

# SIMULATED IMPEDANCE BANDWIDTHS, GAINS, RADIATION PATTERNS AND SAR VALUES OF A HELICAL AND A PIFA ANTENNA ON TOP OF DIFFERENT GROUND PLANES

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In this paper the antenna performances i.e. impedance bandwidths, gains and radiation characteristics, including Specific Absorption Rate (SAR) values, of two commonly used antennas, namely a helical and a Planar Inverted-F Antenna (PIFA), on top of different ground planes are studied. The main idea of this study is to compare the performances of these two antennas when the size of the ground plane and the locations of the feeding and shorting points are altered. The Global System for Mobile communications (GSM) 900 system specifications are chosen as a starting point and then the free space impedance bandwidths, gains and radiation patterns are simulated by method of moments (IE3D 7.0, Zeland Software Inc.) and SAR values by finite difference method (XFDTD 5.0, Remcom Inc.) using a homogeneous phantom. These results are finally compared and conclusions of optimal ground plane structures as well as differences between the two antennas are made.

## INTRODUCTION

Common interest in using small integrated antennas in mobile phones has increased during the last few years. Reasons for this are mainly economical; integrated antennas are cheap, durable and easy to manufacture. But there exists also an electromagnetic point of view; integrated antennas have more flexibility in the radiation performance than external ones. For example, a PIFA can be designed somewhat omnidirectional or, alternatively, with some directivity thus improving the overall efficiency due to reduced SAR values. However, the antenna performance level of integrated antennas still remains a bit lower compared to external ones, but in the future the score will most likely even out.

One of the main challenges in using integrated antennas is the trend for size reduction among mobile phones. Reducing the physical size of the phone also limits the antenna volume as well as its location possibilities. It is clear that, at the same time, the antenna performance level comes down and more efforts are needed to compensate this loss of efficiency. Electromagnetically thinking the whole phone, including the antenna, the ground plane, shields, covers etc, acts as a radiating element and thereby participates in the antenna performance. For small antennas the impedance bandwidth is directly proportional to the antenna volume so in order to maximize the antenna performance level all the

elements inside the phone should be considered and evaluated also from the antenna point of view.

One important aspect when improving the antenna performance level is the choice of an optimally designed ground plane. Of course in this case, as the printed circuit board of the phone, at the same time, acts as the ground plane for the antenna, there are also many other points that dictate the size, shape and architecture of it. However, choosing for example too short or too long ground plane can have a significant effect on the antenna performance or SAR values and thereby should always be considered when designing the circuit board. By investigating the effects of different ground planes on the antenna performance and SAR it is possible to find the optimal as well as limits for the phone size.

## IMPEDANCE BANDWIDTH

The behaviour of an electrically small antenna can be analyzed in the same way as a normal resonator with the resonance frequency  $f_r$  and the quality factor  $Q$ . Pues and Van de Capelle (4). Similarly, the total losses of the antenna can be divided into internal and external ones, represented by the unloaded quality factor  $Q_u$  and the external quality factor  $Q_e$ , respectively, Nyfors and Vainikainen (3). The loaded quality factor  $Q_l$ , representing the total losses of the antenna, can be computed by (3)

$$Q_l = \frac{f_r}{B_{hp}}, \quad (1)$$

where  $B_{hp}$  is the half-power bandwidth. The unloaded quality factor can now be computed by (3)

$$Q_u = \frac{2Q_l}{1 \pm |\rho(f_r)|}, \quad (2)$$

where  $\rho(f_r)$  is the reflection coefficient at resonance frequency. In equation 2 the plus or minus sign refers to under- or overcoupled antenna, respectively. Instead with critical coupling the equation 2 reduces to

$$Q_u = 2Q_l. \quad (3)$$

The unloaded quality factor is a physical constant and specific to each antenna structure. Thereby it is not affected by coupling and the impedance bandwidth for matching criterion  $VSWR \leq S$  can then be given by (4)

$$BW = \frac{S-1}{Q_u \sqrt{S}}. \quad (4)$$

Equation 4 assumes critical coupling although the maximum bandwidth is obtained with a slight overcoupling (4).

