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Design of low power RF to DC generator for energy harvesting application

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Abstract: This paper describes the design of a voltage doubler with matching circuit using Schottky diode HSMS-2850 and microstrip rectangular patch antenna array for RF energy harvesting application. Microstrip rectangular antenna array and two stage voltage doubler or charge pump circuit are designed for capturing directed electromagnetic energy and convert into suitable DC voltage. Simulation results show that a DC voltage of 0.747 V can be achieved at -10dBm input energy level at 2.4 GHz when load is 20 Kohm. This paper also describes microstrip rectangular patch antenna array (2x2) for increase the input energy level at 2.4 GHz frequency.

Key words: Harvesting energy, RFID tags, voltage doubler circuit, microstrip rectangular antenna array.

1. Introduction

The process of capturing energy which are available from different types of sources like RF source, solar energy, piezoelectric is called energy harvesting. Radio frequency (RF) energy harvesting is the process of capturing ambient electromagnetic energy and converting into suitable DC power. In the radio frequency energy harvesting, ambient and controlled sources are the different types of microwave sources. The study of technology for harvesting and recycling wireless power is essentially based on the radio frequency identification or RFID. In case of the power from ambient RF sources, the amount of captured energy is extremely low. So a single antenna does not suffice and antenna array is essential as the incident power level low. Besides, the antenna design is highly influenced by size constraints for sensor nodes in RFID [1, 2]. This work focuses on design, testing and measurement of microstrip antenna array to capture electromagnetic energy from the RF signals that have been radiated by communication and broadcasting system at ISM band 2.4GHz. Momentum Simulation method in ADS-2008 has been used for design antenna array and Harmonic Balance method in ADS-2008 has been used for design the voltage doubler with matching circuit.

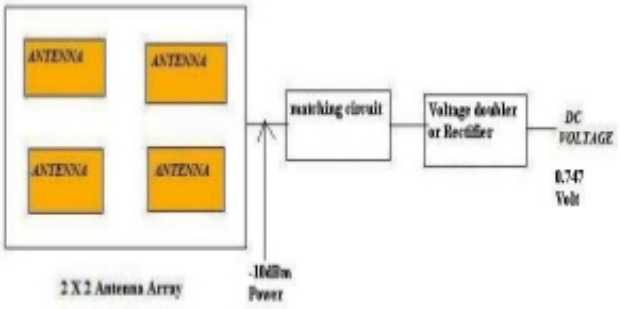

Figure 1: Block diagram of energy harvesting system

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2. Materials and methods

2.1. Design of Microstrip Rectangular Patch Antenna

The main objective is to design microstrip rectangular patch antenna array (2x2) of sharp return loss curve and high gain over narrow bandwidth. Microstrip patch in its simplest configuration consists of a radiating patch on one side of a dielectric substrate, which has a ground plane on the other side. The path and ground plane are separated by the dielectric. The patch conductor normally copper and can assume any shape. There are many configurations that can used to feed microstrip antenna. Four popular feeding are microstrip line (inset feed), coaxial feed, aperture coupling, and proximity coupling. The feed techniques we are using here insert feed. The dielectric material that is used in this design of the Microstrip Patch Antenna is R04003C from Rogers corps with $\varepsilon_r = 3.5$. The selection of substrate depends on the type of circuit, operating frequency of operation and the amount of dissipation from the circuit. The properties of substrate materials should be high dielectric constant, low dissipation factor, high purity high resistivity, high stability, surface smoothness and thermal conductivity [3]. The operating frequency of the Patch antenna has been selected as 2.4GHz. Therefore the height of the antenna is calculated to be 1.52mm.

The parameter that are decided by the default in order to continue to the design process are -

Dielectric substrate= 3.5

Velocity of light=3×10^8 m/s

Loss tangent=0.002

Operating frequency(f)=2.4GHz

Conductivity=$5.8\text{x}10^7$(copper)

Hight of substrate(h)=1.52 mm

Thickness of ground plane=35µm

Feeding metho=-microstrip line (inset feed)

Polarization = linear

Name of Substrate metal=R04003C

Figure 2 shows (2x2) microstrip rectangular patch antenna array. First effective length, effective dielectric constant and width are calculated using the value of parameter which is discussed above. It is observed that 50 ohm line width is 3.5 mm with the help of ADS software.

