Design and Simulation of Metamaterial based Terahertz Antenna for Satellite Imaging Application

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I. INTRODUCTION

Abstract—A novel compact, planar, and coplanar waveguide (CPW) -fed antenna is designed and proposed using composite metamaterial. Such composite metamaterial consists of an inner split-ring resonator (SRR) and an outer closed-ring resonator (CRR). The composite metamaterial can provide frequency at 0.285THz with reflection coefficient better than -10 dB by the resonant modes of SRR and CRR, respectively. A CPW-fed line with trapeziform ground plane and tapered impedance transformer line is employed to improve the impedance matching of the antenna. In this paper presents design, and characterization of a planar and compact CPW-fed antenna with composite metamaterial. The proposed antenna is designed for 0.285THz using CST Microwave studio. For validation of the proposed work, the structure is scaled down at the frequency of 2.45GHz have been simulated, fabricated on FR4, and tested. The simulation of THz antenna show return loss of about – 26.7dB at frequency of 0.285THz. Gain around 9dBi which is better than conventional antenna due to the collimation effect. Compared result of simulation & measured coefficients of both return loss and gain shows the enhanced gain by composite metamaterial antenna which is suitable for satellite imaging application in terahertz frequency.

Index Terms—Dual-band antenna, metamaterials, planar antenna, split-ring resonator (SRR).

RECENT progress in the design of metamaterial antennas has attracted comprehensive research interests in wireless

It is well known that impedance matching is a challenge when designing electrically small antennas because of their high reactance and low radiation resistance [32]. To overcome this, we employ a CPW line, consisting of trapeziform ground plane and tapered impedance transformer line, to feed the antenna. The trapeziform ground plane has two bases with lengths d1 and d2 the vertical lateral side l. The width of the tapered transmission line at the feed point is w_f, and the widths of the other tapered transmission lines are

$$w_n = \alpha^n + w_f \qquad (n = 1,2) \;\ldots\ldots\ldots \qquad (1)$$

communications, radio frequency identifications, microwave energy harvesting, wireless sensor networks, as well as multiple-input–multiple-output systems because it can reduce the numbers of antennas, improve the space usage, and save the cost as much as possible. Compared to conventional antennas (e.g., horn antenna or Yagi–Uda antenna), microstrip antennas [1]–[4] have advantages of light weight, low profile, High Gain and allow easy integration with surface-mount devices.

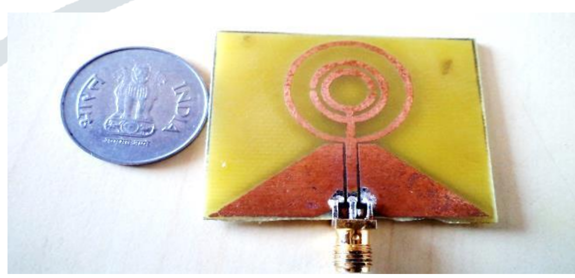
By etching slots (e.g., L-shaped or U-shaped slots) on the surface of a planar antenna or shortening pins, the planar antenna can be operated in two frequency bands [7]–[11].

Metamaterials [15]–[18] are a kind of artificially structured media that have unnatural properties derived from their sub wavelength configurations rather than the composite materials, leading to many exciting capabilities for electromagnetic applications [19], [20]. A split-ring resonator (SRR) [15], consisting of two concentric metallic rings with splits at opposite sides, is one of the fundamental elements for constructing metamaterials. The SRR can behave as an artificial magnetic metamaterials with a high quality factor, opening a novel approach for antenna miniaturization [21]–[29].

However, the radiation patterns of this antenna cannot be maintained symmetric in the -plane and omnidirectional in the -plane when the SRR works at high frequency since the SRR is asymmetric and cannot be regarded as an electrically small resonator when the radiation wavelength is comparable to its size. However, this antenna requires a multilayer structure and an inductive/capacitive coupling feeding network.

