

SOME THOUGHTS ON HUMAN BODY EFFECTS ON HANDSET ANTENNA AT THE FM BAND

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Abstract—Human body interaction is an important issue to take into account when designing handset antennas due to the effect that it has on the electromagnetic performance of the antenna. By means of electromagnetic simulation, three different antennas (a 1-meter length monopole and two small handset antennas) in three different situations (free-space, hand holding, and in pocket position) have been analysed at the FM band (88 MHz–108 MHz). Results prove that it is possible to predict the antenna behaviour in terms of quality factor (Q) by assessing the variations of the near electric field and the radiation efficiency in said environments. The estimated Q can be verified by calculating the Q using the input impedance. Results show that human body may improve the efficiency when the antennas become an extension of the human body.

1. INTRODUCTION

Since the early 1990s, mobile phones and, in general, all wireless communications have experienced a booming growth, and the design of antennas for mobile devices has become an issue of crucial importance. It is important to take into account the human body effects and ways to mitigate it [1–10]. This paper analyses three antennas for mobile devices at the FM band in a numerical way when the human body is present, trying to predict Q variations, so as to answer the next question: What is the difference in terms of Q between an antenna radiating in free-space conditions and radiating in contact with the human body?

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The aim of this research is to find how the human body modifies the efficiency of the three antennas and also discuss qualitatively the change of the Q (which determines the bandwidth) from free-space to human body conditions. The paper is divided into three sections. First of all, the fundamental theory is presented. Second, numerical results obtained by means of simulation are shown, and finally, the conclusions are drawn.

2. FUNDAMENTAL THEORY

A basic summary of the Q is presented here to make a clear distinction between the Q of the antenna and the Q of the antenna taking into account the radiation mechanism. The general definition is given by (1):

$$Q = Q_{\text{antenna}} = 2\pi \frac{W_s}{W_d^{\text{cicle}}} = \omega \frac{W_s}{P_d} = \omega \frac{W_s}{P_r + P_\Omega} \quad (1)$$

where W_s is the stored energy, W_d^{cicle} is the dissipated energy per cycle, P_d is the dissipated power, P_Ω is the ohmic loss and P_r is the radiated power.

Regarding the antenna, the Q_{antenna} factor (or Q in general) must be as low as possible if one is interested in obtaining broad bandwidth. In other words, stored energy by the antenna must be minimized and the dissipated power maximized. However, it is important to consider that dissipated power includes both ohmic loss and radiated power. So the Q factor can be low because of the lost power. Therefore, the lossy Q factor (or Q_Ω) must be discriminated, which is achieved introducing the radiation efficiency (η_r) ratio. Thus, Equation (2) is used instead of Equation (1), which results in Q_r factor.

$$Q_{\text{antenna}} = \omega \frac{W_s}{P_r + P_\Omega} \cdot \frac{P_r}{P_r} = \omega \frac{W_s}{P_r} \cdot \frac{P_r}{P_r + P_\Omega} = Q_r \cdot \eta_r \quad (2)$$

$$Q_r = \frac{Q_{\text{antenna}}}{\eta_r}$$

The objective of this research is to determine in a qualitative manner, by means of simulation, an increase or decrease of the stored energy and radiated power in presence of the human body in different scenarios in order to predict how the Q_r can change, and therefore, know the variation of antenna performance. This analysis is carried out for handset antennas operating at the FM band.

The stored energy by the antenna can be found by calculating the near field around the antenna [11, 13]. The electric field of a current

distribution in an antenna is given by (3), where \vec{A} is the potential vector and $k = 2\pi/\lambda$. The potential vector is given by (4).

$$\vec{E} = \frac{1}{j\omega\mu\epsilon} [k^2\vec{A} + \nabla(\nabla \cdot \vec{A})] \quad (3)$$

$$\vec{A} = \mu \iint_{S'} \vec{J}(r') \frac{e^{-jkR}}{4\pi R} dS' \quad (4)$$

where $\vec{J}(r')$ is the current over the antenna surface S' .

