A printed monopole antenna for cellular handsets

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Abstract— In this paper we propose a modified monopole antenna for use as internal antenna in mobile handsets. In this antenna, called the MB antenna, the radiating element (monopole) is implemented in parallel to a ground plane, without degradation of its radiation characteristics. Simulations show that the MB antenna performs similar to the conventional monopole antenna and has superior performance over PIFA. The proposed antenna can be used as an embedded antenna in compact cellular handsets, and seem promising for application to MIMO antenna systems subject to space limitation.

Keywords—Monopole , PIFA , cellular handset , MB antenna, ground plane.

I. INTRODUCTION

Historically, monopoles have been the first antennas widely employed in radio engineering. Although a detailed description of this antenna has been provided by the classical works on the theory of antennas [1], at the present time, i.e. one hundred years after the beginning of its conception, some of its properties, advantages and disadvantages are still subject to discussions. For example, the difference between a monopole antenna and a dipole, and also the different behavior of monopole in the transmitting (Tx) and receiving (Rx) modes is not yet well understood. In some published literature, the ideal monopole implemented on a perfectly conducting surface is considered as one half of a vertical dipole of the same arm length [2].

Implementation of monopole antennas in modern wireless communication systems is subject to different constraints imposed mainly due the shape and position of the ground plane relative to the monopole. In particular, the relatively small ground plane of small-sized handsets, e.g. the counterpoise acting as ground, is not a real ground, resulting in some ambiguities in how to define the parameters of the antenna [3,4].

To make things even more complicated, the unavoidable presence of a PCB (printed circuit board) in the compact cellular handsets dramatically impairs the efficiency of radio waves radiation and reception. These problems has resulted in exclusion of monopole as an internal antenna in compact cellular handsets, even though for a long time it has been the preferable choice in cellular phones. The main advantages of the monopole antenna are omnidirectional pattern in the horizontal plane, easy design procedure and light weight.

In recent years the cellular phone handset antennas are required to be of small size, and installed inside the handset in proximity to a large PCB which acts as a ground plane. This has led to replacing the monopole antenna by other types of antennas, such as the planar inverted F antenna (PIFA) [4]. PIFAs are characterized by broad bandwidths and pure resistive input impedance. Theses antennas are currently widely used in compact cellular handsets. However, the performance of the PIFA is very sensitive to variations in its dimensions and the feeding point, making it difficult to achieve an optimal design of this antenna.

In this paper we shall first describe some basic characteristics of monopole antennas. It will be shown that the monopole efficiency under transmitting mode is different from its value in receiving mode. This distinction is very important for link budget calculations, especially in cases that the grounding schemes of the transmitter and receiver are different. Grounding effects due to lack of proper grounding are also addressed.

In order to allow for implementation of monopole antennas in compact handsets, we introduce a modified monopole, called the MB antenna, whose radiating element is in parallel to a ground plane. The proposed antenna can be easily implemented in handsets that require internal antennas and are subject to space limitations such as the mobile phone handsets. Simulation studies show that the MB antenna performs similar to the conventional monopoles offering all advantages of the latter for use in cellular handsets.

II. DIPOLE AND MONOPOLE PARAMETERS IN DIFFERENT MODES

The effectiveness of a receiving antenna is usually estimated by either its effective height (h_e) or its effective area (aperture). The effectiveness of a transmitting antenna, on the other hand, is measured by its gain (G).

The effective height a monopole or a dipole antenna depends on its length. Let's consider two cases: $h = \lambda/4$ and $h << \lambda/4$, where h is the arm length (height) of the monopole or the dipole, as shown in Fig. 1.

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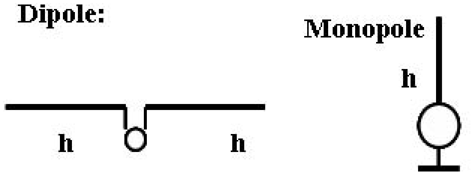


Fig. 1- Dipole and monopole antennas

Table 1 shows the values of h_e, G and radiation resistance (R_{rad}) for such antennas in the transmitting mode [5].

