Harvesting microwave energy from WiMax bands based on a Dual-Band Antenna

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Abstract. There is pressure caused by increasing electromagnetic radiation in our areas, for example, UHF, VHF, WIFI, and WiMAX bands. In this context, the concept of energy recycling plays an important role. It is expected that WiMax technology with different standards is going to come to market (IEEE 802.16d and IEEE 802.16e). There are many cases where it is desirable to acquire energy form many radiofrequency stations, to produce electricity and efficiently charge any electronic device through the RF-DC conversion circuit. In general terms, the system is divided into two parts: Harvesting microwave energy around us and the RF-to-DC conversion circuit. The purpose of this work is to harvest microwave energy from two bands of operating frequencies \((f_{01}= 2.4GHz)\) and \((f_{02}= 3.84GHz)\) using Dual-band slot-loaded pin-fed linear-polarised rectangular patch antenna. The efficiency of acquiring RF depends on the amount and types of antenna and the efficiency of the RF-DC conversion circuit. However, the microwave energy obtained from the environment is usually at the scale of milliwatts which is a serious problem that limits the popularity of the WiMax power harvest. This paper presents a novel rectenna for highly efficient WiMax power harvesting. We evaluate the possible application of microwave harvesting, to charge a battery of a sensor.

1. Introduction

Recently, wireless telecommunication bears dramatic progress. There is a growing number of radio stations in the urban environment such as GSM mobile base stations, satellite, digital and digital TV towers, WiMax, and Wifi routers [1]. Various bands are available for WiMAX technology stage in different parts of the world. The frequencies commonly used are 3.5 and 5.8GHz for ieee802.16d and 2.3, 2.5 and 3.5GHz for ieee802.16e [2]. There are many places in our areas where applications on telecommunication media that involve WiMax bands with two band frequencies are made \((f_{01}= 2.4GHz)\) and \((f_{02}= 3.84GHz)\) [3]. Because of the attractive features of the Dual-band slot-loaded pin-fed linear-polarized rectangular patch antenna, such as planar profile, ruggedness, and low cost, there has been considerable interest in the development of these antennas to recycle energy microwave available mainly in an urban zone, as shown in figure 1. It is sometimes possible that a broadband rectangular microstrip antenna can cover the frequencies of interest [4]. Yet, the advantage of using a Dual-band slot-loaded pin-fed linear-polarized rectangular patch antenna is that it receives two operating frequencies [5]. We can collect and recycle more microwave energy into our electronic harvesting PCB circuit. On the other hand, the advantage of the dual-frequency antenna is that it focuses on the frequencies of interest and is thus more directive [6] [7]. This paper is part of a radiofrequency ampler project that aims to construct a prototype of a WiMax harvesting energy system. Accordingly, we show the initial results of our present research. In the future, we will propose new methods to improve our initial results, and we will continue to analyze and make new PCB boards.
including the antenna with the harvesting circuit. In this work, we show the possibility of harvesting energy from two signal powers; first operating frequency \( f_0 = 2.4 \text{GHz} \) and second operating frequency \( f_0 = 3.84 \text{GHz} \). To validate our analysis, we conduct an RF simulation at three software’s CST, Antenna Magus, and Agilent ADS. This work is organized in the following structure. In section II, we present the antenna design. The design of a microwave to electricity conversion circuit is presented in section III. In section IV, we describe the results of the research. Finally, section V concludes the work.

![Diagram](image)

**Figure 1.** Typical of an RF energy harvesting and the concept of energy recycling.

2. **Antenna design**

Simulation design involves the types of materials for the substrate and ground plane dimension. WiMax technology covers the IEEE 802.16d standard for nomadic users using 2.3-2.4GHz frequency band and IEEE 802.16e for mobile users using 3.3-3.7GHz frequency band. For this reason, Dual-frequency patch antennas provide an alternative to wideband planar antennas in applications [8] [9]. The size of the ground plate and superstrate is \( L_g = 126.25 \text{mm} \) and \( W_g = 95.44 \text{mm} \). The antenna is a simple probe-fed on FR4 substrate which operates at 2.45GHz and 3.84GHz respectively. The geometry and the size of the Dual-band slot-loaded pin-fed linear polarized rectangular patch antenna are given in figure 2.

