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HARVESTING MICROWAVE SIGNAL POWER FROM THE AMBIENT ENVIRONMENT

Dinesh kumar S[1], Veeramani R[2]
[1]PG Final year student (M.E) Dept of ECE, K.S.R College of Engineering.
[2]Assistant professor Dept of ECE, K.S.R College of Engineering.
Email:dineshsenth@gmail.com Email:rveeramani1@yahoo.co.in.

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***Abstract*- To harvest microwave frequencies in the ambient environment and convert into DC is presented in this paper. The RF harvester replaces a dedicated RF source which is used in an applications like wireless sensor networks to battery operated wireless handheld devices. The focus of work is divided into two parts. The first is to design a compact planar prototype microstrip patch antenna using HFSS for the frequencies of 900&1800MHz (GSM band), 1575MHz (GPS band) and 2.4GHz (ISM band). Antenna is fabricated using MITS PCB prototype machine and tested in VNA. Results obtained from the VNA indicates -30dB and -35dB for GSM 900& 1800 MHz, -15dB for GPS 1575 MHz band and -28dB for ISM 2.4GHz band. Second part consists of RF circuit model includes matching and rectification unit which determines the RF to DC conversion efficiency up to 60%. Voltage doubler RF rectification circuit using schottky diode is designed in ADS and it is tested practically. A lumped T type matching network is implemented to provide a proper impedance match.**

***Index Terms* - HFSS (High Frequency Structure Simulator), ADS (Advance Design Software), DC (Direct Current), GSM (Global System for Mobile communication), and VNA (Vector Network Analyzer)**

I. INTRODUCTION

Energy is one of the important requirements for all the systems. RF energy harvesting provides an opportunity to harvest the microwave signal from an ambient environment. There are lots of sources available to generate the power, like solar systems, nuclear energy but this microwave signals paves a new way to generate the power. Available RF energy in the ambient specifically close to transmission tower provides an opportunity to harvest the energy. Applications like battery operated sensors, small handheld devices can be energized by RF energy harvester and this may be the more convenient solution to provide power to these kinds of devices from ambient RF environment such as mobile phone signals and microwave signals. Hence the need for dedicated source, its limited lifetime and often replacement can be avoided.

The RF energy harvesting uses the idea of harvesting transmitted RF energy and directly power the low power circuit or storing it for later use. Efficient antenna along with a circuit is needed to convert RF signals to DC voltage. The efficiency of an antenna mainly depends on its impedance and the impedance of the rectifying circuit. If these impedances aren't matched then it will be unable to receive all the available power from the free space at the desired frequency band [10]. Block diagram of energy harvesting unit is shown in Fig.1. Maximum power transfer is generally achieved by using additional passive matching networks connected between source and load. To increase efficiency of conversion and DC power harvested, we can use the special RF source to feed the devices [9].

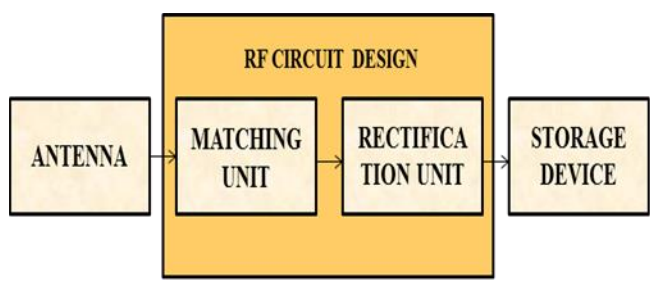


Fig.1.Block Diagram of Energy Harvesting Unit.

II.MULTIBAND ANTENNA

Antenna is act as a transducer that converts one form of energy into another form. Multiband antenna is designed to cover up the frequencies of GSM900, GSM1800, GPS 1575MHz and ISM band of 2.4GHz [1]. Design was made through HFSS software. The design of antenna is shown in

Fig.2. An optimized length of the feeding line and defect ground structure are used to reject the second and the third harmonics [8].

The total size of the antenna is 120*120 mm. In Fig.2, gray color represents the ground and yellow color represents the patch, in between patch and ground there is the substrate of 3mm height with FR4 material. Patch is divided into three parts patch1, patch2, patch3,center is the patch1,left from the center patch is patch2, right from the center patch is patch3, in-between the patches there is a gap of 0.1mm.Gap provides the electromagnetic coupling between the patches so that multiband is achieved.