In this letter, we present the design, and characterization of a planar and compact CPW-fed antenna with composite metamaterial. Such composite metamaterials consists of an inner SRR and an outer closed-ring resonator (CRR) in order to drive two different resonant modes. One of the effective ways to obtain high gain with narrow beam width in metamaterial antenna, A possible explanation of this effect is based upon the fact that in the operating frequency band the structure behaves as a metallic metamaterials with a near-zero negative refractive index. For example, for near zero positive refractive index and dielectric photonic crystal exhibiting near zero negative refraction indexes can be generated high gain. The proposed antenna is designed by using Advanced Design Simulation-2009 and is fabricated.

II. ANTENNA DESIGN



In Fig. 1(a), we give a schematic diagram of the scale down planar compact CPW-fed antenna using composite metamaterial, is shown in Fig. 1(b).

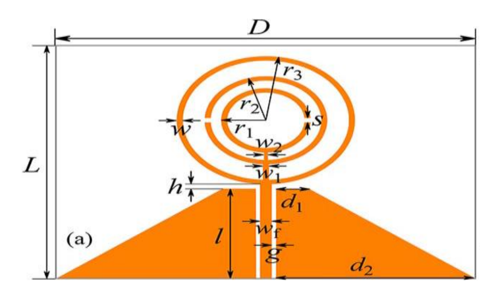


Fig. 1. (a) Schematic presentation of the planar compact CPW-fed dual-band antenna, which consists of a composite metamaterial (SRR+CRR) and a CPW-fed line.

where the coefficient α can be optimized by numerical simulations. It is expected that the proposed antenna shows high gain. In such a way, the composite metamaterials with outer CRR and inner SRR can provide two resonant modes with high gain while keeping a compact size. It should be pointed out that this design can maximize maintaining a good omnidirectional radiation pattern in the H-plane and a typical figure eight radiation pattern in the E-plane. This is because although the SRR is an asymmetric structure (especially for very high frequencies). Without loss of generality, the frequency of the resonant dominant mode of a CRR can be approximately determined by using a transmission-line model [33]

$$fclosed = \frac{c}{[2\pi r_3\sqrt{Re(\varepsilon r)}]} \quad (2)$$

where is the speed of light in free space. The overall size of the antenna is D x L, and it is fabricated by etching the 35μm-thick copper pattern on a 1.6-mm-thick FR4 epoxy substrate (relative permittivity εr =4.4+0.888i).As shown in Fig. 1(a), the three rings have radii r1,r2,r3 and from inside to outside, respectively, all the rings have an equal width , and the widths of the SRR's splits are equal to be .The spacing between the signal strip and the coplanar ground plane is g, and the gap between the feed point and the ground plane is h .

$$fSRR = \frac{c}{2\pi^2}\sqrt{\frac{3(r2-r1+\omega)}{Re(\varepsilon r)\, r1^3}} \quad (3)$$

It is worth mentioning that the coupling between the CRR and SRR has not been considered in (2) and (3), which yields the results to be approximate effective only. In order to get more accurate dimensional dependence and fully account for the effect of mutual coupling, it is necessary to optimize the antenna
by full-wave simulation.

III. SIMULATIONS AND MEASUREMENTS

After fine-tuning and careful optimization using numerical simulations, the final antenna with total sized D x L=31.7 x27mm^2 is obtained. The geometrical parameters of the CRR and SRR are r1 = 3.1 mm,r2 = 4.5 mm, r3 = 7.5 μm,$w = 0.6mm$, and s = 0.5 mm. In our experiment, since the antenna is terminated with a 50-Ω subminiature A (SMA) connector for measurement purpose, w_f= 1.3 mm and g = 0.2mm are chosen in order to fit the impedance matching. The dimensions of trapeziform ground plane mm, h = 0.5μm, d_1 = 2mm, and d_2 = 15= mm are obtained through quasi-Newton optimization. It is also found that [i.e.,w1=1.04 mm,w2=0.83 mm from (1)] for tapered impedance transformer line yields to the best impedance matching for the antenna. Clearly, two resonances are observed in SRR and CRR. We require a SRR resonant frequency for our application. Because SRR act a metamaterial having the property of Double negative refractive index.