2.1. **Simulated and analysis**

To make a Dual-band slot-loaded pin-fed linear polarized rectangular patch antenna, we use FR4 (Generic) substrate in single element relative permeability \( \varepsilon_r = 4.35 \) with substrate wall thicknesses \( h = 1.5 \text{mm} \). Subsequently, 2.45 and 3.84GHz dual-band antennas are proposed in this work for the intent of simple and common antenna. The antenna bandwidth and gain specifications are expected to satisfy various applications. Usually, the patch antenna requires 100 MHz of bandwidth at 2.4-2.95GHz frequency band, and a wider bandwidth can be obtained in the 3.1-3.84GHz frequency band [10]. This antenna is designed and simulated with Antenna Magus and CST microwave software. After simulating the proposed patch antenna, we can calculate the parameters values; Gain, VSWR, 3D radiation pattern, directivity, and S-parameter.
2.2. Gain plot
The radiation pattern of the proposed patch antenna showing the gain at 2.45GHz and 3.84GHz is 4.35 dBi and 2.78 dBi respectively. The gain plot can be seen in figure 3.

![Gain Plot](image)

**Figure 3.** The power gain of the proposed antenna.

2.3. VSWR plot
VSWR is a measure of how well matched the dual-band patch antenna is to the SMA connector impedance. Perfect results would have a VSWR of 1:1. VSWR obtained from the simulation on antenna magus and CST is 1.451 at 3.79GHz and 1.52 at 2.4GHz which approximately equals to 1:1 as shown in figure 4. We can conclude the effect of the rectangular dimension, as feed gap as well as the effect of feed length on the impedance bandwidth. This presents the perfect impedance matching of the rectangular antenna with the port at 50Ω.

![VSWR Plot](image)

**Figure 4.** Simulation VSWR of dual-band antenna.
2.4. 3D radiation pattern

We can see from figure 5 the simulation resulted from Gain for proposed Dual-band slot-loaded pined linear polarised rectangular patch antenna that the gain in second operating frequency (E-plane 5.950 dBi and H-plane 5.947dBi) lesser than the gain of the first operating frequency (E-plane 7.350 dBi and H-plane -17.01 dBi).

![3D radiation pattern](image)

**Figure 5.** 3D radiation of the proposed antenna model in Antenna Magus.

2.5. Directivity

Using the CST microwave software, the directivity shows at radiation frequencies 2.4 and 3.84 GHz, is very high. So, the rectangular patch antenna is very directive. The radiation pattern will be maximum towards phi=0 or 180 degrees and minimum towards phi=90 or 270 degrees. The simulation resulting from the directivity is shown in figure 6.

![Directivity](image)

**Figure 6.** Direction radiation pattern for the proposed antenna (dBi) model in CST MWS.
2.6. $S$-parameter
The $S$-parameter plot is illustrated in figure 7. From figure 7, we observe that the minimum $S_{11}$ value is at 2.38GHz and 3.85GHz. This means the optimized frequency for the antenna is shifted to 2.38 and 3.83GHz due to the slot-loaded pin-fed linear-polarised.

3. Design of a microwave to the electricity conversion circuit
However, the microwave energy obtained from the WiMax access point is usually at the scale of milliwatts which is a critical problem that limits the popularity of the energy harvest. For this reason, the rectifier circuit should be highly efficient. A rectifying antenna, called a rectenna, receives the transmitted power and converts the microwave power to electricity. The rectifier is a GaAs Schottky barrier diode whose impedance is matched to the dipoles by a low pass filter [11]. The rectifying diodes in this application are connected to the patch antenna. This work presents some details for studying and constructing a new electronic device that can harvest energy and store inside the lithium battery or super capacitor [12]. The goal of the WiMax to DC conversion circuit is to take the incoming microwave energy from the array patch antenna and rectify it into electricity that could be used to power devise or sensor. To design the full wave bridge rectifier using HSMS 2820 Schottky diode for microwave energy circuit, the following components in figure 8 were used.

![Figure 7. Proposed antenna response.](image)

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![Figure 8. Circuit diagram of the WiMax harvesting device.](image)

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The output voltages as a function of time for the input power of 2.45 and 3.8GHz and the simulated value of $P_{IN}$ versus $V_{out}$ load are presented in figure 9.
Figure 9. Output voltages as a function of time for an input power of 2.45 GHz.

Figure 10. Simulated Value of $P_{in}$ versus $I_{out}$.

