DESIGN CONSIDERATIONS FOR INTEGRATED MOBILE PHONE ANTENNAS

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Abstract – Based on the investigation of the board effect on the bandwidth of integrated antennas for mobile phones a concept for a tripleband antenna suitable for GSM/DCS/PCS is developed. The antenna concept comprises a parasitic element to enlarge the bandwidth. The performance of the antenna is analyzed by means of numerical simulations based on the FDTD method.

Introduction

Aesthetical design and marketing aspects have a large impact on the development of mobile phones. Therefore there is a remarkable trend to fully integrate the antenna in the mobile phone. Compared to traditional antennas it is more complicated to master the typical parameters like bandwidth, efficiency and influence of the user within the limited antenna volume. This becomes even more critical with respect to multiband functionality which is an essential feature of modern mobile phones. To enable a rapid and efficient design some general relations concerning the physical behavior of an antenna in a small mobile have to be considered.

In this paper some of these relations will be discussed. Based on these design guidelines a concept for a GSM/DCS/PCS antenna suitable for the integration into a mobile will be presented. The investigation is carried out using EMPIRE^{TM} which is a commercial FDTD software from IMST GmbH.

Interaction of the antenna with the board

Due to the ongoing miniaturization of components and for marketing requirements the size of modern mobile phones decreases. Typical lengths vary between 80 mm and 130 mm. Assuming a quarter-wave antenna on a small PCB, it is obvious that there is a strong interaction between the antenna-module and the board [1]. In [2] the effect of varying PCB lengths on the impedance bandwidth at 900 MHz is investigated for a c-patch antenna, a capacitively loaded patch antenna and a dielectrically loaded patch antenna. An equivalent circuit model of the interactions of the antenna module with the board is derived in [3]. It describes the antenna module as a high-Q resonator and the board as a low-Q resonator. Both are coupled to each other by a certain coupling coefficient.

The board effect for 900 MHz and 1800 MHz

With respect to multiband antennas the same investigation has to be carried out for the 1800 MHz frequency band additionally. For multiband functionality folded patch antennas derived from the c-patch concept with one or more resonators are commonly used. By folding the antenna path it is possible to place two or more resonant radiators on a small antenna-module. Coupling between the radiators provides an additional parameter to tune the resonances to the right frequency and adjust the matching in all frequency bands with one feeding point.

In order to get a fair comparison between 900 MHz and 1800 MHz antennas the investigation presented in the following is restricted to single resonant patches. The investigation for 900 MHz is performed with a c-patch antenna module of 4.3 cm³ on a realistic model of a mobile phone. For the 1800 MHz frequency band some parts of this antenna are removed in order to get the right frequency. This results in a L-shaped antenna. Please note that in this case not all the available surface on the module is used for the antenna.

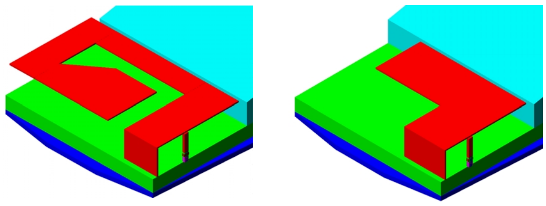


Figure 1: Folded patch antennas on a realistic model of a mobile phone for 900 MHz and 1800 MHz.

The upper part of the mobile and the antennas are given in Figure 1. The mobile consists of a PCB, a battery and a RF-shielding where the antenna is mounted on. The mobile is covered by a plastic casing of 1 mm thickness with a relative permittivity of $\varepsilon_r = 3$. In the simulation all remaining parts of the mobile are treated as perfect conductors. In the following investigation the length of the mobile is enlarged from 80 mm to 150 mm without changing any dimension in the upper part of the phone near the antenna. The antenna itself is retuned to the right frequency for every board.

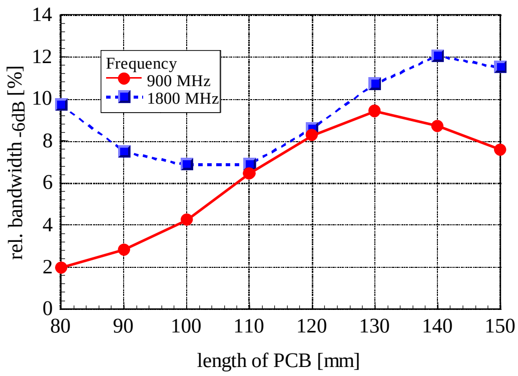


Figure 2: Interaction of antenna-module and PCB: Influence on the bandwidth.

