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Design and Implementation of Microstrip Antenna for RF Energy Harvesting

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Abstract

This paper describes the antenna design for RF power harvesting system. The design goes through three phases designing of antenna, matching network and rectifier. A dual band Microstrip antenna suspended above ground plane is designed to operate in GSM 1.8 and ISM 2.4 GHz bands. The antenna incorporates the capacitive feed strip which is fed by coaxial probe technique where the inductive impedance of probe is effectively cancelled by the capacitive patch. The designed antenna provides good frequency response and fairly directional radiation pattern. For designing and simulation of proposed antenna we have used IE3D software.

Keywords: IE3D- Integral Equation 3Dimensional software, MSA- Microstrip antenna, GSM-Global System for Mobile Communications, EH- Energy Harvesting, ISM-Industrial, Scientific and Medical Bands, Rectenna.

Introduction

Over past two decades, wireless systems have been developed and implemented to such an extent that frequency spectrum has become dense. These systems are Wi-Fi, cellular radio, radio broadcast and TV broadcast. Large amount of ambient energy (e.g. wind, solar and tide) is widely available and large-scale technologies are being developed efficiently to capture it. Also, there are small amounts of "wasted" energy that could prove to be useful if captured. Recovering even a fraction of this energy would have a significant environmental and economical impact. This is where energy harvesting (EH) comes in. The concept of energy harvesting is not new rather it came into picture 100 years back [1]. The method of extracting energy from environment to generate electricity is called energy harvesting or energy scavenging. This technology offers two main advantages a) Energy is freely available b) It is "green" for the environment. The ambient energy present around us can be harvested using a rectifying antenna, popularly known as rectenna [14]. RECTENNA is a rectifying antenna that is used to convert electromagnetic energy into direct current electricity. The components of the energy harvesting system [7] (antenna, matching network and rectifier) are usually referred as a Rectenna, which is able to harvest high-frequency energy in free space and convert it to DC power. Harvesting RF energy and converting it into useful DC power requires careful design:

- An efficient antenna is designed to boost RF signal.
- A matching circuit to transfer maximum RF power from source to load.
- Rectifying circuit to convert input RF to DC.

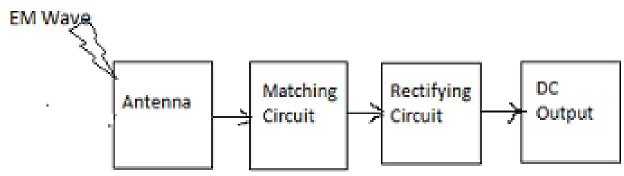

Figure 1: Block diagram of RF energy harvesting system

Related Work

In literature different research works have been presented on RF energy harvesting systems. Dual-stage RF energy harvester circuit consisting of seven and ten stage has been designed for unlicensed ISM band at 915MHz with multiple antennas to increase the amount of energy harvested [1]. To harvest energy for GSM 900 band at a distance of 10m from cell towers electromagnetically-coupled square microstrip antenna has been proposed using single stage and six stage voltage doubler RF circuit [2]. This provides an alternative source of energy and protects people living in nearby areas from hazards of radiation from towers. Study of different antenna parameters, feeding techniques, basic concepts of antenna design, formulas to calculate height and width and other parameters of antenna, design of broadband antennas frequency range [3]-[4], [6]. Basics of antenna design, use of IE3D software tools in designing antenna such as define port, add feed line etc [5]. An efficient dual band antenna for boosting reception of ambient RF signals with wide bandwidth in Wi-Fi bands 2.45GHz and 5GHz has been investigated in [7] which provides an alternative source to power sensors in harsh environments and remote places. For

