

# Power Recollecting in Wireless Power Transfer Using Sheet-like Waveguide

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## Abstract

We propose a power recollecting circuit in wireless power transfer system using sheet-like waveguide. This circuit consists of a phase shifter with a small transmission loss and feedback loop of RF power to the source to improve the overall efficiency of the system. This paper shows this recollecting method and experimental results. In experiment, this circuit recollects 76% of waste power, and in ideally case, the value is 93%. Moreover, the power gain is up to 4.1dB at the waveguide input port.

**Keywords:** Wireless power transfer Sheet-like waveguide Power recollecting

## 1. Introduction

Many communication system connecting electronic devices are unwired because the wireless communication technology has developed dramatically. The transmission performance and reliability are near to wired communication. In addition, many mobile devices have useful operating time because of development of secondary battery technology. Although we must still connect to electric power line to charge the battery, the devices are not perfectly wireless yet. Then the wireless power transfer system has been studied by many researchers.

This paper proposes a power recollecting circuit in wireless power transfer system using a sheet-like waveguide and demonstrates this system. RF power is propagated in the sheet-like waveguide, and is coupled to a receiving element closing to the waveguide. However the power not coupled with the receiving element is consumed at the end of waveguide termination. If there is no receiving element on the waveguide, all of power is waste. Therefore we propose the power recollecting system using a phase shifter to recollect this waste power, and demonstrate this circuit to improve the overall efficiency of this wireless power transfer system.

## 2. Sheet-like Waveguide

The sheet-like waveguide using as transmission element is one-dimensional array of ribbon-wire-interconnect [1]. As shown in Fig. 1, stub resonators by microstrip lines are connected to the input and output ports, which are electromagnetically coupled by a parasitic element. The sheet-like waveguide is given by arraying this structure.

We make three sheet-like waveguides. Two of them have the straight shape, which we call “Short” and “Long” according to their length. We make not only the straight shape but also the bent shaped structure whose resonator and parasitic elements are cranked called as “Racetrack”. Fig. 2 shows the measured  $S_{21}$  characteristics. The  $S_{21}$  is decreased by the length of waveguide in straight shape. The power loss of Racetrack is larger than the effect of the waveguide length. This is caused by connection parts of the waveguide. This waveguide is divided to several parts in our manufacturing process. In addition, we bend the stub resonators and parasitic elements to make the bent shape waveguide, which also increases the loss.

## 3. Power Recollecting Circuit

### 3.1 Power Recollecting Method

We show the diagram of wireless power transfer system using sheet-like waveguide in Fig. 4. The recollecting circuit consists of a phase shifter, and the power feedback from the output of waveguide is given to the power source in phase. The conventional recollecting method is given by DC feedback after rectifying the RF power, which increases the power conversion loss. The proposed method is expected to have high efficiency because of no power conversion in RF to DC. This phase shifter provides the phase adjustment of recollecting power to the source phase.

### 3.2 Experiment Result

We show the power recollecting experiment diagram as shown in Fig. 5. The Signal Generator (SG) outputs at 2.45 GHz RF is provided to the waveguide through the circulator. The reason of using the circulator is to remove the reflection effect at the input of waveguide. The waveguide output connects to the phase shifter, and the recollecting power is fed back to the power source. The power is finally combined with the power source by a power combiner. In the experiment, we connect a divider to the latter stage of the combiner to compare with before and after phase shifter connection. One port of the divider is used for measurement, and we use the Spectrum Analyser (SA) to monitor the power. We insert the phase shifter to adjust the phase difference due to phase shifts by the connection components and the waveguide length so that the source and recollecting power are combined in same phase. In the experiment, the waveguide characteristic is changed by a position of receiving element on the waveguide as shown in Fig. 3, which depends on the waveguide structure. Thus this phase shift value uses an average phase of  $S_{21}$ .

We show the experimental recollecting results in Table. 1, when the input power to the waveguide is changed and there is no receiving element on the waveguide. The successful recollecting power is 75.7% of the waste power at the end of the waveguide for the short waveguide. This value is given by dividing the feedback power by the waste power in Table. 1. In the long waveguide, we also recollect 63.8% of the waste power. These recollecting rates depend on the transmission loss of the phase shifter and coaxial line, and coaxial line occupies the large part of the loss. If we can make those losses small, in specific part of coaxial wire, the transfer system is expected to increase in efficiency much further. Therefore this recollecting circuit have a much greater impact on power transmission efficiency in wireless power transfer system using the sheet-like waveguide. In the ideally case that is transmission loss is only the phase shifter loss, the power recollecting rate given by dividing the ideal feedback power by the waste power in Table. 1 is 92.9% in short waveguide and 94.8% in long waveguide.

