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OPTIMIZATION OF THE MOUNTING POSITION AND ANGLE FOR RKE ANTENNAS

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ABSTRACT−This paper proposes optimization of a mounting position and angle for vehicle RKE antennas. To take into consideration the platform effect that degrades the radiation characteristic of the antenna, both interior and exterior vehicle structures are re-modeled as piece-wise mesh elements in a full-wave electromagnetic (EM) simulator. The optimum placement is found by evaluating radiation characteristics for all possible placements, and its average gain is improved by 4.7 dB, while the minimum gain is increased by 8.4 dB, compared to the conventional placement. The results demonstrate that the proposed method is suitable for maximizing the reading distance of the antenna by minimizing the platform effect.

KEY WORDS : Remote keyless entry, RKE antenna, Vehicle antenna, Mounting position, Mounting angle

1. INTRODUCTION

A growing demand for safety and convenience in commercial vehicles has brought various remote control systems into the automotive industry (Dar *et al*., 2010; Leen *et al*., 1999; Leen and Heffeman, 2002). A remote keyless entry (RKE) system is an example of a device that has become essential to provide a convenient access control for vehicle doors and other mechanical parts (Alrabady and Mahmud, 2005). The RKE system consists of a handheld radio-frequency transmitter and a receiving RKE antenna, mounted on a control unit, that communicate with each other via electromagnetic (EM) waves. Since the EM waves are easily blocked, distorted, scattered, and diffracted by a platform effect, it is difficult for the system to provide reliable operation for all directions. To overcome these difficulties, many of the previous research have focused on the design of a stand-alone RKE antenna to improve its radiation characteristics (Rabinovich *et al*., 2006; He and Xia, 2008; Oh *et al*., 2005; Al-Khateeb *et al*., 2006). Although researchers have reported good performances with a reduced size, the reading reliability of the system for all directions cannot be guaranteed without considering the platform effect. For this reason, Yegin *et al*. and Ribbenfjard *et al*. investigated performance variations according to antenna positions and mounting angles in a vehicle to minimize the platform effect for a vehicle global positioning system (GPS) (Yegin, 2007; Ribbenfjard and Lindmark, 2004). However, most of the previous studies on antenna placement are limited to either GPS or AM/FM radio systems; thus, more sophisticated studies are required for the RKE system to provide more reliable operations.

In this paper, we investigate optimization of a mounting position and angle for vehicle RKE antennas in order to achieve the maximum reading distance by minimizing the platform effect. In our approach, a full-wave EM simulator is used to consider the platform effect from the EM standpoint, and then the geometries of the antenna and the vehicle are modeled as piece-wise mesh elements. To estimate the performance of the antenna, such as reflection coefficients, gains, and radiation patterns, we also include interior structures, such as the vehicle frame, steering wheel, levers, seats, and electronic devices, which are placed close to the receiver. However, we exclude dielectric materials like leather, plastics, and glass to achieve faster analysis without significant accuracy degradation (Abou-Jaoude and Walton, 1998). Then, the radiation characteristics at each position and angle are evaluated by the average and the minimum gains to find the optimum placement. The optimized results show that the average and the minimum gains can be improved by 4.7 dB and 8.4 dB, respectively, compared to the conventional position, which demonstrates that the proposed method is suitable to be used for RKE antennas in commercial vehicles.

2. ANTENNA AND VEHICLE MODELING

Figure 1 shows the geometry of a commercial RKE antenna that consists of a helical arm and a cylindrical base. The antenna has an omni-directional radiation pattern at 433 MHz, and its detailed design parameters are specified in Table 1. For the radiating helical arm, a single line was

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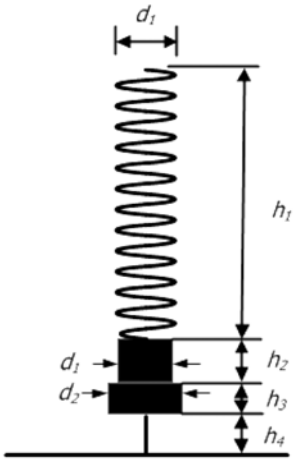


Figure 1. Geometry of the RKE antenna.

Table 1. Parameters of the RKE antenna.

Parameters	Values
h_1 (mm)	66
h_2 (mm)	5.5
h_3 (mm)	2
h_4 (mm)	5
d_1 (mm)	3
d_2 (mm)	4
Number of turns (turns)	13.5
Wire radius (mm)	0.1

used, but a folded arm can also be used to improve the matching characteristics (Steve, 2004).

Figure 2 shows the reflection coefficients of the antenna. The solid line indicates the measured data obtained by using an Agilent 8753D network analyzer in a semi-anechoic chamber, and the dashed line presents the simulated data. The antenna structure is modeled as piece-wise mesh triangles in FEKO EM simulator (EM Software and Systems, 2012) and is placed at the center of a circular ground plate whose diameter is 1.2 m. Both results show a good agreement with half power bandwidths of 83 MHz and 70 MHz for the measurement and the simulation, respectively.

