Design of an U-slot Folded Shorted Patch Antenna for RF Energy Harvesting

Diponkar Kundu, Ahmed Wasif Reza, and Harikrishnan Ramiah

***Abstract*—N**ovel optimized U-slot Folded Shorted Patch Antenna (FSPA) is proposed and designed in this paper for the application of Radio Frequency (RF)-harvesting antenna capable of receiving radio frequency of GSM-900 band (860MHz – 960 MHz). The antenna simulation software, Computer Simulation Technology (CST) microwave studio 2012 is used for designing and performing the simulation of the proposed antenna. One U-slot is incorporated into the upper patch of the FSPA. Simulated results show that this antenna can attain an impedance bandwidth of 17.73% from 839 MHz to 995 MHz at the centre frequency of 880MHz. The results also reveal the good unidirectional radiation pattern and the stable gain over the operating frequencies. It is attained from the simulation outcome that this antenna is well compatible for using in RF energy harvesting to receive signal of GSM-900 band.

***Keywords*—F**olded Shorted Patch Antenna (FSPA), GSM-900, RF energy harvesting, U-slot.

I. Introduction

ENERGY harvesting is a process by which energy obtained from the environment can be converted into usable power that is used for any kind of low power devices. Demand of energy is increasing day by day. That is why findings of new alternative energy sources are the main target of all scientists. There are so many energy harvesting sources such as Radio Frequency (RF) energy sources, wind energy, water energy, acoustic noise, thermo-electric, vibration, piezoelectric, mobile phone base station, etc., having different power densities from where we can get electrical power if it is harvested very effectively and efficiently. Since the development of radio in early 1900s, the world has witnessed the open air as a viable medium for radio waves to propagate. It is where different types of electromagnetic waves are used to transmit and receive information from long distances. Unfortunately, the energy carried by electromagnetic waves is very less as compared to the energy conventional batteries can provide. The challenge here is to capture that energy to power low-power devices. The receiving antenna is an essential element for having harvesting of RF energy as it is used for absorbing energy from any nearby sources which is radiating energy. The design of a suitable receiving antenna is vital since the performance parameters of the antenna, such as return loss, impedance bandwidth, radiation pattern, and gain can affect the volume of harvestable energy.

There are so many works have been done by researchers for developing antenna to meet in different applications. Novel compact small size, single feed, single layer, multi frequency microstrip antenna is presented that has multiple resonant frequencies at 2.30631 GHz, 2.819GHz, 3.941GHz and 4.265 GHz before defecting the ground plane. Resonant frequency has been shifted significantly to 4.68GHz by cutting unequal slots at the edge of the patch. The size of the antenna is reduced to 57%. Novel, compact, probe-fed dual polarized MPA with symmetrical four cross slots etch out in the patch creates size reduction of 51 % is proposed where antenna design and analyze are carried out by finite-difference finite time (FDFT) method [1]. The resonant frequency of this antenna for compact size is 979.7 MHz. There is one compact folded shorted patch antenna had been developed and analyzed for the application in 2.4 GHz ISM band where impedance bandwidth was 4% [2]. The impedance bandwidth in [2] is not higher. For eliminating this problem, low profile FSPA was introduced for wideband application in [3]. Another type of folded uni-planar meander line slot antenna having short circuit is introduced in [4] with the impedance bandwidth of approximately 5%. In [5], FSPA was improved for dual band operation by adding two slots in the patches with respect to the [3]. Both impedance bandwidth and gain are better in [5] compared to [3], but the size of the antenna is too large than [3]. In [6], there is also double-band stacked folded shorted patch antenna was presented by the same authors in [5] where impedance bandwidth was about 20%. Full and half-size V-slotted triangular patch antennas with shorting walls are proposed and compared which have central frequency 3.5 GHz, 5.2 GHz having bandwidth of 12.9% and 8.1% and 3.72 GHz, 5.39 GHz having bandwidth 10.6% and 9.1%, respectively [7]. Later, with the modification of [5], another compact FSPA for outdoor RF energy harvesting for energizing wireless sensor network was designed in [8] where dual band was obtained. In the another latest design, Circularly polarized antenna by applying array of folded-shorted patch is proposed in [9] for having good pattern of radiation at 400 MHz, but the impedance bandwidth is not good.

