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PRINTED 2.45 GHZ PBG MICROSTRIP PATCH ANTENNA FOR LOW POWER ENERGY HARVESTING APPLICATION

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ABSTRACT

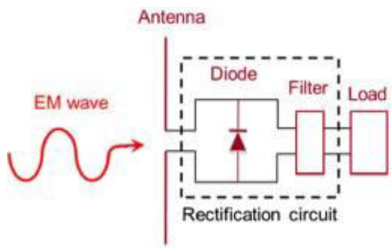
Low power energy harvesting system is one of the rectenna applications. For this purpose, the compact receiver antenna is needed in order to reduce the power losses. In this paper, A Photonic-Band-Gap (PBG) rectangular microstrip patch antenna is designed for a receiver antenna in rectenna system. It has a compact size with a combination of PBG antenna with Defected Ground Structure (DGS) low pass filter (LPF) in the same substrate. The compact PBG rectangular antenna is built on a low-cost FR-4 substrate with relative permittivity of 4.7 and a thickness of 1.6 mm operating at 2.45 GHz. The antenna is simulated by using CST microwave software and fabricated by using photolithography technique. The prototype has been measured by using vector network analyzer and the results of the proposed antenna are in good performances and steady efficiency.

Keywords: photonic band gap antenna, defected ground structure, low pass filter, harmonic suppress, rectenna.

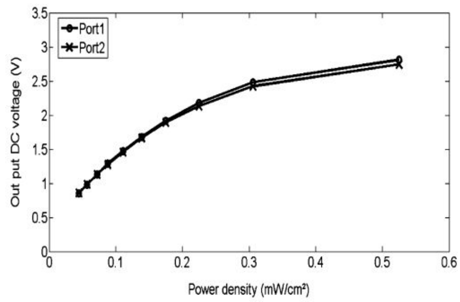
INTRODUCTION

Low-power energy harvesting is becoming an important technology in the 21st-century. The technological developments of the late 20th-century jump started this emerging field. In just the last 10 years, the ability to decrease the power requirements of portable devices by orders of magnitude has made formerly unthinkable waste energy sources realistic for the next generation of portable and remote devices. For example, some systems convert motion, such as that of ocean waves, into electricity to be used by oceanographic monitoring sensors for autonomous operation. Another application is in wearable electronics, where energy harvesting devices can power or recharge cell phones, mobile computers and radio communication equipment. All of these devices must be sufficiently robust to endure long-term exposure to hostile environments and have a broad range of dynamic sensitivity to exploit the entire spectrum of wave motions. Energy harvesting also has the potential to replace batteries for small, low power electronic devices. This has several benefits such as maintenance-free, environmentally friendly and opens up a new application. The future of energy harvesting applications may include high power output devices deployed at remote locations to serve as reliable power stations for large systems.

Energy harvesting is a process where energy is derived from external sources such as solar power, thermal energy, wind energy, radio frequency (RF) energy and kinetic energy. The energy is captured and converted into power supply. This concept is suitable to use with wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. In this case, radio frequency (RF) energy is used as an energy that will be converted into DC power. RF energy is a renewable energy that can be collected from publicservices. There is a large



(a)



(b)

Figure-1. Block diagram of rectenna system (a) input sytem (b) rectenna system output.

number of RF energy such as broadcasting radio and TV stations, mobile telephone base stations, and wireless networks in cities and very populated areas.

Generally, rectenna is a device that uses as a RF energy harvester. Rectenna is an interesting technology that captured many researcher's attention due to its capability in microwave power transmission and electromagnetic energy harvesting. The term rectenna is commonly denoted as rectifying antenna at microwave power transmission system. It is a combination of the antenna and high efficient rectifier circuit as shown in Figure-1(a). The graph in Figure 1(b) show that the power

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efficiency of the rectenna output system. The output power is increase due to the higher power input.

Rectenna applications are mainly for receiving power where the physical connections are not possible or battery-less. There are a lot of applications that can be seen using rectenna as a devicethat cansupply DC voltage. Base on the applications, a small and compact antenna are needed. A microstrip patch antenna is a good candidate as a receiver antenna for the rectenna system. They are lighter in weight, low volume, low cost, low profile, smaller in dimension, ease of fabrication and conformity. Moreover, microstrip patch antennas can provide dual and circular polarizations, dual-frequency operation, frequency agility, broad bandwidth, feedline flexibility and beam scanning omni-directional patterning (Singh, 2011).

