Global Test Specification for

PCs with embedded modules and datacards

Radiated Performance Measurements
- Performance TST -

Radiated Performance
VF_Ant_Req_V1.99

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Classification

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This document has been classified as “public”. It is allowed to share it with interested persons and bodies to promote a discussion about a certain measurement method.

Table of Content

1 Document Information

1.1 Scope

Vodafone buys terminals (PCs with embedded modules, datacards and USB modems) to be used within its network. Through purchasing contract and by accompanied product requirement specification, Vodafone requires that all terminals supplied are tested and comply with relevant standards and guidelines appropriate for that device. Launching a terminal is subject to technical acceptance (TA, see [1]). The purpose of this test case description is to define the Vodafone test requirements for performing Radiated RF Power and Receiver Performance measurements on terminals.

Good radiated performance is critical to the effective operation of a mobile station in today's networks. A comprehensive and accurate characterization of radiated performance will enable network providers and manufacturers to determine how well mobile stations will work within the constraints of a specific cellular network design.

Generally, peak EIRP (Effective Isotropic Radiated Power) or measurements assuming a dipole like pattern for all frequencies (as in GSM 11.10, [4] chapter 13.3) are not good indications of radiated performance in the field.

Therefore the test case description below is focused on:

- Spherical effective isotropic radiated power (termed Total Radiated Power, TRP) as well as
- the appropriate Spherical effective isotropic radiated sensitivity (termed Total Radiated Sensitivity, TRS) ,
- Both to be measured basically using the methodology outlined by CTIA [2] and for UMTS by 3GPP [3], but with a special concept in order to reduced effort for sensitivity measurements.

In order to streamline testing in particular in respect to 3GPP, Vodafone is asking for test results for PCs with embedded modules, datacards and USB modems

- in free space conditions

Additionally Vodafone is requesting sensitivity measurements providing visibility of so called

- Self-interference or de-sense effects.

Due to the fact a PC/notebook includes several components which produce RF noise which are mainly related to clock signals situated close to a very sensitive receiver, there are specific interference effects known. The most common disturbance is caused by the GSM typical 13 MHz internal clock signal. Two harmonics of the 13 MHz are effecting channel 5 and 70 (72 x 13 MHz = 936 MHz = ARFCN 5 and 73 x 13 MHz = 949 MHz = ARFCN 70). For Notebooks with data cards, embedded modules or USB modems there are even more interfering signals which can disturb the TRS performance.

1.2 Document History

Version	Date	Editor	Remarks
0.1 – 1.92			See history in separate documents
1.99	0.5.01.07	Markus Larkamp	New document by merging: v0.68 for data devices and v1.92 for handheld devices; same explanation of fault priorities; self-int assessment method updated; general angle for PC display = 110° (was 120°); and a number of editorial changes
2.00		Markus Larkamp	

1.3 Terms and Definitions

AFAR	Antenna fully anechoic room
3GPP	3rd Generation Partnership Project
BER	Bit error rate or bit error ratio
BEP	Bit error probability
BS	Base station
CTIA	Cellular Telecommunications & Internet Association
DUT	Device under test
GSM	Global System for Mobile Communication
MS	Mobile station = terminal = mobile phone
Power	In GSM average power during burst, in WCDMA: average current rms-power.
RF	Radio Frequency
S	Sensitivity: Output power of BS to get a specific BER: • GSM modes, circuit switched: BS output power to get a BER of 2.4% for residual class II (unprotected) bits • WCDMA mode: BS power in terms of <REF I_{or}> to get BER = 0.1%.
RX	communication direction: MS is receiving, BS transmitting = downlink
SAM	Standard anthropomorphic model (human head phantom)
TIS	Total Isotropic Sensitivity = TRS
TP	Talk position (phone is situated at SAM)
TRP	Total Radiated Power
TRS	Total Radiated Sensitivity = TIS
TX	communication direction: MS is transmitting, BS receiving = uplink
UE	User Equipment (here = DUT)
<X>	Average of value X. (e.g. over channels, physical correct = averaging in “Watt”; e.g.: use: TRP_band_average_in_dBm = 10*LOG10(1/3*(POWER(10;TRP_low/10)+POWER(10;TRP_mid/10)+POWER(10;TRP_high/10)))

1.4 References

[1] Ready for Acceptance and Technical Acceptance Criteria for Terminals (RFA_TA_Terminal_Vendors_V2.0.pdf)

[2] Cellular Telecommunications & Internet Association Method of Measurement for Radiated RF Power and Receiver Performance, Revision 2.2
(see: http://www.wow-com.com/certification/eval_criteria/index.cfm)

[3] 3GPP TR 25.914: “Measurements of radio performances for UMTS terminals in speech mode”, (Release 7), Version V7.0.0, June 2006.

