Limit values for Downlink Mobile Telephony in Denmark

Pedersen, Gert Frølund

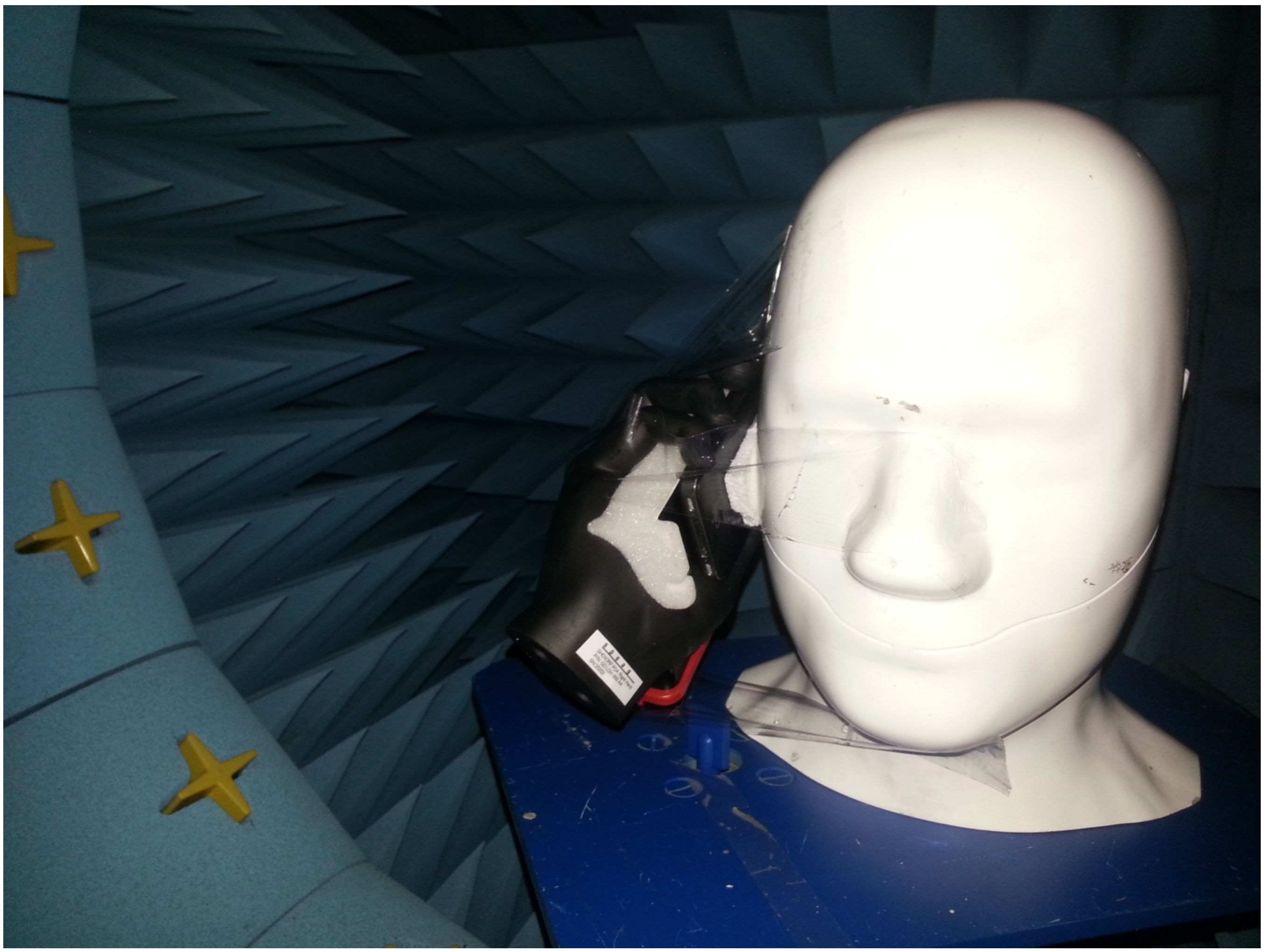
Publication date:
2012

Document Version
Accepteret manuscript, peer-review version

Link to publication from Aalborg University

Citation for published version (APA):
Pedersen, G. F. (2012). *Limit values for Downlink Mobile Telephony in Denmark*.
http://kom.aau.dk/~gfp/SmartphonesAntenneKvalitet2013.pdf

Limit values for Downlink Mobile Telephony in Denmark.



