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Gain enhancement of circular fractal microstrip antenna

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Abstract
The method presented here is simple, and in order to have higher gain values, it can be used along with other established techniques also. Two different methods are used to carry out the analysis and the results obtained are in good agreement.

Keywords: Gain enhancement and circular fractal

Introduction
The microstrip antennas are the popularly used due to their well-known advantages. Microstrip antennas can be designed in so many shapes like square, rectangular, elliptical, circular etc. Out of these configurations, the circular microstrip antenna can be designed with smaller dimension. In recent years, there has been a prodigious growth of the telecommunications services in the L-band frequencies such as the GPS, mobile communication systems etc. In order to fulfill the growing demands of communication systems, researchers have been continuously evolving new and efficient methods to enhance the various characteristics of microstrip patch antennas e.g. bandwidth [1], polarization [1-9], gain [5] etc. Out of all these characteristics, gain is one of the significant parameter, which decides the application domain of an antenna. Recently reported techniques for the gain enhancement of microstrip antenna can be found in [6, 7]. Slots were strategically introduced in the ground plane, such that adjusting their lengths leads to excitation of two orthogonal near-degenerate resonant modes [6]. In [7] a cross dielectric resonator was mounted over microstrip patch along with quasi planar surface mounted short horn. Yildirim *et al.* and Cetiner *et al.* have shown the enhancement in gain using square microstrip patch and square parasitic element [8]. In our earlier work [9], it was shown that introduction of T – shaped notches in the sides of equilateral triangular shaped patch antenna leads to enhancement of gain.

In this paper, I have proposed a new method which is simple and different than other methods reported in [6-11]. In the present work, gain enhancement of a circularly fractal shaped patch antenna is achieved using electromagnetically coupled parasitic ring. The antenna is excited using standard coaxial feed arrangement. The parasitic element is vertically stacked at a height (h) of λ/8 from the active element, where λ is free space wavelength at design frequency. The reference antenna is one which has a single substrate (the lower substrate in Fig. 1), with the circular metallic patch mounted on it. Upper substrate and circular parasitic ring are the parts of the proposed antenna. Parametric study is also carried out to investigate the effects of the varying the upper substrate height (h), on the gain of the antenna.

Antenna structure
The circular shaped coaxially fed antenna is one of the most popularly used radiators, after the rectangular microstrip antennas. Also the design equations are well written in the literature [12-13]. The radius of the circular patch is given by [13]:

$$r = \frac{F}{\sqrt{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]}} \qquad (1)$$

Where

$$F = \frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

In equation (1), h must be in cm and in equation (2) fr must be in Hz.
With the given design, the circular patch operates at the fundamental frequency with dominant mode TM_{110}. The first resonant frequency is given by –

$$(f_r)_{110} = \frac{1.8412}{2\pi r\sqrt{\mu\varepsilon}} = \frac{1.8412 v_0}{2\pi r\sqrt{\varepsilon_r}} \quad (3)$$

where v_0 is the speed of light in free space.
The reference antenna designed at operating frequency 1.8GHz, having FR4 substrate with height of 1.59mm, dielectric constant 4.4 and tan δ=0.02. The radius (r) of circular patch is 22mm. Coaxial feed is used to excite the antenna, which is located at the offset of 5mm from patch center to provide impedance matching at the operating frequency. The feed radius is kept 1.12mm.

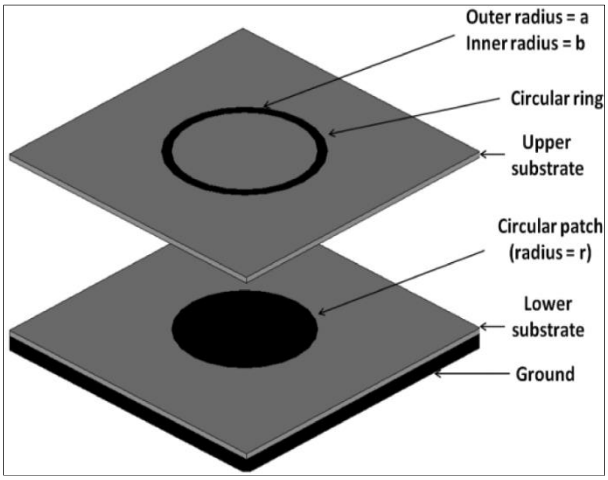


Fig 1: Geometry of proposed antenna

The geometry of the proposed antenna is shown in Fig. 1. The antenna has two substrate layers. The upper substrate with a circular ring of outer radius (a) 25mm and inner radius (b) 22mm is placed upon the reference antenna. The material chosen for the upper substrate is foam with the height (h) of 20mm. The circular patch and parasitic ring are concentric. The height of upper substrate (h) on top of which the parasitic radiator lies is varied from 5mm to 40mm to obtain the resonant condition for optimum gain performance. The parametric study and the effect of 'h' variation are presented in next section.

