Presentation of the study “Technical support relating to performance of antennas of mobile phones”, prepared for the European Commission — Enterprise and Industry Directorate-General

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1. Foreword

❒ Excem is a small company founded in 1988, based near Paris, France. The Excem Group has 3 companies: Excem, Eurexcem and Tekcem.

❒ Our main activities:

- ◆ engineering and R&D services in radio design, EMC, signal integrity and analog electronics design;
- ◆ technical assistance related to radio and EMC standards and regulations;
- ◆ selling patents produced by our internal R&D.

❒ Eurexcem prepared a report entitled *Technical support relating to performance of antennas of mobile phones — Final report — 2nd Edition* for the DG enterprise and industry.

❒ This presentation of the report can in no way be taken to reflect the views of the European Commission.

2. Definitions used in the presentation

radio performance test
A test of a wireless device, the result of which is representative of the performance of the wireless device as regards reception of radio signals or emission of radio signals.

conducted radio performance test
A radio performance test during which the power used for radio transmission is transferred via one or more conductors.

radiated radio performance test
A radio performance test during which the power used for radio transmission is transferred through space in the form of electromagnetic fields propagated in space without artificial guide.
A radiated radio performance test is sometimes referred to as over-the-air (OTA) test.

mobile phone
A portable cellular phone comprising one or more integral antennas, which is intended to be held by the user during wireless communication, and which bears the CE conformity marking defined in Annex VII of the R&TTE directive.

GSM mobile phone
A mobile phone intended to be able to operate as a mobile station (MS) of a GSM network. This also covers the possible GPRS or EDGE capabilities.

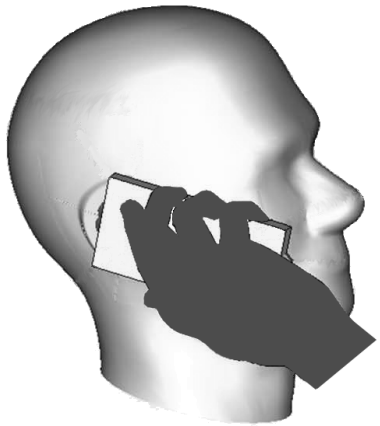
UMTS mobile phone
A mobile phone intended to be able to operate as a user equipment (UE) of a UMTS network or its upgrades which use CDMA as multi-access technique.

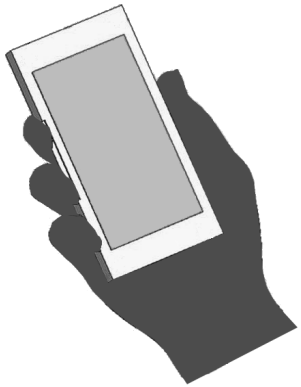
LTE mobile phone
A mobile phone intended to be able to operate as a user equipment (UE) of an LTE network and its upgrades which use OFDMA in the DL and SC-FDMA in the UL.

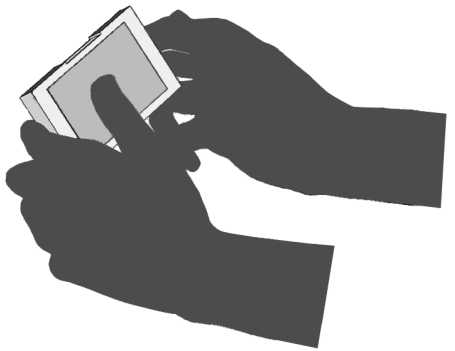
user effects

The effects, on a wireless link comprising a mobile phone, of the coupling between the user of the mobile phone and one or more integral antennas of the mobile phone. These effects comprise:

- a variation in the impedance of the antenna, or in the impedance matrix of the antennas;
- a variation in the radiation efficiency of the system formed by the mobile phone and the user;
- a variation in the directivity of the system formed by the mobile phone and the user.







anthropomorphic phantom
A physical model of a human body or of one or more parts of a human body, intended to be used in some radiated radio performance tests, or in tests relating to human exposure to electromagnetic fields.

observed radio performance
The performance of a wireless device as regards reception of radio signals or emission of radio signals, as it is experienced by a user.

