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A Broadband Star-Shaped Slotted Microstrip Antenna for RF Energy Harvesting Applications

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***Abstract* – This paper presents design of a broadband antenna for RF/microwave energy harvesting applications. The antenna operates within the frequency range 790 MHz to 3.4 GHz. The antenna is designed over wide frequency range to collect energy of signals of various communication systems such as: digital TV, GSM-900, GSM-1800, UMTS, LTE, WiFi, and WiMax. The antenna is designed using microstrip technology on an FR-4 substrate with dielectric constant of 4.3 and thickness of 1.6 mm. The conducting element is formed of a star-shaped microstrip patch. Moreover, crescent and rectangular slots are cut onto the patch element to broaden the bandwidth. The antenna is designed using CST simulation software and the maximum simulated in-band gain reaches 3.93 dBi at 1.7 GHz.**

***Keywords* – Broadband Antenna, Energy Harvesting, Microstrip Antenna, Slotted Antenna, Star-shaped Antenna.**

I. Introduction

Recently, RF energy harvesting is increasingly attracting researchers as an alternative solution to short-life batteries. Harvesting of ambient energy available in RF signals enables empowering low-power devices such as wireless sensors and medical implants. An energy harvesting system is mainly formed of an antenna, a matching circuit and a rectifier circuit to convert the AC signal into a DC signal. There has been extensive research reported in literature on designing antennas to scavenge the electromagnetic waves for harvesting applications. The vast majority of proposed antennas are based on microstrip technology and they are designed with various objectives. Some antennas are reported for multi-band operation to increase the amount of harvested power while other researches focused on increasing gain by employing array structures. Some antennas have been reported for single band operation [1, 2] and others working on dual-bands have also been proposed [3, 4]. Increasing energy harvesting capacity can be achieved with multi-band operation and hence several works targeted to enhance antenna bandwidth for wideband/multi-band operation [5-11]. In [5], a bent triangular antenna operating within the frequency range 850 MHz to 1.94 GHz with antenna gain of 2 dBi is presented. In [6], a collar-shaped antenna is proposed and it works from 1.7 GHz to 3.6 GHz. The antenna consists of two folded diploes laid on circular FR-4 substrate. Moreover, a broadband antenna is reported for harvesting over frequency range of 900 MHz to 3 GHz [7]. In [8], a wideband antenna with ice-cream cone structure is proposed and it operates within the range from 2.17 GHz to 4.2 GHz. However, this frequency range does not include many mobile signals. A triple band antenna is also reported in [9] for energy harvesting and it operates at 900 MHz, 1900 MHz and 2.4 GHz. In [10], another broadband antenna operating over the frequency band from 2.1 GHz to 7 GHz has been presented. This antenna also does not operate at GSM signals. Other researches were focused on increasing antenna gain to capture more energy by implementing an antenna array configuration [12-14]. This leads to larger antenna structures as a trade-off with higher gain. Moreover, circularly polarized antennas have been proposed for energy harvesting applications [15]. A recent interesting design of an antenna matched to the input impedance of the rectifier has been proposed to eliminate the need for a matching circuit [16].

In this paper, a novel microstrip antenna is proposed for RF energy harvesting over broadband frequency range from 790 MHz to 3.4 GHz. This range includes variety of wireless applications and it incorporates not only mobile and WiFi signals as in [5-11] but also some digital terrestrial TV signals. The broad bandwidth covered by the proposed antenna in addition to its reasonable size makes it an excellent candidate for harvesting applications. The standard wireless applications operating within the aforementioned frequency range are: digital terrestrial TV (portion of 700 MHz band and all 800 MHz band), GSM-900 (890 MHz-960 MHz), GSM-1800 (1710 MHz-1880 MHz), UMTS (1920 MHz-2170 MHz), LTE (bands 1-8, others), WiFi 2.45 GHz and WiMAX 2.3 GHz and 2.5 GHz.

II. Antenna Structure

The proposed antenna structure is depicted in Fig. 1. The metallic surface consists of star-shaped microstrip patch. Crescent and rectangular slots are cut onto the patch element to broaden the operating frequency range of the antenna. The substrate used is FR-4 with dielectric constant of 4.3 and thickness of 1.6 mm. The substrate length is 140 mm and its width is 60 mm and the microstrip feed line is designed such that the characteristic impedance is 50 Ω with width of 3.1 mm. The ground plane is cut beneath the star-shaped patch to widen the antenna bandwidth and the length of ground plane from the port to inside is 81 mm. Fig. 2 presents a clear top view of the star-shaped patch along with its dimensional parameters. The antenna parameters have been optimized using CST simulation software and the final dimensions of the antenna are listed in Table 1. The main goal in optimization is matching input impedance of the antenna to 50 Ω over wide operating frequency range.

