DESIGN OF MULTIBAND AND ULTRAWIDBAND CIRCULAR FRACTAL ANTENNA WITH PARTIAL GROUND PLANE

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Abstract: Due to advancements in communication technology, there is an increase in the demand of small size, low cost, multiband and ultra-wideband antennas. With a view to address these demands, a fractal design was employed in this study. Despite the advantages provided by these antennas, performance enhanced further by using a partial ground plane. This research work presents an antenna which is based on the well-known Sierpinski Carpet fractal with iteration factor of 1/3. A multiband circular patch antenna using third order Sierpinski Carpet was designed to operate at 1.88GHz. The proposed antenna was modified with a partial ground structure to achieve ultra-wideband behaviour with a bandwidth of 8.18GHz at centre frequency of 2.54GHz. The antenna was simulated using three dimensional finite integration time domain commercial software microwave studio.

Keywords: Multiband and ultra-wideband antenna, fractal geometries, partial ground structure

Introduction

Due to modern wireless communication system requirement of an antenna with improved performance, there is an increase in extensive research of compact antennas (Tiwari *et al.*, 2013). This system requires an antenna that possesses some characteristics like small size, very light in weight and low cost in other for the antenna to be incorporated inside a mobile telephone without extending out (Debatosh and Yahia, 2011). The Microstrip antenna is suitable for this requirement due to its characteristics like small size, light in weight and low cost. Although, the microstrip antenna also has limitations such as: low gain and narrow bandwidth. With the conventional antenna design using an infinite ground plane, this narrower bandwidth limitation cannot be curtailed as the bandwidth can only be increased by a small percentage. The release of the ultra-wideband frequency band in the range of 3-10GHz by the FCC in 2002 (Dinesh and Karunakar, 2015) has urged researcher to find a new approach in designing an antenna with ultra-wideband behaviour.

Several works of literatures have employed different technique such as the use of truncated ground plane and a rectangular patch tapered from the microstrip feed (Baskaran *et al.*, 2011), also using of defected ground structure (Pan *et al.*, 2012) to enhance the bandwidth of the microstrip antenna. One of the techniques to construct a multiband antenna is to make use of fractal geometry (Mohanamurali and Shanmuganantham, 2012). The application of fractal geometry to conventional antenna structures optimizes the shape of the antennas in order to increase their electrical length, which thus reduces their overall size. Krishna *et al.* (2009) proposed a compact wideband antenna covering bandwidth from 2.33-6.19 GHz using Koch snowflake printed slot antenna. The antenna is suitable for WLAN and WiMAX applications. A wide slot antenna with a fractal slot for bandwidth enhancement was designed by Chen *et al.* (2009).

Experimental results show that 56.2% impedance bandwidth at the center frequency of 3.825 GHz was obtained. Design of Multiband Sierpinski Fractal Carpet Antenna Array for C-Band was proposed by Cao and Krzysztofik (2018). Although the propose antenna has a dual band operating frequency. The antenna did not exhibit ultrawideband and multiband behaviour. In this work, a circular fractal antenna with a partial ground plane is designed to meet the modern wireless communication demand of compact, light, multiband and ultra-wideband.

Antenna design

In circular patch antenna mode, the ground plane, patch and the material between them are treated as two circular cavities. The substrate height of the circular patch is small ($h \ll \lambda$). Unlike the rectangular patch antenna which is controlled by length and width, the circular patch has only one degree of freedom to control the patch which is the patch radius (Balanis, 2005). By changing the radius of the patch, the patch resonant frequency also changes but without having an effect on the patch mode. Analysis of the circular patch antenna can be conveniently carried out using the cavity model. The actual radius of the patch can be obtained using the given equation (Balanis, 2005):

$$R = \frac{F}{\sqrt{1+\frac{2h}{\pi\epsilon_r F}[\ln\left(\frac{\pi F}{2h}\right)+1.7726]}} \quad (1)$$

Where: R is the radius of the patch, h is the substrate height and ϵ_r is the relative permittivity.

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

Where: f_r is the resonant frequency.

The circular patch was designed with a radius of 21.2 mm on a FR-4 lossy substrate with relative permittivity of 4.5 and loss tangent of 0.012. This is called the initial stage without iteration (zero iteration).

The first iteration was achieved by creating a circle of radius R/3 using sierpinski iteration factor of $(1/3)^n$ whose centre lies on the diameter of the main radiating patch. This middle circle was subtracted from the main patch and this is called the first iteration. The second iteration was achieved by creating four circles of radius R/9 and subtracted from the main patch. The third iteration was formed by creating circles of radius R/27 and subtracted from the main patch. The schematic diagram of the antenna is shown in Fig. 1.

