propagation conditions that can be simulated by using different fading profiles.

3.2 Downlink signal generation

The R&S® SMU200A vector signal generator can be used to generate any kind of LTE downlink signal: FDD as well as TDD. This signal can be used to stimulate for example an UE's receiver chain. By setting different power values for the synchronization and reference signals, the UE receiver design can be stressed and tested to detect the signal, get synchronized, and properly decode information such as cell identity. Adding noise and real-time fading as defined by the fading profiles for LTE within 3GPP, the tests can be further enhanced to make them more closely resemble actual operating conditions.

Figure 21: R&S® SMU200A vector signal generator applying fading and noise to an LTE DL signal

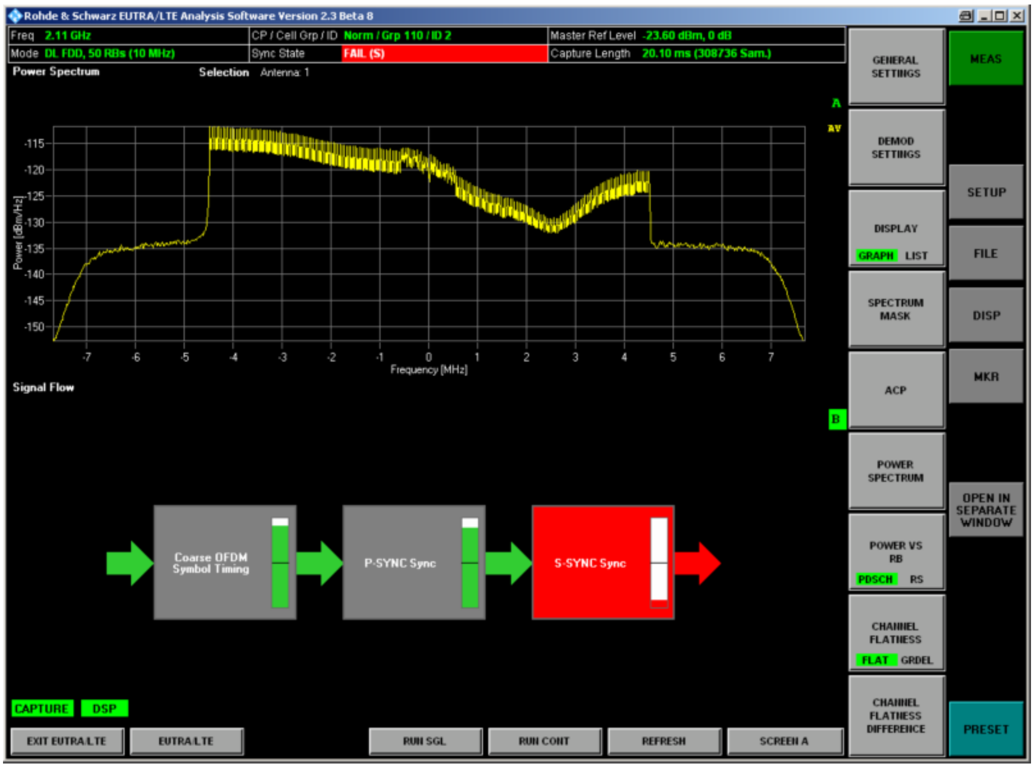


3.3 Downlink signal analysis

For testing the transmitter of an eNB, the R&S® FSQ signal analyzer is one of the various choices Rohde & Schwarz is offering for LTE signal analysis. The instrument offer various possibilities to prove the quality of the generated downlink signal and its components required for cell search and selection for LTE FDD and TDD.

Figure 22 shows the analysis (signal flow and power spectrum) of an LTE downlink signal with the R&S® FSQ-K100 EUTRA/LTE downlink/BS analysis option that can be used as remote control software or as an option for inclusion in the instrument.

Figure 22: Checking signal flow and power spectrum with R&S® FSQ-K100, Part I



The downlink signal was generated with the SMU and fading (EPA 5 Hz low) and AWGN were applied. In this example, 485 was selected as the cell identity ($N_{ID}^{(1)} = 161$, $N_{ID}^{(2)} = 2$), and the power settings for the primary and secondary synchronization signal were lowered from the reference signal by 15 and 30 dB respectively. These settings are shown in Figure 23.

