LTE UE RF measurements – An introduction and overview
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Your presenters today…

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Outline

- Introduction,
  - Overview and market update,
  - Status of standardization,

- LTE UE RF measurements,
  - Prerequisites, LTE Call Setup,
  - TX measurements
    - Power measurements, transmit signal quality, spectrum,
  - RX measurements,

- Summary & conclusion.
Overview, market update

The LTE eco-system is building up,
- Several LTE platforms have been announced and demonstrated by leading device / chipset manufacturer on various trade shows around the globe in 2009,
- Various field trials are ongoing, using different infrastructure providers,
- Several test systems and instruments are available,
- 1st (pre-)commercial network launch in Europe end of 2009, more expected during 2010 with a rapid deployment in 2011/2012,
- 51 global network operator commitments to LTE in 24 countries,
- LTE offers migration part not only for traditional GSM/WCDMA carrier but also for CDMA2000® 1xRTT/1xEV-DO carrier,
- Market research or what analyst say about LTE,
- The global LTE handset market will increase from 70 million sales units in 2012 to 150 million by 2013,
- LTE subscribers to reach 380 million by 2015,
- By 2013 operators will spend over $8.6 billion on LTE base stations infrastructure,
- LTE will grow faster than 3G,

Status standardization (3GPP),
- Actual specification is Dec'09 baseline,
- Core specification (RAN1 to RAN4) now stable,
- UE test specifications (RAN5) is subject to change.
UE testing according to standards (3GPP)
RF, RRM and protocol conformance

I 3GPP TS 36.521,
   I Part 1 RF conformance testing,
      Section 6 (= Tx), Section 7 (= Rx), Section 8 (= Performance),
      Section 9 (= CQI, PMI reporting),
   I Part 3 Radio Resource Management (RRM) conformance testing,

I 3GPP TS 36.523,
   I Part 1 Protocol conformance specification,

I Work items closed¹), specification of priority #1 and #2 test cases
used for LTE UE certification are complete.

¹) based on TSG RAN#46 in Sanya/China, December 1st-4th 2009
### Migration to R&S® CMW500 hardware platform

<table>
<thead>
<tr>
<th>R&amp;S® CMU200</th>
<th>R&amp;S® CRTU-G/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio Communication Tester</td>
<td>Protocol Test Platform</td>
</tr>
</tbody>
</table>

**One HW platform configurable as…**
- Non-signaling production unit
  - All cellular standards, WLAN, FM, GPS, WiMAX, DVB
- LTE/HSPA+ Protocol Tester,
- LTE/HSPA+ RF Test Set,

**Also**

- 2G/2.5G
- CDMA2000/1xEV-DO, Bluetooth, FM

**R&S® CMW500**

(picture showing configuration as LTE RF Tester)

...as well as future proofed platform for the upcoming challenges...

<table>
<thead>
<tr>
<th>Rel-99</th>
<th>Rel-4</th>
<th>Rel-5</th>
<th>Rel-6</th>
<th>Rel-7</th>
<th>Rel-8</th>
<th>Rel-9</th>
<th>Rel-10</th>
</tr>
</thead>
</table>

**LTE UE RF measurements**
A. Roessler and G. Pfeifer | February 2010 | 6
LTE UE RF testing aspects
User Equipment (UE) according to 3GPP TS 36.521-1

Tx characteristic (section 6),
- Transmit power,
  - Maximum UE output power, Maximum Power Reduction (MPR), Additional MPR, configured UE transmitted output power,
- Output power dynamics,
  - Minimum output power, Transmit OFF power, ON/OFF time mask, power control,
- Transmit Signal Quality,
  - Frequency error, EVM vs. subcarrier, EVM vs. symbol, LO leakage, IQ imbalance, In-band emission, spectrum flatness,
- Output RF spectrum emissions,
  - Occupied bandwidth, Spectrum Emission Mask (SEM), Adjacent Channel Leakage Power Ratio (ACLR), spurious emission band UE coexistence,
- Transmit Intermodulation,