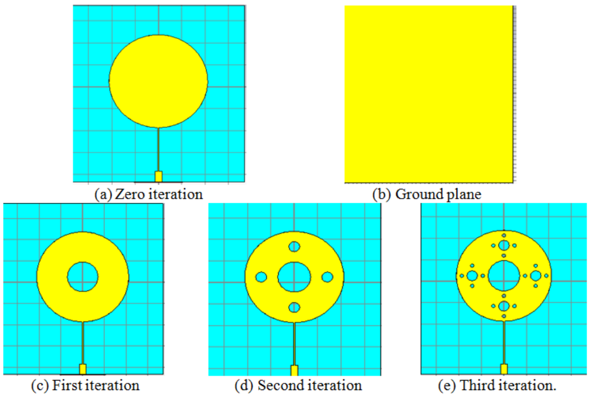

Fig. 1: Schematic diagram of the designed circular fractal antenna

Results and Discussions

CST Microwave Studio 2014 was used in simulating the proposed antenna. The performance of the antenna was analyzed in terms of return loss, bandwidth, radiation pattern, gain and efficiency. The results were summarized in Tables 1 - 3.

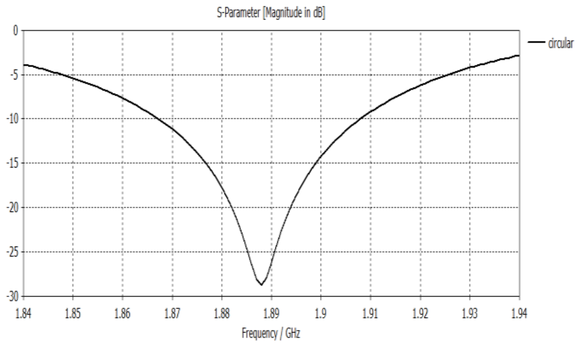

Fig. 2: Return loss plot of zero iteration

In its conventional form, the zero iteration circular patch antenna is resonating at the frequency of 1.888GHz with bandwidth of about 41MHz. The antenna has a gain of 2.59dB with an efficiency of 41%. The radiation pattern is shown in Fig. 3.

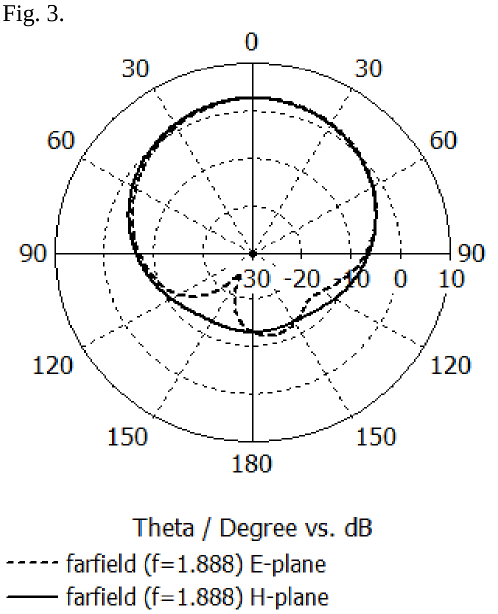

Fig. 3: Polar plot radiation pattern for zero iteration

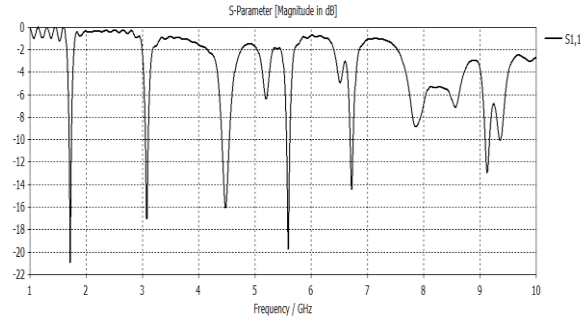

Fig. 4: Return loss for first iteration

The first iteration was simulated at higher frequency to see the multiband behaviour. The antenna is resonating at six different frequencies with first resonant occurring at 1.71GHz with a return loss of -20.7dB. Table 1 shows the behaviours exhibit by the antenna in the first iteration.