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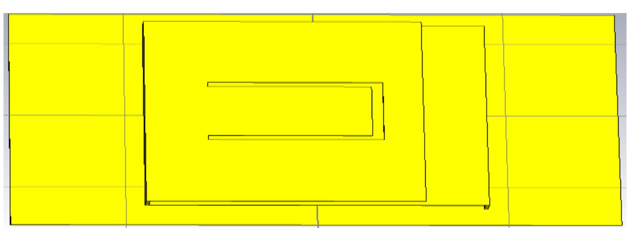
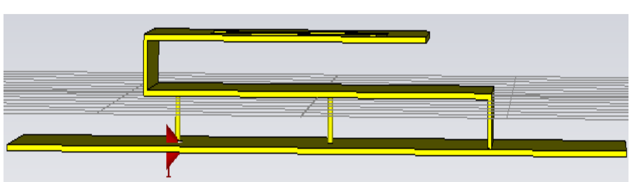
In this paper, new U-slotted FSPA is presented for functioning at GSM-900 band that covers the frequency range from 839 MHz to 995 MHz that is equivalent to 17.73% impedance bandwidth. These results indicate that this antenna can be performed as a harvesting antenna for receiving signal at the range of 839 MHz to 995 MHz. It is also observed from the results of radiation pattern and gain that radiation pattern is unidirectional and good over the operating ranges of frequencies and the value of gain is stable in the same range of frequencies.

II. Antenna Geometry

The top view and side view geometry of the FSPA designed in CST is shown in Fig. 1. There are two rectangular shaped patches are positioned on the top of the ground plane. Among the two patches, the patch near to the ground plane is called lower patch and the other remaining patch is called upper patch. The media between the ground plane & lower patch and also the lower and upper patch are air. The material used for making the ground plane and the patch is copper. The thickness of the ground plane and the both patches is 1 mm. The one end of the lower patch is shorted with the ground plane and the other end of the patch is folded back for connecting with the upper patch in the middle of a square ground plane. The feeding technique used for exiting this proposed antenna is coaxial feed technique. There is also one shorting post has been used between the ground plane and the lower patch. The shorting post and the coaxial feed cable are placed in the midline position of the patch along the x-axis. One slot having U shape is added into the upper patch of the folded shorted patch antenna proposed here. U-slot has a great impact on the performance of the designed antenna.



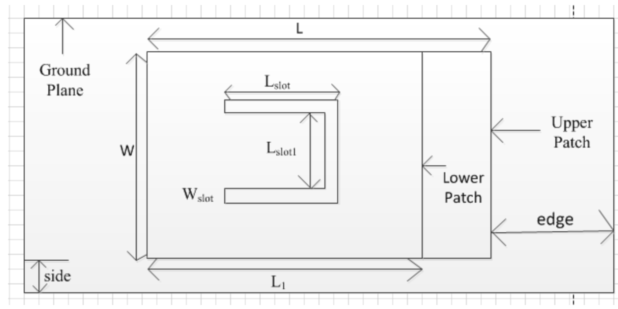
a) Top view of the proposed FSPA designed by CST



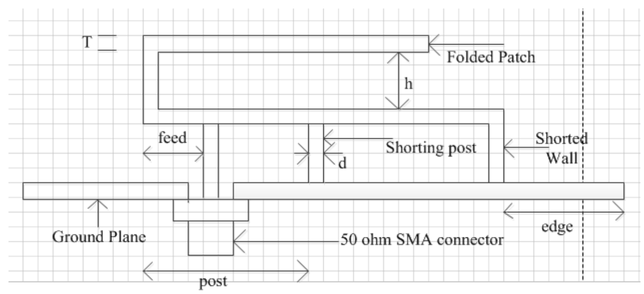
b) Side view of the proposed FSPA designed by CST