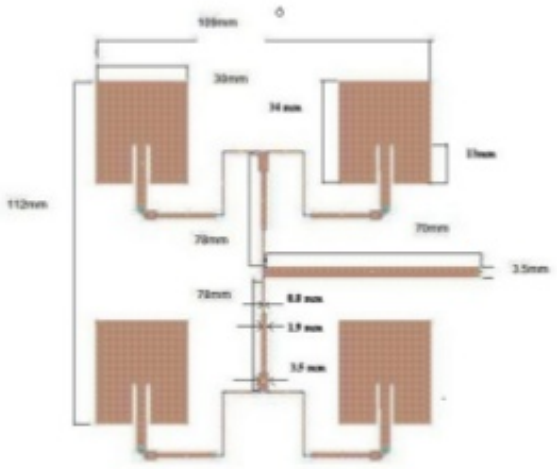

Figure 2: (2x2) Microstrip rectangular patch antenna array

2.2. Design of two stage voltage doubler with matching circuit

Rectifier, also called charge pump device or voltage multiplier ,convert input RF signal received by the antenna into a suitable DC supply voltage [4].The voltage multiplier converts a part of incoming power supply to DC for power supply [5]. Some time voltage multiplier is also called charge pump. A basic schematic of a Villard voltage doubler, sometimes also called Cockcroft-Walton voltage multiplier. The design of voltage multiplier circuit has been described in various literaturs [6-11]. A DC voltage of twice the peak amplitude of the input AC signal can be generated at the DC output. A LC matching circuit is placed between antenna terminal and voltage doubler circuit. Here Schottky diodes HSMS-2850 are used. The two stage voltage doubler is designed and simulated using Harmonic Balance simulation in ADS-2008.

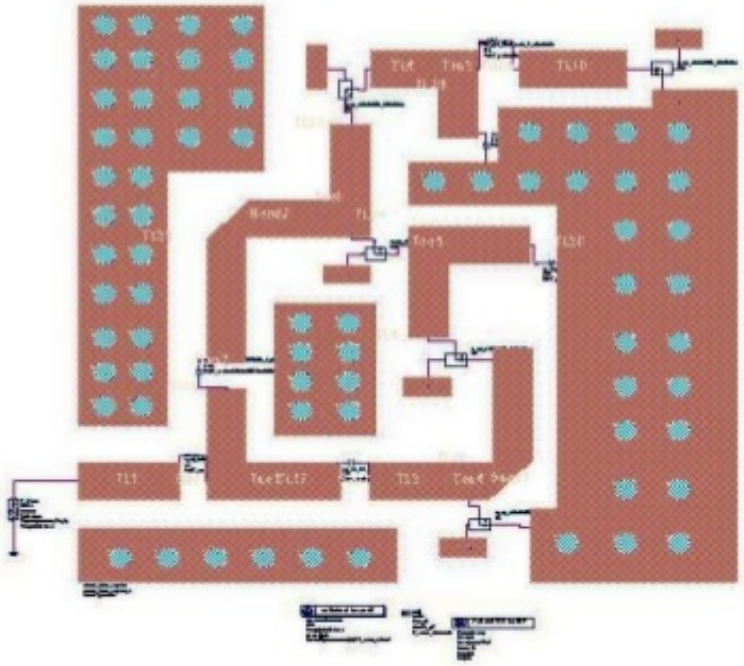

Figure 3: Layout of the two stage voltage doubler circuit in ADS using impedance matching

3. Result and discussion

3.1. Simulation Result of 2x2 Microstrip Rectangular Antenna

The 2x2 microstrip patch antenna array antenna array is simulated using Momentum Simulation method of ADS-2008. The return loss of the 2x2 microstrip patch antenna is 16.44 dB when resonance frequency is 2.363 GHz. The gain of (2x2) microstrip antenna array is 11.570 dB and the directivity of this antenna array is 13.07739 dB.

