Polarization-Independent Aperture-to-Aperture Transfer Scheme for Simultaneous Wireless Information and Power

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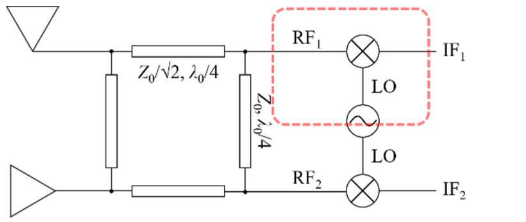
Abstract

Information cannot be transferred wirelessly independent from power. Therefore, an aperture-to-aperture transfer with high efficiency is critical for no matter information and power transfer systems. Nevertheless, the aperture-to-aperture transfer efficiency always suffers TX/RX antenna polarization misalignments. In this work, an aperture-to-aperture transfer scheme is proposed to enable maximum power link from linearly polarized electromagnetic wave without any worry on polarization tilt (i.e., polarization-independent). The aperture-to-aperture scheme is modeled by S-parameters of three-port network, and validated with rigorously theory analysis and experiment measurements, which is perfect for the simultaneous wireless information and power transfer.

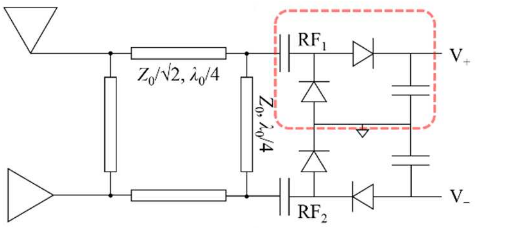
1 Introduction

Wireless information and power transfer enable effective operations of wireless sensor networks (WSNs) [1, 2]. As demonstrated by dash boxes from Fig.1(a, b), the wireless information and power transfer highly rely on mixers or rectifiers, respectively, to decode or rectify incident radio frequency (RF) into IF or DC voltages for implemented electronics in the WSNs. Typically, two linearly polarized directional transmitting (TX) and receiving (RX) antennas [3, 4] are introduced to maintain a maximum aperture-to-aperture transfer, however, which always suffers antenna polarization misalignments. Consequently, it is unable to maintain a wireless link with high efficiencies for wireless information and power simultaneously.

In this work, an aperture-to-aperture transfer scheme with antenna polarization independence is proposed in Fig. 1(a, b), which sustains maximum wireless power links without any worry on tilts of an antenna polarization. As shown in Fig. 1(a, b), a dual-linearly-polarized (DLP) RX antenna is connected with the input and isolation ports of a hybrid coupler. Therefore, an incident electromagnetic linearly-polarized wave can be entirely distributed through hybrid coupler to another two ports (i.e., direct and coupled ports) for successive mixers or rectifiers. The distributions of the power at the direct and coupled ports maintains constant and unaffected from any antenna misaligned polarization, which guarantees maximum aperture-to-aperture transfer for simultaneous wireless information and power.



(a) Information (Intermediate Frequency: IF_1 and IF_2)



(b) Power (direct current (DC) voltages: V_+ and V_-)

Figure 1. The proposed wireless information and power transfer schemes.

To achieve compact circuit, shared-aperture dual linearly-polarized antennas can be implemented. The polarization-independent aperture-to-aperture transfer scheme is hence modeled by the S-parameters of a three-port network, and validated with rigorous theory analysis and experimental measurements. The proposed aperture-to-aperture transfer scheme is perfect for simultaneous wireless information and power transfer.

2 Operational Mechanism

As illustrated from Fig. 1(a, b), the implemented hybrid coupler is a symmetrical four-port network (i.e., input, direct, coupled, and isolation ports). When a signal is incident into input port, it can be evenly distributed to the direct and coupled ports with the isolation port isolated. Owing to its symmetrical structure, the isolation port can also be used as an input port to distribute another incident signal evenly to the direct and coupled ports, similarly. According to the odd-even mode theory analysis, the S-parameters of the hybrid coupler can be derived as shown in (1), which is critical for following polarization-independent aperture-to-aperture transfer scheme analysis.

$$S = \begin{bmatrix} 0 & -\frac{i}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \\ -\frac{i}{\sqrt{2}} & 0 & 0 & -\frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} & 0 & 0 & -\frac{i}{\sqrt{2}} \\ 0 & -\frac{1}{\sqrt{2}} & -\frac{i}{\sqrt{2}} & 0 \end{bmatrix} \quad (1)$$

To analyze such novel proposed polarization-independent aperture-to-aperture transfer scheme, a three-port network is modeled as illustrated in Fig. 2. A vertically-polarized antenna is introduced as a TX antenna, while another DLP antenna is introduced as a RX antenna. The distance (d) as illustrated in Fig. 2 preserves fixed. When rotating the polarization tilts (15°, 30°, 45°, 60°, and 75°), the S-parameters can be measured to evaluate antenna aperture-to-aperture transfer efficiency.