In (Shuai, 2014), the combination of the receiver antenna and filter is designed. However, the combination increases the antenna patch size and make the power losses higher. The measured result shows the increasing of the power losses about -10 dB. It will affect the output voltage at the rectifier circuit. The higher the power loss, the lower the output voltage.

There is no limitation in designing an antenna, but it must have a good performance as a receiver antenna in order to capture as much as the transmitted signal. The RF input signal captured by the receiving antenna must high to obtain high power output. As a result, a receiver antenna must be designed to have a high gain, low loss and compact in size. In (Huang, 2013), the RF-to-DC conversion efficiency of a rectifier circuit strictly depends on the input power captured by the receiving antenna and the load resistance.

In this paper, a receiver antenna is designed by incorporating PBG rectangular inset feed antenna with DGS low pass filter at the feedline. The purpose of the design is to overcome the increases of the patch size and to avoid high power losses. The antenna will be operating at 2.45 GHz. Each optimum configuration of the PBG antenna and DGS LPF will be fabricated and tested separately.

ANTENNA DESIGN

Structure of antenna

There are many types of antenna designs, such as half-wave dipole, horn, parabolic antenna, and microstrip patch antenna. Some of these can be cast-off for rectenna application, due to their weight or size. For rectenna application, the microstrip patch antenna is the most suitable one. The proposed microstrip patch antenna is PBG rectangular inset feed antenna that can operate at 2.45 GHz. The dimensions of the length (L) and width (W) of the rectangular inset feed antenna are calculated by using (Joshua, 2013):

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-\frac{1}{2}} \tag{2}$$

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\Delta L = 0.412h\,\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{4}$$

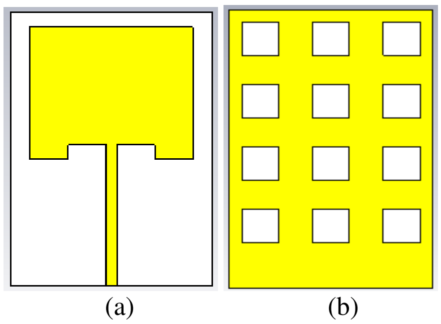
$$L = L_{eff} - 2\Delta L \tag{5}$$

Where; c = speed of light
f_o = resonance frequency
ε_r = relative dielectric constant
h = height of substrate

Besides that, impedance input can be calculated by using following formula

$$Z_A = 90\frac{\varepsilon_r^{\,2}}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2 \tag{6}$$

The structure of the receiver antenna with PBG substrate (PBG antenna) is presented in Figure-2. The PBG antenna was fabricated on FR4 substrate with a thickness of 1.6 mm and dielectric constant of 4.3. The dimension of the substrate is 58 mm x 39 mm while the dimension of the 50Ω inset feed line is 20 mm x 1.9 mm. From the simulation, the optimized dimension of the patch antenna is 30 mm x 30 mm while for the PBG structure, the dimension of 3 x 4 square hole at the ground plane is 7.0 mm x 7.0 mm. The PBG structure at the ground plane is designed to improve the gain and the directionality of the antenna. This increase in gain corresponds to improve power transmitting efficiency (Shuai, 2014). On the other hand, the harmonic frequencies are also suppressed. Based on the previous study related to rectenna design, most of the papers discussed the harmonic frequencies that generates from nonlinear component and the antenna itself (Sun, 2012), (Zhang, 2013), (Gangwar, 2014). PBG is one of the solutions employed to suppress the higher order harmonic frequency. In (Horii, 1999) the single microstrip patch antenna which has two-dimensional (2-D) PBG pattern in the ground plane beneath the square patch is demonstrated experimentally. From the result, the harmonics were perfectly suppressed except the operating frequency. This concept will be used in the receiver antenna design in order to make the antenna resonate at 2.45 GHz frequency.



(a) (b)

Figure-2. Rectangular PBG antenna (a) front view (b) back view.