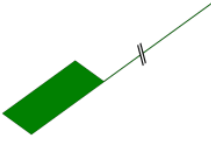
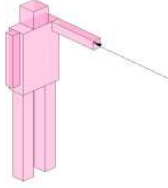
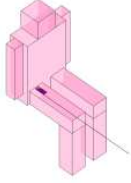

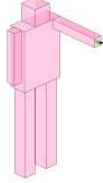
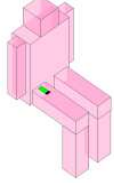

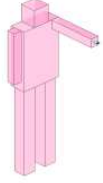
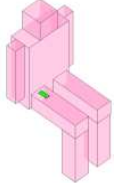
Basically, the first term of the equation $k^2\vec{A}$ (see Equation (3)) dominates in the far field[†] whereas the second one $\nabla(\nabla \cdot \vec{A})$ (gradient of the divergence) dominates in the near field, being this the term of interest because the human body is very close to the radiating structure. Regarding the potential vector \vec{A} , it follows the spatial variations of the current distribution $\vec{J}(r')$, which is why one can calculate the near field using the current distribution. This near field can be found via numerical computation using MoM. For the present case, the IE3D software has been used.

Regarding the calculation of the radiated power (P_r), which is directly proportional to the radiation efficiency, can be calculated through simulation using MoM.

3. NUMERICAL RESULTS

Three electrically different antennas for mobile devices which operate at the FM band have been analysed (Fig. 1): a 1-meter monopole, a packed monopole following a spiral geometry and a U-shaped monopole antenna. Said 1-meter monopole is an example of a FM handset antenna used in some commercial phones where a long cable (approximately 1-meter long) is currently used for FM reception. The two other antennas are examples of very small antennas in terms of the wavelength (Fig. 1). The packed monopole is a resonant antenna at 100 MHz and the U-shaped is a non-resonant antenna [14–16]. Moreover, phantom human bodies with dielectric properties corresponding to human tissues such as blood, bones, muscles or fat, at the frequencies of interest, have been used for these experiments [8]. Specifically, each antenna has been analysed in three scenarios (Fig. 1): free space, located at the end of the arm on a standing man and located above the leg of a sitting man. In this point, it is important to say that these scenarios are an approximation of a real one. Therefore, in the

[†] Strictly speaking the term $k^2\vec{A}$ dominates in the far field taking out the radial component A_r [11, 12].

Free space 1-meter monopole	Standing man with 1-meter monopole	Sitting man with 1-meter monopole
		
Free space packed monopole	Standing man with packed monopole	Sitting man with packed monopole
		
Free space U-shaped monopole	Standing man with U-shaped monopole	Sitting man with U-shaped monopole
		

1-meter monopole: Ground plane: 100 x 40 mm ² Wire length: 1 meter (0.33 λ)	Packed monopole: Ground plane: 80 x 40 mm ² Wire length: 2262 mm (to have a resonance at 100 MHz) Antenna size: 40 x 20 x 5 mm ³ (0.013 x 0.007 x 0.0017 λ^3)	U-shaped monopole: Ground plane: 113 x 60 mm ² Wire length: 90 mm Antenna size: 40 x 15 mm ² (0.013 x 0.005 λ^2)	Human body: $\epsilon_r = 53.0$ $\sigma = 0.58$ S/m
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Figure 1. Analysed antennas and scenarios.

case of *standing man*, it represents the situation where a hand holds a mobile phone, whereas in the case of *sitting man*, the mobile phone is placed on the thigh, which means that it is in total contact with the human body.

The procedure finds the near electric field around the antennas as well as the radiation efficiency so as to make a prediction, taking into account the effects that these variations have on the Q_r factor. An increase in the near reactive field implies an increase in the Q_r factor, as more near field means more stored energy, and vice versa. On

