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CORPORATE FEED WITH DUAL SEGMENT CIRCULAR POLARIZED ARRAY RECTENNA FOR LOW POWER RF ENERGY HARVESTING

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Abstract

This paper focuses on the investigation of the level powers that can be scavenged from the ambient environment by using corporate feed with dual segment circular polarized antenna array . It will converts the received power to direct current (DC). Being a circular polarized antenna, it has higher inductance per unit area, a good Q-factor and compact capability. The design of corporate-series feed rectenna array is to achieve a high gain antenna and maximize the RF energy received by the rectenna system at ultra low power levels. The entire structure was investigated using a combination of harmonic balance nonlinear analysis and full wave electromagnetic field analysis. The results show that 5.0 dBi gain for circular polarized antenna array can be achieved at frequency 956 MHz. When the input power of 20 dBm fed into the transmitting antenna, the maximum distance for radio frequency (RF) harvesting is 5.32m. The output DC voltage for various values of incident RF power is also presented. There are noticed reasonable agreements between the simulated and measured result and the works concludes that the investigation of RF energy harvesting system was successful.

Keywords: Rectenna, Corporate feed, Circular Polarized, Array, RF Harvesting.

1. Introduction

Nowadays, energy harvesting is considered one of the energy sources that rapidly growing in the engineering and scientific field. Typically the energy harvesting usually is a free energy source. For example, the thermoelectric generator can be attached to an aircraft engine [1] because the heat generating from the aircraft engine can convert the temperature difference into useful electrical energy. Vibrating sources like a wing or aircraft airframe can be attached by a piezoelectric

Nomenclatures

C	Capacitance
D_0	Outer diameter
D_i	Inner diameter
F	Resonant frequency
h	Height of substrate
K_g	Presence of ground plane
L	Inductance
l	Length of inductor
N	Number of turns
Rs	Resistivity
s	Spacing
w	Width

Greek Symbols

ρ	Copper resistivity
δ	Skin depth

Abbreviations

ADS	Advance design system
CST	Computer simulation technology
DC	Direct current
FIT	Finite integration technique
HPBW	Half power bandwidth
GSM	Global system for mobile
RF	Radio frequency
RFID	Radio-frequency identification

transducer [2] to convert the small strain or vibration difference into electrical energy.

Besides that, RF energy that currently broadcasted 24 hours from the transmitter such as mobile telephone, mobile base station and others is a relatively stable and available in wide areas [3]. It can be scavenged to allow continuous charging or operate for low power applications such as medical sensor, radio frequency identification (RFID) tag or headsets. Thus, the use of battery, battery access panels or cables could be eliminated [4]. Mobile phone presents a large RF energy source of transmitters. When the mobile subscriber continues to increase [5], the RF energy will also be increasing. As radio frequency energy is available anytime and everywhere, this is the reason why the RF source has been very attractive.

Basically, the RF harvesting process is to scavenge ambient electromagnetic energy, and then converts it into useful DC power for the purpose of energy saving and power management. Different RF harvesting methods have been employed using different techniques. In [6], the Archimedean spiral was employed; helix antenna was used in [7], meander line in [8], whereas patch antenna was used in [9]. In this paper, corporate feed with dual segment one arm spiral antenna array is proposed. The proposed one arm circular polarized antenna is expected to detect the radio frequency energy and convert the electromagnetic wave into the useful DC power. The primary focus is to characterize the proposed antenna on its ability to scavenge the ambient electromagnetic energy. After that, the article will be focusing on the rectification of the captured input RF signal to DC power. Thus, corporate feed 2 x 4 element array was designed, simulated and measured at 956MHz resonant frequency to improve its gain and output DC power. The designs were modelled using Agilent ADS software and CST microwave studio to further characterize the proposed design.

2. Spectrum Harvesting

The spectrum exists in the environment has different characteristic depends on a different area. For example, distance from the transmitter and humidity of the location will affect the results of measurement. To inspect the RF signal level in the environment, the experiment and measurement were conducted using a dipole antenna and spectrum analyzer HP_345. Figure 1 shows the result of measurement of the spectrum in the university campus.

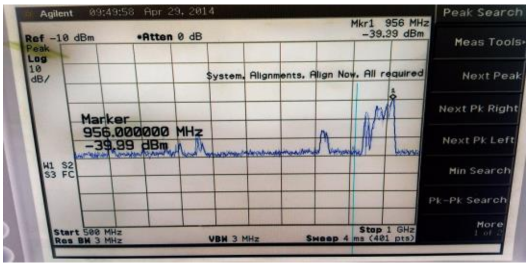

Fig. 1. Spectrum Harvesting.

