Wireless Power Transfer System Using Rectangular Waveguide with Cutoff Parallel Plate

Hiroyasu Sato, Daisuke Nakamichi, Qiang Chen
Graduate School of Engineering, Tohoku University
Aramaki Aza Aoba 6-6-05, Aoba-ku, Sendai, Japan

***Abstract*- A wireless power transfer (WPT) system using rectangular waveguide with cutoff parallel plate waveguide is proposed. The operating frequency is set to be lower than the cutoff frequency of the parallel plate waveguide (PPW) in order to make the WPT system leakage-free. A rectangular waveguide at the end of a parallel plate waveguide is provided and the operating frequency is set to be higher than the cutoff frequency of the rectangular waveguide in order to extend the coupling length. It is shown numerically that the strong coupling between transmitting antenna and receiving antenna is maintained over a long distance by selecting the operating frequency near to the cutoff frequency of rectangular waveguide with PPW.**

I. INTRODUCTION

In the near-field wireless power transfer (WPT) systems, we constructed a state in which transmitting and receiving antennas are placed in the near-field area of the antennas, resulting in no radiation from the antennas. Furthermore, the impedance matching circuit was designed for the transmitting and receiving antennas when they were strongly coupled and highly efficient power transmission was realized [1, 2].

It is known that the rectangular waveguides and the parallel-plate waveguides have the cutoff and electromagnetic waves are not transmitted at frequencies below the cutoff frequency, resulting in evanescent waves. In this case, it is possible to construct a radiation-free state by using the cutoff of the waveguide and also to obtain strong coupling by selecting the distance between the transmitting and receiving antennas placed in this evanescent field. NRD (Non-Radiative Dielectric) Waveguide [3] and the photonic crystal [4] are well known as the waveguides utilizing this feature. In NRD guide, low-loss, leak-free transmission is possible by inserting a dielectric inside the cut-off parallel-plate waveguide and releasing the cutoff only in the dielectric part. In the photonic crystal, leak-free transmission is made possible by forming a waveguide by providing defects in a periodic structure having a band gap. In this research, a cut-off parallel plate waveguide is utilized for a WPT system.

As a problem of the near-field WPT system, the efficiency is greatly reduced due to the movement and misalignment of the transmitting and receiving antennas, due to change of the impedance of the transmitting and receiving antennas. It is also a problem that the efficiency between Tx/Rx antennas is reduced when the scatterers exist in the vicinity of those antennas and give effects on the input impedance of these antennas.

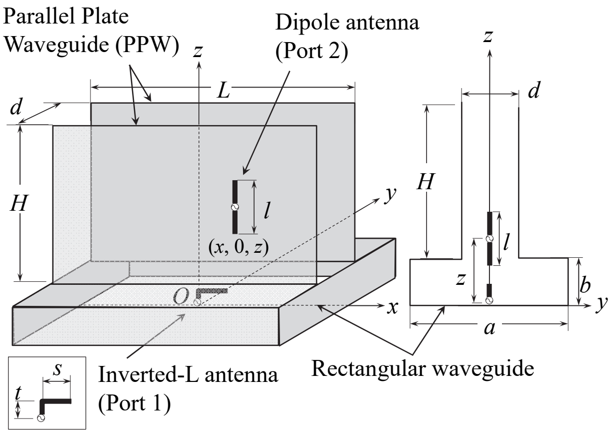

Figure 1. Cutoff-PPW WPT system with rectangular waveguide.

In this paper, a highly efficient WPT system using rectangular waveguide with cutoff parallel plate waveguide is proposed. In the cutoff mode of parallel plate waveguide (PPW), the leakage of EM-wave from the WPT system is perfectly prevented by choosing the operating frequency band below the cutoff frequency. While, the cutoff is released in the rectangular waveguide at the bottom of the PPW for power transfer. A design of proposed WPT system using FDTD method is presented.

II. CUTOFF-PPW WPT SYSTEM

The proposed WPT system is shown in Fig. 1. The system is composed of a rectangular waveguide with (a, b) and a cutoff parallel plate waveguide (PPW) with a height H, a length L, and a width d. A transmitting antenna is placed in a rectangular waveguide and a receiving antenna is placed at the bottom of PPW. In this paper, we use an inverted-L antenna as the transmitting antenna and a dipole antenna as the receiving antenna. The operating frequency band is set as the 2 GHz band. The cutoff frequency of PPW is set as $f_{c\text{-}PPW}=c/2d$=3.75 GHz so that the operating frequency band is in the cutoff frequency region, and the width of parallel plate is determined as $d = \lambda_{c\text{-}PPW} / 2$ = 40 mm. The height H and the length L of the PPW should be selected so that the TE_1 mode of the PPW is sufficiently attenuated. In this design, H=200 mm and L= 600 mm is selected. Dimensions of wide and narrow walls of a

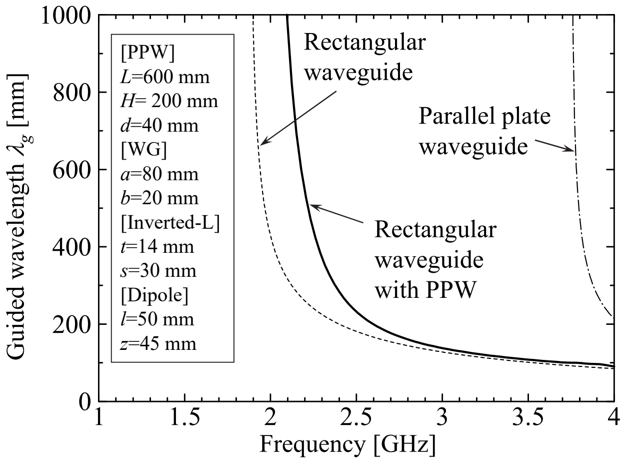

Figure 2. Effective wavelength λ_g of waveguides.

