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Microstrip Antenna Array for RF Energy Harvesting System

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***Abstract*—This paper presents microstrip patch antenna array for RF energy harvesting system. The goal of proposed and fabricated antenna is to harness energy from surrounding environment consisting of mobile phone towers. The antenna has been designed to work in GSM1800 band. Initially a two patch antenna array has been designed and was later modified to four patch antenna array. Antenna simulation, analysis, computation of return losses, 3D polar plot and gain of the antenna has been done using High Frequency Simulator Software (HFSS). The simulated results show that the antenna array provides good performance in terms of return loss of -25 dB and a high gain of 9.2dB resonating at 1.78GHz frequency.**

I. INTRODUCTION

Energy harvesting, energy scavenging, free energy and ambient energy are all terms derived from renewable sources of energy. Energy harvester takes its fuel from ambient sources such as wind, solar, vibration, electro-magnetic waves. Radio waves are ubiquitous in our lives from various signals which are transmitted from TV towers, mobile phones towers, radio towers and wireless routers. In recent years the use of wireless devices has increased resulting in an increased demand for energy hence new techniques of energy scavenging are being developed. For employing ambient RF energy, the most appropriate bands to be explored are GSM 900 (935-960 MHz), GSM 1800 (1805.2-1879.8MHz), Wi-Fi (2.4GHz)[1]. The amount of energy harvested from RF signals depends on transmitted power, wavelength of RF signal, distance between the RF energy source and the harvesting node. Power transmitted by a transmitter in free space is calculated using Friis equation[2]

$$P_R = P_T (G_T G_R \lambda^2)/((4\pi d)^2 L) \qquad (1)$$

Where,
P_R = received power
P_T = transmitted power
L = path loss factor
G_T = transmitting antenna gain
G_R = receiving antenna gain
λ = wavelength of emitted signal
d= distance between the transmitting and receiving antenna.

The RF signal received by antenna is an AC signal which has to be converted into DC signal in order to charge low power devices. The RF-DC conversion efficiency η is represented as:

$$\eta = ((P_{DC})/(P_{received})) * 100 \qquad (2)$$

Where, $P_{DC} = V_{DC}/R_L$
V_{DC} is the output DC voltage at load
R_L is load resistance
$P_{received}$ is the RF power at the input of rectifier.

The basic block diagram of RF energy harvesting circuit consists of an antenna, matching circuit, voltage multiplier, energy storage as shown in Fig.1[3]. There are two basic

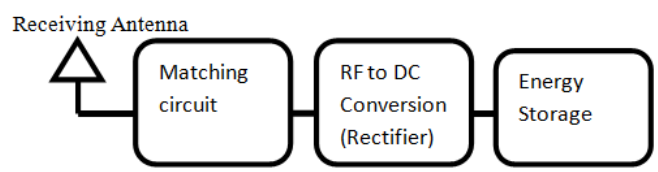


Fig. 1. Basic block diagram of RF energy harvesting

sub components in RF harvesting system, first one is the receiving antenna and second is the circuit to convert RF power to DC output. This paper discusses one of the components i.e receiving antenna. Various antenna structures have been designed and investigated in literature [4]. Section II describes the design of single patch microstrip antenna and antenna array (two and four patch), section III contains the results and discussion and Section IV is the conclusion of the paper.

II. ANTENNA DESIGN

An antenna is a the major component responsible for capturing RF signal. Main aim of antenna technology for RF harvesting system is to achieve high gain. Different structures of antenna design have been investigated [5], [6]. Microstrip patch antenna (MPA) is chosen for implementation in RF energy harvesting system but it has few limitations like low efficiency and low gain when implemented as single patch antenna. In order to overcome these limitations we investigated and proposed antenna array for RF harvesting system.

A. Design consideration for Microstrip patch antenna (MPA)

The proposed inset fed rectangular microstrip patch antenna (MPA) design shown in Fig. 2 is a single patch antenna having dimensions of 39mm x 52 mm. This planar structure of patch is resting on substrate FR_4 with dimensions 62.5mm x 70 mm. The dielectric constant of substrate E_r =4.4 has been used to improve the efficiency.The patch antenna dimensions were calculated at resonant frequency 1800 MHz. For efficient signal reception antenna parameters such as length and width, are calculated using mathematical computations listed below [7]. By substituting C=3x10^8 m/s, E_r = 4.4, f_0= 1.8GHz.