MIMO
MIMO stands for multiple-input and multiple-output. In the field of wireless transmission, spatial diversity and spatial multiplexing, which involve multiple antennas for emission and/or reception, are often collectively referred to as MIMO techniques.

3. Motivation

❒ The observed radio performance of a mobile phone, that is to say its performance as regards reception of radio signals or emission of radio signals, as it is experienced by a user, depends on the characteristics of its antenna(s).

❒ Because of poor antenna performance, the observed radio performance of a mobile phone is not always satisfactory in places where the signal from the base station is weak.

❒ The report investigates whether the technical requirements of harmonized standards are adequate to avoid this problem, and analyses the need for and the feasibility of the introduction of additional requirements.

4. Preliminary technical discussion

❒ Some wireless communication engineering aspects:

- ◆ different performance measures apply to the three fading scenarios;
- ◆ at places where the average path gain is low, the capacity and the ε-outage capacity are proportional to the SINR;
- ◆ the "reception quality" depends on DL and UL performance;
- ◆ MIMO techniques are very effective to reduce the outage probability;

❒ Some electromagnetic engineering aspects:

- ◆ the *absolute gain* of an antenna, in a given direction, is the product of the *radiation efficiency* and the *directivity* in the given direction;
- ◆ several definitions are possible for the path loss and the body loss;
- ◆ we use definitions for which the averaged link budget at a given place is

$$< P_{AVA} >_{dBm} = P_{T\,dBm} + G_{BSN\,dB} + 10\log(e_{MP}) - 3\,\mathrm{dB} + < G_5 >_{dB} + < G_{BOD5} >_{dB}$$

- Some electronic engineering aspects — conducted sensitivity:
  - a conducted sensitivity of a wireless receiver may be defined;
  - a conducted radio performance test is used to measure it;
  - this sensitivity does not take into account the actual performance of the antennas used by the receiver;
  - a conducted sensitivity is typically a total average power of electrical signals at the antenna inputs of the receiver, for instance the received power P_{IR} or an applied power such as $P_{50\,\Omega}$;
  - from the link design standpoints, choosing $P_{50\,\Omega}$ or P_{IR} to define the conducted sensitivity does not lead to a result which can be used in the link budget;
  - a specified sensitivity, termed reference sensitivity and expressed as a power level applied to one or more antenna connectors, is defined for mobile phones;
  - it is based on assumptions on the technology used in the mobile phone, and it is not very demanding.

❒ Some electronic engineering aspects — optimal impedance of an antenna:

- ◆ for a given Z_{IR}, there exists an optimal value of Z_{SANT} for reception;
- ◆ a mobile phone having a single antenna input may use an adaptively controlled tunable integral antenna to automatically modify Z_{SANT};
- ◆ a mobile phone using a single antenna may comprise an adaptive single-antenna-port antenna tuner to automatically modify Z_{IR};
- ◆ both techniques can compensate the fact that Z_{SANT} varies significantly over the frequency bands used for reception and is influenced by the user effects ;
- ◆ these techniques have been used in mobile phones, but they are not yet common;
- ◆ they are not always compatible with conducted radio performance tests defined in many specifications of 3GPP and the harmonized standards.

❒ Some electronic engineering aspects — optimal impedance matrix of antennas:

- ◆ In the case of a mobile phone using simultaneously multiple antennas to communicate with the base station, $\mathbf{Z}_{SANT}$ is typically non-diagonal;
- ◆ for a given $\mathbf{Z}_{IR}$, there exists an optimal value of $\mathbf{Z}_{SANT}$ for reception;
- ◆ a mobile phone having multiple antenna inputs may use an adaptively controlled array of tunable integral antennas to automatically modify $\mathbf{Z}_{SANT}$;
- ◆ a mobile phone using multiple antennas may comprise an adaptive multiple-antenna-port antenna tuner to automatically modify $\mathbf{Z}_{IR}$;
- ◆ both techniques can compensate the fact that $\mathbf{Z}_{SANT}$ varies significantly over the frequency bands used for reception and is influenced by the user effects ;
- ◆ these techniques do not seem to be currently used in mobile phones, but they are being investigated;
- ◆ they are not always compatible with conducted radio performance tests defined in many specifications of 3GPP and the harmonized standards.

