Radiation Performance and Specific Absorption Rate (SAR) Analysis of a Compact Dual Band Balanced Antenna

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***Abstract*—This paper presents a compact dual-band dipole antenna with meander line radiating elements. The proposed antenna has a balanced structure with dimensions of $35\times6\times1.52$ mm^3, and mounted on a 36.2×100 mm^2 floating ground plane. The balanced operation of the design is validated by incorporating a differential feed in the software simulation and a 180° hybrid junction is used for measurement with the network analyzer to verify the balanced concept of the prototype. Simulated and measured results of the S-parameters along with the de-tuning of the antenna in the presence of the human body shows good agreement. Moreover the proposed design is used as an exposure source to the simulated human head model. The human head is modeled as six layers in the Electromagnetic (EM) software HFSS to study the interaction between the proposed balanced antenna and the human head model. The Electric field (E-field) distribution in the six layers of the human head model is shown to estimate the penetration of the field when the antenna is placed at a distance of 7 mm from the proposed design. Also Local Specific Absorption Rates (SARs) and average SARs simulation results at 3.78 GHz and 4.29 GHz are shown. The SARs analysis showed that in all the six layers of the human head model, local SAR values are greater in fat and Cerebrospinal fluid (CSF) for both the frequencies while the average SAR values are not very high.**

***Index Terms*—Balanced antenna, Electromagnetic Interference (EMI).**

I. Introduction

Printed antennas are used in wireless devices such as cellular phones, cordless, wireless LAN Access points, GPS handheld devices, Personal digital assistants (PDAs), and Public switched telephone network (PSTN) series [1]. These patch antennas are not only miniature in size but also manufactured using simple and cost effective techniques [2], [3]. However, radiating currents can be induced on the ground planes of these antennas when they are being used in the devices held by users. This is because the ground planes of these antennas are in direct contact with the human hand/head that results in current flow in the body, which degrades the antenna performance, introduces mismatching, affect Specific Absorption Rates (SARs) and E-field penetration strength. Thus the main objective of this work is to consider a new balanced antenna design that is effected minimally by the presence of the user [4]. This phenomenon gives the main advantage of having almost negligible EMI with the human body. Moreover, the maximum SAR of these antennas are likely to be reduced when placed next to the user's head [5]. Antennas similar to dipoles are symmetric in nature and become balanced when fed with a differential source.

These balanced structures are a good choice for the PDA applications because of their property to mitigate the degradation caused by the human body and reduced SAR effect. Furthermore, current in the ground plane is remarkably reduced because of the differential current flow in the dipole antenna arms [6]. This also helps in the reduction of EMI caused by the integration of other electronic devices on the ground plane. The probable biological effects of the EM field with printed antennas using the HFSS equivalent head models have been reported in [7], [8], thus confirms the validation of these human head models for the evaluation of SARs values and E-field strengths.

In this paper the balanced antenna design is presented using a meandered type structure which reduces the physical size of the antenna. HFSS v. 13.0 [9] is used for the simulation of the design and optimization of the antenna dimensions at resonant bands. Moreover the equivalent six layer human head is modeled in HFSS using the dielectric properties of the head tissues given in [10]. The E-field strength in all six layers of the human head tissue is presented along with the SAR of the human head in the presence of the proposed dual-band balanced antenna.

II. Antenna Design Procedure, Structure and Head Equivalent Model

The proposed balanced antenna structure on a Rogers TMM4 substrate with ϵ_r=4.2 and a thickness of 1.52 mm is shown in Fig. 1(a). The geometry of the proposed antenna

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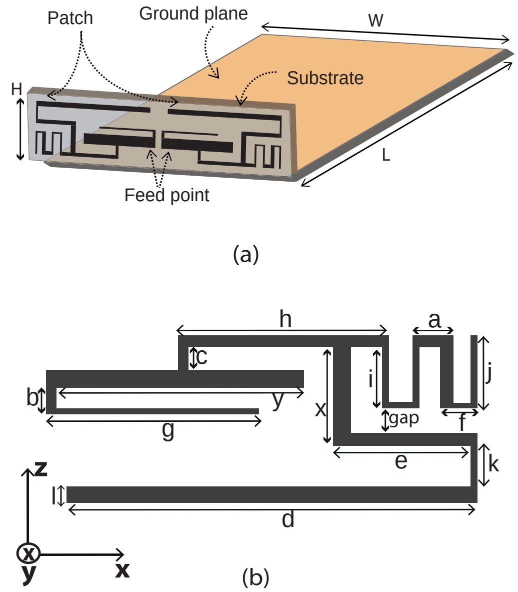

Fig. 1. (a). Configuration of proposed Microstrip Dipole antenna with L=100 mm, W=36.2 mm and H=6 mm. (b). Proposed Balanced antenna (a =1.4 mm, b=1.3 mm, c=0.7 mm, d=16.3 mm, e=4 mm, f=1.3 mm, g=9 mm, h=7.85 mm, i=2.2 mm, j=2.6 mm, k=1.2 mm, l=0.3 mm, x=3.4 mm, y=11 mm and gap=0.2 mm).

