Novel mmWave Wireless Power Transfer Systems Using Broadband Circularly Polarized Rectennas and Leaky Wave Transmitters

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***Abstract*—Millimeter wave wireless power transfer (WPT) has attracted an upsurge of interest recently. Here we present the design of a novel WPT system consisting of a wideband circularly polarized leaky wave antenna transmitter and wideband circularly polarized rectenna receiver, over the frequency band of 24–35 GHz (fractional bandwidth: 37.3%). Due to the simultaneous dual-CP radiation of the leaky-wave antenna, the proposed system overcomes the polarization misalignment issue of the antennas in the far field, thereby enabling a robust WPT. Our rectenna also realizes state-of-the-art performance in terms of bandwidth, RF-DC efficiency, and CP radiation. This is the first mmWave CP WPT system and will be experimentally verified.**

I. Introduction

Recent advances in wireless power transfer (WPT) using mmWave power have enabled improved power delivery at longer distances and with higher power transfer efficiency [1-3]. Compared to the conventional sub-6 GHz system, the mmWave power has a larger EIRP (up to 75 dBm) and less path loss if the antenna physical aperture is effectively exploited for a high gain and high aperture efficiency transceiver [4]. However, another major issue for mmWave WPT is around the transmitter and receiver misalignment in terms of antenna polarization. This is like the coil misalignment for inductive power transfer, but more specifically, relates to the antenna polarizations in such as linear polarization (LP) and circular polarization (CP). It is known that a CP antenna has better flexibility for antenna orientation alignment with either LP and CP, and a dual-CP antenna is characterized as an all-polarization antenna that can receive all random waves [5].

Therefore, in this paper, we report a novel mmWave CP WPT system using wideband leaky wave antennas (LWA) as a transmitter and wideband mmWave CP rectennas as a receiver. The proposed system can support multi-target wireless charging and tracking by using frequency-modulated beam scanning due to the LWA. Importantly, we have mitigated the significant challenges in the receiver design, in which the wideband CP rectenna has never been reported for frequencies > 24 GHz.

II. Dual CP Leaky-Wave Antenna Transmitter

A dual CP leaky wave antenna transmitter has been designed for the proposed mmWave WPT system. As shown in Fig. 1 (a), the CP generation originated from a series of novel fan-shaped slots, which are periodically cut on a linear substrate integrated waveguide (SIW). For such an LWA design, the dual CP radiation could be achieved by feeding the antenna waveguide from two different ports simultaneously, in which port 1 generates the right-hand circular polarization (RHCP) and port 2 leads to the left-hand circular polarization (LHCP). Such that the leaky E-field from the fin slot on the SIW steers either in clockwise or anti-clockwise directions for the dual-CP radiation. The proposed LWA has a wide impedance bandwidth covering from 27 to 36 GHz as well as a CP bandwidth of around 28 – 35 GHz (FBW = 22.2%), as depicted in Fig. 1 (b) and (c). Experimental prototypes for a single LWA and conformal LWA array for a wide-angle coverage are shown in Fig. 1. The beam scanning range of this LWA is from −51° to 0° or from 51° to 0° in the elevation when the frequency varies from 27.4 to 37.3 GHz, with a sharp beam and high scanning resolution down to unit degree per MHz. The gain of the LWA varies from 12.4 to 17.9 dBi. More details can be seen in our recent paper [6].

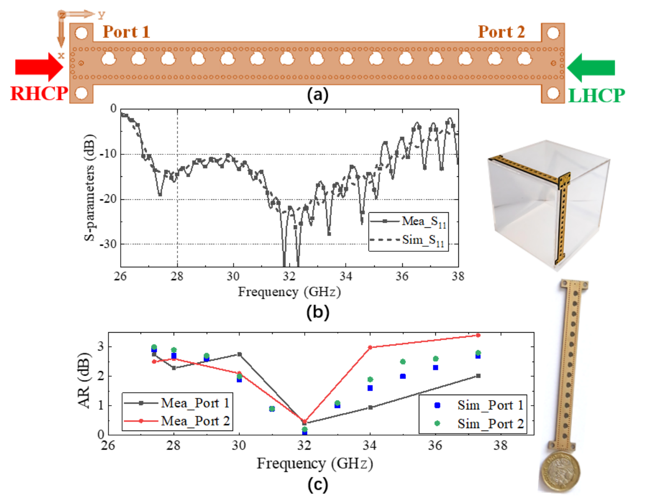

Fig. 1. (a) Geometry (b) S_{11} and (c) axial ratio of the proposed dual-CP LWA transmitter. The prototypes of a single antenna and conformal array are shown.

III. Wideband mmWave CP Rrectenna design

The wideband CP rectenna design at mmWave frequencies is very challenging and has not been reported in the existing literature. Here we propose the first-of-its-kind mmWave CP rectenna for a wideband using a magnetoelectric (ME) dipole and high-frequency diodes MA4E1317.