Table 1- properties of monopole and dipole antennas in transmitting mode

	monopole $h = \lambda/4$	monopole $h \ll \lambda/4$	dipole $h = \lambda/4$	dipole $h \ll \lambda/4$
R_{rad}, Ω	52	$14(kh)^2$	73.2	$20(kh)^2$
G	2.15	1.76	2.15dB	1.76dB
h_e	$\lambda/2\pi$	$h/2$	λ/π	h

Fig. 2 shows the equivalent circuit for a transmitting dipole antenna, consisting of a total input resistance R which is divided into two resistors each of R/2. In this case, the antenna gain is given by

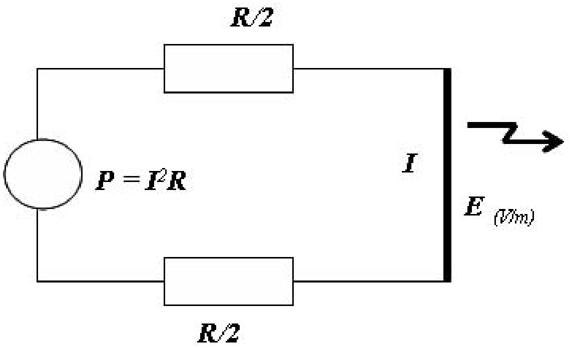


Fig. 2- Transmitting dipole equivalent circuit.

$G_{dipole} \propto (E^2/Z_0)/(I^2R)$,

where E is the field strength and $Z_0 = 120\pi\ \Omega$. In the case of a monopole operating in the transmitting mode, the equivalent circuit is shown in Fig. 3.

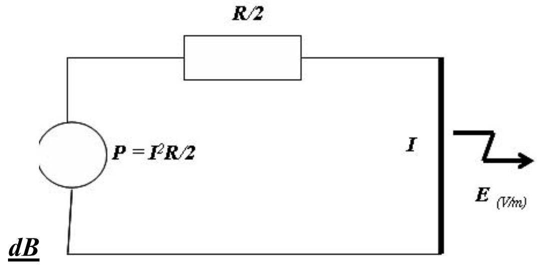


Fig. 3- Transmitting monopole equivalent circuit.

In this case the input impedance of the antenna is one half of the dipole's input impedance, i.e. R/2 and the antenna's gain is equal to

$G_{mon} \propto (E^2/Z_0)/(I^2R/2)$,

And hence

$G_{mon(dB)} = G_{dipole(dB)} + 3$

In other words, if the monopole and the dipole are driven with the same current, to achieve the same field strength the required power level in the case of monopole, installed above a ground plane, is half of that required in the dipole. If the input power levels are the same, then the field strength in case of monopole above ground will be $\sqrt{2}$ times stronger than its value in the case of dipole.

In the receiving mode (R_x) the situation is different. Fig. 4 shows the equivalent circuit in the case of a receiving dipole antenna, and Fig. 5 shows the equivalent circuit of an unloaded receiving monopole antenna having ground plane.

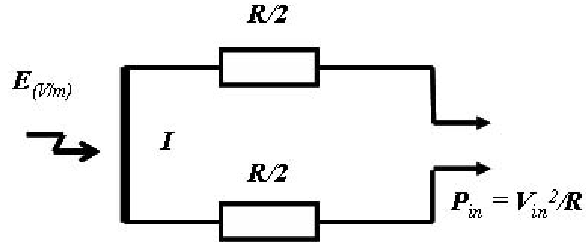


Fig. 4- Receiving dipole equivalent circuit

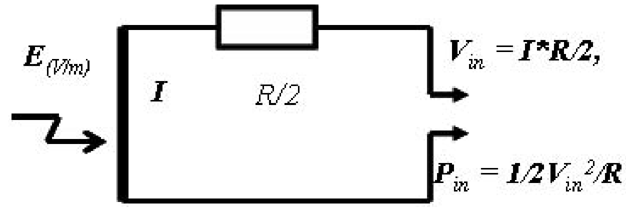


Fig. 5- Receiving monopole equivalent circuit

In this case, the received power level is only one half of the power obtained in the case of a dipole. Reducing the monopole's effective height h_e by a factor of two causes a power decrease by a factor of four, but if the input resistance R of the monopole is reduced by a factor of two, the power level increases by a factor of two. That is

$G_{mon(dB)} = G_{dipole(dB)} - 3$ dB

The parameters of a monopole over a ground plane are as follows [3]:

in transmission mode:

for $h = \lambda/4$: $R_{rad} \cong 36\Omega$, $G = 5.15$ dB, $h_e = \lambda/2\pi$.

