EFFECT OF GROUND PLANE SIZE ON THE FREE-SPACE PERFORMANCE OF A MOBILE HANDSET PIFA ANTENNA

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ABSTRACT

In this paper the free-space performance of a commonly used planar inverted-F antenna (PIFA) on top of various rectangular ground planes is studied by simulations. Special attention is given to impedance bandwidth and antenna efficiency. The study is carried out for five frequency bands; CDMA800, GSM900, GSM1800, GSM1900 and UMTS. Optimal ground plane dimensions for each frequency band are given and performance results for selected bands are shown as a function of the ground plane dimensions. Finally effect of the ground plane size on the performances of multiband antennas comprised of different combinations of selected frequency bands are discussed.

INTRODUCTION

Modern trends in mobile phone technology require the use of multiband handset antennas so that the user is able to use the phone globally, make a wireless connection to a PC, exploit high-speed multimedia applications etc. However, extending the operational frequency range of a fixed-sized handset from, let us say, 824MHz (CDMA800 lower frequency) to 2.17GHz (UMTS upper frequency), giving at maximum 23cm difference in wavelengths, can spoil the performance of the handset antenna at some frequency bands in between. This is due to the sensitivity of the antenna performance to the electrical size, i.e. the physical size compared to the wavelength, of the handset. 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, Geissler et al (1). 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, Hansen (2).

The performance of a mobile handset antenna is largely defined by the coupling between the antenna element and the chassis, i.e. the ground plane. Theoretically an antenna should be compounded of a small resonating antenna element inducing currents flowing on a resonating ground plane, Vainikainen et al (5). However, whether the ground plane is in resonance or not depends on its electrical size so, in practice, the antenna becomes a compromise between different frequency bands. By investigating the effect of the ground plane size to the performances of several single-band antennas tuned to desired frequency bands it is possible to compare the results between different band combinations and find theoretically optimal dimensions. However, it is important to see that this study speaks out only for the effect of the ground plane size on the antenna performance. In practice there are also many other points that affect on the performance, like mutual coupling and exploitation of parasitic antenna elements. Same kind of studies involving the effect of the ground plane size on the impedance bandwidth of a microstrip antenna can be found in references (5)-(9), on the efficiency in (9) and (10) and on the field patterns in (9)-(11).

SIMULATION SETUP

The studied GSM900 PIFA antenna is shown in figure 1 with a 40×100mm ground plane. The thickness of the patch (i.e. the antenna element) and the ground plane are 0.1mm and 1mm, respectively (σ=4.9·10^7S/m for both), and they were kept constant in all of the simulations. Also the shape and the location of the patch remained the same while the tuning into different frequency bands was made by changing its dimensions and height. At each band the antenna was tuned into system center frequency with a 40mm wide and ~λ/3 long ground plane. The antennas were simulated by method of moments (IE3D 7.0, Zeland Software Inc.) and both the width and the length of the ground plane were varied by 40-160mm. It should be noted that cases of width>length are (nearly) symmetrical to the cases of length>width and they were included in the study just for comparative reasons.

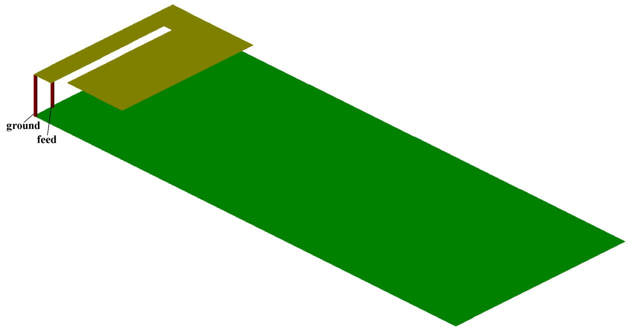

Figure 1: Studied PIFA.

TABLE 1 – Optimal ground plane dimensions.

	width×length (mm)	length (×λ)	width + length (×λ)
CDMA800	40×130	0.376	0.491
GSM900	40×120	0.375	0.500
GSM1800	90×90	0.540	1.080
GSM1900	80×90	0.604	1.140
UMTS	80×80	0.563	1.125

The simulated scattering parameters were re-computed by tuning the reference impedance according to the simulated resonance input impedance using conversion formulas given in Marks and Williams (3). This "matched" scattering parameter data was then used to compute the impedance bandwidth. The unloaded quality factor Q_u was also received from the matched scattering parameters by

$$Q_u = \frac{2 f_r}{B_{hp}}, \qquad (1)$$

where f_r is the resonance frequency and B_{hp} the half-power bandwidth, Nyfors and Vainikainen (4).

