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Best Practice Guide: Guidelines for the evaluation of uncertainties when measuring LTE signals with diode based sensors

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List of Abbreviations

LTE	Long Term Evolution
MIMO	Multiple input multiple output
SNR	Signal to noise ratio
STBC	Space-time block coding
SFBC	Space-frequency block coding
RF	Radio Frequency
SI	International System of Units
dB	decibels
DC	Direct current
3GPP	3rd Generation Partnership Project
CSR	Cell-Specific Reference signal
FDD	Frequency Division Duplex
OFDMA	Orthogonal Frequency Division Multiple Access
TDD	Time Division Duplex
QAM	Quadrature amplitude modulation
DSP	Digital signal processing
SISO	Single input single output

1 Scope of the document

The report serves as the best practice guide for the power measurement of the 4th generation wireless signal i.e. LTE signals using (1) Diode based sensors, (2) Thermal Power Sensors and finally (3) Scope based measured with METAS digital offline processing algorithm. Uncertainty budget of all the above methods have been listed and the comparison is drawn henceforth.

2 Introduction

Power measurement is a key parameter in the Radio Frequency (RF) domain, which quantifies then performance of the RF equipment. For a RF communication system it's very important to be able to measure the received power which is accurate, repeatable and traceable.

2.1 Units and definitions

Power is defined as the amount of energy consumed per unit time.

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} \tag{1}$$

The International System of Units (SI) has established the watt (W) as the unit of power.

$$1\,\text{watt} = 1\frac{\text{joule}}{\text{second}} \tag{2}$$

Often while measuring power, it's important to measure the gain or attenuation, hence the relative power is the desired quantity than the absolute power. The relative power is the ratio between the P to a reference power level and is expressed in decibels (dB) which is defined as

$$\text{dB} = 10 \cdot \log_{10}\left(\frac{P}{P_{ref}}\right) \tag{3}$$

When the reference power is 1 milliwatt then the dB can be expressed as dBm which is defined as

$$\text{dBm} = 10 \cdot \log_{10}\left(\frac{P}{1\,\text{mW}}\right) \tag{4}$$

Depending upon the characteristics of the signal different "power definitions" are possible [1-4]. Here in LTE signal measurement, power often refers to average power.
The signal can also be characterizes with the peak power and the peak to average ratio.

2.2 Average power

Average power is defined as the energy transfer per unit time averaged over many periods [4].

$$P_{avg} = \frac{1}{T}\int_0^T p(t)dt \tag{5}$$

where $p(t)$ is the instantaneous power of the signal and T is the period.
Most of the RF power measuring instrument measure the average power P_{avg} .

2.3 Thermistor mount based power sensors

Thermistor mount power sensors operate in the bolometer principle that the resistance changes with the change in temperature. Thermistors are elements with negative temperature coefficient.
A balanced bridge configuration along with a thermistor mount is used to measure the RF power. In such a device a DC bias power is pumped into the circuit to balance the bridge thereby maintaining a constant resistance for the thermistor element. As the RF energy is converted into heat thereby changing the temperature and the resistance in the bridge, the bias power is withdrawn by an equal amount to balance the bridge and keep the same resistance value. The decrease in the bias power is then used to indicate the incident RF power.

Figure 1: Agilent 478A Coaxial Thermistor Mount[1].

2.4 Thermocouple based power sensor

Thermocouple sensors are based on the principle that the dissimilar metals generate a voltage due to the temperature difference at a hot and a cold junction of the two metals.
A thermos couple sensor has high sensitivity and features an inherent square law detection characteristic. Hence these sensors are "averaging sensors" and are best suited for handling signals with complex modulations because these signals require high sensitivity and change rapidly.

Figure 2: R&S NRP Z51 Thermal power sensor. It has a frequency range from DC – 18GHz and dynamic range from -35dBm to 20dBm[2]

[1] Picture taken from: http://www.keysight.com/de/pd-1000001379%3Aepsg%3Apro-pn-478A/coaxial-thermistor-mount?nid=-33893.536880079&cc=CH&lc=ger

[2] Picture taken from: https://www.rohde-schwarz.com/en/product/nrp-z51var03-productstartpage_63493-

2.5 Diode based sensors

Diodes convert the AC signals to DC by the way of rectification which rises from their non-linear IV characteristics. For small signal the diodes work in the square law region and for the higher levels the diodes work in a linear range. In between (transition regime) the diodes work in a mixed mode where the higher order terms becomes very significant and is known as quasi-square law regime [2, 3].

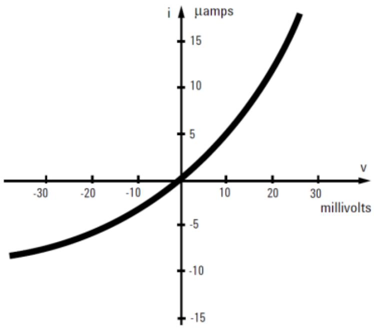

Figure 3: The junction rectifying characteristics of a low-barrier Schottky diode, showing the small-signal, square law characteristics around the origin. [3]

The modern diode sensors offer a full working range between the square law and the linear regime. Here the dynamic range is -70dBm - +20dBm. These sensors offer a precise measurement of CW signals as well as the complex modulated signals such OFDM and higher QAM [3].

Figure 4: R&S NRP-Z91 Average Power Sensor. It has a multi-diode technology which gives it a very large dynamic range. This is achieved by splitting the measurement voltage among several diodes. So that each diode is driven exclusively in the square law region and each diode is driven less[3].

2.6 Probe with diode based sensor

Diode sensor coupled with isotropoic antennas can also be used for the RF power measurement. These sensors offer a flat frequenct response and use the diode sensor technology. Moreover these instrument can offer sensitivity of 0.2V/m.

40128.html

[3] Picture taken from: https://www.rohde-schwarz.com/en/product/nrpz91-productstartpage_63493-8584.html

Figure 5: Field probe for measuring the electric fields (100kHz – 3GHz). It has isotropic antenna and a sensitivity of 0.2 V/m.[4]

[4] Picture taken from: http://www.narda-sts.us/pdf_files/DataSheets/NBM-Probes_DataSheet.pdf

3 General Principle of methods of measurement

The Third Generation Partnership Project (3GPP) produces globally applicable technical specifications and technical report for a 3rd Generation Mobile System based on evolved GSM core network and radio access technologies that support Universal Terrestrial Radio Access (UTRA) both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) mode[5]. This section gives an overview of the LTE downlink physical layer technical specification for the FDD mode[6].

Technologies implemented in LTE:

1. Multicarrier technology

LTE uses OFDMA (Orthogonal Frequency Division Multiple Access) for down link and SC-FDMA (Single Carrier Frequency Division Multiple Access) for uplink.