From the observations, the highest peak power levels are within the GSM bandwidth (920 – 960) MHz. Higher power densities of existing ambient signal direct the research towards RF energy harvesting and its antenna to be designed within a GSM band. The center frequency was selected to be 956 MHz that has an approximate bandwidth of 40 MHz.

3. Theory

Spiral rectenna could be in the shape of circular or rectangular. Rectangular and circular spiral retina has good inductance per unit area; however, circular spiral has a better area efficiency [10], higher Q-factor than rectangular rectenna and uniform magnetic field distribution of surface due to the lack of sharp field discontinuities at corners [11]. Besides that, it was found that for equivalent values of inductance, circular shaped spiral rectenna exhibited 10% lower resistance [12]. For a reasonable dimension, all of the nearest conductors in a circular spiral rectenna will exhibit positive mutual inductance with each other. This allows the rectenna to create a larger inductance value within a given area subsequently harvests more RF energy. Other than that, circular polarized antenna will transmit and receive signal strength in all planes and thus increase the harvesting available power signal.

Circular polarized also can avoid the changes in output voltage due to the circular characteristic of the antenna [13]. Figure 2 shows the proposed one arm circular polarized rectenna.

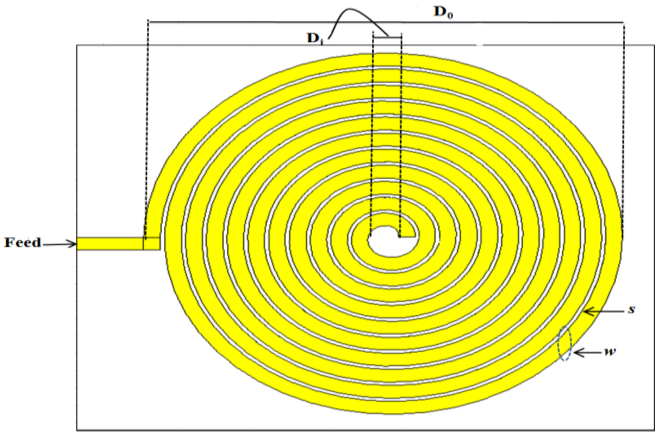

Fig. 2. Circular Polarized Antenna.

The amount of magnetic energy storage is represented by an inductance, *L* given in as [14].

$$L = 0.03937 \frac{a^2 n^2}{8a + 11c} \times K_g \tag{1}$$

where

$$a = \frac{D_o + D_i}{4} \tag{2}$$

$$c = \frac{D_o - D_i}{2} \tag{3}$$

$$D_o = D_i + 2Nw + (2(N-1)s) \tag{4}$$

$$K_g = 0.57 - 0.145 \ln \frac{w}{h}, \frac{w}{h} \rangle 0.05 \tag{5}$$

The diameter D_o and D_i of the inductor is stated by Eq. (3). Equation (4) describes the relationship between the outer, and the inner diameters with respect to the numbers of turn (*N*), conductor width, *w*, and their spacing, *s*. Also, K_g, is the presence of a ground plane. Equation (6) states the formula to determine the inductor resistance [15], where R_s is the resistivity, ρ is copper resistivity, l is the total length of the inductor, *h* is thickness of the substrate, δ is the skin depth of the circular spiral inductor and lastly Eq. (7) describes the capacitance between the conductors' gaps.

$$R_s = \rho l \left(\frac{1}{wh} + \frac{1}{2\delta(h+w)} \right) \tag{6}$$

$$C = 3.5e^{-5} D_o + 0.06 \tag{7}$$

Finally, the resonant frequency of the antenna array was determined using the popular equation stated in Eq. (8)

$$F = \frac{1}{2\pi\sqrt{LC}} \tag{8}$$

4. Material and Method

4.1. Array configuration

Due to the air signals carry very low power levels, array configuration was employed to gather more power. Corporate feed arrays are common and versatile. This method has more control of the feed to each radiating element both in terms of phase and magnitude. Besides scanning phased arrays, multi beam arrays [16] or steering, the corporate feed also enhanced performance in terms of great design flexibility and operated with a relatively wide bandwidth.

The corporate feed network is used to provide power splits or power combination. This is accomplished by using either using tapered lines or quarter wavelength transformers [17]. Figure 3 shows the arrangements of microstrip feed line for the corporate feed array rectenna. The rectenna has a single 50Ω input transmission line which is the basic form of a linear array. It provides simplicity and ease of fabrication for circuit modelling as well as impedance input matching.