Table 1: Results of the circular patch first iteration

Centre Freq. (GHz)	S11 (dB)	Upper Freq. (GHz)	Lower Freq. (GHz)	Bandwidth (MHz)	Gain (dB)	Efficiency (%)
1.71	-20.7	1.735	1.6918	43	0.166	25
3.07	-17	3.1012	3.0496	51	-1.38	25
4.48	-16	4.546	4.412	134	3.59	51
5.59	-19.7	5.6184	5.5578	60	-2.48	15
6.72	-14.5	6.7497	6.693	55	-0.914	13
9.12	-12.9	9.1704	9.092	78	4.44	44

From the result shown in Fig. 4, it was observed that the first iteration demonstrates multiband behaviour resonating at six frequencies. The antenna has highest efficiency of 51% occurring at 4.48 GHz.

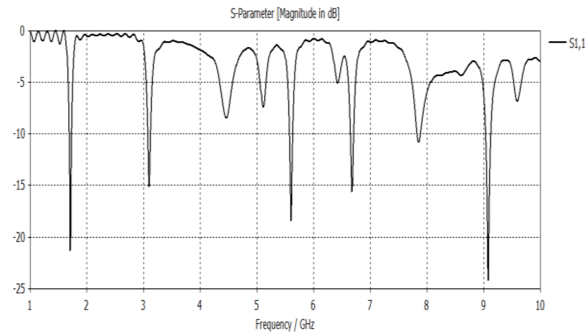

Fig. 5: Return loss for the second iteration

The second iteration which was simulated up till 10GHz has a multiple band of operation with six different resonant frequencies.

Table 2: Results of the circular patch second iteration

Centre Freq. (GHz)	S11 (dB)	Upper Freq. (GHz)	Lower Freq. (GHz)	Bandwidth (MHz)	Gain (dB)	Efficiency (%)
1.7	-21.2	1.7284	1.6849	43	0.12	27
3.09	-15	3.1234	3.0729	50	-1.23	25
5.6	-18	5.6308	5.5713	59	-0.213	16
6.79	-15.4	6.7112	6.652	59	-2.24	13
7.85	-10.8	7.8886	7.8241	64	-1.6	10
9.08	-24	9.128	9.0327	95	-0.172	11

It was observed from Table 2 that after the second iteration, the antenna performance start diminishing. The antenna shows low gain and low efficiency. This might be due to antenna losses and also fractal cuts made in the antenna.

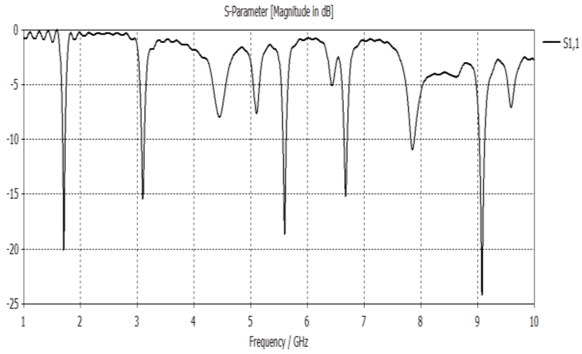

Fig. 6: Return loss for third iteration

Table 3: Results of the circular patch third iteration

Centre Freq. (GHz)	S11 (dB)	Upper Freq. (GHz)	Lower Freq. (GHz)	Bandwidth (MHz)	Gain (dB)	Efficiency (%)
1.7	-20	1.7278	1.6828	44	0.107	27
3.09	-15.2	3.1272	3.0748	52	-1.27	25
5.6	-18.5	5.6668	5.627	60	-0.32	16
6.65	-15.5	6.7078	6.649	58	-2.5	13
7.85	-10.8	7.8886	7.8241	64	-1.63	10
9.08	-24	9.1288	9.0294	99	-0.03	15

From the tabulated results of third iteration, it was observed that the third iteration has almost similar result to the second iteration in terms of return loss and bandwidth but with some reductions in gain and efficiency due to fractals cut and losses in the antenna.

It was observed that the antenna demonstrate a multiband behaviour after the third iteration. The circular fractal antenna has lower gain, lower bandwidth and efficiency after the third iteration. This problem of low gain, Bandwidth and efficiency will be tackled by using partial ground plane.

Circular fractal with partial ground plane

In most common form of microstrip patch antennas, the metal patch is on the top of grounded dielectric substrate. When the patch antenna is energized, it radiates Electromagnetic waves in all directions and the Electromagnetic waves that travel in the substrate is known as surface waves. Losses due to these surface waves is known as surface wave losses, this is the main loss associated with microstrip patch antennas that reduce the gain of microstrip patch antennas. For suppression of surface wave, metallic ring was introduced on to the radiating patch with defected ground structure in Kumar and Kumar (2014) to enhance the gain of the patch antenna. The surface waves were provided with an in phase excitation rather than suppressing them and this was achieved by introducing parasitic patches at the partial ground plane (Reddy, 2012). In this study, partial ground plane comprising of circular and slotted rectangular structure placed above and below the feed line was used in enhancing the gain and achieving ultra-wideband behaviour. The structure of the antenna is shown in Fig. 7.