Version 3.0, 19 November 2012

Gert Frølund Pedersen
Professor, PhD
Aalborg University

Purpose

The purpose of this report is to set limits on the minimum average field-strength need in the downlink (from the mobile base-station to the mobile phone) for the mobile systems GSM900 and GSM1800 as well as the CDMA based UMTS900 and UMTS2100 systems in Denmark.

The main assumptions made in this work are:

1. The downlink is the limiting link as only downlink fieldstrengths are available and a good link balance is then assumed.
2. The limit-values are valid for telephony using a mobile phone i.e. phonecalls and are not necessarily valid for receiving an alert (the phone is ringing) or a data call.
3. The limiting factor is the field-strength and not e.g. capacity, interference or blocking.
4. The limits are based on average values and as it is a statistical value no guarantees can be given that there will be coverage in all single cases but only on a statistical basis.
5. The bodyloss is obtained largely by the measured bodyloss for the most popular phones in the network, here taken as the most sold phones in 2011 [Mob12].
6. The limits given can be used both for outdoor, in a car and indoor but values given by the mobile operators are often given for outdoor radio coverage only.

The minimum average signal-strength values are mainly based on the receiver sensitivity as given in the system requirements for the terminals and the excess loss or gain due to implementation losses or gains in mainly the antenna and the receiver of the phone and the excess loss by the user of the phone also called the bodyloss.
The basic sensitivity requirements of e.g. the GSM system for the mobile terminals are -102 dBm but here the measured values will be used for the phones in talk mode. The measured values will be obtained with the phone placed next to the head and a hand holding the phone.

Assumptions in details
The assumption "*The downlink is the limiting link as only downlink fieldstrengths are available and a good link balance is then assumed*" might be correct for the GSM systems. In GSM the transmit power for the mobile is nominal 30 and 33 dBm where the base stations nominal power is often 43 dBm but the receiver sensitivity is typical better at the base station and the base station typical use receiving antenna diversity. This makes it possible to have a close to balance between uplink and downlink in GSM. The sensitivity for the mobile receivers are significantly improved over the years due to more sensitive receiver chipsets whereas the transmit power of the phones has stayed the same which have improved the downlink by some 5 dB over the years for GSM. If the mobile networks has compensated for this link unbalance over the years is not known but assumed.
UMTS in a coverage limited situation is uplink limited and here it will not give a fair picture of the coverage by only considering the downlink [Har00]. As the traffic load in the UMTS network is drastically influencing the downlink it is possible to use the

downlink signal level as the basis for coverage for a loaded network. As an example, excess value for a low loaded macro cell to a link balanced load of some 8 dB is shown in [Har00].
The main purpose of the limit values is to be able to follow the roll out of the mobile coverage in areas with poor coverage, and even if the limiting factors may be on the uplink the additions of more base stations in areas with poor coverage will results in improved coverage. But if only the transmit power will be increased to gain better downlink levels the coverage will not improve.

The assumption "*The limits given can be used both for outdoor, in a car and indoor but values given by the mobile operators are often given for outdoor radio coverage only*" is really not an assumption but rather a note. A fieldstrength value represents the conditions it is measured or calculated at. Typically the fieldstrength values are reported for outdoor coverage and a value needs to be added for the penetration loss to use the outdoor values for estimating the signal strength indoor. A power attenuation of some 8 to 14 dB [Tan08] is reported to have the same coverage inside a car as outside. For indoor or deep indoor a power loss of some 10-15 dB is often seen [Turk87, Turk92, Agu94].

Calculation of limits

The reported values are fieldstrengths 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 freespace wavelength and η is the freespace 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 [CTI11]. 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 testplan, 3.2 (draft 24) from May 2012 for speech calls with the SAM head and in the right hand. Relies 3.2 will be public available by the end of October 2012 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

Table 1: Frequency of operation for the downlink in the mobile systems investigated and the freespace wavelength at the centre of the downlink.