Then, it divides into a pair of 100 Ω lines by T-junction equal divider rule. The power will split equally to the direction of P1, P2, P3, P4, quarter wave transformers. Lastly, these transformers will transform 100Ω feed line and the pair of transmission line used to divide the incident power to each pair of circular spiral rectenna as in Fig. 3.

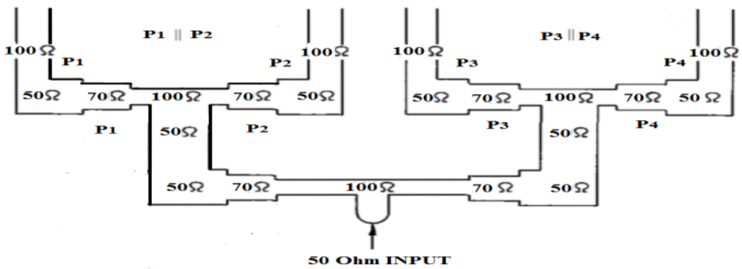

Fig. 3. Corporate Feed with Dual Segment.

The resulting designs were then fabricated on laminate Roger Duroid RO4003C microwave board of size 27.3×13.5 sq. mm, with dielectric constant (ε_r) of 3.38, with a thickness of 0.813 mm, loss tangent of 0.0027, and ground thickness of 35 µm is excited by the microstrip line. Therefore, the designs were modelled using the transient analysis method in Computer Simulated Technology (CST) software so as to better characterize them.

4.2. Rectifier element design

In order to improve the system efficiency, active and passive components were used in this design. The next components of the energy harvesting system are the rectifier. The rectenna system is the combination of an antenna array and rectifier. Rectifier that consists of a zero bias Schottky diode are used to convert the RF signal that received from the antenna to generate DC voltage. The input power from the circular polarized antenna to the load should be high enough in order to make the Schottky diode forward biased. In these designs, zero bias Schottky diode HSMS 2852 from Agilent Technology were used. This is because the features of Schottky diode have very fast switching and low substrate loss [18].

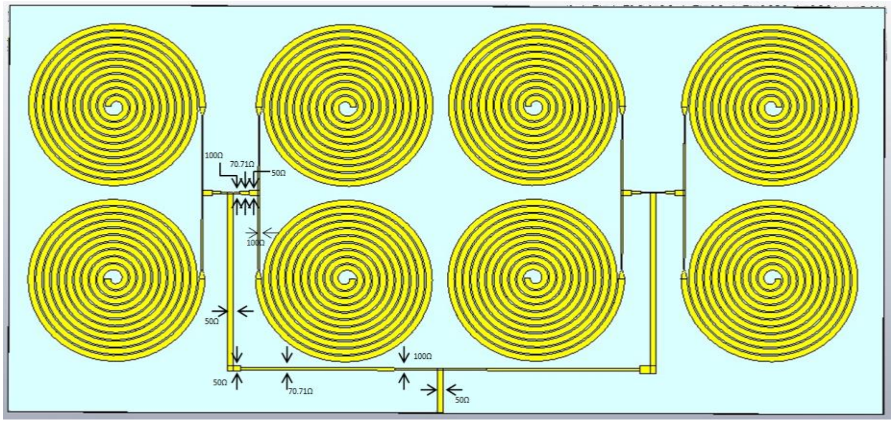

Fig. 4. Layout of 2×4 Circular Polarized Antenna Array.

The rectified DC power is characterized as a function of DC load and DC circuit topology which is composed by a resistive load and in parallel with a filter capacitor of 10uF. The simulation of a rectifier circuit is carried out by using the Harmonic Balance in Advanced System Design (ADS) software as in Figure 5. A filter capacitor across the load is used in the circuit design in order to provide a good DC signal. A load resistor is connected at the end of the circuit to complete the circuit node. Without the load resistor, the voltage will be held indefinitely in the capacitor.