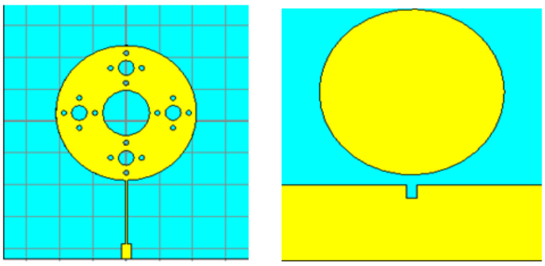

Fig. 7: Front and back view of third iteration with partial ground plane

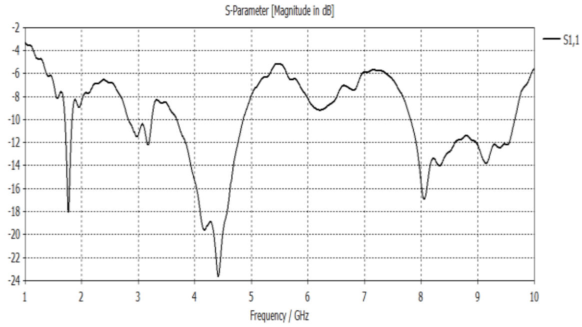

Fig. 8: Return loss plot for partial ground third iteration

From the return loss plot, it was observed that the antenna shows multiband and wideband behaviour with highest bandwidth of 1.86GHz at centre frequency of 8GHz. To further enhance the bandwidth of the antenna in order to cover the ultra-wide band range of (3-10) GHz, quarter wave transformer is used to match the load to 50 Ω microstrip. The proposed designed is shown in Fig. 9.

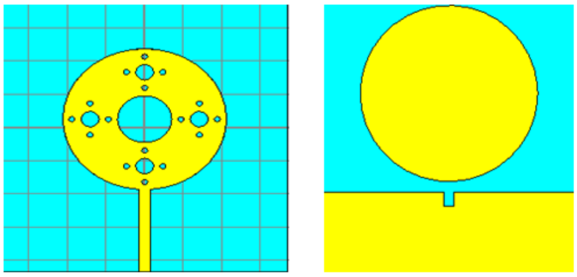

Fig. 9: Showing front and back view of proposed design

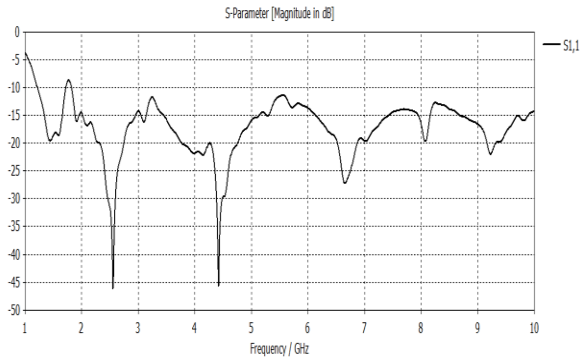

Fig. 10: Return loss plot of the proposed design

From the return loss plot, the antenna shows multiband with ultra-wideband behaviour having a bandwidth of 8.18GHz in the frequency range of 1.81GHz-10GHz with centre frequency of 2.54GHz.

Table 4: Results of the proposed design

Centre Freq. (GHz)	S11 (dB)	Upper Freq. (GHz)	Lower Freq. (GHz)	Bandwidth (MHz)	Gain (dB)	Efficiency (%)
1.88	-15	10	1.8196	8180	2.67	83
2.54	-45	10	1.8196	8180	3.49	95
3.0	-15	10	1.8196	8180	5.06	94
4.45	-45	10	1.8196	8180	3.85	86
5.18	-15	10	1.8196	8180	5.42	86
6.65	-15.5	10	1.8196	8180	3.8	87
7.85	-10.8	10	1.8196	8180	3.49	86
9.08	-24	10	1.8196	8180	5.66	82

With the use of partial ground, it was observed that the antenna exhibit ultra-wide band and multiband behaviour compared to the conventional circular patch in the previous iterations. With the use of partial ground on the circular fractal shape, performance enhancement in terms of bandwidth, gain and efficiency were achieved which is better than the third order Sierpinski carpet using circular patch. Plot of radiation patterns of the proposed antenna measured at some frequencies were shown in Fig. 11. From 1.88GHz-3GHz the antenna H- plane radiation pattern has main lobe magnitude along the zero degree. At higher frequencies, the pattern becomes directional.

