Design of Rectenna for Energy Harvesting From Ambient GSM and WLAN Frequency Bands

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Abstract

Ambient wireless energy harvesting is a process of collecting unused wireless energy, which is abundantly available around us. Most of today's wireless communication services use GSM 900, GSM 1800 and WLAN frequency bands. The energy in these three frequency bands are available at most of the places at all the times. For harvesting this energy, this paper targets the design of a multiband antenna that encompasses the above said three frequency bands completely. For this purpose, a planar microstrip tri-band dipole antenna is proposed and designed. The antenna output drives a voltage doubler circuit through an impedance matching network (IMN). The simulations of antenna are performed in ADS, EMDS and EM-Pro simulation softwares. The targeted rectenna is simulated in ADS, which has the capability to harvest one third of the available power.

Key Words: Rectenna, Stubs, Impedance Matching Network, Rectifier and Power Splitter.

1. INTRODUCTION

Energy harvesting, also popular as power harvesting (or energy scavenging), is the measure of deriving the energy taken away from different kind of sources such as solar energy, wind energy, thermal energy along with kinetic energy, confined by the harvesters and efficiently reformed into direct current (DC) energy or power. Several possibilities of harvesting resources are discussed in [4]. In recent days, wireless power harvesting is a well-known issue in Radio Frequency (RF) engineering.

The increasing demand for wireless services has directed increase in existing RF energy. The ambient RF energy, available in the environment due to existing communication systems, is not always utilized at all times and places. Energy harvesting is a promising technology which is an alternative for batteries in low power electronics [1]. RF energy harvesting is possible using a rectenna element [2], [3], which comprises of antenna and a rectifier circuit, connected through an IMN for maximum power transfer. The harvested energy can either be directly used or stored.

Rectenna circuits have been dedicated for single band operation at 2.45 GHz [1], for broad band operation from 850-1950 MHz [2] and 1800 to 2450 MHz [3]. Most of the communication services at present use GSM900, GSM1800, UMTS (2100 MHz), WLAN (2.45 GHz) bands. To be able to harvest energy from all these communication services, a multi band antenna that encompasses all the frequencies in each band is necessary.

A planar inverted F antenna (PIFA) is developed for dual band operation (GSM900 and GSM1800) [5]. A dual band antenna for GSM900 and WLAN bands is developed for ultra-low power applications [6]. Covering frequencies of GSM 900, GSM 1800 and WLAN, a square ring antenna is designed [7]. All the above said antennas are narrow band in nature.

Tetra band rectennas encompassing different bands are available [8]-[10]. However, these are either four different rectennas operating at single band, or antennas developed with complex structures developed using genetic algorithms (GA) and with narrowband IMN. A tetra band rectenna is addressed [11], where the broadband antenna design is not addressed and rather the impedance bandwidth of the IMN has not been analyzed. Based on the previous discussion, it can be observed that a broadband rectenna which can encompass the bands GSM900, GSM1800, UMTS and WLAN, with a broadband matching network is still an open problem. This is due to the fact that if bandwidth criterion is satisfied, radiation pattern may not be stable at all the bands or if pattern is stable, proper impedance matching may not be possible. If individual rectennas are designed, the space may be a restriction. Hence, a low profile rectenna with broadband antenna, broadband IMN, efficient rectifier, having stable radiation pattern at all the bands one of the design concerns.

One of the sub-concerns is the design of a rectenna with broadband nature that encompasses three wireless communication bands (namely GSM900, GSM1800 and WLAN). In this regard, the paper presents a multi band antenna, which can receive the three targeted bands completely. It is based on the principle that using two resonant structures, and proper coupling between them, a tri-band antenna can be designed [7]. However, the developed antenna encompasses the three communication bands completely unlike that in [7]. Further, a multiband IMN that encompasses the three required bands completely, is designed by incorporating a power splitter.

2. Antenna Design

Using Arlon diclad 880 substrate, which has dielectric constant (ϵ_r= 2.2) and thickness of about 1.6 mm, the proposed antenna is designed. The choice of the substrate is to obtain a fair comparison between the proposed antenna and the ring antenna developed in [7]. In [7], the principle behind the antenna design is that, using two square ring antennas, and proper stub matching a tri band antenna is achieved. However, owing to the ground plane backing, the antenna becomes narrow band. The geometry of the dual ring antenna (obtained using optimized dimensions given in [7]) and its S parameter results are shown in Figure 1 and Figure 2 respectively. In Figure 2, it can be observed that the deign frequency of target and the simulated results are approximately matching.