2. Multiple Antenna technology

LTE uses MIMO (Multiple Input Multiple Output) antenna capabilities thereby increasing the spectral efficiencies of the system

Below is the LTE frame structure is expressed as a number of time units [5-7]

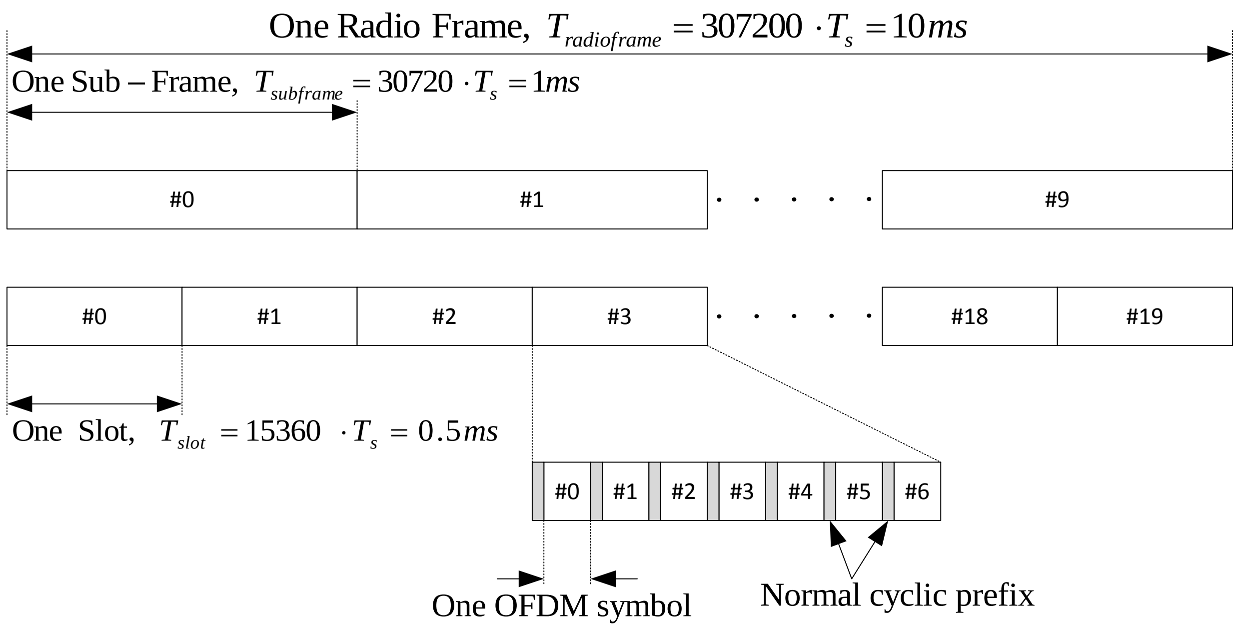

Figure 6: Frame structure of the LTE downlink FDD mode depicting the Radio frame and the sub-division of sub-frame, slot and OFDM symbol with cyclic prefix. Here 7 OFDM symbols along with normal cyclic prefix are stacked in a slot and 14 OFDM symbol in one sub-frame. Hence a radio frame consists of 140 OFDM symbols [8].

LTE is defined by its resource grid taking the advantage of the multicarrier technology

[5] http://www.etsi.org/about/our-global-role/3gpp

[6] We focus on the FDD mode for the LTE downlink mobile communication systems since this is widely deployed in Europe.

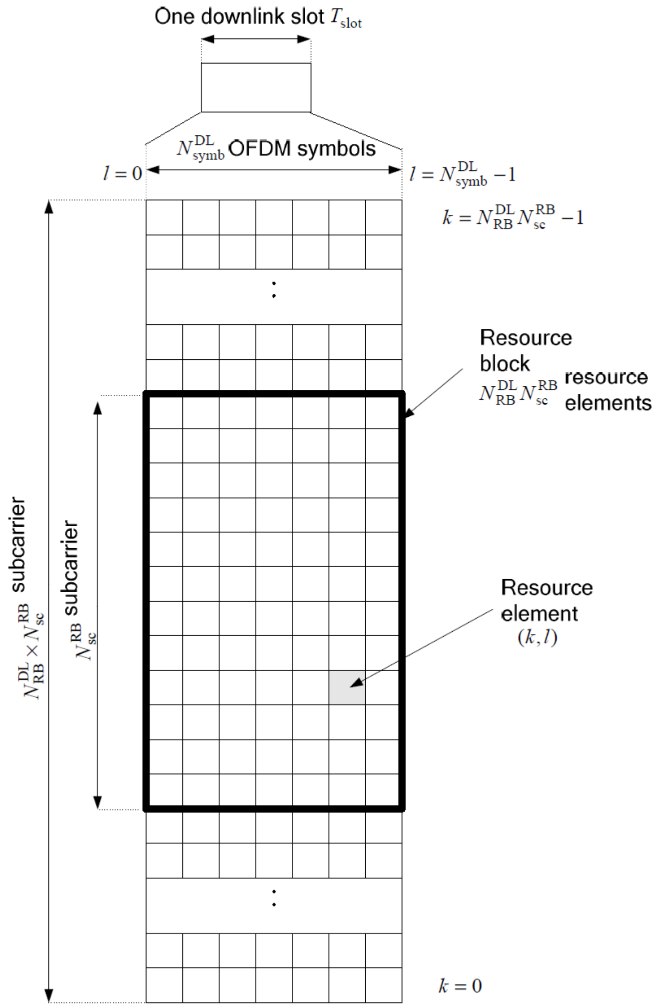

Figure 7: LTE downlink resource grid [Reproduced from [9] *]*

LTE takes the advantage of the MIMO technology thereby transmitting with more than one antenna at the same time and in the same frequency range by using the robust MIMO precoding techniques[7] [9].

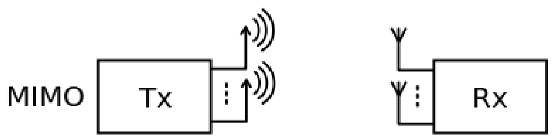

Figure 8: MIMO communication system configuration [9].

Hence to ensure a good comparison of the LTE signal power measurement, it's very important to define the LTE signal scenario. Herein three different LTE scenarios are proposed and used thereof for the comparison and validation. The description of each scenario is given in the table below:

[7] LTE Defines two different types of precoding techniques: (a) transmit diversity using space-time block coding (STBC) or space-frequency block coding (SFBC) and (b) Spatial multiplexing

Table 1: The LTE scenarios for the downlink configured at the LTE signal generator for the evaluation of different power sensors and scope based measurement methods.

