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# A COMPACT CIRCULAR MICROSTRIP ANTENNA WITH HARMONIC SUPPRESSION AT 2.45 GHZ

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## ABSTRACT

A new class of compact circular microstrip antenna with harmonic suppression for 2.45GHz is proposed. The purpose of harmonic suppression antenna is to eliminate additional insertion loss of filter used in rectenna circuit. This compact circular patch antenna has an advantage of excellent higher harmonic suppression. This characteristic is achieved by suitable introducing stub at the transmission feed line to suppress spurious radiation exhibit near third order effectively. Then, rejection characteristics have been improved using defective ground structure and slit. It is found that, the harmonic rejection technique applied improved the return loss level to -43.65dB at desired frequency with bandwidth around 122MHz. In addition, the antenna structure provides simple design with harmonic suppression capability. The single element of antenna harmonic suppression is design on FR4 substrate with relative permittivity, $\varepsilon r$ =4.7 and a thickness of 1.6mm offers a moderate gain 2.61dB and suppress the second and third harmonic up to -3dB. Thus, the proposed antenna harmonic suppression is recommended to be applied in rectenna and active integrated antenna applications, so that gives size reduction, inexpensive and efficient.

**Keywords:** antenna harmonic suppression, circular microstrip antenna, defected ground structure, rectenna, wireless power transfer.

## INTRODUCTION

Filtering is one of the important technologies in microwave circuit design (Haiwen Liu *et al.*, 2005). In conventional RF front end subsystem, the filter is used between the antenna and the circuit that usually contain of nonlinear device is use to reject undesirable signals. However, this nonlinear device generates unwanted harmonic power at high order in the system and thus degrades the overall system performance. The present of filter introduces additional insertion loss to the system rather than costly and required extra space.

Nowadays, there was a lot of effort in exploring new sources of energy to generate electricity as an alternative way to the existing technology which mostly depends on the fuel energy. Hence, energy scavenging or energy harvesting is found as the only way to transport the energy wirelessly using microwave wireless power transmission technology to the earth station where the RF power is collected and converted back into dc voltage at the receiving point (Rajiv Dahiya *et al.*, 2013; SikaShrestha *et al.*, 2013). Most of the researchers in the literature focusing on the receiving part of wireless power transfer system known as rectenna system (Dasgupta, S. *et al.*, 2010).

The efficiency of the overall wireless power transfer system depends on the efficiency of each component; the conversion of RF-to-DC or vice versa which is transportation of energy wirelessly. Thus, an effort to achieve high efficiency at the receiver part is emphasized for a component named as rectenna due to this component do the RF-to-DC conversion (Young-Ho Suh *et al.*, 2002). However, the diode used in rectenna system generates the radiation power at the harmonic frequencies and the disturbed signal is added together with the desired signal in the signal conversion process causing a degradation of output and gives rectenna system not efficient (Fu-Ren Hsiao *et al.*, 2001; JihwanAhn *et al.*, 2008; Shaoqiu Xiao *et al.*, 2008; YunxueXu *et al.*, 2012). Filter can be used to reject the undesired signal but it yield additional insertion loss which eventually still attenuate the output of the rectenna system. Since miniaturization is inevitable, a compact circular microstrip patch antenna at 2.45GHz is proposed to eliminate the use of filter to suppress unwanted harmonics produces by the diode in rectifier circuit.

This paper is organized as follows. A compact circular microstrip patch antenna at 2.45GHz is designed and analyzed based on transmission line theory and circuit simulation of EM simulation in CST software, while next presents the combination of harmonic rejection techniques used such as stub, defective ground structure and slit. Then, followed by results, conclusion, acknowledgement and reference respectively.

## ANTENNA DESIGN

The circular patch antenna is designed using FR4 substrate with a thickness 1.6mm and dielectric constant is 4.7. The radius, a and effective radius, ae of the circular patch antenna are determined based on transmission line theory where given formula in (Rahim, R.A *et al.*, 2012).

