Wireless Power Transfer Using One-Dimensional Free Access Mat

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1. Introduction

From the beginning we had used the electricity, wireless power transfer have been desired. There are several solutions for the wireless power transfer using the electromagnetic (EM) wave. For example, Felica utilizes the electromagnetically inductive coils [1]. And the evanescent wave through the surface of two-dimensional transmission sheet is studied [2]. In addition non-radiative mid-range energy transfer is one of the hottest issues [3]. There are some limitations for those solutions. The wireless power transfer using magnetic induction for very close range or very small power has small positioning tolerance of several mm. The wireless power transfer using omni-directional or high directional antenna has large free space transmission loss and is not good at NLOS condition or for mobile objects. In addition two-dimensional transmission sheet needs special connectors to excite the sheet.

There are some wireless networks for the confined area such as indoor sensor networks, personal area networks and body area networks. For these networks, EM power concentrated inside two-dimensional plane or a transmission line is useful and good for interference problem. We can put wireless devices anywhere on the two dimensional waveguide without a contact. The devices couple to the waveguide and power is supplied through the waveguide. We need a sheet-like waveguide which is efficient, safe and easy to use.

We proposed a free access mat [4] with a simple structure of two layers of patch array. Those patches are tightly coupled to each other. The EM wave is concentrated into the free access mat and transmits in a small loss. The general antennas couple to it with a small loss. Good coupling provides efficient power transfer. One or two-dimensional array of the free access mat is available to a variety of uses of the wireless power transfer. It presents wireless energy transfer along the transmission line or through the planar waveguide. In addition, it is easy to use. We can just put the device on the free access mat and power is transferred by coupling. The free access mat is hard to be interfered. The wireless devices only on the free access mat can couple to it. The wireless devices outside of the free access mat barely couple to it. In addition the EM wave is strongly concentrated into the free access mat so that it has a small radiation electric field.

In this paper we propose and demonstrate the wireless power transfer using one-dimensional free access mat. Figure 1 shows the configuration of the free access mat and the image of wireless power transfer using the free access mat. The free access mat is connected to the power source and the power is wirelessly transferred to the devices on the free access mat. The wireless devices couple to the free access mat without contact points so that the safety and maintenance problems caused by contact points could be solved. In this paper we present the basic study of wireless power transfer using one-dimensional array of the free access mat. We design the free access mat which has a center frequency around 2.45 GHz. We present small transmission loss through the free access mat, good coupling between general antennas and the free access mat and power transfer efficiency.

2. One-Dimensional Array of Free Access Mat for 2.45 GHz

Free access mat consists of two layered patch arrays and the dielectric substrate is sandwiched between those two layers. This structure is simple and easy to fabricate. Patch elements are tightly coupled to each other and the EM wave which is coupled to the free access mat transmits through the free access mat with very small loss. In [4], the transmission loss inside the free access mat is 0.83 dB/λ around 6 GHz and coupling loss of two external standard dipoles is estimated as 3.6 dB. We use 2.5 times larger model than the 1-D array model in [4] along the line in order to bring the center frequency to 2.45 GHz. The configuration of the free access mat for ISM band is shown in Figs. 2 (a) and (b). We use the infinite ground plane only for the simulation. Each port is perfectly matched to the patch elements and terminated by 50 Ohms. Figure 2 (c) shows simulated transmission losses along the one-dimensional free access mat when the length of it (L) changes. The transmission loss keeps small even though L increases to 467 mm, which is smaller than 1 dB. The average of the transmission loss is 0.13 dB/λ or 1.05 dB/m. The transmission loss along the free access mat increases in proportion to L, where the free space transmission loss increases as the square of it. We use the free access mat which has the L of 345 mm in the convenience of the fabrication.

We fabricate one-dimensional free access mat using dielectric substrate as shown in Fig. 3. We measure S21 characteristics of each free access mat using network analyzer. The free access mat has small transmission loss around 2.7 GHz. The measured S21 is smaller than the simulated one. The change of the center frequency and the transmission loss is caused by the loss of the connector at port 1 and port 2, the effect of the finite ground plane and the change of the dielectric constant. We put the standard dipole whose resonant frequency is around 2.45 GHz over the free access mat in the height of 5 mm. The distance between the dipole and the free access mat is about 295 mm. The coupling between dipole and the free access mat is shown in Fig. 4. They couple to each other strongly around 2.7 GHz. The coupling loss is 5.8 dB. We can reduce the coupling loss more by adjusting the center frequency of the free access mat.

In addition only devices on the free access mat couple to the free access mat and the effect of the interference could be negligible. The wireless power transfer using the free access mat is possible only when the transmitter and the receiver are very close. Therefore the power transfer to undesired devices outside of the free access mat is preventable.

3. Power Circuit

Figure 5 shows the wireless power transfer using the free access mat. The signal is connected to the free access mat. The standard dipole is placed over the free access mat in the height of 5 mm. The distance between the feeding point and the dipole (L) is about 295 mm. The coupled power is transferred to the load through the rectifying circuit. The rectifying circuit consists of Schottky Barrier diodes (HSC276a) and laminated ceramic capacitors (GRM series by Murata). It has voltage doubler configuration as shown in Fig. 6. The rectifying circuit is designed at 2.45 GHz.

