SICE Annual Conference 2012
August 20-23, 2012, Akita University, Akita, Japan

Coupler Combination for Blind Spot Elimination in Two-Dimensional Waveguide Power Transmission

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Abstract: In two-dimensional waveguide power transmission systems, receiving couplers put on a waveguide sheet can extract electricity through the sheet surface. As the sheet edges are open- or short-terminated instead of power absorbing termination, standing waves are generated. It leads to generation of undesired blind spots where the couplers cannot receive significant power. In this paper we examine the effect of multiple coupler output combining on blind spot elimination. Experiment results show that the blind spots can be eliminated by combining the dc outputs of the couplers.

Keywords: Two-dimensional waveguide power transmission, rectifying coupler, output combining.

1. INTRODUCTION

Two-dimensional waveguide power transmission (2DWPT) [1, 2] can potentially support safe and high-wattage wireless power transmission (WPT) in general environments. A two-dimensional waveguide sheet guiding a microwave generates an evanescent filed around its surface. Receiving couplers put on the sheet can extract power across the sheet surface. Fig. 1 shows a demonstration setup of 2DWPT.

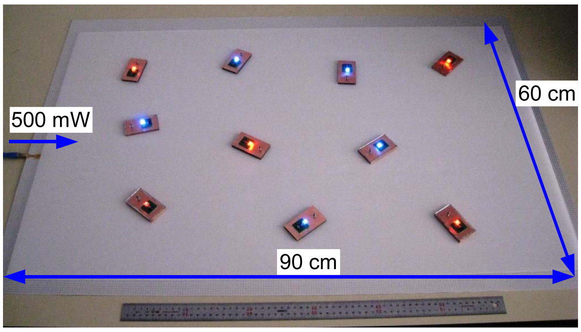

Fig. 1 2DWPT demonstration setup. Ten LED-loaded couplers are distributed on the waveguide sheet.

A 2DWPT system can be easily enhanced to a large area at low cost, because the waveguide sheet has a simple structure with no active elements. Recently we have proposed a scheme to improve the electromagnetic compatibility (EMC) while remaining the power transmission efficiency [2].

Since the sheet edges are open- or short-terminated, standing waves are generated in the sheet. Therefore the coupler output depends its position and blind spots are distributed over the sheet.

Although amplitude distribution of the standing wave can be controlled by using multiple RF feeding port into the sheet with variable phase shifters, the system will be complicated and will increase in cost. For a fixed standing wave distribution, multiple coupler array will be useful, if users can compromise on the overall coupler array size.

In this paper we examine the effect of multiple coupler output combining on blind spot elimination. A pair of couplers are mechanically connected so that they never fall blind spots simultaneously. Each coupler is the same as developed in our recent work [3]. The coupler contains a radio frequency to dc (RF-dc) converter circuit and outputs dc power. Their dc output ports are connected in parallel to drive a common load. As a result, the blind spots are eliminated.

This paper is organized as follows. Section 2 examines blind spot distribution in the sheet. Section 3 presents experimental results of blind spot elimination by combining two coupler outputs. This paper is concluded in Section 4.

2. BLIND SPOTS IN WAVEGUIDE SHEET

In practical 2DWPT systems, the sheet edges should be open- or short-terminated instead of power absorbing terminations. Although power absorbing terminations are suitable for focus forming in the sheet [4], absorbed power is wasted and the efficiency is decreased.

The open/short edges reflect the microwave and generate standing wave in the sheet. Due to the standing wave, the power extracted by a coupler depends on its position. In this work, an open-edged sheet is employed due to ease of fabrication. Note that short terminations, i.e., shielding edges with conductors, are more desirable than open terminations in terms of electromagnetic compatibility (EMC).

Preliminarily measured position-dependence of power transmission efficiency is shown in Fig. 2. The efficiency was defined as the ratio of the dc output power of the coupler to the RF input into the sheet and was measured in a setup shown in Fig. 3. The couple posture, i.e., rotation angle in the xy-plane, was fixed as shown in Fig. 2(a). Note that the efficiency actually depends on the posture as well as the position.

