Aalborg Universitet

Mobile Phone Antenna Performance 2013

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Publication date:
2013

Document Version
Early version, also known as pre-print

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Version 2.2, 28 November 2013

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Introduction

This study investigates the radio coverage capabilities of mobile phones. The study is based on the Danish mobile networks and the current phones used in 2013.

The radio coverage for a phone depends on the available signal from the antenna mast but also on the phone's ability to collect this signal. This ability depends strongly on the antenna in the phone and on the way the user's hand is holding the phone to the head during a call [Pel09]. If the phone is not used hand held but used in e.g. a handsfree installation or connected to a headset, the phone itself may be placed free of any close-by objects. In this case the ability to collect a radio signal is typically very different.

The current study focuses on the receiver performance of mobile phones as this is crucial for how well a connection can be made in weak radio signal conditions. Such a test is often referred to as the antenna test, even though the test includes more than the antenna itself. The transmitter and receiver electronics are also included in these tests, but since these parts are adjusted to mandatory limits during manufacturing, only the antennas can give significant performance differences among phones.

The study is a follow-up on a similar study conducted in 2012 on a smaller series of phones common in the market in 2012 [Ped12]. The aim of that study was to establish the field strength limit for mobile telephony and set the minimum field strength needed to ensure coverage. The predicted field strength values for all mobile nets[1)] everywhere in Denmark was then compared to the minimum values and a combined coverage map was produced by the Danish authorities [www.erhvervsstyrelsen.dk].

1) All mobile networks using the mobile standards GSM and UMTS for the 900, 1800 and 2100 MHz frequency bands

Test Procedure

The tests conducted in the current study are based on the agreed standard test of mobile phones, created by the Cellular Telecommunications Industry Association (CTIA) [CTIA13]. In addition, phantom head and hands were used which are standardised by the 3rd Generation Partnership Project (3GPP). The tests in this study only cover telephony and are not applicable to any data modes where the hand locations on the phones may be very different.

To limit the number of tests on each phone only the frequency bands used in Denmark (and all of Europe) were measured and further only one channel was measured as a representative for the band. All phones were measured next to a phantom head, held by a right phantom hand next to the right side of the head. This will be referred to as the "*head-hand*" case in the following.

The receiver performance is evaluated in terms of the so-called Total Receiver Sensitivity (TIS) for each frequency band. The lower the value of the TIS, the smaller a signal the phone requires for operation and therefore the better the phone is to receive in weak signal areas.

The best and worst performing phones were also measured in free space, i.e. with no phantom hand and head. By comparing the TIS results obtained with and without the phantom head-hand, the robustness of the antenna to the user's influence can be seen. The difference between hand-head and free space is often called the body loss.

After the radiated test, the best and worst performing phones were disassembled and measured directly with a cable connected to a point just before the antenna, i.e, the antenna was bypassed. Comparing the results for the conducted and free space measurements the antenna loss can be seen. Further, the conducted measurement shows whether the phone is malfunctioning, since the phone needs to fulfil mandatory limits in the conducted setup.

The setup with the phantom head and hand. Three different hands were used, one for bar phones, one for clam cell phones and one for PDAs. All hands are as specified in the CTIA test plan [CTIA13] and made by Speag.

As shown in the figure above, three different hands were used to fit the different phone types. The phone types in the study are; monoblock, clam shell and PDA phones [CTIA13].

The performances of the phones are ranked according to the TIS for the GSM 900 system. For radio coverage, the GSM 900 frequency band and system is the most important among the investigated, since it gives the best coverage and has the largest penetration in Denmark. A change in TIS of approximately 2 dB can be taken as resulting in a significant difference in coverage.

Mobile phones tested

The phones for test were provided by Danish Business Authority and listed below.

1	Samsung Galaxy III mini
2	Samsung S4 (4G)
3	Samsung S4 mini
4	Samsung Galaxy note II (3G)
5	Samsung Galaxy note II (4G)
6	Sony Xperia Z
7	Sony Xperia Go
8	HTC One
9	HTC One mini
10	HTC Desire X
11	LG Optimus
12	LG A250
13	Nokia Lumia 620
14	Nokia Lumia 820
15	Nokia Lumia 920
16	Nokia Lumia 925
17	Nokia Asha 300
18	Huawei Ascend P2
19	Huawei Y300
20	Doro Phone Easy 605
21	iPhone 5C
22	iPhone 5S
23	Nokia Lumia 925 (second phone as an extra test)

List of all the phones tested. The list is provided by the Danish Business Authority with the addition of phone number 21 and 22 requested before the test began, and phone 23 after the test of all the 22 phones were conducted. Phone 23 is an identical model of phone 16 and included to verify that the particular phone was not just broken.