$forh << \lambda/4:\ Rrad \cong 10(mh)2\Omega,\ G = 4.76\ dB,\ he = h/2.$

in receiving mode:

$for\ h = \lambda/:\ Rrad \cong 36\Omega,\ G = -1.15\ dB,\ he = \lambda/2\pi.$
$For\ h << \lambda/4:\ Rrad \cong 10(mh)2\Omega,\ G = -2.24\ dB,\ he = h/2.$

These values show that in contrast to the commonly accepted view, the antenna parameters in the transmission mode are different from those of receiving mode [5]. The reciprocal property holds only when the antennas have the same grounding conditions.
Let us consider the product of the antenna gains in different modes**.** In case that both Tx and Rx use dipoles (dipole-dipole case), the gains product will be $\mathbf{G_T * G_R}$. In the case of monopole-monopole antennas, the product will be:

$$(GT + 3dB) * (G_T - 3dB) = G_T * G_R.$$

III. GROUNDING EFFECTS ON THE RECEIVER SENSITIVITY

Lack of proper grounding complicates the calculation of the cell phone sensitivity.
In real conditions the cellular handsets are not grounded, and usually they are held about 1 - 1.5 m above ground. In [3] it is shown that in the cellular frequency bands the receiver is practically grounded through capacitive coupling to ground, as depicted in Fig. 6. Ref. [3] presents a method for calculating the receiver sensitivity under these conditions, where the capacitive coupling between the handset and ground is taken into account.

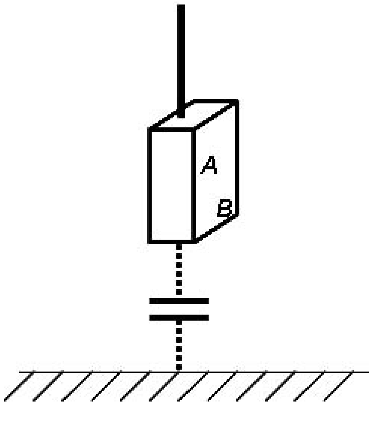


Fig. 6- Capacitive coupling between cellular handset and ground.

It has been shown that the handset capacitance can be evaluated, with sufficient
accuracy for practical calculations, by the following formula

$$C_b(pF) \approx 0.4h_{max}\ (cm),$$

where h_{max} is the largest dimension (e.g. A or B in Fig.6) of the handset (in cm) [3]. For a typical handset, . For example h_{max} = 10 cm, and hence C_b = 0.4*10=4pF.
For sensitivity calculations in case of short monopoles (h <λ/4), it is necessary to evaluate also the handset's antenna capacitance (C_a), which is connected in series to C_b. This capacitance can be calculated by the following formula [3]:

$$C_a = \frac{1}{2\pi f \rho} \cdot \frac{k_f^2 - 1}{k_f ctgm_1 h - ctgm_2 h}$$

$$\rho = 120\ln(\frac{2h}{r} - 1)$$

$$k_f = \frac{f_1}{f_2} \qquad m = \frac{2\pi}{\lambda} = \frac{2\pi}{c} f = \frac{2\pi}{300} f_{MHz}$$

For a superheterodyne receiver, f_2 is the lowest receiving frequency, and f_1 is highest image frequency.

IV. THE MB ANTENNA

The proposed MB antenna is a modified version of the monopole antenna that allows for the radiating element to be mounted in parallel to the ground plane. Fig. 7 illustrates the directions of the currents when the radiating trace of a monopole antenna is implemented in parallel to a ground plane. As seen in this Figure 7, the currents in the printed conducting trace and in the ground plane flow in opposite directions, resulting in a very low radiation efficiency because of the destructive superposition of the fields produced by these currents.

The main idea behind the MB antenna is to

introduce a phase shift of 180^0 in the feed path of the radiating trace (relative to the ground) so that the two currents become in-phase and flow in the same direction. In this way, the fields emanating from the monopole and the ground plane will be in-phase and hence add up, resulting in a high radiation efficiency similar to that of conventional monopole antennas.
The phase shifter can be implemented in various ways, provided the following two requirements are fulfilled: 1) it must be realized in a non-radiating shape, 2) its electric length (corresponding to the center frequency) must be designed such that the currents in the radiating element and the ground plane are in-phase and flow in the same direction.
Fig. 8 shows schematics of the proposed antenna for two different schemes of the phase shifting element. The phase shifter may consist of a simple delay line whose electrical length is λ/2, where λ corresponds to the center frequency of the monopole bandwidth. The radiating trace as well as the delay line can be implemented either as a separate wire (outside the substrate) or as a printed line on the same substrate on which the radiating element is printed, e.g. the handset's PCB. The MB antenna can be designed for multi-band operation. For this purpose one should implement a number of radiating elements of different lengths fed by the same number of phase shifters each corresponding to the central frequency of one of the

required bands. Fig. 9 shows a double band MB antenna.