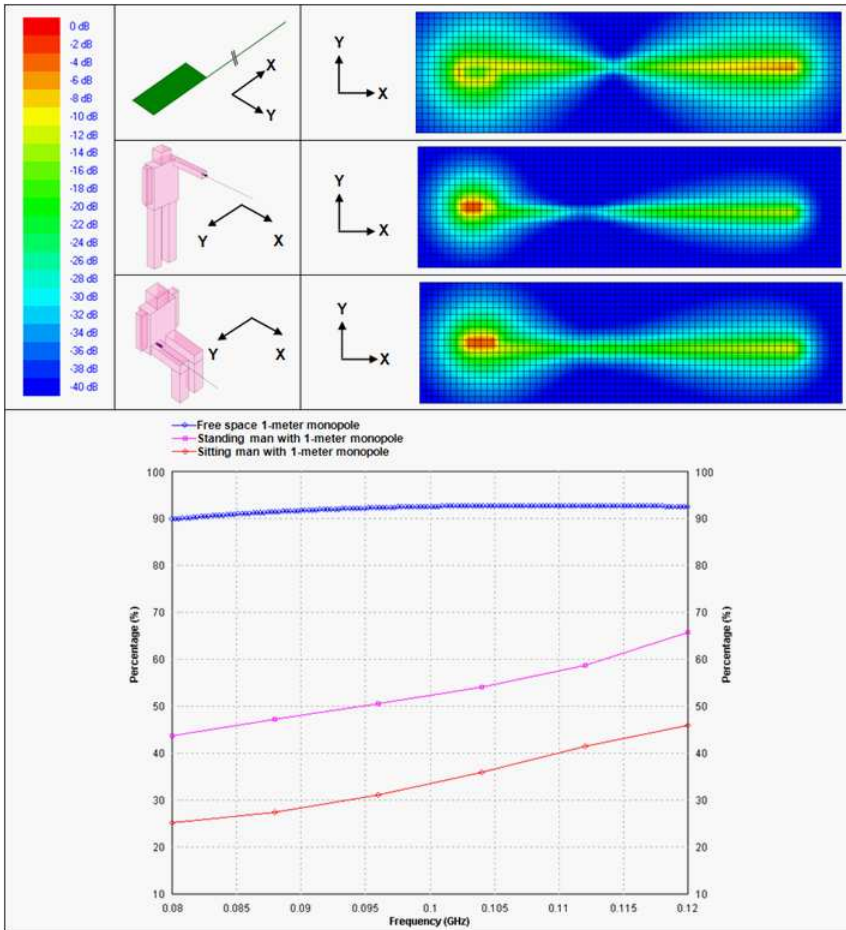


Figure 2. Electric near field^{††} (\vec{E}) generated by the 1-meter monopole antenna at 105 MHz (XY plane) and normalized to 250 V/m and radiation efficiency for each scenario.

the other hand, if the radiation efficiency increases, this means more radiated power into space so the Q_r factor decreases, and vice versa. It should be noted that only near electric field has been taken into account since for this particular antennas, the magnetic near field presents less magnitude than the electric near field. It should be pointed out that Q_r

^{††} The computed electric field represents the reactive electric field since the radiated field component in the near field has much less magnitude than the reactive electric field in the near field [11, 12].