Figure 23: Power versus time

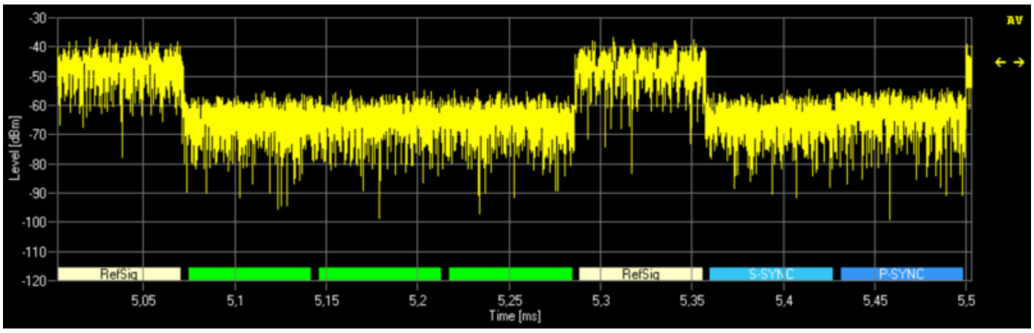
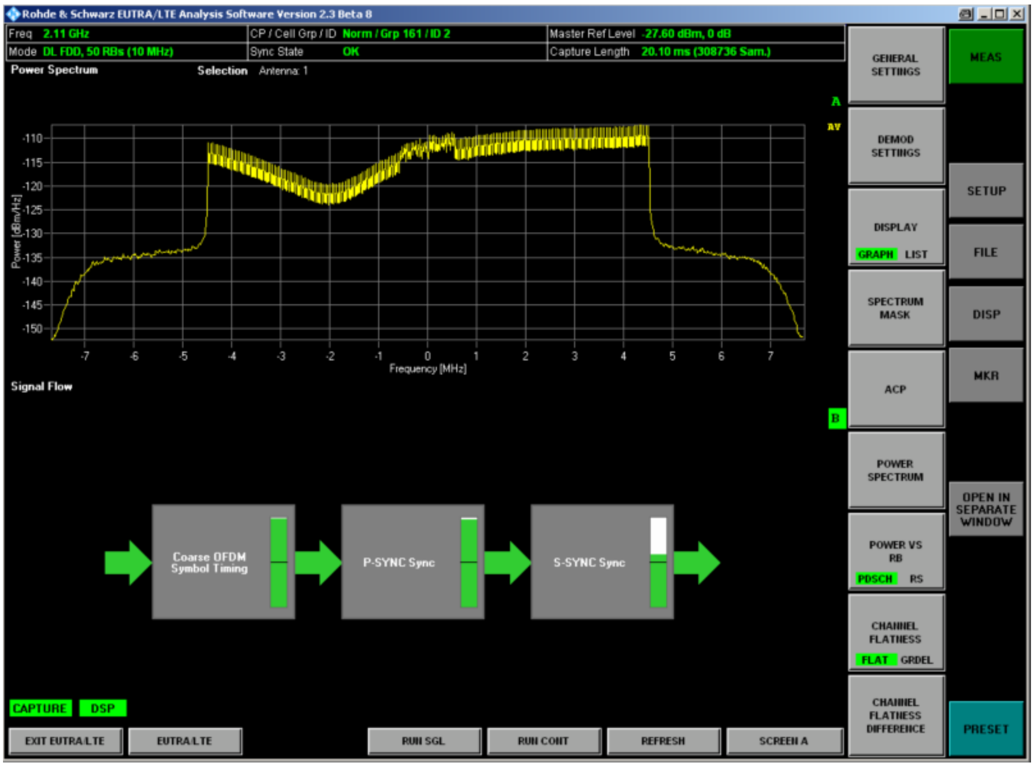


Figure 24 shows the analysis of the signal with the same configuration but at a different moment in time when fading is not affecting the center of the transmission so that decoding is still possible (as shown by the signal flow). It can be seen that by applying fading and noise to the signal testing complexity would increase. It would also stress the receiver design and show the quality of the transmitter circuit.

Figure 24:Checking signal flow and power spectrum with R&S® FSQ-K100, Part II



3.4 R&S® CMW500 – UMTS LTE Protocol Tester

The R&S® CMW500 LTE Protocol Tester can be used for verifying that the UE performs cell search and selection compliant with the 3GPP specification for UMTS LTE FDD now and later TDD. The validation of the cell-search procedure is described in Section 3.4.3 of this application note and the CMW500 and required software tools are described in the following sections.

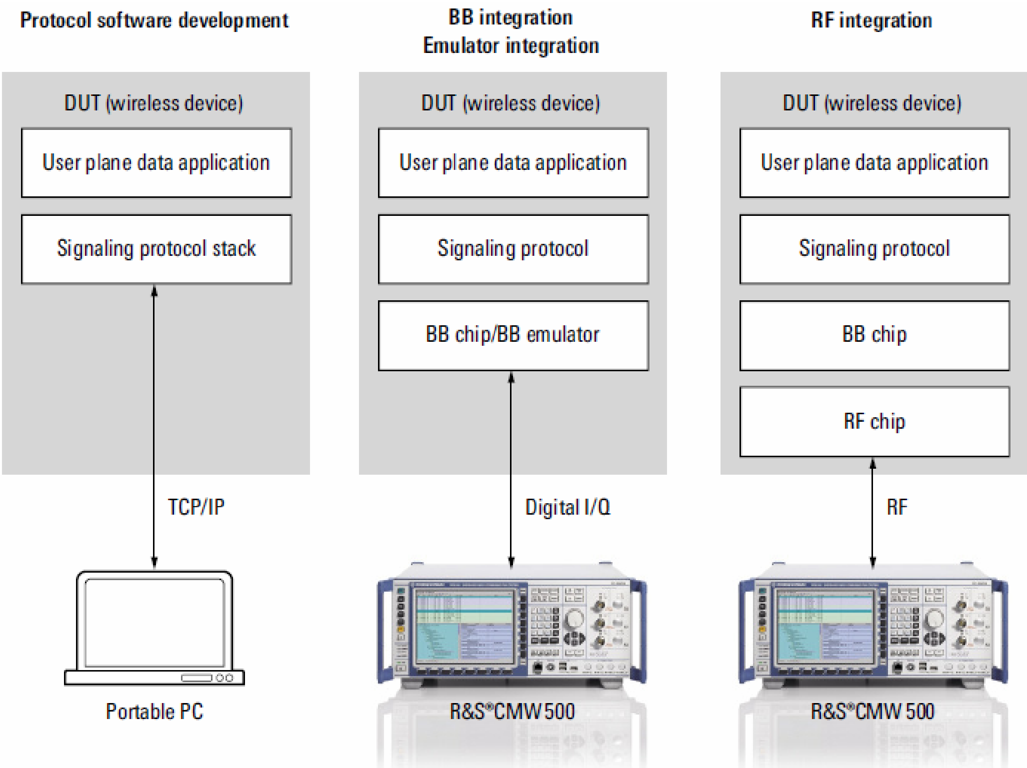
3.4.1 Introduction

By simply adding options to the R&S® CMW500 wideband radio communication tester (Figure 25), the instrument can be expanded to make it a powerful UMTS LTE protocol tester.