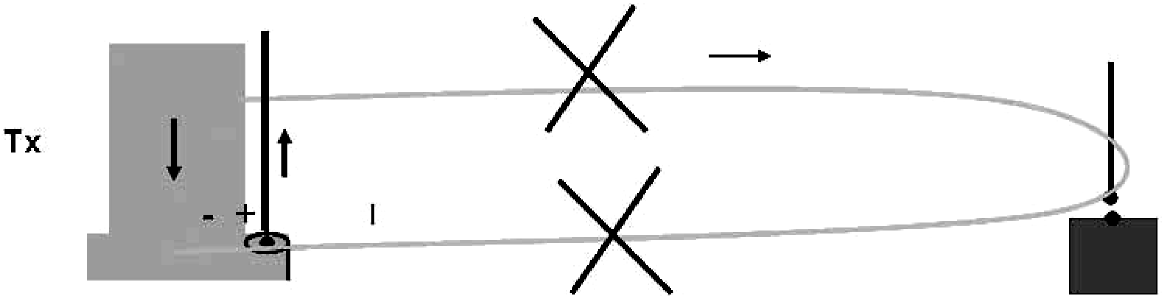


Fig. 7- Monopole in parallel to ground plane

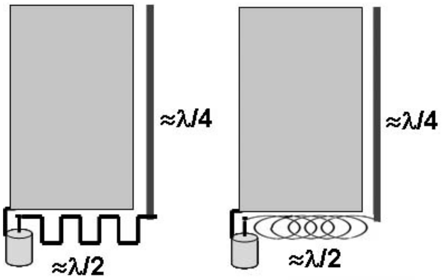


Fig.8- The MB antennas using different types of phase shifter

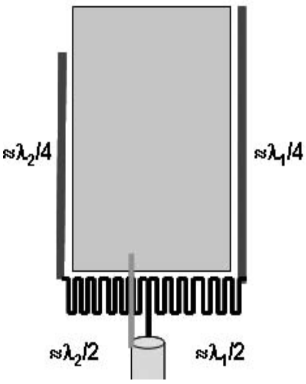


Fig. 9- Multiband MB antenna.

The PCB of the handset, used for the electronic hardware of the cellular phone, may act as the substrate and ground plane for the antenna. In this case, the radiating trace and the delay line, either one or both of them, can be printed on a certain area of the PCB provided that this area is a pure dielectric material.

V. SIMULATION RESULTS

The design and simulation of the proposed MB antenna was carried out using the CST Microwave Studio, and compared with a PIFA. The MB antenna and the PIFA were designed for two closely spaced centeral frequencies in the cellular frequency range.

Fig.'s 10 and 11 show the simulation results of the S11 characteristics for the MB antenna and the PIFA, respectively. The simulation results for the MB antenna (Fig. 10) show a S11 of -20dB at the resonance frequency.
As it can be seen in Fig. 11 the PIFA has a triple band.

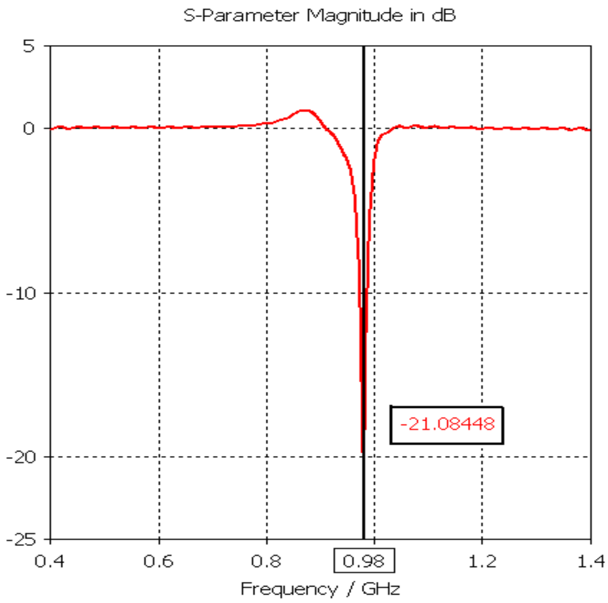


Fig. 10- S11 simulation results for the MB antenna

Simulations were carried out also for estimation of the SAR values, the antenna efficiency and directivity.
Fig.'s 12 and 13 show the far field simulation results for the MB antenna and PIFA. As it can be seen in these figures the gain of the MB antenna is 4.4 dB which is higher by 2.5 dB compared to PIFA's gain of 1.92 dB. In addition to its higher gain, the MB antenna exhibits a very low level of radiation in the vertical direction, as shown in Fig.12.