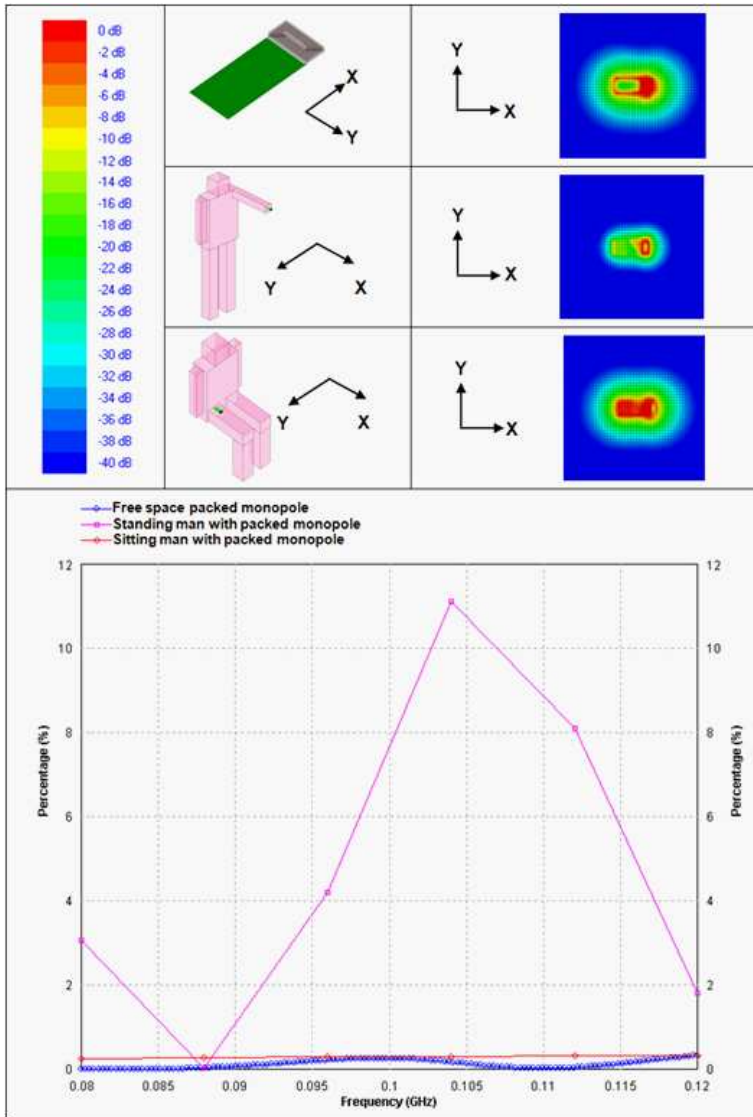


Figure 3. Electric near field (\vec{E}) generated by the packed monopole antenna at 105 MHz (XY plane) and normalized to 250 V/m and radiation efficiency for each scenario.

is used instead of Q_{antenna} (Eq. (2)) because Q_{antenna} is misleading. For example, if the Q_{antenna} decreases due to the presence of the human-body, it may be concluded that the overall system has been improved.

However, Q_{antenna} may decrease because of the losses introduced by the human body. For this reason, Q_r is used instead in the following analysis.

The near field analysis for the three antennas and the three scenarios is shown along with the radiation efficiency for each case (Figs. 2 to 4). It is important to emphasize that this is a qualitative analysis, and therefore the near field is only shown in the XY plane, corresponding to the plane 0.5 mm above the ground plane of the handset antenna. The near field corresponds to the electric field originated for each antenna in each scenario at the frequency of 105 MHz and normalized to 250 V/m in all cases. Thus, determining an increase or decrease in near field values as well as in radiation efficiency, the relative variation of the Q_r factor compared to free space conditions can be qualitatively predicted (Table 1).

As it can be observed, there is a case in which to make a qualitative prediction is rather difficult. This occurs when changes in the radiation efficiency and the near field increase or decrease at a time (see Table 1, 1-meter length monopole). As a qualitative method, the behaviour of the Q_r factor cannot be qualitatively predicted. In this case, a possible solution is to calculate the Q_r in a quantitative way using input impedance formulation [17]. However, for the small antenna cases, Q_r can be predicted.

To check the usefulness of the qualitative predictions, the real value of the Q_r factor (Fig. 5) is needed, which has been calculated using the input impedance [17]. In this method the Q_{antenna} factor, which depends on the frequency, can be approximated by (5). The input impedance is calculated with MoM numerical simulation by using the IE3D simulator, so that the Q_{antenna} factor is found. Therefore,

Table 1. Prediction of the Q_r factor variation for each antenna when it is affected by the human body. Arrows indicate the qualitative variation with respect to free space. Symbol “?” indicates that a qualitative prediction can not be made. Symbol “ \approx ” indicates that the near field variation respecting Free-space condition is negligible.

Antenna	Scenario	η_r	Near field	Q_r
1-meter monopole antenna	<i>Standing man</i>	↓	↓	?
	<i>Sitting man</i>	↓	↓	?
Packed monopole antenna	<i>Standing man</i>	↑	↓	↓
	<i>Sitting man</i>	↑	\approx	↓
U-shaped monopole antenna	<i>Standing man</i>	↑	\approx	↓
	<i>Sitting man</i>	↓	\approx	↑