It can be observed from Figure 2 that the resonance effect of the board can have a large impact on the impedance bandwidth of the resulting antenna system [2], [3]. Especially for 900 MHz the bandwidth becomes very low for a small mobile.

Consequence for a dualband application

Based on the analysis of the single resonant antennas in the prior investigation a dualband antenna is developed by using both paths in one module.

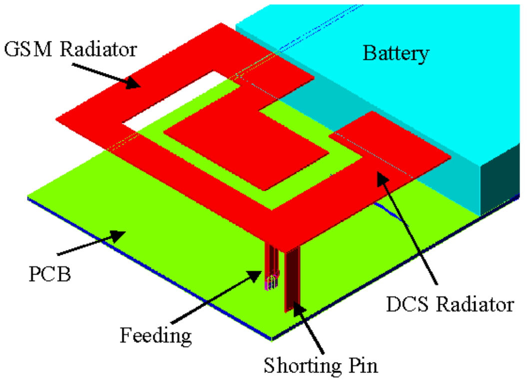


Figure 3: Dualband antenna composed out of two folded resonant paths on a mobile of 110 mm length.

The coupling of the combined elements has an additional effect on the resonances especially in the upper frequency range. With some modifications it is possible to succeed in a proper matching for a single feed solution in both frequency bands.

In order to investigate the worst case scenario for the upper frequency band this antenna concept is investigated with a board length of 110 mm. At this length the coupling effect with the board is only small for the DCS resonance as shown in Figure 2. This results in a narrow bandwidth at this frequency range. The size of the antenna-module is 5 cm³ and it is situated with some distance to the edges of the PCB in the upper part of the mobile. The distance to the battery, which is simulated as a metal block is 2 mm.

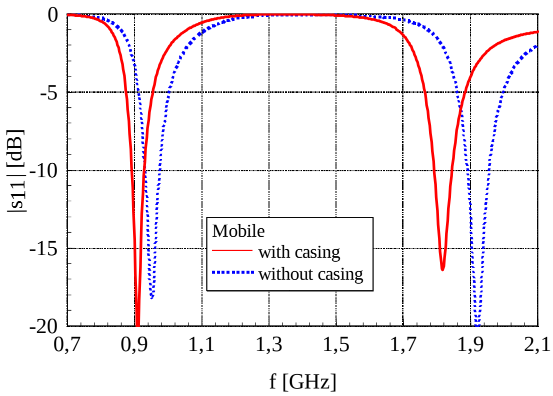


Figure 4: Matching of the dualband antenna with/without plastic casing.

Figure 4 shows the matching in both frequency bands and the influence of the plastic casing on the tuning of the resonance frequencies. Due to the dielectric properties of the plastic casing the GSM resonance is reduced by 4.5 % and the DCS resonance is reduced by 5.6 %. This shift has to be taken into account in the design of the antenna. Figure 4 demonstrates that good matching is provided at both center frequencies. In accordance to the above investigation the bandwidth of the DCS mode (110 MHz at a matching of –6 db) is quite narrow. To get a wider matching in DCS the antenna module could be enlarged, but in most cases the size is strongly limited.

A dualband solution with parasitic element

Another possibility to enlarge the bandwidth of an antenna is the use of parasitic elements. This principle is widely reported in the literature [4] for microstrip patch antennas. An application for mobile phone antennas has recently been published in [5].

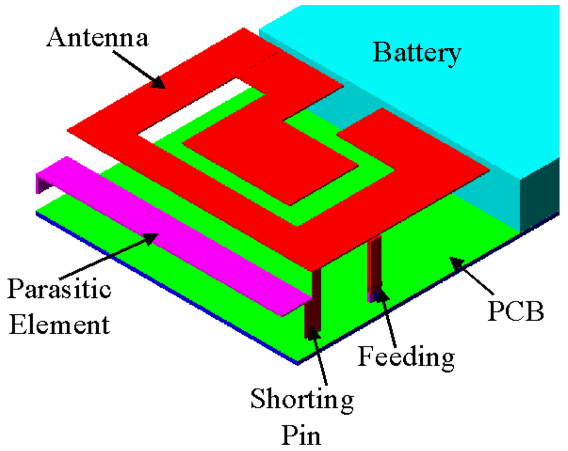
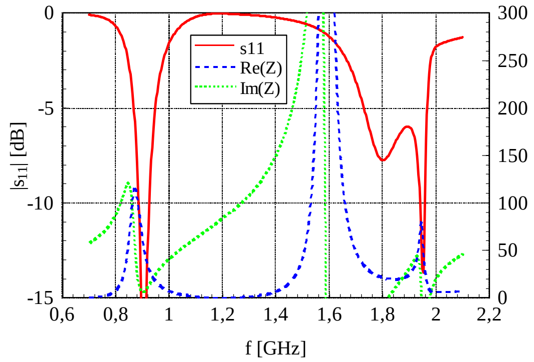