- Some compliance engineering aspects — conducted radio performance tests:
  - conducted radio performance tests either require that a tested mobile phone comprises one or more antenna connectors, or a modification of the tested mobile phone to install such antenna connectors;
  - they are simpler in the case where the nominal input impedance at each antenna connector is 50 Ω ;
  - they are not compatible with some mobile phone designs using adaptively controlled tunable integral antenna(s) or an adaptive antenna tuner;
  - thus, they are neither applicable to all mobile phones, nor unbiased;
  - they do not use the antennas of the mobile phone, so that the tests neither take the actual antenna characteristics nor the user effects into account.

❒ Some compliance engineering aspects — radiated radio performance tests:

◆ radiated radio performance tests use the antenna of the mobile phone to transfer the power used for radio transmission;

◆ they should in principle be always preferred;

◆ however, radiated radio performance tests are more expensive and are affected by higher measurement uncertainties than conducted radio performance tests;

◆ the total radiated power (TRP) can be used in a link budget since, if measured without phantom, it satisfies

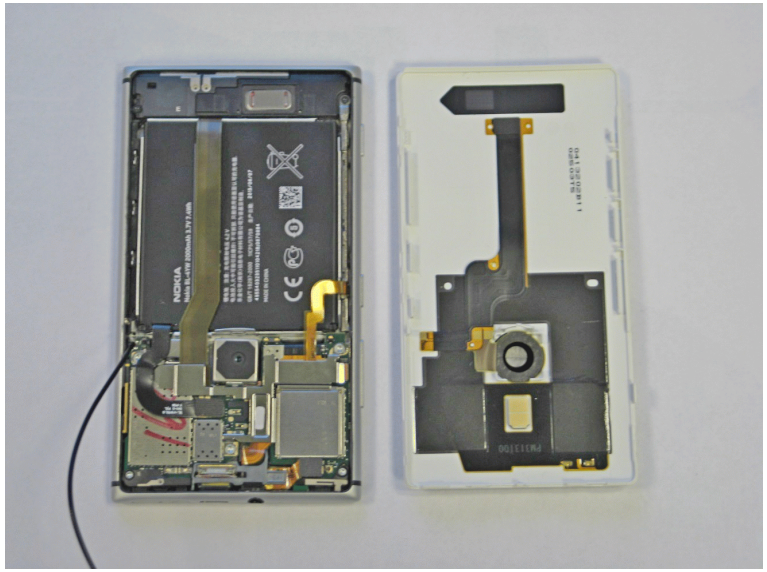
$$P_{TRP\,dBm} = P_{TMP\,dBm} + 10\log e_{MP}$$