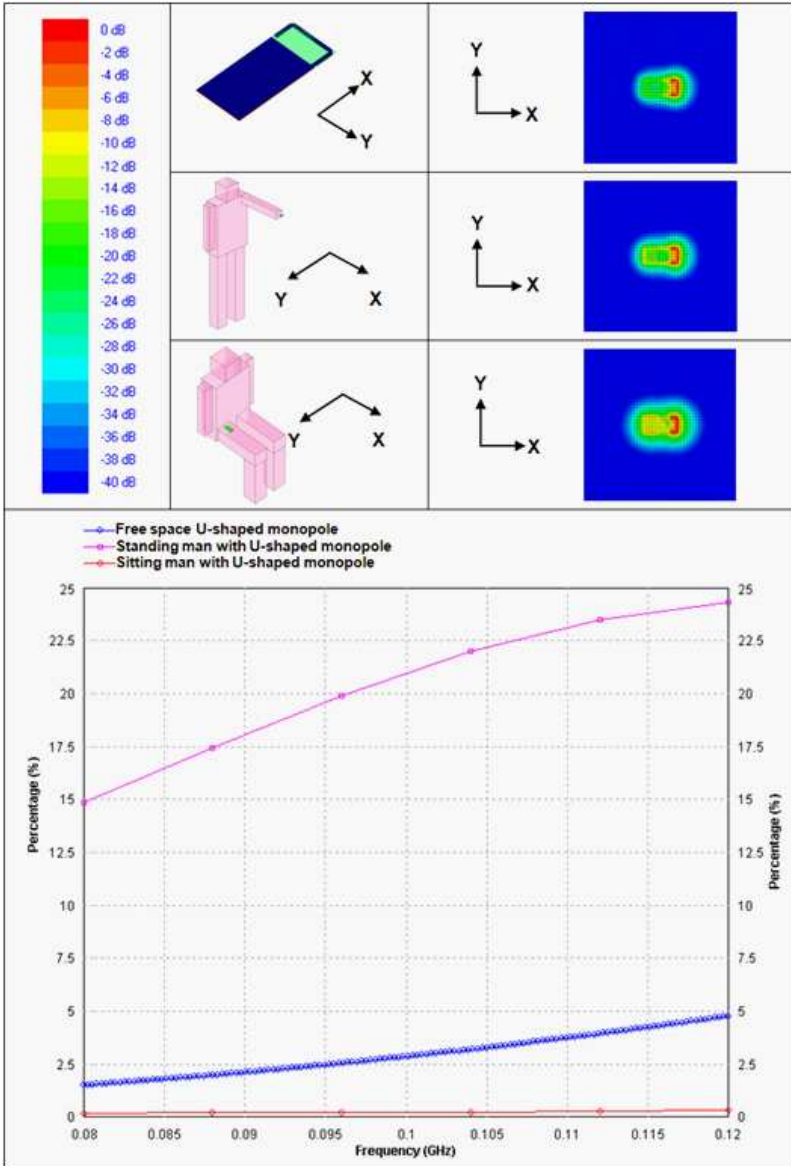


Figure 4. Electric near field (\vec{E}) generated by the U-shaped monopole antenna at 105 MHz (XY plane) and normalized to 250 V/m and radiation efficiency for each scenario.

Q_r factor is easily calculated with only dividing it by the radiation efficiency, Eq. (2).

$$Q_{antenna}(\omega_0) \approx \frac{\omega_0}{2R_0} \sqrt{\left(\frac{dR(\omega_0)}{d\omega}\right)^2 + \left(\frac{dX(\omega_0)}{d\omega} + \left|\frac{X(\omega_0)}{\omega_0}\right|\right)^2} \quad (5)$$

Analysing the 1-meter length monopole antenna, although no prediction can be made in this case, it is clear that the Q_r factor decreases in the case of *standing man*, whereas for *sitting man* the Q_r is similar to the free-space. It should be emphasized that for the standing man, Q_r is lower than the Q_r for free-space, but the radiation efficiency is better in free-space. A similar situation occurs for the sitting man, that is, although Q_r is similar to that in free-space, radiation efficiency is lower than the free-space situation. This means that both near electric field and radiation efficiency decreases in a similar portion so as to maintain the same Q_r .

Regarding the packed monopole antenna, both qualitative predictions using electric near field data are correct. Furthermore, if one analyses the near field and radiation efficiency values in a qualitative way, the Q_r factor for *standing man* is lower than the *sitting man* one, as it is proved in Figs. 3 and 4.

Finally, predictions of the Q_r using near electric field data for U-shaped monopole antenna are also correct. For this case, the best situation in terms of Q_r and radiation efficiency is the *standing man* as the packed monopole antenna case.

Among these three antennas, the 1-meter monopole has the best performance in terms of Q_r and efficiency. Regarding the other two antennas, it is concluded that the U-shaped monopole is better than the packed monopole, because in spite of the fact that both antennas have the same size, the Q_r factor is lower for the U-shaped antenna.