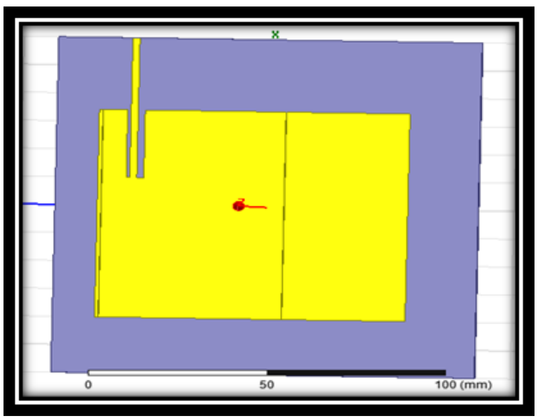


Fig. 2. Multiband Antenna design in HFSS

Length of the total patch is 74.2mm and width of the patch 1,2,3 is 51.8mm,1mm,35mm.Total Width of the patch is 88mm.Design suited for GSM band of 900,1800 and GPS band of 1575Mhz and ISM band of 2.4 GHz. Simulation result of the designed multiband microstrip patch antenna is shown in Fig.3.

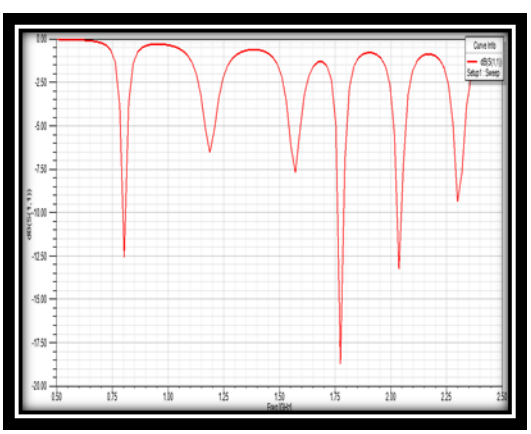


Fig.3. Simulated result of multiband microstrip patch antenna design

From the simulation result GSM 900 band has the return loss gain of -28 dB and GSM 1800 band has the return loss gain of -22 dB, GPS band has -5dB and ISM band has -15dB of return loss gain.

III.ANTENNA FABRICATION PROCESS

Antenna is fabricated using MITS PCB prototype machine. MITS PCB Prototyping machines are especially useful for making RF/Antenna circuit boards. Design pro software is used to interface the computer and MITS PCB prototype machine. Conversion Chart for fabrication process is shown in Fig. 4.

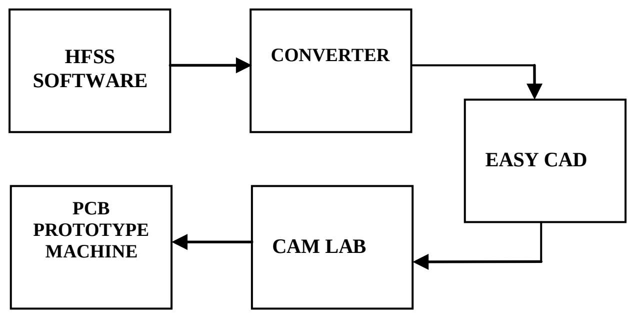
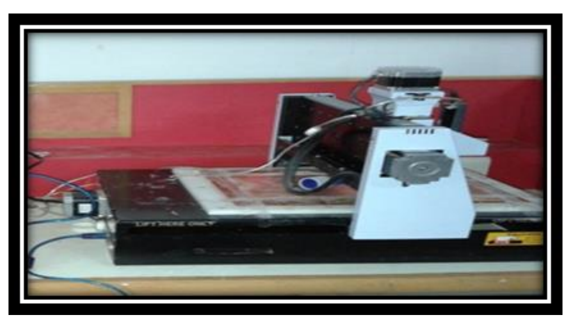


Fig. 4. Conversion chart for fabrication process

A design of antenna is made through HFSS software and exports design to .dxf format. Design pro contains converter and CAM application. The function of Converter is editing PCB pattern data and data import/export and CAM application is designed to control our PCB prototyping machines. Finally antenna is fabricated using MITS



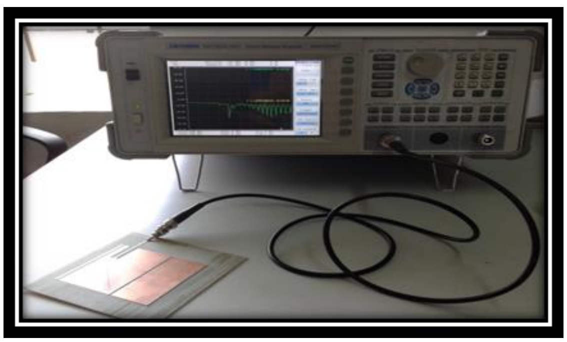
prototype machine is shown in Fig. 5.