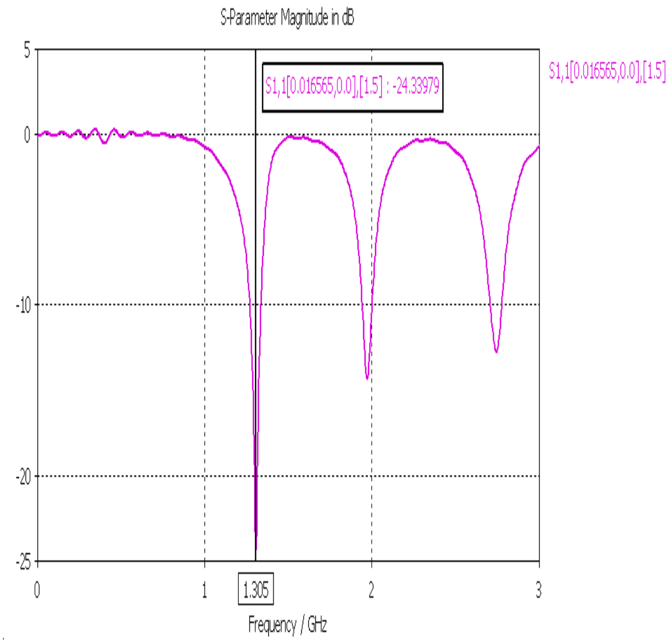
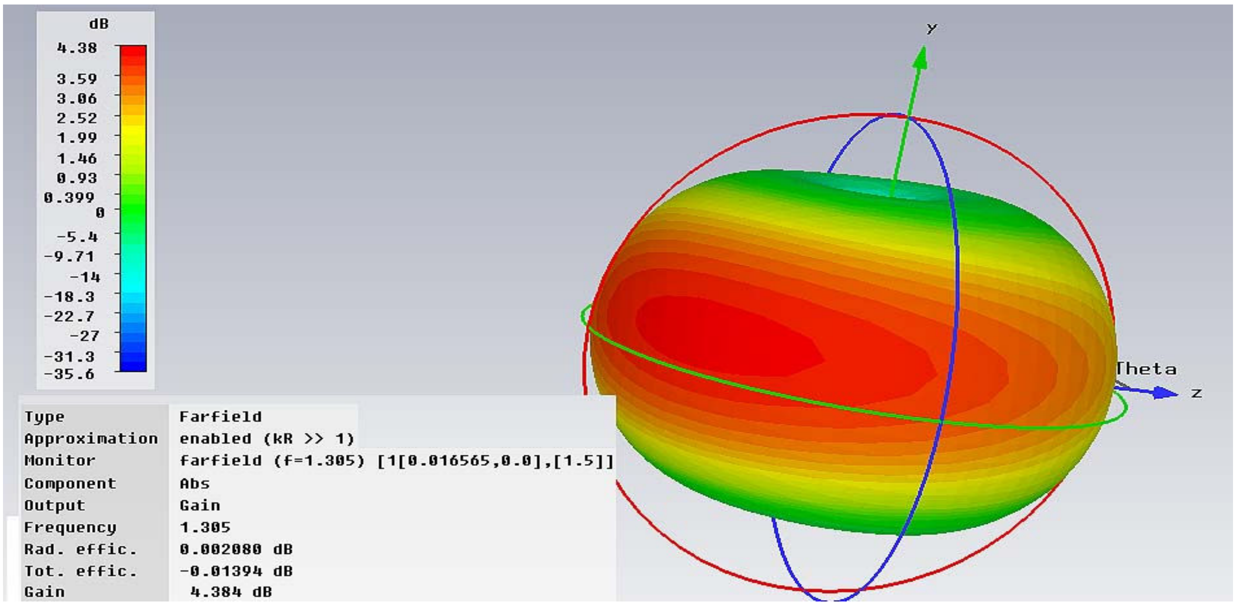


Fig. 11- S11 simulation results for the PIFA

Table 2 summarizes the main characteristics of the MB antenna, including SAR (Specific Absorption Rate) simulation results, in comparison to those of the PIFA. A detailed description of the SAR reduction method applied to the MB and PIFA is given in [6-9].

