A Novel Dual-Polarized Millimeter-Wave Antenna Array with Harmonic Rejection for Wireless Power Transmission

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***Abstract*—A novel millimeter wave antenna array with harmonic rejection property is designed for wireless power transfer applications. The proposed antenna is a proximity coupled dual-polarized antenna with a coupled dual-mode open-stub resonator in the feed for suppressing higher harmonics. Odd and even mode resonance of open-stub loaded resonator is tuned to the second and third order harmonics of the antenna element respectively to realize the configuration as a dual-band reject filter. The designed dual-polarized antenna has a bandwidth of 2.23 GHz (centred at 35 GHz) and worst case isolation of 20 dB between the two feeds. The antenna element has a high gain of 7.76 dB. The proposed four-element antenna array has a very good gain of 12.4 dB, dual polarization, and harmonic rejection which makes it a good solution for wireless power transfer (WPT).**

***Index Terms*—Antenna array, dual-polarized, energy harvesting, harmonic rejection, mm-Wave antennas, rectennas, stub resonators, wireless power transfer.**

I. Introduction

Recent advancement in wireless connectivity offers a strong communication between people and machines in the era of the Internet of Things (IoT). A potential technique for providing energy to low profile and low power IoT modules is a critical research area. Present WPT methods like near-field WPT are of limited applications due to the restriction in flexible spatial configuration and limited range [1]. RF WPT using rectennas is a promising technology because of the high range. Millimeter wave frequencies have great importance due to the ability to realize antenna array in low profile efficiently [2].

Most of the WPT rectennas are based on linearly and circularly polarized antennas [3]. But for receiving the RF power irrespective of the polarization, dual linear polarized and dual circular polarized antennas have been utilized for some rectennas [4]. Usually, WPT dual-polarized antennas are developed using one output port to make the rectenna design simpler. This kind of single feed designs is poor in RF conversion efficiency because its performance in combining RF energy in orthogonal polarizations to the feed is not optimized. So, dual polarized antennas with two distinct output ports are required to receive the RF energy in all polarizations. Antennas used for WPT applications are always followed by a bandpass filter in rectenna designs to optimize the energy conversion efficiency [5]. Thus, some researchers have worked on developing antennas with harmonic rejection capability to remove the use of bandpass filters in rectifier circuits to make significant size reduction [6].

In this paper, a novel high gain millimeter wave dual polarized antenna array with harmonic rejection capability is proposed for WPT and energy harvesting applications. In Section II, the design of proposed dual-polarized antenna array with harmonic rejection capability is discussed. Sections III and IV describe the antenna element and the array performance respectively.

II. Millimeter Wave Dual Polarised Antenna Array Design

The proposed antenna array is an electromagnetically coupled dual-polarized square patch array at 35 GHz. The feed line is aligned between the patch and ground plane, which is separated by two layers of RT Duroid substrate of 0.254 mm thickness each with a relative dielectric constant 2.2, tangential loss of 0.001 as shown in Fig 1. The top layer consists of the square patch, which is excited by the microstrip line feed with dual-mode resonator configuration. The length of the square patch is slightly less than $0.5\lambda_{eff}$ at 35 GHz. Spurious radiations from the feed line and the dual mode resonators are eliminated due to the sandwiched structure. In order to provide isolation and polarization purity, the two feed lines coupled with dual modes stub resonator are properly placed below the orthogonal edges of the patch to excite TM_{10} and TM_{01} modes. The square patch is rotated by 45^0 angles to provide symmetric shape to the antenna element and array. It enables to reduce the coupling effects between the two polarizations and helps to make the array design simple. The proposed antenna has -45^0 and $+45^0$ polarization angles. Dual mode stub resonators are placed close to the feed line for harmonic suppression. Two stub resonators are placed on both sides of each feed line in a side coupled manner. The antenna element is excited using a pair of 90 Ω feed lines in order to avoid the overlap between stub resonators of the two orthogonal feeds by reducing the feed line width. The arrangement of the feed line and resonator are carefully performed to enhance the isolation between the orthogonal ports and for proper impedance matching. The antenna is having an overall dimension of 20 mm × 20 mm.