Results

All the receiver sensitivities measured are listed in the table below as the average over all directions and both polarisations, the so called Total Isotropic Sensitivity (TIS), defined in, e.g., the CTIA test plan [CTIA13]. The values are in logarithmic scale as customary for these measurements and are given in *dBm* values (dB above 1 *mW*). The smaller the value, i.e. the more negative number, the smaller the signal required for a satisfying connection, and therefore the better the phone.

The phones are sorted according to the performance in the most important system and band; GSM900 for coverage in the downlink.

Phone ranking	Model	GSM900 TIS Performance	UMTS900 TIS Performance	GSM1800 TIS Performance	UMTS2100 TIS Performance
1	Doro Phone Easy 605	-98.8 dBm	N/A	-97.7 dBm	N/A
2	Sony Xperia Z	-98.1 dBm	-100.8 dBm	-104.0 dBm	-105.4 dBm
3	Sony Xperia Go	-97.7 dBm	-99.6 dBm	-101.5 dBm	-101.6 dBm
4	Samsumg Galaxy III mini	-97.5 dBm	-99.5 dBm	-101.4 dBm	-102.3 dBm
5	LG A250	-97.5 dBm	N/A	-101.5 dBm	N/A
6	Nokia Asha 300	-97.2 dBm	-100.3 dBm	-102.4 dBm	-103.7 dBm
7	Nokia Lumia 620	-97.2 dBm	-100.8 dBm	-101.9 dBm	-103.8 dBm
8	HTC One	-96.2 dBm	-100.8 dBm	-101.0 dBm	-103.0 dBm
9	Huawei Y300	-96.0 dBm	-96.9 dBm	-101.5 dBm	-102.0 dBm
10	HTC One mini	-95.5 dBm	-99.5 dBm	-97.8 dBm	-104.3 dBm
11	LG Optimus	-95.4 dBm	-97.8 dBm	-100.0 dBm	-101.5 dBm
12	Huawei Ascend P2	-95.1 dBm	-98.8 dBm	-104.4 dBm	-105.0 dBm
13	Nokia Lumia 920	-94.7 dBm	-97.7 dBm	-102.2 dBm	-104.5 dBm
14	Samsung Galaxy note II (4G)	-94.5 dBm	-97.2 dBm	-102.8 dBm	-102.8 dBm
15	Samsung Galaxy note II (3G)	-94.5 dBm	-97.4 dBm	-102.5 dBm	-104.8 dBm
16	Samsung S4 (4G)	-94.5 dBm	-97.3 dBm	-101.3 dBm	-105.0 dBm
17	HTC Desire X	-94.4 dBm	-94.4 dBm	-100.9 dBm	-103.3 dBm
18	Samsung S4 mini	-94.0 dBm	-96.8 dBm	-101.0 dBm	-101.0 dBm
19	Nokia Lumia 820	-93.0 dBm	-98.8 dBm	-100.9 dBm	-101.1 dBm
20	iPhone 5C	-92.3 dBm	-100.9 dBm	-95.8 dBm	-99.9 dBm
21	iPhone 5S	-90.2 dBm	-98.9 dBm	-88.3 dBm	-100.3 dBm
22	Nokia Lumia 925 (second phone as an extra test)	-88.1 dBm	-94.5 dBm	-102.2 dBm	-105.8 dBm
23	Nokia Lumia 925	-88.0 dBm	-92.3 dBm	-102.0 dBm	-106.0 dBm

Measured TIS performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 23) according to GSM900 performance, as this is the most important for coverage. Measurements were made according to the CTIA specifications for talk mode in right hand [CTIA13].

Free space and conducted measurements

The best and the worst performing phones were also measured without the phantom hand and head to disclose the influence of the human body. The best performing phone is the "Doro Phone Easy 605" and the worse performing phone is the "Nokia Lumia 925". The free space results are shown in the table below.

