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Self-sustained RF Energy Harvesting Antenna design for GSM band applications

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ABSTRACT: Self Sustainable operation is one of the most significant concerns in today's low power electronics for smart environments namely IOT. The periodical replacement of the batteries apparently is practically impossible and cost consuming. Hence, the present challenge is to develop the energy harvesting systems which are smaller in size compared to the wireless sensor devices and increased signal reception efficiency. Energy harvesting is a conversion process of the ambient energy into electrical energy. This paper aims to design a self-sustainable Metamaterial inspired Compact open split Ring resonator Antenna for GSM 900 band(940 MHz) and GSM 1800 band which harvests the RF Energy fields of the bands from cellular towers and utilizes the captured RF energy to power IOT devices. The system consists of the metamaterial inspired open split ring resonator antenna, 8-stages voltage multiplier modules, low power IOT device. The subsystems have been developed, fabricated and characterized in an anechoic chamber. This proposed prototype can efficiently charge the energy storing devices like super capacitor. In order to power up the wireless sensor networks of Internet of things and low power Mobile electronics

KEYWORDS: RF Energy harvesting, OSRR antenna, Broadband antenna, GSM 900, GSM 1800, self-sustained antenna and low power IoT device.

I. INTRODUCTION

Eventually, everything connects, this famous quote highlights the colossal potential that the new flourishing technology the Internet of things (IoT) encompasses. Internet of things has secured its foothold as one of the major technological innovations along with Artificial intelligence that will pave the way to a new era that will transform our lives as we know it. Internet of things (IoT) is the network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators, and connectivity which enable these objects to connect and exchange data. They are generally composed of low power radios, several smart sensors and embedded CPUs (Central Processing Units).These devices are used to form wireless sensor network (WSN) which is necessary to provide sensing services and to monitor environmental conditions towards Internet of things create a world where each of its entities is communicating and sending information i.e. there is prolonged and ubiquitous transmission and reception of information. This furthermore emphasizes the vitality of the role trillions of wireless sensors play in the worldwide collection of data into the IOT system which requires Trillions of batteries to charge these sensors. The periodical replacement of the batteries apparently is practically impossible and cost consuming, not to mention the hazardous effects the periodic replacement of batteries has on the environment. The continuous availability of power is of utmost importance for the deployment of such large networks. Energy harvesting has become a field of interest due to the need to acquire power in situations where the use of wires and/or batteries is impractical.

II. BACKGROUND AND RELATED WORK

A comparative study was performed among 4 antennas to narrow down to the best RF energy harvesting antenna. The following antenna was majorly studied and compared: multiband patch antenna, Double Koch slot antenna, DRA, and Split ring resonator.
The patch antenna is a good candidate for energy harvesting due to its low weight, ease to manufacture, low profile, and high radiation efficiency. The antenna works with the same polarization at all downlink frequency ranges. The total efficiency is higher than 70%for all the investigated frequency ranges, specifically, 74% in the band GSM900, 86% in

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the band GSM1800, 80% in the 3G band, and 85% in the WiFi band.The Koch fractal provides the opportunity to prolong the magnetic current line of the antenna. Therefore, we are able to design the antenna with smaller dimensions, while maintaining the same resonant frequency. The procedure allows prolonging the physical length of the designed structure by factor $(4/3)^n$, where ^{n} is the number of the iteration, but the final dimension of the structure is still the same. The designed double slot loop antenna consists of two Koch snowflake shapes created from the third and second iteration of the Koch fractal. The largest loop resonates at lower frequency f1=0.95GHz and using the third iteration of Koch fractal.The dielectric resonator antenna was selected as another candidate for suitable harvesting antenna.Its main advantages are high radiation efficiency, wideband operation, relatively omnidirectional radiation patterns.
A metamaterial inspired compact open split ring resonator (OSRR)antenna is investigated for multiband operation. The proposed antenna uses closely employed open split rings as a radiating element which provides efficient size reduction and broader bandwidth performance. The proposed antenna with the overall size of $27.5X16.08X1.6mm^3$ is fabricated and tested. The measured results indicate that it covers 2.4/5.2/5.8 GHz (Wireless LAN), 5.5 GHz (WiMAX) and 7.4 GHz (X-band downlink) applications. The OSRR antenna has achieved size reduction of 38.83% and52.83% compared to the split ring resonator and ring antennas respectively. It is observed that the proposed antenna produces better performance than the existing antennas in the literature.