LTE Scenario	Scenario 1	Scenario 2	Scenario 3
LTE Transmission mode	FDD	FDD	FDD
Link Direction	Downlink (OFDMA)	Downlink (OFDMA)	Downlink (OFDMA)
MIMO	2×2	2×2	2×2
Carrier Frequency	806 MHz	806 MHz	803.5 MHz
output power	Varied between -30 dBm to 10 dBm		
RS0 power per relative display	-27.579	-22.089	-20.45
LTE Bandwidth	10 MHz	10 MHz	5 MHz
Number of subcarrier	601	601	301
Occupied bandwidth	9.015 MHz	9.015 MHz	4.515
Data traffic	Full	partial	partial

4 GTEM Cell Measurement Method with field probe (diode based sensor)

The Gigahertz Transverse Electromagnetic (GTEM) Cell is a high frequency version of the (Transverse Electromagnetic) TEM cell. This is widely used for the EMC emission and immunity testing.
The GTEM cell in METAS, Bern, Switzerland is used in the present study. The measurement set up and the procedure for the RF power measurement is detailed in the following sections.

4.1.1 Experimental set-up

Figure 9 depicts the typical experimental set-up for the diode based sensor in a GTEM cell. Here the LTE signal is generated using a LTE signal generator (Rohde & Schwarz SMW200A). This signal is amplified with the help of an amplifier and the power regulation is controlled with a RF-Switched relay (Schaffner). This amplified signal is fed into the GTEM cell using a coupler and the radiated power before the GTEM cell is measured using a reference thermal power sensor. The DUT i.e. here the field probe is placed inside the GTEM Cell and finally the power measurement for the wideband RF signal is recorded using a computer program.

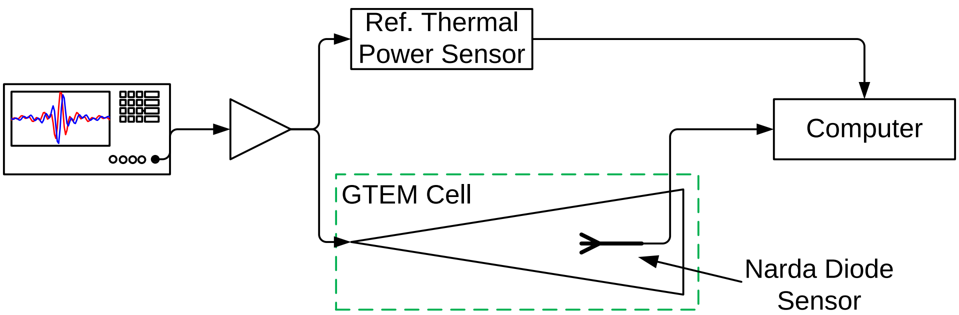

Figure 9: The experimental set-up for the wideband over-the-air power measurement of LTE signal using a diode based sensor (Narda) in a GTEM Cell.

The computer software is used record the field strength detected in the GTEM cell and power inserted in the GTEM cell, thereby regulating the output power of the amplifier.

First the measurement is performed with a pure sine wave (no modulation) for the respective frequencies of different LTE scenarios. Thereof the electric field of due to LTE signals for difference scenarios is measured.

Table 2: The list of instrument used for the measurement

Device	**Manufacturer**	**Type**	**Inventory**
GTEM Cell	Emitec AG	Hybrid	4665
LTE Signal Generator	Rohde &Schwarz	SMW 200A	7737
Amplifier	Amplifier Research	-	-
Reference: Thermal Power Sensor	Rohde & Schwarz	NRVD	4155
Relay	Schaffner	RF-Switched	4058
DUT	Narda	EMR Series	4612

Above is an exemplary table describing the instruments used in the experiment.

4.1.2 Typical power measurement result using a diode based sensor

An example of the typical measurement result of the LTE power measurement (power sweep) using the procedure explained in section 4.1.1 is shown in Figure 10. In this case the "delta" i.e. the deviation between the power measured by the reference thermal power sensor and the diode based sensor is plotted in the vertical axis in the dB scale. The different scenarios as explained in section 3 are plotted in the horizontal axis. The measurement was also performed for the respective frequencies and varying power level without LTE modulation for comparison.
The CW signal in Figure 10 (a) corresponds to the pure sine wave without the LTE modulation for a carrier frequency of 806 MHz which corresponds to the carrier frequency of scenario 1 and scenario 2 and similarly the CW signal in Figure 10 (b) corresponds to the pure sine wave without any modulation for a carrier frequency of 803.5 MHz which corresponds to the carrier frequency of scenario 3. It important to note that we are interested in the uncertainties from LTE modulation and the absolute power measurement doesn't give any information about the same. Nevertheless the uncertainty contribution from the LTE modulation can be attributed to the relative difference between the signal power without modulation and with modulation for a specified frequency and power level.

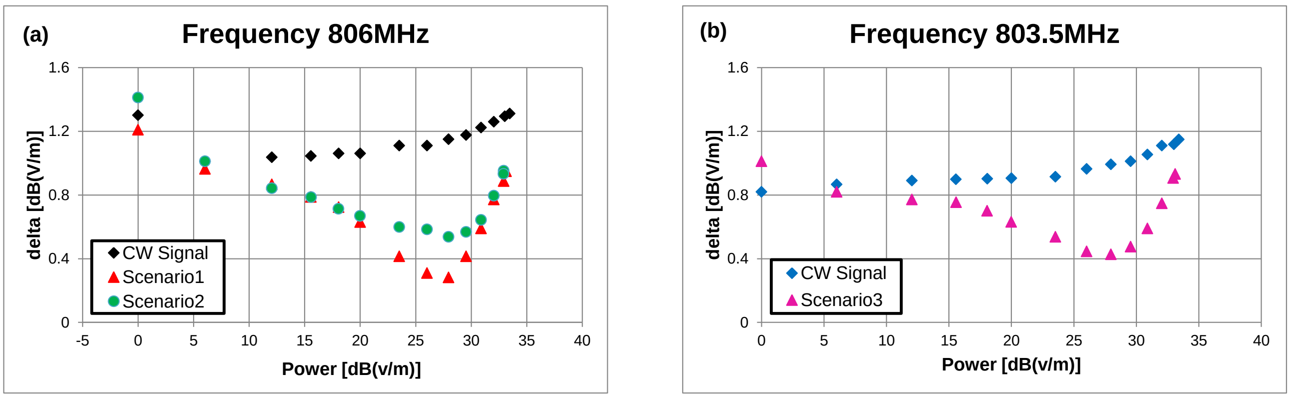

Figure 10: The difference between the reference power level and the measured signal power level in the GTEM cell for different RF signal power with and without LTE modulation.

4.2 Things to keep in mind

1. The height of the probe in the GTEM cell is according to the GTEM cell calibration.

2. The transmit frequency isn't far away from the calibrated frequency of the GTEM cell. If not, please take into account the linearity of the calibration for interpolation.
3. Remember to apply the GTEM cell calibration to the measurement's

5 Conducted configuration power measurement

Now in this section we present the LTE power measurement set-up for the conducted configuration. Here we use two different types of power sensor as a DUT for the different scenarios.

1. Thermal power sensor
2. Diode based power sensor

Finally some typical power measurement results are presented here.