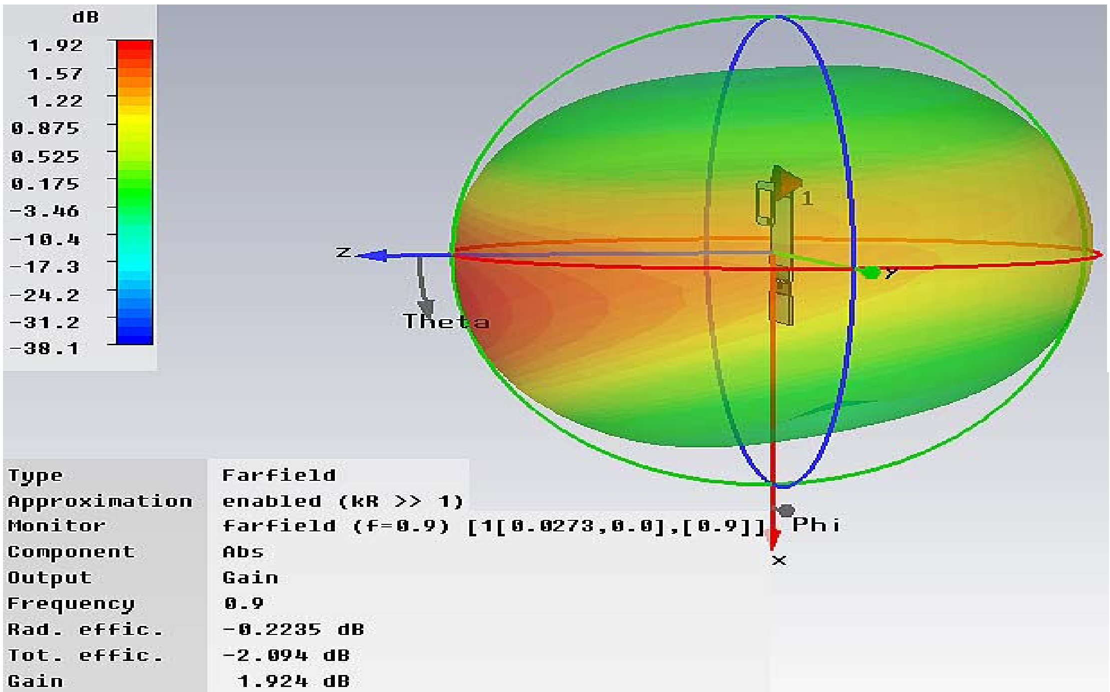
The simulation results presented in Table 2 and Fig.'s 12 and 13 clearly show that the MB antenna has superior performance over the PIFA in the main electrical parameters, including efficiency, directivity and gain. As seen in Fig. 13 the unwanted vertical radiation in the MB antenna is very small, as compared to the PIFA.

The MB antenna allows for increasing its effective height, and reducing the SAR level in the user's head [9].