GSM bands 1800 MHz and 915 MHz the RF energy harvesting circuit with planar dual band monopole antenna is designed to support green technology and wireless sensor network applications [8].Nevertheless, this kind of design should be improved in terms of bandwidth by increasing substrate thickness or by adding parasitic elements. For mobile and portable devices capacitive feed compact microstrip UWB antenna has been introduced in [9] to reduce size and increase impedance bandwidth. The capacitive feed strip design provides with 50% improvement in impedance bandwidth and reduces spurious radiations. The microstrip antenna with capacitive fed element having ground plane, radiating patch and small patch located between ground plane and radiating patch analyzed using moment method which gives desired frequency response [10]. To increase bandwidth the microstrip antenna with capacitive feed, slots across radiating and non-radiating sides has been presented in [11].Slotted patch is complex but provides with constant radiation pattern. For GSM 900 band a differential microstrip antenna with improved gain for RF energy harvesting has been presented in [12]. A differential input to rectifier results in reduced efficiency of harvesting circuit. So electromagnetically coupled microstrip antenna with improved gain, efficiency and bandwidth has been designed. RF energy harvesting circuit [13] with broadband bent triangular monopole antenna with a stable radiation pattern has been proposed which receives both horizontal and vertical polarized waves. RF energy harvesting system using rectifying microstrip antenna to harvest energy from cell phones in GSM band i.e. 900 MHz has been presented [14] which is used in low cost devices for wireless power transmission. To obtain optimum parameters matching and rectifying circuit has been studied for the energy harvesting system and multistage rectifiers to produce higher efficiency [15].In this paper a novel dual band microstrip antenna with capacitive feed strip is designed to operate in GSM 1.8 and ISM 2.4 GHz bands. In the following section simulation and fabrication results of microstrip antenna are discussed and evaluated. And finally conclusion is drawn from the results.

Antenna Design

The geometry of the proposed antenna is shown in "Fig.3." The substrate material is FR4 as one of the most accepted industry-wide standard substrate material for electronic circuit boards.

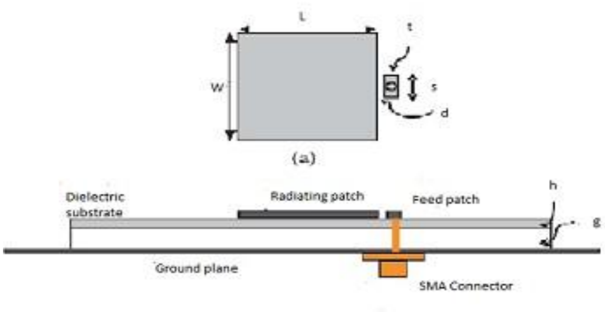

Figure2: Basic geometry of capacitive fed Microstrip antenna

The configuration is basically suspended micro strip antenna in which the radiating patch and feed strip are placed above the substrate of thickness "h"mm. A SMA connector is used to connect feed strip which capacitively couples energy to radiating patch. The specifications for the design are given in table 1.

All parameters are optimized using IE3D software. The antenna is designed and optimized to capture the energy from the ambient at radio frequency range of ISM 2.4GHz and GSM 1800 band. The challenge is to design an antenna able to operate in both 2.4GHz and 1.8 GHz band. This antenna is highly desired for system flexibility. The design is based on suspended capacitive fed MSA. The antenna substrate is placed above the ground plane with height 'h' with an air gap'g'. The idea behind capacitive fed is simple. At resonance, probe capacitance and inductance inherent to antenna equivalent circuit cancel out each other leaving real impedance.

The specifications for the design is as follows

Table 1: Design values of the Antenna

Parameter	**Value**
Length and Width of patch	42.8X53 mm
Length and Width of ground plane	80X80 mm
Length of feed strip(s)	6.2 mm
Width of feed strip(t)	1.8 mm
Separation of feed strip from patch(d)	0.5 mm
Air gap(g)	19.2 mm
Dielectric constant	4.4
Loss tangent	0.02
Thickness of substrate	1.6 mm

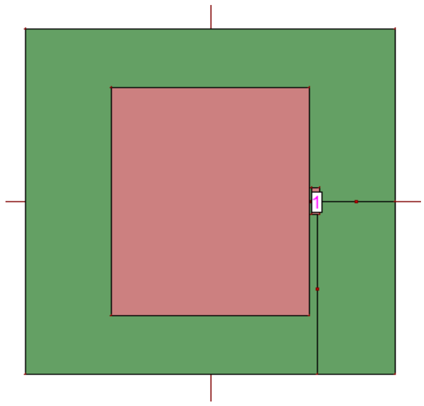

Figure 3: Geometry of the dual-band Microstrip antenna

Simulation Results

With the objective of efficient RF energy harvesting, we focused on the fabrication and development of a dual-band antenna.