III. PROPOSED METHODOLOGY AND DISCUSSION

As the primary objective of this project is to implement a self -sustained system that scavenge the RF energy fields of the GSM 900 Band and GSM 1800 band and to subsequently utilize that energy to power low power IOT sensors.
The RF energy harvesting system consists of the components: The antenna component for the reception of the maximum amount of the ambient RF signal. It depends on efficiency, polarization, bandwidth and gain of the antenna; Lumped circuit; Voltage multiplier which amplifies the input RF power; IOT device which consumes low power.

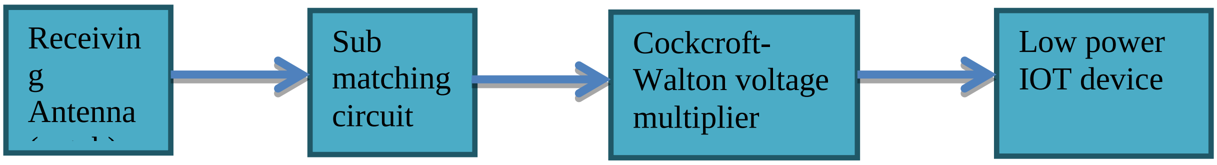

Figure 1 block diagram of RF energy harvesting system

Our intent is to create energy harvesting systems which are smaller in size compared to the wireless sensor devices and enhance signal reception efficiency. A crucial element in this system is the antenna whose performance has implications On the whole harvester; hence selection and design of the antenna must be carried out fastidiously with extra caution and precision.

IV. METAMATERIAL INSPIRED COMPACT OPEN SPLIT RING RESONATOR ANTENNA

A metamaterial inspired compact open split ring resonator (OSRR) antenna is investigated for multiband operation. The proposed antenna uses closely employed open split rings as a radiating element which provides efficient size reduction and broader bandwidth performance. The proposed antenna with the overall size of 27.5 9 16.08 9 1.6 mm3 is fabricated and tested. The measured results indicate that it covers 2.4/5.2/5.8 GHz (Wireless LAN), 5.5 GHz (WiMAX) and 7.4 GHz (X-band downlink) applications. The OSRR antenna has achieved size reduction of 38.83% and 52.83% compared to the split ring resonator and ring antennas respectively. It is observed that the proposed antenna produces better performance than the existing antennas in the literature.
Since this antenna had the best features and observed results we chose this antenna.
After conducting an extensive literature survey where numerous antennae for RF energy harvesting and antennae for the GSM bands were scanned and properties were extrapolated and the antenna which best served the purpose i.e. to harvest the RF energy bands and which exhibited enhanced bandwidth and increased gain along with compact size as we require the antenna to be comparable in size with the Low power IOT sensors Metamaterial inspired antennas achieve all our desired properties of compact size, increased gain and enhanced bandwidth.
Research in metamaterials is relatively new and unexplored field of study with objectives for synthesizing materials with customized parameters that would otherwise be difficult or impossible to achieve with naturally occurring

materials. The exotic properties of metamaterials arise not from the composition but in the assembling of its building blocks. Metamaterials are constructed with assemblies of a 2- D or 3- D array of structures within a substrate. The choice of the structures used in the array is the primary determinant of the characteristics of the metamaterial.Periodic alternating arrangements of SRR(split ring resonator) and band gaps of 180 degrees are used to realize metamaterials in which the band gaps serve as capacitances While the SRR structure serves as an inductor and together they imitate the functionalities of a LC resonant circuit.External magnetic field penetrates through the rings and currents are induce gap prevents currents from flowing around the ring, which considerably increases the resonance frequency of the structure.