[4] ETSI EN 300 607-1, V8.1.1, (2000-10): “Digital cellular telecommunications system (Phase 2+); MS conformance specification; part 1 (GSM 11.10, Release 1999)”.

[5] IEEE 1528: “Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body Due to Wireless Communications Devices: Experimental Techniques”, Draft CBD 1.0, April, 2002.

2 Test Methodology

2.1 Set Up

In order to get as reproducible results as possible, an antenna fully anechoic room (AFAR) shall be used. The recommended distance between measurement antennas and the device under test (DUT = terminal) shall be at least 1.5 m. Lower distances are acceptable when CTIA calibration requirements are met (see [2]). There exist two acceptable principle test up's: The DUT is being rotated in two axis and only a few (usually one) measurement antenna is used, or the DUT is rotated in one axis and there is an arch containing a number of measurement antennas. The pictures in Fig. 1 and Fig. 2 show the set up respectively.

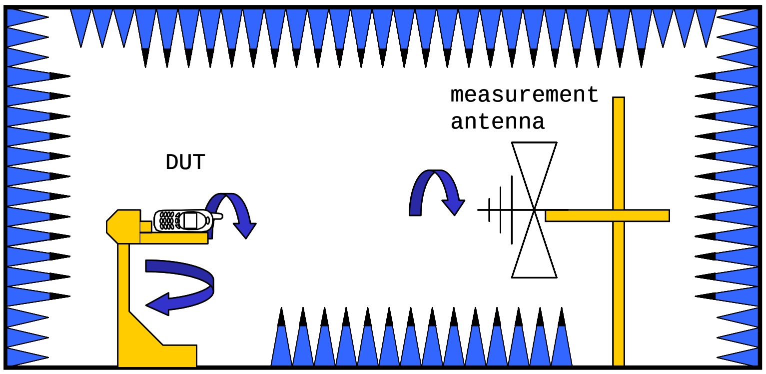

Fig 1: Set up using a two-axis controller and one (or a few) measurement antennas.

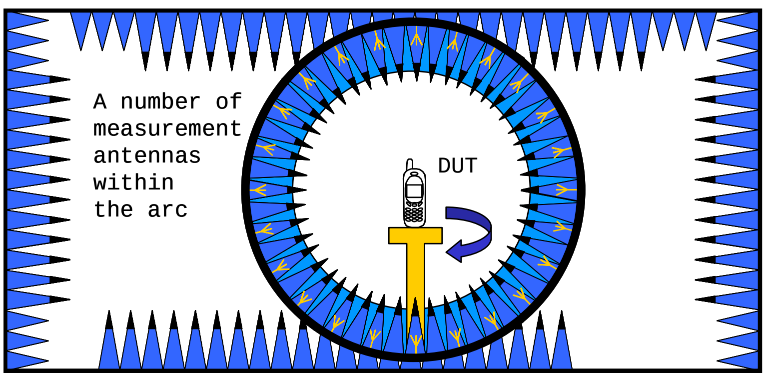

Fig 2: Set up using a one-axis controller and a larger number of measurement antennas forming an arc.

The system shall be handled as DUT (device under test) as shown in Fig. 1 or Fig. 2. with the origin at the ear reference point of the phantom and the phantom defining the coordinate system.

2.2 Procedure and Equations to be used

The basic methodology requested by Vodafone is following mostly the four principles outlined in CTIA the test plan [2]:

1. Measure all radiation in all directions for determining the antenna pattern. Consider for output power measurements the full sphere around the DUT in order to cover all power sent out.
2. Measure both polarizations to get the power flux density (Pointing Vector).
3. Calculate the total radiated power by taking into account the appropriate area and performing a mathematically correct integral over the full sphere surrounding the DUT and taking into account no isotropic distribution of measurement points.
4. To get one value per frequency band by means of linear average over three channels: low, mid and high. Linear means: take all powers in Watt).