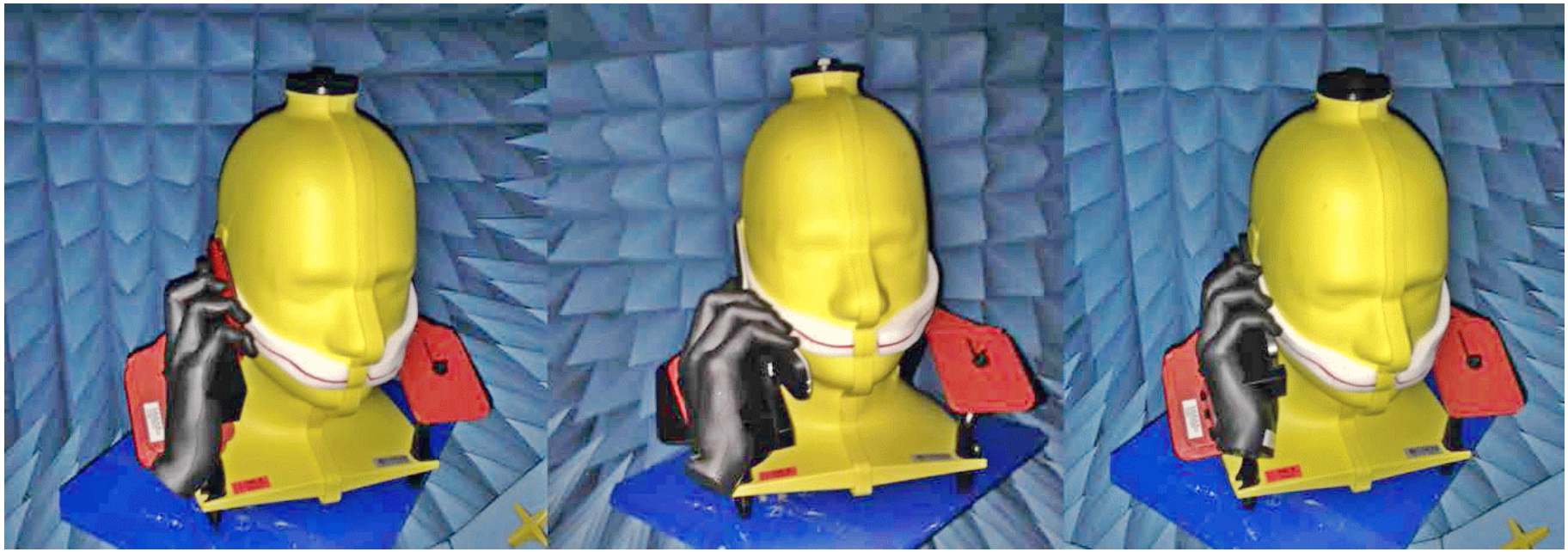
◆ the total radiated sensitivity (TRS or TIS) can be used in a link budget since, if measured without phantom, it satisfies

$$P_{TRS\,dBm} = P_{AVTH\,dBm} - 10\log e_{MP}$$

◆ the TRP and TRS may also be measured with a phantom.

A mobile phone during conducted radio performance test (right) or during a radiated radio performance test with head and hand phantoms (left), courtesy of Prof. G. F. Pedersen.





5. Performance requirements on emission and reception

❒ Requirements applicable to mobile phones are found in:

- ◆ harmonized standards covering the essential requirements of article 3.2 of the R&TTE directive;
- ◆ specifications of 3GPP;
- ◆ other specifications.

❒ The harmonized standards do not contain any requirement on the TRP or TRS.

❒ However, the harmonized standards and other specifications of 3GPP require or allow some radiated radio performance tests, depending on the presence of an integral antenna or of an antenna connector.

❒ A survey found that radiated radio performance tests are not typically used to establish compliance of a mobile phone with the harmonized standards.

❒ The specifications of 3GPP allow the use of radiated radio performance tests for demonstrating the compliance of a UMTS mobile phone or LTE mobile phone to the conformance specification.

❒ 3GPP TS 34.114 is available for testing the "over-the-air (OTA) antenna performance" of a GSM mobile phone and of a UMTS mobile phone:

- ◆ it describes radiated radio performance tests for TRP and TRS measurements;
- ◆ it includes a free space configuration measurements with a phantom head.

❒ The "Test Plan for Mobile Station Over the Air performance" of "CTIA - The Wireless Association" describes radiated radio performance tests which can be applied to a GSM mobile phone, a UMTS mobile phone or an LTE mobile phone:

- ◆ it describes radiated radio performance tests for TRP and TRS measurements;
- ◆ it includes a free space configuration measurements with a phantom head and/or with phantom hand(s).

❒ Though the characteristics of the antenna(s) play an essential role in the observed radio performance, it is not desirable to directly specify them.

