# COMPARISON OF THE AVERAGE OUTPUT POWER OF GSM AND UMTS MOBILE PHONES AND THE IMPACT IN EXPOSURE TO ELECTROMAGNETIC WAVES

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*In this paper are analyzed the differences in terms of output power and power control mechanisms between GSM and UMTS mobile phones and is investigated the magnitude of the reduction of output power brought by UMTS as compared with GSM. The migration to UMTS is proposed as a simple way to reduce exposure to electromagnetic waves of the mobile telephony user.*

**Keywords:** Output power, GSM, UMTS, electromagnetic field

## 1. Introduction

When the UMTS system, also known as the third generation mobile system or simply 3G, was launched in 2001, it was expected to quickly replace the older, yet very successful, GSM system. However, this did not happen and most of the mobile phone users today make their voice calls through the GSM networks.

In the same time, the concern among mobile phone users regarding the potential health hazards caused by low-level electromagnetic field (EMF) emissions is growing, although the scientific evidence to demonstrate this is currently lacking [1]. Under the current European EMF exposure regulations, the exposure created by a mobile phone during a call is characterized with the help of the localized specific absorption ratio (SAR), which is limited to 2 W/kg, averaged over 10 g of tissue [2]. As the processing power of computers has grown, the finite-difference time-domain method has become easier to employ when calculating SAR and offers more accurate results than more simplistic analytical methods. A detailed description of this method can be found in [3]. The results show that in some exposure scenarios, it is possible for the localized SAR to exceed the current limits in specific internal organs.

Under these circumstances, it is desirable to reduce the exposure from the mobile phone. One of the relatively effective methods is the use of a wired hands-free kit that creates a separation between the head and the mobile phone and thus

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reduces the energy absorbed by the former even up to ten times [4] [5]. Furthermore, a wireless hands-free kit that uses *Bluetooth* can decrease the energy absorbed by the head up to 100 times [6]. Of course, depending on where the phone is positioned during a call made using a hands-free kit, the exposure can increase in other parts of the body, for example the waist, the hand etc. There is also the possible discomfort of having to use the mobile phone in an way that is different to what the user is accustomed to.

One has to consider that the value of SAR is calculated using as input the maximum transmit power of the terminal and not the usual transmit power, which in most cases is lower. The actual level depends on the environment in which the user is located and on the manner the terminal is used, as it was observed following a study for which GSM mobile phones were employed [7]. Besides these factors, it will be shown that the technology factor is also very important. UMTS was designed to be more efficient than GSM in terms of transmitted power and has several advantages over the previous generation that reduce the exposure of the user. The purpose of this paper is to illustrate these advantages and to assess their impact in real life usage through the investigation of measurements.

## 2. Analysis of the transmit power of GSM and UMTS terminals

One of the basic differences between GSM and UMTS are that the former is a FDMA system, while the latter uses WCDMA. This means that in the same time interval, two or more mobiles will transmit on different frequency channels in GSM, but in UMTS they will use the same channel. Thus UMTS is much more sensitive to the level of power emitted in uplink and a good power control algorithm was set in place to avoid as much as possible situations in which one of the mobiles blocks the receiver of the base station.

In GSM, the mobile begins the call by transmitting at full power and after several seconds the power control algorithm reduces the power to the minimum required to maintain the radio link. The procedure is renewed after every hand over to another cell. This behavior of the system led to the general advice for limited usage of the mobile phone while travelling fast (and changing many cells) and also against initiating the call with the phone next to the head.

The UMTS terminal on the other hand starts the call by transmitting at the lowest possible power and gradually increases it until the base station receives its access request message and sends back an acknowledgement. This procedure avoids the unnecessary increase of the uplink noise in the cell and guarantees that the initiating of a call is done directly at the minimum transmit power required by the radio link. Similarly, the handovers between different cells are made without increasing the power.