The determination of the power flux density is based on the far field relation:

$$power\ \ flux\ density = E \times H = \frac{E^2}{Z_0}$$

Where *H* is the magnetic and *E* the electric field. Only *E* will be measured and the power flux density than calculated by using Z_0, the free space impedance (Z_0 = 377 Ω).

The total radiated power (TRP) is calculated using power readings in spherical coordinates. The total radiated power therefore equals to:

$$TRP = \oiint \frac{E_{eff}^2}{Z_0} r^2 \sin\Theta \, d\Theta \, d\phi$$

Where *r* is the measurement distance and E_{eff} is the effective field strength measured in certain directions and by taking into account both polarizations according to:

$$E_{eff} = \sqrt{E_{vertical}^2 + E_{horiz}^2} \ .$$

In case of discrete, constant angle steps ΔΘ and Δϕ the integration becomes a summation in terms of:

$$TRP = \sum_{\Theta,\phi} \frac{E_{eff}^2(\Theta,\phi)}{Z_0} w(r,\Theta,\phi,\Delta\Theta,\Delta\phi)$$

Where *w* is the area:

$$w = r^2 \Delta\phi \left(\cos\left(\Theta - \frac{\Delta\Theta}{2}\right) - \cos\left(\Theta + \frac{\Delta\Theta}{2}\right)\right)$$

shown in figure Fig. 5. Note, a good approximation for small ΔΘ is:

$$\left(\cos\left(\Theta - \frac{\Delta\Theta}{2}\right) - \cos\left(\Theta + \frac{\Delta\Theta}{2}\right)\right) \quad \approx \quad \Delta\Theta \cdot \sin(\Theta)$$

This is used in the CTIA test plan [2].

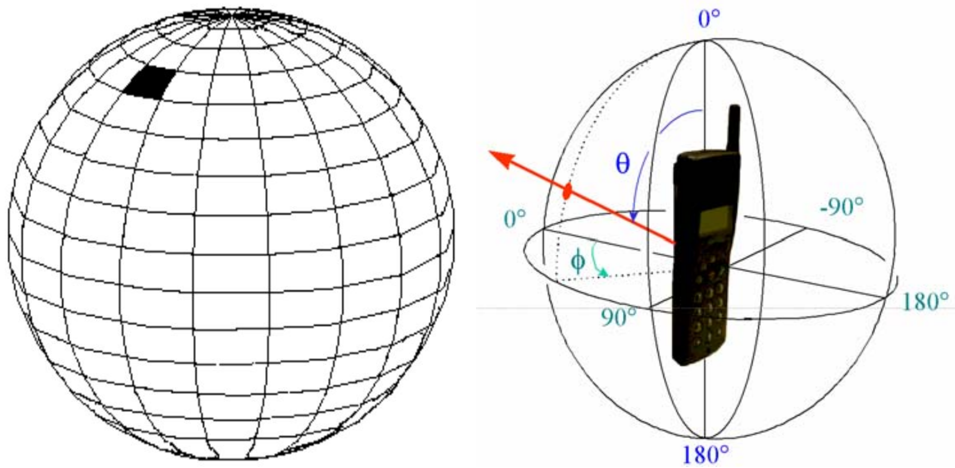

Fig. 3: Net in spherical coordinates assuming constant steps in Θ and ϕ as used in measurements.

At the poles the area w is considered to become:

$$w = r^2 \Delta\phi \left(1 - \cos\left(\frac{\Delta\Theta}{2}\right)\right)$$

Because of the fact some of the measurement positions are used more than once there is a need for additional weighting dependent on measurement procedure (usually weighting with 1/n, where n is the number of measurement at the pole).