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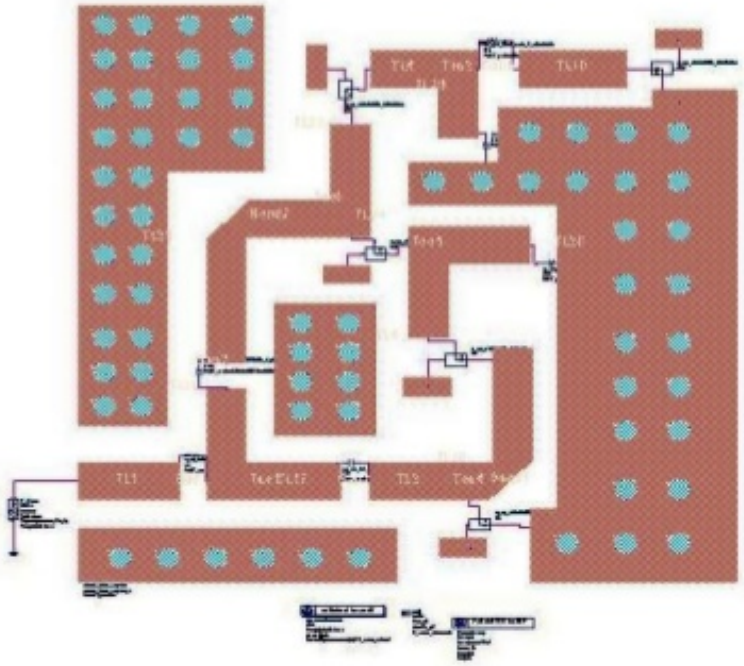

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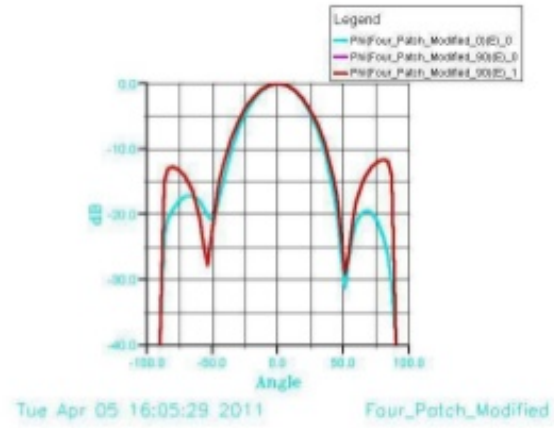