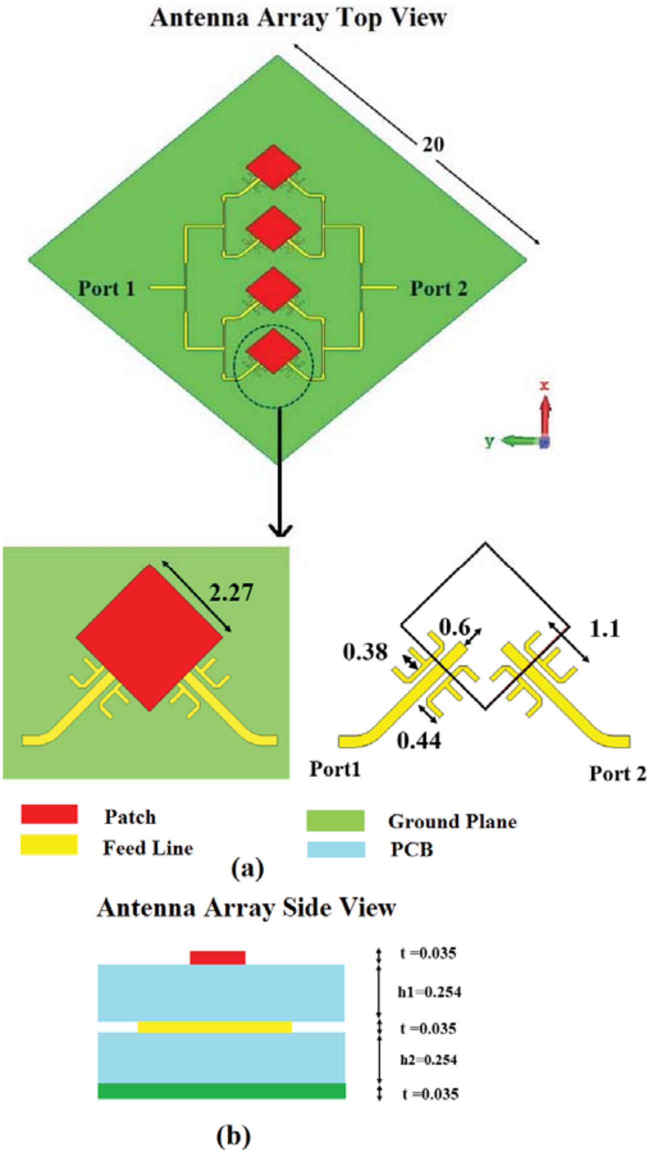

Fig. 1. Proposed dual polarized antenna array (a) Antenna array top view – PCB substrates hidden (b) Antenna array side view

A pair of open stub resonators is coupled to each feed line for eliminating the higher harmonics of the proposed antenna. For the characterization of a dual-mode resonator, odd and even mode analysis is required to adopt, due to the symmetrical structure [7]. Fig 2 illustrates the working of dual-mode open stub resonator. It can be observed that there is no current flow in the open stub of the resonator at 70 GHz. Odd mode excitation creates a voltage null in the middle of the resonant structure and the central open stub got isolated from the resonator. For even mode excitation, a magnetic wall is formed along the center and there is no current flow across the two arms of the microstrip line. Resonator structure behaves like an open circuit at the center.

The odd and even-modes of the dual mode resonator are tuned to resonate at 70 GHz and 105 GHz respectively.

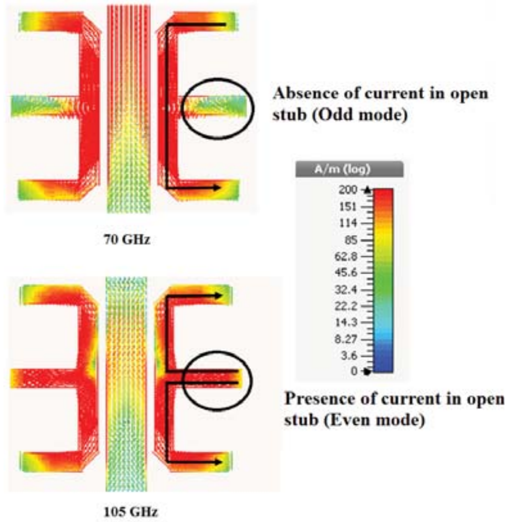

Fig. 2. Current distribution in resonator at 70 GHz and 105 GHz

Dimensions of the dual-mode stub resonator are optimized as shown in Fig 1. Therefore, the antenna feed line coupled with dual-mode resonator can behave like a band-stop filter with two stop bands. The gap between the resonators and feed line is optimized to 0.1 mm for maximize coupling. A ‘3’ shaped open stub loaded resonator is designed to maximize the odd mode excitation.

III. Single Antenna Performance

The simulated reflection coefficient of the antenna is shown in Fig. 3. It can be observed that more than 10 dB return loss has been achieved over a 2.23 GHz bandwidth from 33.9 GHz to 36.13 GHz.