The antenna impedance bandwidth was computed using equations 1,3 and 4. First the terminating impedance was tuned according to the simulated antenna input impedance to get a perfect matching (i.e. critical coupling) using conversion formulas given in Frickey (1). Then the resonance frequency and the half-power bandwidth, needed in equation 1, were retrieved from the matched reflection coefficient data. The 6dB matching criterion (i.e.  $VSWR \leq 3$ ) was used in equation 4.

## SIMULATION SETUP

The studied helical antenna is shown in figure 1 with a 40x100mm ground plane. The diameter of the helix is 7.64mm, the axial length is 8mm and the number of turns is 4. The feeding point is located 2mm from the ground plane top. In the simulations the ground plane width and length were altered by 10-50mm and 40-120mm, respectively, and, further, the antenna was transferred horizontally along the ground plane.

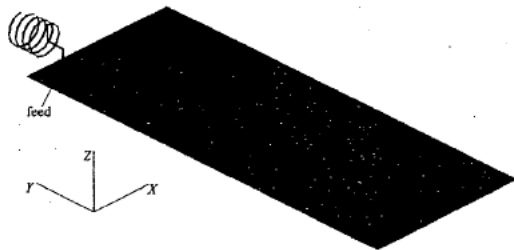


Figure 1: Studied helical antenna.

The studied PIFA is shown in figure 2 with a 40x100mm ground plane. The size of the patch is 20x40x8mm with a 14x2mm slot 12mm from the top. The shorting point is located at the upper left corner of the patch and the feeding point 2mm downwards. In the simulations the ground plane width and length were altered by 20-50mm and 40-120mm, respectively, and, further, the antenna was transferred horizontally along the ground plane.

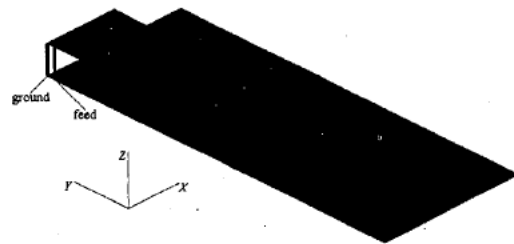


Figure 2: Studied PIFA.

In the SAR simulations the antenna and the ground plane were placed vertically beside a spherical, homogeneous phantom ( $\epsilon_r=44$ ,  $\sigma=0.9S/m$ ,  $\rho_f=1050kg/m^3$ ), representing the human head. The diameter of the phantom was 18cm including a 6mm shell ( $\epsilon_r=17$ ,  $\sigma=0.2S/m$ ,  $\rho_f=1850kg/m^3$ ), representing the skull, User's Manual for XFDTD (5). The minimum distance between the phantom and the ground plane was 8mm. During the simulations the upper left corner of the ground plane remained fixed compared to the phantom.

## RESULTS

### Helical antenna

Figures 3-5 show the relative (compared to the maximum) 6dB impedance bandwidth, gain and 10g averaged SAR value (with fixed input power) of the helical antenna as a function of the ground plane dimensions, respectively. Gain and SAR do not include mismatch losses. The effect of the ground plane dimensions and helix location on the ground plane to the free space field pattern is shown in figures 6 and 7, respectively.

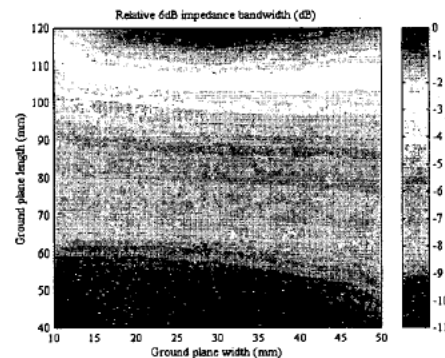


Figure 3: Relative 6dB impedance bandwidths of the helical antenna.