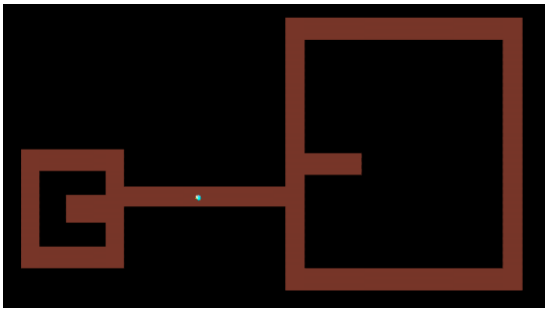

Figure 1: Dual ring antenna [7]

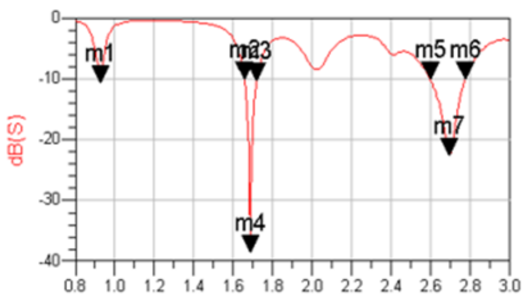

Figure 2: S-parameter results of geometry in Figure 1

The proposed antenna is based on the same principle as that of [7]. Using two dipoles and proper coupling between them, three required resonances that completely encompass the required bands has been obtained. The geometry of the proposed antenna on the same substrate as that used in [7], and its S parameter results obtained from EMPro are shown in Figure 3, Figure 4 respectively.

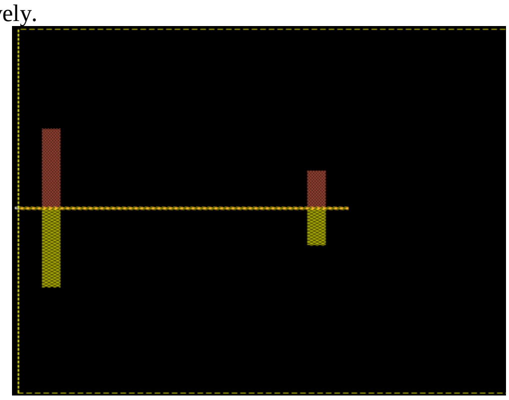

Figure 3: Proposed tri-band dipole antenna

Figure 5 shows a comparison of the S parameter results obtained from ADS, EMDS and EMPro solvers. It can be observed that the results from all the three solvers are similar. Further, note that the proposed antenna encompasses the three targeted bands completely.

However, it is observed that the radiation pattern of the proposed antenna is quasi-omni in GSM900 band, but highly directive with multiple lobes in the other two bands. Thus, the bandwidth target has been satisfied at the cost of radiation pattern stability. The gain obtained for the proposed antenna is around 3dB at 900MHz, 5dB at 1800 MHz and 2400 MHz.

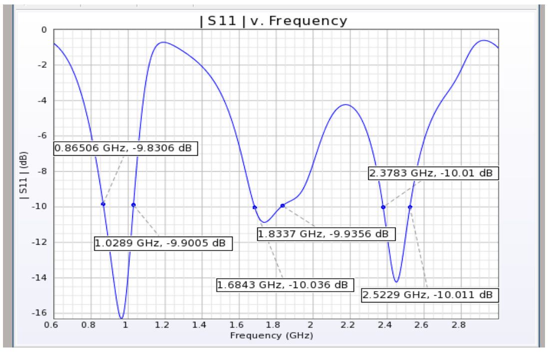

Figure 4: S-parameter results of proposed antenna

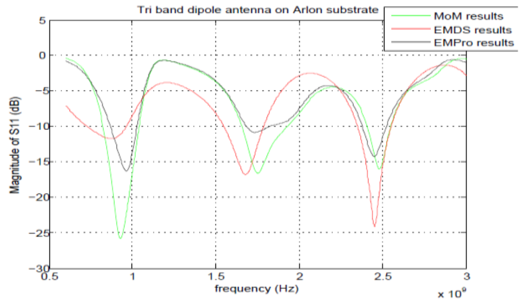

Figure 5: S parameters of the proposed tri-band dipole antenna

For the proposed antenna, the design criteria are given below. The length of the first dipole (resonant at f_1=900MHz) is notated as L_1, that of second dipole (resonant at f_2=1800MHz) is L_2, coupling gap between the two dipoles is G, length of the open stub after the second dipole is F. To obtain the values of L_1, L_2, G and F, the following are used