When we transmits a 2.4 GHz, + 40 dBm signal to the free access mat, the measured voltage at 3.8 Ω load is 3.8 V. The transferred power is measured as 3.8 W. Therefore the efficiency of the whole system is measured as 38 %. At this time the frequency where good coupling between the free access mat and the dipole is obtained and that of the rectifying circuit are not matched. The insertion loss of the rectifying circuit at 2.7 GHz is larger than 2.45 GHz about 2 dB. We assume better efficiency is obtainable when the frequencies of each part are well matched.

At 2.45 GHz, Z_s is measured as 26.5 Ω. The input impedance of the rectifying circuit (Z_{in}) is measured as 23.9 Ω. The equivalent circuit is as shown in Fig. 6. When the signal generator transmits a 2.7 GHz, + 23 dBm signal to the free access mat, the received signal at the dipole is measured as 17.65 dBm, equivalent to 1.7 V and 58.184 mW. Provided the frequency is matched, the rectenna efficiency would be estimated as 47 % from the equivalent circuit in Fig. 6.

In addition, the radiation electric field is smaller than 65 mV/m when the input power is 40 dBm. It is much smaller than the guidelines ruled by radio law in Japan.

4. Conclusion

This paper presented wireless power transfer using one-dimensional free access mat. The power is transmitted to the free access mat and is wirelessly transferred to load through the general antenna and rectifying circuit. The efficiency is measured as 38 %. We need to adjust the frequency of the device at 2.45 GHz for ISM band usage and better efficiency.

References

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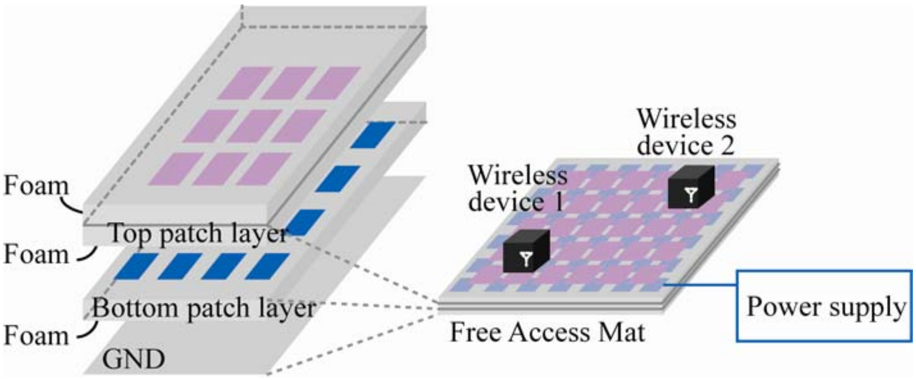

Figure 1: Configuration of free access mat and the image of wireless power transfer

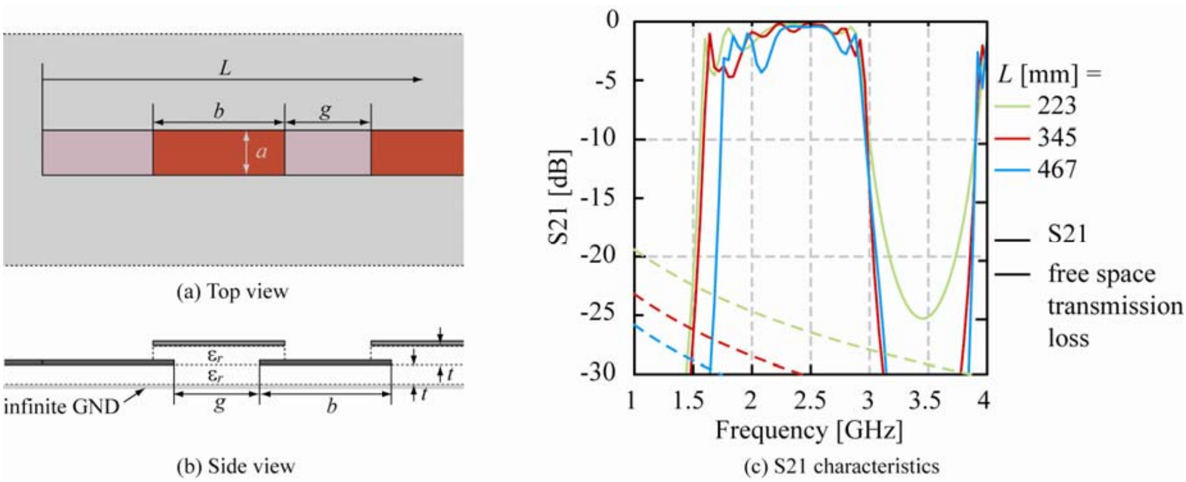

Figure 2: One-dimensional array of free access mat, (a) top view and (b) side view of the free access mat are shown. a = 4.3 mm, b = 40 mm, g = 21 mm, t = 0.8 mm, ε_r = 2.6. (c) Simulated transmission loss