In Fig. 1 we compare the evolution of the transmitted power of a GSM terminal placed in a certain location and that of an UMTS terminal in the same location. The GSM phone starts transmitting at 33 dBm (2 W) [8] and then reduces the power down to the minimum value of 4 dBm (2.5 mW). As the mobile moves into an area with poorer radio propagation conditions, it increases the power again. The UMTS terminal starts close to the minimum transmit power of -50 dBm (10 nW) [9] and, as the network coverage worsens, the power rises. However, the maximum power of 21 dBm (125 mW) is never reached. Another observation is related to the frequency of the modifications of the transmit power due to differences in the power control algorithm. In UMTS the modifications are very rapid, in order to compensate the fast fading effect, while in GSM it takes longer to change the power and it is only done in relatively limited steps.

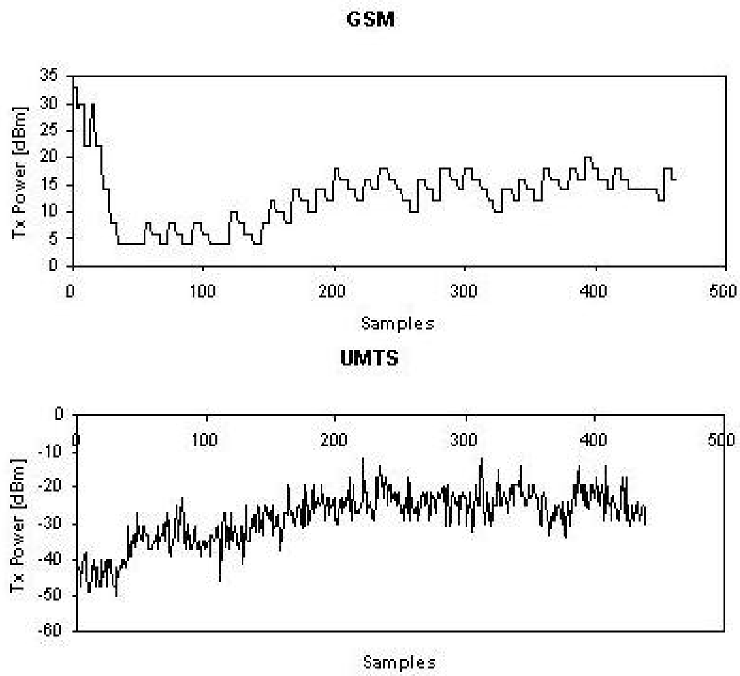


Fig. 1. Comparison between the evolution of the transmit power of a GSM and of an UMTS terminal

However, the power control mechanism isn't relevant in poor coverage conditions, when the mobile is forced to transmit close to or even at the maximum power in order to maintain the radio link. Under these circumstances a higher sensitivity is required from the base station. In (1) it was defined the minimum detectable signal by a GSM base station, based on the standard equation of the minimum detectable signal by a radio receiver [10] and on the main factors that influence the power budget of the GSM radio link [11].

$$S_{GSM} = 10\lg KT + 10\lg B + NF + \frac{C}{I} - G_A + L_F - G_{RxD} - G_{FH} + M_F \qquad (1)$$

The terms are explained below:

- $B$ is the 200 kHz bandwidth of the GSM channel.
- $NF$ is the noise figure of the base station that is usually around 2 dB.
- $C/I$ is the carrier to interference ratio for which value required by the GSM standard for voice is 9 dB.
- $G_A$ is the antenna gain, which for a typical dual-polarized antenna with a half-power beam width of 65 degrees in the horizontal plane and 7 degrees in the vertical plane is around 17 dB.
- $L_F$ represents the losses on the feeders connecting the base station with the antenna. The usual value is 2 or 3 dB, but it depends on the frequency and length and thickness of the feeders.
- $G_{RxD}$ is the gain provided by the polarization diversity of the antenna and the value is around 3 dB in an urban environment.
- $G_{FH}$ represents the gain produced by the use of frequency hopping for the GSM traffic channels, which is a good method for countering fast fading. The typical value is 2 dB.
- $M_F$ is the shadow-fading margin. We considered an outdoor urban environment, which corresponds to a margin of 4.2 dB.