Figure 25: R&S® CMW500 UMTS LTE protocol tester

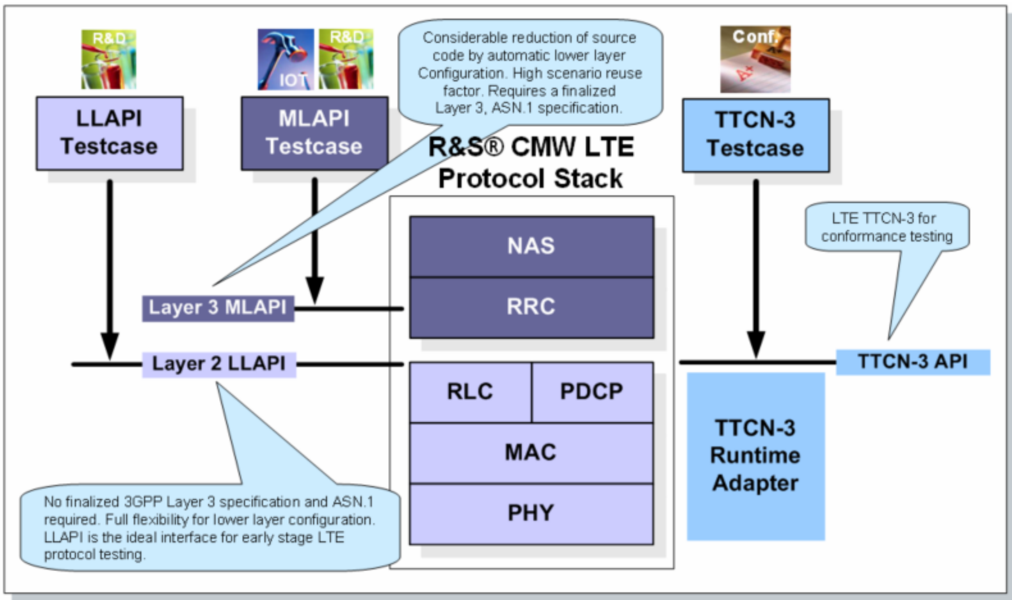
Depending on the integration of the protocol layers, various approaches for performing protocol tests can be used. The unit simulates an LTE radio access network for the development and testing of chipsets as well as wireless devices, covering every stage from development to conformance tests. The CMW500 offers various interfaces to enable testing via an RF connection or in future via a digital baseband I/Q interface (Figure 26). In addition, if a Layer 1 implementation is not yet provided or if integration has not yet been performed, the LTE virtual test software (for PC) from Rohde & Schwarz can be used to test just the protocol software. The LTE virtual test software emulates the behavior of the radio protocol layers at the network end and an abstract Layer 1 is used. The software sets up an IP connection to the protocol stack to be tested. It then runs through special signaling test scenarios that verify the behavior of the protocol stack at the wireless device end. All essential functions of the Layer 2 and Layer 3 protocols have been implemented.

Figure 26: R&S® CMW500 provides different interfaces to do protocol testing



Maximum flexibility must be provided for developing test scenarios so that numerous aspects can be covered and complex sequences can be recorded. The CMW500 distinguishes between the low-level application programming interface (LLAPI) and medium-level application programming interface (MLAPI), depending on whether the interface accesses Layer 2 or Layer 3. The LLAPI offers direct access to protocol Layers 1 and 2, which provides extra flexibility in programming the R&S CMW500. Depending on the progress in the Layer 3 definition the MLAPI becomes an efficient approach. The user need not bother with the configuration of Layer 1 and 2 as Layer 3 messages because the instrument handles that task automatically. The CMW500 can be programmed using the testing and test control notation 3 (TTCN-3) programming language. Signaling conformance test cases have been agreed by 3GPP written in this programming language. In addition to test cases for RF and Radio Resource Management (RRM), 3GPP agreed that numerous Layer 2, Layer 3, and non-access stratum test cases should be written in this programming language. The R&S CMW500 has the required software tools for creating, implementing, and preparing these test cases. Figure 27 shows the different programming interfaces for the R&S® CMW500.

Figure 27: Programming interfaces for R&S CMW500 (LLAPI, MLAPI and TTCN-3)



3.4.2 Operating software for protocol tests

The R&S® CMW500 comes with a number of software tools to develop test cases based on LLAPI and MLAPI, to reconfigure, run, and manage test campaigns, and to analyze test results. The same software tools are reused for the CMW500 as for the Rohde & Schwarz CRTU-G/W protocol test platform . The test case development is based on Microsoft Visual Studio (R&S® CMW-XT015 option). The other tools are the *R&S® Project Explorer*, *R&S® Message Analyzer*, *R&S® Message Composer* explained in the following sections, and *R&S® Automation Manager*. The automation manager (R&S® CMW–KT014) is used to remotely control the DUT by using well-defined AT commands. It can control other test equipment such as the R&S® AMU200A baseband signal generator to apply 3GPP-defined fading profiles to the signal as required for different RF or RRM test scenarios.