❒ The radio performance in places where the signal from the base station is weak should be assessed based on radiated radio performance tests applicable to the mobile phone regarded as a system, meeting 7 criteria.

❒ The criteria applicable to all mobile phones are:

- ◆ (a) delivering one or more parameters representing the minimum power density of incident waves providing a good enough communication in the DL;
- ◆ (b) delivering one or more parameters each representing the power radiated by the mobile phone in the UL;
- ◆ (c) using an unaltered mobile phone for all measurements;
- ◆ (d) being neutral as regards the internal design of the mobile phone;
- ◆ (e) satisfactorily representing the user effects in a sufficient set of realistic uses of the mobile phone.

❒ Two additional criteria only relate to MIMO techniques:

- ◆ (f) for a mobile phone supporting multiple antenna reception techniques, delivering one or more parameters representing a minimum DL performance in one or more MIMO fading channels presenting a large path loss;
- ◆ (g) for a mobile phone supporting multiple antenna emission techniques, delivering one or more parameters representing a minimum UL performance in one or more MIMO fading channels presenting a large path loss.

❒ The report does not address the question of the limits which could be applied to the parameters referred to as in the criteria (a), (b), (f) and (g).

❒ These limits might impact the interests of users, mobile phone manufacturers, wireless network operators and base station manufacturers.

❒ However, limits for TRP and TRS without anthropomorphic phantom could be derived from the limits of current harmonized standards.

❒ The compliance of a mobile phone with the harmonized standards does not entail a satisfactory observed radio performance in places where the signal from the base station is weak.

❒ Tests for the measurement of the TRP and the TRS meet the criteria (a) to (d). Phantoms can be used to meet the criterion (e).

❒ Radiated radio performance tests meeting the criteria (f) and (g) are not fully mature yet.

❒ The definition of radiated radio performance tests applicable to a UMTS mobile phone or an LTE mobile phone using MIMO techniques in the DL, is a topical subject addressed by RAN4 of 3GPP:

- ◆ direct measurement techniques and indirect measurement techniques are being considered;
- ◆ only direct OTA measurement techniques can meet the criteria (c) and (d).

6. Antenna performance and SAR

❒ Concerns have been raised on the compatibility between a good observed radio performance in places where the signal from the base station is weak, and a low user's exposure to electromagnetic fields.

❒ In a link budget, a body loss accounts for the user effects. The body loss is caused by the current induced, in the user, by the electromagnetic fields of the mobile phone.

❒ Since a small body loss is correlated with a good link and a low SAR, there is no conflict between a good observed radio performance in places where the signal from the base station is weak, and a low user's exposure to electromagnetic fields.

7. Promoting an improved observed radio performance

❒ The introduction of additional technical requirements and/or of a labeling system promoting an improved observed radio performance make sense only if the improvement can be brought to market without significant price increase.

❒ The possibility of improvement based on standard technology is shown by the spread in TRP and TRS measurement results among mobile phones.

❒ Techniques for mitigating the user effects can be used to further improve the observed radio performance in places where the signal from the base station is weak.
Examples:

- integral antenna(s) with higher directivity;
- adaptive antenna selection;
- adaptive beamforming;
- adaptively controlled tunable integral antenna(s); and
- adaptive single-antenna-port or multiple-antenna-port antenna tuner.

❒ New systematic and consistent technical requirements for placing a mobile phone on the market in the EU, which would guarantee that the mobile phone should provide a satisfactory observed radio performance in places where the signal from the base station is weak, are technically feasible.

❒ Such new technical requirements might duplicate some requirements of current voluntary certification programs, for instance offered by:

- ◆ the Global Certification Forum, which seems to be required by many European wireless network operators;
- ◆ CTIA - The Wireless Association, which seems to be required by many non-European wireless network operators.

❒ New labeling requirements for placing a mobile phone on the market in the EU, ensuring that consumers are informed of the observed radio performance to be expected of a mobile phone in places where the signal from the base station is weak, are technically feasible and could use at least 3 performance levels.