The minimum detectable signal in the case of the GSM base station calculated with the above-mentioned parameters is -124.8 dBm. This value will be compared to that of the minimum detectable signal by an UMTS base station, which is detailed in (2). This is also based on the standard equation of the minimum detectable signal by a radio receiver [10] and on the main factors that influence the power budget of the UMTS radio link [12].

$$S_{UMTS} = 10\lg KT + 10\lg B + NF + \frac{E_B}{N_O} - G_A + L_F - G_{RxD} - G_{\Pr} - G_{SHO} + \\ + M_I + M_S + M_F \qquad (2)$$

Most of the parameters are the same as in the case of GSM, with the exception of B, which is of 3.84MHz instead of 200 kHz. There are however several new parameters:

- $E_B/N_o$ is the energy per bit per noise ratio and is 5.6 dB for CS voice in UMTS.
- $G_{Pr}$ represents the processing gain and it is calculated as the ratio between the maximum chip rate (3.84Mcps) and the bit rate of the voice service (12.2 kbps). It is 25 dB.
- $G_{SHO}$, the soft handover gain, is usually considered to be around 3 dB.
- $M_I$ is the interference margin, also known as the uplink noise rise, and depends on the uplink load in the cell. The system is typically designed taking into account a 50% load in order to leave room for the cell breathing effect that occurs when the load rises. For the chosen load of 50%, the margin is 3 dB.
- $M_S$ represents the saturation margin, which is meant to preserve a headroom for the transmit power when the mobile is in poor radio coverage conditions. Because the power control algorithm is changing the transmit power with a frequency of 1500 Hz in order to compensate the fast fading, it requires a safety margin to avoid entering saturation when there isn't enough power available for allocation. The value of this margin is 3 dB.

The result of the minimum detectable signal calculation in the case of the UMTS base station is -135.4 dBm, which is 10.6 dB lower than the GSM base station. This means that given the same propagation path loss, the UMTS terminal will emit at a power level at least 10 dB lower than the GSM one.

Another limitation of GSM that should be taken into consideration is that the output power has a dynamic range of 30 dB, varying from 33 to 3 dBm. Thus, in good radio propagation conditions, even though the necessary transmit power could be lower than 3 dBm, the GSM terminal is unable to transmit below this value.

The UMTS phone however has a much broader dynamic range at around 70 dB, going from 21 or 24 dBm to -50 dBm. This allows it to transmit at a lower power when the radio conditions permit it. Mathematically, the basic dependence of the transmit power on the received signal level and, consequently, on the propagation path loss is given in (3).

$$MS_{TxP} = BS_{TxP} - L_F - S + RxLev \tag{3}$$

The *RxLev* is the value reported by the mobile after measuring the BCCH (Broadcast Control Channel) in GSM or the C-PICH (Common Pilot Channel) in UMTS. The usual output power ($BS_{TxP}$) of the BCCH channel is 43 dBm and that of the C-PICH channel is 33 dBm. $S$ was calculated with (1) and (2) and the feeder losses ($L_F$) are again considered 3 dB. By using these inputs and (3) we calculated the variation of the transmit power of the two terminal types, which are both illustrated in Fig. 2.

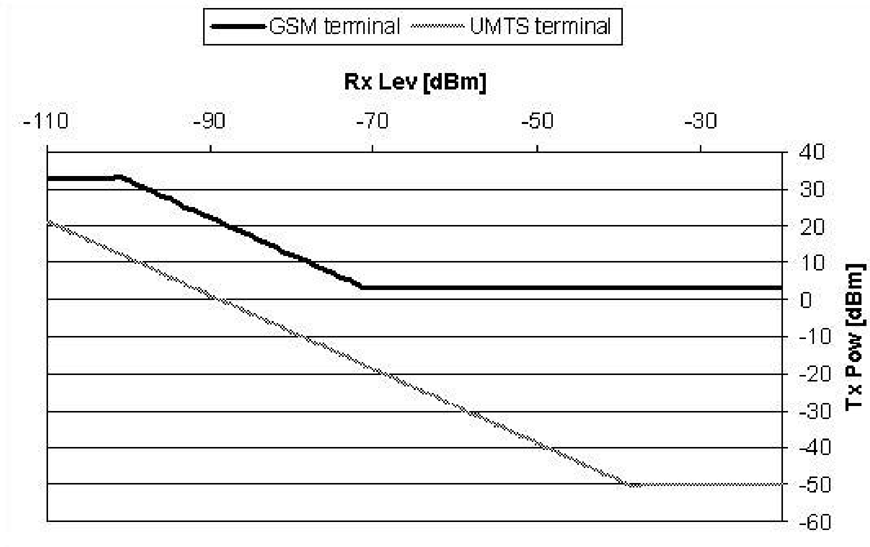


Fig. 2. Variation of the transmit power of a GSM and of an UMTS terminal

However, GSM and UMTS are usually deployed in different frequency bands, the most common being 900 MHz for GSM and 2100 MHz for UMTS. Thus the propagation will also be different and, in the same location, the propagation losses for UMTS will be higher than for GSM and hence the received signal level will be lower.

