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Research Article

Design of a Bidirectional Antenna inside a Vehicle and Measurement of Power Link for Vehicle-to-Vehicle Communication at 5.8 GHz

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Communication between moving vehicles is very important for safety. In this paper, a bidirectional antenna that can be installed inside a vehicle is proposed and tested in a real vehicular environment at 5.8 GHz. The forward link and backward link seated by two persons and three persons were compared in terms of received RF power and the peak-to-average power ratio (PAR). It was found that, even with three persons, the power link fulfilled the communication requirements using the proposed antenna.

1. Introduction

Currently, road traffic is becoming heavier, so that intelligent communication between moving vehicles is very important [1]. Vehicle-to-vehicle (V2V) communication for IEEE 802.11p Wireless Access in Vehicular Environments (WAVE) has been achieved by antennas installed on the roofs of vehicles [2–4]. Installation of the antenna should cut part of the roof of the vehicle. In this paper, an antenna that can be installed inside a vehicle is proposed for WAVE communication operating at 5.8 GHz. Experiments on a power link between two vehicles are also done. Forward and backward links are compared, and the backward link seated by two persons and three persons is described.

2. Antenna Design

Figure 1 shows the structure of the proposed bidirectional array antenna. The designed frequency is 5.8 GHz. Figure 1(a) shows a transparent view of a single radiation patch: the single-layer substrate has a dielectric constant of 2.2, loss tangent of 0.0009, and thickness of 0.508 mm. The patch is denoted by green shading and has a size of 15 mm × 15 mm. The hatched rectangular box is the ground positioned on the other side of the patch. The feeding port is positioned at the end of the microstrip line. Figure 1(b) shows an array with two patches. The interelement spacing is 24.5 mm. Figure 1(c) shows an array with three patches and a power divider that is closer to a port and has a 1 : 2 power ratio. The single patch shown in Figure 1(a) is similar to a previous model [5], but the array models in Figures 1(b) and 1(c) have not been reported previously to the best of our knowledge, even though they can be easily configured [6]. The radiation pattern of the proposed array antenna is expected to be bidirectional, since the ground plane behind the radiation patch is etched.

A simulation was performed using the commercial software ANSYS Designer. Figure 2 illustrates the current distribution for each antennas at their resonant frequencies. The currents on the patches flow in the feeding direction and distribute on patches equally. The optimized antenna was fabricated with an etching process, as shown in Figure 3(a), and the reflection coefficient was measured for three kinds of antenna. The reflection coefficient (S_{11}) was

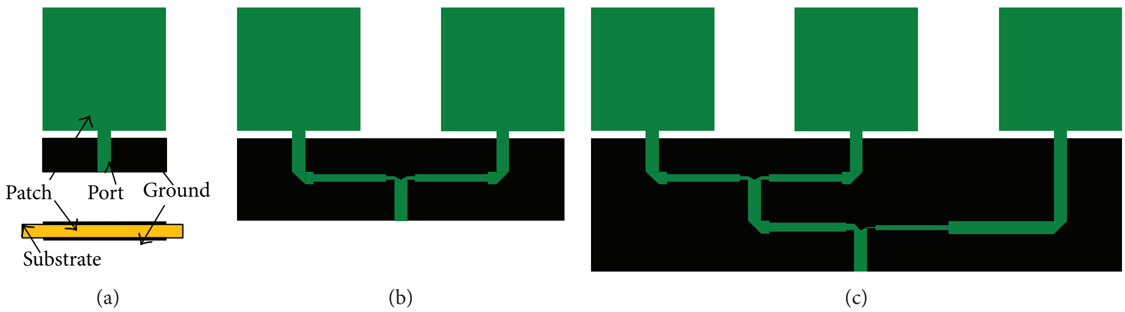

Figure 1: Structure of the proposed bidirectional antenna: (a) single radiation patch; (b) two patches; (c) three patches.