Thus, differences are really significant when considering the human body as part of the radiating structure. For instance, the 1-meter length monopole antenna is electrically comparable to the wavelength and results in an efficient antenna in free space. In this case, the presence of the human body reduces the radiation efficiency, as the human body behaves as a lossy dielectric medium. On the other hand, the packed monopole and U-shaped monopole antennas are electrically small antennas and, therefore, less efficient. In these cases, if the antenna is placed at the end of the arm, the human body works as an extension of these electrically small antennas, and, although being a lossy medium, it increases the radiation efficiency because as a whole the radiating structure considering the antenna and the human body is electrically larger. However, if the antenna is placed in the pocket,

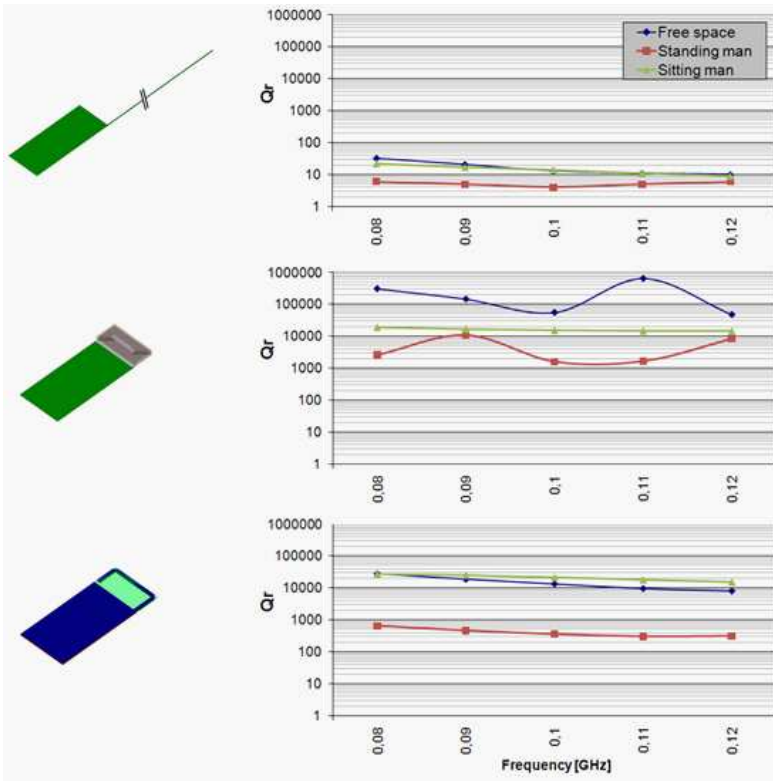


Figure 5. Q_r factor for each antenna and scenario.

it does not excite the human body effectively, and thus, the radiation efficiency is low again.

4. CONCLUSIONS

As a result, the three antennas vary their performance when radiating with the presence of the human body. Particularly, when the human body becomes an extension of the antenna, it improves, to a greater or lesser extent, the radiation efficiency of the electrically small antennas (U-shaped and packed monopole). This is the case of the standing man scenario. The key is the location of the antenna, as the human body works as an extension of the antenna at the end of the arm, working as a dielectric antenna. Thus, the radiating structure is formed by the antenna itself plus the human body. Since the volume is greater, the obtained Q_r factor is lower. In this sense, the 1-meter length monopole which is an efficient antenna in free-space is affected by the

human body which causes the radiation efficiency to drop. However, for the electrically small antennas (the U-shaped and packed monopole) which have lower efficiencies than the 1-meter length monopole, the radiation efficiency for those antennas is increased by the human body if the human body works as an extension of the antenna. Otherwise, the radiation efficiency is also poor.

It has been proved that not only the radiating structure directly affects the parameters of an antenna but also the environment directly influences its performance. In addition, the reliance of the method has been demonstrated, and it is possible to predict antenna performance by only analysing changes in the near field and the radiated power. In the present paper, the near electric field has been calculated in the vicinity of the antenna regarding the plane of the ground-plane. By comparing the electric field in free-space and that in the human-body case and taking into account the radiated power, a qualitative prediction of the Q_r has been made. This simple calculation gives a good physical insight into the behaviour of handset antennas in the presence of the human body which may help in understanding antenna-human body interaction.

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