1. The width of patch is given as (W):

$$W = C/(2f_0\sqrt{E_r}+1)/2) \quad (3)$$

2.The effective dielectric constant (E_{reff}):

$$E_{reff} = (E_r+1)/2 + (E_r-1)/2\sqrt{[1+12h/w]} \quad (4)$$

3.The effective length(L_{eff}):

$$L_{eff} = \frac{c}{(2f_0\sqrt{E_{reff}})} \quad (5)$$

4. Calculation of length extension:

$$\Delta L = 0.412h \frac{(E_r+0.3)(W/h+0.264)}{(E_r-0.258)(W/h+0.8)} \quad (6)$$

5. The actual length of patch (L):

$$L = L_{eff} - \Delta L \quad (7)$$

The calculated values for the antenna parameters using the above listed formulae are listed in Table I as below.

TABLE I
PARAMETERS FOR SINGLE AND ARRAY PATCH ANTENNA

Design considerations			
Sr No.	Antenna parameters	value	units
1.	Height of substrate	1.6	mm
2.	Central frequency	1.8	GHz
3.	Dielectric constant	4.4	FR_4
4.	Length of the patch (L)	39	mm
5.	width of the patch (W)	52	mm

As power is the main concern hence at the input of harvester we need to receive maximum transmitted signal. In such a case a weak signal or false signal detected will result in unnecessary power loss. To achieve this initially we proposed a single microstrip patch antenna and then later on modified it two patch antenna array. Finally four patch antenna array with enhanced gain was designed. The four patch antenna resonates at 1.8 GHz frequency. The proposed antenna consists of four rectangular patches each with a slot of 11mm X 3mm within the structure. The patches form a planar structure on top of substrate FR_4 all resting on the same ground plane. Designing of all the three antenna models has been done using High Frequency Simulator Software(HFSS)[8].

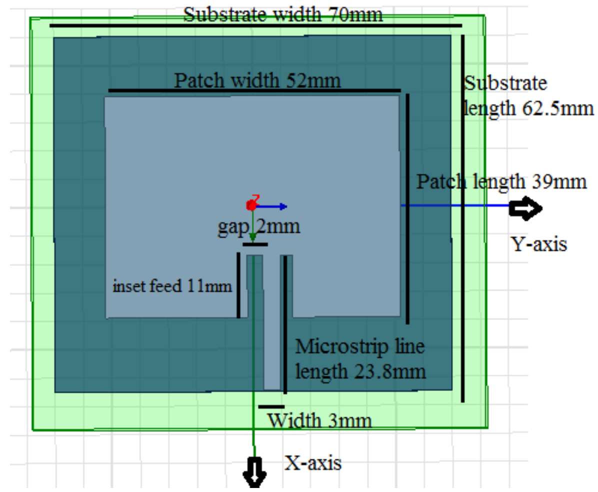


Fig. 2. Inset fed Microstrip single patch antenna

B. Antenna Array design

Different techniques have been investigated to feed array Antenna[9]. The significant steps in designing a patch antenna array are the dimensions of patch and the feeding configuration. The patch dimensions are considered as 39 mm X 52 mm for each single patch which is also responsible for maintaining the operating frequency at 1.8GHz. The feeding technique used is microstrip line with dimensions as 23.8 mm X 3 mm which is used for controlling impedance matching advantageous for obtaining high gain.

In the proposed design of antenna array, patches are to be fed by a single feed line, the power from which has to be divided equally among each patch. T-junction power divider is used in symmetric configuration as shown in Fig.3.