We can see from figure 10 that the output current of the circuit using the full wave bridge rectifier circuit is 0.44A at 45dB.

The maximum microwave power distribution from proposed patch antenna to the full wave rectifier circuit is ensured by the matching circuit. We are sure that the VSWR obtained from the simulation on CST is 1.48 at 2.45GHz and 1.315 at 3.84GHz. From the maximum microwave power, the transfer occurs when the circuit is matched to the rectangular patch antenna, the impedance matching is mostly performed at the particular input signal (50Ω). The matching circuit design performs impedance transformation to guarantee maximum power between the antenna and the converter circuit. A matching circuit that operates at 2.45 and 3.8GHz, respectively, is shown in figure 11. The input impedance of 50Ω and the load resistance of 50Ω was made.

Figure 11. Input Impedance simulation vs. Frequency.

Figure 12. Photograph of the proposed RF harvesting circuit under testing phase.

4. Simulation results

We approved a dual-band patch antenna for both WiMax technology occupying two frequency bands 2.45GHz and 3.8GHz. From the parametric studies, we observed that the bandwidth is 22.87 MHz at $f_{(01)}$ and 11.05 MHz at $f_{(02)}$. The comparison of the other parameters is shown in Table 1.

Table 1. Results for the simulation of the proposed antenna.

| Antenna performance parameters | Value $f_{(01)}$ | Value $f_{(02)}$ |
|-------------------------------|-----------------|-----------------|
| Gain (dB)                     | 5.961           | -17.01          |
| Directivity (dBi)             | 7.365           | -22.06          |
| Bandwidth (MHz)               | 22.87           | 11.05           |
| VSWR                          | 1.48            | 1.315           |
In the next step, we fabricated, and we tested the PCB Board of the full wave bridge rectifier circuit using HSMS 2820 Schottky diode as shown in figure 12.

In our proposed rectifier, the HSMS 2820 diode was selected to fabricate WiMax harvesting energy. The microwave signal generator ROHDE&SCHWARZ SMC 100A is used as a source signal. The experiment that this RF-DC rectifier has the DC voltage of 7.03 V at 2.45 GHz and 4.23 V at 3.8 GHz when the load 230 Ω. The efficiency reaches 64.3% in the first operating frequency f_{(01)}, and lower efficiency reaches in f_{(02)} near 39.6%. The comparison of the other parameters is shown in Table 2.

### Table 2. DC voltage output of the rectifying circuit on 230 Ω load.

| P_{in}(dBm) | Frequency f_{(01)} | V_{DC} (V) | P_{in}(dBm) | Frequency f_{(02)} | V_{DC} (V) |
|-------------|-------------------|-----------|-------------|-------------------|-----------|
| 0 dBm       | 2.45 GHz          | 1.03 V    | 0 dBm       | 3.8 GHz           | 0.87 V    |
| 5 dBm       | 2.45 V            | 0.87 V    | 5 dBm       | 5.02 V            | 1.89 V    |
| 10dBm       | 5.67 V            | 5.02 V    | 10dBm       | 6.13 V            | 3.8 GHz   |
| 15 dBm      | 6.13 V            | 15 dBm    | 20 dBm      | 7.03 V            | 5.02 V    |
| 20 dBm      | 7.03 V            | 20 dBm    | 20 dBm      | 5.22 V            |

5. Conclusions
A new compact geometric rectenna has been designed for RF energy harvested from WiMax bands with high efficiency. The idea is to collect maximum microwave energy that can be used in charging any electronic device like a mobile phone, camera, smartwatch, etc. Initially upon applying the gain and directivity with the second operating frequency f_{(02)} higher and better efficiency than the first operating frequency f_{(01)} is obtained. The measured results show that the patch antenna has a minimum reflection coefficient of -38 dB at 2.48 GHz with a bandwidth of 2.4 to 2.51 GHz, and the realized gain is 2.2 dBi at 2.45GHz. The maximum conversion efficiency of a rectifier is around 64.3% in the first operating frequency and reaches 39.6% in the second frequency. We observed that the efficiency with the second operating frequency is higher and better than the first operating frequency. Due to the high performance, the proposed circuit can provide energy to a range of low power electronic devices and wireless sensors by acquiring the ambient WiMax power. In this work, we have reaches 64.3% conversion efficiency rectifier at input power level 20 dBm. In future research work, the objective is to increase the rectifier performance and the harvesting more power.

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