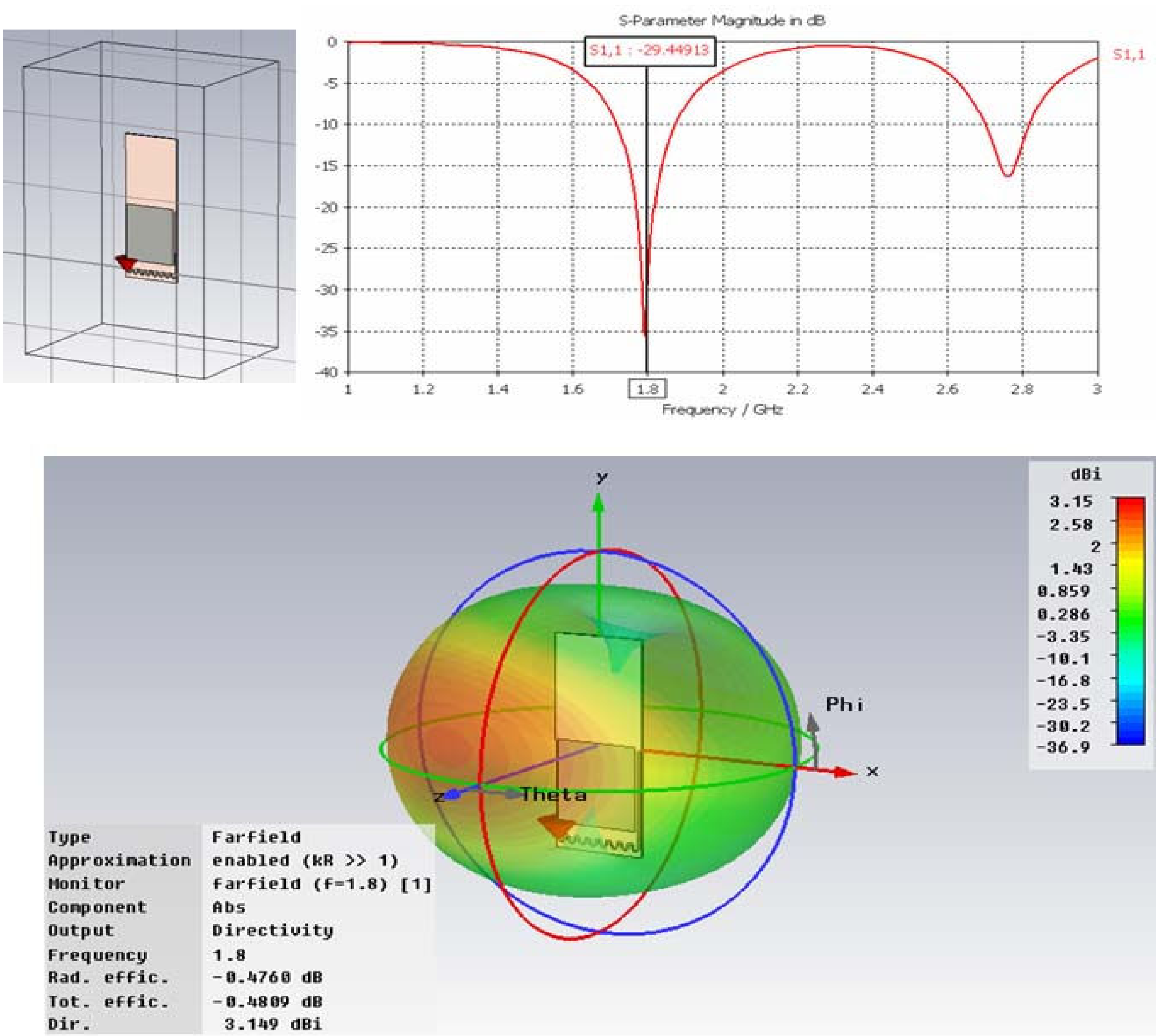
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.305) [1[0.016565,0.0],[1.5]]
Component	Abs
Output	Gain
Frequency	1.305
Rad. effic.	0.002080 dB
Tot. effic.	-0.01394 dB
Gain	4.384 dB

Fig. 12- Far field simulation results for the MB antenna.



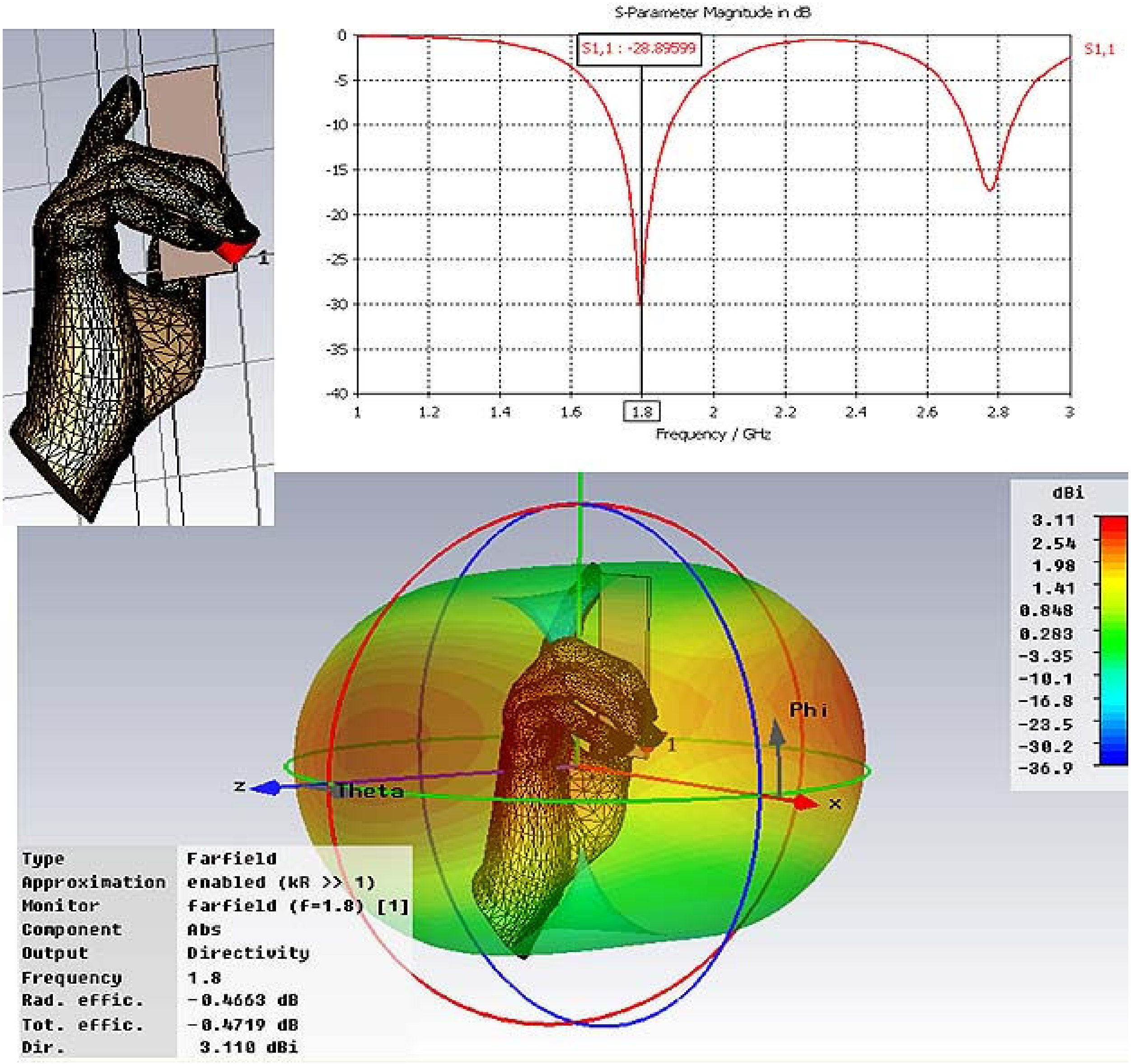
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=0.9) [1[0.0273,0.0],[0.9]]
Component	Abs
Output	Gain
Frequency	0.9
Rad. effic.	-0.2235 dB
Tot. effic.	-2.094 dB
Gain	1.924 dB