Moreover, we measure and calculate the power gain at the input port of the waveguide to discover how much gain is obtained, when assuming that a car having a receiving element is running on the waveguide. This calculation uses the transmission characteristics of each connection components because this gain cannot be measured directly. This result is shown in Fig. 6 when the input power to the waveguide is changed. The power gain is up to 4.1dB and depends on the waveguide structure. However, there are little changes in these power gains. This is assumed by the effect of resonance of the waveguide by positive feedback to increase the radiation loss. We propose the switching circuit to suppress this resonance. If the power voltage reaches the resonance level, the switch is turned off and the source is stopped to provide power to the waveguide. After a few moments, if the voltage decreases, the switch is turned on and the source provides power.

## 4. Conclusion

This paper proposed the power recollecting circuit using a phase shifter in the wireless power transfer system and experimentally examined this circuit. When we used short waveguide, we obtained 75.7% power recollecting from the waste power by this circuit. In the ideally case, the value is 92.9%. We also found that the recollecting power depends on the waveguide structure. In addition, we found that a resonance arises from positive feedback. This resonance increases the radiation loss of waveguide and affects the environment. If we use this recollecting circuit in

high-power system, the recollecting efficiency becomes worse due to this resonance. Therefore we should suppress this resonance, and we will study the suppressing system.

## References

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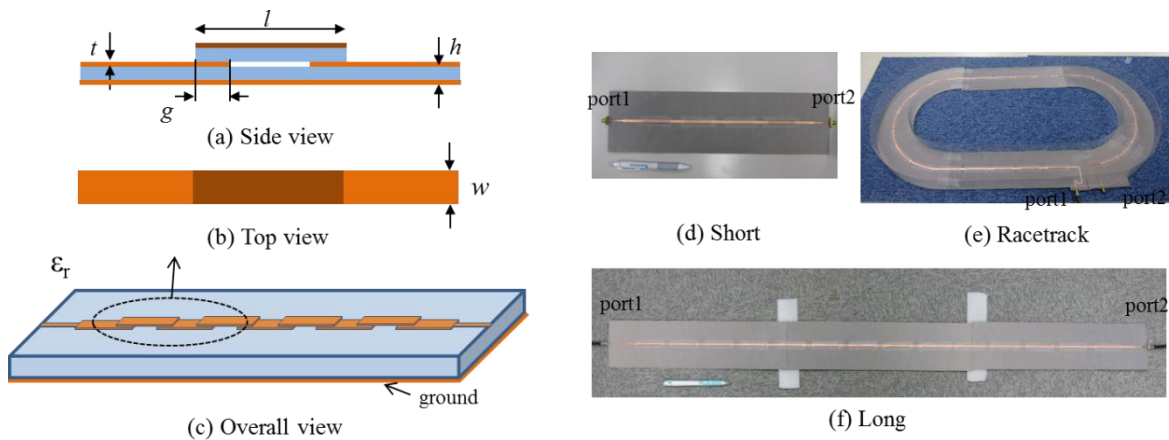


Figure 1: Sheet-like waveguide, (a) Side view, (b) Top view and (c) Overall view of the Sheet-like waveguide are shown.  $l = 41.8$  mm,  $w = 4.19$  mm,  $g = 9.5$  mm,  $h = 0.8$  mm,  $t = 0.035$  mm,  $\epsilon_r = 2.6$ . (d)  $L = 38$  cm, (e)  $L = 228$  cm (along line) and (f)  $L = 109$  cm are actually made waveguides

