Near-field Wireless Power Transfer for Moving Vehicle Using Collinear Array Antenna

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Abstract:
Near-field wireless power transfer scheme using collinear array antenna for moving vehicle is proposed. Although a collinear array antenna is known as a high-gain antenna for far-field communication system, this antenna can generate near-field distribution along the cable. In the proposed scheme, a collinear array antenna is set under the road to feed running vehicle. As a receiving antenna, half-wavelength dipole antenna is set under the vehicle. The transmitting collinear-array antenna and receiving dipole antenna couples in near-field to feed power to a vehicle. Experimental demonstration shows that this scheme is applicable for power feeding to running vehicle.

Keywords: Wireless power transfer, Collinear array antenna, Near-field coupling, Feeding for moving vehicle

References

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1 Introduction

In recent years, application of wireless power transfer (WPT) [1] for a moving vehicle is getting large interests. Several types of WPT for moving vehicle have been proposed. One is using a coil array [2]. It is attractive that this scheme has high efficiency because the transmitting (Tx) side and the receiving (Rx) side are in strong coupling [3]. However, this scheme requires many coils in Tx side, which increase costs and installation space. Another type uses parallel line in the Tx side, which utilize magnetic-field coupling [4] or electric-field coupling [5]. In this type, a pair of lines should be used in Tx side, which requires wider space.

A collinear array antenna [6] is widely known as a far-field communication antenna [7]. Since this antenna can produce one-dimensional near electromagnetic field distribution along a cable, it is possible to apply this antenna for wireless power transfer to moving vehicle.

In this paper, we propose wireless power transfer scheme using a collinear array antenna for moving vehicle. The collinear array antenna is used as a transmitting antenna, that is laid under the road. Under the moving vehicle, a half-wavelength dipole antenna is set as a receiving antenna. The Tx collinear-array antenna and the Rx dipole antenna couples in near field to transfer power to the load of the Rx antenna. Compared to the parallel-line method, this scheme requires less space.

This paper organizes as follows. In Section 2, a numerical simulation verifies frequency characteristics of the proposed method. In Section 3, a distance characteristics of transmission efficiency is experimentally verified by using vector network analyzer. In Section 4, proposed method is applied to a mini model vehicle to demonstrate validity of the scheme.

2 Simulation

2.1 Antenna structure

To verify the proposed concept, numerical simulation is conducted. The structure of proposed model is shown in Fig.1(a).

A collinear array antenna is used as transmitting antenna (Tx). The collinear array antenna is composed of eight elements of half wavelength coaxial cables. The length of the element is 261 mm to resonate at 433 MHz. 5D-2V coaxial cable is used.

A half wavelength dipole antenna is used as a receiving antenna (Rx). The length of the receiving antenna is set to 328 mm to resonate at 433 MHz. A 50 ohm load is connected to the receiving antenna. The Rx antenna is set 25 mm above the Tx antenna. The Tx antenna and Rx antenna have port 1 and 2, respectively.

2.2 Simulation result
Calculated distance characteristics of the S-parameter are shown in Fig. 1(b). In this calculation, matching circuit is used to achieve simultaneous conjugate matching to both transmitting antenna and the receiving antenna. It can be confirmed that both the transmitting and the receiving antenna resonate at 433 MHz band. At the resonant frequency, -5.9 dB of transmission efficiency is achieved.

3 Experimental validation

3.1 Experimental model
We fabricated experimental model of the proposed model shown in Fig. 1(a). By using a vector network analyzer, S-parameters between Tx collinear array antenna and Rx dipole antenna are measured with changing the transmission distance from 0 m to 2 m. A definition of transmission distance is shown in Fig. 2(a). To prevent common-mode current, sleeve balun (Sperrtopf) is used in Tx side. In Rx side, common-mode choke is used.

3.2 Result
The measured distance characteristics of S-parameters are shown in Fig. 2(b). In the configuration in Fig. 1(a) (the end of the receiving dipole antenna is on the feeding point), the distance \( D \) becomes 0.164 m. In this situation, the simulated \( S_{21} \) was -5.9 dB (Fig. 1(b)) and the measured \( S_{21} \) was -4.3 dB (Fig. 2(b)), which
are in good accordance within a precision of simulation and experiment. It is remarkable that at the center of the collinear array antenna, $S_{21}$ drops to $-23.2$ dB. It is considered that this is due to standing waves.

![Image of experimental model and measured S-parameters](image)

**Fig. 2.** Experimental validation

### 4 Demonstration

To verify a capability of proposed method for running vehicle, experimental demonstration is performed using a mini model vehicle. A half-wavelength dipole antenna is set under the vehicle, shown in Fig. 3(a). Through rectifier circuit, direct current (DC) power is fed to motor. As shown in Fig. 3(b), full bridge rectifier circuit with five parallel HSMS-2820 diode is used. Under the road, eight-section collinear array antenna (total length $2.08$ m) is set as shown in Fig. 3(c). 5 W power at $433$ MHz is fed to the collinear array antenna through matching circuit. As a result, the mini model vehicle successfully run the road as shown in the movie file of Fig. 3(d). In the measured S-parameters shown in Fig. 2(b), $S_{21}$ dropped at the center of the collinear array antenna. It can be confirmed that the speed of the vehicle was decreased at the center of the road. It should be noted that the measured $S_{21}$ does not directly represent transmission efficiency for this demonstration since the impedance of the motor varies as a function of torque and revolution speed. However, the effect of standing wave was confirmed.
Fig. 3. Demonstration model

5 Conclusion

Wireless power transfer scheme using collinear array antenna for moving vehicle is proposed. The tx side collinear array antenna generates one-dimensional electromagnetic field along the cable. The Rx dipole antenna couples to the Tx antenna in near-field coupling. Experimental demonstration
shows that this scheme is applicable for power feeding to running vehicle.

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