The measured bandwidth of 10-dB reflection coefficient for 2.5GHZ. It is seen that the resonant surface current concentrates on the inner SRR at 2.5GHz, while at 10.66 GHz, the surface current mainly resides on the outer CRR. This indicates that the lower and higher radiation modes of the antenna are contributed by the SRR and the CRR, respectively, in accordance with our prediction. To investigate the operation modes of the proposed planar compact CPW-fed dual-band antenna, we show in Fig.
As we can see frequencies, the antenna has nearly omnidirectional radiation pattern in the co polarization -plane, while in

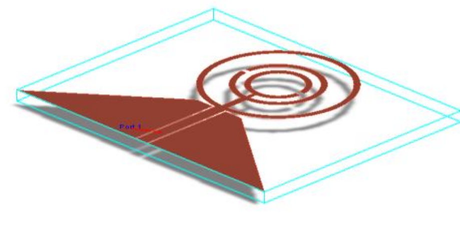


Fig 1(b):3D view of Metamaterials Dual band.
Proposed Monopole antenna are very low for all the patterns:
30 dB below. It is a good agreement between simulation, and a monopole-like radiation pattern is obtained at each frequency.

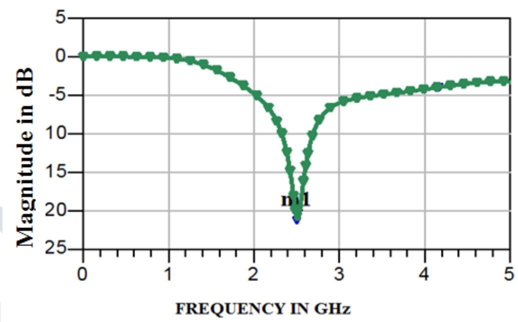


Fig. 2. Reflection coefficient of the planar compact CPW-fed multi-band antenna as SRR functions of the 2.5GHz frequency.

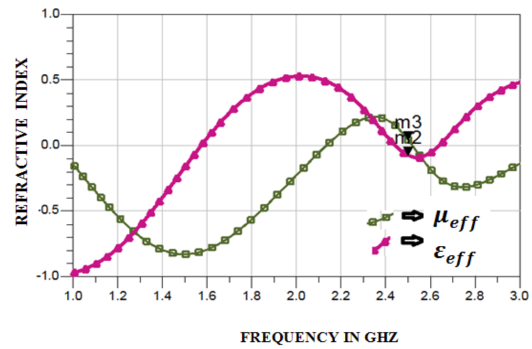


Fig.2.a. Single Negative Refractive Index of the planar compact CPW-fed antenna as SRR functions of the 2.5Ghz frequency with $\boldsymbol{\varepsilon_{eff}}$ = -0.075 dB, $\boldsymbol{\mu_{eff}}$ = 0.043dB

Especially for Satellite imaging applications, Radar applications scale down the above mentioned frequency to 0.285 THz by using silicon substrate relative permittivity εr = 11.9

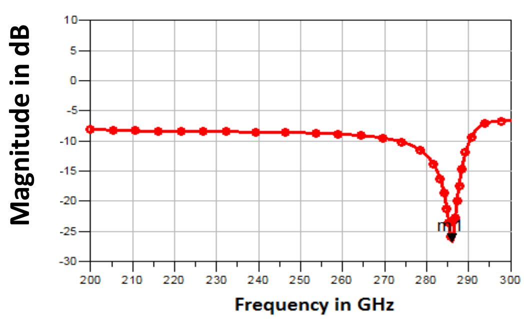


Fig. 3. (a) Reflection coefficient of the planar compact CPW-fed antenna as SRR functions of the 0.285Thz frequency using Silicon Substrate.