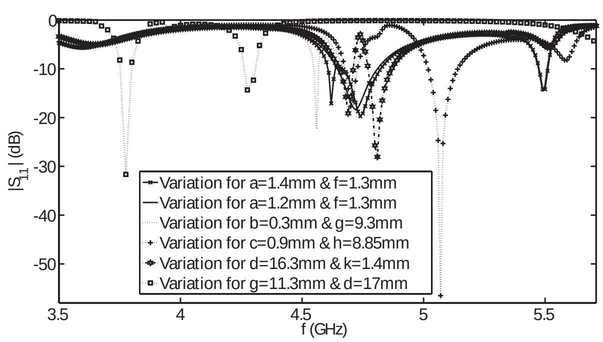

Fig. 2. Parametric Analysis.

with detailed dimensions is shown in Fig. 1(b). The antenna is fed using a coaxial line. Each arm of the proposed antenna contains three branches (y, g, and d), as shown in Fig. 1(b), while two extended branches (x, and h) elongating from the main strip (y) are responsible for the resonance at the require bands. Changing the length and width of these strips results in the shifting of the resonant bands. An extensive study of the proposed design shows that the length (a, b, c, d, e, f, g, h, and k) and width (i, b, and k) of the strips are responsible for the different resonant bands. The variation in length and width of the strips provide discontinuity in the current path also. A parametric analysis of the variations are shown in Fig. 2. It was noticed that introducing more meandered lines results in more resonant bands.

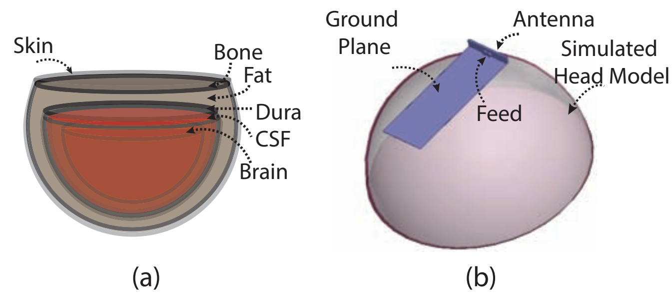

Fig. 3. (a). Six-Layer Equivalent Head Model (Side View) (b).Proposed Design as exposure source to the Head Model

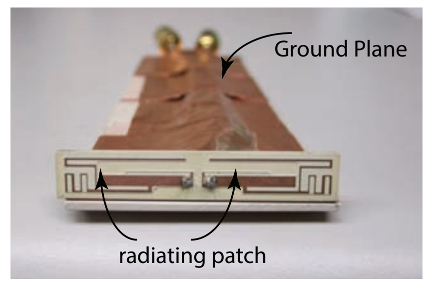

Fig. 4. Balanced antenna prototype.

Furthermore, the equivalent model of the human head with Skin, Fat, Bone, Dura, and Cerebrospinal Fluid (CSF) is modeled in the HFSS, as shown in Fig. 3(a). The thickness, mass densities of these six layer [8] and dielectric properties [10] of the human head tissues at 3.78 Ghz and 4.29 Ghz are used for defining all the six layers. In order to estimate the SARs value and E-field strength, the proposed antenna is used as the exposure source of an input power of 1W, as shown in Fig. 3(b).

III. Results and Discussion

The design with the optimized values (listed in Fig. 1(b)) was fabricated next and is shown in Fig. 4. The balanced antenna performance was measured in terms of its return loss by placing the design in isolation mode, with human hand alone, and with human head and hand both. These parameters were validated using HFSS and the S-Parameters were measured in a chamber using the network analyzer. Fig. 5 shows the measured and simulated results of the proposed design without using a balun [11] in the presence of the human hand and head. The antenna resonates at 3.78 GHz and 4.29 GHz with bandwidths of 80 MHz and 100 MHz, respectively. The balanced operation of the design was verified using a balun by measuring the S_{11} parameters in isolation mode and in the presence of the human head and hand, as illustrated in Fig. 6. The return loss is 25 dB at 3.78 GHz and 18 dB at 4.29 GHz. It was observed that there was lesser degradation in the $|S_{11}|$ parameters of the antenna in all positions, showing the advantage of using a balanced design. The current distribution