Figure 4: 2D cut out of radiation pattern in phi-plane in fourth

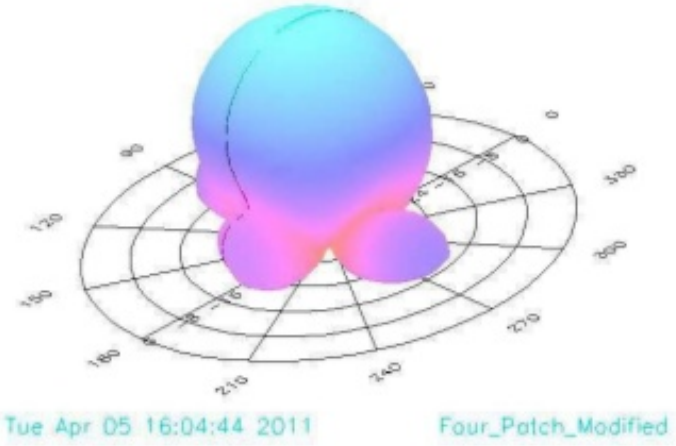

Figure 5: 3D Radiation pattern of four patch antenna array

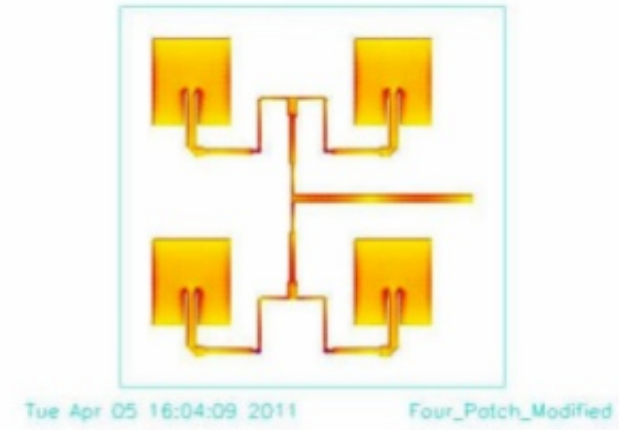

Figure 6: Current distribution of 2x2 microstrip rectangular antenna array

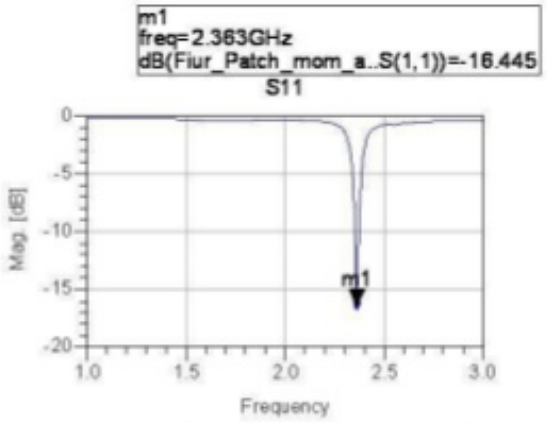

Figure 7: Returns Loss Curve of 2x2 Microstrip Patch Antenna Array

Table 1: Result of 2x2 Microstrip Patch Antenna

Parameters	2x2 antenna array
Power radiated(watts)	0.004816154208
Effective angle(degree)	35.45
Directivity(dB)	13.07739891
Gain	11.58704428
Maximum intensity(Watts/steradian)	0.007784494403
Angle of U max(theta, phi)	0.00
E(theta)Max(mag, phase)	2.394637799
E(phai)Max(mag, phase)	0.3619677709
E(x)Max(mag, phase)	0.02007801732
E(y)Max(mag, phase)	2.41757157
E(z)Max(mag, phase)	0

3.2. Simulation Result of Two Stage Voltage Doubler with Matching Circuit

The two stage voltage doubler with matching circuit is simulated using Harmonc Balance Simulation method of ADS-2008. Figure8 and figure9 represents the V_{out} and V_{in} at frequency 2.4 GHz. It is observed that Vout depends on the design parameters like value of capacitors and inductors. Vout also depends on the number of the stage,size of schottky diode. The outputs have measured when input power Pin= -10dBm and 0.00 dbm with the help of Harmonic Balance simulation method.

Table 2: Summary of Simulation Result

P_{in}(dBm)	Open circuit	When load=20Kohm
-10 dBm	1.053 Volt	0.747Volt
0.00 dBm	2.971Volt	2.048Volt

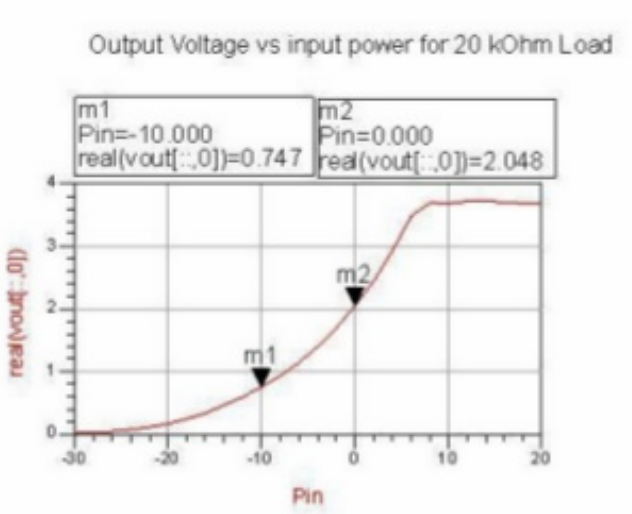

Figure 8: Simulated Value of P_{in} Vs V_{out} When Load is 20Kohm

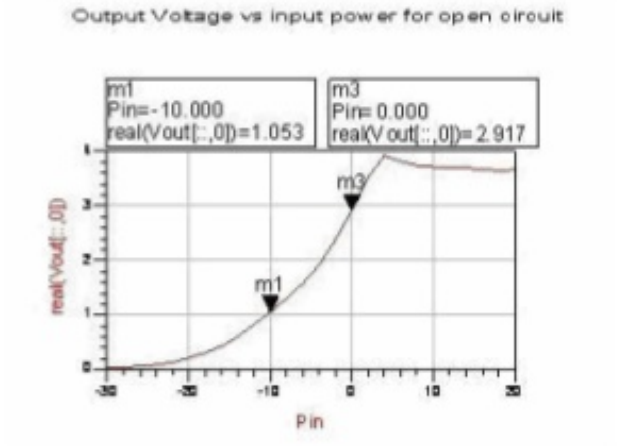

Figure 9: Simulated value of P_{in} Vs V_{out} in open circuit

4. Conclusions

First 2x2 microstrip patch array has been designed and simulated using ADS 2008 momentum simulation method. Simulated gain is 11.58 dB. This four elements array of dimension 109 mm X 112 mm can capture significant electromagnetic energy. Also two stage voltage doubler circuit is designed and simulated using a Harmonic balance simulation in ADS2008 software. Simulated DC output voltages are obtained as 0.747V and 1.053V for -10dBm input power for 20Kohm load and open circuit respectively. After combining this antenna section with rectifier, this system may be used harvesting directed electromagnetic energy.

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