RESULTS

Simulated performance results for GSM900 are shown in figures 2-7. In the figures the resonance frequency, the input resistance, the input reactance, the 6dB impedance bandwidth, the unloaded quality factor and the antenna efficiency are illustrated as a function of the ground plane dimensions, respectively. The colouring is chosen according to the specification (or desirable) value of the property in question such that white colour represents the specification value and red and blue colours illustrate the deviation up- and downwards, respectively. The antenna efficiency includes losses due to antenna mismatch and it is presented as bandwidth giving frequency band where the efficiency exceeds 80%.

The results for GSM900 are very similar to the results for CDMA800 and, therefore, they can be said to represent "low-band" –results. In the same way, results for GSM1800, GSM1900 and UMTS are somewhat similar and so the results for UMTS, shown in figures 8-13, are chosen to represent "high-band" –results. This grouping into low- and high-band results can be clarified by table 1 showing optimal ground plane dimensions for each frequency band. In the table the dimensions are given in millimeters and in wavelengths, compared to simulated resonance frequencies. It can be observed that at the low-band case the antennas perform optimally when the length of the ground plane is ~3λ/8 and width+length is ~λ/2. For high-band case the optimal shape of the ground plane is a square with a side length of ~λ/2.

It is well known that current on a metallic strip is concentrated on the edges. This is what happens also on the ground plane which, as stated in (1), acts as an active counterpole to the antenna element. Depending on the locations of the feed and ground posts the current on the ground plane is divided into two main branches flowing along the opposing edges. The dimensions given in wavelengths in table 1 represent the lengths of the two current branches and the results imply that the antennas perform optimally when both of these lengths coincide with certain resonance lengths, given above. Figures illustrating the impedance bandwidths and antenna efficiencies (i.e. figures 5, 7, 11 and 13) show that the antennas also have local performance peaks when at least one of the dimensions coincide with any of the resonance lengths.

For GSM900 the impedance bandwidth is close to its specification value when Q_u is around 30. For a resonating ground plane Q_u decreases to 8 thus increasing the impedance bandwidth by a factor of 3.5 and the antenna efficiency bandwidth by a factor of 2. For UMTS Q_u changes from 15 to 7 and the impedance and antenna efficiency bandwidths are increased by factors of 2 and 1.6, respectively. It can also be observed from figures illustrating the input reactances (i.e. from figures 4 and 10) that the antennas perform optimally with a slightly inductive input impedance.

CONCLUSIONS

Ground plane dimensions giving optimal performances for a mobile handset PIFA antenna tuned to five different frequency bands were shown. Also some theoretical aspects on the results were discussed. These results can now be exploited in choosing ground planes for multi-band antennas comprised of selected combinations of these bands. Basically, the dimensions should be chosen such that the lengths of the two current branches, as explained above, coincide with resonance lengths in the selected frequency bands. However, in practice this is not possible for antennas mixing low- and high-bands when the size of the handset is expected to be usable.

The effect of a resonating ground plane on the performance of a low-band antenna is substantial but is valid only for particular dimensions, as shown in figures 5 and 7. A high-band antenna, on the other hand, performs reasonably well for a number of ground plane dimensions (figures 11 and 13) thus offering flexibility to the selection. So the best compromise on the performance, when a low band is included, is reached with optimal low-band dimensions, given in table 1. As an example, the optimal compromise for an antenna comprised of all five frequency bands would be 40×130mm, according to the lowest band CDMA800. When only high bands are included the optimal size is 80×90mm. However, a more practical size for this case would be 60×130mm still giving very good performance in all three high bands. On the other hand, including only GSM1800 and GSM1900 the minimum size with a reasonable performance would be 60×60mm.