Fig. 1 Top and side view of the FSPA geometry designed by CST

FSPA was designed in [3] and [5] for operating at the frequency ranges from 1.48 GHz to 2.99 GHz. But here more compact FSPA is presented for meeting the frequency ranges of GSM-900 band that is from 860 MHz to 960 MHz. In this paper, designed folded shorted patch antenna is more compact with respect to the other FSPA proposed in the former work. The complete geometry of the proposed antenna is given in Fig. 2. And the optimized dimension of the proposed antenna is given in Table I.



a) Top view of the proposed FSPA with labeling



b) Side view of the proposed FSPA with labeling

Fig. 2 Complete geometry of the proposed antenna

TABLE I
PARAMETERS FOR FSPA

Parameters	Description	Value [mm]
L	Length of the lower patch	90.0
h	Height of each patch	8.00
W	Width of both patch	125
d	Diameter of feed	1.30
edge	Length of edge	35
feed	Length of the feed to the centre	7.5
post	Length of the post	47.5
side	Length of side	11
L_1	Length of the upper patch	73
L_{slot}	Length of the parallel arms of the U slot	43
L_{slot1}	Length of the other arm of the U slot	40
W_{slot}	Width of the slot	3
T	Thickness of patch and ground plane	1

III. Results and Discussion

The return loss of the antenna for the optimized dimension as given in Table I is shown in Fig. 3. The figure shows the minimum return loss is -26.26 dB at the frequency of 880 MHz. Single band obtained at 880 MHz, which is in the range of GSM-900. From the figure, it is clearly observed that the proposed FSPA covers the frequency range from 839 MHz to 995 MHz for the return loss below -10 dB. So, the impedance bandwidth of this antenna is 156 MHz that is equivalent to 17.73% at the centre frequency of 880 MHz. The result describes that this antenna is well-suited for receiving the signals of GSM-900 band and then this antenna can be cascaded with the RF energy harvesting circuit for RF energy harvesting application.

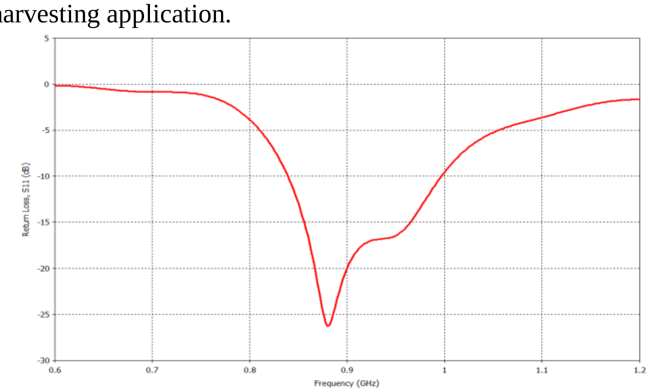


Fig. 3 Simulated return loss over frequency for FSPA

The standard value of the voltage standing wave ratio (VSWR) for any antenna to receive the signal properly should be below 2 over the operating ranges of frequency. The voltage VSWR is below 2 for this antenna over the frequency ranges from 839 MHz to 995 MHz that is shown in Fig. 4.