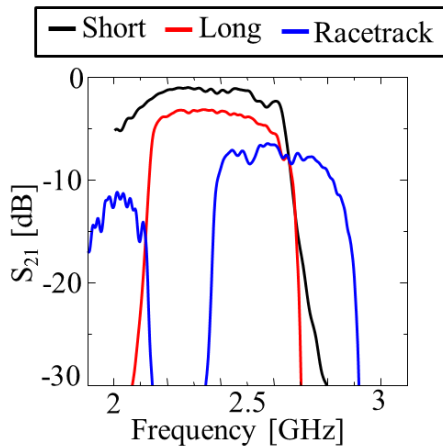


Figure 2:  $S_{21}$  characteristics of waveguides

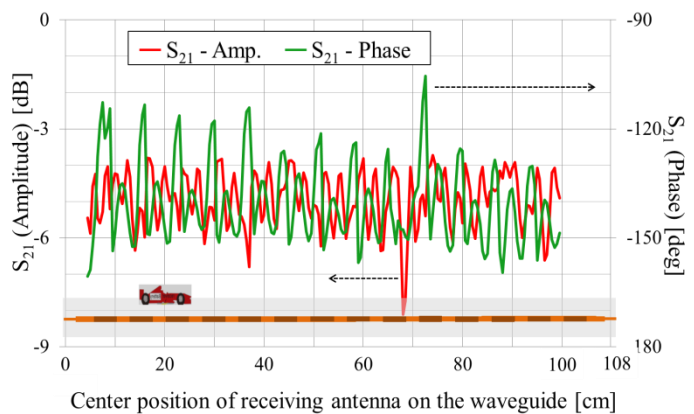


Figure 3: Characteristic variation of long waveguide by position of receiving element

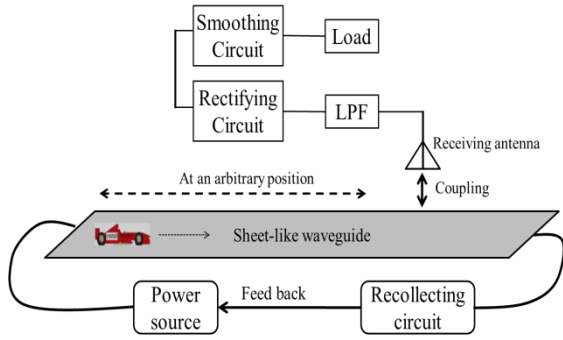


Figure 4: Diagram of wireless power transfer system using sheet-like waveguide.

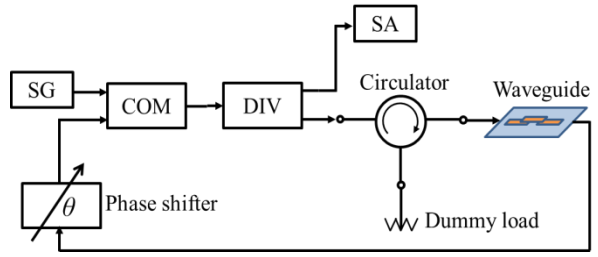


Figure 5: Experiment diagram.

Table 1: Power recollecting experiment result.

Waveguide	Input power to waveguide [dBm]	S21 [dB]	Waste power [dBm]	Feedback power [dBm]	Ideal Feedback power [dBm]
Short	0	-1.08	-1.08	-2.29	-1.40
	5		3.92	2.71	3.60
	10		8.92	7.71	8.60
	12.67		11.6	10.4	11.3
Long	0	-3.89	-3.89	5.85	-4.12
	5		1.11	-0.845	0.879
	10		6.11	4.16	5.88
	12.67		8.78	6.83	8.55

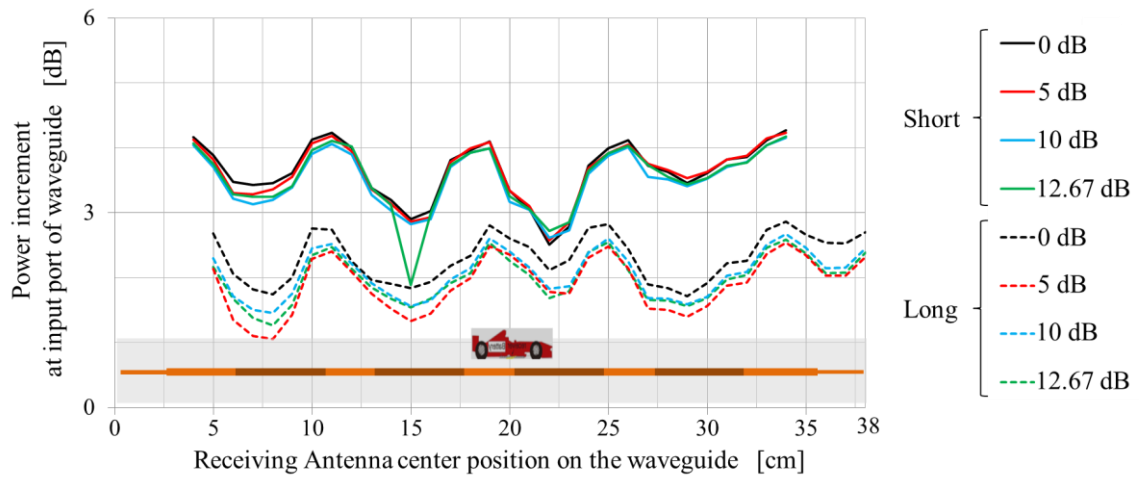


Figure 6: The input power increments of waveguide when a car runs on it.