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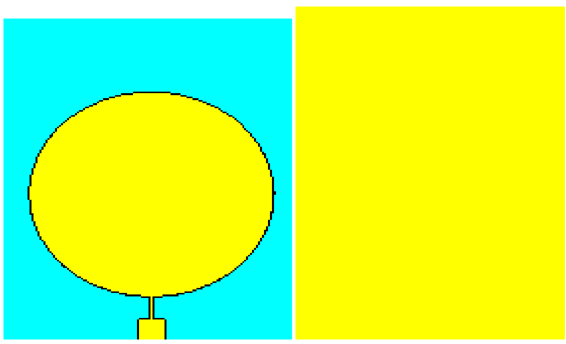
$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\mathcal{E}_r}} \quad (1)$$

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \mathcal{E}_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]}} \quad (2)$$

$$a_e = a\left[\sqrt{1 + \frac{2h}{\pi a \mathcal{E}_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]}\right] \quad (3)$$

Where;
a = Radius of circular patch
F = Fringing field
$f_r$= Resonant frequency
h = Height of substrate
$\mathcal{E}_r$ =Relative dielectric constant
$a_e$= Effective radius

The proposed harmonic suppression circular microstrip antenna is excited with a microstrip line feeding method where the connection of the patch and the feed is direct connection and they are on the same substrate to provide planar structure. In this design, the input impedance of the antenna usually allows second order harmonic to excite but the improvement has been made using quarter wave section in the transmission line feed since its require a matching between the microstrip patch and 50Ω feeding line and thus compensates the difference in impedance between it (Radisic, V. *et al.*, 1997). Figure-1 shows the design layout for basic Circular Microstrip Antenna (CMA) with full ground plane. From the return loss characteristics of basic circular patch displays in Figure-2, the spurious radiation exhibit near high order.



(a) Front View (b) Back View

**Figure-1.** Design layout for basic circular microstrip antenna (CMA).

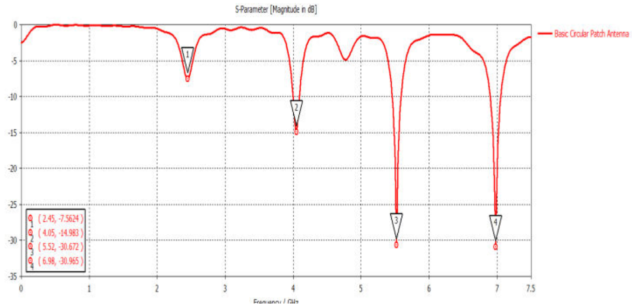



**Figure-2.** Return loss of the basic circular microstrip antenna (CMA).

**Table-1.** Design parameter.

| **Antenna parameters** | **Unit** (mm) |
|---|---|
| Radius of circular patch | 16.25 |
| Length of feed line | 3.8 |
| Width of feed line | 3.52 |
| Length of matching line | 6.25 |
| Width of matching line | 0.72 |
| Radius of circular DGS | 2.5 |
| Slit dimension | 1.35 x 3 |
| Size of substrate | 40 x 55 |

## HARMONIC REJECTION TECHNIQUES

To achieve a compact radiating element, a circular patch with partial ground area is 30mm x 50mm with circular slot etched beneath the ground plane as defected ground structure is applied. Hence, this technique yields lower reflection coefficient since return loss at fundamental modes is improved from -8.2 dB up to -17.16dB and ability to control the desired resonance frequency.

From Figure-2, the deep resonance near third order at 6.98GHz is suppressed using open stub (Hiroyuki Arai, 2011) to the feed line with the length of stub use the guided wavelength at that frequencies and optimized their parameter to get the best result. The solid black line in Figure-3 shows the result of initial antenna whereas the dashed red line in Figure-3 shows that initial antenna structure with combination of stub at the transmission line. The effect of this techniques to block harmonics at high order. So, the length of the stub from the calculated values is 4.96mm at that frequency. The width of the stub is smaller than width of the matching line. As a result, the deep resonance at 6.98GHz with -30.97dB of it returns loss is suppressing up to -2dB effectively. The best position of the stub along the transmission line is use to optimize the length and width of stub in order to gives better suppression. It reveals that the technique adopted for a CMA with stub is use to perturb the excitation at third order modes more than fundamental modes without degrades the antenna performance. Thus, first stub which represent low pass filter effectively removes dual band both

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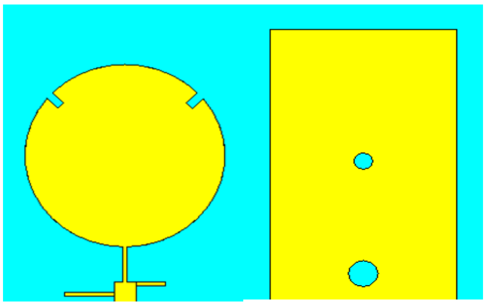
high order at 5.52GHz and 6.98GHz up to greater than -10dB until acceptable range. The harmonic rejection capability was incorporated using this simple technique with the minimum reflection coefficient values of -22.61dB at 2.45GHz.