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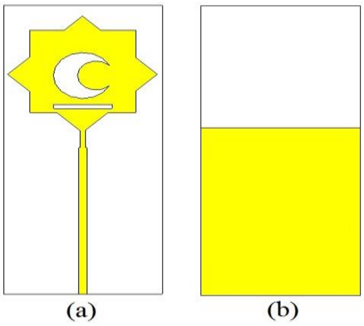

Fig. 1. Proposed antenna structure (a) Top view (b) bottom view

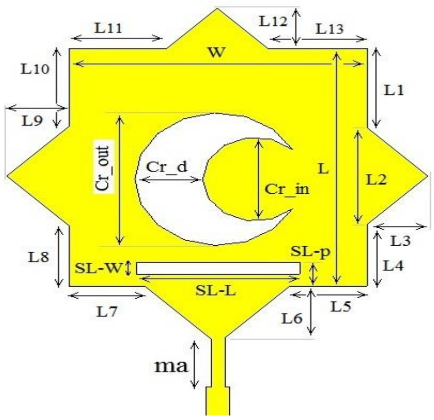

Fig. 2. Parameters of star-shaped patch

Table 1. Optimized parameters of the antenna

Parameter	Value (mm)	Parameter	Value (mm)
L	40.0	L10	13.074
W	40.0	L11	13.074
L1	13.287	L12	6.819
L2	16.355	L13	13.287
L3	8.178	Cr_out	22.360
L4	10.357	Cr_in	14.142
L5	10.358	Cr_d	9.109
L6	8.849	SL-L	22.0
L7	10.145	SL-W	2.0
L8	10.145	SL-p	4.0
L9	8.390	Ma	8.045

III. Simulation Results

The simulation results of the return loss S_{11} of the antenna is presented in Fig. 3 and it can be noticed that the return loss is below 10-dB from 790 MHz to 3.4 GHz. This broad 10-dB bandwidth of the proposed antenna makes it convenient for energy harvesting of signals of many standard wireless systems.

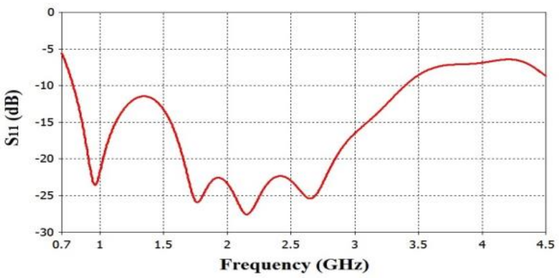

Fig. 3. Simulated return loss of the antenna

Fig. 4 (a) exhibits the three-dimensional simulated radiation pattern at 900 MHz and it shows an omni-directional pattern with a maximum directivity of 2.33 dBi. The simulated radiation patterns in both xz-plane (ϕ = 0) and yz-plane (ϕ = 90) are shown in Fig. 4(b) and Fig. 4(c), respectively. Viewing the radiation pattern at 900 MHz in yz-plane, a null is observed at θ = 90 and maximum radiation is noticed in broadside direction at θ = 0 and θ = 180. The three-dimensional radiation patterns are also simulated at other frequencies of interest for standard wireless applications and they are shown in Fig. 5(a) to Fig. 5(f) for the frequencies 800 MHz, 950 MHz, 1.83 GHz, 2.12 GHz, 2.45 GHz and 2.62 GHz. The realized gains at those frequencies are 0.902 dBi, 1.79 dBi, 3.65 dBi, 2.31 dBi, 1.7 dBi and 2.83 dBi, respectively. It can be noticed that the radiation patterns in Fig. 5 at the given operating frequencies also exhibit omni-directional characteristics. In the proposed design with cut in ground plane the bandwidth is broadened, however, it is traded-off against the gain. This explains the relatively low values of gain when compared to full-grounded standard patch antennas in addition to the high loss tangent of the FR-4 substrate (tan δ = 0.02) that contributed to decreasing antenna gain. Nevertheless, the broad bandwidth of the antenna in addition to its omni-directional radiation patterns makes the proposed antenna an excellent candidate for RF energy harvesting.