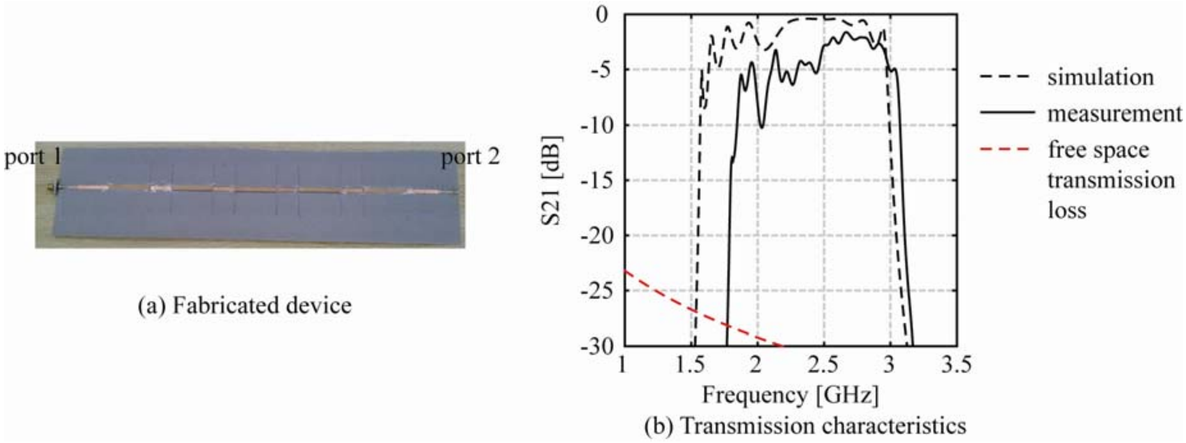

Figure 3: Fabricated device and measured S21 characteristics

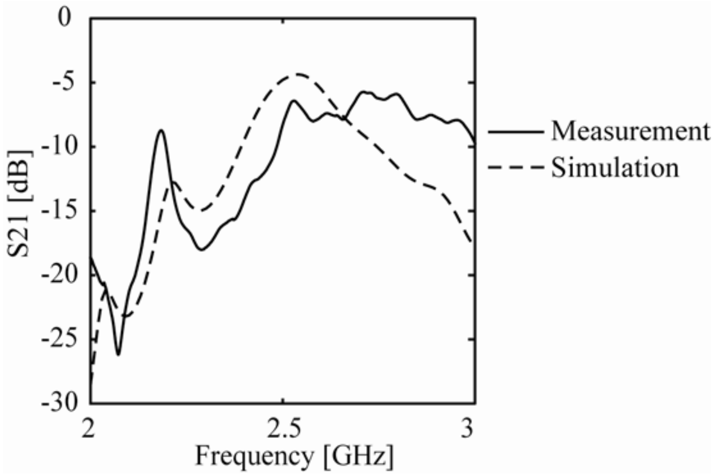

Figure 4: Coupling loss of dipole antenna

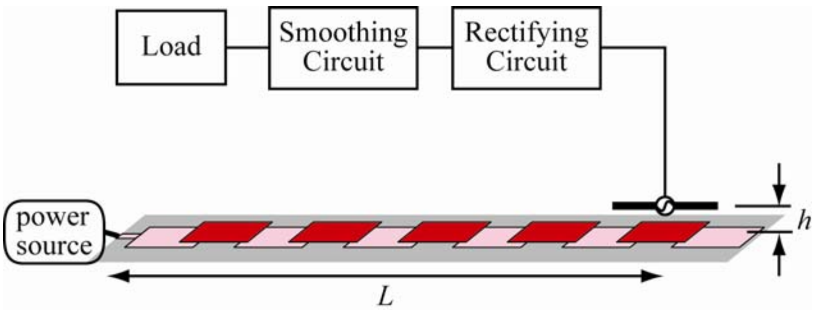

Figure 5: Block diagram of wireless power transfer using free access mat

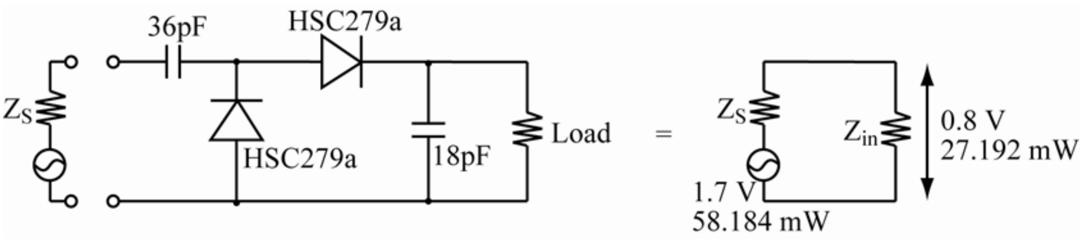

Figure 6: Equivalent circuit of rectenna