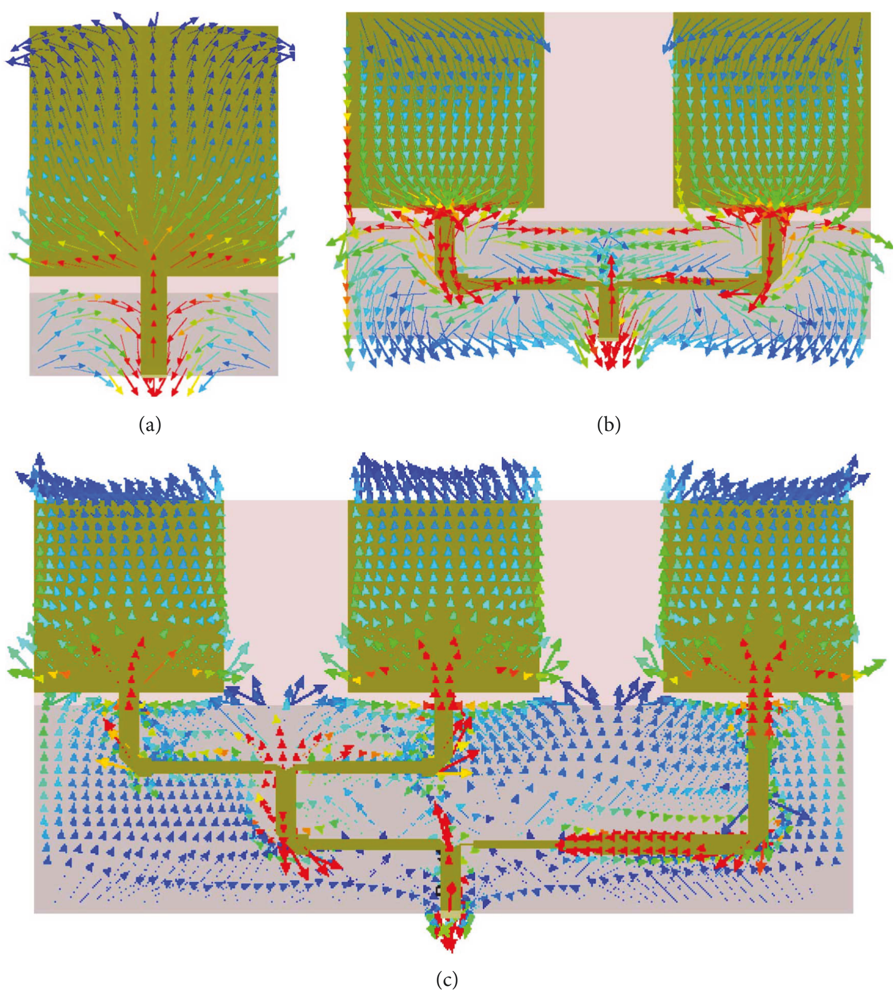

Figure 2: The current distribution of the proposed antenna: (a) single radiation patch; (b) two patches; (c) three patches.

below −10 dB for the measurement as shown in Figure 3(b). The simulated and measured radiation patterns on the H-plane are shown in Figure 4 and had very good agreement. The photograph of the fabricated antenna is inserted in the radiation pattern. The measured 3 dB beam width was omnidirectional, 51°, and 36° for the one, two, and three radiation patches, respectively, and the measured gain was 2.70, 5.78, and 6.62 dBi, respectively. As shown in Figure 4, the array antennas with two and three patches are bidirectional, and they are more directive compared with the single-patch antenna.