Selected Phones

To find valid TIS values there are mainly two approaches; 1) an average of TIS for the phones in the Danish networks or 2) to ensure most phones can work, a certain outage probability of the phones in the Danish networks can be used e.g. 90 % of the phones.
I suggest to use the average TIS but will then recommend guidelines on TIS to be provided to the public. This way it is possible for everyone to select the phones which can provide the coverage performance needed without requiring unnecessary infrastructure.
To represent the phones in the Danish networks I have used the list of the top ten sales for the 4 operators in 2011 [Mob12]:

Mest solgte hos Telia i 2011

1. Apple iPhone 4 / 4S
2. HTC Wildfire S
3. Nokia X3-02
4. Nokia C2-01
5. Nokia 2730
6. HTC Wildfire
7. Sony Ericsson J10I2 Elm
8. Nokia C3-01
9. Nokia N8-00
10. Samsung Galaxy S II

Mest solgte hos Telenor i 2011

1. Apple iPhone 4 / 4S
2. Nokia 3720
3. HTC Desire S
4. HTC Wildfire S
5. HTC Wildfire
6. Nokia C2-01
7. Nokia C5
8. Samsung Galaxy S II
9. Sony Ericsson Xperia X8
10. HTC Desire

Mest solgte hos TDC

1. Apple iPhone 4
2. Nokia 1800
3. HTC Wildfire S
4. Nokia 3710
5. HTC Wildfire
6. Nokia 3720
7. Nokia C3 – 01
8. Sony Ericsson Xperia X8
9. Nokia X3-02
10. Sony Ericsson Cedar

Mest solgte hos 3 i 2011

1. Apple iPhone 4 / 4S
2. Samsung Galaxy S II
3. Sony Ericsson Xperia Arc
4. Samsung Galaxy S
5. HTC Desire
6. Samsung Galaxy 5
7. Sony Ericsson Xperia X10 Mini
8. Nokia C7
9. Nokia C3
10. LG Optimus 2X

From the list above I have selected the following phones:

Apple iPhone 4, Apple iPhone 4S, Samsung Galaxy S II, HTC Wildfire S, Nokia C2-01, Nokia 1800 and Nokia C3-01. But due to delay in receiving the Nokia C3-01 (ordered 18-10-2012 and in stock from CineMagic but received emails with postponements and finally received an email 23-10-12 that the phone is sent today (day of deadline)) I selected the Nokia C1-01 to have 3 non smart phones included. The C3-01 was selected to include more than one non-smart phone with UMTS capability. Most of the non-smart phones in the list is only equipped with GSM.

And from the most sold phones in 2012 I have also selected: Samsung Galaxy S III and Apple iPhone 5.

This gives the following phones:

Apple iPhone 4
Apple iPhone 4S
Apple iPhone 5
HTC Wildfire S
Samsung Galaxy S II
Samsung Galaxy S III
Nokia C2-01
Nokia 1800
Nokia C1-01

The TIS is measured at the centre channel as a representative for the average TIS value for each of the systems and bands requested. The results are in Table 2 to 4 for average of all phones, average of the smart phones and average for the non-smart phones, respectively.
The TIS is measured according to the CTIA testplan 3.2 [CTI11] where all details of the measurements are specified. I have used a Satimo StarLab for the measurements and compared several of the results with measurements on the same phone in a single antenna measurement setup. All measurements are for the case of a Speag right hand holding the phone towards the right-hand side of the SAM head. The PDA hand is used for the Smart phones and the block hand is used for the non-smart phones. The position of the hand, head and the phone is according to the CTIA testplan [CTI11]. One example of the hand, head and phone during a measurement in the Satimo StarLab is shown in the picture on the front page. The measurement accuracy is specified by Satimo to be better than ±1.8 dB.
An alternative measure could be actual measurements by a human test person either in an anechoic room or in the real environment where a low signal is present as the limit case to where a call can be made. Such a method is used by e.g. Telstra in Australian [Tel12] and they actually mark the good phones by “Blue-Tick” on their web page, but it will be subject to the rather large variation from person to person and will also be rather time consuming.