Rx characteristics (section 7),
- Reference sensitivity level, Maximum input level, Adjacent channel selectivity (ACS), Blocking characteristics, Spurious response, Intermodulation characteristics, Spurious emissions,

Performance requirements (section 8),
- Demodulation of PDSCH (FDD/TDD),
  - Single antenna, transmit diversity (2x2, 4x2), open and closed loop spatial multiplexing (2x2, 4x2),
- Demodulation of PCFICH/PDCCH (FDD/TDD),
  - Single antenna, transmit diversity,
- Demodulation of PHICH,
  - Single antenna, transmit diversity,
- Demodulation of PBCH,

Reporting of CQI/PMI (section 9),
- CQI reporting under AWGN and fading conditions, single and multiple PMI reporting.
Why testing LTE at all?
Some bullet points…

- LTE uses a complex physical layer with a high demand on testing,
  - OFDM is in general very sensitive to frequency and clock offsets,
  - SC-FDMA: verify that the PAPR\(^1\) is really low(er) to minimize UL interference,
- Bandwidths up to 20 MHz are used by LTE, which requires power amplifier and IQ modulators to have a flat frequency response,
  - Usage of higher-order modulation schemes (16QAM, 64QAM) requires high modulation accuracy even when noise, fading and interferences are present,
- No transmit filter definition in LTE, as for 3G technologies,
  - In-channel performance (i.e. EVM) and out-of-channel performance (i.e. ACLR, SEM) requirements need to be met by the design,
- Testing multiple use of antennas (MIMO) as part of performance requirements,
  - Transmit diversity, spatial multiplexing (closed-looped and open loop).

\(^1\) Peak-to-Average Power Ratio
On what type of channels and signals measurements can be made in the uplink?

Path loss
Multipath propagation
UL interference

Physical Uplink Control Channel (PUCCH)
(Demodulation Reference Signal, occupied time slot position depends on used format)

Sounding Reference Signals (SRS)

Physical Uplink Shared Channel (PUSCH)
(Demodulation Reference Signal, over entire bandwidth in time slots #3 and #10)

LTE-capable base station
(enhanced Node B, eNB)

LTE-capable terminal
(User Equipment, UE)
A first challenge – LTE frequency bands...

<table>
<thead>
<tr>
<th>E-UTRA Operating Band</th>
<th>Uplink (UL) operating band BS receive UE transmit</th>
<th>Downlink (DL) operating band BS transmit UE receive</th>
<th>Duplex Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1920 MHz – 1980 MHz</td>
<td>2110 MHz – 2170 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>2</td>
<td>1850 MHz – 1910 MHz</td>
<td>1930 MHz – 1990 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>3</td>
<td>1770 MHz – 1735 MHz</td>
<td>1805 MHz – 1830 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>4</td>
<td>1710 MHz – 1755 MHz</td>
<td>2110 MHz – 2155 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>5</td>
<td>624 MHz – 649 MHz</td>
<td>609 MHz – 694 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>6</td>
<td>830 MHz – 840 MHz</td>
<td>875 MHz – 885 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>7</td>
<td>2500 MHz – 2570 MHz</td>
<td>2620 MHz – 2690 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>8</td>
<td>880 MHz – 915 MHz</td>
<td>925 MHz – 960 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>9</td>
<td>1749.9 MHz – 1784.9 MHz</td>
<td>1844.9 MHz – 1879.9 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>10</td>
<td>1710 MHz – 1770 MHz</td>
<td>2110 MHz – 2170 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>11</td>
<td>1427.9 MHz – 1452.9 MHz</td>
<td>1475.9 MHz – 1500.9 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>12</td>
<td>608 MHz – 716 MHz</td>
<td>728 MHz – 746 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>13</td>
<td>777 MHz – 787 MHz</td>
<td>746 MHz – 756 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>14</td>
<td>788 MHz – 796 MHz</td>
<td>758 MHz – 766 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>15</td>
<td>704 MHz – 716 MHz</td>
<td>734 MHz – 746 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>16</td>
<td>815 MHz – 830 MHz</td>
<td>860 MHz – 875 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>17</td>
<td>930 MHz – 945 MHz</td>
<td>975 MHz – 990 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>18</td>
<td>1900 MHz – 1920 MHz</td>
<td>1900 MHz – 1920 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>19</td>
<td>2010 MHz – 2025 MHz</td>
<td>2010 MHz – 2025 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>20</td>
<td>1850 MHz – 1910 MHz</td>
<td>1850 MHz – 1910 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>21</td>
<td>1930 MHz – 1950 MHz</td>
<td>1930 MHz – 1950 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>22</td>
<td>1910 MHz – 1930 MHz</td>
<td>1910 MHz – 1930 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>23</td>
<td>2570 MHz – 2620 MHz</td>
<td>2570 MHz – 2620 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>24</td>
<td>1880 MHz – 1900 MHz</td>
<td>1880 MHz – 1900 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>25</td>
<td>2300 MHz – 2400 MHz</td>
<td>2300 MHz – 2400 MHz</td>
<td>TDD</td>
</tr>
</tbody>
</table>
...but the R&S® CMW500 supports already all bands and bandwidths!