3.4.3 Verification of cell-search & selection procedure with R&S® CMW500

3.4.3.1 PHY scenarios – Physical Layer Testing

The physical layer (PHY) testing scenarios available for the R&S® CMW500 verify the cell-search and cell selection procedure to verify the ability of the design to receive the downlink signal, synchronize to it, and extract the transmitted system information such as bandwidth. This basic scenario can be executed for two modes using one transmitting and one receiving antenna (SISO) as well as using more transmission and reception antennas ((MIMO).

SISO

In the SISO scenario a downlink signal is generated using different bandwidths (e.g. 20, 10, 5, or 3 MHz) and cell identities (e.g. 10, 20, 30 and 40) as well as different power levels (-20, -30, -40 and -50 dBm) to validate the receiver's design. This configuration is saved in a .xml file that can be edited and configured with the message.

MIMO

In terms of control channels and the broadcast channel in the downlink MIMO equates to transmit diversity (Tx diversity). In other words, the same information is transmitted via the antenna ports but coded differently. Only in terms of user data transmission are different data streams transmitted over the antenna ports. The terminal can distinguish between the different antenna ports as each antenna is defined by its own reference signal pattern. Primary and secondary synchronization signals are only available on antenna port 0 – the first antenna.

3.4.3.2 IOT – Interoperability Testing

Conformance testing is an essential part of proving a terminal's behavior according to the current status of the related specification. Test cases are defined covering all conformance aspects, RF performance, Radio Resource Management (RRM), for mobility as well as protocol. For LTE, both certification organizations, the Global Certification Forum (GCF) and PCS Type Certification Review Board (PTCRB), have started related work. This work includes several RF and RRM as well as protocol test cases, in which a specific percentage must be passed by the device to be certified by the related organization. These test cases are based on the prose versions defined by the 3rd Generation Partnership Project (3GPP). This work is ongoing and the target date for completion is September 2009. In terms of protocol testing, the 3GPP definition is translated by a programming language (TTCN[6]-3) to executable test cases on validated test platforms such as the R&S® CMW500 LTE Protocol Tester. As there is still much work to do, certification is planned to begin at the end of 2010. Several network operators are planning a pre-commercial launch before that date. Interoperability testing (IOT) is an adequate way to perform validation on a device until official certification is started, and even at that time can complement the testing strategy.

Rohde & Schwarz supports interoperability testing with three different packages on the R&S® CMW500 . They combine different test cases developed by Rohde & Schwarz that follow different aspects of testing.

- ***CMW–KF502.*** This packages is called ***"Basic LTE Procedures"*** and provides 10 test cases. It includes basic RRC[7] and NAS[8] procedures, registration, EPS bearer setup, detach, cell selection/reselection, GUTI reallocation, and TA update.
- ***CMW–KF503.*** This packages combines 20 different test cases for ***"EPS Bearer Verification"*** allowing the activation and verification of EPS bearers, SISO/MIMO bearers, multiple EPS bearer contexts, and the verification of the 'Always on' connectivity.