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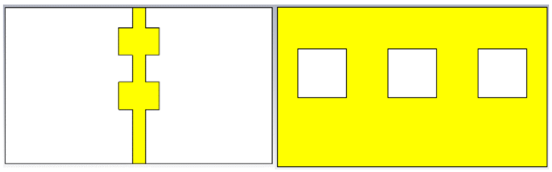
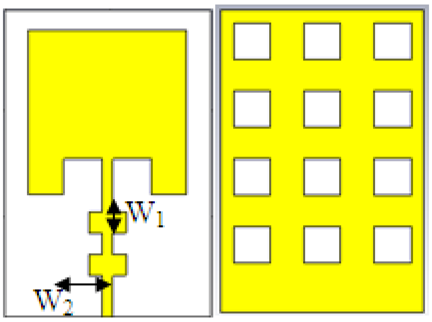


(a) (b)

Figure-3. DGS low pass filter (a) front view (b) back view.



(a) (b)

Figure-4. PBG rectangular antenna with DGS filter (a) front view (b) back view.

The combination of receiver antenna and filter is the important element in rectenna system. The filter is designed to achieve higher order harmonic rejection of unwanted signals. To achieve the required low pass filtering performance, the simple DGS is applicable on 50 Ω feeder lines. DGS is chosen because it has been extensively applied to design microwave circuits such as filters, power dividers, couplers, amplifiers and oscillators (Lim, 2005). The LPF with DGS can suppress and isolate second and third order harmonic signals. The filter has been added at the feedline in order to reduce the additional size of the patch, as shown in Figure-4. The optimal dimensions for theDGS LPF are given as follows: W_1 = 4 mm and W_2 = 6 mm. Besides, DGS low pass filter also has been designed to suppress the higher order harmonics generated by the nonlinear component, so it can prevent from power losses.

Simulated result

The rectangular inset feed antenna design is simulated using CST microwave software. Further optimization and fine tuning of dimensions are carried out to bring the resonance back at 2.45 GHz with acceptable return loss. The return loss of the rectangular inset feed antenna is shown in Figure-5. It can be observed that a few harmonic frequencies particularly at 4.2 GHz, 8.0 GHz and 8.9 GHz need to be suppressed in order to make the antenna operates at 2.45 GHz. This step is important because in rectenna system, there is a rectifier circuit that will be designed to operate at 2.45 GHz. If there is another signal other than 2.45 GHz, it will distract the rectifier circuit to operate at high performance.

Figure-6 illustrates the comparison of the radiation pattern between PBG rectangular antenna with rectangular inset feed antenna. It shows that the radiation pattern become omni-directional when the rectangular inset feed antenna is added with PBG structure at the ground plane.

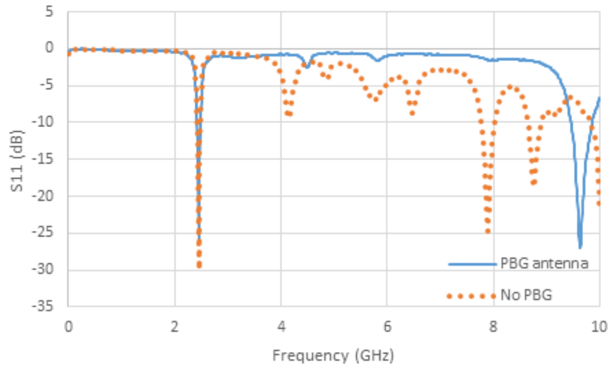


Figure-5. Comparison of return loss between rectangular inset feed antenna with PBG rectangular antenna.

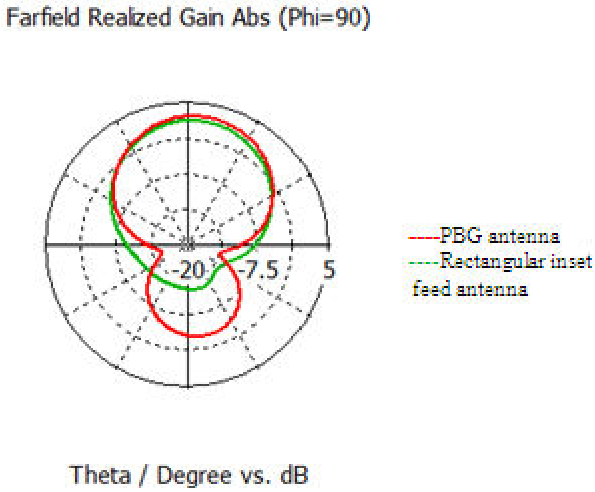


Figure-6. Comparison of gain between PBG rectangular antenna at 2.45 GHz.