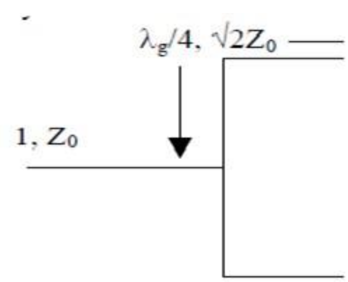


Fig. 3. Symmetric T-junction Power Divider

The top line shows the dielectric layer and ground plane underneath. It can also be considered as two lines having a characteristic resistance $\sqrt{2}Z_o$ and length L = $\lambda_g/4$ where λ is wavelength at the centre frequency (f_0) 1.8GHz. With Z = $2Z_0$ the divider matches $S_{11} = S_{22} = S_{33} = 0$ at f_0. Symmetry guarantees that a signal incident on port 1 will split equally at the centre frequency. The two patch antenna is designed with substrate dimensions as 82.5 mm X 130 mm. Distance between the two patches is calculated as 4λ where λ is the wavelength at central frequency at 1.8GHz obtained as 60.6 mm. The symmetrical T-junction power divider dimensions are obtained as 50 mm X 1 mm for top line and dimension for main line as 19 mm X 3 mm[10]. Fig.4 and Fig.5 show the two and four patch antenna array structures. Obtaining higher gain is the purpose of our RF signal capturing antenna. To achieve this the two patch array is further modified to four patch antenna array. The dimensions of substrate for four patch antenna array is 144 mm X 130 mm. To design four patch antenna array a copy of the two patches is made by separating them with a distance of 4λ = 66mm where λ is the wavelength at 1.8GHz resonant frequency. Patch length and width for each element is same as that used for single and two patch element antenna which is described above. Optimization process followed to achieve higher gain involves varying the length and position of microstrip line feed. Higher gain is obtained at the cost of increased size of antenna array but size optimization is not a consideration in case of RF energy harvesting system; where our target is to achieve maximum gain.

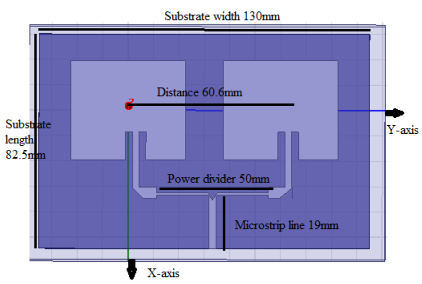


Fig. 4. Two Patch Antenna array

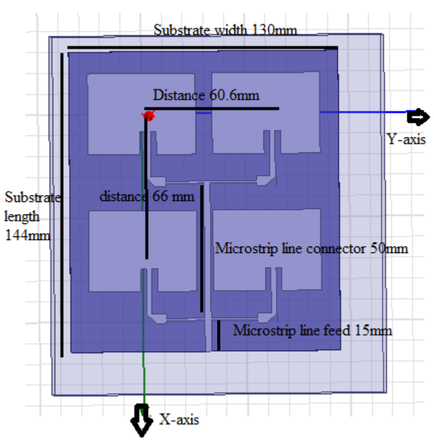
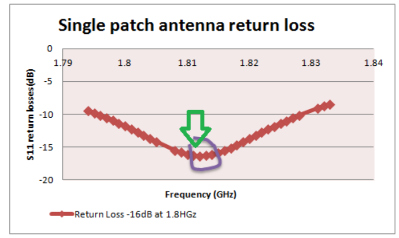


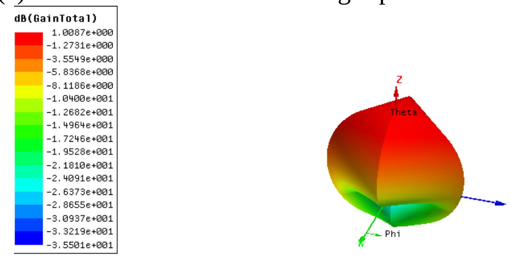
Fig. 5. Four Patch Antenna array

III. Simulation Results and Discussions

Further optimization and fine tuning of dimensions is carried out using High Frequency Simulator Software(HFSS) to bring the resonance at the desired frequency with acceptable return loss. Fig.6(a) demonstrates the return loss obtained for



(a) Return loss obtained for single patch antenna



(b) Gain of Single patch antenna

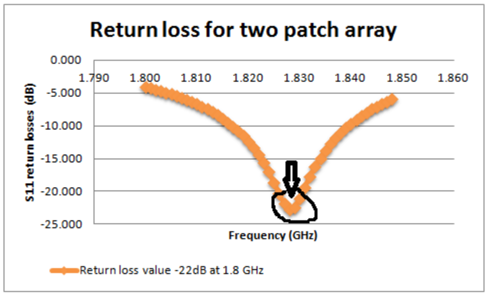
Fig. 6. Simulated results (a) Return loss and (b) gain of single element patch antenna

a single patch antenna is -16.33dB.