V. DESIGN AND ANALYSIS OF THE ANTENNA

A. Design of the Open Split Ring Resonator antenna:

The main aim of the proposed RF energy harvest system is to design a low profile broadband antenna for GSM 900 and GSM 1800 bands which are capable of collecting the energy from all directions. The design topology chosen for the proposed work is based on the open split ring resonators. The design evolution of the proposed open split ring antenna is shown in Table. 1. The optimization work started with the antenna's rings of length $\lambda g/4$ for the inner ring (1.8GHz) and $\lambda g/2$ for the outer ring (940MHz) with center frequencies 940 MHz and 1.8 GHz of the GSM 900 band and GSM 1800 band. A shows a rectangular monopole antenna and has a partial ground plane, to suppress back radiation and to reduce wave diffraction. The partial ground also helps to direct the current to the feed line. The rectangular monopole is fed by a 50 Ω micro strip line. This structure is used to generate a dual-band resonance at 940MHz and 1.8GHz.

The design formulas for the feed network width of the stripline 'w' are as given

$$\frac{w}{h} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} & ; \dfrac{w}{h} > 2 \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B-1) + \dfrac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \dfrac{0.61}{\varepsilon_r}\right\}\right] & ; \dfrac{w}{h} < 2 \end{cases}$$

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

The proposed OSRR antenna uses FR-4 substrate in the design with er of 4.4, fed by a 50 X coplanar waveguide (CPW) transmission line. It has feed length (FL) of 11.50 mm and feed width (FW) of 1.48 mm.