(a)

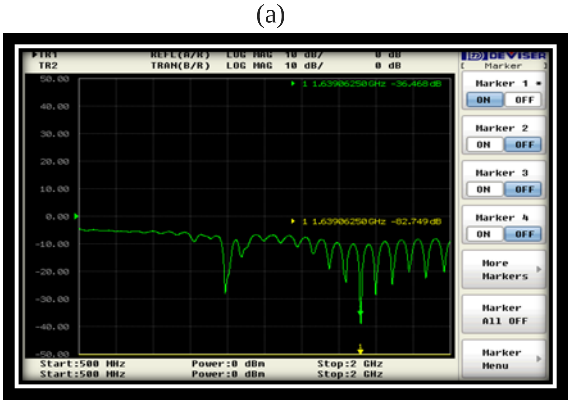
(b)

Fig.5. (a) Photograph of MITS prototype machine (b) Photograph of Fabricated multiband antennas design.

Fabricated antenna is tested using Vector Network Analyzer is shown in Fig.6. (a).



(a)



(b)

Fig .6. (a)Fabricated antenna is tested using Vector Network Analyzer (b) Result of the fabricated antenna.

From the practical result it shows that GSM 900 MHz has -30dB of return loss gain, GPS 1575 MHz has -15 dB, GSM 1800 MHz has -35 dB, and ISM 2.4 GHz has -28 dB of return loss gain, shown in Fig.6.(b). The comparison of simulated and practical result is shown in Fig.7.Fabricated result is more effective than simulation result.

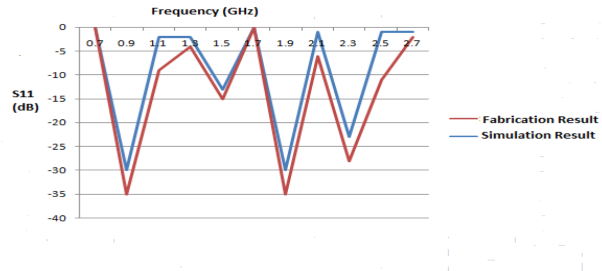


Fig.7. Comparison of simulated and practical result

IV.MATCHING NETWORK

RF matching circuit helps to match the impedance of antenna to rectifier unit and rectifier unit to battery. A good impedance match was achieved by employing proper matching circuit [1]. A series lumped element inductor was used to absorb part of the capacitive reactance from series diode and the quarter-wavelength short circuit shunt stub was employed to achieve the desired 50Ω impedance. After the optimal load was found, further broadband optimization was performed to the matching network and the load to ensure good impedance matching throughout the target frequency range. The Power Management Module (PMM) capable of performing Maximum Power Point Tracking (MPPT) [5]. In the RF region, there are a number of parasitic elements in the diode and capacitor that cause degradation of the RF boosting properties. Moreover, RF receiving signal is so weak, the enhancement circuit should be needed in RF region, such as LC resonant circuit [6].

Matching is usually done with L- type matching, In order to eliminate unwanted harmonics in the output signal; high-Q network should be achieved. L-type matching network provide no control over the value of the Q-factor. One needs to introduce a third element in the matching network so two combination of network possible one is T-matching networks and other one is ∏-matching network. In this system T-matching was given through smith chart matching in ADS [4] is shown in Fig.8.