Phone ranking	Model	GSM900 TIS Performance	UMTS900 TIS Performance	GSM1800 TIS Performance	UMTS2100 TIS Performance
1	Doro Phone Easy 605	-103.2 dBm	N/A	-104.0 dBm	N/A
23	Nokia Lumia 925	-105.4 dBm	-107.1 dBm	-106.2 dBm	-107.5 dBm

Free space TIS performance of the best and the worst performing phones. Free space is a measurement of the phone without the phantom head and hand included. Comparing free space to the measurements including the phantom, the head-hand influence can be seen.

From the table with the free space performance results it can be concluded that both phones perform very well if not used next to the human body. Free space is the situation when used in, e.g., a handsfree installation. The performance of the worst performing phone (phone no.23) is actually very good in free space and even better than the best performing phone (phone no.1) in free space.

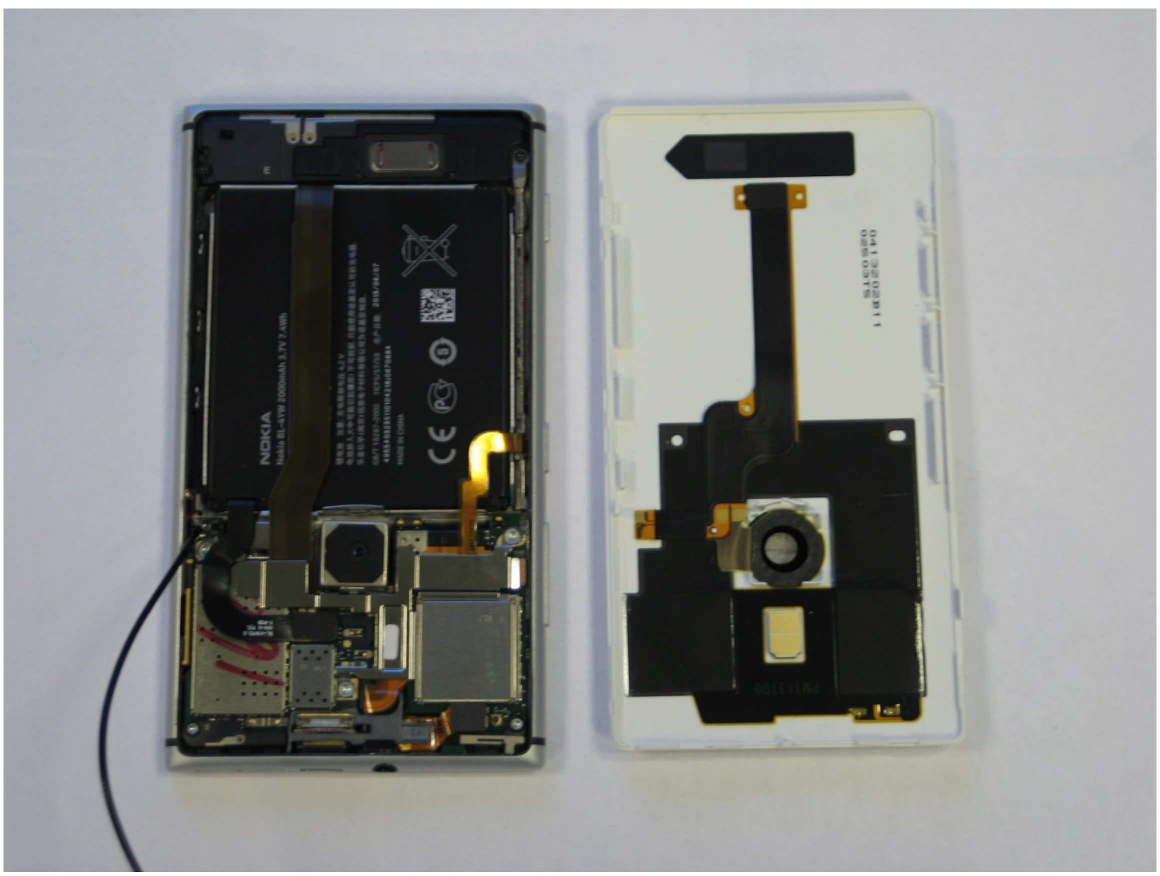
The difference between free space and the hand-head results is for the best phone only some 4 dB. For the worst performing phone, the difference between free space and the hand-head position is some 17 dB at the GSM 900 band.