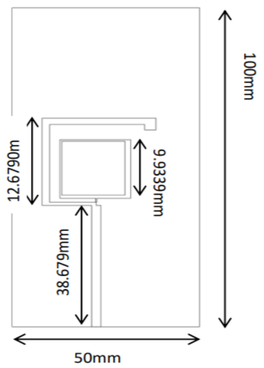

Figure 2 Proposed antenna designs

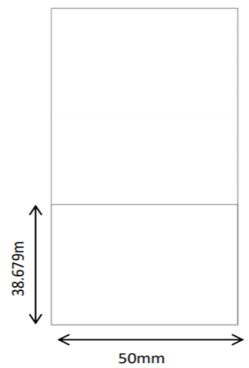

Figure 3 Ground Plane

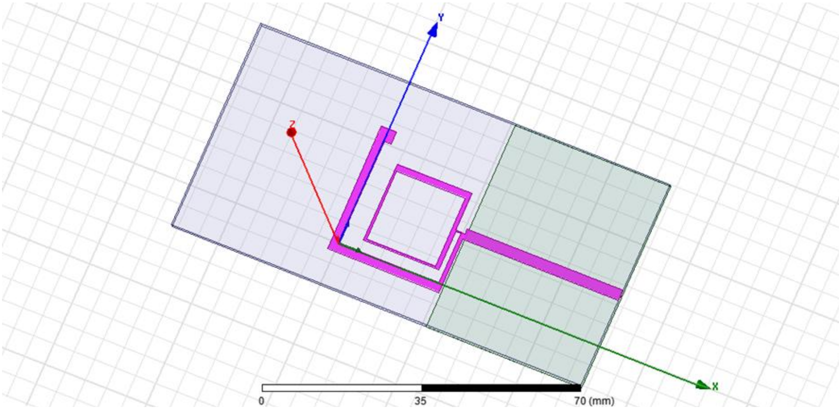

Figure 4 HFSS design of proposed antenna

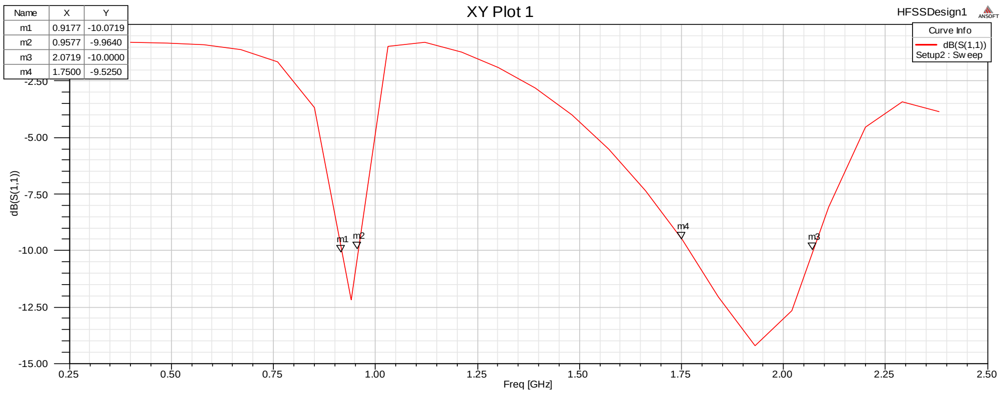

Figure 5 HFSS results of proposed antenna

The fabricated compact open split ring antenna is tested with the vector network analyzer (N9918A FieldFox Handheld Agilent Vector Network Analyzer (VNA)) as shown in Fig. 8. Fig. 5 shows the return loss graph of the tested antenna in ambient condition (outside the chamber) using the above vector network analyzer (VNA). It has the good operating bandwidth at 900 MHz and 1.8 GHz covering both of the GSM 900 and GSM 1800 bands.

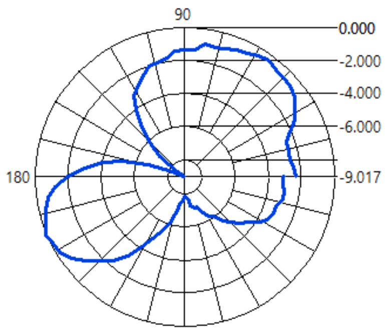

Figure 6.a. E plane of 940 MHz

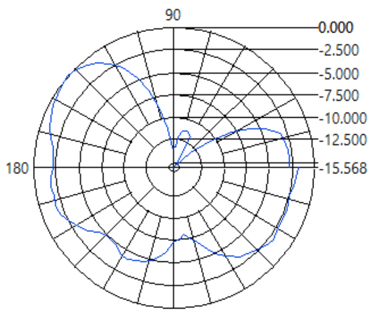

Figure 6.c. H plane of 940 MHz

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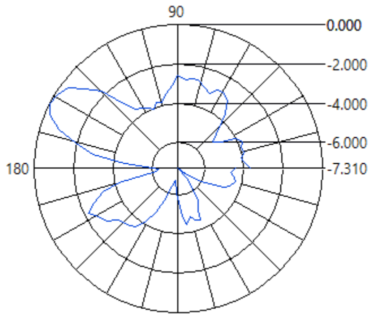

Figure 6.b. E plane of 1800 MHz

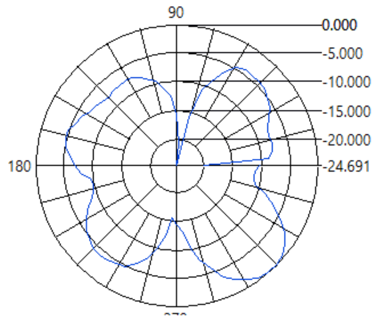

Figure 6.d. H plane of 1800 MHz

Later the proposed the quad polarized triangular bent antenna has been characterized inside the anechoic chamber for the various parameters like gain and radiation pattern. The measurement setup in the anechoic chamber at VIT University Chennai is given in the Fig. 7. The measured return loss bandwidth inside the chamber through an automated VNA interfaced software is 880MHz to 1 GHz is having a resonance at 940 MHz frequency as shown in the Fig. 5. The improvement in the return loss is observed to be in the range from -12dB to -16dB inside the chamber.

