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A CIRCULARLY POLARIZED HARMONIC-REJECTING ANTENNA AT 2.45GHZ FOR WIRELESS POWER TRANSFER

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ABSTRACT

A novel compact proximity coupled microstrip antenna harmonic suppression with resonant at 2.45 GHz of rectenna application is presented in this paper using inexpensive FR4 substrate. An unbalanced slot has been fit on the radiating element to block the harmonic signals and achieve circularly polarized antenna. The evolution of the harmonic rejecting techniques began with a circular slot on the circular patch antenna followed by another circular slot positioned on the other side of radiating patch. Adequate suppressions of the second and third harmonics are obtained with minimum reflection coefficients up to greater than -3 dB respectively. The return loss of proposed design yields -29.16 dB at 2.45 GHz and offer high gain with 6.23 dB with bandwidth around 125 MHz. The proposed antenna also gives 24% size reduction compare with conventional circular patch. From the simulation result, the proposed antenna can be a good choice in the rectenna system for future wireless power transmission application.

Keywords: circularly polarized, harmonic rejection, microstrip patch antenna, rectenna, wireless power transfer.

INTRODUCTION

The rapid development of wireless applications ranging from Bluetooth, WiFi, GSM, satellite and military applications requires more efficient, low profile and flexible antennas. Typical wireless communication systems modulate data at a resonant frequency. Research into microwave energy scavenging has resulted in resonant frequency systems also being used to convert RF energy to DC power or vice versa. A key component of these energy harvesting systems is the rectenna since this component used for RF-to-DC conversion. A conventional rectenna is combination of several components such as antenna, low pass filter, diode and resistive load.

In order to power sensor networks, there are several issues to be considered in the deployment of energy harvesting systems. The more prominent design challenges concern the RF-to-DC conversion efficiency at the output of rectenna system as well as gain of the overall system performances. Research discussed in [1] shows the improvement of conversion efficiency from the rectenna through the introduction of a filter at the antenna to eliminate the higher resonances created by diode. However, this harmonic suppression filter contributes additional insertion loss and requires extra space since the filter is installed separately from the antenna [2-5]. Thus, the compact rectenna can be done by implementing antenna harmonic suppression. This is due to harmonic rejection techniques on the radiating element can performs as low pass filter to block harmonic signal [6-9].

Various techniques have been proposed in literature studies. One technique involves introducing slots on the antenna structure, using defected ground structure and stub at the transmission line. As mentioned in literature studies, an unbalanced circular slot on the circular patch can be used to block the harmonic signals with advantage of circularly polarized antenna. The dimensions of the circular slot were carefully optimized until get the minimum reflection coefficient at fundamental frequency and greater than -10 dB at higher order.

In this paper, a compact proximity coupled circular patch antenna with harmonic rejection is presented for rectenna application. An unbalanced slot was embedded on the radiating element to block the harmonic signal. The harmonic rejection capability was incorporated by introducing two circular slots, which suppress the second and third order effectively.

Antenna miniaturization

The compact circular patch antenna is designed using FR4 substrate with a thickness 1.6 mm and dielectric constant is 4.3. The radius, "a" and effective radius, "a_e" of the circular patch antenna are determined by using the given formula in [10].

$$F = \frac{8.791X10^{9}}{f_r\sqrt{\varepsilon_r}} \tag{1}$$

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]}} \tag{2}$$

$$a_e = a\left[\sqrt{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]}\right] \tag{3}$$

Where
a = Radius of circular patch
F = Fringing field
f_r = Resonant frequency
h = Height of substrate
ε_r = Relative dielectric constant

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a_e =Effective radius

The proposed initial antenna structure is a circular patch microstrip antenna fed by proximity coupling. The design of compact antenna for rectenna is achieved by using high dielectric constant substrate since this method reduce the guided wavelength underneath the patch and thus resonating patch size is also reduced. By employing the unbalanced slot in the circular microstrip disk antenna at 2.45 GHz, the antenna radius is reduced from the calculated result of 16.6mm to 14.6 mm of the proposed one, yielding 24% size reduction. The unbalanced slot embedded on the radiating element is to increase their electrical length that prolong the current path and cause a shift in the resonant frequency. It realized that compact design can be achieved compare with conventional counterpart with the same resonance frequency.

Harmonic-Rejection techniques

This section discusses the antenna harmonic suppression by examining the antenna and then unbalanced slot introduced on the patch element to block spurious radiation exhibit near the second and third order respectively. The proposed initial antenna structure is a circular patch microstrip antenna fed by proximity coupling. The substrate consists of two same material layers in a sandwich configuration. The upper layer of substrate consists of a patch element only with unbalanced slot embedded on it, while the bottom layer consists of a transmission line and ground.