5.1.1 Experimental set-up

Figure 11 depicts the typical LTE power measurement set-up for the conducted configuration using a thermal based and diode based power sensor. The input RF signals are generated using a LTE signal generator, which is split into two arms equally with a power splitter. One arm is used for the reference power measurement using a calibrated thermal power sensor and the second arms is used to measure the signal power with a step attenuator for the power sensitivity measurement for different. First the measurement is performed with an input of pure sine wave (no modulation) and then finally the measurement of LTE Signals is recorded for different RF frequency and power level with both the reference power sensor and the DUT.

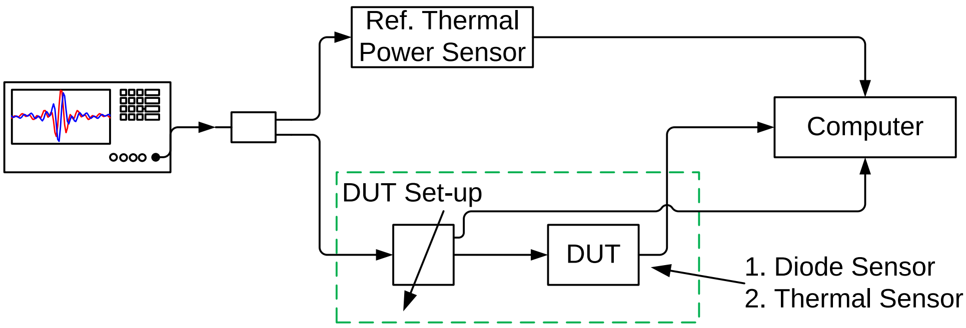

Figure 11: The experimental set-up for the wideband power measurement of the LTE signals using (1) Diode based sensor and (2) Thermal sensor. Here the LTE signal for a defined signal power is generated using a LTE signal generator (R&S SMW200A). This signal is split into two different arms of equal power using a 1×2 power splitter (Weinschel 1870A). The RF power level of the LTE signal in the first arm is measured using a calibrated Reference Thermal power sensor. The RF power of the LTE signal in the second arm is measured by varying the attenuation using step attenuation with both the diode based and thermal power sensors.

Table 3: The list of instrument used for the measurement

Device	**Manufacturer**	**Type**	**Inventory**
LTE Signal Generator	Rohde & Schwarz	SMW 200A	7737
Power Splitter	Weinschel	1870A	6765
Reference: Thermal Power Sensor:	Rohde & Schwarz	NRP-Z51 (DC – 18GHz)	6056
Attenuator	Agilent	8496H	7412
Attenuator Switch Driver	Hewlett Packard	11713A	7420
DUT	Rohde & Schwarz Diode Power Sensor	NRP-Z21 (10MHz – 18GHz)	6869
	Rohde & Schwarz	NRP-Z51	5874

	Thermal Power Sensor	(DC – 18GHz)	

5.1.2 Power measurement using thermal based sensor

The LTE power measurements are performed using a DUT i.e. thermal power sensor. The power sweep is performed from 5dBm till -25dBm (which is very near to the saturation limit of the power sensor). An example of the typical measurement result of the LTE power measurement using the procedure explained in section 5.1.1 is shown in Figure 12. The vertical axis represents the difference in power measurement between the reference (calibrated thermal power sensor) and the DUT (thermal power sensor) in millidB [mdB] and the horizontal axis represents the different RF signal power level recorded by the reference thermal power sensors for different scenarios as explained in section 3.

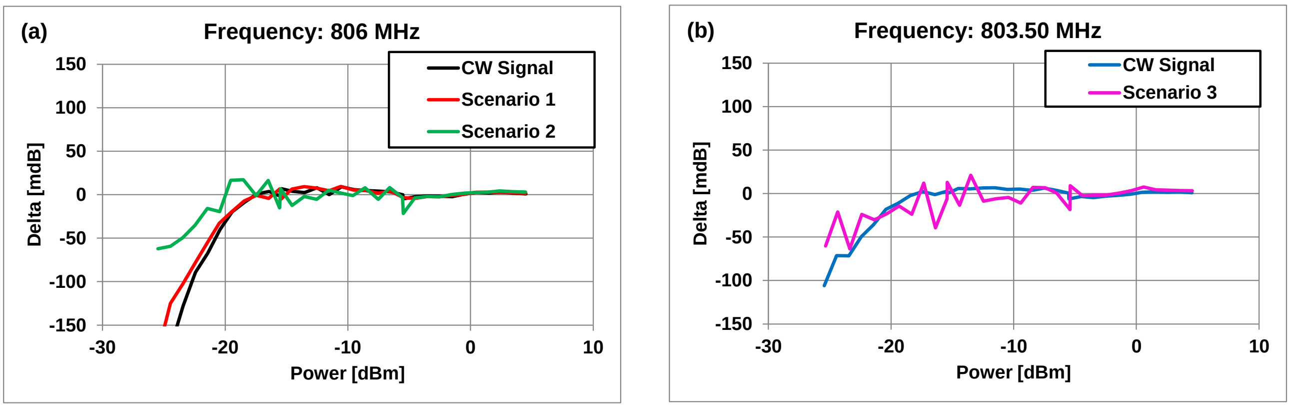

Figure 12: The deviation between the reference signal power and the power measured by the DUT (in mdB -> milliDB) for the different RF signal power level (in dB) with and without LTE modulation.

As discussed earlier the Figure 12 (a) depicts the deviation in the power measurement in the set-up with a CW signal (in black solid line) and with LTE modulation for scenario 1 (in red solid line) and scenario 2 (in green solid line). The entire above RF signals have the same carrier frequency of 806MHz. In Figure 12 (b) the deviation in power measurement of CW signal with frequency 803.5MHz (in blue solid line) is presented along with LTE modulation for scenario 3.

5.1.3 Power measurement using diode based power sensor

Similar to the section above the RF signal power is measured using a diode based power sensor as a DUT and the thermal power sensor as a reference power sensor.
Below we present some exemplary plot of the typical measurement result of the LTE power measurement using the procedure explained in section 5.1.1 in. Figure 13. The vertical axis represents the difference in power measurement between the reference (calibrated thermal power sensor) and the DUT (diode based power sensor) in millidB [mdB] and the horizontal axis represents the different scenarios as explained in section 3.