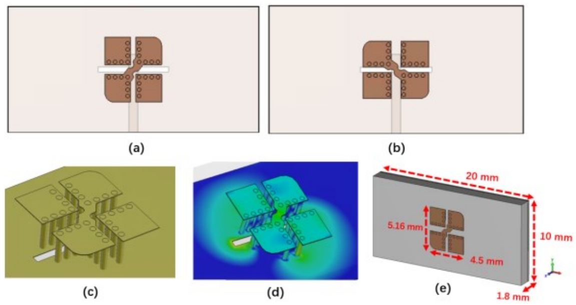

Fig. 2. (a) ME dipole for RHCP. (b) ME dipole for LHCP. (c) Prospective view of the radiator at mmWave band. (d) Surface current distribution at 30 GHz. (e) Overall antenna geometry and dimensions.

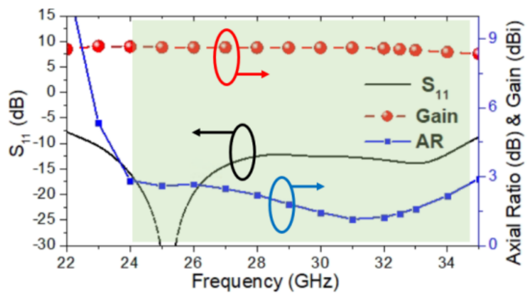

Fig. 3. S_{11}, realized gain and axial ratio of the proposed ME-dipole antenna.

A. Antenna Design

The ME dipoles for RHCP and LHCP are shown in Fig. 2 (a) and (b), whereas four shorted patches are used to form the electric dipole arm. A bridge connection is designed between 2 patches for CP generation. The ME dipole is aperture fed, as shown in Fig. 2 (c). A microstrip line is printed underneath the feeding aperture and separated with a substrate [7]. The surface current distribution in Fig. 2 (d) shows clockwise radiation of the E-field around the feeding slot and driven by the patches. The overall antenna is printed using high-frequency RT5880 substrate with a relative permittivity of 2.1 and a loss tangent < 0.001 at 40 GHz. The overall dimension of the radiator is 5.16 mm by 4.5 mm, while the PCB is $10 \times 20 \times 1.8\, mm^3$ .The simulated $S_{11,}$ gain, and axial ratio of this ME-dipole are shown in Fig. 3. The overlapped CP bandwidth (S_{11}< -10 dB and AR < 3 dB) is around 24 – 35 GHz (FBW = 37.3%) and the realized gain over the band of interest is larger than 8.8 dBic.

B. Antenna-Rectifier Co-Simualtation

The ME dipole is used for co-simulation with a rectifier on PCB, which is back-to-back attached to the antenna ground, as shown in Fig. 4 (a). The microstrip feed is extended for rectifier integration with a single series-diode rectifier using high-frequency MA4E1317 diodes (up to 80 GHz).

After co-simulation, the proposed rectenna has over 50% RF-DC power conversion efficiency in a wide bandwidth from 24 – 35 GHz (FBW = 37.3%) at an input power level of 15 dBm (see Fig. 4 (b) and (c)). Therefore, the proposed CP wideband rectenna could be jointly used with the proposed CP LWA transmitter to form a novel mmWave multifunctional WPT system, as shown in Fig. 5. Some new research could be pursued, i.e., using the LHCP waves for wireless powering and RHCP waves for communication, tracking, positioning and imaging etc.

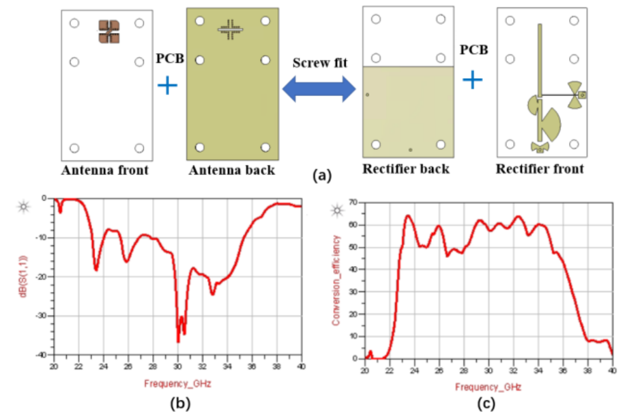

Fig. 4. (a) Antenna-rectifier integration and co-simulation model. (b) S_{11}. (c) RF-DC conversion efficiency of the proposed rectenna.

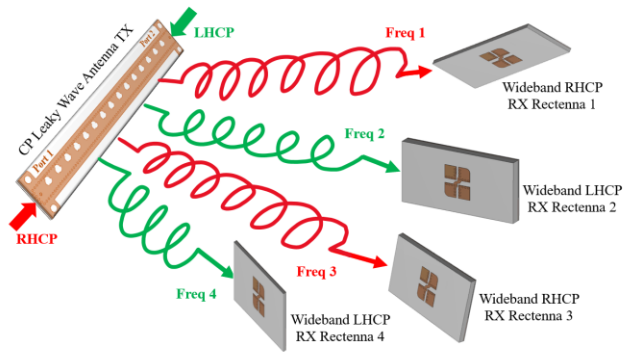

Fig. 5. Illustration of the proposed mmWave CP WPT system.

IV. Conclusion

We have presented a novel mmWave WPT system using a CP LWA transmitter and CP mmWave rectennas with state-of-the-art performance in terms of bandwidth and efficiency. More experimental data will be presented at the conference.

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