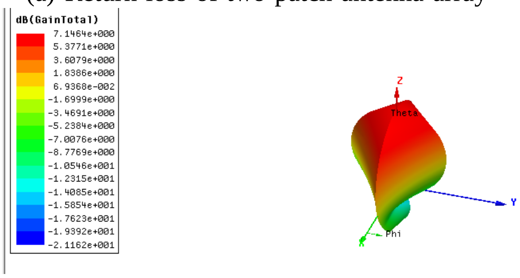
Fig.6(b) shows that the gain obtained for single patch antenna as 1dB at 1.8GHz. The microstrip patch antenna array has been designed first for two patch antenna array which obtained return loss of -22.7dB as shown in Fig.7(a), and Fig.7(b) shows that the gain obtained for two patch array antenna is 7.14dB at 1.8GHz. Our proposed antenna is a four patch array which obtained return loss of -25dB as shown in Fig.8(a), and Fig.8(b) shows that the gain obtained is 9.2dB at resonant frequency of 1.78GHz but a slight shift in central frequency from 1.8GHz to 1.78GHz has been observed. The antenna still works in 1810-1880 MHz (GSM) 1800 band and hence is suitable to capture RF signal for RF energy harvesting circuit. Table II shows the comparison of single and multiple patch antenna array (two and four). This table justifies the purpose of designing a four patch antenna array as it shows that has obtained highest value of gain as 9.2dB. The proposed structure is fabricated to work as a receiver for capturing RF signal in RF harvesting circuit. The fabricated two patch antenna array and four patch antenna array is shown in Fig.9 and Fig.10.

TABLE II
Comparison of single and multiple patch antenna array structures

Parameters for designing antenna single and array			
Parameters	single patch	two patch	four patch
Central frequency	1.8GHz	1.8GHz	1.78GHz
Return loss	-16dB	-22.7dB	-25dB
Gain	1dB	7.14dB	9.2dB

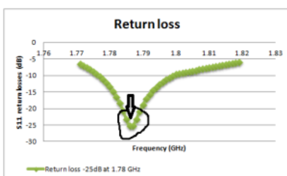


(a) Return loss of two patch antenna array

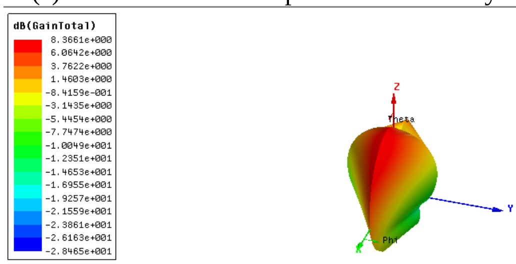


(b) Gain of two patch antenna array

Fig. 7. Simulated results (a) Return loss and (b) gain of two patch antenna array



(a) Return loss of four patch antenna array



(b) Gain of four patch antenna array

Fig. 8. Simulated results (a) Return loss and (b) gain of four patch array antenna

IV. Conclusion

In this paper, a high gain microstrip four patch antenna array has been presented and developed. It has successfully achieved a gain of 9.2dB at resonant frequency of 1.78GHz, the designed and fabricated antenna will work as receiver for capturing RF signal in 1800MHz GSM band. Two and four patch antenna has been fabricated and can be used for receiving RF signal emitted from mobile phone towers operating at GSM 1800 MHz band. Higher gain antenna should work better as it capable of capturing more RF signal. Designing and fabrication of RF to DC conversion circuit is in our

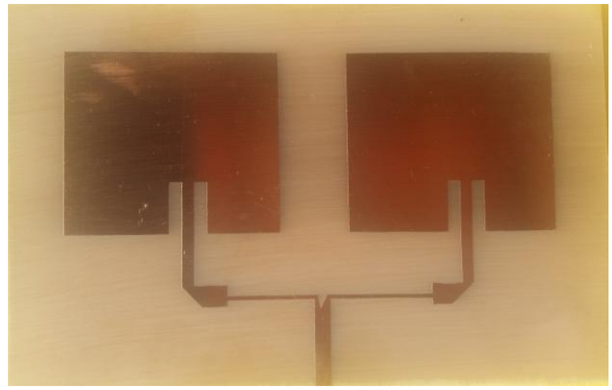


Fig. 9. Fabricated two Patch Antenna array

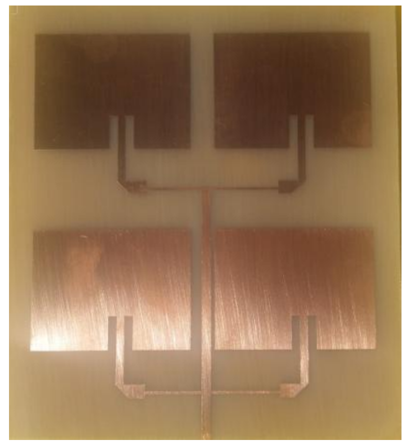


Fig. 10. Fabricated four Patch Antenna array

future scope of work. When this antenna is combined with rectifier, this system can be used for harvesting electromagnetic energy.

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