Figure 5: Integrated antenna with parasitic element situated on a simplified mobile.

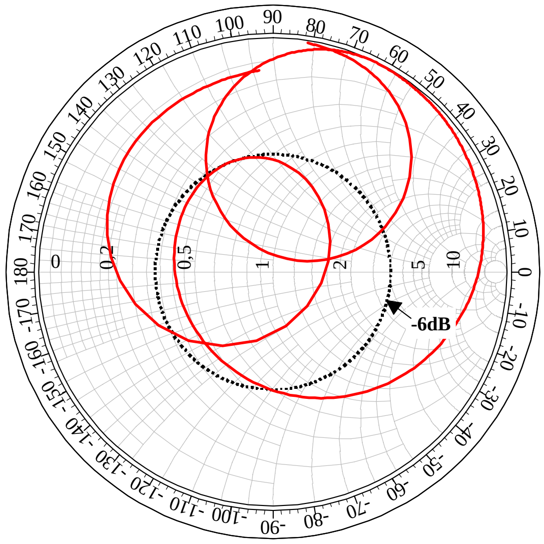
Figure 5 shows the two radiator dualband antenna in combination with a parasitic element. The parasitic element is situated above the original antenna at the top of the phone. As the height of the parasitic element is lower than the original antenna-module this additional space (0.4 cm³) is available at this position taking into account a rounded casing at the top of the phone.

In Figure 5 the resonators for the upper frequencies are placed orthogonal to each other. This provides less coupling from the electric nearfield of the resonators compared to having the parasitic resonator in parallel to the DCS resonator. Nevertheless the other configuration works also, as it is reported in [5].

Using a parasitic element the bandwidth can be increased by a large amount. Therefore it is interesting especially for future applications where more frequency bands have to be covered by only one antenna. On the other hand with a parasitic element matching becomes more complicated because more parameters compared to the original antenna have to be considered.



a) Matching and impedance behavior.



b) Smith Chart.

Figure 6: Matching and impedance behavior using a parasitic element.

The point of most interest is the efficient coupling of the upper modes. As it can be observed from Figure 6 the impedance behavior of the upper resonances is different compared to an ordinary first order resonance matching. The lower resonance (at 1.6 GHz) is tuned to have a quite high impedance maximum. This generates a flat curve of the radiation resistance until the third resonance appears. Sufficient matching is provided in-between. With respect to the Smith Chart in Figure 6b it may still be possible to optimize the antenna, but even with the current solution a bandwidth of 225 MHz according to a matching of –6 dB is obtained. For the GSM resonance the bandwidth is 80 MHz. This is sufficient to cover the whole frequency band in this standard. With regard to the above investigation on the board effect the bandwidth at GSM is dependent of the dimensions of the board, too.

Parameters for tuning the coupling

In order to optimize the coupling a parameter variation is performed.