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} \quad (1)$$

$$\lambda_{res} = \frac{c}{f\sqrt{\epsilon_{reff}}} \quad (2)$$

where, ϵ_{reff} is the effective dielectric constant of the substrate and λ_{res} is the resonant wavelength at a frequency f. Let wavelengths at f_1, f_2 and f_3 be λ_{f1}, λ_{f2} and λ_{f3} respectively. Correspondingly,

$$L_1 = \frac{\lambda_{f1}}{2} \quad (3)$$

$$L_2 = \frac{\lambda_{f2}}{2} \quad (4)$$

$$G = \frac{\lambda_{f2}}{2} + \frac{\lambda_{f3}}{2} \quad (5)$$

$$F = \frac{\lambda_{f3}}{10} \quad (6)$$

The width of the dipoles, W is given as

$$W = \frac{\lambda_{res}}{30} \quad (7)$$

Using these design formulae, the obtained geometry parameters and the optimized parameters to obtain the results shown in Figure 4 are compared in Table I.

Table I: Design parameters for proposed antenna

Parameter	Design value (mm)	Optimized value (mm)
L_1	132	140
L_2	66	65
G	115	108
F	10	10
W	9	9

The antenna bandwidths obtained at the three target bands from the square ring antenna developed in [7] and the proposed tri-band antenna are compared in Table II. It can be observed that the proposed antenna encompassed the three target bands completely.

Table II: Comparison of Antenna Bandwidths

	Center frequencies	**10dB Bandwidth**
Target	917MHz	876MHz – 959MHz (83 MHz)
	1.795GHz	1.71GHz – 1.88GHz (170 MHz)
	2.45GHz	2.41GHz – 2.48GHz (70 MHz)
Square ring antenna [7]	925.4MHz	-
	1.687GHz	1.66GHz – 1.72GHz (61 MHz)
	2.694GHz	2.59GHz – 2.77GHz (176 MHz)
Proposed Antenna	927.8MHz	828MHz – 1.04GHz (211 MHz)
	1.750GHz	1.66GHz – 1.93GHz (270 MHz)
	2.481GHz	2.41GHz – 2.55GHz (135 MHz)

3. RECTIFIER AND IMN

A rectifier is an electronic apparatus or circuit that changes RF current to DC. Rectifier input impedance changes with respect to frequency and incident power [5]. There are three types of rectifier circuits, namely series rectifier, voltage doubler, Greinacher circuit. A voltage doubler circuit uses two diodes and has less ripple factor and better efficiency than the series rectifier. A Greinacher circuit has four diodes, and requires more incident power to turn on the diodes. Hence, a voltage doubler is chosen for converting RF energy to DC. The circuit is built using a high frequency Schotky diode HSMS6250. The return loss of the diode based rectifier circuits shows no match in the required bands of operation namely GSM and WLAN. Hence, an IMN is used before the rectifier circuit, for obtaining a proper impedance matchingThree different single stub matching networks are designed at GSM900, GSM1800 and WLAN frequencies respectively. At GSM900, a radial stub is observed to provide better bandwidth than short and open stubs. Similarly, at GSM1800 and WLAN, shorted stubs are observed to have better matching performance. As the number of stubs increase, the bandwidth can be increased. However, this requires a large number of stubs to obtain the final circuit.

Further, when the single band IMNs are connected in parallel, so as to be able to connect to the antenna output, the stub parameters have to be re-tuned to obtain the tri band resonance. Hence, using only a single stub at each desired band, the three stub matching networks are connected to the three arms of a power divider. This reduces the harvesting capability of the rectenna by three. However, the targeted bands are completely encompassed