The Sensitivity calculation can follow the same procedure: Treat 1/*S* as a power, where *S* is sensitivity:

The total radiated sensitivity (TRS) equals to:

$$\frac{1}{TRS} = \oiint \frac{1}{S_{eff}\, 4\pi r^2} r^2 \sin\Theta \, d\Theta \, d\phi$$

where *r* is the measurement distance and S_{eff} is the effective sensitivity taking both polarizations into account:

$$\frac{1}{S_{eff}} = \frac{1}{S_{vertical}} + \frac{1}{S_{horizontal}}$$

In case of discrete, constant angle steps ΔΘ and Δϕ the integration becomes a summation in terms of:

$$\frac{1}{TRS} = \sum_{\Theta,\phi} \frac{1}{4\pi r^2 S_{eff}(\Theta,\phi)} w(r,\Theta,\phi,\Delta\Theta,\Delta\phi)$$

where *w* is again the area:

$$w = r^2 \Delta\phi \left(\cos\left(\Theta - \frac{\Delta\Theta}{2}\right) - \cos\left(\Theta + \frac{\Delta\Theta}{2}\right)\right)$$

For more information about the theory and derivations of the equations presented here, please see CTIA test plan [2], appendix E.

2.3 Frequency Ranges

Frequencies used in Europe and U.S.A. and which are of interest for Vodafone are given in Tab. 1, Tab. 2 and Fig. 6.

TX	Low channel			Mid channel			High channel		
Mode	ARFCN	Frequency		ARFCN	Frequency		ARFCN	Frequency	
GSM 850	128	824,2	MHz	190	836,6	MHz	251	848,8	MHz
EGSM 900	975	880,2	MHz	38	897,6	MHz	124	914,8	MHz
GSM 900	1	890,2	MHz	62	902,4	MHz	124	914,8	MHz
3G UMTS (Band 8)	4452	880,4	MHz	4512	902,4	MHz	4573	914,6	MHz
DCS / GSM 1800	512	1710,2	MHz	698	1747,4	MHz	885	1784,8	MHz
3G UMTS (Band 4)	8552	1710,4	MHz	8737	1747,4	MHz	8923	1784,6	MHz
PCS / GSM 1900	512	1850,2	MHz	661	1880	MHz	810	1909,8	MHz
3G UMTS (Band 1)	9612	1922,4	MHz	9750	1950,0	MHz	9888	1977,6	MHz

Tab. 1: Frequencies and channel numbers to be used for TX measurements.

RX	Low channel			Mid channel			High channel		
Mode	ARFCN	Frequency		ARFCN	Frequency		ARFCN	Frequency	
GSM 850	128	869,2	MHz	190	881,6	MHz	251	893,8	MHz
EGSM 900	975	925,2	MHz	38	942,6	MHz	124	959,8	MHz
GSM 900	1	935,2	MHz	62	947,4	MHz	124	959,8	MHz
3G UMTS (Band 8)	4627	925,4	MHz	4713	942,6	MHz	4798	959,6	MHz
DCS / GSM 1800	512	1805,2	MHz	698	1842,4	MHz	885	1879,8	MHz
3G UMTS (Band 4)	9027	1805,4	MHz	9212	1842,4	MHz	9398	1879,6	MHz
PCS / GSM 1900	512	1930,2	MHz	661	1960	MHz	810	1989,8	MHz
3G UMTS (Band I)	10562	2112,4	MHz	10700	2140,0	MHz	10838	2167,6	MHz

Tab. 2: Frequencies and channel numbers to be used for RX measurements.

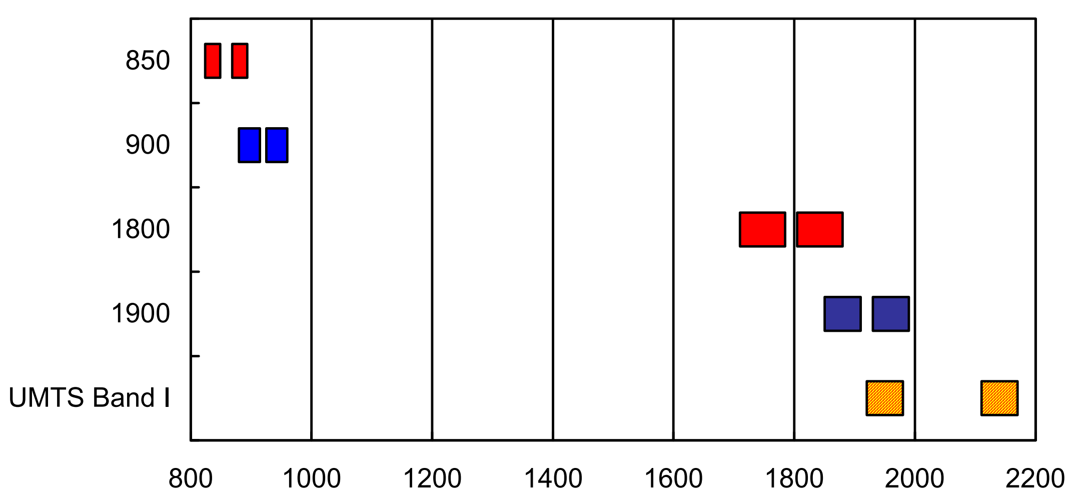

Fig 4: Overview about Frequency bands.