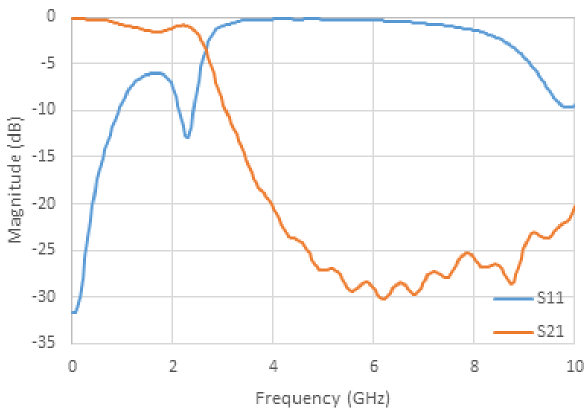


Figure-7. S-parameter for DGS low pass filter.

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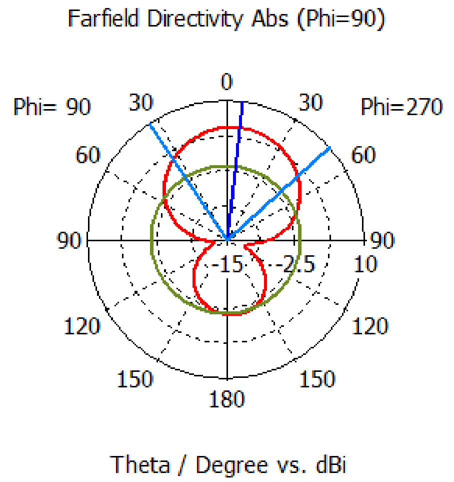
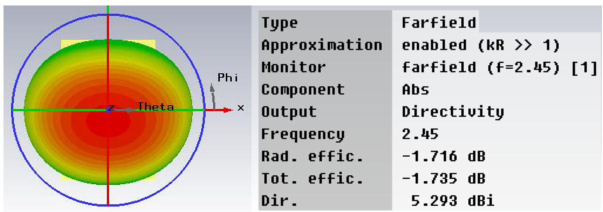
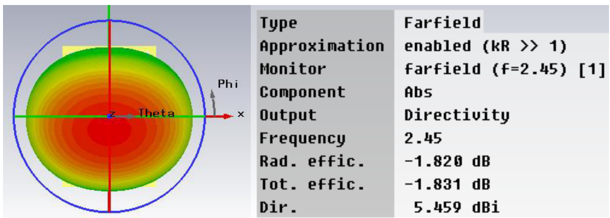


Figure-8. Gain of the PBG antenna with DGS filter at 2.45 GHz.



(a)



(a) (b)

Figure-9. Gain of PBG antenna (a) with filter (b) without filter

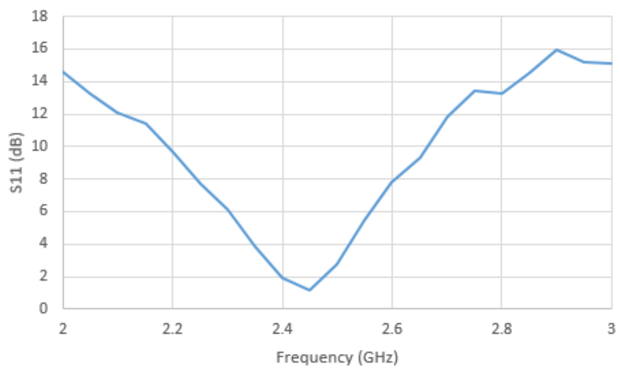


Figure-10. VSWR of PBG antenna with DGS filter at 2.45 GHz.