For the higher frequency bands the differences between free space and the hand-head results are significantly less. For the worst performing phone only some 2-4 dB on the high bands, GSM1800 and UMTS2100. This clearly shows that the body influence is highly dependent on the antenna and that it can be very different for the frequency bands. For coverage the most important band is, as mentioned above, the GSM 900.

Last, measurements without the antenna were made by connecting the phones directly to the "base station" emulator. By comparing results based on the conducted measurements with those based on the free space measurements, the antenna loss is disclosed. Further, the total antenna loss can be seen by comparing the conducted results to the hand-head results.

The best and worse preforming phones were disassembled with guidance found on the web, and the antenna was located with assistance from the FCC web page, using the FCC number printed on all phones sold in USA. A small connector was identified and used for the measurements of conducted power – se pictures below.

Pictures showing the Doro phone during conducted measurements. The phone is connected to the same base station emulator as used for the radiated measurements (a CMU200 from R&S serial number 110106).



Picture showing the Nokia Lumia 925 phone during conducted measurements. The phone is connected to the same base station emulator as used for the radiated measurements (a CMU200 from R&S serial number 110106).

The results of the conducted measurements are shown in the table below. The numbers shown have been corrected for the loss introduced by the short cable used between the phone and the base station.

Phone ranking	Model	GSM900 TIS Performance	UMTS900 TIS Performance	GSM1800 TIS Performance	UMTS2100 TIS Performance
1	Doro Phone Easy 605	-109.7 dBm	N/A	-108.7 dBm	N/A
23	Nokia Lumia 925	-111.7 dBm	-114.2 dBm	-110.6 dBm	-113.0 dBm

Measured TIS performance of the best and the worst performing phone without the antenna included. Conducted measurements are measurements on the phone without the antenna where a cable is used to connect the phone and the basestation.

The conducted measurements show a very good performance and a rather similar performance of the measured phones. This is as expected, since the radio chips used are of a few types and all comply fully with the required performance. This shows very clearly that only the antenna cause the phones to have very different coverage performance.

The antenna loss is some 6 dB for both phones at the GSM 900 frequency and a little less at the high frequency. The antenna loss is the difference between the free space and the conducted measurements. This is a rather high antenna loss; it is possible to make a good practical antenna design with only half the loss seen here.

Conclusions

The results clearly show that it is possible to make good performing smartphones – especially the Sony phones have very good performance in the absolute top.

Similar to the results of last year's campaign, also this year the iPhones and most of the Samsung phones dominate the absolute bottom of the performance list. Further, some Nokia phones are at the bottom of the list as well. It is a bit surprising to see Nokia phones at the bottom of the list, since Nokia has generally had focus on the performance in the past.

In the free space case where the phone is not held by the hand next to the head but, for example, placed in a handsfree installation, the performance changes significantly. The best and worst performing phones in the head-hand situation have for the free space case similar performance. The free space performance for the worst performing phone is significantly better than in talk position next to the head-hand. The difference is an astonishing 17 dB which means 50 times more signal is needed to make a call next to the head that in a handsfree installation.

Measuring the phones without the antenna, the so-called conducted measurements, shows very similar performance. The receiver chips are of very good quality in all phones and only the antenna makes a significant difference in the performance.

If a few bad performing phones are removed, the spread in all bands can be within 6 dB. (3 out of 22 models for GSM900, 4 out of 22 models for GSM1800, 2 out of 22 models for UMTS900 and none for UMTS2100). About half of the phones are within 4 dB of each other – a spread which might be accepted in a selection criterion.

The phones measured this year are spreading a bit more in performance than the ones measured last year, but as more phones are included this may be expected. The performance of the worst performing phone measured this year is even some 1 dB worse than the worst performing phones in 2012. The average performance is improved by some 2 dB at the GSM900 band. This may be caused by the selection of phones last year, where only the 9 most popular phones were selected whereas this year 22 phones are included. Calculating an average reflecting the impact on the network coverage will require knowledge of the proportion of the particular phones models used in the network.