Result and discussion

The comparison between the return loss characteristics of the reference antenna and that of proposed antenna is shown in Fig. 2 for h=20mm. As can be seen, the return loss of proposed antenna improves to 36dB from 11.5dB, which is the return loss of the reference antenna. The proposed antenna shows improvement in operating bandwidth also. The return loss is well below -10dB from 1.77GHz to 1.83GHz, exhibiting a bandwidth of 60MHz.

The simulated gain of the reference antenna at 1.8GHz is 2.1dB. During the investigations of antennas performance, it is noticed that the antenna's gain varies upon stacking a circularly shaped patch. The gain of the proposed antenna for h = 20mm is 5.9dB, which is 3.8dB greater than that of the reference antenna.
The simulated radiation characteristics (elevation and azimuthal planes) of the reference antenna and that of the proposed antenna from Finite Integration Technique and Method of Moment techniques are shown in Fig. 4 and Fig. 5 respectively.

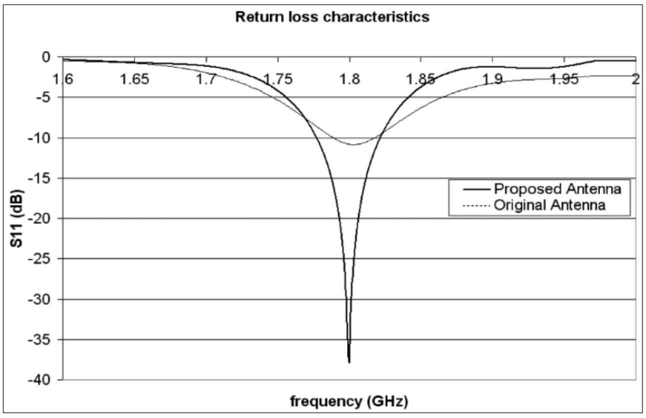
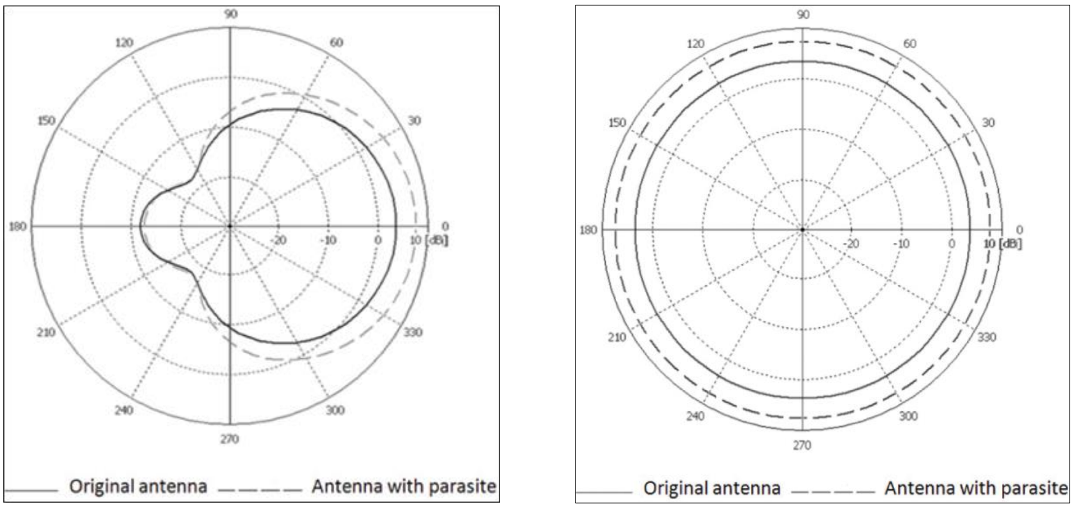


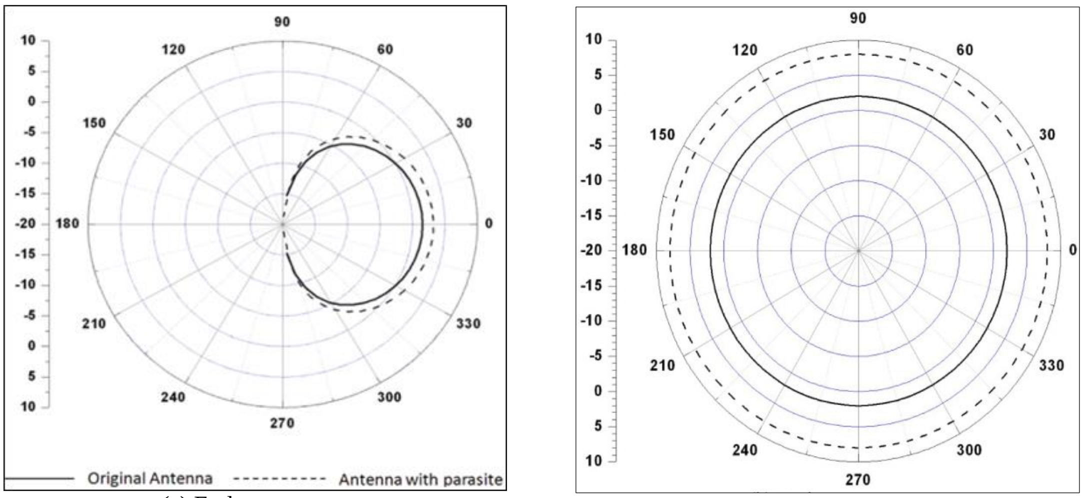
Fig 2: Return loss vs frequency characteristics comparison (CST simulation) for h=20mm