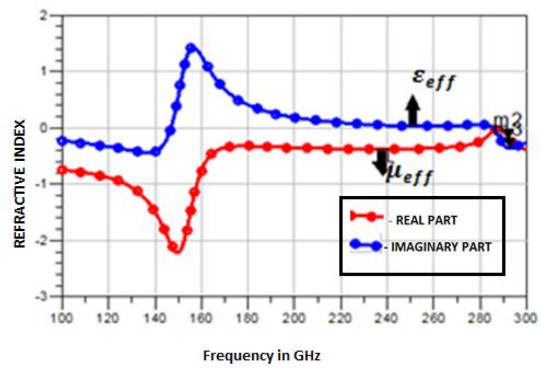


Fig. 3. (b)Double Negative Refractive Index of the planar compact CPW-fed antenna as SRR functions of the 0.285Thz frequency with $\boldsymbol{\varepsilon}_{\mathbf{eff}}$ = -0.186 dB, $\boldsymbol{\mu}_{\mathbf{eff}}$ = -0.360dB.

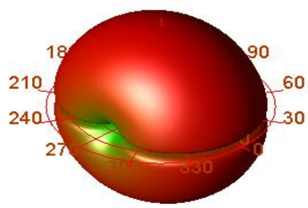


Fig.4 Far field radiation pattern of the antenna.

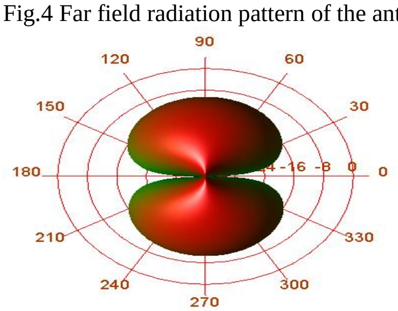
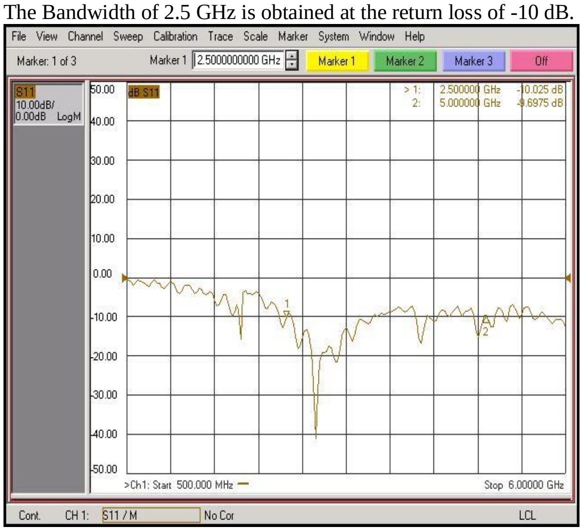


Fig.4.a.Far field radiation pattern of the antenna E-theta plot.

IV.MEASURED RESULT

The RF performance of the fabricated antenna was measured using Agilent PNA series N5230A Vector network Analyzer. After etching the antenna is excited using flat feed SMA female connector. The return loss of the antenna, S11 is measured at -10 dB. The measurements were made from a start frequency of 1GHz to a stop frequency of 8 GHz with 201 points in between. The Bandwidth of 2.5 GHz is obtained at the return loss of -10 dB.



IV. CONCLUSION

A compact, planar, and CPW-fed dual-band antenna inspired by composite metamaterial has been designed. The two-frequency-bands operation was originated from the dual-band resonances of the composite metamaterial, which consists of an inner SRR and an outer CRR. Clearly, two resonances are observed in SRR and CRR. We require a SRR resonant frequency for our application because SRR act a metamaterial having the property of Double negative refractive index. Moreover, a CPW line with trapeziform ground plane and tapered impedance transformer line was used for antenna impedance matching. It was demonstrated that the proposed antenna has bandwidth at 0.286THz using Si in the higher frequency band. The antenna can generate good omnidirectional, monopole-like radiation pattern. The proposed antenna exhibiting simple planar structure, High gain, and a good radiation performances, which can be easily fabricated with printed circuit board technology is sure to find wide applications in the modern wireless communication systems.

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FUTURE WORK

To design an equivalent circuit model for metamaterials and compare the performance of lumped and distributed model.

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