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シート状導波路を用いた電力伝送の一検討

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あらまし 無線機器の増加に伴い無線電力伝送への要望も強くなっている．アプリケーションの一つとして電気自動車の非接触充電が考えられる．接触端子において雨や埃によるスパークや端子の摩耗等が懸念されている．そこで，パッチアレーの２層構造を用いたシート状導波路，フリーアクセスマット，を用いた電気自動車の非接触充電の手法を提案する．フリーアクセスマットはその上方から任意の場所において外部のアンテナを結合させることで，自由空間伝搬損失より伝搬損失が非常に少ない導波路内を伝搬させることができる．電磁波がフリーアクセスマット内に閉じ込められて，さらに外部のアンテナの結合損失も少ないため，高効率な無線電力伝送が期待できる．本研究では，基礎検討として一次元アレーのフリーアクセスマットを用いた無線電力伝送法を提案し，高効率無線電力伝送への可能性を示す．

キーワード フリーアクセスマット，シート状導波路，無線電力伝送

A Study of Power Transfer Technique Using Sheet-like Waveguide

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Abstract As wireless device increases, desire for wireless power transfer technique also increases. As an application, contactless charging system for electric vehicle is anticipated. At the contact points, the charging system has a risk to occur electric shock caused by rain drops and dust, so that contactless charging system is desired. This paper propose contactless charging system of electric vehicle using free access mat, the sheet-like waveguide which consists of two layers of patch array. Using free access mat, external antennas couple to the mat from the top of the mat at arbitrary points without contact. The coupled EM wave transmits through the free access mat with small transmission loss. The EM wave is concentrated into the free access mat and the coupling loss of external antennas is very small. High efficiency of wireless power transfer is expected from these characteristics. This paper propose wireless power transfer using one-dimensional array of free access mat and presents the possibility of high efficiency of wireless power transfer.

Keyword Free access mat, sheet-like waveguide, wireless power transfer

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 EM wave. For example, Felica [1] and IPT (inductive power transfer) [2] utilizes the electromagnetically inductive coils. And the evanescent wave through the surface of two-dimensional transmission sheet is studied [3],[4]. In addition non-radiative mid-range energy transfer is one of the hottest issues [5],[6]. For the wireless networks of confined area such as indoor sensor networks, personal area networks and body area networks, the concentrated EM power inside two-dimensional plane or a transmission line is useful.

As an application of wireless power transfer using sheet-like waveguide, electric vehicle charging is desirable. Charging problem is one of the key solutions to encourage broad use of electric vehicle, a promising approach to solve environment problems. The conventional charging system has several problems caused by contacts between terminals of the vehicle and the power supply. For example, there are the safety problem such as electric shock hazard caused by rain drops and dust, and the maintenance problem such as wear at points of contact. The wireless power transfer using microwave which has sheet-like transmitter and receiver on the floor and the bottom of the vehicle is able to solve this problem as shown in Fig. 1.

Free access mat, which has simple structure of two layers of patch array, concentrates the EM wave into the free access mat and couples to the external antennas with small loss [7]. One or two-dimensional array of the free access mat is expected to present wireless energy transfer along the transmission line or through planar waveguide. In this study we present the basic study of wireless power transfer using one-dimensional array of the free access mat.

2. Free Access Mat

Figure 1 shows the image of wireless power transfer using the free access mat. Device 1 is placed on the floor and device 2 is attached on the bottom of the electric vehicle. Device 1 is connected to the power source and Device 2, the receiver, is

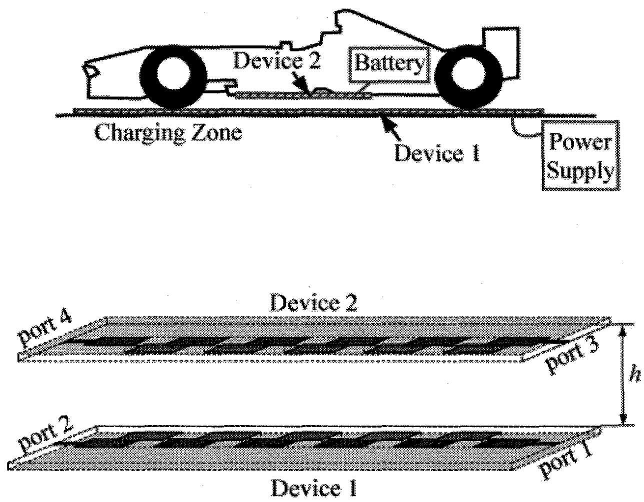
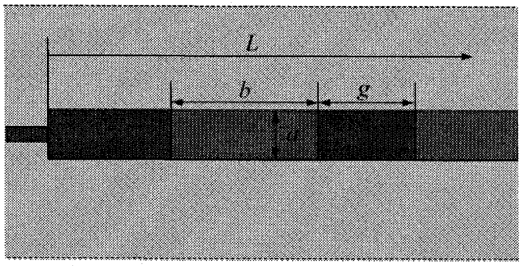


Figure 1. An Image of the wireless power transfer using two free access mats. Device 1 and 2 is one-dimensional array of free access mat. h shows the distance between two devices.

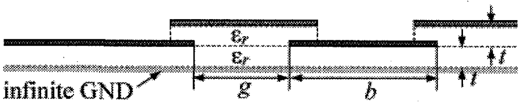
connected to the battery of the electric vehicle. When the electric vehicle comes to the charging area, Device 2 couples to device 1 with small loss. Device 1 and 2 couple to each other without contact points so that the safety and maintenance problems caused by contact points could be solved.