References

[Ped12]	*Limit Values for Downlink Mobile Telephony in Denmark*. Pedersen, Gert Frølund http://vbn.aau.dk/files/75767053/Limit_values_for_Downlink_Mobile_Telephony_in_Denmark.pdf
[CTI13]	Test Plan for Wireless Device Over-the-Air Performance, revision 3.3 October 2013 http://ctia.org/business_resources/certification/index.cfm/AID/11259
[Pel09]	*A Grip Study for Talk and Data Modes in Mobile Phones.* Pelosi, Mauro; Franek, Ondrej; Knudsen, Mikael; Christensen, Morten; Pedersen, Gert Frølund. In: IEEE Transactions on Antennas and Propagation, Vol. 57, No. 4, 2009, p. 856-865.

Appendix I: Results from phones measured in 2012

Phone	GSM900 TIS [dBm]	GSM1800 TIS [dBm]	UMTS B8 TIS [dBm]	UMTS B1 TIS [dBm]
Iphone 4	-95,8	-99,3	-98,4	-99,7
Iphone 4s	-93,3	-94,9	-101,6	-98,6
Iphone 5	-88,8	-87,3	-98,2	-97,5
Samsung SII	-93,2	-99,8	-94,7	-99,9
Samsung SIII	-89,9	-101,0	-95,3	-104,0
HTC Wildfire S	-93,5	-101,0	-94,1	-100,1
Nokia 1800	-96,0	-95,9		
Nokia C2-01	-93,1	-99,9	-95,2	-98,8
Nokia C1-01	-93,9	-95,8		

Measured TIS performance of all phones measured in 2012 [Ped12]. Measurements were made according to the CTIA specifications for talk mode in right hand [CTIA13].

Appendix II: Measurement equipment used

Equipment	Serial number	Uncertainty on TIS
TIS test system Starlab-15 (BC)	0125B-0009	± 1.8 dB
Communication tester R&S Cmu 200	110106	± 1.0 dB
Phantom hand incl. spacer + test cube Speag SHOV 2 RP	25382	
Phantom hand incl. spacer + test cube Speag SHOV 2 RB	25382	
Phantom hand incl. spacer + test cube Speag SHOV 2 RC	25382	
Phantom head V 4.5 BS Speag SAM	3481	

The test equipment consists of a ring with test probes and some instruments to establish a phone call and receive the measured data from the phone under test. The antenna ring with the probes is from Satimo and called the Starlab, the tester for communication with the phone is the CMU200. Further a head-phantom is used; it is the so called SAM head as specified by the CTIA [CTIA13]. And the last part is the hands where 3 different hands are used to fit the different types of phones tested as specified by CTIA [CTIA13].

Appendix III: Calculation of limits

The reported values are field strengths and the required minimum levels by the mobile phones are power values. The relation is:

$$P = \frac{|E|^2 \lambda^2 G_0}{4\pi\eta}$$

Where E is the RMS value of the Electric field strength, λ the free space wavelength and η is the free space impedance, 120 π and G_0 the maximum gain. If it is assumed that the incoming power to the mobile phone is arriving equally likely from all directions and both polarisations as is commonly the assumption taken in mobile communication [Jak74] it is possible to use the terms Total Isotropic Sensitivity (TIS) as is agree upon by 3GPP and CTIA [CTI13]. The TIS include all the losses in the phone (like impedance matching losses, ohmic and dielectric losses) and can include the losses in the human user of the phone. For the present values the TIS is measured according to the CTIA test plan, 3.3 from October 2013 for speech calls with the SAM head and in the right hand. Releases 3.3 is now public available at the CTIA web page: http://ctia.org/business_resources/certification/index.cfm/AID/11259
This gives the following relation between TIS and the Root Mean Square (RMS) value of the magnitude of the electric fieldstrength:

$$|E| = \frac{\sqrt{4\pi\eta \cdot TIS}}{\lambda}$$

The wavelength is related to the frequency of operation and the medium of radio propagation. The medium is free air and the relation is simply

$$\lambda = \frac{c}{f}$$

Where *c* is the speed of light. The frequency is given by table 1. For the calculations the centre frequency is used.

Mobile System	Frequency Band	Downlink frequency [MHz]	Wavelength [meters]
GSM	900	925 – 960 MHz	0.3183
GSM	1800	1805 – 1880 MHz	0.1628
UMTS	900	925 – 960 MHz	0.3183
UMTS	2100	2110 – 2170 MHz	0.1402

Frequency of operation for the downlink in the mobile systems investigated and the free space wavelength at the centre of the downlink.