Pick any 3GPP frequency band and...

...select channel number or carrier frequency!

\[
F_{DL} = F_{DL\_low} + 0.1 \cdot (N_{DL} - N_{Offs\_DL}) \\
F_{UL} = F_{UL\_low} + 0.1 \cdot (N_{UL} - N_{Offs\_UL})
\]
Setup a LTE call with R&S® CMW500

http://www.youtube.com/watch?v=3dTAOCFvuEg
Measurements as usual?
No! – Multi-evaluation measurement for LTE FDD/TDD

- Power, power control
- Modulation
- Resource Allocation Table
- Spectrum
One power class has been defined for all applicable 3GPP frequency bands:
– Power class 3: $+23 \text{ dBm} \pm 2.7 \text{ dB}$, at the edge of spectrum lower tolerance is $-4.2 \text{ dB}$,
– The period of measurement shall be at least one subframe ($= 1\text{ms}$),
– Measurement defined for all bandwidths, using QPSK modulation and partial RB allocation (always 1 RB, size of $2^{nd}$ allocation depends on BW, i.e. 18 RB @ 20 MHz),

However the flexibility of the LTE air interface in terms of bandwidth and modulation requires *Maximum Power Reduction* (MPR) when using higher order modulation schemes and increasing transmission bandwidth,

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Channel bandwidth / Transmission bandwidth configuration [RB]</th>
<th>MPR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.4 MHz</td>
<td>3.0 MHz</td>
</tr>
<tr>
<td>QPSK</td>
<td>$&gt; 5$</td>
<td>$&gt; 4$</td>
</tr>
<tr>
<td>16 QAM</td>
<td>$\leq 5$</td>
<td>$\leq 4$</td>
</tr>
<tr>
<td>16 QAM</td>
<td>$&gt; 5$</td>
<td>$&gt; 4$</td>
</tr>
</tbody>
</table>

– For some 3GPP frequency bands network signaling informs the UE about an additional maximum power reduction (A-MPR) to meet additional requirements, i.e. for SEM or spurious emissions,
LTE power measurements with R&S® CMW500

RB power = Resource Block Power, power of 1 RB
TX power = integrated power of all assigned RBs

TX power value corresponds to the maximum UE output power depending on the settings!

\[ 10 \times \log(40 \text{ RB}) \approx 16.02 \text{ dB} \]
In-band emissions measurement

- Estimate the interference to non-allocated resource blocks, as the UE shares transmission bandwidth with other UE’s,
- 3 types of in-band emissions: general, DC image and IQ image.
Transmit signal quality

Frequency error
$|\Delta f| = \pm 0.1\text{ppm} + 15\text{Hz}$

IQ component

Power level

RF carrier

EVM,
Spectrum flatness

In-band emissions
Error Vector Magnitude (EVM)

EVM vs. subcarrier

Integration of all Error Vectors to Display EVM curve

Limits: BPSK+QPSK (17.5%), 16QAM (12.5%), 64QAM (tbd)