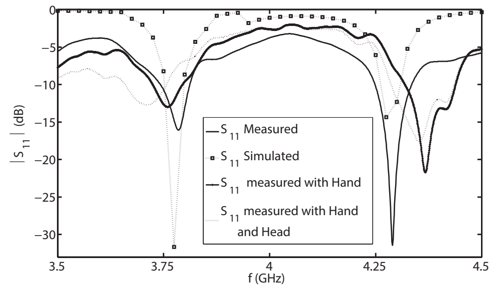

Fig. 5. S-parameters of the antenna without using Balun

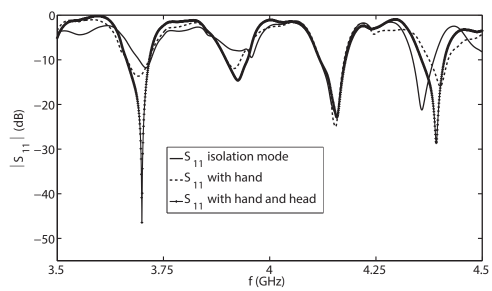

Fig. 6. S-Parameters of antenna using Balun.

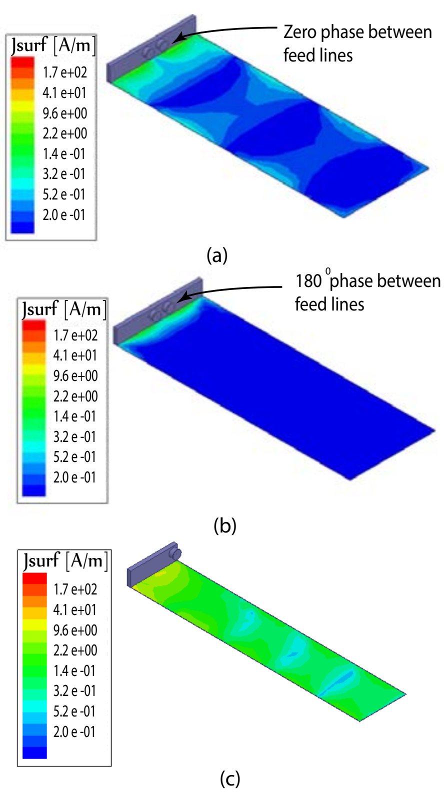

Fig. 7. Simulated ground plane current at 3.78 GHz for (a) Balanced antenna with zero phase (d) Balanced antenna with differential phase and (c) Unbalanced antenna. (similar results were observed at 4.29 GHz for a, b, and c)

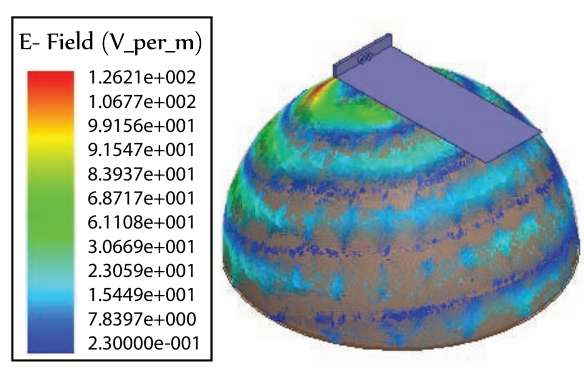

Fig. 8. E-field strength in the Skin tissue at 4.29 GHz

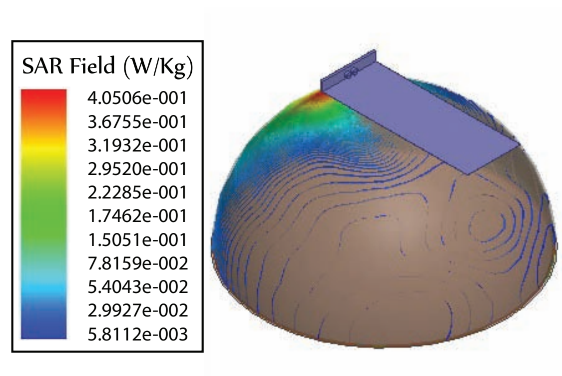

Fig. 9. Average SAR value of the Skin tissue at 4.29 GHz.

on the ground plane of the proposed antenna was simulated for the design with the in-phase feed currents, balanced design with the differential feed and the unbalanced design . It is shown in the Fig. 7 that the current distribution on the ground plane for the proposed balanced antenna is much lower than the unbalanced design and in-phase feed line. It is shown that with the balanced antenna design approach, the ground plane currents can be minimized, thus reducing the human body effects on the antenna performance, reduced SAR effect and E-field penetration strength in the human head.