Following other methods ([2], [3] and [4]), measurement at three channels or frequencies shall be used to find a final averaged value. Note, “linear” averaging based on physical units such a Watt must be applied, see end of chapter 1.3.

2.4 TRP Measurement Procedure and Settings

The following procedure shall be applied:

- Establish a call to the mobile, set maximum RF output power.
- Execute a full three dimensional (3D) measurement as described in [2], [3] and chapter 2 by using:
  $\Delta\phi \leq 22.5°$
  $\Delta\Theta \leq 15°$
  and at three TX frequencies according to Tab. 1: low, mid and high.
  (Note: CTIA asks for: 15° and 15°)
- Measure both vertical and horizontal polarization's.
- Calculate one TRP value for the appropriate band as described in 2.

2.5 TRS Measurement Procedure and Settings

The following procedure shall be applied:

- Establish a call to the mobile, set maximum RF output power.
- Execute a full three dimensional (3D) measurement as described in [2],[3] and chapter 2 by using:
  $\Delta\phi \leq 30°$
  $\Delta\Theta \leq 30°$
- Measure both vertical and horizontal polarization's.
- Calculate one TRP value for the appropriate band as described in 2.

In order to save time, an alternative method can be applied:

- Execute TRP measurement in the appropriate band first
- Vodafone is requesting that in general all channels are considered and meet the target values (e.g. relevant channels checked in one position).
- Establish a call to the mobile
- Check at one position whether the output power does have an impact on the sensitivity (usually it should not have any impact). In case there is an impact or in case of doubt, set maximum RF output power. When the output power does have no impact on the sensitivity, reduce the output power to a reasonable minimum to save battery lifetime.
- Execute sensitivity measurements based on bit error measurements* (BER) in 3D or one plane by using:
  $\Delta\Theta \leq 22.5°$ (at least)
  $\phi = 0°$ or $\phi = 180°$ and $\Delta\phi = 360°$
  and at three RX frequencies according to Tab. 2: low, mid and high.
  Contrary to CTIA, Vodafone allows to check whether it can be assumed the same pattern for RX and TX. Doing so it becomes possible to calculate the 3D-TRS value by using results form a one plane TRS measurement procedure. The plane should be a so called *E*-plane, which is according to Fig. 3 the plane for $\phi = 0°$ and $\phi = 180°$.
- Measure both vertical and horizontal polarization's.
- Check whether the pattern is sufficient similar to the appropriate pattern for the TX direction. Provide a picture of both patterns.
- Calculate TRS_{one_plane} value for the appropriate band as described in 2.2 by using $\phi = 0°$ and $\phi = 180°$, assuming $\Delta\phi = 360°$.
- Calculate TRP_{one_plane} value for the appropriate band as described in 2.2 by using $\phi = 0°$ and $\phi = 180°$, assuming $\Delta\phi = 360°$.
- Calculate the TRS value by scaling (assuming all variables in dBm):
  $TRS = TRS_{one\_plane} - TRP + TRP_{one\_plane}$
- An estimation of the additional uncertainty caused by the "pattern is equal" assumption shall be provided

2.6 Measurement of the Self-Interference Effect

The following procedure shall be applied:

- Position the terminal to the appropriated/maximum gain position (in respect to pattern, angle, polarisation and a low variation between low, mid and high channels).
- Select an appropriate channel list. The relevant channels are usually related to e.g. different terminal clock signals. If the testing entity is not aware of the relevant channels, all channels have to be measured for GSM. In case of WCDMA a fixed channel list shall be used with a separation of 23 (e.g.: for band I: 10562, 10585, 10608…).
- Execute sensitivity measurements based on bit error measurements (BER) at this fixed position. Correct data by using the appropriate effective gain to correlate self interference data with TRS data.
- Compile the
    - Peak values,
    - Number of peaks not meeting the target value, and
    - Average sensitivity (see Fig. 7).