Error vector

Limits: BPSK+QPSK (17.5%), 16QAM (12.5%), 64QAM (tbd)

Error vector

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Error Vector Magnitude (EVM)

EVM vs. symbol

1 Time Slot = 0.5 ms → 7 SC-FDMA symbols (normal Cyclic Prefix (CP))

1 SC-FDMA symbol

1 subframe = 1 ms [minimum Transmit Time Interval (TTI)]

...but there are 2 results displayed per SC-FDMA symbol... Why?
## Error Vector Magnitude (EVM)

### EVM vs. symbol – How is this EVM measured?

- **4.7** (144 samples), **5.2** (160) µs for normal CP,
- **16.7** (512) µs for extended CP

**SC-FDMA Data Symbol #0**

**T_{Symbol} = 66.7 µs** (2048 samples)

- **FFT length (2048 samples)**
- **CP**
- **Symbol part equal to Cyclic Prefix (CP) length**

**FFT window size does not capture the full length: symbol + CP**

**FFT window size depends on system bandwidth and CP length**

<table>
<thead>
<tr>
<th>Channel Bandwidth [MHz]</th>
<th>Cyclic Prefix (CP) length $N_{cp}$ for symbol 0</th>
<th>Cyclic Prefix (CP) length $N_{cp}$ for symbols 1 to 6</th>
<th>Nominal FFT size</th>
<th>Cyclic prefix for symbols 1 to 6 in FFT samples</th>
<th>EVM window length $W$ in FFT samples</th>
<th>Ratio of $W$ to CP for symbols 1 to 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>160</td>
<td>144</td>
<td>128</td>
<td>9</td>
<td>[5]</td>
<td>[55.6]</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>256</td>
<td>18</td>
<td>[12]</td>
<td>[66.7]</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>512</td>
<td>36</td>
<td>[32]</td>
<td>[88.9]</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td>1024</td>
<td>72</td>
<td>[66]</td>
<td>[91.7]</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td>1536</td>
<td>108</td>
<td>[102]</td>
<td>[94.4]</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td>2048</td>
<td>144</td>
<td>[136]</td>
<td>[94.4]</td>
</tr>
</tbody>
</table>

3GPP TS 36.101 V8.8.0, Annex F, Table F.5.3.-1 for normal cyclic prefix
Error Vector Magnitude (EVM)

EVM vs. Symbol – How is this EVM measured?
Spectral flatness

Nominal subcarriers
Amplitude Equalizer coefficients
Equalized subcarriers

Integration of all Amplitude Equalizer Coefficients to display spectral flatness curve
Output RF spectrum emissions

- SEM
- ACLR

From modulation process:

Harmonics, parasitic emissions, intermodulation and frequency conversion

Worst case:
Resource Blocks allocated up to/at channel edge
Adjacent Channel Leakage Ratio (ACLR)

Active LTE carrier, 20MHz BW

1 adjacent LTE carrier, 20MHz BW

2 adjacent WCDMA carriers, 5MHz BW
OBW: Occupied bandwidth, defined as 99% of power spectral density

SEM: Spectrum Emission Mask, measured with different resolution bandwidth, 1 MHz (away from carrier) or 30 kHz (close to carrier) RBW
**LTE FDD RX Measurements**

1. **Receive Sensitivity Tests**

   - **Transmit data on PDSCH**
   - **Receive data on PUSCH or PUCCH**
   - **ACK/NACK Counting**

   Specifies DL scheduling parameters like RB allocation, Modulation, etc. for every TTI (1ms).

   - **AWGN Blockers Adjacent channels**
LTE FDD RX Measurements

- Rx Measurements
  - Counting
    - ACKnowledgement (ACK)
    - NonACKnowledgement (NACK)
  - Calculating
    - BLER (NACK/ALL)
    - Throughput [kbps]
Thank you for your attention.

Question & answers

Visit us at the Mobile World Congress 2010 in Barcelona, Hall 1, booth 1D33.