Each device consists of two layered patch array and between those two layers dielectric substrate is sandwiched. This structure is simple and easy to fabricate. Patch elements of each device are tightly coupled to each other and the EM wave which is coupled to the free access mat transmits inside the free access mat with very small loss. In [7], the transmission loss inside the free access mat is smaller than 1 dB and coupling loss of two external standard dipoles is estimated as 3.6 dB. Using two free access mats as the transmitter and the receiver, the coupling loss could be reduced.

We use 2.5 times larger model than the 1-D array model in [7] along the line in order to bring the center frequency around 2.45 GHz as shown in Fig. 2. In Fig. 2, b and g is enlarged. We use the infinite ground planes for two devices. Each port is perfectly matched to the patch elements and terminated by 50 Ohms.



(a) Top view



(b) Side view

Figure 2. Structure of one-dimensional array of free access mat. (a) Top view and (b) side view of part of free access mat are shown. a = 4.3 mm, b = 40 mm, g = 21 mm, t = 0.8 mm, ε_r = 2.6 and L is the length of the device.

Figure 3 shows simulated transmission losses along Device 1 when the length of Device 1 (L) changes. The transmission loss increases when L increases. The transmission loss keeps small even though L increases to 467 mm, which is smaller than 1 dB. 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 move to next simulation using the device whose L is 345 mm. The transmission loss at that L is – 0.4 dB at 2.4 GHz.

We put device 2 which is the reversed model of device 2 in the height of h. Figure 4 shows the coupled power between port 1 and 3 when the two devices couple to each other in the interval of h. Two free access mats couple to each other tightly. The coupled power decreases significantly as h increases. The peak frequency shifts to the higher frequency. When h = 5 mm, the S31 is – 0.87 dB at 2.8 GHz. The coupling loss between two devices is estimated to be smaller than – 0.5 dB.

Figure 5 shows the coupled power between port 1 and port 4 when we change the h from 5 to 30 mm. As the same way to S31, the coupled power decreases significantly as h increases and the peak frequency shifts to the higher frequency. When h = 5 mm, S41 is – 0.73 dB at 2.8 GHz. The coupling loss between two devices is smaller than – 0.4 dB. Although $L_{S41} - L_{S31}$ is larger than 340 mm, where the free space transmission loss is – 32 dB, the coupling loss is almost the same. Because the EM wave transmits through the free access mat and the EM wave is strongly concentrated into the free access mat, the transmission loss of each device is very small.

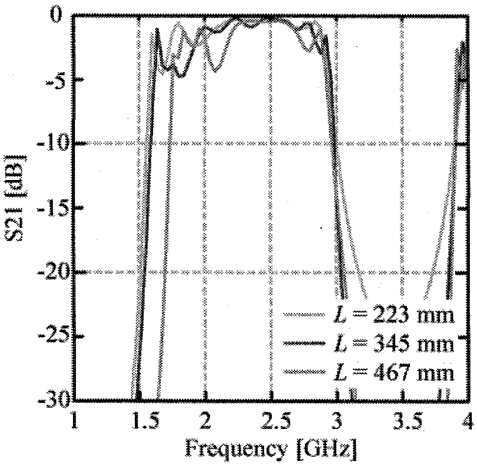


Figure 3. Simulated transmission loss of Device 1 without device 2. L is the transmission length of the device.

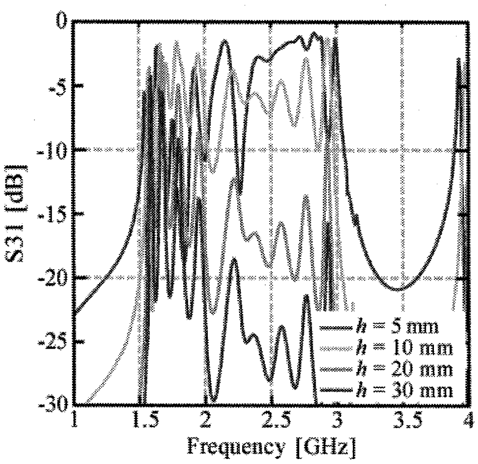


Figure 4. Simulated coupling loss between port 1 and port 3 where L = 0 mm.

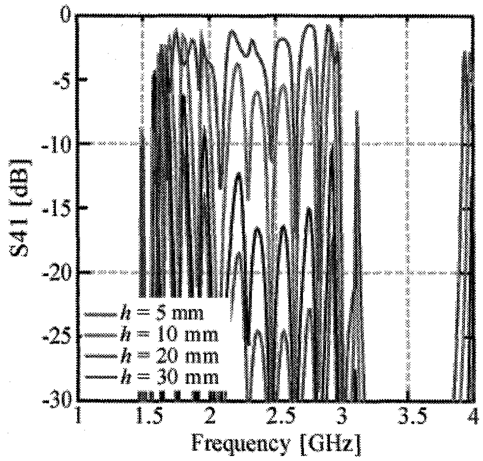


Figure 5. Simulated coupling loss between port 1 and port 4 where L = 345 mm.

The coupling loss between two devices is very small, smaller than – 0.5 dB. That between free access mat and two standard dipoles are estimated as – 3.6 dB in [7]. Therefore, it is efficient to use two free access mats as the transmitter and the receiver.

3. Conclusion

This paper proposed wireless energy transfer using one-dimensional array of the free access mat. The free access mat has very small transmission loss along the length of it. We used two free access mats as transmitter and receiver. One is connected to the power source and the other collects the transferred wireless power.

The coupling between two free access mats was simulated and the loss is very small, smaller than 1 dB at the interval of 5 mm. This is much smaller than that when standard dipoles couple to the free access mat.

More optimization in order to increase h and to bring the center frequency to ISM band is needed.

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