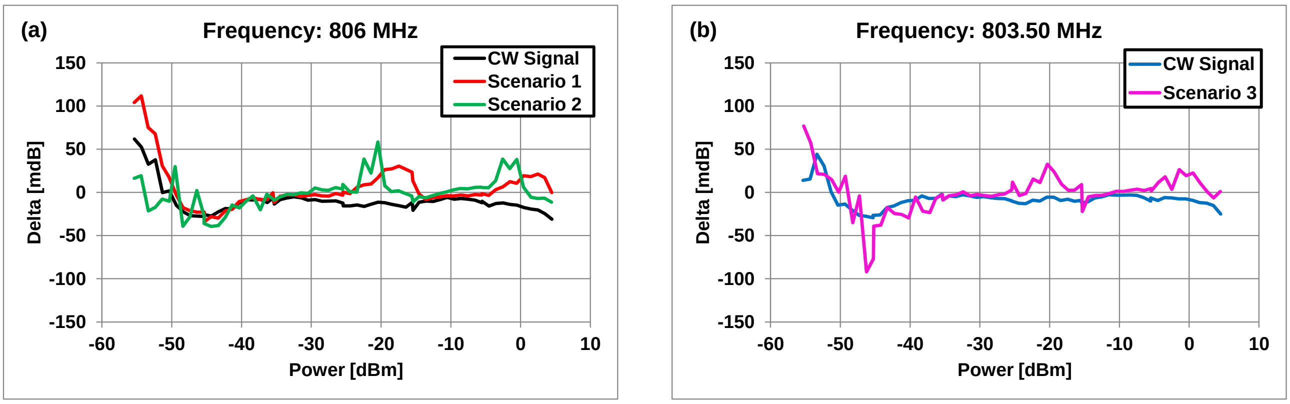

Figure 13: The deviation between the reference signal power and the power measured by the DUT (diode based sensor) for the different RF signal power level (in dB) with and without LTE modulation.

As discussed earlier the Figure 13 (a) depicts the deviation in the power measurement in the set-up with a CW signal (in black solid line) and with LTE modulation for scenario 1 (in red solid line) and scenario 2 (in green solid line). The entire above RF signals have the same carrier frequency of 806MHz. In Figure 13 (b) the deviation in power measurement of CW signal with frequency 803.5MHz (in blue solid line) is presented along with LTE modulation for scenario 3.

5.1.4 Things to keep in mind

1. Signal power measurement set-up for the diode and the thermal power sensor are same.
2. The reference power sensor for both DUTs is a thermal power sensor
3. The section 5.1.2 can be used as a check point for the experimental set-up. Since in this configuration both the reference and DUT are thermal power sensor a very stable power measurement behavior can be expected, if not the configuration should and the power sensors should be checked before further use.
4. Don’t forget to include the attenuators calibration factor in the computation.
5. Please note the saturation regime of the reference thermal power sensor and thereof decide on the range/limit of the power sweep.
6. Please don’t measure the signal power outside the recommended limit of the power sensors. If measured and taken into account this would contribute to higher uncertainties.
7. The sweep time for the power sensors is set to auto mode.
8. Set the reference power sensor to channel A and DUT to channel B.

6 Scope measurement method

Here in this section we give an overview of the METAS scope based measurement technique [10] and the related uncertainty.

6.1.1 Experimental set-up

As depicted in Figure 14 the system is composed of a LTE signal generator (with or without MIMO). The RF signal is combined using a RF power combiner and thereof mixed with a local oscillator in a frequency mixer. This process down-converts the RF signal to the difference frequency between the RF signal generated by the LTE signal generator and local oscillator also known as intermediate frequency. Now this down-converted signal is passed through a low pass filter thereby eliminating the influence of higher order frequency components generated during the non-linear frequency mixing. Finally this filtered signal is captured using a Digital Storage Oscilloscope (DSO). The DSO digitizes the received signal and records the voltage level of the signal. The measurement is thereof processed using the self-developed software for both the offline Digital Signal Processing (DSP) and the power evaluation of the LTE signals.

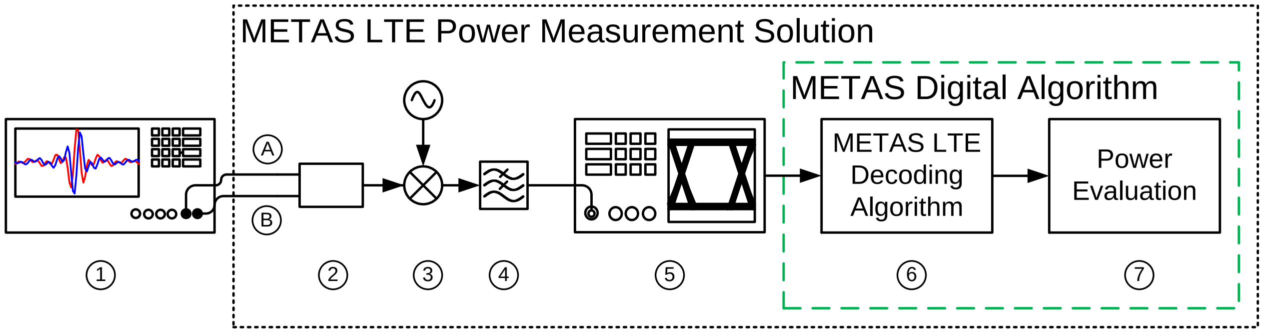

Figure 14: The experimental set-up for the LTE power measurement using the scope measurement method followed by the digital offline processing of the recorded data using the METAS digital algorithm.

Table 4: The list of instrument used for the measurement

Device	**Manufacturer**	**Type**	**Inventory**
LTE Signal Generator	Rohde & Schwarz	SMW 200A	7737
Attenuator	Hewlett Packard	8491A (10dB)	4897
		8491B (10dB)	4864
Power Divider/Combiner	Agilent	11636A (DC – 18GHz)	6409
Local Oscillator	Rohde & Schwarz	SMIQ 03B	5085
Frequency Mixer	Mini-Circuits	ZX05-C24LH-S+	8116
Low Pass Filter	Mini-Circuits	ZX75LP-70-S+	8114
Digital Storage Oscilloscope	Agilent	DSO90254A	6587

Herein a computer software is used to set the appropriate scenario in the LTE generator and the thereof perform a sweep of RF signal power with different pre-defined LTE scenarios.

6.1.2 LTE signal power measurement

Here in the scope measurement method we are interested in the RS0 power level relative to the RF signal power. [8, 11]