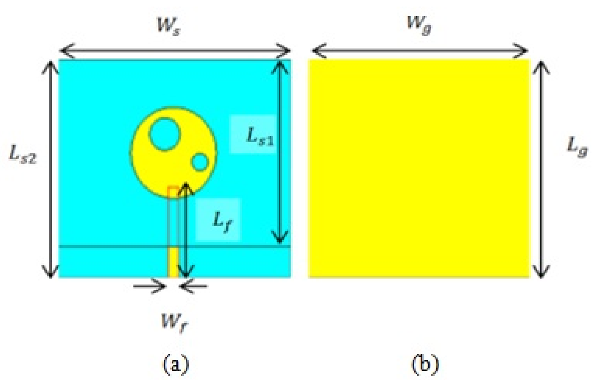

Figure-1. Geometry of the proposed antenna design, (a) Front view of the double layer stack substrate, (b) Back view.

Figure-1 (a) shows the detailed geometry of the proposed antenna design with a parameter dimensions. The circular patch with radius 15.48 mm and the size of ground plane same with the bottom substrate with L_{s2} = 70 mm while the upper layer of substrate $W_s = W_g$ is 80 mm and L_{s1} = 60 mm. L_f and W_f stands for length and width of the transmission feed line. The two slots with different radius on the radiating element were adjusted at the best position. From Figure-2, it shows the harmonic suppression performance with combination of two slots. The basic circular antenna (solid black line) resonates at 2.45 GHz with excitement of harmonic signals. The combination of two slots (dashed red line) used to block signal at high order effectively. The radius of two slots and its positioned was optimized in order to improve the harmonic suppression performance.

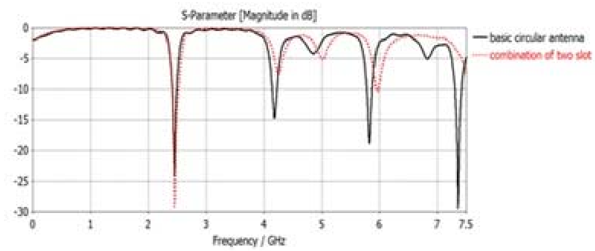

Figure-2. Harmonic suppression performance with combination of two slots.

RESULT AND DISCUSSIONS

Based on the simulation result in Figure-3, the proposed design yields return loss -29.163 dB at resonant frequency. Both simulated reflection coefficients at the harmonic signals also gives better suppression up to -3 dB. The proposed antenna yield 122 MHz of its bandwidth with good radiation efficiency and total efficiency at fundamental modes. This is because the excitation of surface wave guides the maximum energy transfer to the patch at resonant frequency. Then, the overall system impedance is improved since matched at desired frequency while unmatched at second and third harmonic.

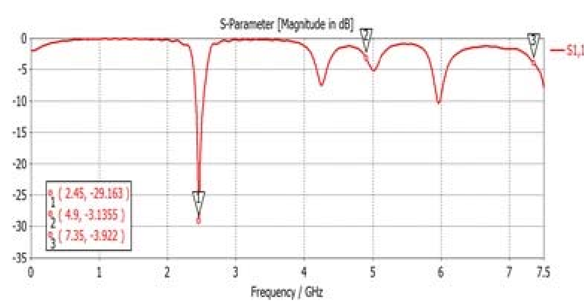

Figure-3. Reflection coefficients performance of the proposed antenna.

The proposed antenna reduced the flow of current to circular patch without perturb the fundamental modes. This cause re-radiated power at the harmonic frequencies reduce without degrade the overall system performance. Figure-4 shows the plotted electric current distribution in the proposed antenna structure. This demonstrates that the fundamental resonance at 2.45 GHz passes through the transmission line while the second and third harmonics are blocked at the transmission areas. Thus, power transfer to circular patch is maximized at 2.45 GHz while reduce at harmonic frequency 4.9 GHz and 7.35 GHz.

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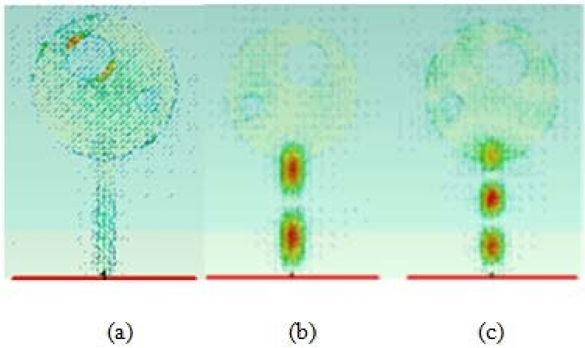

Figure-4. Electric current distribution in proposed antenna harmonic suppression, (a) 2.45 GHz, (b) 4.9 GHz, and (c) 7.35 GHz.