3. Measurement of Path Loss and PAR

To test the ability of wireless communication between vehicles, the received power was measured. Figure 5 shows the antenna installation and experimental setup. The transmitting (Tx) antenna connected to the signal generator (SG)

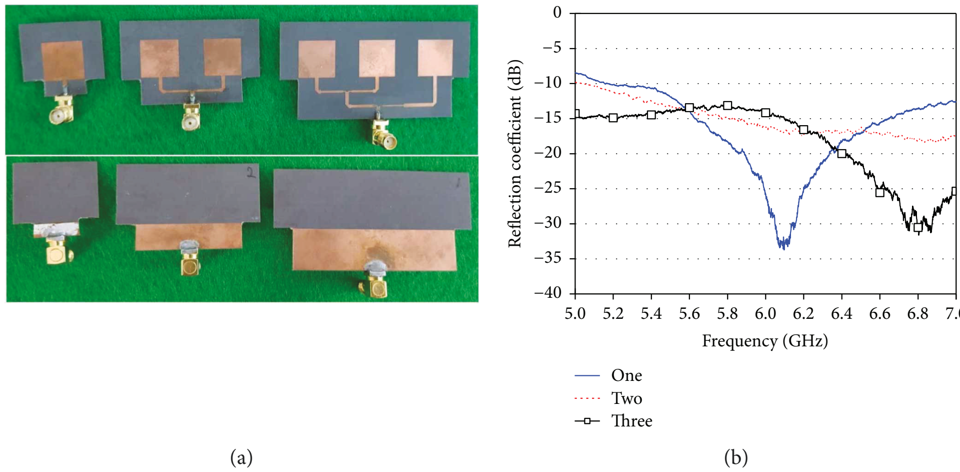

Figure 3: The fabricated antenna: (a) photograph; (b) the reflection coefficient (S_{11}).

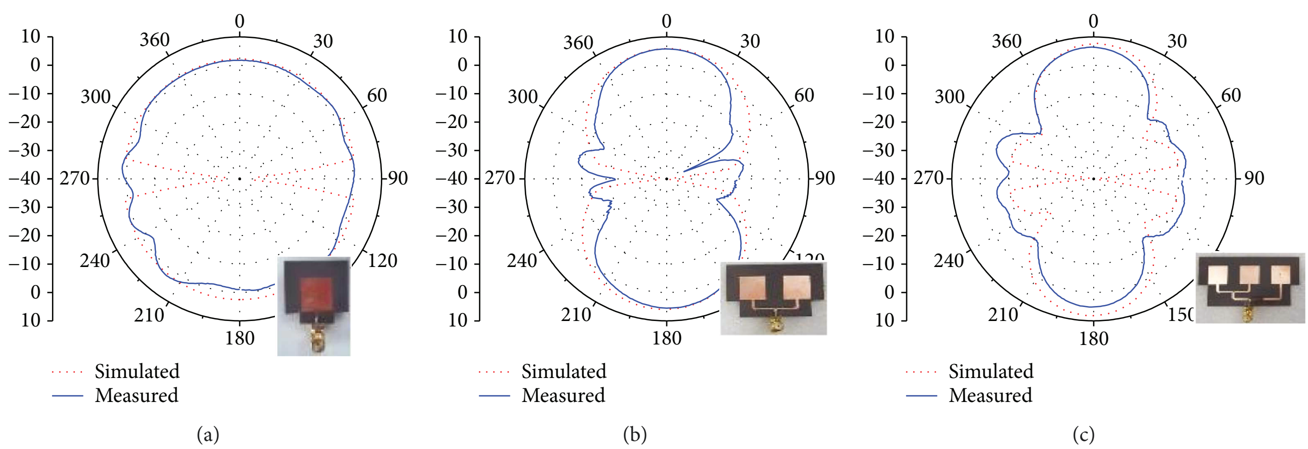

Figure 4: Simulated and measured H-plane radiation patterns of the bidirectional antennas at 5.8 GHz: (a) single radiation patch; (b) two patches; (c) three patches.