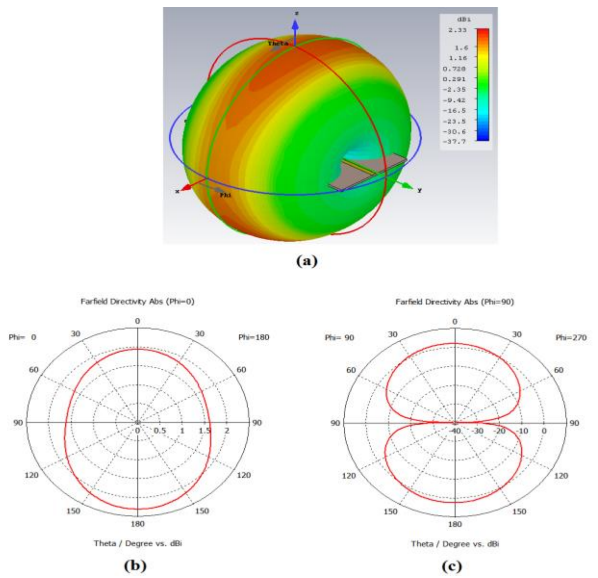

Fig. 4. Simulated radiation pattern of the antenna (a) 3D pattern, (b) xz-pane, (c) yz-plane

The simulated radiation patterns are also shown in the yz-plane (θ = 90) in Fig. 6 for the aforementioned frequencies of interest where nulls are observed at θ = 90.

To give a good insight about the performance of the antenna over wide frequency range, the simulated peak realized gain is depicted in Fig. 7 over the frequency range from 750 MHz to 3.25 GHz. It can be noticed that the antenna has satisfactory gain over wide frequency range and the gain is above 1.6 dBi within the range 900 MHz to 3.25 GHz. It can also be noticed that the maximum gain reaches 3.93 dBi at frequency 1.7 GHz.

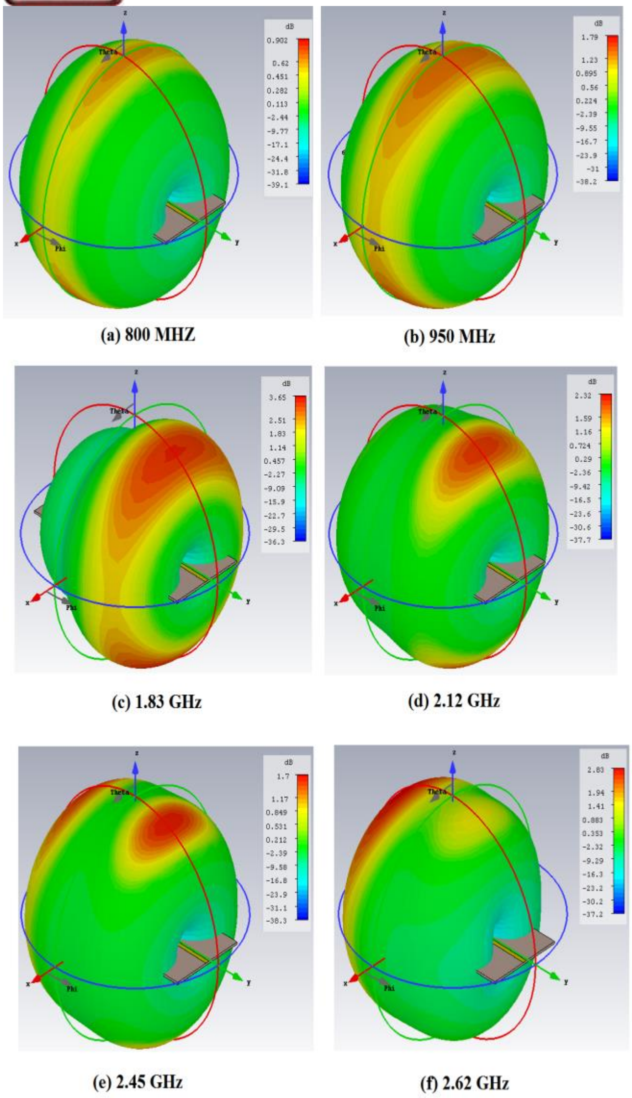

Fig. 5. 3D radiation patterns of the antenna at (a) 800 MHz, (b) 950 MHz, (c) 1.83 GHz, (d) 2.12 GHz, (e) 2.45 GHz, (f) 2.62 GHz