The efficiency fluctuates and blind spots appear nearly periodically with respect to the x-axis. By combining the outputs of two couplers that work complementarily, i.e., one of them achieves a maximum efficiency when the other falls into a blind spot, the overall efficiency fluctu-

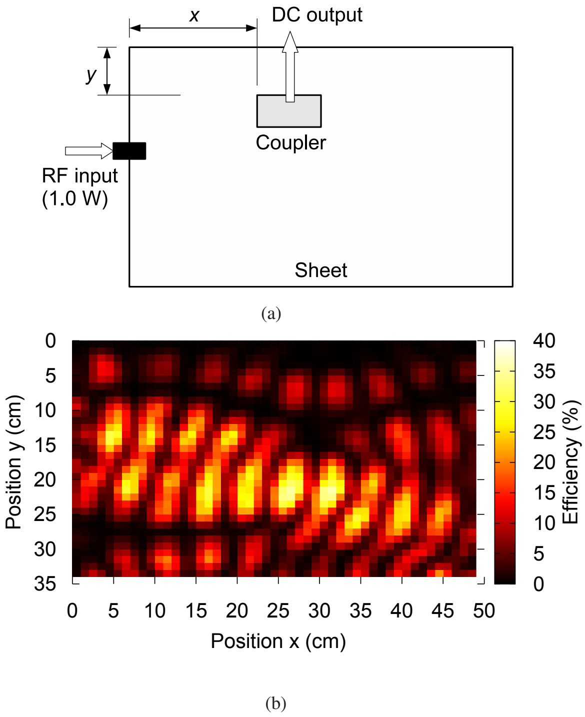

Fig. 2 (a) Position-dependence measurement setup. Dimensions of the sheet and the coupler are 56 × 39 cm^2 and 64 × 37 mm^2, respectively. (b) Measured RF-to-dc power transmission efficiency with a single coupler. The RF input was 1.0 W at 2.452 GHz.

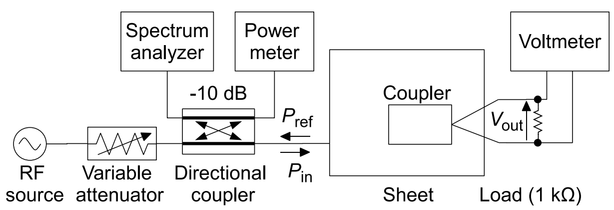

Fig. 3 Measurement setup diagram. P_{in} was fixed at 1.0 W. The load resistance was fixed at 1010 Ω, which is an optimum value determined preliminarily.

ation can be reduced. This scheme will be useful in practical 2DWPT systems in which users can compromise on the overall size of coupler array and RF feeding into the sheet via a single port is desired.

3. OUTPUT COMBINING OF TWO COUPLERS

In this section we present an experiment of coupler output combining. A complementary coupler pair is fabricated as shown in Fig. 4. Each coupler is the same as developed in our recent work [3], and they are mechanically connected with a fixed pitch of 70 mm.

The position-dependence of the efficiency is measured in a setup shown in Fig. 5. In this work, the coupler position in the y-direction was fixed at y = 21 cm and the position in the x-direction was varied.

Firstly, each coupler was individually loaded with a 1010-Ω resistor, as shown in Fig. 6(a). Each efficiency,

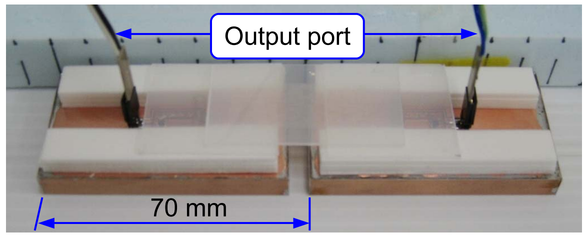

Fig. 4 A complementary coupler pair. Two couplers are mechanically connected with a fixed pitch of 70 mm.

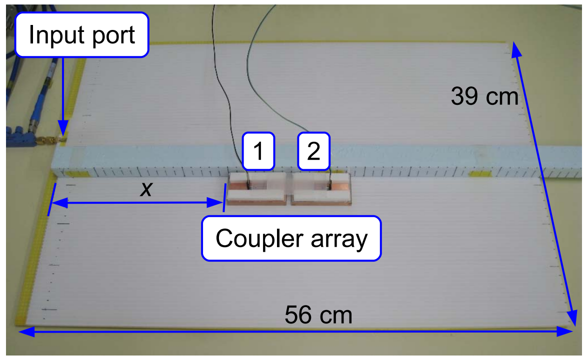

Fig. 5 Position dependence measurement setup. The coupler array consists of two identical couplers. They are aligned in the x-axis and are mechanically connected with a fixed pitch of 70 mm.