Return Loss

The *S11* graph of simulated design is shown in below "Fig.4" below. The *S11* graph gives us the relationship between return loss and frequency. From the result it is observed that the antenna is resonating at 1.8 GHz and 2.34GHz with return loss below 12 dB.

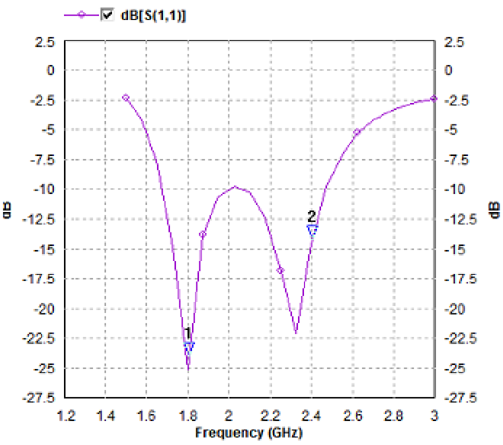

Figure 4: Simulated S11(dB) Vs Frequency (Ghz)

VSWR (Voltage Standing Wave Ratio)

The simulated VSWR plot for micro strip feed antenna is shown in “Fig.5”.The VSWR or Return Loss determines the matching properties of antenna. It indicates how efficiently antenna is transmitting and receiving electromagnetic wave over particular band of frequencies. VSWR lie in the range of 1-2 which has been achieved for the frequency 1.8GHZ, 2.34GHZ, which is near the operating frequency value. The value of VSWR is 1.11and 1.2 resp.

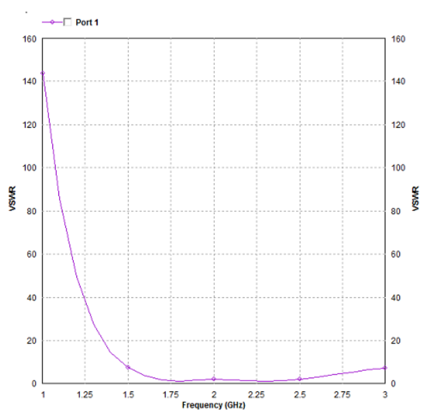

Figure 5: VSWR plot of Microstrip antenna

Radiation Pattern

Microstrip patch antenna has radiation patterns that can be calculated easily and it can be said that the power radiated or received by the antenna is the function of angular position and radial distribution from the antenna. The shape of radiation differs. According to frequency pattern, a directional radiation is obtained.

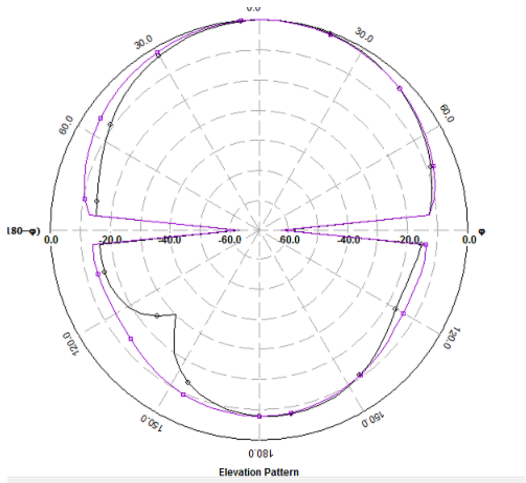

Figure 6: 3D Radiation pattern of Microstrip antenna

Smith chart

The value of impedance should be near 50Ω to perfectly match the port with the antenna. The impedance for this antenna is 51.89Ω. The results of the simulated impedance are shown in “Fig.7” above. The real part of the impedance at the resonant frequencies is close to 50Ω, 51.33Ω,and 57.76Ω for1.8 GHz and 2.34GHz, respectively.

