Current Development of Antenna Designs with Harmonic Suppression for Wireless Power Transfer

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***Abstract*—This paper presents the results of ongoing research in the area of the wireless power transfer application focusing on the receiving antenna. The invention of antenna harmonic suppression has been investigated to get high conversion efficiency at the output of rectenna by suppressing re-radiation of harmonics generated in diode of rectifying circuit. Various techniques that incorporate with harmonic rejection with circularly polarization were reviewed to propose an optimum topology that suits in energy scavenging and most importantly, the new proposed structure must have high gain for overall system performance. The printed microstrip antenna is designed and analyzed using the CST Software. This antenna with harmonic suppression would be useful in microwave systems and can be integrated with rectenna system or wearable energy application where the systems give size reduction.**

***Index Terms*— Antenna Harmonic Suppression, Circularly Polarized, Rectenna, Wireless Power Transmission (WPT).**

I. INTRODUCTION

The rectenna is one of the most important components in the Wireless Power Transmission (WPT) application. A typical rectenna or RF Energy Harvesting System consists a receiving antenna, two filter elements and a diode [1]. Figure 1 illustrates the block diagram of rectenna. The wireless technology powered by ambient radiation used for efficient monitoring and so forth, for example Figure 2(a) shows the biomedical implantable devices used for healthcare management, whereas Figure 2(b) shows the agricultural management to enable a single plant for monitoring and nurturing effectively.

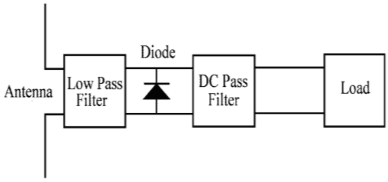


Figure 1: Block diagram of a rectenna [1]

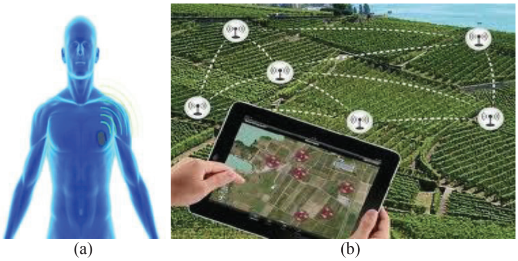


Figure 2: Wireless communication application; (a) Biomedical implantable device; (b) Agricultural management

In order to implement the wireless power transmission (WPT) technology successfully, a high efficiency system is required and these are the main challenges in the development of wireless power transmission systems as it must operate efficiently and the losses of energy during receiving and conversion of signal processes should be minimized by suppressing the unwanted signal. Most of the researchers in literature [2-9] focus on the receiving part of WPT system, which is known as the rectenna system. However, the interface between the antenna and the rectifying circuit consists nonlinear circuit component such as a diode used for active integrated antenna (AIA) has a harmonic suppression filter which contributes additional insertion loss. The invention of antenna with harmonic suppression is to avoid spurious radiation that is easily produced at high-order resonant frequencies of the antenna from the circuits [10]. This weak signal then flows to the rectifier circuit for the RF-to-DC conversion and the process is repeated, causing a low rectenna output for wireless power transfer system [11-16]. Researchers in [17] found that the input impedance of the antenna design would allow the second harmonic at high-order frequency which occurs twice in its design frequency. However, higher order harmonic can be blocked as input impedance at higher order reaches almost zero or unmatched.

There are a lot of techniques and designs of a harmonic suppression antenna presented in the literature, for example, the implementation of stub and slits in microstrip patch antenna, a photonic band gap structure [18-19], a circular sector patch antenna, defected ground structure (DGS) [20-22], shorting pin [23] and inserting slot [24-29]. To receive the transmitted signal effectively, the polarization of the antenna must be matched with the polarization of the wave, which is the same as the polarization of the transmitting antenna. Usually, the waves will be refracted or reflected if there are obstacles on the way of the signal transmission journey. However, the receiving antenna which is capable of receiving both types of polarization such as the dual circular polarized antenna can be used for wireless power transfer [30-32].

In this paper, the antenna structure with their design discrepancy was reviewed. The antenna performances as well as the electromagnetic fields of the structures were analyzed through simulations using CST Microwave Studio software. Through this work, we hope the antenna harmonic suppression can improve the overall system performance by maximizing the power transfer at the desired frequency.

II. Antenna Design

A. Circular Polarized Antenna

The circularly polarized antennas have been greatly used in wireless communications application and have received wide concerns as it can be used to avoid the polarization mismatch due to its flexible position. Thus, antenna harmonic suppression with circularly polarization gives an advantage for wireless power transmission application as it is able to maintain a constant output even though there exists misalignment between the transmitter and receiver. For example, the receiving antenna will receive RF signal or radiate it in circulation and always perpendicular to the direction of the propagation. As mentioned previously, a high efficiency system is required and most of the researchers in literature adopted various methods to attain circularly polarization for antenna design. Therefore, Table 1 records the method used by many researchers in achieving circular polarized and hopefully the best method will be applied on the antenna harmonic suppression to improve the efficiency of wireless power transfer applications.