[6] TTCN-3 – Testing and Test Control Notation 3

[7] RRC – Radio Resource Control

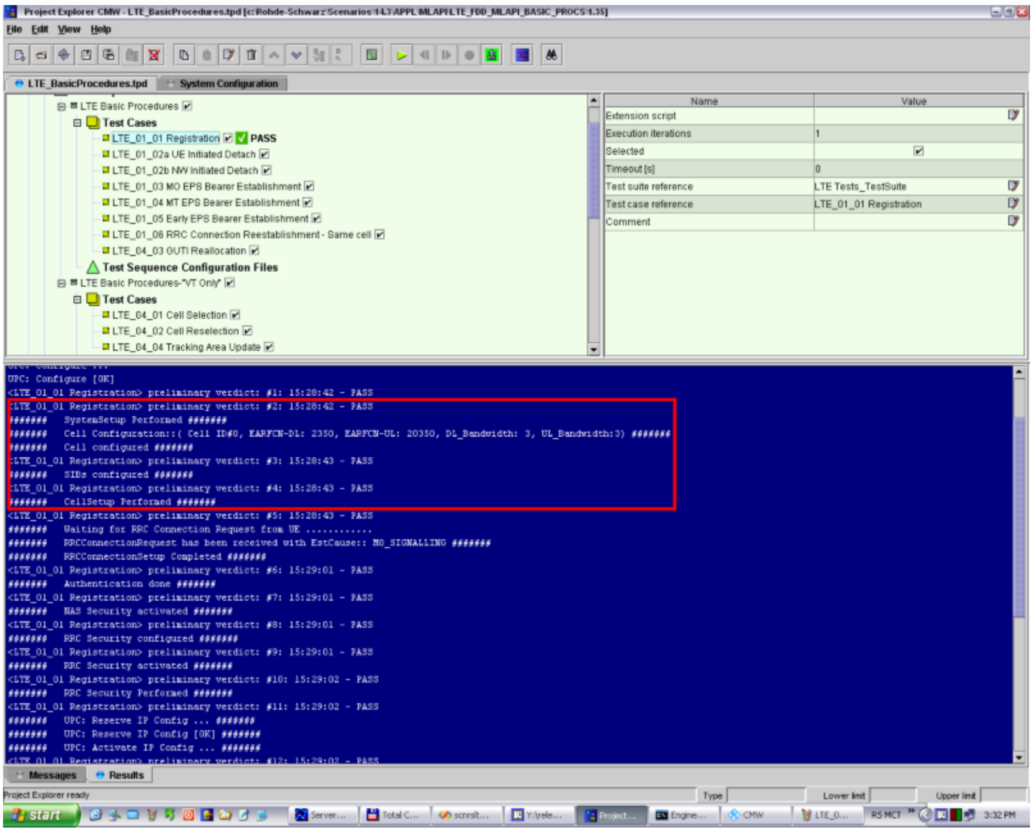
[8] NAS – Non-Access Stratum

CMW–KF504. As the standard has more evolved in terms of mobility, this package will be made available as it provides 20 test cases for ***"Intra-LTE Mobility and Handover"***.

A fourth package, ***CMW–KF505***, provides interoperability test cases that are defined by the LTE/SAE Trial Initiative (LSTI). LSTI is an industry alliance with the goal of ensuring interoperability and ensuring fast market entry for UMTS LTE.

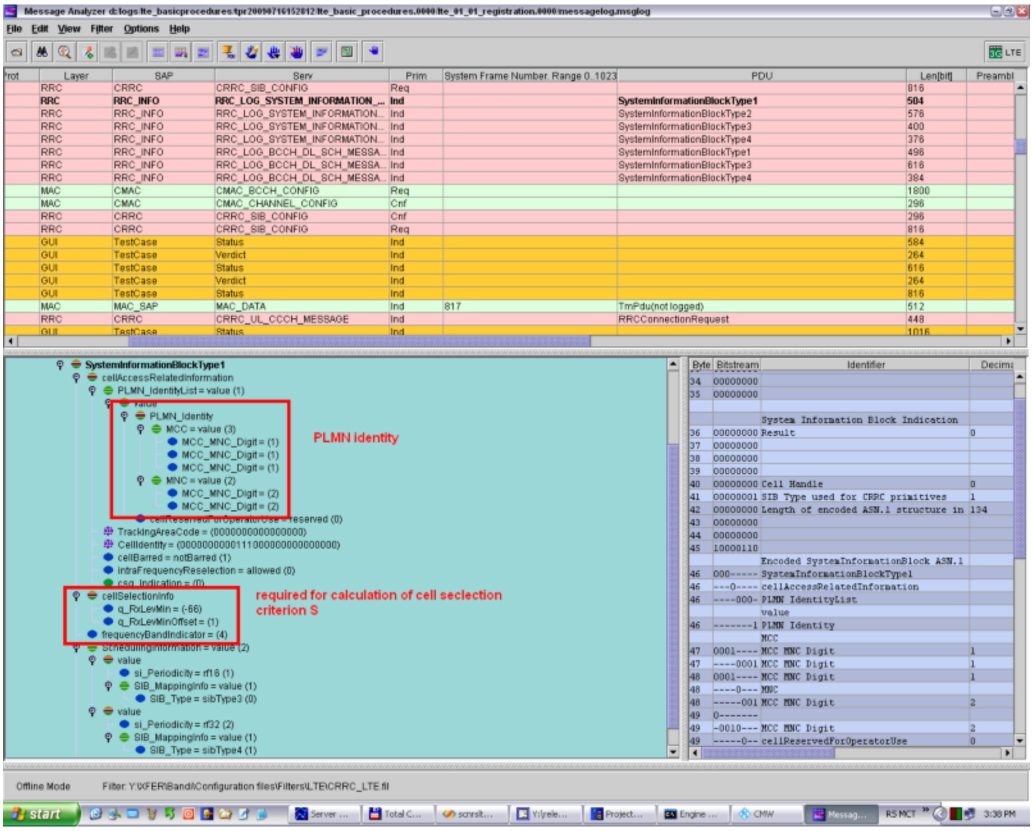
Cell selection and reselection is the initial procedure in LTE and is therefore part of the CMW–KF502 package. Cell selection is part of other test cases such as the one verifying the registration of the UE to the network. The following screenshots are taken from executing this test case. Figure 28 shows the R&S® project explorer (R&S® CMW–KT010 option) after successful testing of the UE's capability to register with the simulated network. The red mark shows the configuration of the cell using cell identity 0, frequency band 4, and a bandwidth of 10 MHz. The project explorer is used to manage the test campaign by setting up and controlling the hardware and software of the R&S® CMW500. After configuration and execution of the test campaign the project explorer generates the test report.

Figure 28: Test case 'Registration' out of CMW–KF502 package shown in the project explorer