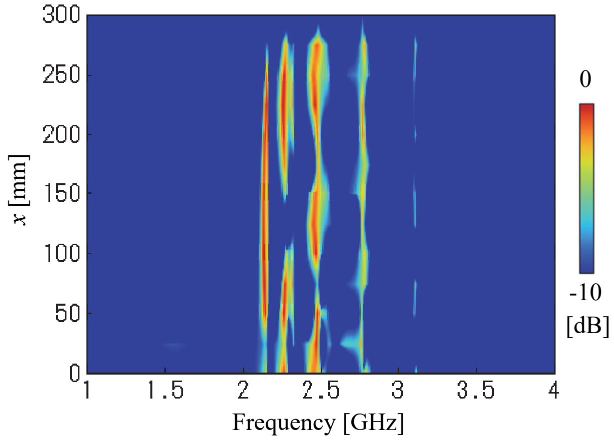

Figure 3. Frequency characteristics of |S21| when position of dipole antenna x changes.

rectangular waveguide a, b are selected as a=80 mm and b=20 mm with the cutoff frequency of $f_{c\text{-}WG}=c/2a$=1.875 GHz so as to release the cutoff of PPW in the operating frequency band.

The effective wavelength λ_g of waveguides in the case of TE_1 mode of PPW, TE_{10} mode of rectangular waveguide and the proposed rectangular waveguide with cutoff-PPW are shown in Fig. 2. In the case of PPW and the rectangular waveguide, the cutoff frequency of $f_{c\text{-}PPW}=c/2d$=3.75 GHz and $f_{c\text{-}WG}=c/2a$=1.875 GHz were observed and the wavelength goes to infinity because of β_g=0. Providing rectangular waveguide at the bottom of the PPW, the cutoff is released in the waveguide. The propagation mode of rectangular waveguide with PPW appears in a frequency range between $f_{c\text{-}WG}$ and $f_{c\text{-}PPW}$ and a cutoff frequency of almost f_c =2.1 GHz is observed. As a design guideline based on the above results, dimensions of the waveguide and the PPW can be selected so that the operating frequency band is in $f_{c\text{-}WG} < f < f_{c\text{-}PPW}$.

III. Numerical Results and Observations

Frequency characteristics of transmission coefficient S21 with changing the position of dipole antenna are shown in Fig. 3. Several transmission modes were observed in the range of $f_{c\text{-}WG} < f < f_{c\text{-}PPW}$. Also the standing waves were observed in all transmission modes and the number of nodes in the standing waves decreases as the frequency decreases. S21 of -0.3 dB, -0.33 dB and -3.18 dB were observed when the position of dipole antenna is x=100 mm.

Fig. 4 shows the electric field $|\boldsymbol{E}|$ distribution in xz-plane at the frequency of 2.14 GHz, 2.46 GHz and 2.78 GHz, when position of dipole antenna is x=100 mm. It is note that 2.14 GHz is the lowest mode near the cutoff frequency of parallel-plate waveguide f_c = 2.1 GHz with longest effective wavelength, and high transmission efficiency with large misalignments of x = 0 mm to 300 mm were realized.

Also it was found that strong coupling between the transmitting and receiving antennas can be maintained even if position misalignment is large by selecting the transmission

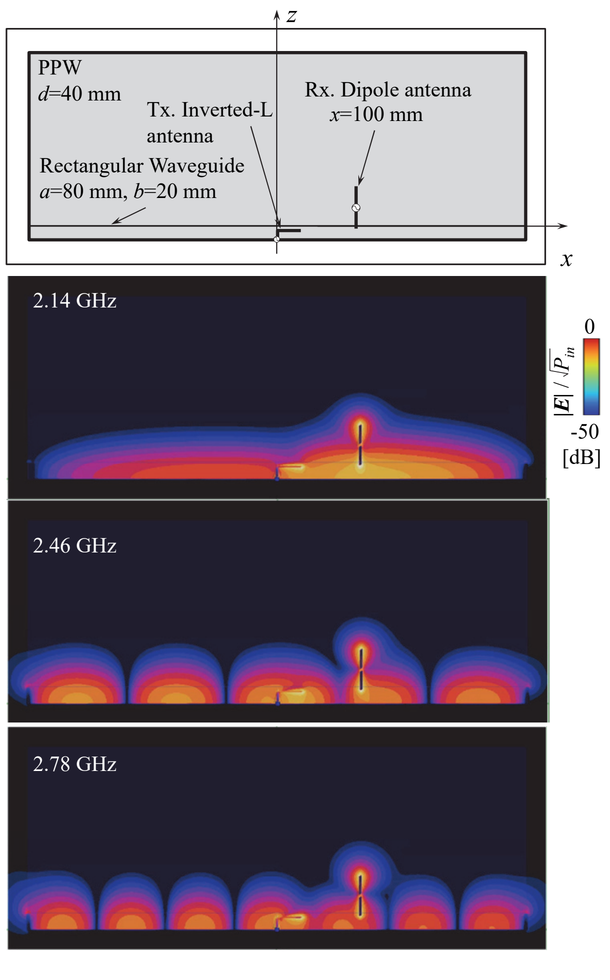

Figure 4. Electric field $|\boldsymbol{E}|$ distribution in xz-plane.

mode near the cutoff frequency of a rectangular waveguide with PPW f_c.

IV. Conclusion

In this paper, a near field wireless power transfer system composed of a rectangular waveguide with a parallel plate waveguide was proposed. It was demonstrated that the strong coupling between transmitting antenna and receiving antenna is maintained over a long distance by optimizing the operating frequency near to the cutoff frequency of rectangular waveguide with PPW.

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