Table 1
Method of circularly polarized antenna at 2.45 GHz applications

(Author (s), Year)	**Research's title**	**Circularly Polarization**	
		Method	**Performance**
(M.F.Jamlos, 2012) [33]	2.3 GHz – 2.45 GHz Circular Polarization U-Slot Patch Antenna	U-Slot with truncated patch antenna	$S11_{sim}$: 10 dB BW : 300 kHz $Gain_{sim}$:4.2 dBi
(C.S Ong, 2010) [34]	A Compact 2x2 Circularly Polarized Antenna Array For Energy Harvesting.	Unbalanced slots.	$S11_{meas}$: $<$20 dB AR_{meas} : 0.15 dB $Gain_{meas}$:10.8 dBi
(Z.Harouni, 2011) [35]	A Dual Circularly Polarized 2.45GHz Rectenna For Wireless Power Transmission.	Compact DCP patch antenna.	BW : 2.1GHz 3 dB (AR) : 705MHz Efficiency : 63% $RHCP_{gain}$: 25.24 dB $LHCP_{gain}$: 6.8 dB
(F.J Huang, 2012) [36]	Design of Circular Polarization Antenna with Harmonic Suppression For Rectenna Application.	Four right-angles slit.	S11 : -45 dB Efficiency : 37.8% BW : 137 MHz 3 dB (AR) : 30 MHz AR_{min} : 0.32 dB
(J.Hung, 2012) [37]	Novel T-Shape Slot Couple Feed Dual Circular Polarized Rectenna.	T-shape slot.	BW : 70 MHz AR_{min} : 0.6 dB 3 dB (AR) : 40 MHz $RHCP_{gain}$: 7.98 dBic $LHCP_{gain}$: 8 dBic
(R.A Rahim, 2013) [38]	Harmonics Suppression Single-Fed Dual-Circularly Polarized Microstrip Patch Antenna For Future Wireless Power Transmission.	Circular slot defected ground structures.	S11 : -20 dB Dir_{tot} :9.887dBi AR : 0.26 dB $RHCP_{gain}$: 4.119 dB $LHCP_{gain}$: 4.149dB $Gain_{tot}$: 6.655dB
(M.A Sennouni, 2013) [39]	Circular Polarized Square Patch Antenna Array For Wireless Power Transmission.	Inclined slot.	VSWR : 1.054 **Main lobe** Magnitude : 9.2 dBi Direction : 35.0^o

B. Harmonic Suppression Antenna

In this section, the harmonic rejection techniques proposed by previous researchers are discussed. Additionally, the information featuring the antenna design at 2.45GHz (ISM) Band) applications [40] where the antenna is categorized as a harmonic suppression antenna is described. The proposed antenna design is able to resonate at the fundamental frequency while attenuates at the harmonic frequencies. Several studies have been conducted on antenna harmonic rejection technique in order to proposed new design with improvement in overall system performance in term of its minimum reflection coefficients, voltage standing wave ratio (VSWR), radiation pattern, directivity and gain. Figure 3 illustrates a new design of harmonic suppression rectangular shape microstrip patch antenna at 2.45 GHz. The techniques used by authors in [41] introduced a row of small size circular slot in the middle of the rectangular patch as well as U-shaped slot of defected ground structure beneath the ground plane of antenna design. Furthermore, the RF choke or stub designed at the inset feed transmission line has successfully suppressed the harmonic frequencies. From this technique, U-shaped slot of the defected ground structure introduces capacitance, and thus suppress the inductance at the transmission feed line. The RF choke or stub used allows only certain signals to flow at the input of an antenna, while attenuates the harmonic frequencies at high-order. As a result, Figure 3 (c) illustrates the proposed antenna that yields -25 dB return loss at the fundamental modes, while suppresses up to -3 dB respectively both at the second and third order effectively.