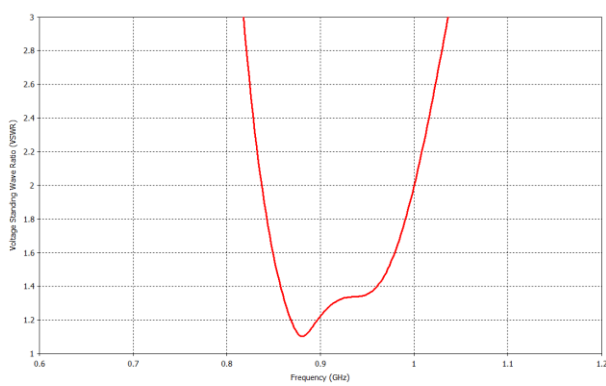


Fig. 4 Simulated VSWR over frequency for FSPA

Other important performance parameters of the antenna are gain and radiation pattern. The radiation pattern and gain of this antenna at the frequency of 839 MHz, 880 MHz and 995 MHz has been simulated that are shown in Figures 5, 6 and 7, correspondingly.

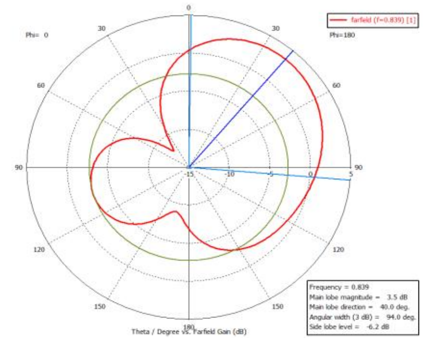


Fig. 5 Farfield radiation pattern and gain at 839 MHz

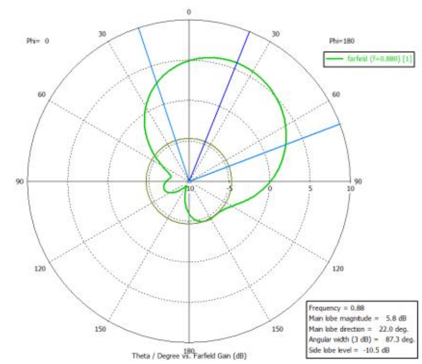


Fig. 6 Farfield radiation pattern and gain at 880 MHz

From the above result shown in Fig. 5 and 6, radiation pattern for both the frequency of 839 MHz and 880 MHz are unidirectional and the far field gain of the antenna are 3.5 dB and 5.8 dB, respectively. Main lobe direction of the radiation pattern is 40 degrees at frequency 839 MHz and 22 degrees at the frequency of 880 MHz. The angular width at 3 dB points of the main lobe is 94 degrees for 839 MHz and 87.3 degrees for 880 MHz that are wider and suitable for good performance antenna. The value of side lobe levels of the radiation pattern at both frequencies is good since its value is below -15 dB. The gain at the centre frequency of 880 MHz of the proposed antenna is well matched to employ in the GSM-900 application. That leads to use this antenna as a part of full RF energy harvester circuit for receiving signal from 860 MHz to 960 MHz. The radiation pattern and gain of this antenna at the frequency of 995 MHz is shown in Fig. 7.

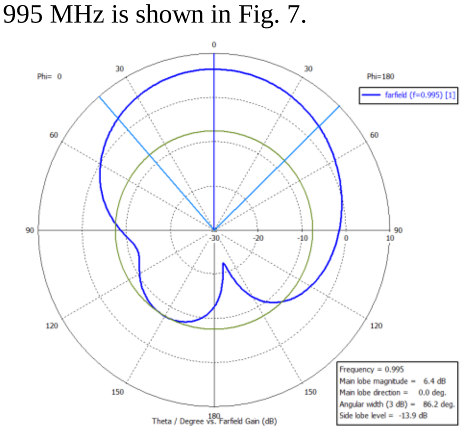


Fig. 7 Farfield radiation pattern and gain at 995 MHz

From the Fig. 7, it can be stated that far field radiation pattern at 995 MHz is also unidirectional and gain of the antenna at 995 MHz is 6.4 dB that is very good for the GSM-900 application as well as RF energy harvesting. The main lobe direction, the angular width at 3 dB points, side lobe level of this antenna at 995 MHz are 0 degrees, 86.2 degrees and -13.9 dB respectively. So, it can say the angular width of the proposed antenna is broader that will finely suitable for the application of GSM-900 and the side lobe level is below -15 dB that is also good.