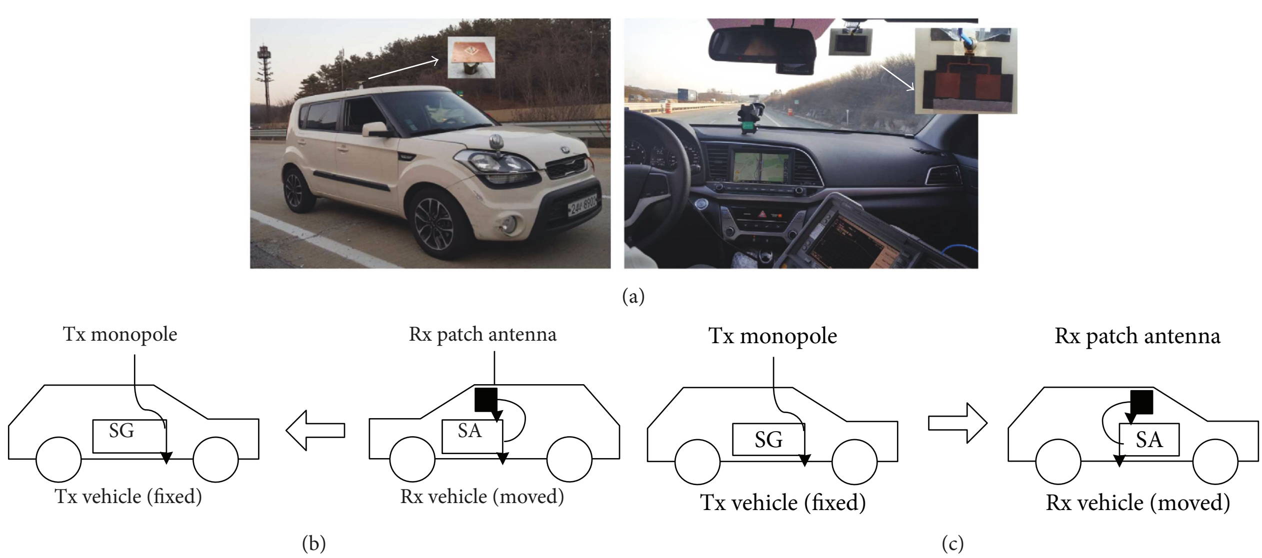

Figure 5: Experimental setup for vehicle-to-vehicle (V2V) communication at 5.8 GHz: (a) transmitting (Tx) vehicle (left) and receiving (Rx) vehicle (right); (b) forward link; (c) backward link.