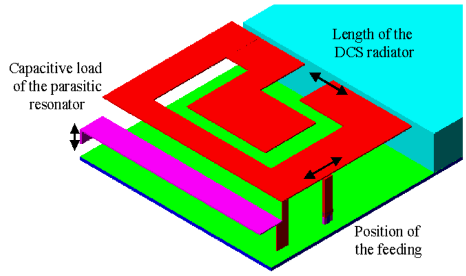
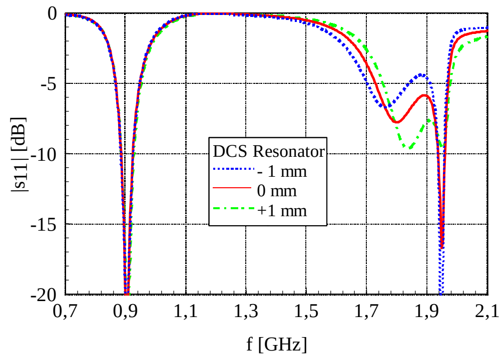
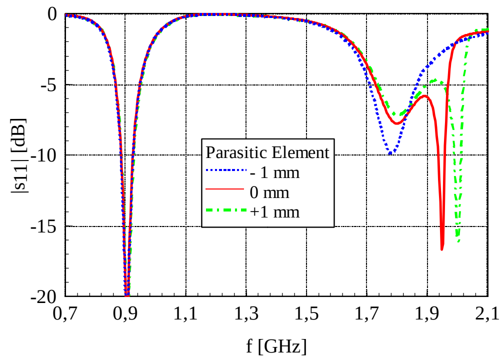


Figure 7: Parameters for tuning the coupling.

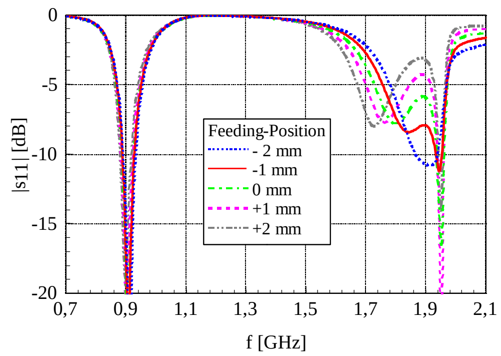
For this purpose at least three parameters can be found that influence the coupled resonances.



a) Variation of the DCS resonator.



b) Variation of the parasitic element.



c) Variation of feeding point.

Figure 8: Parameter variation for tuning the coupling.

The first variation is performed by varying the length of the DCS resonator. It can be seen from Figure 8a that this variation does not affect the resonance of the parasitic element very much. On the other hand it can be observed from Figure 8b that a change in the capacitive load of the parasitic element results mainly in a change of the resonance according to this resonator. Taking the results from both analysis it can be stated that the position of both resonances can be tuned nearly independently from each other by the lengths of the related elements. The reason for this independent behavior has its origin in the orientation of both radiators relative to each other. The distant orthogonal placement provides decoupling by means of the electric nearfield generated at the end of both resonators. A galvanic coupling is only present at the common shorting pin.

Figure 8c shows that matching can be adjusted by varying the feeding point. Please note that the DCS resonance is not independent from this parameter. Finally it can be observed that there is only a minor effect on the GSM resonance in all variations.

A GSM/DCS/PCS antenna on a realistic mobile

Based on the concept derived above an integrated tripleband antenna for the GSM, DCS and PCS is developed.

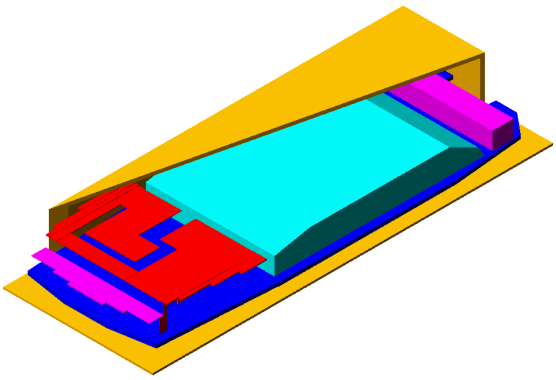


Figure 9: Tripleband antenna in a realistic configuration.

The size of the antenna module in Figure 9 is 6.3 cm³. The height above the PCB is 7 mm. The parasitic element needs additional space of 0.66 cm³ with a reduced height of 4 mm. This results in a total volume of less than 7 cm³. The shape of the antenna has been modified in order to fit closer to the shape of a realistic mobile. In accordance to the prior investigation the length of the PCB is 110 mm. The relative permittivity of the plastic casing is $\varepsilon_r = 3$ and its thickness is 1 mm.

FDTD simulations are performed for the model of the mobile in free-space and in the vicinity of a model of the human head. The model of the human head is presented in Figure 10. It consists of 16 different tissues. The spatial resolution of the head phantom is 1 mm.