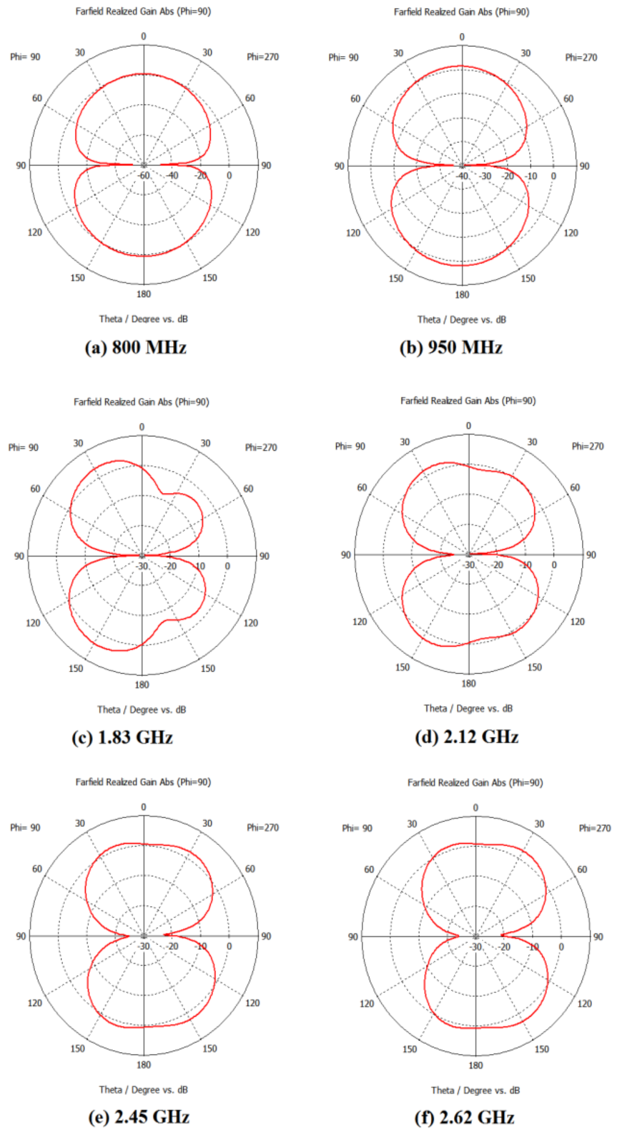

Fig. 6. 2D radiation patterns of the antenna in yz-plane at (a) 800 MHz, (b) 950 MHz, (c) 1.83 GHz, (d) 2.12 GHz, (e) 2.45 GHz, (f) 2.62 GHz.

IV. Conclusion

A broadband microstrip antenna is proposed for energy harvesting applications. The patch element is star-shaped conductor with two slots in the form of a crescent and a rectangle. The ground plane is cut underneath the patch to extend the bandwidth and thus enabling antenna to harvest more energy. The proposed antenna operates within the frequency range 790 MHz to 3.4 GHz and this range incorporates various wireless communications systems such as digital TV, GSM, UMTS, LTE and WiFi. The realized gain is simulated over wide range and it reaches 3.93 dBi at 1.7 GHz and it is above 1.6 dBi within the range 900 MHz to 3.25 GHz. The radiation patterns are simulated at the operating frequencies of the given wireless systems and omni-directional patterns are obtained. The good performance of the antenna in terms of broad bandwidth, omni-directional radiation pattern and acceptable realized gain makes it a good candidate for energy harvesting.

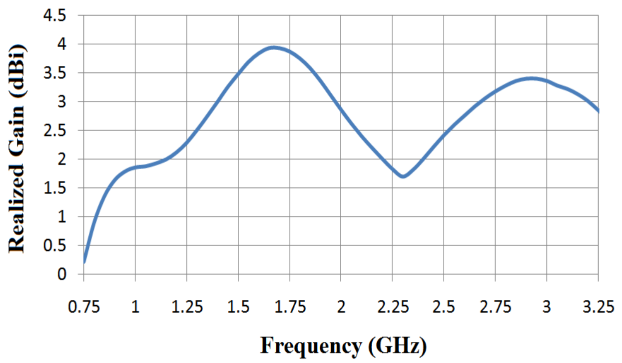

Fig. 7. Simulated peak realized gain of the antenna

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