An assessment will be done based on absolute sensitivity data representing TRS values. Vodafone will assess such a TRS over frequency / channel number in terms of a limit line allowing a certain number of channels with a worse sensitivity than target TRS sensitivity values provided in Tab. 3. See Tab. 4 for exceptions.

2.7 General Test Conditions

- A data card and laptop combination is regarded as one DUT.
- Test requirement for PCs:
    - angle between LCD and main system: 110°,
    - default settings for internet browsing
    - no power savings activated.

3 Vodafone Acceptance Criteria

3.1 Priorities Concerning Radiated Performance in Different Bands

1a: TRS WCDMA (1a = launch critical)
1b: TRP WCDMA (1b = critical, must be changed during launch)
2: TRS and TRP EGSM 900
3: TRS and TRP GSM 1800
4: Other bands like e.g. GSM 850 and GSM1900 (4= to be tested on special request only)

3.2 Summary of Target Values

Contrary to CTIA is Vodafone requesting that in general all channels are considered and meet the target values. Therefore all thee individual values for TRP and TRS must meet the appropriate limit or target values.

Device Type		GSM 850	EGSM 900	WCDMA Band 8	GSM 1800	WCDMA Band 4	GSM 1900	WCDMA Band $I_{PCL\ 4/3}$
PC's or data cards in free space situations	TRP	25.5	27.0		24.0		22.5	16/18
	TRS	-98.5	-100.0		-100.0		-98.5	-103.0

Tab. 3: Vodafone target values in dBm for different device types and bands.

3.3 Sensitivity Limits and Exceptions

In case the self-interference test shows at all channels TRS values are better than the required target sensitivity given in Tab. 3 this can be considered as a “passed” for TRS for of the appropriate band. In case the self-interference test shows sensitivity degradations, but at a limited number of channels only, Vodafone allows some deviations from the target values. In such a case the final verdict is based on the number und level of sensitivity values. To illustrate a typical example result including a limited number of sensitivity issues is presented in Fig. 7 and Fig. 8.

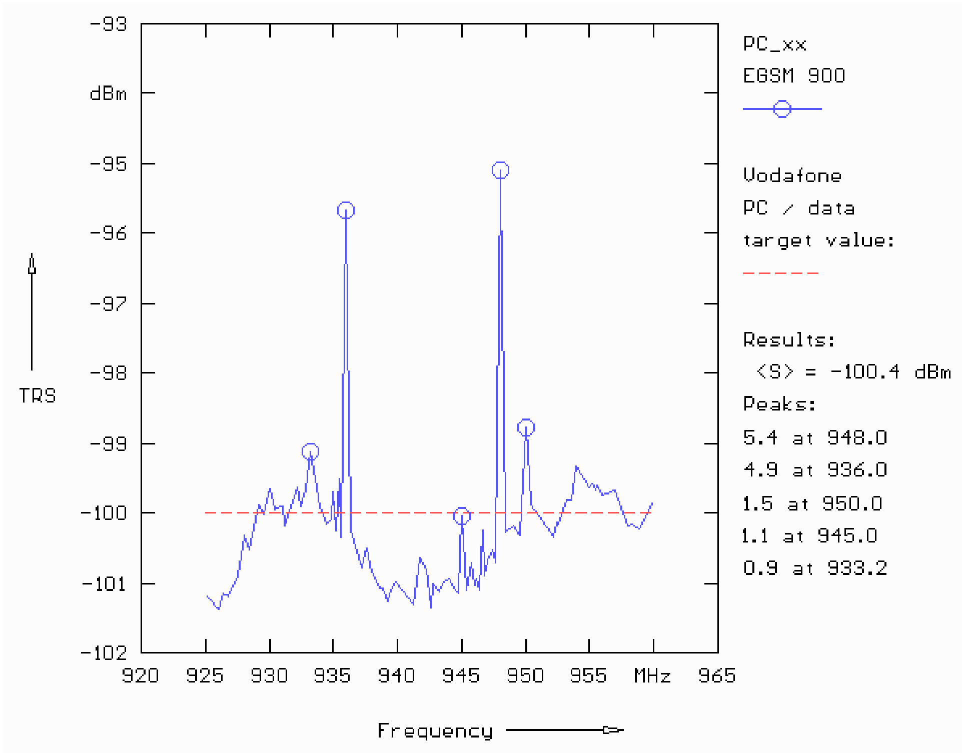

Fig 5: Example for TRS values for a hand held device in free space position over frequency with violations of the appropriate target value requirement.