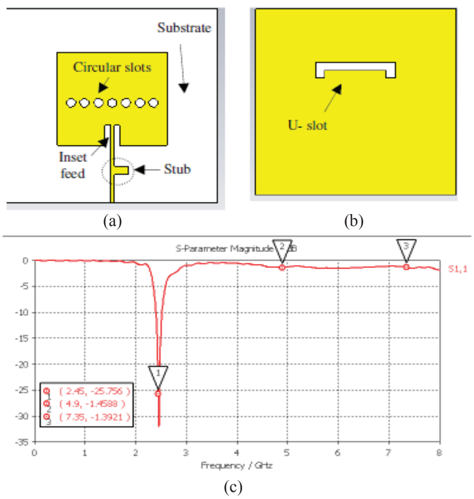


Figure 3: The geometry of the proposed harmonic suppression rectangular patch antenna; (a) Front view; (b) Back view; (c)Minimum reflection coefficient of proposed antenna [41]

In [42], the researchers proposed a compact proximity coupled with microstrip patch antenna and harmonic rejection capability at 2.45 GHz applications. Figure 4 (a) shows the obtained compact design due to a square ring slot that has been fit at the ground structure. This design has resulted in a 46 % reduction of patch element area as compared to the conventional designs. The width and length of the square ring is studied to achieve compactness. Then, the researchers used the U-shaped slot followed by a pair of symmetrical inverted arm stubs created on the transmission feed line, as shown in Figure 4 (b). As a result, this technique has adequate suppression at higher order up to an acceptable range. Figure 4 (c) shows that both simulations have good agreement with the measurement result. The antenna has a moderate gain at 5.5 dBi.

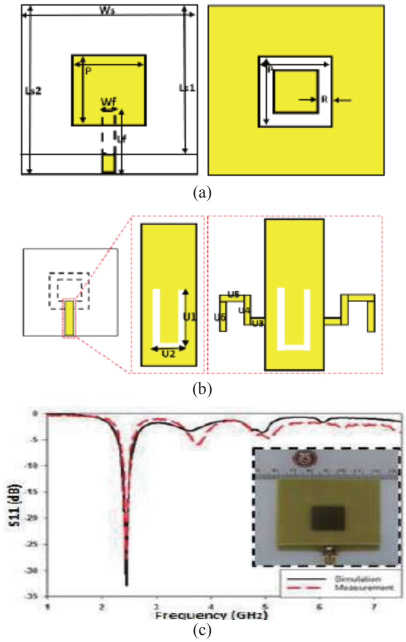
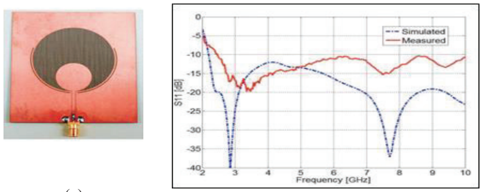


Figure 4: Proximity coupled antenna harmonic suppression; (a) Geometry antenna structure both front and back view; (b) Symmetrical inverted arm stub with U-slot on feedline; (c) Validated result of simulation and measurement [42]

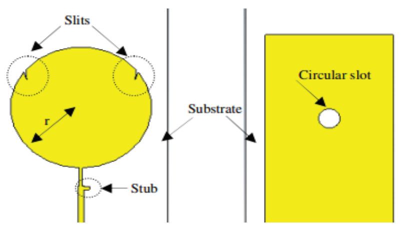
Harmonic suppression characteristic of a CPW-fed circular slot antenna using a single slot on a ground conductor was demonstrated by authors in [43] and this design has a multi-band rejection characteristic, where the second and higher rejection bands are an integer-multiple of the first band. This is generated by inserting a single slot on a ground conductor of the antenna. The simulated and measured results show good agreement and the integer-multiple notch bands can be adjustable by varying the length of the slot on the ground plane. Figure 5 depicts 70 mm x 80 mm of antenna dimension, in which the notched frequency bands can be modified by adjusting the length of the arc-shaped slot itself. As illustrated in Figure 5 (c), this circular slot antenna exhibits wider bandwidth, resulting from the technique to etch the antenna element on 0.508mm thick Taconic RF-35 board, employing a low relative permittivity, ε_r=3.5 [44].



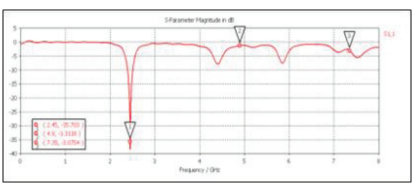
(a) (b)

Figure 5: CPW-fed circular slot antenna with an arc-shaped slot on a ground conductor; (a) Fabricated antenna; (b) Return loss characteristics without slot on ground conductor [43]

Researchers in [45] demonstrated a 2.45 GHz Circular Patch Antenna with Harmonic Suppression for Wireless Power Transmission. The proposed harmonic suppression circular patch antenna is excited with a microstrip feeding method and the advantage of this method is the connection of the patch and the feed is directly connection and they are on the same substrate to provide a planar structure. The improvement of the input impedance matching has been made by the quarter-wave section in the transmission line feed. The slits at the patch and the stub at the transmission line feed are proposed to suppress the harmonics at the higher order modes. Parallel slits function as controlling the current flows on the top patch. However, the current distribution on the circular patch is very complex and the harmonics are still able to re-radiate. Thus, the open stub is introduced at the microstrip line feed to provide additional suppression on the harmonics frequencies and the geometry of antenna design can be observed in Figure 6. The antenna return loss is -48 dB at 2.45GHz and has realized gain 2.229 dB.