IV. Parametric Analysis

It is necessary to have a parametric analysis of this antenna to find out optimized dimensions of FSPA for what the performance of the antenna will be good. Parametric analysis has done by varying some important parameters to observe the return loss and the impedance bandwidth of this proposed antenna. The key parameters that have great impact on the performance of the antenna are the length and width of the upper and lower patch, length of the side, the length of the edge and the height of each patch. There is also impact on the impedance bandwidth of the antenna of U-slot that has added to the upper patch of the antenna. In the section, the comparison between the performance with and without the U-slot is also explained. Firstly the return loss as well as impedance bandwidth of this antenna with and without U slot is shown in Fig. 8.

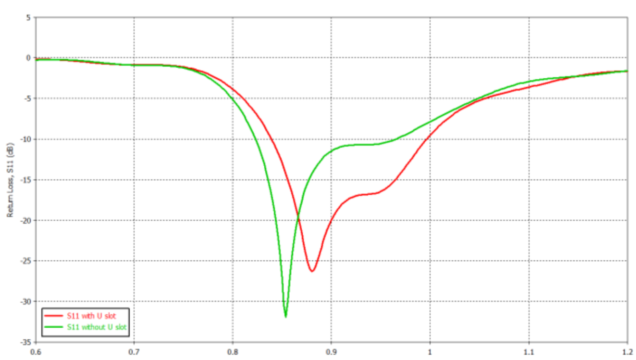


Fig. 8 Return losses with and without U slot on the patch

From the above Figure 8, it can say the impedance bandwidth has been increased in a broad range after inserting U-slot on the upper patch of the designed antenna. The lower and upper frequencies of the bandwidth are also shifted with having U-slot in the antenna that helps to cover the range of GSM-900 band. The variation of return losses at different length of the lower patch is shown in Fig. 9.

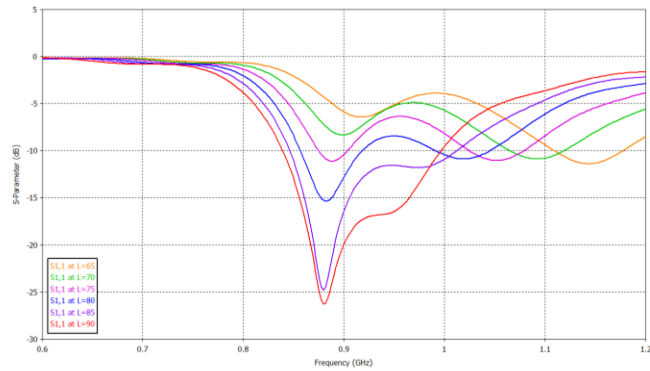


Fig. 9 Return losses at the different length of lower patch

The return loss as well as the bandwidth of the antenna decreased with decreasing the length of this antenna observed from the above curves. The better impedance bandwidth is obtained at the length of 90 mm that is shown by the red color curve of Fig. 9. The variation of the return losses with the width of the patch is shown in Fig. 10.

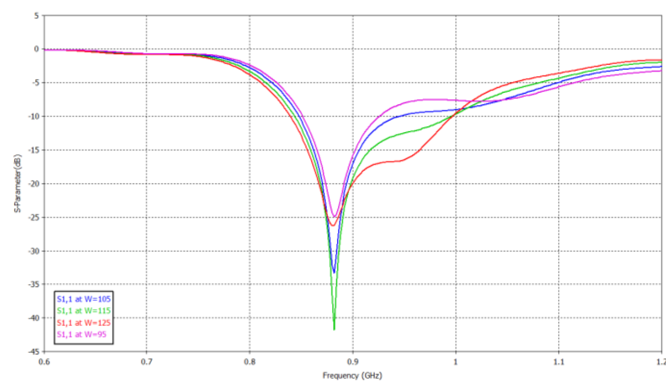


Fig. 10 Return losses at the different width of the patch

The impedance bandwidth of the antenna is decreased with decreasing the value of the width of the patch and best result is obtained at W=125. The variation of return losses and impedance bandwidth with different values of the length of the upper patch, length of the edge and the height of the patch are shown in Figures 11, 12 and 13, respectively.