Fig. 13- Far field simulation results for PIFA.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.8) [1]
Component	Abs
Output	Directivity
Frequency	1.8
Rad. effic.	-0.4760 dB
Tot. effic.	-0.4809 dB
Dir.	3.149 dBi

Fig. 14 a - Simulation results for S11 and far field of the MB antenna in free space



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Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=1.8) [1]
Component       Abs
Output          Directivity
Frequency       1.8
Rad. effic.     -0.4663 dB
Tot. effic.     -0.4719 dB
Dir.             3.110 dBi
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Fig. 14 b- Simulation results for S11 and far field of the MB antenna held by the user

Table 2. comparison of PIFA and the MB antenna characteristics

Antenna type	Freq. [GHz]	S11 [dB]	Rad. efficiency [dB]	Total efficiency [dB]	Directivity Far field [dBi]	V_{in} at excitation port for E = 30mV/m at distance 5m, [mV]	Gain [dB]	Maximum SAR (rms ,1g) [W/kg]	Total SAR (rms) [W/kg]:
MB antenna	1.305	-21.1	-0.002	-0.0139	4.382	16.565	4.384	2.8×10^{-4}	2.0854×10^{-4}
PIFA	0.9	-24	-0.224	-2.094	2.148	27.3	1.92	2.69×10^{-3}	3.73×10^{-5}

The effect of user's hand on the MB antenna characteristics was studied using CST simulations. Fig. 14 shows the simulation results. The results for the case of free space (Fig.14a) are shown for comparison. As it can be seen from Fig.14b the MB antenna is relatively robust against hand effects.

The MB antenna has superior performance over PIFA in terms of compactness, gain, and radiation pattern. It can be used in MIMO antenna system where space limitation is of concern. The MB antenna lends its self well for implementation of the compensation method for SAR reduction in cellular handsets [9].

VI. CONCLUSIONS

In conclusion, we have presented a novel modified monopole antenna, which can be implemented in parallel to a ground plane.

The gain of the proposed MB antenna is larger by 2.5dB compared to PIFA.

The proposed antenna is particularly well suited for use as internal antenna in cellular handsets, in which the PCB acts as a ground plane. The influence of the user's hand on the antenna characteristics is relatively low. The gain of conventional monopoles in the transmitting and receiving modes as well as grounding effects of cellular handsets are also discussed.

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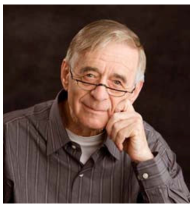

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