Mobile System	Average TIS [dBm]	Electrical fieldstrength [µV/m]
GSM900	-92,4 dBm	164 µV/m
GSM1800	-94,5 dBm	252 µV/m
UMTS900	-96,2 dBm	106 µV/m
UMTS2100	-99,4 dBm	165 µV/m

Table 3: Minimum electrical field strength needed for the different mobile systems and bands to ensure a call to the phone. ***Average of all phones****.*

Mobile System	Average TIS [dBm]	Electrical fieldstrength [mV/m]
GSM900	-91,8 dBm	177 µV/m
GSM1800	-93,7 dBm	277 µV/m
UMTS900	-96,4 dBm	104 µV/m
UMTS2100	-99,6 dBm	163 µV/m

Table 4: Minimum electrical field strength needed for the different mobile systems and bands to ensure a call to the phone. ***Average of smart phones****.*

Mobile System	Average TIS [dBm]	Electrical fieldstrength [mV/m]
GSM900	-94,2 dBm	134 µV/m
GSM1800	-96,8 dBm	193 µV/m
UMTS900	-95,2 dBm	119 µV/m
UMTS2100	-98,8 dBm	178 µV/m

Table 5: Minimum electrical field strength needed for the different mobile systems and bands to ensure a call to the phone. ***Average of non-smart phones****.*

Margins to the average field strength

The needed minimum field strength which can be calculated directly from the TIS values apply only under the circumstances where the phone where tested, i.e. a static channel. To account for the mobile channel and the variations over a large area (tens of wavelengths say 10 x 10 meters) and the spread among users etc the following margins are included:

1. Fast-fading – here defined as the margin needed from the specified nominal sensitivity to the sensitivity needed to pass all fading tests. A typical value for GSM is some 6 dB and for UMTS is some 2 dB.
2. Slow-fading – the fading of the local mean power within the pixel area of 100 by 100 meters. This ensures that not only the mean value of the field strength of the whole pixel is above the minimum value but also that nearly all the area inside the pixel are above the minimum value. As an example, if the field strength in 10% of the pixel is 10 times higher than the minimum value the average over the whole pixel will be above the minimum value even no signal exists in the reminding 90% of the pixel. The standard deviation of the slow fading is reported to be some 8 dB at 900 MHz and some 9 dB at 1800 and 2100 MHz [Ibr83, ITU99]. This value is suggested to be included as margin in the link calculations to arrive at trust worthy minimum signal strength values.
3. Spread among phone users – different persons using the exact same phone results in rather different bodyloss. This spread is reported to give a spread of some 10

dB [gfp98, gfp99] mainly due to different ways of holding the phone. To ensure most users to be able to use a given mobile phone a margin of some 5 dB should be included.

4. Mean Effective Gain (MEG) – in a real environment the orientation of the user do impact the ability to receive a signal from the base station. This is not included in the TIS value as TIS assumes that all directions can receive equally well. This is not the case and especially at more rural areas where coverage can be a problem the difference between MEG and TIS is the largest [jni06]. A margin of some dB should be included to ensure that a call can be completed even when the person is turning around during the call.

This gives the following margins to the TIS values for the different systems and frequency bands in dBs.

Mobile System	Frequency Band	Additional margin [dB]
GSM	900	22 dB
GSM	1800	23 dB
UMTS	900	18 dB
UMTS	2100	19 dB

Table 2: Margin to be added to the minimum average electrical field strength limit for each system and frequency bands.

Conclusion

Average values of the needed fieldstrengths are given based on measured realized sensitivity of modern mobile phones in the use scenario of a mobile phone call. The phones are selected among the most sold phones for the networks where the minimum fieldstrength limits are intended to apply. The average value of the sensitivity is calculated for all measured phones. The recommendation is to use this average value or the 90 percentile to ensure customer satisfaction. If a 90 percentile is used the difference is only an additional margin of some 1 to 2 dB on the sensitivity. It should be noted that limits are set only based on the down-link requirements (from the base stations to the mobile phone) which require that the downlink is the limiting link or a good link balance is ensured.