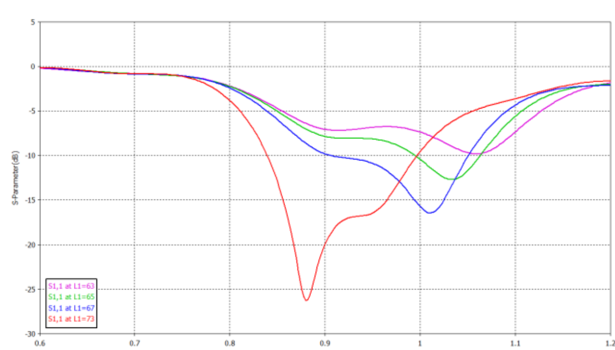


Fig. 11 Return losses at the different length of upper patch

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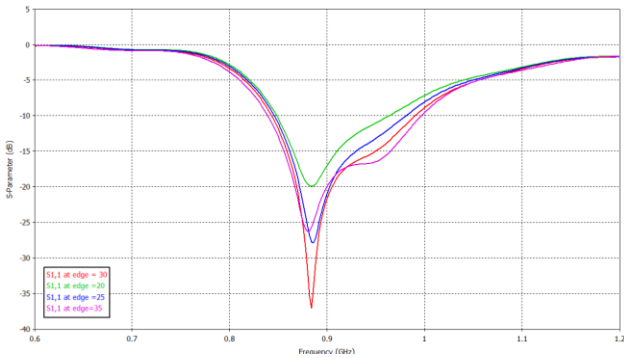

Fig. 12 Return losses at the different length of edge

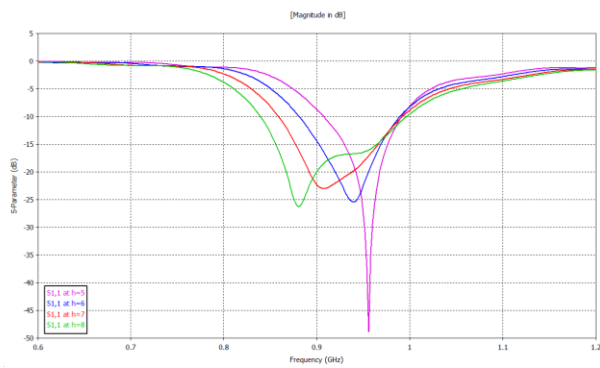

Fig. 13 Return losses at the different height of the patch

From Figures 11 to 13, it is observed that the impedance bandwidth of the antenna is decreased with the decreasing of the different values of length of edge, length of the upper patch and the height of the patch. The best result of the impedance bandwidth has been achieved at L1=73 mm, h=8 mm and edge=35mm. The parametric analysis plays an important role for choosing the proper dimension of the antenna so that antenna can perform well.

V. Conclusion

This paper represents a compact U-slot folded shorted patch antenna that can be used as an RF energy harvesting antenna for receiving the signals of GSM-900 band. There is a great importance of this work in mobile communication since the communication technology is growing day by day and the compact size device is highly acceptable. Therefore, this antenna will be used as a receiving antenna for capturing signal of GSM-900 band as the antenna proposed in this paper is mostly compact with comparing to the other folded shorted patch antenna designed before. This antenna can be connected with RF-DC converter circuit for harvesting RF energy at the frequency ranges from 860 MHz to 960 MHz in the future application. It can be concluded that the simulated result is well-suited for meeting the required application.

Acknowledgment

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