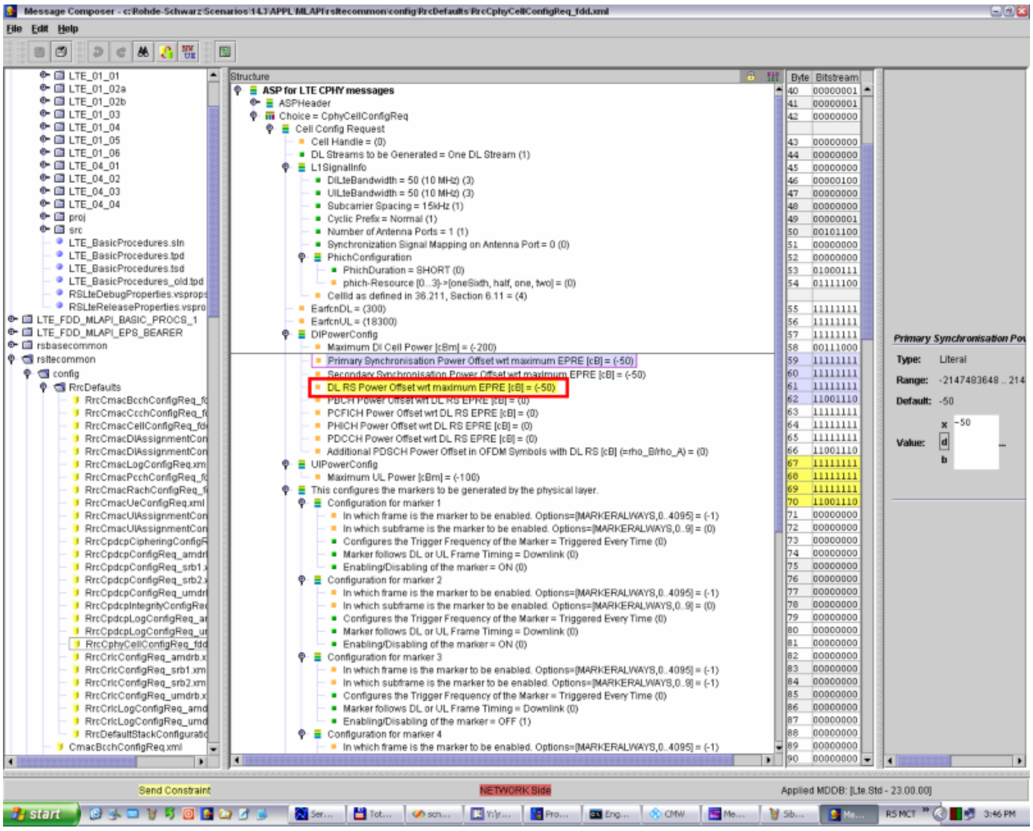
When setting up the cell the system information is also configured. With help from the message analyzer (R&S® CMW–KT011 option) the details of System Information Block Type 1 can be displayed. The message analyzer is used to examine the test results by decoding the message log files provided by the project explorer with the test report. Figure 29 shows the content of SIB Type 1, where the PLMN identity is provided as well as $Q_{rxlevmin}$ and $Q_{rxlevminoffset}$. Both parameters influence the calculation of the cell selection criterion S.

Figure 29: Message analyzer



Another parameter influencing the calculation of the cell selection criterion is the power level at which the Downlink Reference Signals (DL RS) are transmitted. This setting can be configured using the message composer (R&S® CMW–KT012 option) by editing the cell configuration file as shown in Figure 30. The message composer is used to edit (for example) the Layer 3 messages as well as configuration files and is therefore a convenient software tool to configure the test script.

Figure 30: Cell configuration shown with the Message Composer



3.4.3.3 Cell selection and reselection according to 3GPP TS 36.523 Part 1

Protocol conformance is specified in 3GPP TS 36.523 Part 1. Section 6.1.2. deals with different aspects of testing the cell selection and reselection procedure in LTE. Ten test cases have currently been defined.

As explained in the previous section, the prose version of the 3GPP specification is translated by an ETSI related working group using a specific programming language into executable TTCN-3 test cases. As of today[9], the test cases covering cell selection and reselection are available as code but have not been validated on any test platform. This is because, except for one, all test cases deal with a multi-cell environment in which up to three cells are simulated. Leading suppliers of test equipment are already working on supporting these multiple cell scenarios.

Lets take a look at one particular test case, defined in section 6.1.2.2 in [14], which is not requiring a multiple cell scenario. The purpose of this test case is to ensure that the UE will not camp on a cell, which fulfils all requirements for a suitable cell except the cell selection criteria S (S<0; see Section 2.5 in this document) as well as when the cell selection criteria S is met (S>0). The power level for the cell-specific reference signal is initially set to -95 dBm/15 kHz and later the level is increased to -75 dBm/15 kHz. Based on the initial power level for the cell-specific reference signals, the UE should be checked to ensure it does not perform any random access request. After 60 seconds

[9] August 2009

the power level will be increased and the UE must recognize that the S criterion is now met and should perform a random access.

Table 1 shows all the specific cell parameters for this particular test case.

Table 1: Cell selection, $Q_{rxlevmin}$ test case out of [13]

	Parameter	Unit	Cell 1	Remark
T0	Cell-specific RS EPRE	dBm/15kHz	-95	The power level value is such to satisfy $S_{rxlevCell\ 1} < 0$, but the UE is able to read the PLMN identity
	$Q_{rxlevmin}$	dBm	-84	
	$Q_{rxlevminoffset}$	dB	0	
	$P_{compensation}$	dB	0	
T1	Cell-specific RS EPRE	dBm/15kHz	-75	The power level is such that $S_{rxlevCell\ 1} > 0$

3.4.3.4 Cell selection and reselection according to 3GPP TS 36.521 Part 3

Part 3 of the UE conformance test specification covers the *Radio Resource Management* (RRM), that is, mobility aspects [14]. As part of this cell selection more cell reselection tests are defined for the two connected modes: *IDLE* or *CONNECTED* state. In IDLE mode the actual baseline as of June 2009 and does not foresee any cell selection tests. However, many cell reselection tests that do have as their main purpose checking the terminal's ability to reselect another radio access technology when leaving LTE FDD or TDD coverage. These tests are valid only if the UE supports this radio access technology.