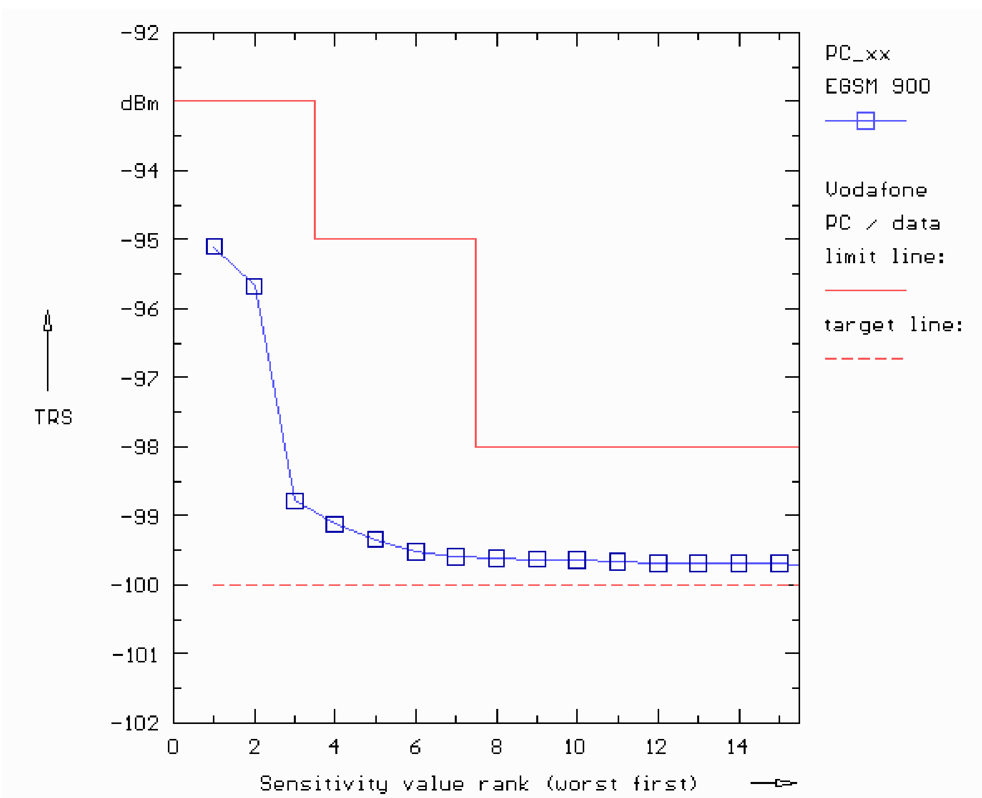

Fig 6: Data representation for a final assessment with permitting some exceptions according to data combined from Tab. 3 and Tab. 4.

Exception in terms of: Number of channels and the permitted difference to target value in dB	GSM 850	EGSM 900	WCDMA Band 8	GSM 1800	WCDMA Band 4	GSM 1900	WCDMA Band I
Number of channels with reduced sensitivity	3	3		6		6	1
Permitted difference in dB	7	7		7		7	4
Additional number of channels with reduced sensitivity	4	4		8		8	-
Permitted difference in dB	5	5		5		5	-
Difference to target value in dB for all other channels (limit)	2	2		2		2	1.5

Tab. 4: Vodafone exceptions and permissible deviations from target TRS values.

3.4 Estimation of Heat Effects

During the operation the DUT may become hot. Since RF output power and sensitivity in principle depend on device temperature an estimation of the heating impact is required. For both, TRP and TRS measurement it is therefore required:

- Store one measured value (either radiated output power or sensitivity value) at the begin of the measurement.
- Redo the exact same measurement at the very same position (and polarisation, channel and so on) at the end of the measurement of before any break, such as due to changing the battery.
- Report the appropriate difference as power or sensitivity “drift”.

4 System Calibration

Vodafone accepts CTIA certification as good and sufficient proof for accuracy of the measurement. Since CTIA requirements for chamber (absorber) quality and equipment are rather high, Vodafone allow an alternative method for system calibration.