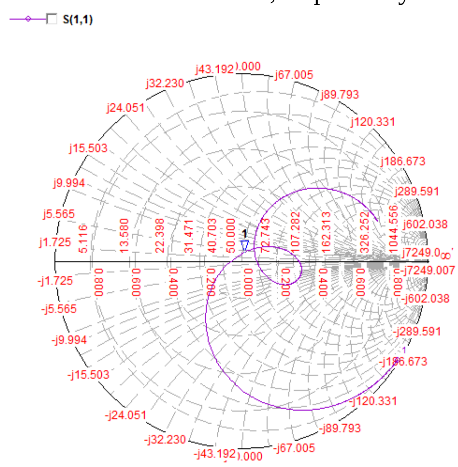

Figure 7: Smith chart of Microstrip antenna

3D Pattern and Gain

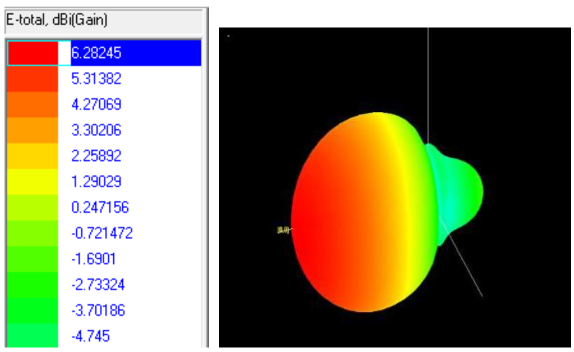

Figure 8: 3D Pattern and gain of Microstrip antenna

The antenna gain defines the antenna's ability to radiate in particular direction when connected to a power source. Gain is usually calculated in the direction of maximum radiation. The gain of proposed antenna is 6.28 dB.

Fabrication and Evaluation

The basic objective of this research is to develop a receiving antenna for energy harvesting to charge passive devices. After designing and simulating proposed micro strip antenna , next thing is to implement this microstrip antenna on hardware. In order to verify the simulated results the proposed antenna was implemented and fabricated on FR4 substrate. Figure 9, 10 shows the fabricated antenna and comparison of simulated and measured results. The antenna was tested using Vector Network Analyzer. The measured return loss is in close agreement with the simulated return loss.

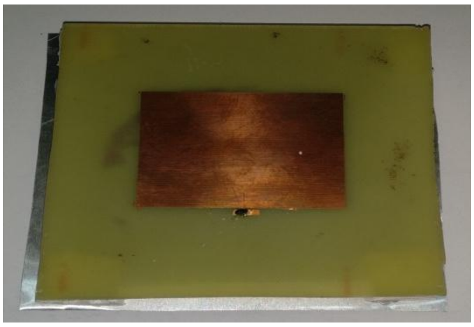

Figure 9: Photograph of fabricated antenna

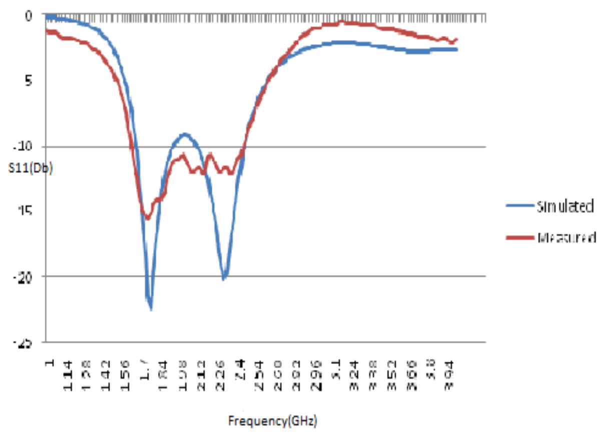

Figure 10: S11 of Measured and Simulated Microstrip antenna

Conclusion

A microstrip antenna with capacitive feed strip suitable for dual band applications is simulated and measured which covers both GSM (1800) and ISM (2.4) bands. The results obtained indicate good performance of proposed antenna for required frequency range, return loss better than 12dB with impedance close to 50 ohm and directional radiation pattern .

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