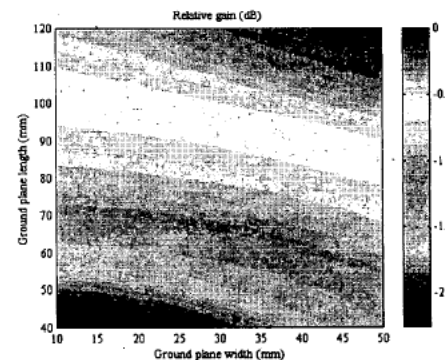


Figure 4: Relative gains of the helical antenna.

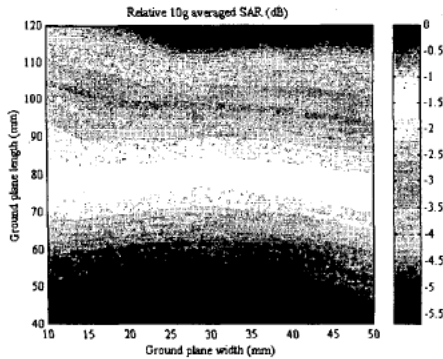


Figure 5: Relative 10g averaged SAR values of the helical antenna.

On a quadratic ground plane both the  $x$ - and  $y$ -directed currents contribute thus rotating the field pattern around the  $z$ -axis. Instead extending the ground plane enhances the  $y$ -directed currents and the field pattern rotates towards the horizontal (i.e.  $zx$ -) plane. Extended current distribution increases also the bandwidth. At the same time, as the ground plane approaches the resonance length, thereby attenuating the maximum current, a reduction in the SAR value can be observed.

Transferring the helix from the ground plane side to the center maintains the bandwidth and the gain but increases the SAR values roughly by 0.3dB mainly because the hot spot inside the spherical phantom moves closer to the antenna. In a real life situation the difference is probably even smaller.

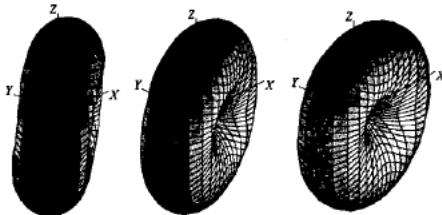


Figure 6: The effect of the ground plane dimensions to the field pattern of the helical antenna. Ground plane width 40mm and length 40mm (left), 80mm (center) and 120mm. Helix at the upper left corner.

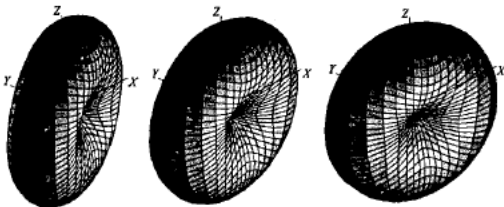


Figure 7: The effect of the helix location to the field pattern of the helical antenna. Helix at the upper left corner (left), top center (center) and upper right corner of the ground plane. Ground plane size 40x80mm.

## PIFA

Figures 8-10 show the relative 6dB impedance bandwidth, gain and 10g averaged SAR value of the PIFA as a function of the ground plane dimensions, respectively. The effect of the ground plane dimensions and patch location on the ground plane to the field pattern is shown in figures 11 and 12, respectively.

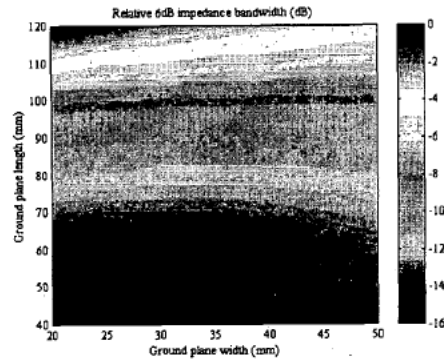


Figure 8: Relative 6dB impedance bandwidths of the PIFA.

