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Design, Analysis and Modeling of Dual Band Microstrip Loop Antenna Using Defective Ground Plane

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***Abstract*—**Present wireless communication demands compact and intelligent devices with multitasking capabilities at affordable cost. The focus in the presented paper is on a dual band antenna for wireless communication with the capability of operating at two frequency bands with same structure. Two resonance frequencies are observed with the second operation band at 4.2GHz approximately three times the first resonance frequency at 1.5GHz. Structure is simple loop of microstrip line with characteristic impedance 50 ohms. The proposed antenna is designed using defective ground structure (DGS) and shows the nearly one third reductions in size as compared to without DGS. This antenna was simulated on electromagnetic (EM) simulation software and fabricated using microwave integrated circuit technique on RT-Duroid dielectric substrate (ε_r= 2.22) of thickness (H=15 mils). The designed antenna was tested on automatic network analyzer and shows the good agreement with simulated results. The proposed structure is modeled into an equivalent electrical circuit and simulated on circuit simulator. Subsequently, theoretical analysis was carried out and simulated. The simulated, measured, equivalent circuit response, and theoretical results shows good resemblance. The bands of operation draw many potential applications in today's wireless communication.

***Keywords*—**Defective Ground plane, Dual band, Loop Antenna, Microstrip antenna, Resonance frequency.

I. Introduction

COMMUNICATION is the essence of life and improvement is the curiosity of human mind. Technical advancements in the present and upcoming generations of communication are most commonly being implemented with microstrip antennas because of their lucrative features such as small size, light weight, low cost, conformability to planar and non-planar surfaces, rigid, and easy installation. Microstrip antennas have a wide range of application in wireless communication especially in mobile communications devices and are becoming more general due to low cost and versatile designs.

Recently, dual-band cellular phones capable of operating in two different cellular systems are increasing. A cellular phone operating at both frequencies requires the antenna to operate equally well at both frequency bands. Dual-band antenna are not used in cellular networks alone, in fact, they are widely used for dual-band ISM applications. As an example, many laptop computers use 900MHz or 1800MHz band for wireless printer and modem connections. The 2400MHz band is used by laptops in wireless local area network (LAN) applications and the Bluetooth is being considered as a cable replacement between portable and fixed electronic devices. The dual frequency planar circularly polarized antenna at S- and L-bands [1], [2], dual polarized dual band microstrip antenna for wireless communications [3] are the designs proposed for microstrip antennas operating in two frequency bands and a compact dual-band microstrip-fed monopole antenna [4] is a design showing two frequency bands of operation for a monopole antenna design, one more compact dual band design is proposed in [5]. To get dual band operation one parasitic inverted-L wire is placed at the side of the inverted-L-folded antenna in [6], in [7] dual-frequency antenna consists of two patches for the upper band and a single patch for the lower band. In some designs by strategically placing two varactor diodes along a bent slot antenna, So many other designs of the dual band antenna are proposed so far but the basic problem arising in these antennas is that these all designs are based on different feeding circuitry for different frequency gaining design but, the design of dual band suggested in this paper is a microstrip line designing which uses the concept of multiple resonance frequency and showing the two frequency bands for the same structure with same feeding circuitry.

The single-turn loop antenna is a metallic conductor bent into the shape of a closed curve, such as a circle or a square, with a gap in the conductor to form the terminals [8]. The electromagnetic field of an electrically small loop antenna is the same as that of a magnetic dipole with moment m =I_0NA, where I_0 = current in the loop, N = no. of turns in loop, A = effective area of loop [9]. Initially the wire loops were implemented for frequencies up to few hundred Mega Hertz like [10] was an implementation of loop for short range radio communication. However for high frequency applications the size of the loop can further be reduced using a microstrip printed loop. Various designs for high frequency microstrip loops are reported as [11] has a reconfigurable microstrip loop by switching the operating frequency by means of physical switches inserted to change the loop dimensions. In the previously reported articles [12] the design was simulated on silicon substrate and the same design was transformed on the RT-Duroid substrate to get a size reduction of 1/3 by inclusion