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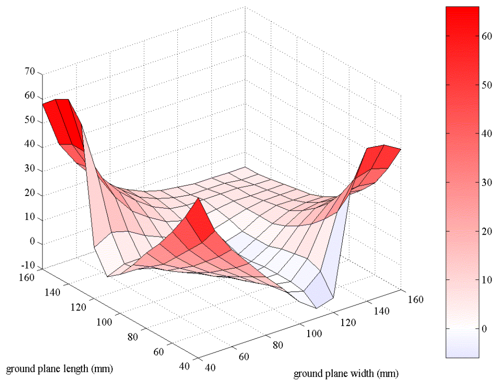

Figure 2: GSM900 resonance frequencies (MHz from center frequency).

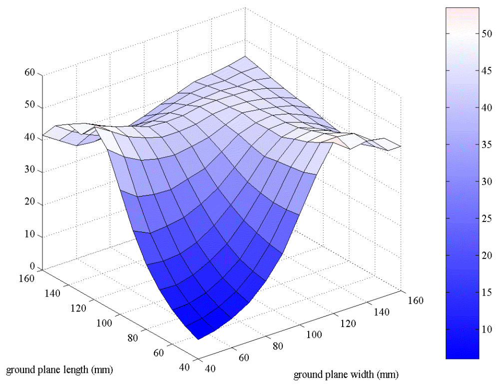

Figure 3: GSM900 input resistances (Ω).

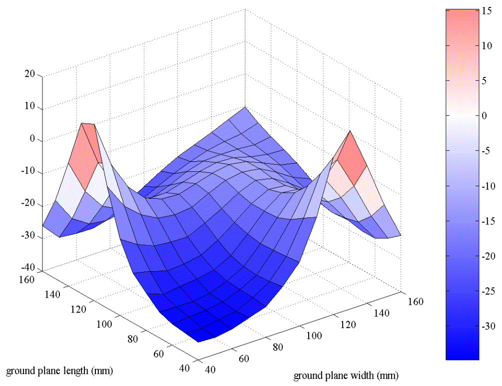

Figure 4: GSM900 input reactances (Ω).

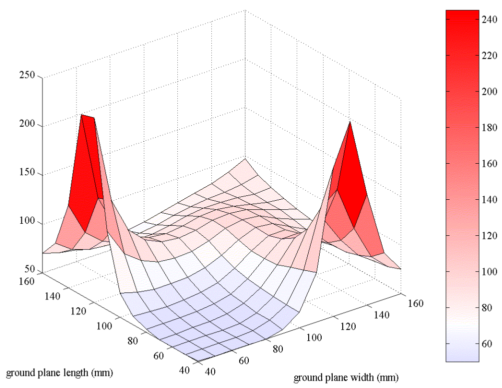

Figure 5: GSM900 6dB impedance bandwidths (MHz).

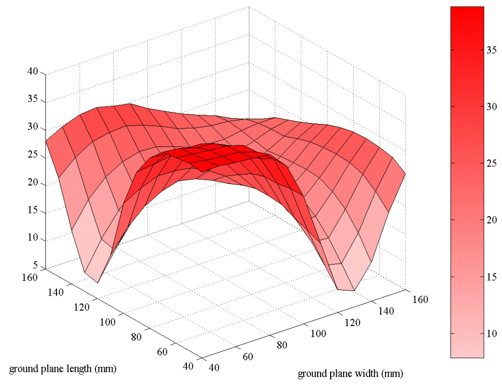

Figure 6: GSM900 unloaded quality factors.

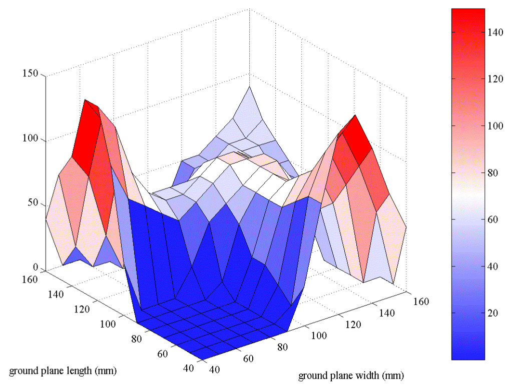

Figure 7: GSM900 80% antenna efficiency bandwidths (MHz).