The minimal extra propagation loss for the UMTS signal, according to the free space propagation model at the same distance between the base station and the mobile, is given by (4).

$$\delta_{PL} = 10 \cdot \lg \frac{f_{UMTS}}{f_{GSM}} \tag{4}$$

For the above mentioned frequency bands, the difference is 3.6 dB, which means that the power transmitted by the UMTS terminal will be at least 7 dB below the level that would be necessary for a GSM terminal. Obviously, the factors influencing the propagation are more complicated and the exact difference will vary from case to case.

Taking into consideration the issues presented in this section, the UMTS mobile phone has on average more chances of emitting less electromagnetic radiation during a call than the GSM mobile phone. In order to determine with more certainty the difference several measurements were conducted. They will be analyzed in the following section.

### 3. Measurement results

The equipment consisted in Sony Ericsson W900i phones with the TEMS Pocket 5.0 software installed on them. For each measurement, two logs were recorded: one with a GSM call and the other with an UMTS call. The data was then extracted from the logs using the Actix Analyzer software. The main parameter in which we are interested in is the terminal's output power, but for GSM we also extracted the received signal level without power control and for UMTS we extracted the received signal code power levels for all the cells in the active set. The samples were taken every 500 ms.

In Fig. 3 and 4 we synthesized the average values recorded during the measurements. They are divided into two categories: fixed positions (10 measurements) and during movement (6 measurements). The former were chosen both indoor, in poorer radio propagation conditions, and outdoor, in the streets of Bucharest, where the coverage is good.

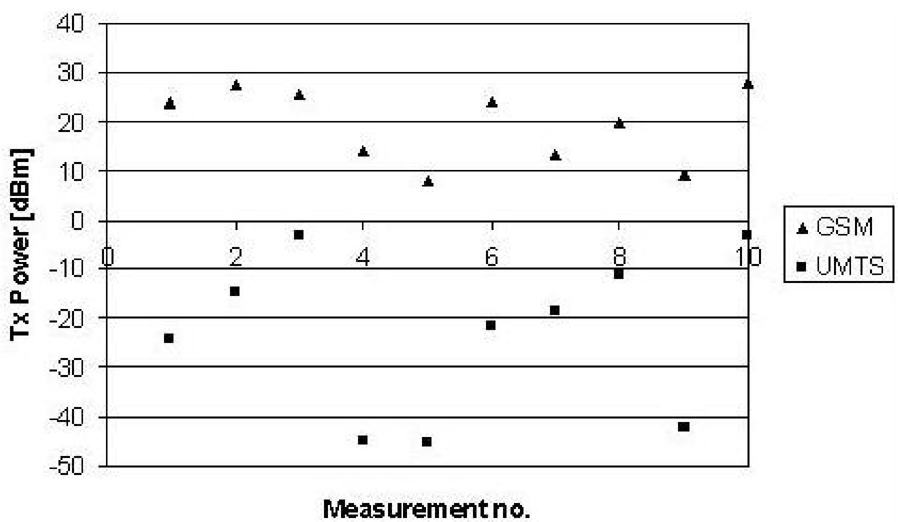


Fig. 3. Distribution of the GSM and UMTS terminals' average transmit power in fixed positions