Next, the E-field strength in the skin tissue at 4.29GHz is shown in the Fig. 8. The E-field strength is maximum at the nearest point of the proposed balanced antenna and has a minimum value away from the exposure source. Fig. 9 shows the average SAR value of the skin tissue because of the proposed balanced design. It was observed that the maximum average SAR value is 0.405 W/kg which is less than the US SAR Limit of 1.6 W/Kg.

Table I summarizes the local and average SAR values of the human head tissues. It is shown that at 3.78 GHz, the most affected tissues are fat tissue and the CSF tissue. This is because of the SAR dependence of these simulations on the layer distance and conductivity of the respective tissues, whereas in the rest of the tissues the local SAR value is less

TABLE I
LOCAL AND AVERAGE SAR VALUES IN THE HUMAN HEAD AT 3.78 GHZ AND 4.29 GHZ

Layer	Local SAR (3.78 GHz)	Average SAR (3.78 GHZ)	Local SAR (4.29 GHz)	Average SAR (4.29 GHz)
Skin	1.40E+00	4.05E-01	6.20E-01	4.05E-01
Fat	1.82E-01	1.80E-01	1.83E+01	8.1E-01
Bone	5.26E-01	4.30E-02	1.2E-01	5.01E-02
Dura	2.77E-01	4.60E-02	1.7E-01	4.82E-02
CSF	1.42E-01	1.42E+00	2.15E-0.1	8.34E+00
Brain	7.04E-01	3.78E-01	5.72E-02	5.7E-02

TABLE II
E-FIELD STRENGTH IN THE HUMAN HEAD TISSUES AT 3.78 GHZ AND 4.29 GHZ

Tissue	E-field strength (V/m) @3.78 GHz	E-field strength (V/m) @4.29 GHz
Skin	1.03E+02	1.2621E+02
Fat	1.85E+02	1.2750E+02
Bone	4.10E+02	1.2833E+02
Dura	1.1584E+02	1.2875E+02
CSF	1.118E+02	1.2827E+02
Brain	1.1586E+02	1.2880E+02

than 1.6 W/kg. Similarly, the local SAR value at 4.29 GHz is maximum for the fat and the CSF tissue, while the average SAR value is less than 1.6 W/kg. The E-field strengths (at both the frequencies) in all the six layers of the human head model are summarized in Table II. The simulation results showed that the E-field strength was maximum at the skin tissue and as it went further in to the inner tissues, strength decreased.

The local and average SAR values as a function of the distance between the human head model and the proposed design are shown in Fig. 10.

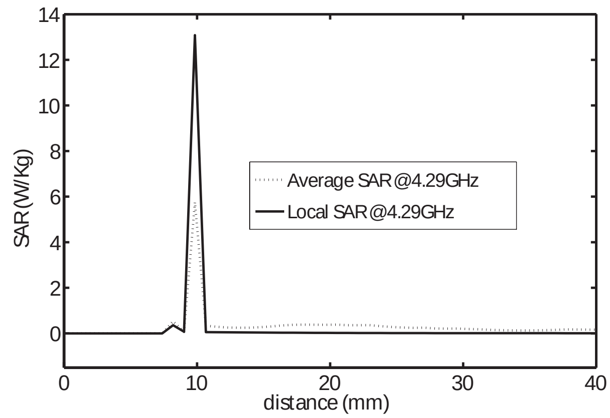

Fig. 10. Head model as a function of the distance between the proposed balanced design and the head model.

IV. CONCLUSION

A compact dual band balanced antenna for possible personal digital assistant (PDA) applications was presented in this paper. Moreover, a parametric study in HFSS on varying the geometric dimensions was also discussed. The balanced structure of the antenna was verified by providing the results of the return loss while placing the proposed antenna in close proximity to the human body. It was observed that the influence of the user's hand and head were negligible in the case of the balanced antenna design approach. Both the simulated and measured results showed good agreement. Moreover, analysis of the E-field strength, local SARs and average SARs were performed when the human head was exposed to the proposed balanced antenna. The results showed that field penetration strength was a maximum in skin tissues and a minimum in brain tissue. The proposed balanced antenna has reduced local SAR deposition at both the frequencies except for the fat tissue and the CSF tissue, whereas the average SAR deposition was observed to be less then 1.6 W/kg in the presence of the proposed balanced antenna. Simulations showed that with the balanced antenna design approach, the ground plane currents can be minimized. This then mitigates the degradation caused by the human body, reduction in SAR and less E-field strength to the inner head tissues.

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