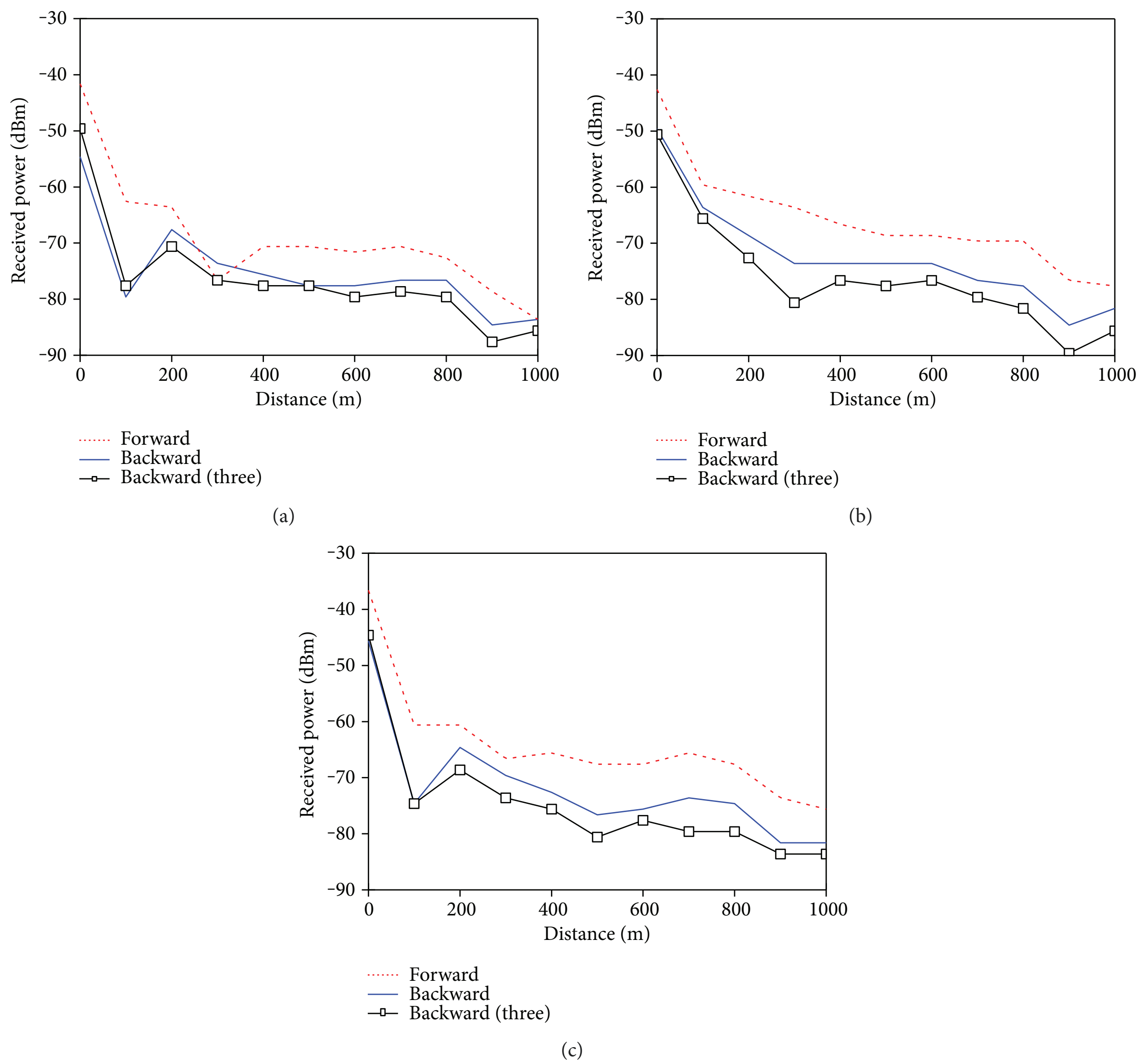

Figure 6: Measured received power for V2V communication at 5.8 GHz: (a) single radiation patch; (b) two patches; (c) three patches.

with a continuous wave (CW) RF output signal of 20 dBm is loaded on top of the static vehicle, as shown in Figure 5(a). The type of the Tx antenna is a monopole antenna with an H-plane gain of 1.05 dBi. The receiving (Rx) antenna connected to the spectrum analyzer (SA) is positioned near the front window inside the moving vehicle as shown in the right figure of Figure 5(a). Forward communication occurs when two vehicles face each other, so that the communication is done via the front window. Meanwhile, backward communication occurs when two vehicles are positioned in the same direction, so that the communication is done via the rear window. It should be noted that forward propagation only has the front window as the obstacle. Meanwhile, backward propagation has several obstacles, such as the interior conductor, seat, rear window, and human body. In particular, the effect of the human body should not be neglected.

Figure 6 shows the received power for the experiment shown in Figure 5. Cable loss is extracted from the received power. As shown in Figure 6(c), the received power increases with an increasing number of radiation patches.

It should be noted that, as shown in Figure 6, the received power for the forward direction is higher than the minimum receiver sensitivity of −95 dBm. Another interesting aspect is that the received power for the backward direction is lower than that for the forward direction, by about 5 to 10 dB. This might be due to absorption by the human body and car seat inside the vehicle and due to reflection from the interior of the vehicle.

For verification of the effect of the human body, one more experiment was performed in the backward direction for three persons instead of two persons. As a result, the received power decreased by about 3 dB. In the investigation shown in Figure 6, however, the received power for the backward direction, even in the three-person scenario, is still higher than that for the minimum receiver sensitivity.

