Coaxial fed defected ground plane square apertures loaded patch antenna

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Abstract. This research paper deals with the design of coaxial fed patch antennas with defected ground planes and square apertures. This antennas work for different applications such as Bluetooth, mobile communication, and biomedical applications. The antenna has resonating frequency at 2.45 GHz and bandwidth is 20%, so antenna has wide range of applications near 2.4 GHz bandwidth. There is slight deviation in theoretical result this is because of assumption made while calculation of S11(dB) such as slots and notches on the patch but actually it is square ring like structure.

Keywords: Apertures, compact antenna, defected ground plane, co-axial fed.

1. Introduction
Form the past few years, significant progress has been made to develop implantable antennas to observe the patients health conditions. This wireless technology adds a new dimension to medical implants that allow remote monitoring and improved treatment. The implanted antennas that are placed in the human tissue must communicate with external devices and data should be collected. Some patients who have the antenna implanted in their tissue regularly return to the hospital for checkups or in case of any health problems, where their status and the status of the implant are verified, while certain patients might require check up everyday. Once the device has been implanted within the human body, it is not removed again for maintenance or even for the replacement of the battery unless absolutely necessary, in case if the patient needs to remove the antenna then he has to undergo further surgery. There are a lot of different technologies possible for wireless communication using implanted devices has been reported.

Kumar[1] detailed analysis performed emphasises on the local temperature elevation/advancement generated by a dual-band implantable antenna was designed for detecting the Intracranial Pressure Monitoring Application. A study of the temperature elevation is carried out in Scientific and Medical Radio(ISM) band. Also the heat dissipation of heat produced inside the human anatomical body was investigated and scrutinized. Amendola [2] studied and examined from a wearable on-body transmit antenna that can be placed into the body.

Srinivasan and Kumar[3] the paper apprises us about the substantial attention received by the implantable for medical for medical purposes and also for diagnosis and CPW fed implant antenna was reported [4]. Shakib [5] the manuscript notifies about the implantable broadband antenna which short patch with line fed for WMTS. Lee[6], incites us about an implantable antenna which is rectangular spiral in shape with U-shaped loop. The proposed Antenna is normally analysed and
designed for medical biotelemetry in (MICS) frequency band which is of the range 402 – 405 MHz. Samal [7] analyses the desired antenna has been analysed and designed for biomedical applications in human body. Compared to other semiconductors, this substrate chosen has an easier fabrication process. The designed antenna is being intended to be used on the skin as well as inside the body by taking into account tissue parameters and other factors. Yuan [8] designed on chip RF energy harvesting antenna for biomedical application. Further, Scarpello [9] reported and tested antenna for implanting over body phantom made up of PDMS. Mak [10] designed antenna for 5 G application through which one can monitor sick patient. In above reported papers are of biomedical antennas that has been used to monitoring the patients. These manuscripts lack design optimization of antennas and SAR on human body for normal and sick patients.

In this view, coaxial fed rectangular patch antenna for biomedical and wireless applications has been presented.

2. Antenna Design

The coaxial fed with crossed shaped ground plane patch antenna is manufactured on using a dielectric constant $\varepsilon_r=10.2$ and its top surface is laminated by supersubstrate. Considering the miniaturization requirement, the radiation surface is designed with several number of slots etched from the surface at the edges of square patch taper is cut of triangular shape. The path of the current is expected to be induced in the edges of top radiating patch. On top of the super-substrate a patch is embedded firmly which consists of dimensions slightly less than that of substrate. The material used for ground in this paper is pure copper, while the material of the substrate which is affixed on the ground plane is made of Rogers 3010 substrate. The material used for the patch is pure conducting material.

Figure 1(a) shows the side view of the coaxial fed with crossed shaped ground plane patch antenna. In this view, the patch antenna placed above the substrate. The patch is truncated at the square patch edges as shown in the figure 1(b). Figure (c) show the back side of antenna on which crossed shape is etched. Antenna is designed and simulated on CST microwave Studio Suite [11].
3. Theoretical Analysis

A coaxial fed defected ground plane square apertures loaded patch antenna[12] can be represented into equivalent circuit diagram of series and parallel resistance (R), inductance (L), and capacitance (C) components. Rectangular patch coaxial fed defected ground plane square apertures loaded patch antenna can be represent as parallel combination of capacitance $C_{cp}$, inductance $L_{cp}$, and resistance $R_{cp}$ as shown in figure 2(a) and equation are given as [13],

$$C_{cp} = \frac{LW_{s}E_{r}e}{2L}\cos^{2}(\pi Y_{o} / L)$$ \hspace{1cm} (1)

$$R_{cp} = Q / \omega^{2}C_{cp}$$ \hspace{1cm} (2)

$$L_{cp} = 1 / \omega^{2}C_{cp}$$ \hspace{1cm} (3)

As per design aperture is etched on the patch that is give as impedance of slot $Z_{sh}$ and $Z_{sh}$ is connected in parallel to $Z_{cp}$ impedance, the equivalent circuit is shown in figure 2(b)
Figure 2. Equivalent circuit of coaxial fed defected ground plane square apertures loaded patch antenna (a) rectangular patch and (b) slots.