Figure 3 (a) shows a top view of a commercial sport utility vehicle that has overall dimensions of 1.68 m × 4.69 m × 1.88 m (width × length × height). Since the radiation characteristic of the antenna is easily distorted by nearby objects, interior structures are also included in our simulation. However, some of the dielectric materials that have an slight effect on the antenna characteristics, e.g. car windows, tires, and interior fabrics are excluded to reduce the simulation time (Schaffner *et al*., 2011). Thus, the simulated structure is re-modeled as 24,000 piece-wise mesh triangles, each of which has an edge length of about l/7 at 433 MHz. Figure 3 (b) shows the geometry of an extended ground that is added to mount the antenna on a vehicle frame located inside the center fascia.

Figure 4 (a) shows a comparison of the measured and the simulated reflection coefficients when the antenna is mounted in the vehicle. Although the measured resonant frequency is slightly shifted toward the lower frequency band by about 5 MHz, it still shows a similar trend compared to the simulation. To examine the omni-

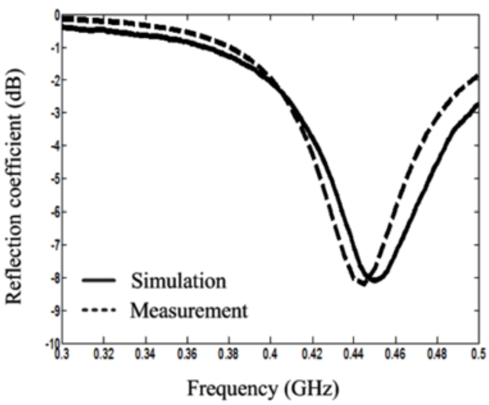
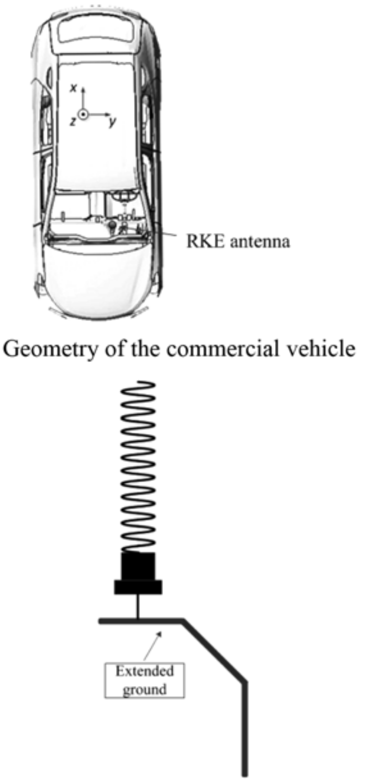


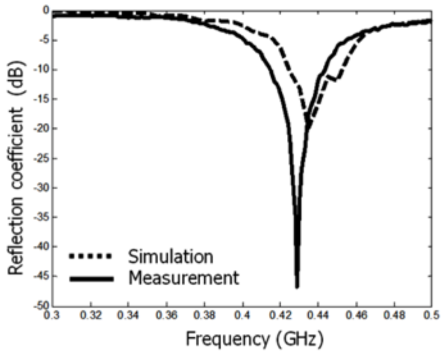
Figure 2. Reflection coefficients of the RKE antenna.



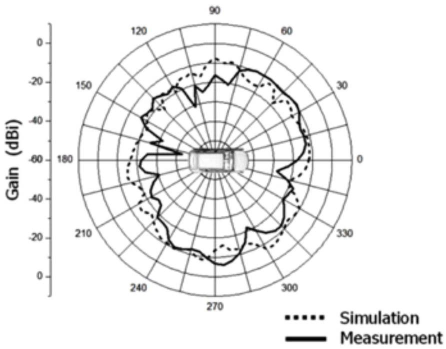
(a) Geometry of the commercial vehicle

(b) Geometry of the mounted RKE antenna

Figure 3. Geometry of a commercial vehicle and an RKE antenna.



(a) Reflection coefficient of the RKE antenna mounted in the vehicle



(b) Azimuth radiation pattern of the RKE antenna mounted in the vehicle

Figure 4. Reflection coefficients and radiation patterns of the RKE antenna mounted in the vehicle.

directional properties of the antenna, radiation patterns were measured in a semi-anechoic chamber at 433 MHz, as shown in Figure 4 (b) (Jesch, 1985; Joseph, 2010). The measured data show an average azimuth gain of –17.4 dBi with the minimum value of –42.9 dBi at f = 170º. As can be seen, the radiation gains are significantly reduced in some directions due to the platform effect. Therefore, minimizing this effect can be an important design consideration of the RKE antenna to achieve reliable performance for all the azimuth directions.