The performance of proposed antenna is analyzed as displays in Figure-5(a) and Figure-5(b) with 6.8 dBi of its directivity and offer high gain 6.23 dB. The proposed antenna radiates with smaller HPBW 90.6 degree due to thin substrate used. Figure 6 shows the radiation pattern for the proposed antenna at 2.45 GHz. The pattern represents the main lobe magnitude of 6.77 dBi at -1.0 degree direction from the origin point.

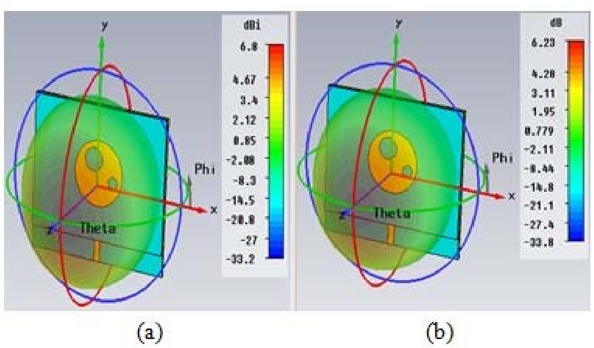

Figure-5. (a) Directivity of proposed antenna, (b) Realized gain of proposed antenna.

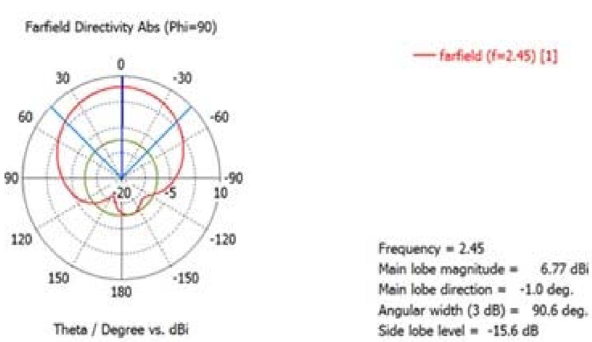

Figure-6. Radiation pattern of proposed antenna.

The patch elements radiate primarily linear polarized waves; however, by using proximity coupled circular patch antenna with unbalanced slot arrangement, circularly polarized antenna can be obtained. The proposed antenna is a good choice since circular polarized system is more suitable in several cases due to its insensitivity to both transmitter and receiver orientation; for instance, in rotating platforms, circularly polarized rectennas help in achieving the same DC voltage irrespective of its rotation and thus avoiding polarization mismatch and loss between it [11, 12]. Figure-7 shows the axial ratio of proposed antenna with 1.12 dB where the value of axial ratio is kept below 3 dB with width of feed line is 3.46 mm.

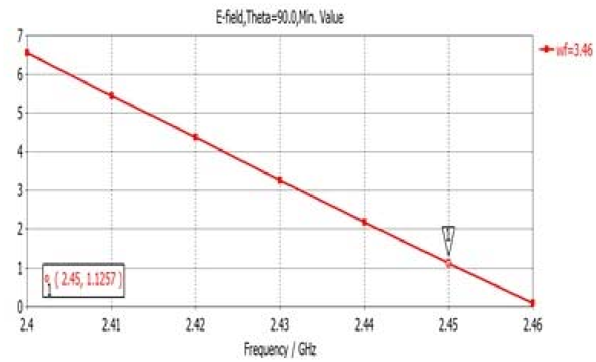

Figure-7. Simulated axial ratio at 2.45GHz.

CONCLUSIONS

A compact circular microstrip antenna at 2.45 GHz with harmonic suppression capabilities is proposed based on transmission line model and the design is simulated using EM simulation in CST software in order to investigate the antenna performance. As result, this work examined the significance performance of unbalanced slot for suppression at harmonic signals up to greater than -3 dB. Therefore, from the simulation results, it successfully demonstrated that the proposed design could be used as antenna harmonic suppression in rectenna system for wireless power transfer without degrade the overall system performance with offer high gain 6.23 dB and size reduction 24% from conventional patch. However, it still has a request to improve the conversion efficiency and gain of rectenna in the low power microwave region, as discussed in this paper. Optimal design for suppression of the harmonic radiation from the rectifiers is an important research topic in rectenna design. Thus, in the future, we can realize the antenna harmonic suppression for wireless power transfer system by examining other technique to be applied on the microstrip patch antenna. This study can be further explored by developing the prototype at future to validate the concept between simulation and measurement results.

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