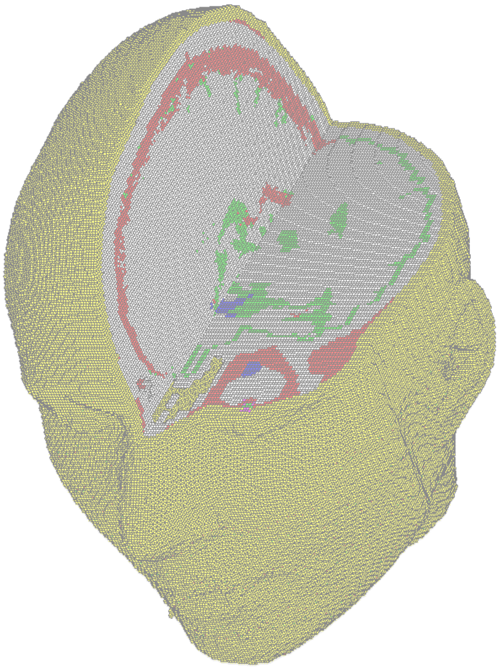


Figure 10: Realistic model of the human head.

The material parameters of theses tissues are taken from Gabriel [6] for two different frequencies under investigation (900 MHz, 1900 MHz). The mobile is attached to the human head in the “intended use” position which is defined in [7].

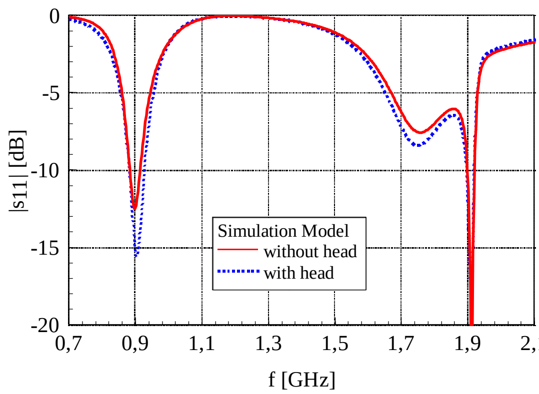


Figure 11: Matching of the antenna with and without the user influence.

Figure 11 shows the matching of the antenna in free-space and attached to the human head in “intended use” position. The bandwidth according to a matching of –6 dB is 85 MHz in GSM and 280 MHz in DCS/PCS. Therefore the antenna is well suited for this tripleband application. Comparing the result with/without the influence of the human head it can be observed that only a minor shift in the resonance frequency occurs due to the dielectric properties of the human head. The bandwidth is increased due to losses in the tissue.

To complete the analysis the radiation efficiency is calculated. As the mobile itself is simulated without any losses the total radiation efficiency is affected by the mismatch of the antenna and the power-loss in the tissue. Therefore the total radiation efficiency can be defined as:

$$\eta_{total} = \frac{P_{rad}}{P_{in}} \qquad (1)$$

According to the different standards GSM, DCS, and PCS the mean input power is 250 mW, 125 mW and 125 mW respectively.

Neglecting the influence of the mismatch of the antenna a different definition of an radiation efficiency can be found that only accounts for the losses in the tissue. It can be defined as:

$$\eta_{absorption} = \frac{P_{rad}}{P_{antenna}} \qquad (2)$$

	η_{total} [%]	$\eta_{absorption}$ [%]
900 MHz	30	31.2
1800 MHz	48.6	57.4
1900 MHz	46.4	58.2
2000 MHz	55.8	59.4

Table 1: Radiation efficiency of the mobile in "intended use" position.

Table 1 shows the calculated values for the radiation efficiency taking into account the mismatch of the antenna or neglecting it. It can be observed that there is a difference of the amount of power absorbed by the tissue comparing the lower and the upper frequency range. This may also be due to the more omni directional characteristic of the antenna in GSM where the interaction with the PCB is larger. For this explanation is only a first assumption this has to be investigated in more detail in the future work.

Conclusion

The interaction of the antenna with the PCB of a mobile has been investigated in terms of bandwidth for 900 MHz and 1800 MHz using folded patch antenna. Based on this study a dualband antenna has been developed. Within the given constraints regarding the size of the antenna-module and the dimension of the board the bandwidth for DCS was too small. To improve the bandwidth in DCS a parasitic element was attached to the antenna module which needed only minor additional space. To adjust the coupling a parametric investigation was performed that provides guidelines for matching the antenna. Based on the developed concept a tripleband antenna for the standards GSM/DCS and PCS has been designed on a realistic platform. The performance of the antenna has been investigated taking into account the influence of the users head.

References

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