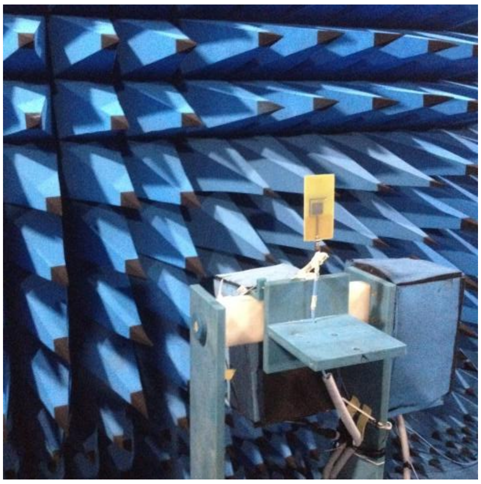

Figure 7 the radiation pattern measurement setup in the anechoic chamber

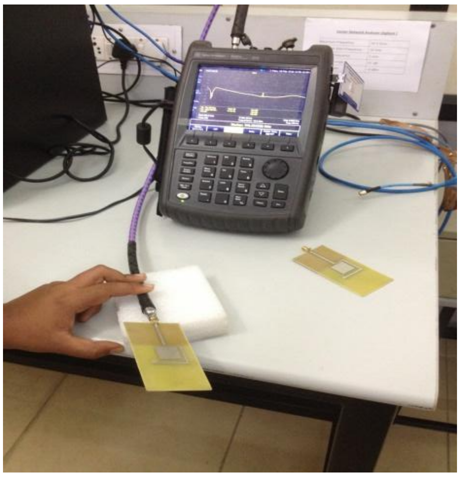

Figure 8 Output of antenna at VIT Chennai Campus

The measured co-planar radiation patterns at 940 MHz for the E-plane and H-plane in the anechoic chamber is as shown in Fig. 6. The pattern shows the quasi omni-directional pattern in the H-plane. The E-plane pattern contains the components of the vertical component of the E-vector. The E co-plane pattern also shows the maximum received signal strengths at ± 45°. Hence the proposed antenna is also polarized for ± 45°. As discussed above the proposed triangular bent four arm antenna demonstrates vertical and ± 45° polarizations due to presence of vertical and 45 degree angle radiating elements in the patch geometry.

VI. MATCHING CIRCUIT

The impedance matching network was synthesized using the Simplified Real Frequency Technique (SRFT).
The advantages of this technique over the other techniques in the practical areas are it consumes real measured impedance data, as opposed to an equivalent circuit or analytical description of the load impedance function it provides the matching network topology, as opposed to simply finding component values as set by the designer in the preselected network.

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The technique provides an insight to matching problems with a perfect estimate for the upper level of theflat transducer power gain, or equivalently the minimum return loss, over the selected frequency band which is 940MHz and 1.8GHz.
The matching network was implemented using lumped components in reference to the distributed transmission lines in order to reduce PCB area consumption
A SRFT synthesized matching network has been implemented and evaluated for enhancing the bandwidth of a standard dual band (940MHz and 1.8GHz) terminal antenna.

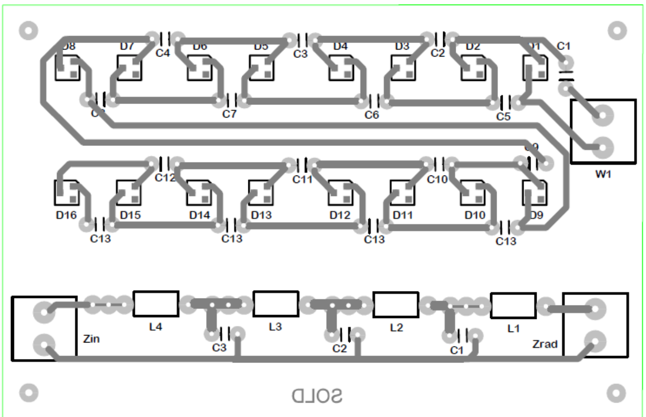
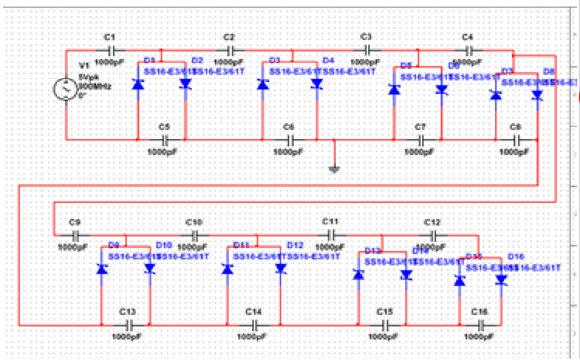