(a) Front View (b) Back View

**Figure-3.** Proposed circular microstrip antenna (CMA).

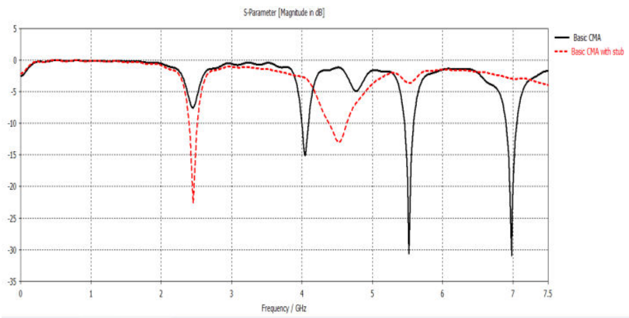



**Figure-4.** Reflection coefficients performances of initial antenna and proposed antenna with the stub.

To control the spurious radiation excited within frequency range 4GHz to 5GHz, we add another stub at the left of transmission line and two slit at the edge of CMA. Then, the length and width of the stub and slit is optimized to seek better result. The return loss at fundamental modes improved up to -43.65dB. From Table-2, it is shown that the proposed CMA effectively suppresses all harmonic frequencies up to -3dB. The filter performances created on this design was further improved by introducing this technique until the spurious radiation in acceptable range.

**Table-2.** Performances comparison of the initial antenna with full ground plane and proposed antenna.

| **Parameter** | **Return Loss** (dB) | |
|---|---|---|
| **Design** | **Initial CMA** | **Proposed CMA** |
| Fundamental modes | -7.55 | -43.65 |
| Second Harmonic | -30.67 | -3.94 |
| Third Harmonic | -30.97 | -3.36 |

**RESULT**

The simulation result show that the proposed antenna resonates at 2.45GHz, with the minimum reflection coefficients values of-43.65dBwith the bandwidth around 122MHz. The good impedance matching achieved at the desired frequency. Figure 6 clearly shows that the impedance at both second and third harmonic is owing to very low impedance (9Ω and 39Ω). Thus, these indicate that proposed CMA can be used as a harmonic tuner in high efficiency power amplifier design as the effective resistance decreases drastically and the resonance is suppressed (Sujith, R. *et al.*, 2010). It is also noted the proposed design offers harmonic suppression without any additional filters and external circuits (Xue-Xia Yang *et al.*, 2012; Guo-Min Yang *et al.*, 2000).

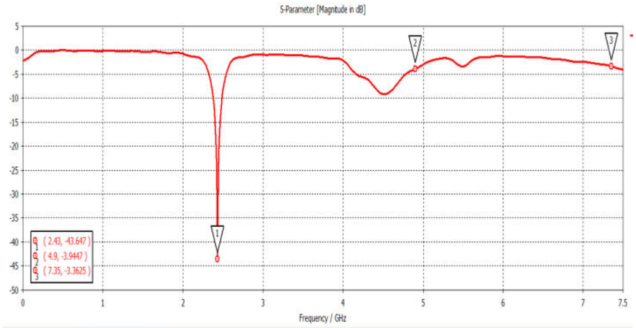



**Figure-5.** Reflection coefficients performances of the proposed antenna.

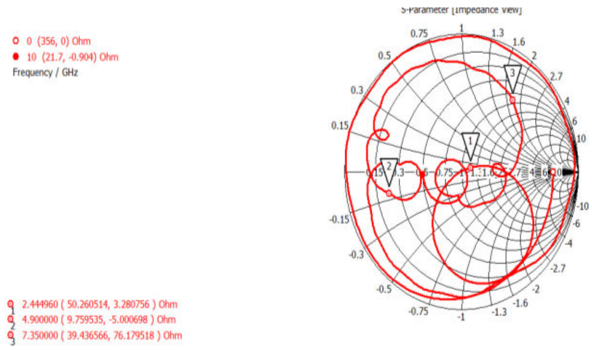


**Figure-6.** Smith chart of proposed antenna.

The performance of proposed antenna is analyzed as displays in Figure-7 and Figure-8 with 4.91dBi of its directivity and offer moderate gain 2.61dB. The proposed antenna radiates omnidirectional with smaller HPBW 88.2 degree due to thin substrate used. Figure-9 shows the radiation pattern for the proposed antenna at 2.45GHz. The pattern represents the main lobe magnitude of 2.61dB at 0 degree direction from the origin point.

The proposed antenna reduced the flow of current to microstrip patch without perturb the fundamental modes. This cause re-radiated power at the harmonic frequencies reduce without degrade the overall system performance. Figure-10 shows the plotted electric current

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distribution in the proposed antenna structure. This demonstrates that the fundamental resonance at 2.45GHz passes through the transmission line while the second and third harmonics are blocked at the stub areas. Thus, power transfer to circular patch is maximized at 2.45GHz while reduce at harmonic frequency 4.9GHz and 7.35GHz.