Now, similarly for X-shaped ground plane of rectangular patch of coaxial fed antenna can be represented into similar circuit diagrams for slots and ground patch. Replacing the parallel combination of capacitance $C_{gp}$, inductance $L_{gp}$, and resistance $R_{gp}$ as shown in figure 3(a) and same equations can be from 1 to 3 for calculation components. Similarly for figure 3(b) replacing the impedance notations for ground slot $Z_{gsl}$ and ground patch $Z_{gp}$.

![Figure 3. Equivalent circuit of crossed-shaped ground plane (a) rectangular patch and (b) slots.](image)

Due to finite ground plane and rectangular patch, there will be mutual inductance and capacitance between radiating patch and ground plane. The equivalent circuit diagram can be given as shown in figure 4

![Figure 4. Equivalent circuit diagram of mutual induction and capacitance for radiating patch and ground plane.](image)

Therefore, total input impedance of the coaxial fed rectangular patch antenna with X-shaped ground plane is shown figure 5

![Figure 5. Equivalent circuit diagram of coaxial fed defected ground plane square apertures loaded patch antenna.](image)

$$Z = \left( \frac{Z_{cp}Z_{gp}Z_{mg}}{Z_{cp} + Z_{gp} + Z_{mg}} \right)$$  \hspace{1cm} (4)

From equation (4), the total input impedance of coaxial fed defected ground plane square apertures loaded patch antenna can be calculated. Using this input impedance $S_{11}$ (dB) and voltage standing wave ratio (VSWR) can be calculated.
Reflection Coefficient $\Gamma = \frac{Z_0 - Z}{Z_0 + Z}$,
where $Z_0$ is the input impedance of the coaxial feed (50 $\Omega$).

Using these circuits and formulas, theoretically $S_{11}$ (dB) is calculated in next section and results are discussed.

4. Results and Discussions
The co-axial fed defected ground plane square apertures loaded patch antenna with and without super substrate is shown in figure 6. It is observed from the figure that with and without super-substrate both are resonating at 2.4 GHz and it is found that proposed antenna has higher bandwidth with super-substrate. It can be used for lots of applications such as Bluetooth, mobile communication, and biomedical applications.

![Figure 6](image_url)

*Figure 6.* Comparison of coaxial fed defected ground plane square apertures loaded patch antenna with and without super-substrate.

Figure 7 shows the reflection coefficient of rectangular coaxial fed defected ground plane square apertures loaded patch antenna and super-substrate. It is observed that results are in close agreement with reported results [12]. The bandwidth is 20%, so antenna has wide range of applications near 2.4 GHz bandwidth. There is slight deviation in theoretical result this is because of assumption made while calculation of $S_{11}$(dB) such as slots and notches on the patch but actually it is square ring like structure.
Figure 7. Comparison results of coaxial fed defected ground plane square apertures loaded patch antenna.

From figure 8, it is observed that electric energy density of antenna on placing above the head at 1mm for detection of tumour. Maximum electric energy density was observed to be $2.0339 \times 10^{-4} \text{ J/m}^3$. Further, power loss due to absorption in human body is under acceptable range.

Figure 8. Electric energy density of coaxial fed defected ground plane square apertures loaded patch antenna placed on human body.

Figure 9 shows the radiation pattern of coaxial fed defected ground plane square apertures loaded patch antenna. From figure 9(a) it is observed that antenna radiated in broadside direction with angular beam of 103.8° in H plane whereas minor lobe is also observed at 2.4 GHz. From figure 9(b) it is observed that E plane radiation pattern has broadside radiation for $\theta=0$ and angular beam width is observed to be 100.2. Further, figure 9 (c) shows the farfield directivity of rectangular patch antenna with X-shaped ground plane. It is observed that main lobe magnitude of antenna is -32dBi and side lobe is -2.2 dBi whereas angular beam width is 115.4°.
Figure 9. Radiation pattern of coaxial fed defected ground plane square apertures loaded patch (a) H-plane (b) E-plane and (c) Directivity at phi=90degree.
5. Conclusion
The theoretical and simulation investigation of coaxial fed defected ground plane square apertures loaded patch antenna have been presented. The defected ground plane square apertures loaded patch antenna depends on ground slots, patch slots and supersubstrate. Further, it also observed that simulation results obtained using CST microwave studio suite matches with theoretical done using circuit theory concept and these both results matches with reported measured results. An antenna with supersubstrate the broadband is observed at 2.4 GHz of 20% bandwidth. It is also observed that antenna electric density and SAR are in acceptable range. The coaxial fed defected ground plane square apertures loaded patch antenna can be used for biomedical and wireless applications.

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