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of defective ground plane, the fact observed is that the size of the loop required to obtain the frequency of 1.5GHz with full ground is 176mm but the size reduces to 66mm (almost one-third) for the same operating frequency while using a defected ground structure [13]. In such a technique named *defected ground structure* or DGS, the ground plane metal of a microstrip (or stripline, or coplanar waveguide) circuit is intentionally modified to enhance performance [14]. The DGS helps in shifting the resonant frequency to get desired frequency [15], by combining with a defective ground plane, the bandwidth is augmented and the resonant frequency is lowed simultaneously [16]. The design is very compact and integrated with the inclusion of a defected ground structure. An electrical equivalent circuit is proposed for the design and the results have resemblance in simulation (with and without defective ground), measurement and for the proposed equivalent resembles to each other. Second section describes the basic designing of the antenna and structure after fabrication. Simulation and measurement results are discussed in the third section; an analysis of the loop presented is there in section four and finally the article is concluded in fifth section.

II. Proposed Design Structure

The antenna is designed using 1.22mm wide metal lines printed on a RT-Duroid substrate (ε_r= 2.22) of thickness (H=15mils) it works like a coplanar waveguide microstrip line of Z_0=50ohm [17]. The loop perimeter can be adjusted according to resonance frequency.

A. Design Equations

As a general observation loop perimeter is compatible to wavelength. The width of the strip as shown in Fig. 1 is calculated using the formula for microstrip line [9]

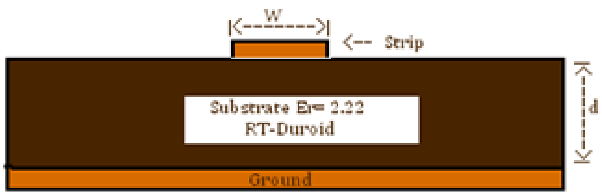


Fig. 1 The cross sectional view of microstrip antenna

W= 1.2mm is the calculated value for given ϵ_r= 2.22, Z_0= 50ohm, and d= 0.37mm. To design the loop for any frequency (f) the loop perimeter must be of the order of wave length(λ).

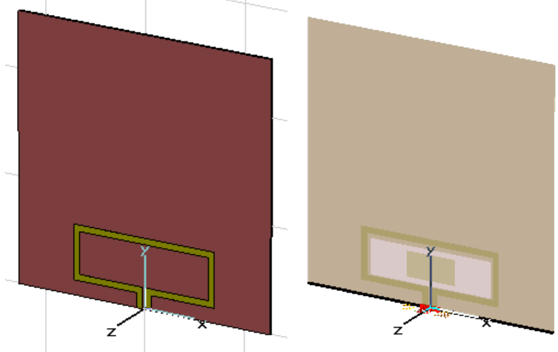
$$\lambda = \frac{1}{f\sqrt{\epsilon_{reff}\epsilon_0\mu_0}} \tag{1}$$

The value of ϵ_{reff} can be calculated using ϵ_r= 2.22, d=0.37mm, and calculated value of *W*.

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\frac{1}{\sqrt{1+12d/W}} \tag{2}$$

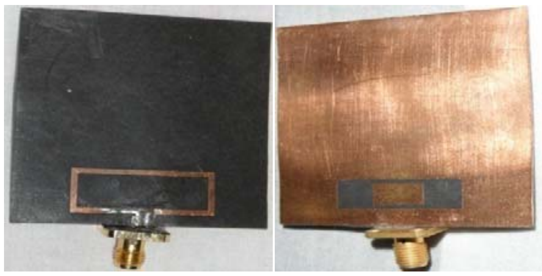
By using (1) and (2), the calculated value of λ=146mm at f= 1.5GHz is obtained, while optimized loop dimension is obtained by simulation, the best results are observed at loop perimeter 176mm. This simulation is carried out on electromagnetic (EM) simulation software. Further inclusion of defect in the ground plane, it reduces the loop perimeter dramatically to 66mm for the same designed frequency [13]. The size of loop antenna using DGS is reduced nearly one third in comparison to without DGS. The both structures are simulated using same dielectric substrate.