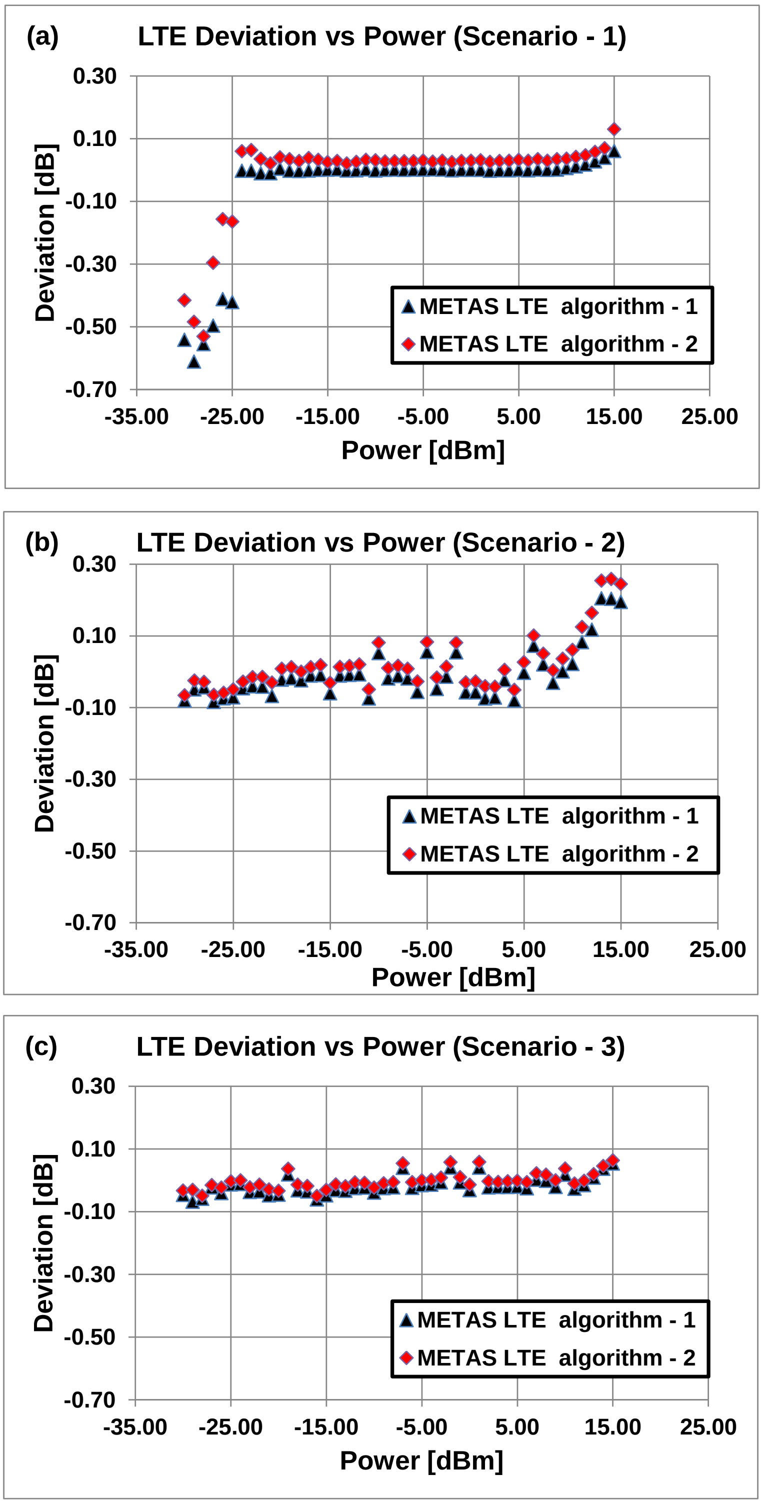

Figure 15: The deviation between the relative power of the RS0 signal power with respect to the signal level set in the signal generator and the RS0 power level computed with the help of software developed at METAS with two different algorithm (1) METAS LTE algorithm – 1 and (2) METAS LTE algorithm -2 for different RF signal power and with different scenarios i.e. (a) scenario – 1, (b) scenario – 2 and (c) scenario – 3.

Hence here we take into account the RS0 power level relative RF signal power and the RF signal power. Moreover the offline DSP computes the RS0 signal power using two different algorithms:

1. METAS LTE algorithm – 1:

This algorithm takes into account the RS0 in the entire signal bandwidth

2. METAS LTE algorithm – 2:

This algorithm takes into account the RS0 in the center 62 sub-carrier of the entire signal bandwidth.

The Figure 15 depicts an exemplary plot of deviation (in dB) for the power sweep of the signal with different scenarios. The deviation between the reference RS0 power relative to the level display and the measured RS0 power is plotted in the vertical axis in the dB scale and the different set RF power level are plotted in the horizontal axis.

6.1.3 Things to keep in mind

1. It's very important to note both the RF power level and the RS0 power level relative to the RF signal.
2. Calibrate the chain before every measurement (if any of the component is changed)
3. Chain calibration can be done with the help of power sweep of the RF signal without modulation.
4. Don't forget to include the same in the power evaluation
5. To further decrease the uncertainties because of the LTE modulation all the devices can be locked to an external reference frequency.
6. Power variable initialization is of the key aspect of the offline DSP.
7. DSO calibration is not necessary because we are interested in the relative quantity rather than an absolute quantity.
8. Please remember to turn off the fading module in the generator.
9. Please take a note of SISO or MIMO scenario configuration.
10. Ensure that the scope memory depth and sampling rate is at least two times the intermediate frequency.
11. Please ensure that the local oscillator frequency is less than the LTE signal generator.
12. It is advised to use a constant intermediate frequency for all the recordings.
13. Please ensure that the scope recording is of at least 20ms or greater than 20ms
14. Please ensure that the intermediate frequency along with the signal bandwidth is below the cut-off frequency of the low pass filter.
15. Please ensure that the local oscillator power level is optimum as per the mixer specification.
16. Optimum operating point with a bandwidth of LTE signal should be identified for the mixer and used for the linearity correction.

7 Typical Uncertainty budget

There are various factors which impact the power measurement of the LTE Signals. Below is an example of the uncertainty budget for all the three different methods. This uncertainty budget provided herein is as per the references [16-19]. Various components that can contribute to the measurement uncertainties have been included in the table.
The correction factor for an unknown probe is given by

$$\text{Correction Factor}(f) = \frac{\text{True Value}}{\text{Reading Value}} \tag{6}$$

We are interested in quantifying the uncertainty in measurement by a device/probe because of the LTE modulation, hence the correction factor can be written as

$$\text{Correction Factor for LTE}(f) = \begin{cases} \dfrac{\text{Probe Value (with LTE Mod)}}{\text{Reference Value (with LTE Mod)}} \\ \times \dfrac{\text{Reference Value (without Mod)}}{\text{Probe Value (without Mod)}} \end{cases} \tag{7}$$

Under Reference value we understand the "True Value". Now this expression can be further simplified as follows

$$\text{Correction Factor for LTE}(f) = \begin{cases} \underbrace{\dfrac{\text{Probe Value (with LTE Mod)}}{\text{Probe Value (without Mod)}}}_{\text{Measurement with the probe}} \\ \times \underbrace{\dfrac{\text{Reference Value (without Mod)}}{\text{Reference Value (with LTE Mod)}}}_{\text{Reference fields measurement}} \end{cases} \tag{8}$$

In dB scale this expression can be re-written as follows:

$$\text{Correction Factor for LTE}(f) = \begin{cases} \text{Probe Value (with LTE Mod)[dB]} \\ -\text{Probe Value (without Mod)[dB]} \\ +\text{Reference Value (without Mod)[dB]} \\ -\text{Reference Value (with LTE Mod)[dB]} \end{cases} \tag{9}$$

7.1 Uncertainty budget for a field probe

In a GTEM cell we measure the electric field (E[V/m]), which is given by the equation

$$E(f) = k_{\varepsilon}(f)\frac{\sqrt{P.Z_0}}{d} \tag{10}$$

where
Z_0 is the impedance of the GTEM cell and is $Z_0 = 50\Omega$
$k_{\varepsilon}(f)$ is the calibration factor of the GTEM cell
P is correction factor of the power sensor/probe
d is the distance from the calibrated point.