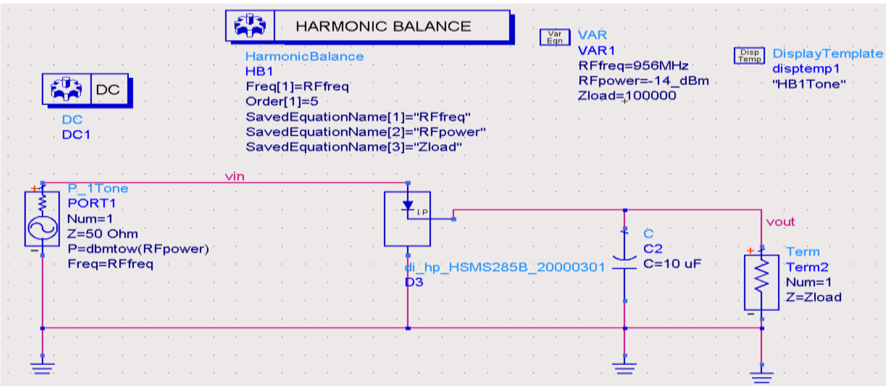

Fig. 5. Single Diode Rectifying Circuit.

5. Results and Discussion

Figure 6 shows the simulation and measurement of the input return loss of 2×4 circular polarized antenna array. The simulation is performed from 900 MHz to 1 GHz frequency range. The simulated return loss was -16.77 dB at 956 MHz with a bandwidth of 3.5 MHz. The measured return loss at 960 MHz was -18.68 dB with a bandwidth of 6.5 MHz by using N5245A network analyzer. Both of the simulated and measured in return loss response were managed to achieve lower than -10 dB. As it is shown, a relatively good agreement between simulation and measurement of return loss was observed. There is a little amount of mismatch around 0.42% between the simulated and measured return loss because the feeding ports in the measurement are not precisely attached to the surface of the microstrip line. The range of frequency in which the circular polarized rectenna operates easily covers over the GSM band of the cellular system.

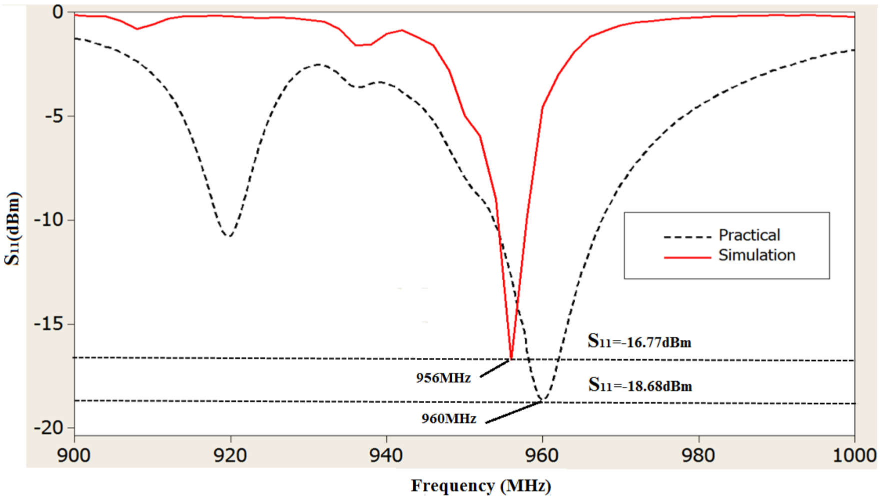

Fig. 6. S_{11} Return Loss.

Figure 7 shows the simulated and measured gain for the 2×4 circular polarized antenna array. The frequency range observation is from 951 MHz to 960 MHz. The gain was considered in the array plane of Φ=0° direction. This direction was the main beam direction at the center frequency. From Fig. 7 above, the maximum simulated gain was 5.0 dBi at 956 MHz and the measured maximum gain was 5.8 dBi at the frequency of 953 MHz. The results indicate that there was a minimal loss between simulated and measured data.

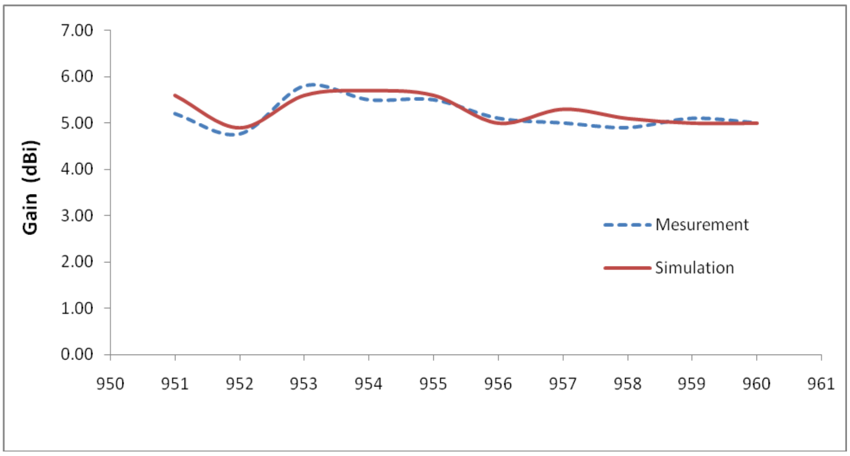

Fig. 7. Simulated and measured gain for the 2×4 circular polarized antenna array.