To test the digital communication function, the peak-to-average power ratio (PAR) was measured for the orthogonal frequency division multiplexed- (OFDM-) modulated signal based on IEEE 802.11p [2]. As expected from Figure 6, the forward link shows higher PAR. The backward link for the

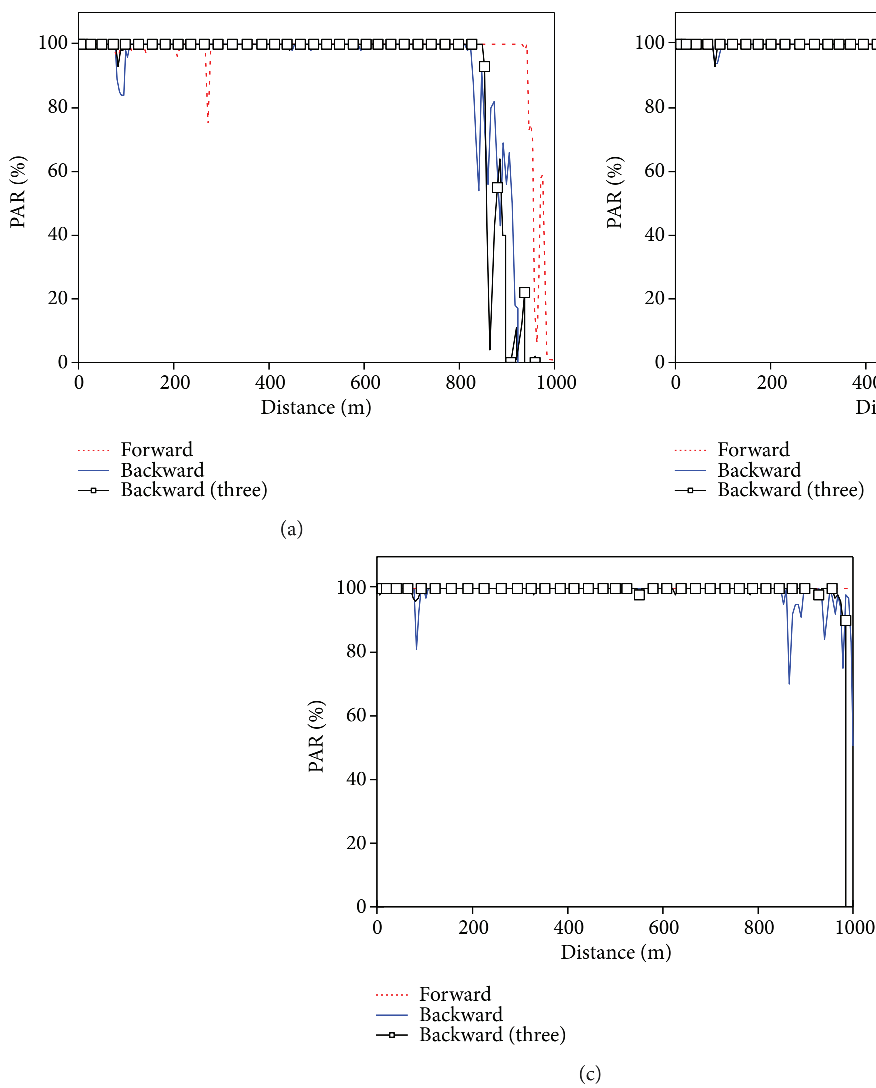

Figure 7: Measured PAR for V2V communication at 5.8 GHz: (a) single radiation patch; (b) two patches; (c) three patches.

two-person scenario has better PAR than the scenario with three persons, as shown in Figures 7(a)–7(c), so that the available distance is longer. Backward communication for the three-person scenario with a single patch is possible up to about 800 m, as shown in Figure 7(a), whereas the distance for three patches is about 950 m.

4. Conclusion

In this paper, a bidirectional antenna installed inside a vehicle was proposed and the experimental results of a power link between two vehicles described. A single radiation patch antenna and array antenna were designed and fabricated. The received power and PAR were measured in a real vehicular environment. Backward link performance for the three-person scenario was also tested. As a result, the array antenna showed better performance than the single-patch antenna. The value of the backward link is deteriorated versus that of the forward link. However, even for three-person scenario, the backward link still showed greater received power and PAR than the required value. From these results, the proposed antenna could be utilized for V2V communication when installed inside a vehicle.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

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