Figure 9 layout design of voltage mutipier and matchning circuit

VII. VOLTAGE MULTIPLIER

The next segment of our project is choosing and designing voltage multiplier. Different prototypes were tested and the best was taken into use. The comparisons between symmetrical versions of VMs were carried out. The features of different VMs as rise time, ripple, and output voltage are compared to each other with regard to the complexity of the topologies and number of components.
Prototypes of VMs have been constructed. BVM, SPNVM, HSVM1, HSVM2, SVM1 and SVM2 have been constructed for comparison. Input is a2 kHz sinusoidal source with variable amplitude which combined with a ferrite core transformer provides the requested voltages. As in simulation a purely resistive 51 kΩ load issued. Capacitors are in range of 1.62 F–1.72 F and have been chosen among many, to be nearly equivalent. Reduction of error produced by non-equal value of capacitors when we compare the topologies was the reason of such selection.



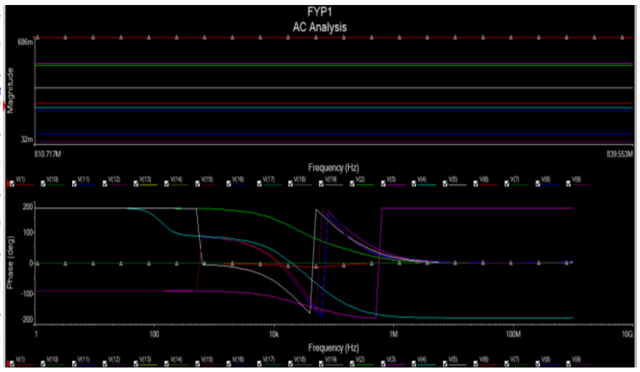


Figure 10 Voltage multiplier design in Multisim

Figure 11 Multisim results of Voltage multiplie

VIII. CONCLUSION

The metamaterial inspired open split ring resonator antenna for GSM 900 and GSM 1800 band was successfully designed and simulated in HFSS and was functioning in the desired bands i.e. at resonant frequencies 940 MHz and 1.8

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GHz with a gain of 4.62 dB and enhanced bandwidth along with accomplishment of miniaturization. This ensures idyllic reception of the RF energy signals and furthermore scavenging the RF energy fields of the GSM 900 and GSM 1800 bands by capturing the energy and amplifying it successfully with a gain of 22 dB to energize low power IOT sensors thereby succeeding in creating a self-sustained system which utilizes the already existing prodigious supply of ambient RF energy signals extensively and solves the onerous task of battery replacement not to mention paves the way to a more "Green" communications system. This self-sustained system has tremendous potential for all IOT applications and would aid in the deployment of trillions of small low power wireless sensor networks which are completely self-reliant. This will lead to a proliferation of more environmentally friendly IOT technologies.

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Saveri Balaji is currently pursuing her Bachelor of technology in Electronics and Communication Engineering from Vellore Institute of Technology, Chennai (2014-2018). Her areas of interest include Smart Antennas, wireless and mobile and Green computing, IOT, Machine Learning, Deep learning and optics. She has worked as a research Intern in Department of computer science, Indian Institute of Technology Madras in the field of machine learning applications in medicine and speech and text processing in the years (2016-2018) as well as development and algorithm engineer for Wireless applications in Indian Institute of Technology.