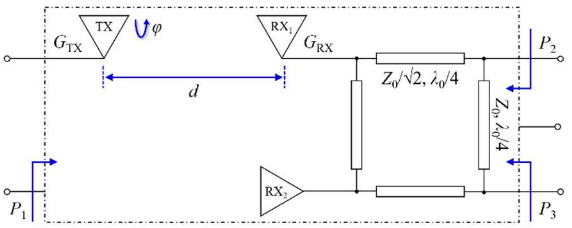


Figure 2. Illustration of three-port S-parameter network.

Assume $\sqrt{2}V_s\cos\omega t$ is an incident signal at P_1 in Fig. 2, two signals delivered to P_2 and P_3 can be calculated by considering its free space path loss and the property of the hybrid coupler.

$$V_{P_2} = -(iV_s\cos\varphi + V_s\sin\varphi)\cos\omega t(\frac{\lambda_0}{4\pi d})\sqrt{G_{TX}G_{RX}} \quad (2)$$

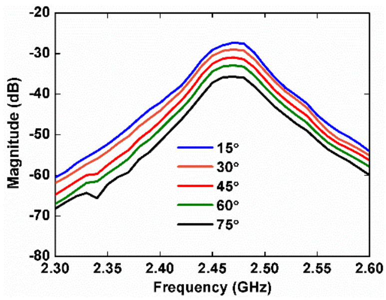
$$V_{P_3} = -(iV_s\sin\varphi + V_s\cos\varphi)\cos\omega t(\frac{\lambda_0}{4\pi d})\sqrt{G_{TX}G_{RX}} \quad (3)$$

It can be observed that the magnitudes of received signals at P_2 and P_3 maintains polarization-independent. Hence, the S-parameters of three-port network in Fig. 2 remains unaffected when rotating the polarization tilts (15°, 30°, 45°, 60°, and 75°). Since P_2 and P_3 have identical power transfer capabilities from P_1, only S_{21} is measured for the validations of equations (2, 3).

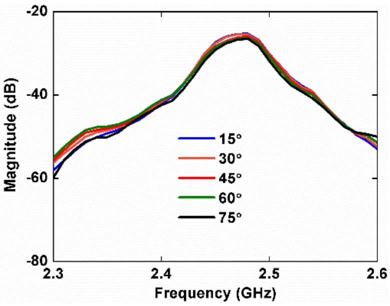
3 Experimental Validations

In this work, the aperture-to-aperture transfer is validated by measured S_{21} between the TX/RX antennas in Fig. 2 at 2.45GHz. For experiment comparison, a linearly polarized RX antenna is connected to input port of hybrid coupler with matched isolation port, which enables evenly power distributions to P_2 and P_3 in Fig. 2. During measurements, the distance (d) between the TX/RX antennas (see Fig. 2) keeps constant with d = 50 cm. Then the polarization tilts φ vary from 15° to 75° with an angle step of 15°. Rohde & Schwarz vector network analyzer ZVA50 is employed to measure the S_{21} from 2.3GHz to 2.6GHz as provided in Fig. 3(a, b).

From the measurement results, the maximum magnitude of S_{21} is achieved at 2.48GHz with a 0.3GHz frequency shift from center frequency of 2.45GHz, which might be caused by some fabrication errors. With an increase of the polarization tilt, the DLP RX antenna in Fig. 2 maintains robust wireless aperture-to-aperture transfer by measuring $\Delta|S_{21}|$<1dB. Nevertheless, the single linearly polarized RX antenna situation gradually undergoes serious degradation.



(a) Single linearly-polarized aperture-to-aperture transfer



(b) Dual linearly-polarized aperture-to-aperture transfer

Figure 3. Experimental validations.

4 Conclusion

An aperture-to-aperture transfer scheme is proposed for a maximum power transfer efficiency without any worry on polarization tilts, which is modeled by S-parameters of a three-port network, and validated with rigorously theory analysis and experiment measurements. It is perfect for simultaneous wireless information and power transfer.

References

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