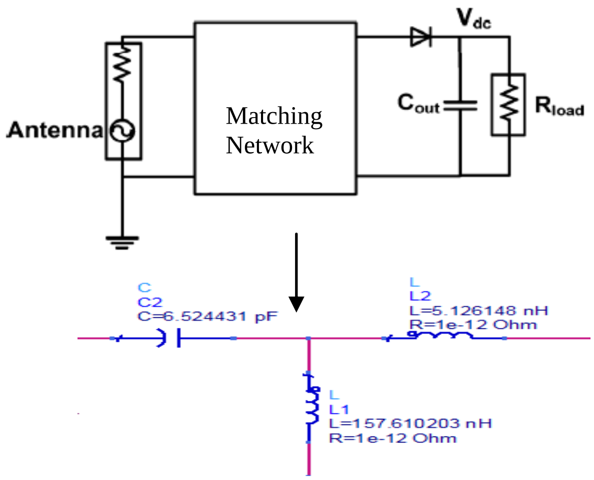


Fig.8: T- Matching Network

V.RECTIFICATION IN ADS

Rectification is the heart of the system. This system is capable to convert RF-AC into DC. ADS software is used to design the rectification unit.ADS is chosen because of its excellence features such as flexibility in schematics and layout editing and time efficient simulation [3]. Advanced Design System is an electronic design automation software system produced by Keysight EEs of EDA. The ADS platform comprises solutions for design entry, synthesis, system, circuit, 3D EM simulation, analysis/post processing, and a complete flow to manufacturing.

A rectifying antenna (Rectenna), which is used to convert the microwaves to the Direct Current, is one of the key components of the MPT systems. A rectanna is a passive element with rectifying diodes that operates without an internal power source. A diode with a lower built-in voltage would realize a higher rectifying efficiency [7]. Schottky diode of model HSMS 285x is used for rectification purpose. The characteristics of HSMSx has B_v=3.8v, C_j=0.18pF, I_{Bv}=3x10-4A, $I_s=3x10^{-6}$A, N=1.06, R_s=25Ω. The single band circuit design of energy harvester is shown in Fig 9. In single band circuit design GSM 915 band is used as source frequency and only one schottky diode is used for rectification.

Working frequency is an important parameter to consider when designing a rectenna. It is often dictated by the desired application. At low frequency (below 1GHz), high gain antenna tends to be quite large. Increasing the frequency thus allows the use of more compact antennas. Friis transmission equation helps to calculate the total power received [4]. Friis transmission equation is given by

$$P_r = P_t G_t G_r [\lambda/(4\pi R)]^2 \qquad (1)$$

P_r is the total power received, P_t is total power delivered to the Tx antenna, G_t is transmitting antenna gain, G_r is receiving antenna gain, R is distance between Tx and Rx, λ is a Wavelength. P_r (Total received power) is directly proportional to the P_t (Transmitting power) and it is also directly proportional to the gain of transmitting and receiving antenna (G_t, G_r) and inversely proportional to R (distance between the transmitting and receiving antenna).

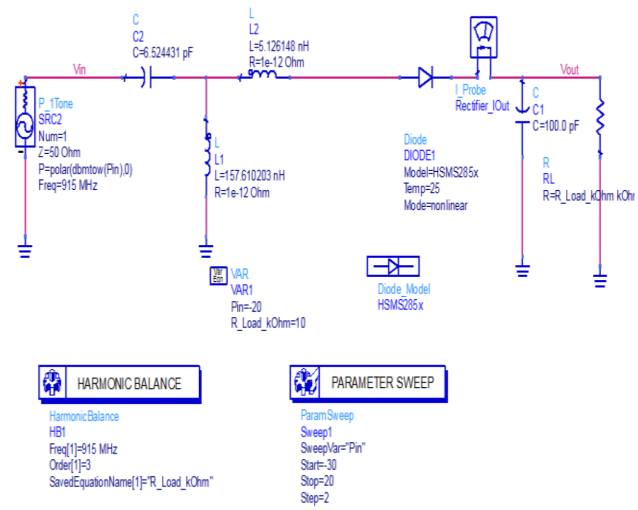


Fig.9. Single band circuit design of energy harvester

In this design, receiving antenna of 915 MHz is used and next to the antenna is a T-matching network comprises of lumped inductor, capacitor that provides impedance matching. Rectification unit in the system uses schottky diode of HSMS285x is used to convert the RF-AC into Direct Current. In this system input power is given as -20dB and load resistor RLoad=10Kohm. The simulation result is shown in Fig.10. From the simulation result at -6dBm of input power the obtained output voltage is 0.187V, for 0dBm of power, 0.468V is obtained and for -10dBm of power, 1.772V is obtained.

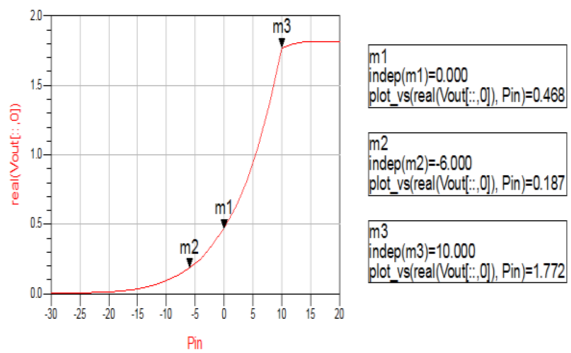


Fig.10.Simulated result of Single band harvester

In the above harvesting design, only one frequency and one schottky diode is used. The design is further improved by using multiband frequency of GSM 900 MHz, GSM 1800MHz, GPS band of 1575MHz and ISM band of 2.4GHz and voltage doublers circuit is used, so that result is further improved. The multiband harvester circuit design is shown in Fig.11.