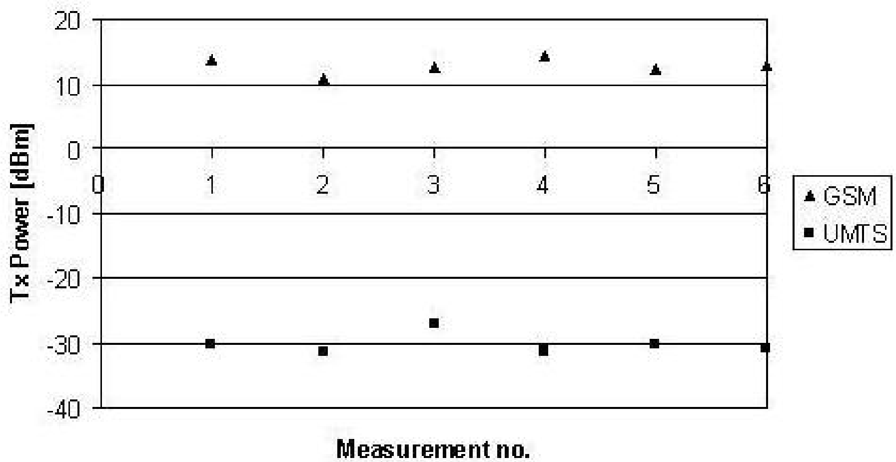


Fig. 4. Distribution of the GSM and UMTS terminals' average transmit power during movement

As expected, the average transmit power of the GSM terminal is much higher and varies between 8 and 27 dBm, while that of the UMTS terminal varies between -45 dBm and -3 dBm. The gap between the two is not constant. It depends on the radio propagation conditions. Only in the case of the measurements made in motion, the difference between the average transmit power of the two technologies is roughly similar. This can be explained through the fact that these measurements were all carried out in the center of Bucharest, where the network is very dense and the radio propagation losses were not high.

It is interesting to illustrate the gap between the average transmit power of the two systems. First it is necessary to determine the corresponding radio propagation path losses for the GSM and UMTS signals, so that the differences are mapped according to them. Equation (5) has been employed for this exact purpose.

$$PL_{\max} = \min(P_{BCCH} - RxLev, P_{C-PICH} - RSCP) \quad (5)$$

*RxLev* represents the average power measured on the BCCH channel in GSM.
*RSCP* represents the average power measured on the C-PICH channel of the UMTS system.
$P_{BCCH}$ and $P_{C\text{-}PICH}$ are the output power levels of these channels at the base station: 43 and 33 dBm.

By using (5) and the data extracted from the measurement logs, the path loss was determined for each location and the results were used to create Fig. 5.

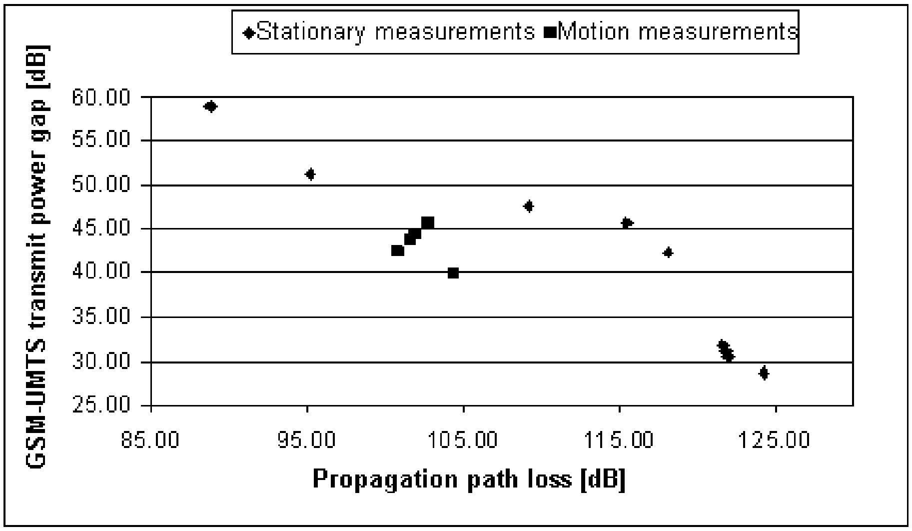


Fig. 5. Difference between the average transmit power of the GSM and UMTS terminals

In the case of stationary measurements, it is easy to observe a major gap between the average transmitted power of the UMTS and GSM terminals when the call benefits from good network coverage. This gap can reach even 59 dB, more than the difference between the minimum output powers of the two terminals, which is only 53 dB. This is due to the power control mechanism of the GSM system, which is not able to decrease the terminal's output power fast enough and thus the average value is significantly higher than it could be in an ideal case. Also, the minimum power output could be set in the network to be higher than the standard value of 3 dBm. Such a setting would increase the average output power of the GSM terminal. As the propagation path loss increases, the gap between the two technologies decreases to 28.6 dB, which is still a considerable value.