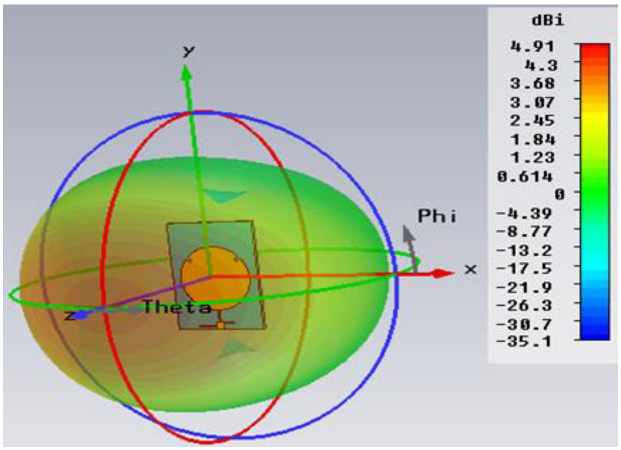



**Figure-7.** Directivity of proposed antenna.

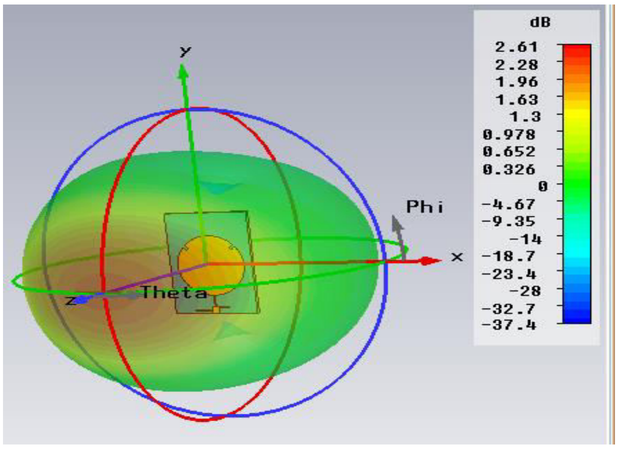



**Figure-8.** Realized gain of proposed antenna.

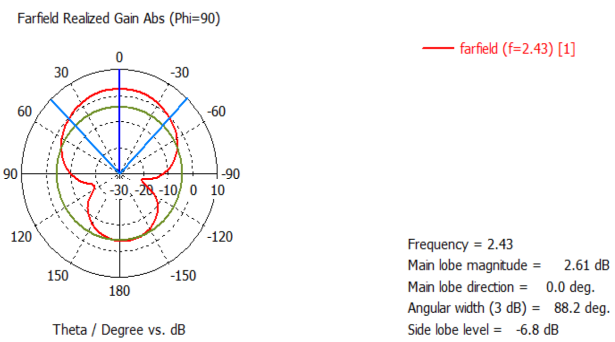
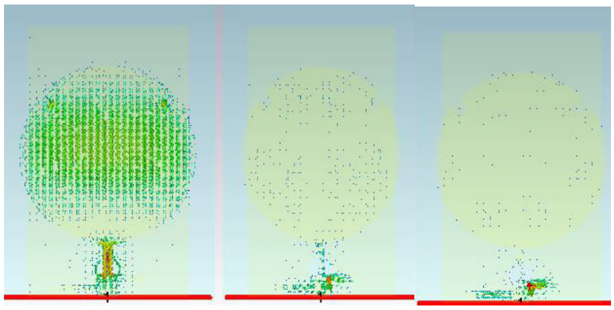



**Figure-9.** Radiation pattern of proposed antenna.



(a) 2.45GHz (b) 4.9GHz (c) 7.35GHz

**Figure-10.** Electric current distribution in proposed antenna.

## CONCLUSIONS

A compact circular microstrip antenna (CMA) with harmonic suppression at 2.45GHz is proposed based on transmission line model and the design is simulate using EM simulation in CST software in order to investigate the antenna performance. As result, this work examined the significance performance of stub for suppression at third order whereas slit and DGS for suppression at second order. Based on these analyses, it has been proposed this design suppressed effectively the harmonic reradiated at second and third order up to -3dB respectively. Therefore, from the simulation results, this work 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. However, this work still has requests 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, at future by examined other technique to be applied on the microstrip patch antenna, we can realized the antenna harmonic suppression for wireless power transfer system. This studies can be further explored by developing the prototype at future to validate the concept between simulation and measurement results.

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