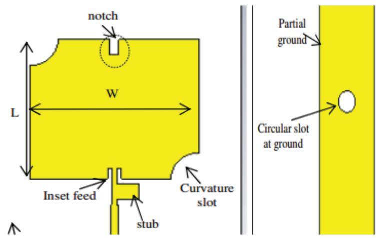
(a) (b)



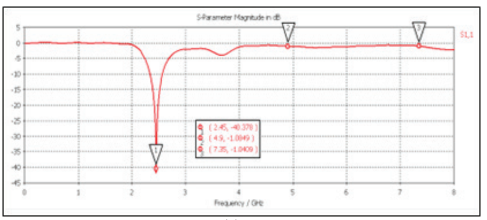
(c)

Figure 6: Circular patch antenna, (a) Top view; (b) Bottom view; (c) Return loss [45]

Besides, authors in [46] proposed a new design, which is A 2.45 GHz Harmonic Suppression Rectangular Patch Antenna. The dimension value of patch shape can be obtained by calculating its transmission line model [45]. The techniques that are used in the suppression of harmonics are a notch-loaded and curvature slots at the antenna patch together with an open stub and inset feed transmission line. The partially ground with a circular slot at ground plane is also introduced to reduce the overall patch size. The patch antenna gives -40dB return loss at 2.45GHz and suppresses all the harmonics up to -1dB. In this design, the open stub and inset feed are adopted to suppress the harmonic for the second time whereas the curvature slot helps to increase the bandwidth. The deployment of technique used in this structure is able to suppress unwanted harmonics up to the third order effectively.



(a) (b)

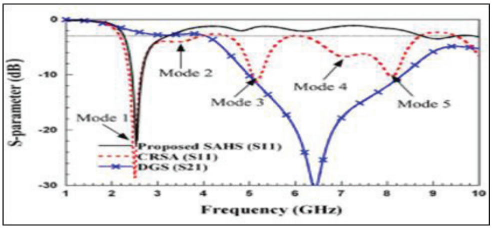


(c)

Figure 7: Proposed design; (a) Top view; (b) Bottom view; (c) Return loss [46]

The recent research in [47] proposed a microstrip-fed ring slot antenna design with wideband harmonic suppression. In order to suppress the additional harmonic modes excited by the ring slot, a single inverted U-shaped slot or defected ground structure was integrated into the CRSA. Through this, harmonic suppression approximately between 3 and 9 GHz is achieved for a wide bandwidth. This DGS can also be applied to other microstrip-fed ring slot antennas, such as square and triangular ring slot antennas and Figure 8 (a) depicts clearly the circular shape of ring slot antenna integrated with the defective ground surface effectively suppresses the unwanted harmonic frequency at high order modes. This geometry gives a measured gain of 3.27 dBi and its corresponding efficiency was between 75% and 79%. The simulated and measurement result in Figure 8 (b) shows good performance of CRSA and proposed antenna. Thus, loading an inverted U-shaped DGS into CRSA achieves harmonic rejection technique effectively.

(a)



(b)

Figure 8: (a) Photograph of the proposed antenna; (b) Simulated and measurement return loss of CRSA and proposed antenna [47]

III. CONCLUSION

The method in attaining a circular polarization antenna has been investigated and recorded. The U slot and truncated at the edge of antenna patch can attain circularly polarized with simple configuration. Other than that, inclined slot embedded on the radiating element also contribute to the circularly polarization. From these studies, some methods can be applied with harmonic rejection techniques for antenna designs to improve overall system performance. The advantages and disadvantages of the various techniques have been highlighted and have a thorough comparison between the techniques has been presented. Discussion has been focused on the performance of each technique to seek the best topology that is suitable for wireless power transfer system. Apart from that, each antenna harmonic suppression structure has pros and cons in terms of complexity, cost, size and its performance. However, some modifications can be made to construct harmonic rejection capability in antenna design. Thus, a study on antenna with harmonic suppression has been reviewed and there are some design issues occurred in wireless power transfer that need to be considered including low conversion efficiency due to excitation at harmonic frequency and polarization mismatch. Improvements in overall system performance are important since a maximum power must be transferred at fundamental frequency. The results of previous studies have been compared to seek the best harmonic rejection technique and it is concluded that the combination of slit, stub and defective ground structure can achieve harmonic suppression characteristics. The verification process of the proposed antenna harmonic suppression will be further explored and implemented through an experiment in laboratory and field works. This new structure of antenna harmonic suppression is useful for RF/ microwave front-end subsystems where it will provide an attractive solution for the miniaturization of overall physical dimensions.

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