Compared with the results of the stationary measurements, those of the measurements done in motion reflect a relatively smaller difference for similar propagation conditions. However, the absolute value is still high, around 40 dB. This is owed to a higher output power of the UMTS terminal while in motion. The network coverage was good, because the measurements were made in the street, in open space, in order to be able to perform several handovers between different cells.

To conclude, the average output power of the UMTS terminal during a call is at least 1000 times lower than the average output power of a GSM terminal during a similar call. Because of this, the electromagnetic field produced during the UMTS call will be inferior to the electromagnetic field owed to the GSM call.

This dependency can be expressed theoretically starting from the strength of the electric field, which can be determined as a function of the transmitted power $P_T$, using the expression (6).

$$E = \sqrt{\frac{Z_o \cdot P_T}{4\pi \cdot d^2}} \text{, with} \tag{6}$$

$Z_o$ - free space impendence
$d$ - distance between the transmitter and the receiver

The specific absorption ratio (SAR) can be calculated with (7), if the field strength $E$, the density of the tissue $\rho$ and its conductivity $\sigma$ are known [1].

$$SAR = \sigma \cdot \frac{E^2}{\rho} = \frac{\sigma \cdot Z_o \cdot P_T}{4\pi \cdot d^2 \cdot \rho} \tag{7}$$

Both the electric field strength and the specific absorption rate are used to quantify the exposure to electromagnetic waves and, both of them, decrease if the average output power decreases.

However, in order to have a more accurate view, one needs to consider also the energy emitted by the terminals, which takes into account the duration of the time interval in which these are actually transmitting. In GSM, one call has one time slot reserved for it from a total of eight in a standard frame, so we can consider that the mobile phone is emitting one eighth of the time. There is also the possibility to activate the mechanism of discontinuous transmission that will stop the emission when the user is not talking. This effect is more difficult to model with accuracy, but one can assume that half of the time one the callers will speak and the other listens and vice-versa. Thus, in average, one can state that the GSM terminal is transmitting 1/16 of the time. Unlike the previous generation, the UMTS terminal has a continuous emission, at least for the Dedicated Physical Control Channel (DPCCH). The voice is transported on the Dedicated Physical Data Channel (DPDCH) when the user is speaking. The power transmitted on the DPCCH is usually equal to that on the DPDCH and one can consider that half of the time the power emitted by the terminal will be half of the nominal power ($P_{DPCCH}$) and the other half, when the user is speaking, the full measured power ($P_{DPCCH}$ + $P_{DPDCH}$). Only starting with the 3GPP Release 7 standard the UMTS terminal is able to stop the transmission of the DPCCH when it is not necessary. This allows it to save battery time and decrease the noise level in the cell. However, the measurements presented in this paper were made on 3GPP Release 6 UMTS network that did not benefit from this feature. Thus, in average, only 3/4 of the measured power is actually transmitted.

Under these circumstances, the ratio between the energy transmitted in average by the GSM terminal and that transmitted by the UMTS terminal during a voice call can be described by equation (8).

$$\frac{W_{GSM}}{W_{UMTS}} = \frac{P_{GSM} \cdot \frac{1}{16} t}{\frac{1}{2} P_{UMTS} \cdot t + P_{UMTS} \cdot t} = \frac{1}{12} \cdot \frac{P_{GSM}}{P_{UMTS}} \tag{8}$$

So, in order to translate the gap between the average output power of the GSM and UMTS terminals into the gap between the average energy emitted by the terminals, the values measured in the field will need to be reduced by 10.8 dB: from 59 dB to 48.2 dB in good network coverage and from 28.6 dB to 17.8 dB in poor network coverage.

## 6. Conclusions

It is clear, both from the theoretical analysis and the field measurements, that the output power of the UMTS terminal is much smaller than that of the GSM terminal in similar situations. This, in turn, leads to a reduced exposure to electromagnetic waves of the mobile phone user, which can be of several orders of magnitude in the right circumstances and does not require a change in the day-to-day use, as other exposure reduction solutions do.

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