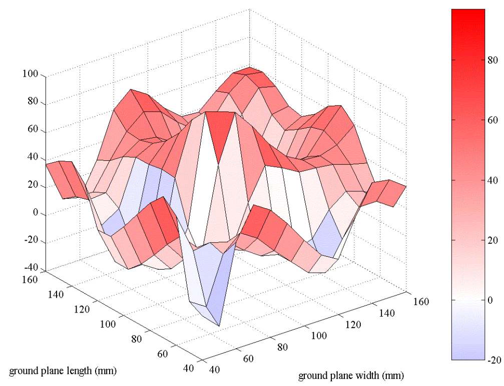

Figure 8: UMTS resonance frequencies (MHz from center frequency).

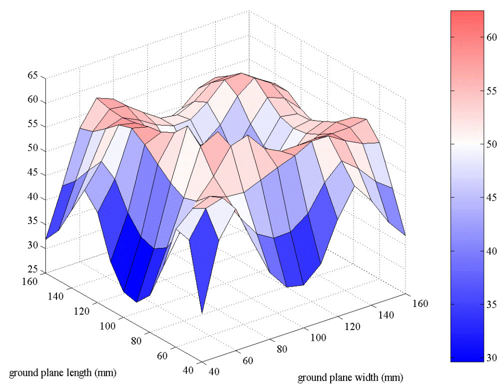

Figure 9: UMTS input resistances (Ω).

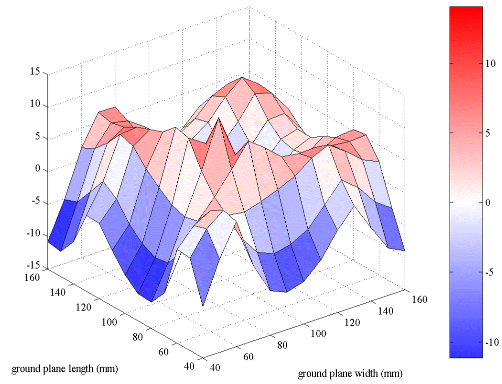

Figure 10: UMTS input reactances (Ω).

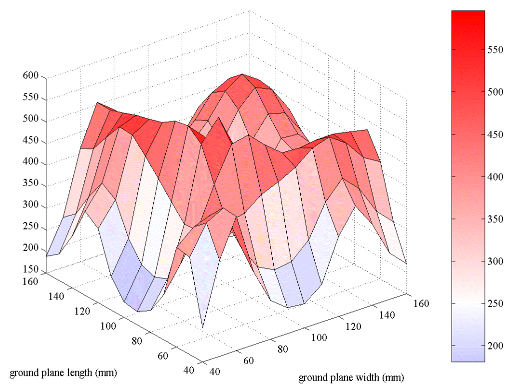

Figure 11: UMTS 6dB impedance bandwidths (MHz).

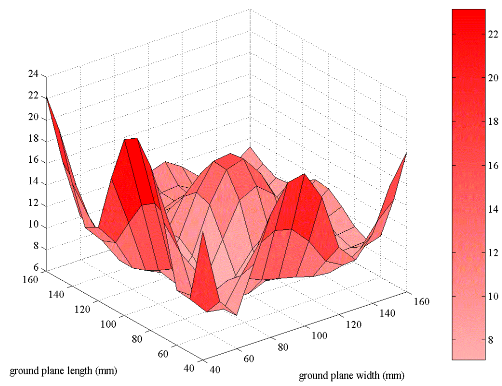

Figure 12: UMTS unloaded quality factors.

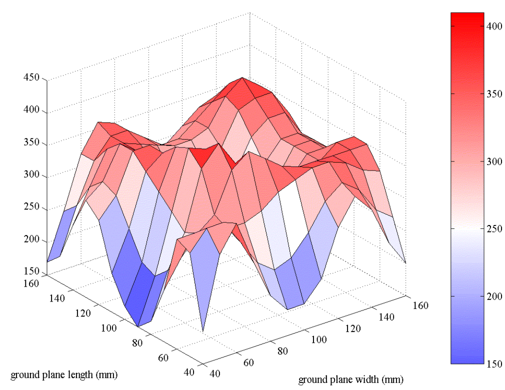

Figure 13: UMTS 80% antenna efficiency bandwidths (MHz).