4.1 Set Up

For calibration the complete set up shall be as close as possible to the one used in the measurements. Therefore we recommend using an actual terminal connected to a reference dipole which shall be assumed to have no losses as reference device.

A reference device sketch is shown in Fig. 9 and shall consist of:

- A terminal capable of operating in the appropriate band at almost the same power levels as for the final measurements
- with a proofed stable output power (watch out temperature/time effects) and
- featuring a connector to connect a RF cable.
- A reference antenna with a matching better than 15 dB at appropriate frequencies and a known efficiency.

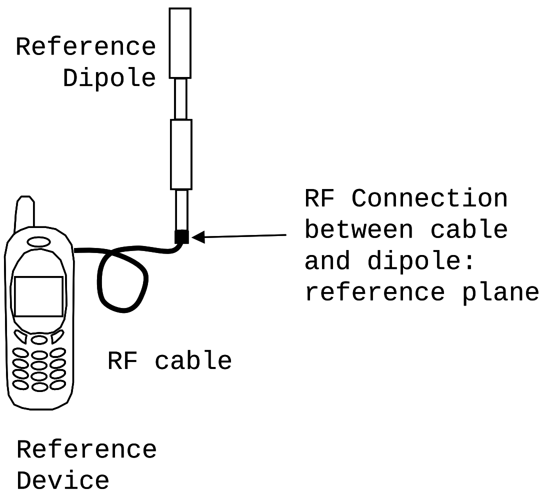

Fig 7: Example reference device for calibration.

4.2 Calibration Procedure

- Measure connected power as well as connected sensitivity at the end of the cable at the “reference plane” for all frequencies as depicted in Fig. 7.
- Create a support holding the reference dipole close to the phone but provide reasonable distance to avoid interactions and matching disturbance.
- Execute measurements as described in this document. Both polarizations must be considered.
- Define appropriate calibration data by comparing connected values to actual radiated values.

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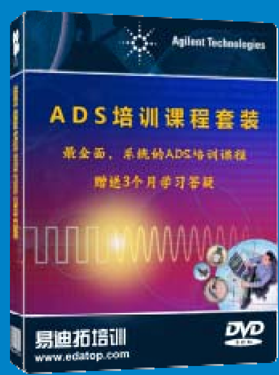

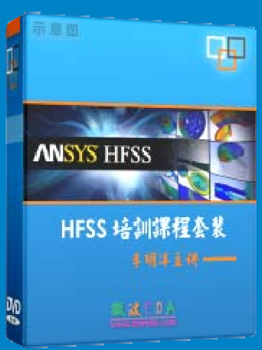

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该培训套装由易迪拓培训联合微波 EDA 网共同推出，是最全面、系统、专业的 CST 微波工作室培训课程套装，所有课程都由经验丰富的专家授课，视频教学，可以帮助您从零开始，全面系统地学习 CST 微波工作的各项功能及其在微波射频、天线设计等领域的设计应用。且购买该套装，还可超值赠送 3 个月免费学习答疑…

课程网址：http://www.edatop.com/peixun/cst/24.html

HFSS 天线设计培训课程套装

套装包含 6 门视频课程和 1 本图书，课程从基础讲起，内容由浅入深，理论介绍和实际操作讲解相结合，全面系统的讲解了 HFSS 天线设计的全过程。是国内最全面、最专业的 HFSS 天线设计课程，可以帮助您快速学习掌握如何使用 HFSS 设计天线，让天线设计不再难…

课程网址：http://www.edatop.com/peixun/hfss/122.html

13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含 4 门视频培训课程，培训将 13.56MHz 线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了 13.56MHz 线圈天线的工作原理、设计方法、设计考量以及使用 HFSS 和 CST 仿真分析线圈天线的具体操作，同时还介绍了 13.56MHz 线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握 13.56MHz 线圈天线及其匹配电路的原理、设计和调试…

详情浏览：http://www.edatop.com/peixun/antenna/116.html

我们的课程优势：

※ 成立于 2004 年，10 多年丰富的行业经验，

※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

联系我们：

※ 易迪拓培训官网：http://www.edatop.com

※ 微波 EDA 网：http://www.mweda.com

※ 官方淘宝店：http://shop36920890.taobao.com