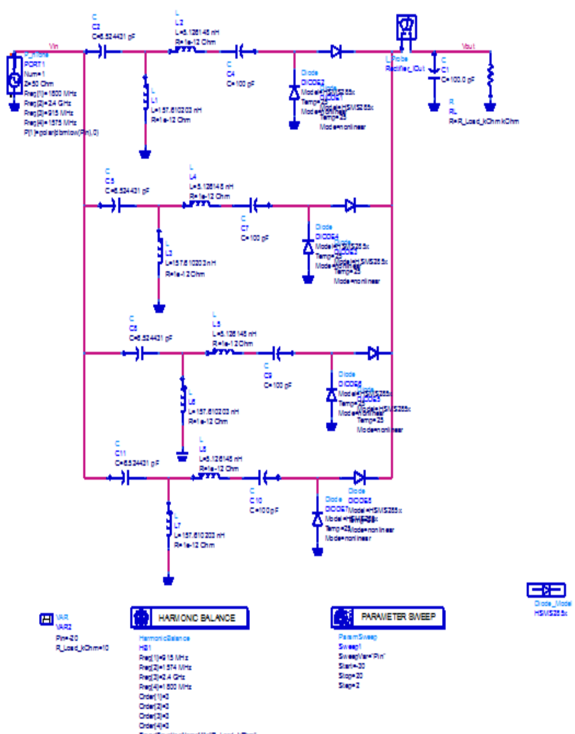


Fig.11. Multiband circuit design of energy harvester

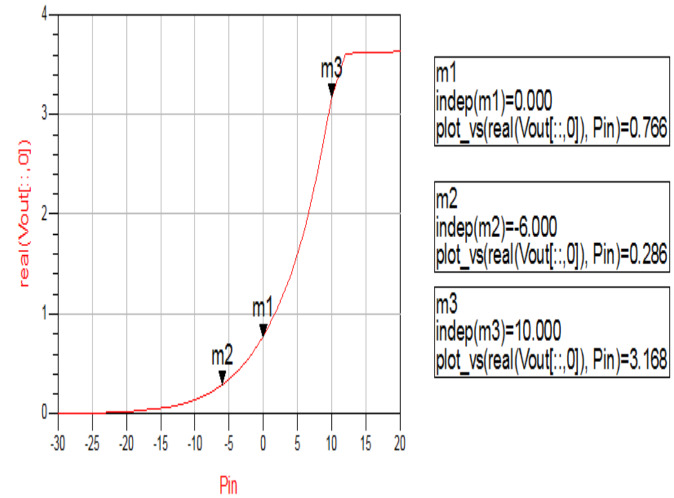


Fig.12.Simulated result of Multiband harvester

The Fig.12 shows the simulation result of combined multiband frequency of harvester design. . From the simulation result at -6dBm of input power, obtained output voltage is 0.286V, for 0dBm of power, 0.766V is obtained and for -10dBm of power, 3.168V is obtained.

Table I: Comparison between Single and Multiband harvester design

Input power Pin (dBm)	Single band(900MHz) Output Voltage(V)	Multiband band(900MHz,1800 MHz,1575MHz,2.4G Hz)Output Voltage(V)
-6dBm	0.187	0.286
0dBm	0.468	0.766
10dBm	1.772	3.168

From the Table I it shows that output voltage in Multiband harvester design is nearly double than that of single band (900 MHz) harvester design.

VI.CONCLUSION

In this paper multiband antenna was designed and fabricated using Mits prototype machine, with the help of this antenna we can able harvest the four bands (GSM 900

MHz,GSM 1800MHz, GPS 1575 MHz and ISM 2.4 GHz). Rectification process helps to convert RF-AC to DC. Design of rectification unit is done with the help of ADS software. Rectifier is one of the key technologies for microwave power transmission and energy harvesting. Rectification is tried with both single band and multiband. Multiband rectication gives more efficiency compare to the single band (GSM 900 MHz).

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