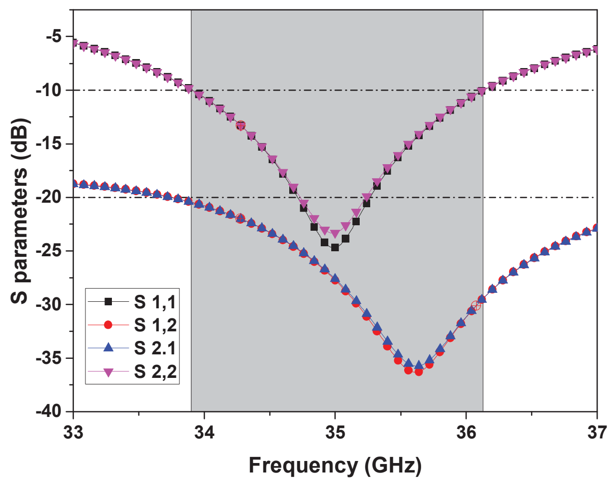

Fig. 3. Simulated reflection coefficient of the proposed dual polarized antenna element

Simulated worst case isolation is 20 dB throughout the band. Fig 4 represents the harmonic rejection performance of the proposed antenna.

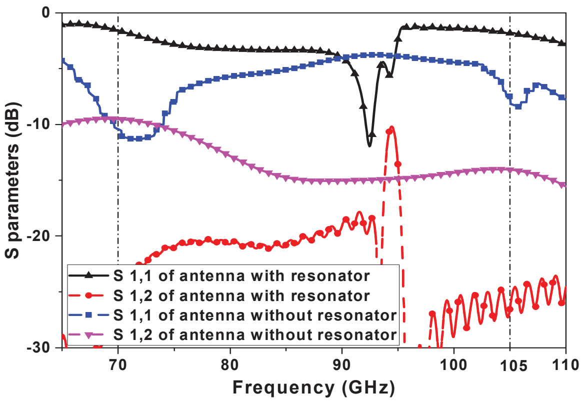

Fig. 4. Harmonic response of traditional dual-polarized antenna and resonator coupled dual polarized antenna

At 70 GHz, the return loss is 10.5 dB in the traditional dual polarized antenna. Presence of resonator shifts the value to 1.5 dB. Similarly, the return loss is shifted to 1.6 dB from 8.2 dB in the traditional antenna. Thus, the dual mode open stub resonator acted like a dual-band reject filter. Isolation of the two ports is also improved due to the presence of dual-mode open stub resonator.

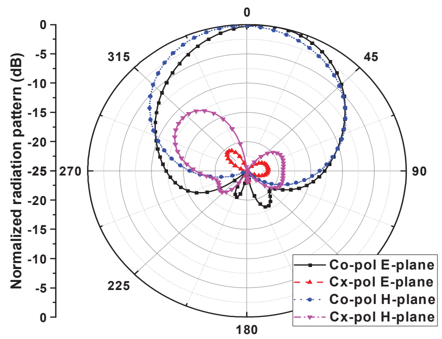

Fig. 5. Normalized radiation pattern of single antenna at 35 GHz

The simulated realized gain of the antenna is 7.56 dB and 7.76 dB are obtained at port 1 and port 2 respectively. The normalized radiation pattern of the proposed single antenna is shown in Fig 5. The efficiency of more than 80% is achieved throughout the band.

IV. Antenna Array Performance

For increasing the required power, an antenna array consists of four elements, is proposed as in Fig 1. The spacing between two adjacent elements of the array is $0.5\lambda_0$ for minimizing mutual coupling among the elements and to avoid grating lobes. A corporate (parallel) feed network is used for the proposed dual-polarized array. The power divider is designed for a transition in impedance from 90 Ω in the antenna element to 50 Ω at the array inputs. Fig 6 represents the 3-D radiation pattern of the four-element antenna array at port 1. A similar kind of radiation pattern is also obtained at port 2. Realized gain of 12.4 dB is achieved with a 36^0 half power beam width by the proposed array configuration.

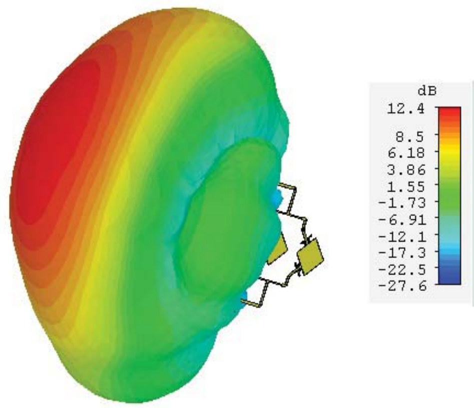

Fig 6. 3-D radiation pattern of the antenna array (port 1)

V. Conclusion

A novel dual-polarized antenna for eliminating higher order harmonics in millimeter wave has been proposed. Odd and even modes of the proposed 3- shaped open stub loaded resonator was properly excited for harmonic suppression. The multilayered dual polarized antenna with feedlines and stub resonators in the middle layer has the ability to achieve good isolation and polarization purity. The single antenna achieved a bandwidth of 2.23 GHz and having the worst case isolation of 20 dB between the two feeds. Then, a four-element antenna array was built by the proposed antenna element to achieve a high gain of 12.4 dB with a 36^0 beam width. The proposed dual polarized antenna array exhibits high gain and good harmonic rejection making it appropriate for energy harvesting and wireless power transfer applications.

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