The following technologies belong to the 3GPP technology evolution path: GSM as well as UTRA FDD and UTRA TDD and also 3GPP2-defined technologies. As the majority of CDMA2000® 1xRTT and 1xEV-DO carriers have announced their intention to migrate to UMTS LTE, this 3GPP standard is likely to become the predominant mobile broadband technology. This is also reflected in the test specification. Section 4.5 (for HRPD cell re-selection) and 4.6 (for CDMA2000® 1xRTT cell re-selection) of [14] are dealing with this aspect. In both cases the test purpose is to verify that the terminal is capable of searching and measuring neighboring HRPD CDMA2000® 1xRTT cells and comparing them to the E-UTRA serving cell to meet the inter-RAT cell re-selection requirements. To perform those types of measurements, the UE must acquire the timing of HRPD cells. This system time as well as the list of HRPD neighboring frequencies (up to 16) and other relevant information are provided within System Information Block Type 8 (SIB Type 8). A cell reselection priority is defined (0…7), where 0 means lowest priority and 7 highest priority. Depending on the selected priority and when the reception of the E-UTRA serving cell falls below a defined threshold, the terminal will measure the CDMA2000 HRPD pilot strength at well defined time steps [11, 14, 15].

4 Abbreviations

3GPP	3rd Generation Partnership Project
BCCH	Broadcast Control Channel
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
DL	Downlink
eNB	E-UTRAN NodeB, enhanced Node B
EPRE	Energy Per Resource Element
ETSI	European Telecommunication Standardization Institue
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
LTE	Long Term Evolution
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PBCH	Physical Broadcast Channel
PHY	Physical Layer
PSS	Primary Synchronization Signal
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RS	Reference Signal
SISO	Single Input Single Output
SSS	Secondary Synchronization Signal
MIMO	Multiple Input Multiple Output
TDD	Time Division Duplex
TD-LTE	TDD mode of LTE (= LTE TDD)
TTCN-3	Testing and Test Control Notation
UE	User Equipment
UL	Uplink

5 Literature

[1]	3GPP TS 36.104 V8.6.0; Base station (BS) radio transmission and reception (Release 8),
[2]	3GPP TS 36.101 V8.6.0; User Equipment (UE) radio transmission and reception (Release 8),
[3]	3GPP TS 36.141 V8.3.0; Base station (BS) conformance testing (Release 8),
[4]	3GPP TS 36.521-1 V8.2.1; User Equipment (UE) conformance specification Radio transmission and reception Part 1: conformance specification (Release 8),
[5]	3GPP TS 36.213 V8.7.0; Physical layer procedures (Release 8),
[6]	3GPP TS 36.211 V8.7.0; Physical Channels and Modulation (Release 8),
[7]	3GPP TS 36.212 V8.7.0; Multiplexing and channel Coding (Release 8),
[8]	Moritz Harteneck, LTE: Testing the physical layer of next-generation mobile communications, Rohde & Schwarz, EDN Europe, October 2008
[9]	Application Note 1MA111_2E; UMTS Long Term Evolution (LTE) Technology Introduction, Rohde & Schwarz,
[10]	3GPP TS 36.304 V8.6.0; UE procedures in idle mode (Release 8),
[11]	3GPP TS 36.331 V8.6.0; Radio Resource Control (RRC) specification (Release 8),
[12]	Stefania Sesia, Issam Toufix, Matthew Baker, LTE – The UMTS Long Term Evolution, From Theory to Practice, published in 2009
[13]	3GPP TS 36.523-1 V8.2.1; User Equipment (UE) conformance specification; Part 1: Protocol conformance specification (Release 8)
[14]	3GPP TS 36.521-3 V8.0.1; User Equipment (UE) conformance specification Radio transmission and reception Part 3: Radio Resource Management (RRM) specification (Release 8),
[15]	3GPP TS 36.133 V8.6.0; Requirements for support of radio resource management (Release 8),

6 Additional Information

This application note is updated from time to time. Please visit the website 1MA138 to download the latest version. Please send any comments or suggestions about this application note to **TM-Applications@rsd.rohde-schwarz.com**.

7 Ordering Information

Vector Signal Generator

R&S® SMU200A		1141.2005.02
R&S® SMU-B102	Frequency range 100 KHz to 2.2GHz for 1st RF Path	1141.8503.02
R&S® SMU-B103	Frequency range 100 KHz to 3GHz for 1st RF Path	1141.8603.02
R&S® SMU-B104	Frequency range 100 KHz to 4GHz for 1st RF Path	1141.8703.02
R&S® SMU-B106	Frequency range 100 KHz to 6 GHz for 1st RF Path	1141.8803.02
R&S® SMU-B202	Frequency range 100 KHz to 2.2 GHz for 2nd RF Path	1141.9400.02
R&S® SMU-B203	Frequency range 100 KHz to 3 GHz for 2nd RF Path	1141.9500.02
R&S® SMU-B9	Baseband Generator with digital modulation (realtime) and ARB (128 M Samples)	1161.0766.02
R&S® SMU-B10	Baseband Generator with digital modulation (realtime) and ARB (64MSamples)	1141.7007.02
R&S® SMU-B11	Baseband Generator with digital modulation (realtime) and ARB (16MSamples)	1159.8411.02
R&S® SMU-B13	Baseband Main Module	1141.8003.02
R&S® SMU-K55	Digital Standard 3GPP LTE/EUTRA	1408.7310.02
R&S® SMU-K255	Digital Standard 3GPP LTE/EUTRA for WinIQSIM2	1408.7362.02
R&S® SMU-B14	Fading simulator	1160.1800.02
R&S® SMU-B15	Fading simulator extension	1160.2288.02
R&S® SMU-K74	2x2 MIMO Fading	1408.7762.02
R&S® SMU-K62	AWGN	xxxx.xxxx.xx
R&S® SMJ100A		1403.4507.02
R&S® SMJ-B103	Frequency range 100 kHz - 3 GHz	1403.8502.02
R&S® SMJ-B106	Frequency range 100 kHz - 6 GHz	1403.8702.02
R&S® SMJ-B9	Baseband generator with digital modulation (realtime) and ARB (128 M Samples)	1404.1501.02
R&S® SMJ-B10	Baseband Generator with digital modulation (realtime) and ARB (64MSamples)	1403.8902.02
R&S® SMJ-B11	Baseband Generator with digital modulation (realtime) and ARB	1403.9009.02