B. Structure of Loop Antenna



(a) (b)

Fig. 2 Proposed microstrip loop antenna (a) top view (d) bottom view with defective ground plane



(a) (b)

Fig. 3 Fabricated structure of loop antenna with DGS (a) top view (b) bottom view

Fig. 2 shows the top and bottom view of the antenna which is the loop structure printed using the metal lines on top and metallic ground plane. The ground below the loop is cut out and a small metal strip is placed at the loop center for the effective convergence of the field which is also responsible for reduction in size. This structure was later fabricated using microwave integrated circuit (MIC) fabrication technique; Fig. 3 shows the snaps of bottom and top view of fabricated structure. The rectangular loop [13] used in design is very easy to reconfigure according to needed combination of resonance frequencies by changing the length of the antenna with keeping width constant so without any alteration in the feeding circuitry.

III. Simulation and Measurement Result

The microstrip patch antenna is simulated using electromagnetic (EM) simulation software that is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the S_{11} parameters, VSWR, current distributions as well as the radiation pattern. Computer simulations were done for different loop perimeter and results were optimized for a center frequency of 1.5GHz. As an observation as the loop perimeter increase the resonance frequencies decreases. The optimized results for the return loss, for both full ground and partial ground structures are shown in Fig. 4.

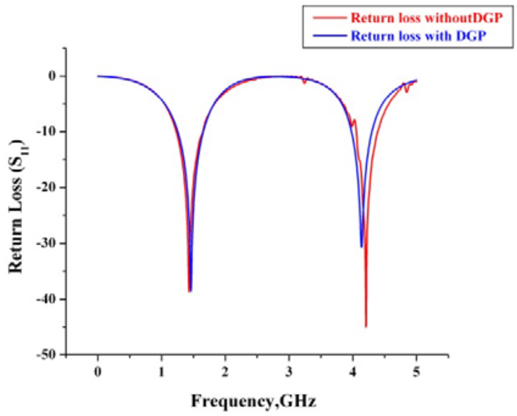


Fig. 4 Simulated return loss of loop antenna with and without DGS.

Percentage bandwidth of the return loss at -10dB point for first frequency band comes out to be 27.4% while that for the second frequency band is 9.5% at operating frequencies 1.5GHz and 4.2GHz respectively. Optimum simulated structure with defective ground plane was fabricated using MIC fabrication technique. The fabricated antenna was tested on automatic vector network analyzer (VNA) and measured results are shown in Fig. 5. It can be observed from the comparison graph (Fig. 5), the simulated and measured results have a good agreement with each other; however, there is a slight shift in first resonance frequency that is due to the measurement and fabrication limitation. The first resonance frequency is slightly shifted to 1.8GHz from 1.5GHz, while the second resonance frequency is almost same for measured as well as simulated results.

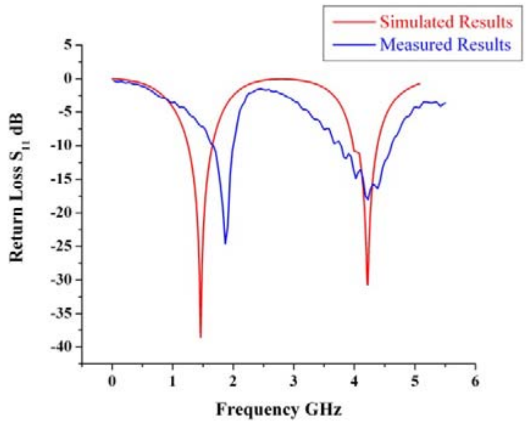


Fig. 5 Measured return loss of loop antenna with DGS

IV. Equivalent Circuit and Analysis of Loop Antenna

A conducting wire can be represented by a combination of inductance and capacitance, simple wire loop the loop inductance is usually considered to be parallel resonated with a variable tuning capacitor so that the driver sees a large real load which must be matched for optimum power delivery [10]. Loop is printed as a microstrip line which has two conductors and a homogenous dielectric that is shown in Fig. 6.