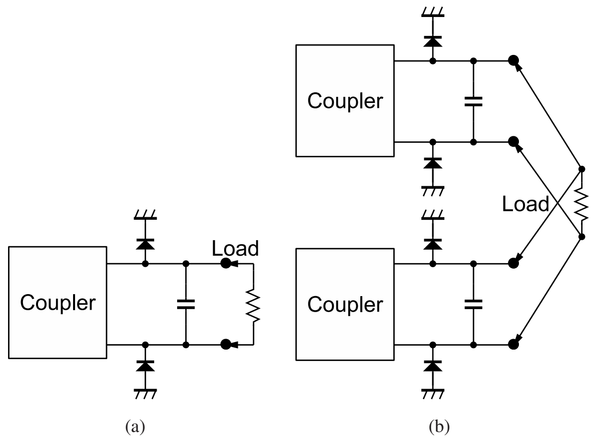

Fig. 6 (a) Single rectifying coupler. (b) Parallel combination of two rectifying couplers. The two outputs are simply combined at the common dc load.

defined as the ratio of each coupler output to the input power, was separately measured. The measured results are shown in Fig. 7. Each efficiency fluctuates nearly periodically, similarly to the single coupler efficiency shown in Fig. 2. Blind spots, where the efficiency is lower than a few percent, also appear periodically with an approximately 5-cm period. The results also show that the two couplers work well complementarily, while the couplers are individually loaded.

Finally, the coupler outputs were combined as shown in Fig. 6(b). The output ports were connected in parallel and were loaded with a common resistor. The resistor was 510 Ω, approximately equivalent to a parallel connection of two 1010-Ω resistors.

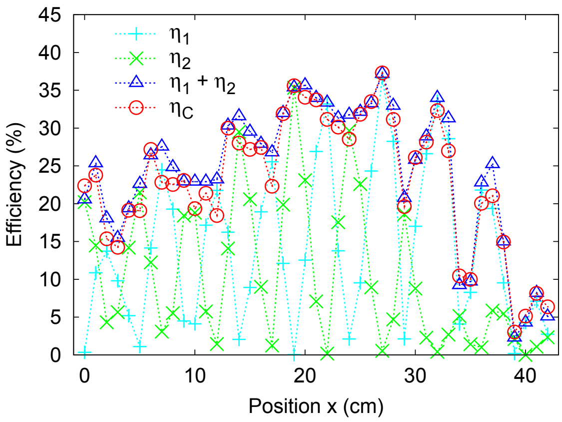

Fig. 7 Position dependence of measured efficiencies with respect to the x-axis. Coupler position in the y-axis was fixed at $y = 21$ cm. η_1 and η_2 are the power transmission efficiencies from the sheet input port to coupler 1 and to coupler 2, respectively, while each coupler is individually loaded with a 1010-Ω resistor. The sum of them, $\eta_1 + \eta_2$ is also shown. η_C is the power transmission efficiency to the coupler array, where the two coupler outputs are connected in parallel and are loaded with a common 510-Ω resistor. The RF input is 1.0 W at 2.458 GHz.

The measured efficiency of the combined coupler pair is also shown in Fig. 7. The result shows that the combined efficiency η_C well agrees with $\eta_1 + \eta_2$, the sum of the efficiencies of the two individually loaded couplers. Thus, the couplers work well complementarily even if they are connected to a common load, and the blind spots can be eliminated by combining two coupler outputs at the dc-side. Blind spots where the efficiency drops to a few percent were eliminated in $x = 0$–38 cm.

4. CONCLUSION

We examined the effect of coupler output combining on blind spot elimination. The coupler pair was fabricated so as to works complementarily, while each coupler drives an individual load. The coupler pair loaded with a common resistor also works complementarily and the blind spots were eliminated.

Although the scheme is effective if the blind spots appear periodically, it is not effective for widely spread blind spots, e.g. around $y = 0$-cm edge in Fig. 2(b). Considering the above problem and taking into account the coupler posture are the future works.

ACKNOWLEDGMENT

The research was partly supported by National Institute of Information and Communications Technology (NICT) 13701 and by Grant-in-Aid for JSPS Fellows (22·6659).

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