The field measured by the probe without LTE modulation is

$$E_{\text{WithoutModulation}}(f) = k_{\varepsilon}(f)\frac{\sqrt{P_{\text{WithoutModulation}} \cdot Z_0}}{d} \tag{11}$$

and the field measured by the probe with LTE modulation is

$$E_{\text{With Modulation}}(f) = k_{\varepsilon}(f)\frac{\sqrt{P_{\text{With Modulation}} \cdot Z_0}}{d} \tag{12}$$

Now from equation (8), (11) and (12) we define the correction factor for LTE signal measurement in GTEM cell as

$$\text{Correction Factor for LTE}(f) = \sqrt{\frac{P_{\text{WithoutModulation}}}{P_{\text{With Modulation}}}} \tag{13}$$

Hence the correction factor for LTE signal field strength measurement for a defined frequency is the equal to the square root of the ratio of signal power measured without and with LTE modulation.

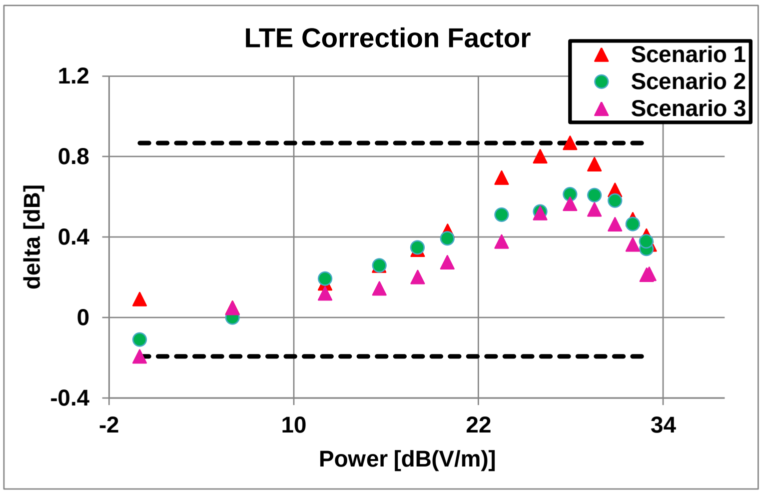

Figure 16: The uncertainty for the LTE signal measurement in the GTEM cell. The correction factor is difference between the delta of measured power level (in dB) with LTE modulation and the measured signal power (in dB) without LTE modulation. The black dotted lines are the positive and negative mask defining the boundaries of the uncertainty.

7.2 Uncertainty budget for thermal and diode based sensors

In the conducted configuration measurement set-up we measured the absolute power received by the power sensors i.e. the reference thermal power sensor and the DUT.
Herein two different power sensors were presented as the DUT as follows:
(a) Thermal power sensor and
(b) Diode based power sensor
The power measured for a specified carrier frequency is given by

$$P_{\text{measured}}(f) = k_{\text{e\_abs}}(f) \cdot P_{\text{incident}} \tag{14}$$

where $k_{\text{e\_abs}}$ is the absolute calibration factor

P_{incident} is the power incident on the power sensor
From equation (9) and (14) we have the for the same incident power

$$\text{Correction Factor for LTE}\left(f\right)=\begin{cases}P^{\text{DUT}}_{\text{with LTE mod}}\,[\text{dB}]\text{ - }P^{\text{DUT}}_{\text{withoutmod}}\,[\text{dB}]\\+\,P^{\text{Ref}}_{\text{withoutmod}}\,[\text{dB}]\text{ - }P^{\text{Ref}}_{\text{with LTE mod}}\,[\text{dB}]\end{cases}\qquad(15)$$

Since we are interested in the relative quantity, we see that the absolute calibration factor disappears from the equation and the uncertainties from the LTE modulation is directly proportional to the difference is the power measurement by the DUT with and without LTE modulation for the specified frequency and incident power.
Furthermore assuming the reference power measured is in the same vicinity of measurement the equation (15) can be further simplified as follows:

$$\text{Correction Factor for LTE}\left(f\right)=P^{\text{DUT}}_{\text{with LTE mod}}\,[\text{dB}]\text{ - }P^{\text{DUT}}_{\text{withoutmod}}\,[\text{dB}]\qquad(16)$$

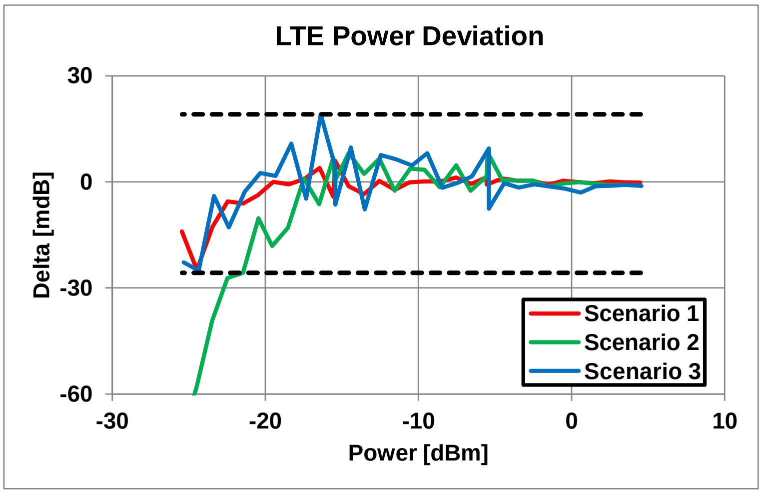

Figure 17: The uncertainty for LTE signal measurement with a thermal power sensor. The uncertainty is computed as the difference in the power measured by the reference power sensor with and without LTE modulation and the DUT (i.e. the thermal power sensor) with and without LTE modulation respectively for a specific frequency and power level. The black dotted lines are the positive and negative mask defining the boundaries of the uncertainty.

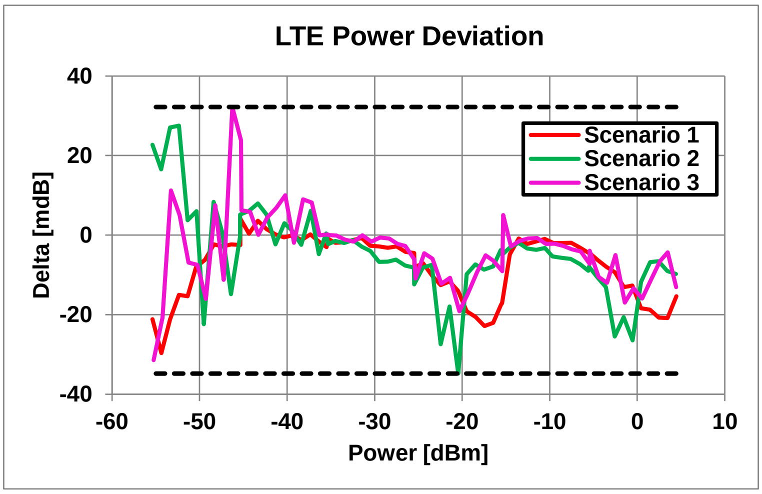

Figure 18: The uncertainty for LTE signal measurement with a diode based power sensor. The uncertainty is computed as the difference in the power measured by the reference power sensor with and without LTE modulation and the DUT (i.e. the diode based power

sensor) with and without LTE modulation respectively for a specific frequency and power level. The black dotted lines are the positive and negative mask defining the boundaries of the uncertainty.