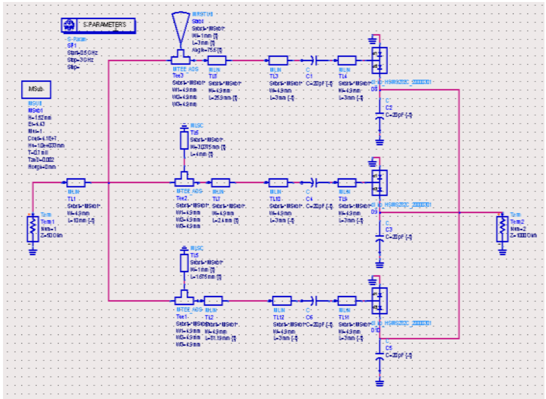

Figure 6. IMN without power divider

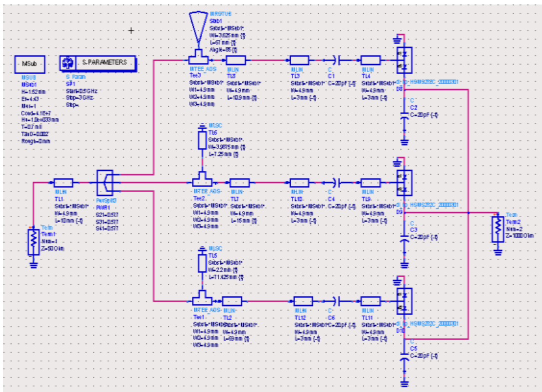

Figure 7: IMN with power divider

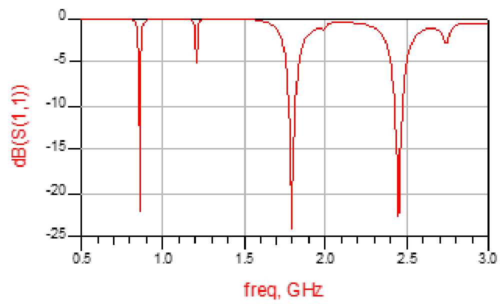

Figure 8. S-parameter result of IMN in Figure 5

The matching networks without the power divider and with the power divider are shown in Figure 6 and Figure 7 respectively. The S parameter results are shown in Figure 8 and Figure 9 respectively. It can be observed from these ADS simulations that the rectenna with power divider connected to three IMN networks followed by rectifiers can render a broadband harvesting circuit.

The bandwidths at 900MHz, 1800MHz and 2.4GHz frequencies are 6MHz, 39MHz and 48MHz, when no power splitter is used. However, when power splitter is used the required bands are encompassed completely. The efficiency of the IMN based rectifier is a function of input power level. For GSM900 band the rectifier conversion efficiency at 900MHz, is shown in Figure 10.

Hence, if antenna output is given to the rectifier circuit through the designed IMN, the energy harvester can be realized with conversion efficiencies 11%, 9% and 18%

at 900MHz, 1800MHz and at 2.4GHz respectively at an input power of 10dBm.

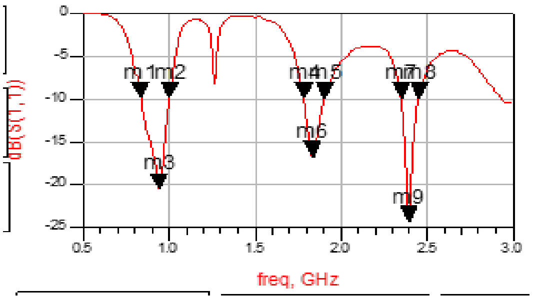

Figure 9. S parameter result of IMN in Figure 6

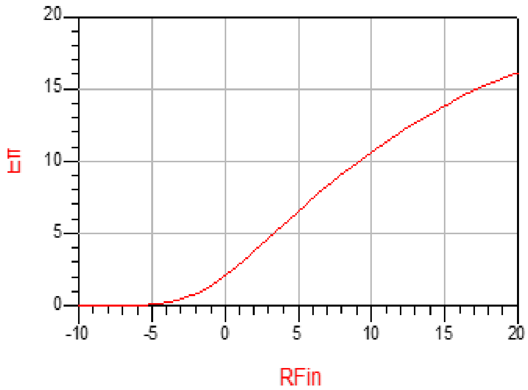

Figure 10. Efficiency at 900MHz

The harvesting capability of the proposed rectenna decreases to one third due to the power divider in the IMN. Further, the radiation pattern is not stable all over the targeted bands. It is quasi omni only in GSM900 band. Hence, the design can be further improved incorporating advanced matching circuits.

4. CONCLUSION

In this paper, a rectenna for harvesting RF energy from ambient GSM900, GSM1800, WLAN bands is designed. The rectenna incorporates a proposed tri-band dipole antenna, which uses two dipole elements, with proper coupling. On Arlon diclad 880 substrate, the proposed antenna is simulated, whose S parameter results show that the antenna is multi band and it encompasses the required three communication bands for energy harvesting. A high frequency Schottky diode based voltage doubler is used for rectification. For multiband IMN that can encompass the three target frequency bands, a power divider based tri branch stub matching network is used, with a single stub in each branch. The efficiency versus power input curve of the IMN followed rectifier circuit shows that the rectenna can harvest with conversion efficiencies 11%, 9% and 18% at 900MHz, 1800MHz and at 2.4GHz respectively at an input power of 10dBm. The antenna and the matching circuit along with rectifier can be integrated on a single low cost FR4 substrate, which forms the future work of this paper.

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