	(16MSamples)	
R&S® SMJ-B13	Baseband Main Module	1403.9109.02
R&S® SMJ-K55	Digital Standard 3GPP LTE/EUTRA	1409.2206.02
R&S® SMJ-K255	Digital standard 3GPP LTE/EUTRA for WinIQSIM2	1409.2258.02
R&S® SMATE200A		1400.7005.02
R&S® SMATE-B103	Frequency range 100 KHz to 3 GHz for 1st RF Path	1401.1000.02
R&S® SMATE-B106	Frequency range 100 KHz to 6 GHz for 1st RF Path	1401.1200.02
R&S® SMATE-B203	Frequency range 100 KHz to 3 GHz for 2nd RF Path	1401.1400.02
R&S® SMATE-B206	Frequency range 100 kHz - 6 GHz for 2nd RF path	1401.1600.02
R&S® SMATE-B9	Baseband Generator with digital modulation (real time) and ARB (128 M samples)	1404.7500.02
R&S® SMATE-B10	Baseband Generator with digital modulation (realtime) and ARB (64MSamples)	1401.2707.02
R&S® SMATE-B11	Baseband Generator with digital modulation (realtime) and ARB (16MSamples)	1401.2807.02
R&S® SMATE-B13	Baseband Main Module	1401.2907.02
R&S® SMATE-K55	Digital Standard 3GPP LTE/EUTRA	1404.7851.02
R&S® AMU200A	Baseband signal generator, base unit	1402.4090.02
R&S® AMU-B9	Baseband generator with digital modulation (realtime) and ARB (128 MSamples)	1402.8809.02
R&S® AMU-B10	Baseband generator with dig. modulation (realtime) and ARB (64 MSamples)	1402.5300.02
R&S® AMU-B11	Baseband generator with dig. modulation (realtime) and ARB (16 MSamples)	1402.5400.02
R&S® AMU-B13	Baseband main module	1402.5500.02
R&S® AMU-K55	Digital Standard LTE/EUTRA	1402.9405.02
R&S® AMU-K255	Digital Standard LTE/EUTRA for WInIQSIM2	1402.9457.02
R&S® AMU-B14	Fading Simulator	1402.5600.02
R&S® AMU-B15	Fading Simulator extension	1402.5700.02
R&S® AMU-K74	2x2 MIMO Fading	1402.9857.02
R&S® AFQ100A	IQ modulation generator base unit	1401.3003.02
R&S® AFQ-B10	Waveform memory 256 Msamples	1401.5106.02

R&S® AFQ-B11	Waveform memory 1Gsamples	1401.5206.02
R&S® AFQ-K255	Digital Standard LTE/EUTRA, WinIQSIM 2 required	1401.5906.02
R&S®SMBV100A	Vector Signal Generator	1407.6004A
R&S®SMBV-B103	RF 9 kHz to 3.2 GHz	1407.9603.02
R&S®SMBV-B10	Baseband & ARB Generator	1407.8607.02
R&S®SMBV-K55	Digital Standard EUTRA/LTE	1415.8177.02
Signal- and Spectrum Analyzer		
R&S® FSQ3	20 Hz to 3.6 GHz	1155.5001.03
R&S® FSQ8	20 Hz to 8 GHz	1155.5001.08
R&S® FSQ26	20 Hz to 26.5 GHz	1155.5001.26
R&S® FSQ40	20 Hz to 40 GHz	1155.5001.40
R&S® FSG8	9 kHz to 8 GHz	1309.0002.08
R&S® FSG13	9 kHz to 13.6 GHz	1309.0002.13
R&S® FSV3	9 kHz to 3.6 GHz	1307.9002.03
R&S® FSV7	9 kHz to 7 GHz	1307.9002.07
R&S® FSV13	9 kHz to 13 GHz	1307.9002.13
R&S® FSV30	9 kHz to 30 GHz	1307.9002.30
R&S® FSV40	9 kHz to 40 GHz	1307.9002.40
R&S® FSQ-K100	EUTRA/LTE Downlink / BS Analysis	1308.9006.02
R&S® FSV-K100	EUTRA/LTE Downlink / BS Analysis	1310.9051.02
R&S® FSQ-K101	EUTRA/LTE Uplink / UE Analysis	1308.9058.02
R&S® FSV-K101	EUTRA/LTE Uplink / UE Analysis	1310.9100.02
R&S® FSQ-K102	EUTRA/LTE Downlink, MIMO	1309.9000.02

About Rohde & Schwarz
Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

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