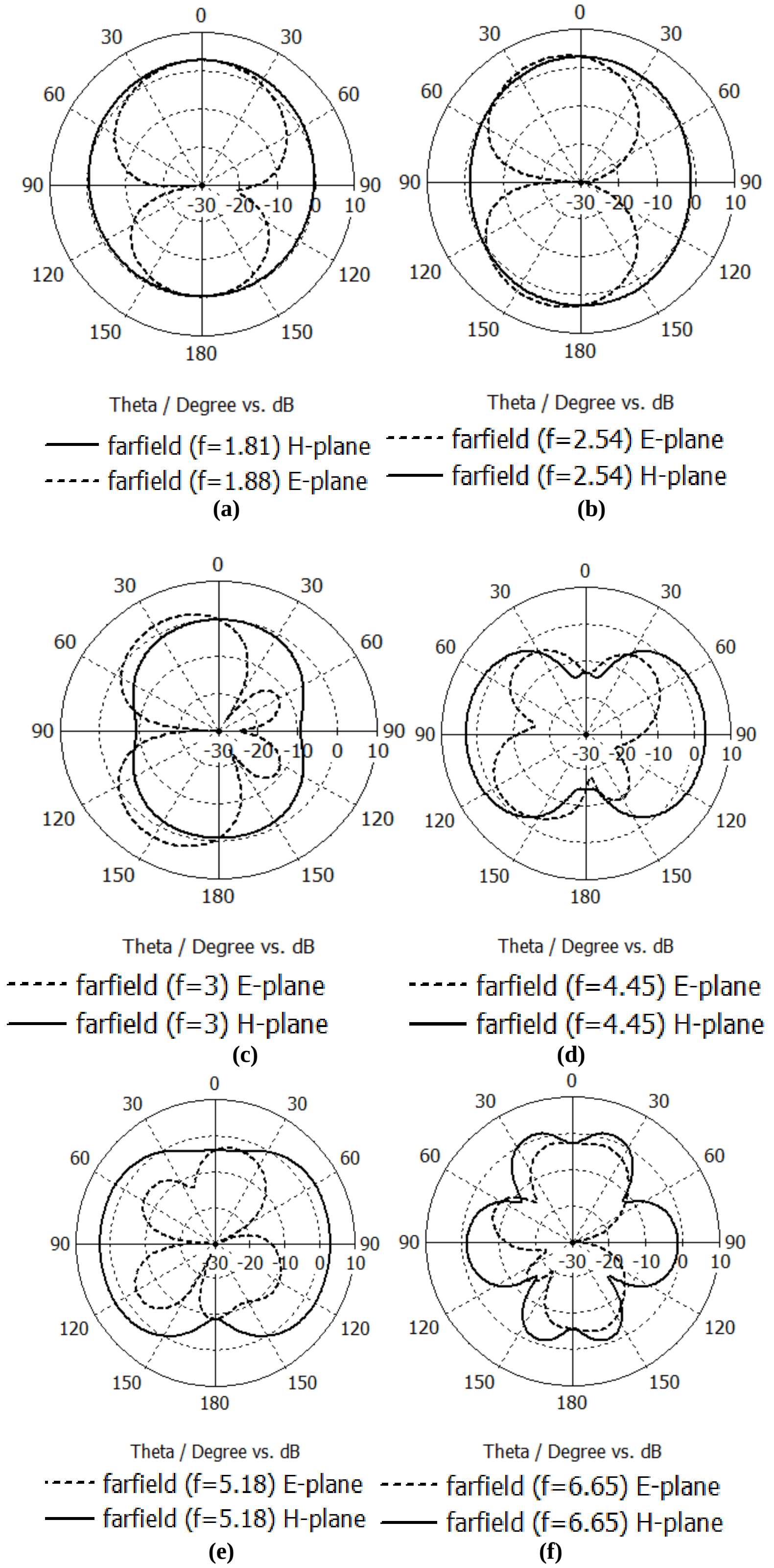

Fig. 11: Radiation pattern of the proposed design

Conclusion

A circular fractal antenna was designed up to third iteration using sierpinski carpet. After the third iteration, the proposed circular fractal antenna exhibits a multiband behaviour with low gain, low bandwidth and low efficiency. A new approach using a partial ground plane technique was proposed to enhance the gain, bandwidth and the efficiency of the circular fractal antenna. The proposed antenna was able to achieve up to 8.18GHz of bandwidth at centre frequency of 2.54GHz. Also, the gain and efficiency was enhanced by achieving up to 95% radiation efficiency.

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