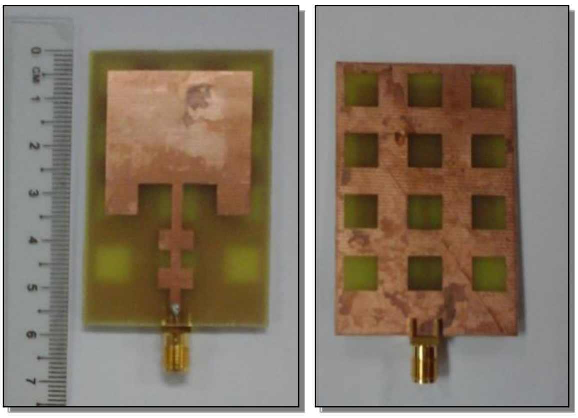
By adding the PBG structure at the ground, the harmonic frequency is suppressed successfully. However, there is one higher order harmonic frequency produced at 9.8 GHz. In order to suppress it, the DGS low pass filter has been designed and added at the feedline. From the simulation, the result shows that the harmonic is perfectly suppressed so that the antenna operates at 2.45 GHz smoothly. Besides, in rectifier design process, due to the nonlinear characteristics of the diode, it can generate some higher order harmonics that may be radiated by the antenna. A DGS low pass filter is also designed to block the harmonics and increase the efficiency of the rectifier. The DGS low pass filter is added at the feedline in order to reduce the additional patch size and prevent from losses. Figure-7 shows the simulation result for the DGS low pass filter. It is very clear that the resonant frequency of the DGS and 3-dB cutoff frequency exist.

Figure-8 illustrates the radiation pattern of the antenna and is found to be similar with the PBG antenna even though there are an additional DGS low pass filter at the feedline. It shows that the additional filter does not affect the radiation pattern of the antenna. Besides, by adding the filter, the gain is increased from 5.293 dB to 5.459 dB as shown in Figure-9.

Figure-10 shows that the VSWR is 1.20 at 2.45 GHz. It is good because the smaller the VSWR, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. For this antenna, the mismatch loss is only 0.04.

Measurement result

A prototype of the PBG antenna with DGS low pass filter is fabricated by using photolithography technique as depicted in Figure-11. By using vector network analyzer, the antenna is measured to get the return loss result. The return loss comparison of PBG rectangular antenna with DGS low pass filter between simulation and measurement is shown in Figure-12. The agreement between simulation and measurement has been achieved. It is noteworthy that there is a little difference between simulation and measurement where the operating frequency is shifted from 2.45 GHz to 2.47 GHz for measurement. This is due to many possible discrepancies between simulation and measurement such as geometric differences (over-etching, over-milling, rounded corners), material properties (anisotropic dielectrics, surface roughness), installed performance (surrounding structures) and feed discrepancies (connector modeling).



(a) (b)

Figure-11. PBG antenna with DGS low pass filter prototype (a) front view (b) back view.

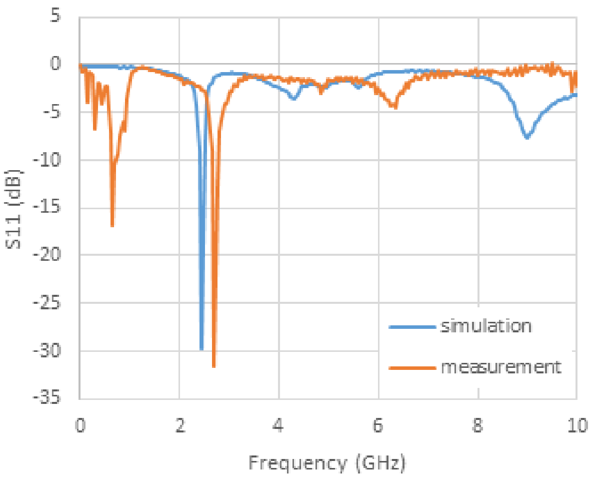


Figure-12. Return loss of PBG antenna with DGS low pass filter.

CONCLUSIONS

The receiver antenna with PBG structure and DGS low pass filter is designed to suppress unwanted harmonics and increases the gain. From the simulation and measurement result, the antenna is found to be perfectly operated at the 2.45 GHz without any harmonic suppression that will distract the rectifier circuit. Besides, the antenna size has been successfully decreased by combining it with the filter in the same patch. The stub filter was added at the transmission line. By adding the DGS low pass filter, the power losses also can be avoided since there is no additional patch. On the other hand, it also increases the gain of the receiver antenna.

To design a good rectenna system, receiver antenna and rectifier circuit must have a good match combination. The receiving antenna must perfectly capture 2.45 GHz and transmit it to the 2.45 GHz rectifier circuit in order to produce high output power. However, this paper covers about the design of receiver antenna for the rectenna system. The rectifier circuit will be designed in the further research in order to design a complete rectenna system.

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