7.3 Uncertainty budget with scope measurement

To start quantifying the uncertainties of the scope based measurement. We start with the quantity measured in the scope. In the scope we record the series of voltage levels which can be given as

$$V_{\text{with LTE Mod}}^{\text{measured}} = \sum_{i=1}^{N} k_{\text{V}}\left(f\right) \cdot V_i^{\text{incident}} \quad (17)$$

Where $k_{\text{V}}\left(f\right)$ is the absolute calibration factor for the scope.

V_i^{incident} is the incident voltage in the scope.

We use the recorded signal to estimate the total power of the signal, taking into account the chain loss and the linearity correction. Furthermore we compute the RS0 power level of the same recorded signal using the software. RS0 are the reference channel in the LTE signals and the uncertainty due to the LTE modulation is reflected in the uncertainty of measurement of the RS0 signal. Hence it can be understood as below

$$a_k^l = \gamma\left(V_{\text{with LTE Mod}}^{\text{measured}}\right)[\text{Volts}] \quad (18)$$

where γ is a function which denotes the complex LTE decoding applied to the scope measurement. a_k^l denotes the complex values in volts with (k, l) representing the symbol number and the subcarrier number of the resource element in the LTE resource grid as explained in the Figure 7. Now the total power can be expressed as the linear average of the sum of all the subcarriers in the operating bandwidth of LTE signal.

$$P_{\text{FullBW}}^{\text{Total Power}} = \left\langle \frac{\sum_{l} \left|a_k^l\right|^2}{50\Omega} \right\rangle_k \text{Watt} \quad (19)$$

Moreover the RS0 power can be expressed as the linear average of the sum of the entire resource element carrying the RS0 signal within the operating bandwidth of the LTE signal.

$$P_{\text{FullBW}}^{\text{RS0}} = \left\langle \left\langle \frac{\left|a_{k'}^l\right|^2}{50\Omega} \right\rangle_l \right\rangle_{k'} \text{Watt} \quad (20)$$

where k' represents the resource element carrying the RS0 signal distributed in the operating BW of the LTE signal.

As explained earlier we are interested in the relative measurement of the RS0 power level with respect to the total power, this can be expressed as follows:

$$P_{\text{FullBW,Measured}}^{\text{RelativeRS0power}}[\text{dB}] = P_{\text{FullBW}}^{\text{Total Power}}[\text{dB}] - P_{\text{FullBW}}^{\text{RS0}}[\text{dB}] \quad (21)$$

Hence the calibration factor can be expressed from the equation (9) and (21) as follows:

$$\text{Correction Factor for LTE}\left(f\right) = P_{\text{FullBW,Measured}}^{\text{RelativeRS0power}}[\text{dB}] - P_{\text{FullBW,Reference}}^{\text{RelativeRS0power}}[\text{dB}] \quad (22)$$

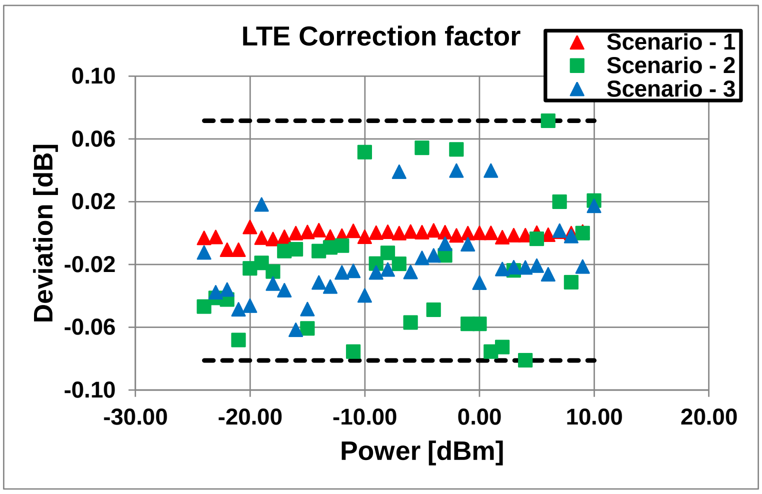

Figure 19: The uncertainty for LTE signal measurement with a scope based measurement method with the LTE algorithm – 1. The deviation is computed as the difference in the relative RS0 power set by the LTE generator and computed by the data recorded from the scope using the METAS LTE algorithm – 1 for different LTE modulation scenarios for a specific frequency and different power level. The black dotted lines are the positive and negative mask defining the boundaries of the uncertainty.

8 Conclusion

Finally a typical uncertainty budget for LTE measurements look like [12]. The probing uncertainty is not taken into account in this budget. It typically lies by 15% [12] due to the interferences.

No.	Source of uncertainty	Uncertainty	Type	Factor	Std Uncertainty	Notes
1	Absolute calibration	±7%	Normal	2	±3.50%	[12-20]
2	Tolerance of linearity deviation	±3%	Rectangular	1.73	±1.7%	[12-20]
3	Uncertainty of linearity measurement	±2.5%	Normal	2	±1.3%	[12-20]
4	Tolerance band of frequency response	±15%	Rectangular	1.73	±8.7%	[12-20]
5	Uncertainty of frequency response measurement	±14%	Normal	2	±7%	[12-20]
6 (a)	**LTE Modulation dependence (total power measurement with field probe and diode based sensor)**	**±0.9 dB**	**Rectangular**	**1.73**	**±6.3%**	**from section 7.1**
6 (b)	**LTE Modulation dependence (total power measurement with thermal power sensor)**	**±0.027 dB**	**Rectangular**	**1.73**	**±0.18%**	**from section 7.2**
6 (c)	**LTE Modulation dependence (total power measurement with diode based power sensor)**	**±0.035 dB**	**Rectangular**	**1.73**	**±0.23%**	**from section 7.2**
7 (a)	**Typical uncertainty of the scaling arbitrarily the RS0 power from the total power. (see table 1) Taking average value of 22 dB correction**	**± 7 dB**	**Rectangular**	**1.73**	**±72%**	**Rough estimation**
7 (b)	**LTE Modulation dependence (RS0 power measurement with scope)**	**± 0.08 dB**	**Rectangular**	**1.73**	**±0.53%**	**from section 7.3**
8	Temperature dependence	±3.5	Rectangular	1.73	±2	[12-20]

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