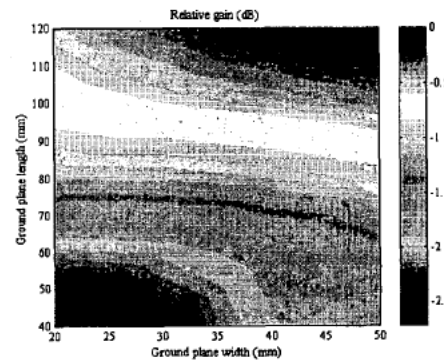


Figure 9: Relative gains of the PIFA.

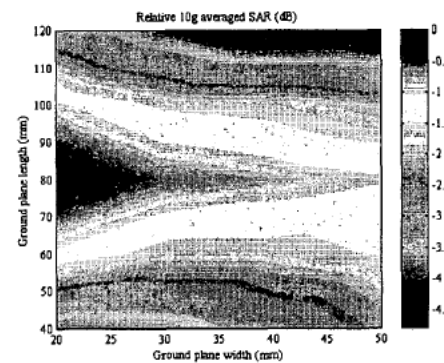


Figure 10: Relative 10g averaged SAR values of the PIFA.

The PIFA is strongly coupled with the ground plane and thereby radiates less compared to the helical antenna with an equal volume and ground plane. With a long ground plane the field pattern of the PIFA is horizontal, similarly to the helical antenna, but instead a more quadratic ground plane rotates the field pattern parallel to the ground plane. In this case the ground post is the main radiating part and the antenna can be understood to function as a top-loaded monopole with  $z$ -directed polarization and field pattern nulls at the  $z$ -axis. This also means that the main current source is perpendicular to the phantom, leading to low SAR values. But on the other hand, it also means that the antenna radiates to an unwanted direction. The bandwidth and the gain behave similarly to the helical antenna, although the PIFA needs a slightly longer ground plane to get a sufficient bandwidth.

Transferring the PIFA from the ground plane side to the center has no significant effect on the bandwidth nor the gain but the SAR values decrease 0.3-1dB, depending on the ground plane length. This is because the currents near the patch are also transferred to the center of the ground plane thus directing the radiation more efficiently away from the head. The antenna location adjusts also the  $x$ -directed currents thus rotating the field pattern around the  $z$ -axis, as with the helical antenna.

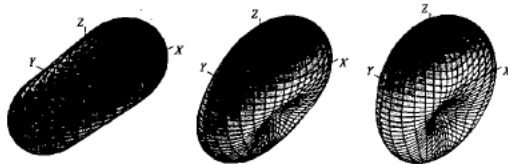


Figure 11: The effect of the ground plane dimensions to the field pattern of the PIFA. Ground plane width 40mm and length 60mm (left), 80mm (center) and 120mm. Patch 10mm rightward from the upper left corner.

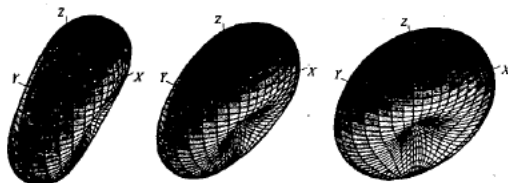


Figure 12: The effect of the patch location to the field pattern of the PIFA. Patch at the upper left corner (left), top center (center) and upper right corner of the ground plane. Ground plane size 40x80mm.

## CONCLUSIONS

The performances of two commonly used small antennas, a helical and a PIFA, on top of different ground planes were studied. The results show that significant reduction in the performance level of both antenna types occur when the ground plane is shortened below  $\lambda/4$ . An

optimal ground plane length for the antennas, considering the GSM 900 bandwidth, gain, radiation pattern and SAR value, is around  $\lambda/3$ . Adjusting the width of the ground plane or the antenna location on the ground plane has no significant effect to the performance of the helical antenna but in the case of the PIFA the best place for the antenna is at the center of the ground plane, because this gives the best SAR performance. However, to get a more detailed picture about the performance of a realistic mobile phone, more electromagnetically active components should be included in the analysis.

## REFERENCES

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