Fig. 3(a) shows the E plane patterns of reference antenna and modified antenna computed from CST simulation. As observed, the main lobe magnotude of proposed antenna improves to 7.5dB from 3.5dB for reference antenna. Also improvement in half power beam width is also observed. The HPBW of reference antenna is 650 whereas that of the proposed antenna is 700. The side lobe level is at -13.8dB which is reasonably good.
From CST simulation (Fig. 3(b)), it is observed that the pattern of the reference antenna is omni directional in azimuth plane with a main lobe magnitude of 5dB, whereas upon stacking parasitic ring, it improves to 10dB. For IE3D simulation in the H plane, approximately the same values of both the radiators are obtained means the results are in agreement.
The radiation patterns computed from MOM technique are given in fig. 4. As observed, addition of parasitic ring enhances the main lobe magnitude from 1dB to 5dB in the E plane. Also the H plane magnitude increases from 0.8dB to 5.5dB. Thus an enhancement of 4dB in E plane and that of 4.7dB in H plane is observed. The result obtained from both the techniques shows a qualitative resemblance but differs quantitatively by a small degree; the possible reason is different simulation approaches.
From IE3D simulation, it is found that the radiation efficiency of the proposed antenna with FR4 substrate is 50.5%, which is much greater than (31.86%) of the reference antenna with the same patch and substrate dimension. The increase in radiation efficiency is probably associated with adding the parasitic element which lowers the quality factor with increased surface current in the parasite, and may account for the observed antenna gain enhancement for the proposed antenna.



(a) E plane patterns (b) H Plane patterns

Fig 3: Radiation patterns comparison for conventional antenna and antenna with parasite (for d=20); CST results



(a) E plane patterns (b) H Plane patterns

Fig 4: Radiation patterns comparison for conventional antenna and antenna with parasite (for h=20); IE3D results

Optimization of circular patch antenna

For the proposed antenna, the parameter chosen for optimization of gain of the modified antenna is the height of the upper substrate (h). The material chosen for the upper substrate is foam material. As foam dielectric material of any arbitrary height can easily be cut in the laboratory, it caters flexibility to antenna design.

Fig. 5 shows the effect of varying 'h' on the gain of the antenna, which is varied from 5mm to 40mm. As observed the gain increases initially as 'h' is increased from 5mm at 1.832GHz, whereas the maximum gain is obtained for h=20mm. Further increasing 'h' degrades the gain. While h=20 mm provides the highest gain of 5.9dB, a thickness of 10mm also provides 5.4dB, which is 3.3 dB more than the original antenna. This value of h can be chosen if the antenna's bulkiness is a constraint.

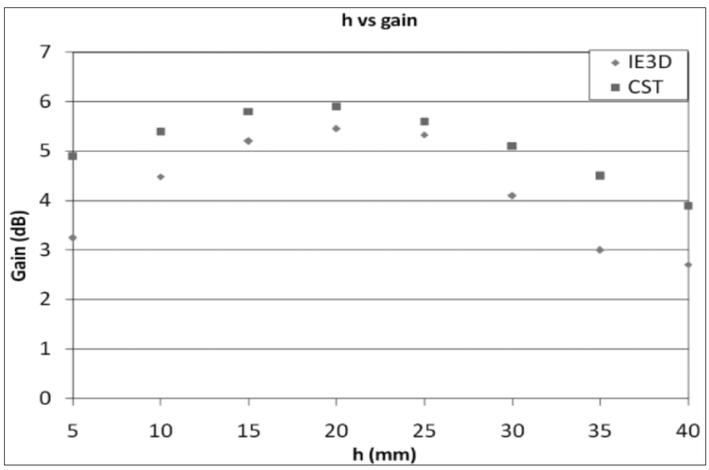


Fig 5: Variation of proposed antenna's gain with 'h'

Conclusion
Comparison of the gain and radiation characteristics of the proposed modified antenna with the conventional antenna is done. A circular ring parasitic element supported by a foam substrate is strategically placed at a height (h) from the main patch element, to enhance the gain of the antenna. Optimization of 'h' has been carried out to find out the optimum height of foam substrate. The method presented here is simple, and in order to have higher gain values, it can be used along with other established techniques also. Two different methods are used to carry out the analysis and the results obtained are in good agreement.

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