The measured sensitivity among the phones has a spread of some 10 dB which is often the spread seen among mobile phones and actually also among different users of the same phone. The variation from the user is not included in the measurements as the measurements are preformed according to the agreed test-plan including a human phantom head and hand also agreed upon by CTIA and possible a follow-up in 3GPP. I have chosen to use this approach as it is a well described method, it is the common way

to measure mobile phone performance worldwide and it is agreed upon by both manufactures of mobile phones and network operators.
For compromise between the involved workload of the measurement and the uncertainty in the resultant average values I have chosen 9 phones and have only measured the center channel for each phone in each band for each system and only for the right hand. I do not expect the average values to change significantly if more channels and or the left hand was included but if more phone models was included the results might change a few dB. But if significant more phones are included the average should be a weighted average to reflect the number of calls made in the networks by the individual phone models. And therefore I trust a reasonable compromise is achieved and the limits are mainly intended to track improvements in the coverage over time and therefore the significantly larger measurement effort involved by including many more phones may not be justified.

Further to the average of all phones also the average for the smart phones and the traditional mobile phones are reported for information. The difference between smart phones and traditional phones in terms of average sensitivity is for the GSM system significant, some 3 dB worse for smart phones. As most of the traditional phones do not have UMTS a conclusion for UMTS between smart phones and traditional phones cannot be made.

As only average electrical field strength is reported the gap between the static channel used for measurements of mobile phones (measurements of TIR) according to the agreed standard and the large area (100 by 100 meter) averaged electrical field strength a margin is introduced. This margin takes fast fading, slow fading, spread in performance among users and difference in directional performance into account. The margin depends on system and frequency bands but is in the order of some 20 dB.

References

[Mob12]	http://www.mobilsiden.dk/nyheder/danskernes-foretrukne-smartphone-er,lid.18763/
[Har00]	*WCDMA for UMTS* edited by Harri Holma and Antti Toskala. Jon Wiley & sons, ISBN 0471720518
[CTI11]	http://ctia.org/business_resources/certification/index.cfm/AID/11259
[Jak74]	*Microwave mobile Communications* edited by William C. Jakes, IEEE Press, ISBN 0780310691
[Tan08]	Emmeric Tanghe, Wout Joseph, Leen Verloock, and Luc Martens*: Evaluation of Vehicle Penetration Loss at Wireless Communication Frequencies* IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 57, NO. 4, JULY 2008
[Agu94]	Aguirre, S. Loew, L.H. Yeh Lo, “Radio propagation into buildings at 912, 1920, and 5990 MHz using microcells”, Universal Personal Communications conference, San Diego, 1994, pp. 129-134
[Turk87]	A.M.D. Turkmany et al, ”Radio propagation into buildings at 441, 900 and 1400 MHz”, Proc. Int. Conf. on Land Mobile Radio, December 1987, pp. 129-138
[Turk92]	A.M.D. Turkmany et al, ”Propagation into and within buildings at 900, 1800 and 2300 MHz”, Proc. VTC Conf., 1992, pp. 663-
[Tel12]	http://exchange.telstra.com.au/2010/07/29/telstra-shows-mobile-phone-coverage-test-process/
[ITU99]	IITU-R P.1406, Radiocommunication Assembly, "PROPAGATION EFFECTS RELATING TO TERRESTRIAL LAND MOBILE SERVICE IN THE VHF AND UHFBANDS", 1999
[Ibr83]	brahim, M.F. et al, ” Signal strength prediction in built-up areas; part 1 and 2”, IEE Proceedings, Vol. 130, Pt. F., No. 5 , August 1983, pp. 377-391
[jni06]	Jesper Ødum Nielsen and Gert Frølund Pedersen, “Mobile Handset Performance Evaluation Using Radiation Pattern Measurements” IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 54, NO. 7, JULY 2006
[gfp99]	Pedersen, Gert Frølund; Olesen, Kim; Larsen, Steen Leth. “Bodyloss for handheld phones” IEEE Vehicular Technology Conference Proceedings. Vol. 1-3 IEEE Press, 1999. p. 1580-1584.
[gfp98]	Pedersen, Gert Frølund; Nielsen, Jesper Ødum; Olesen, Kim; Kovacs, Istvan Zsolt. “Measured Variation in performance of handheld antennas for a large number of test persons.” IEEE 48th Vehicular Technology Conference, 1998 p 505 - 509.

Appendix: Detailed results on each of the phones

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		