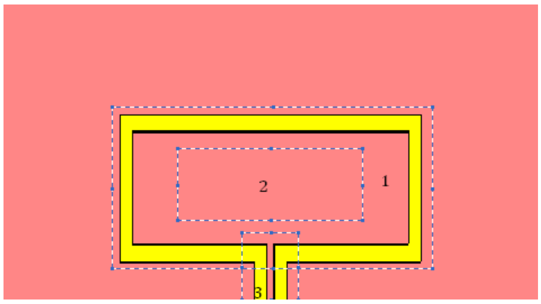


Fig. 6 Sectional view of loop antenna with DGS

The proposed structure of loop antenna with DGS is divided into three sections which are basically resonating cavities, section 1 contains over all loop which equivalently forms a resonating cavity with a large impedance because of a large conducting microstrip strip line while the part of strip line used for feeding the loop in section 3 forms a cavity with relatively small impedance. Section 2 contains metallic strip on the back side at the ground plane immersed in the center of void space of defective ground structure forming the third resonating cavity. Each resonating cavity can equivalently replaced by a parallel LC combination. An additional grounding capacitor is also added to justify the capacitance due to a parallel plate structure formed by two ends of feed lines. Finally, the proposed equivalent circuit of loop antenna with DGS is shown in Fig. 7. The optimized values of components are as follows; L1=2500nH, C1=1.04pF, L2=5.45nH, C2=0.9pF, L3=1.05nH, C3=1.0pF, RL=50 ohms, and C4=0.1pF.

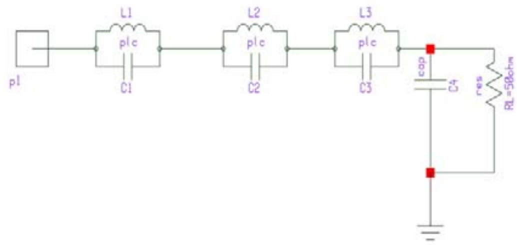


Fig. 7 Proposed equivalent circuit of loop antenna with DGS

Further, transfer function is derived for proposed equivalent circuit of loop antenna with DGS and that is shown by (3).

$$Z_{in} = \frac{L_1 s}{1+L_1C_1s^2} + \frac{L_2 s}{1+L_2C_2s^2} + \frac{L_3 s}{1+L_3C_3s^2} + \frac{R}{1+RCs} \quad (3)$$

After calculating this transfer function (Z_{in}), it is translated in the form return loss represented by (4):

$$S_{11}(dB) = 20 \log \left[\frac{Z_{in}-Z_0}{Z_{in}+Z_0}\right] \quad (4)$$

From (3) of the transfer function, it is clear that it is a function of frequency. The theoretical return loss is calculated with (4) and the frequency response graph of loop antenna with DGS is drawn using mathematical plotter that is shown in Fig. 8.

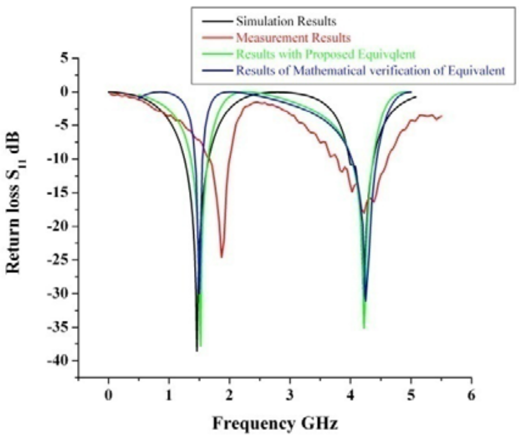


Fig. 8 Overall comparison of return loss of loop antenna with DGS

Fig. 8 shows the comparison of simulated, measured, response of proposed equivalent circuit, and its mathematical model of proposed loop antenna with DGS. All these results show the close agreement.

V. Conclusion

Design, analysis and modeling of dual band microstrip rectangular loop antenna using defective ground structure is presented in this paper. As an observation the resonating structure of conventional loop antenna can also be modeled using a microstrip line with suitable design equations and transformations. The designed loop dual band antenna with a single feed structure shows the resonance frequency of the loop antenna is the inverse function of its loop perimeter. The proposed design shows the defective ground structure (DGS) is an effective technique to reduce the size of antenna as the dimensions of the loop antenna are reduced by almost a factor of three with the implementation of defective ground plane while presenting no significant change in frequency response. A resonating circuit like antenna can be modeled in the form of basic circuit elements like inductor and capacitor. Design is compact and multitasking capable with operating capability in two frequency bands. It can find application in various wireless communication utilities requiring a dual band operation.

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