After the RF energy is harvested by the antenna array, the RF input signal is then rectified and convert to the DC voltage. From the Harmonic Simulation, it can be observed that the system managed to produce output voltage 0.08 V with load of 1 MΩ as in Fig. 8. The output voltage can be express as below.

$$V_{out} = \frac{V_0}{R_L + R_0} R_L \tag{9}$$

where R_0 = internal resistance, R_L = load, V_0 = open circuit output voltage

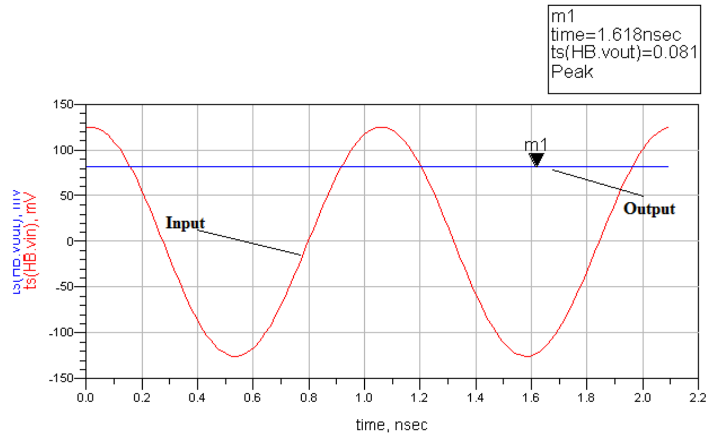

Fig. 8. Input and Output Voltage as Function of Time.

A directional Yagi antenna with 6.5 dBi gain is used as the transmitting antenna to provide the radio frequency power radiated into free space. The circular polarized rectenna system is used as a receiver. From Fig. 9, the output DC voltage of the rectenna increased with increasing of input power density. The maximum transmission between the receive and transmit antenna may be used to characterize the transmission efficiency of the system. When 20 dB input power is fed into the transmitting antenna at 956 MHz, the maximum receiving distance is 5.32 m. Beyond the maximum distance, the signal will be lost.

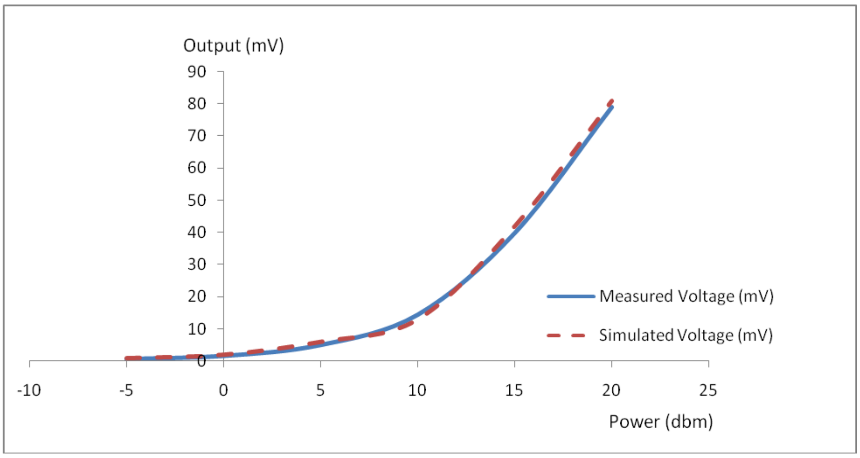

Fig. 9. Simulation and Measurement Results.

6. Conclusions

An experimental study on the design of corporate feed with dual segment circular polarized antenna array was presented. A detail discussion over the design technique and subsequently rectifying results of the antenna was highlighted. A good agreement between the simulation and experimental results was observed. It is found out that the circular polarized antenna array can be operated within the GSM band with reasonable return loss, gain performance and output voltage. It is therefore expected that the proposed antenna array will be a very attractive structure to active low power consumption sensor applications by recycling RF ambient energy. The proposed antenna is simple, cost effective and easy to fabricate.

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