3. OPTIMIZATION OF THE POSITION AND MOUNTING ANGLE FOR THE RKE ANTENNA

To minimize the platform effect and increase the radiation gain of the antenna, its mounting position and angle is optimized by using EM simulation. Figure 5 shows the possible antenna positions below the steering wheel. P_{11} is located at (0.7 m, −0.5 m, 0.7 m), and the interval between points is 5 cm in both y- and z-directions. To evaluate each position, we first estimate the azimuth radiation gain to calculate the average values, as shown in Equation (1) (Bunlon *et al*., 2005). We also observe the minimum gain, as presented in Equation (2), to filter out some positions

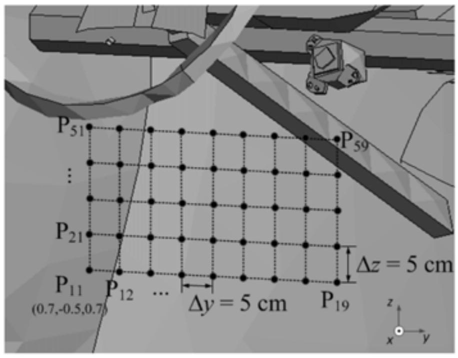


Figure 5. Positions of the mounted RKE antenna.

that have a value lower than −20 dBi.

$$\text{Average gain} = \frac{1}{N}\sum_{\phi=0}^{360^{\circ}} Gain(\phi)\Big|_{\theta=90^{\circ},\ freq=433\ \text{MHz}} \quad (1)$$

$$Minimun\ \text{gain} = Min[Gain(\phi)\Big|_{\theta=90^{\circ},\ freq=433\ \text{MHz}}] \quad (2)$$

Figure 6 shows the simulated results according to the antenna positions. The maximum average gain of −1.8 dBi can be found at P_{44} with the minimum gain of −18.8 dBi, which is greater than the filtering minimum gain value.

To further improve the radiation characteristics, the mounting angle (θ) is adjusted from 0º to 30º at an interval of 10º, as specified in Figure 7. Figure 8 shows a comparison of the simulation results between different mounting angles of $\theta = 0^{\circ}$ and $\theta = 30^{\circ}$. The mounting angle for the RKE antenna can also be an important tuning factor to mitigate the platform effect, especially when improving the minimum gain. For example, the minimum gain is significantly improved by 12.5 dB at P_{34}.

In our optimization process, all the mounting positions and angles are evaluated to find the optimum placement. Figure 9 shows a contour plot of the average radiation gains, and the maximum value is found at P_{44} (0.7 m, −0.25 m, 0.85 m) with a mounting angle of 20º. The result

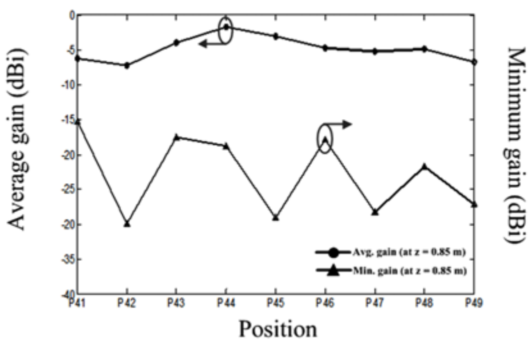


Figure 6. Simulated average and minimum azimuth gain of the RKE antenna depending on the mounting positions.

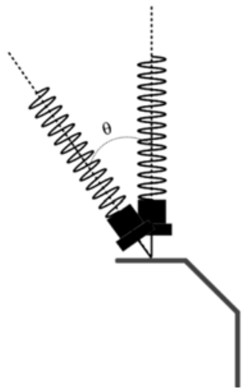


Figure 7. Geometry of the mounted RKE antenna depending on the angle.

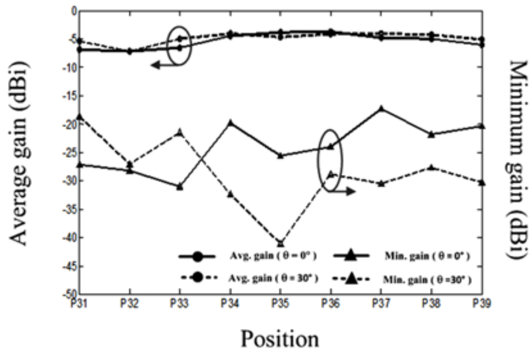


Figure 8. Simulated average and minimum azimuth gain of the RKE antenna depending on the angles.

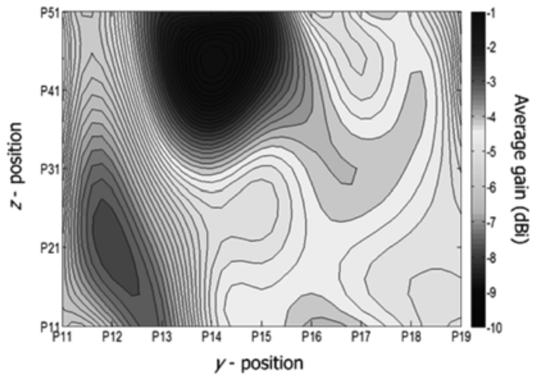


Figure 9. Average azimuth gains of the RKE antenna.

demonstrates that the position and the angle are optimized to minimize the platform effect by straying from nearby scattering objects. As a result, the average and the minimum gains are improved by 4.7 dB and 8.4 dB, respectively, compared to P_{59} ($\theta = 0^o$), which is the current position for a commercial vehicle, as shown in Figure 10.

To interpret how the optimized position and angle

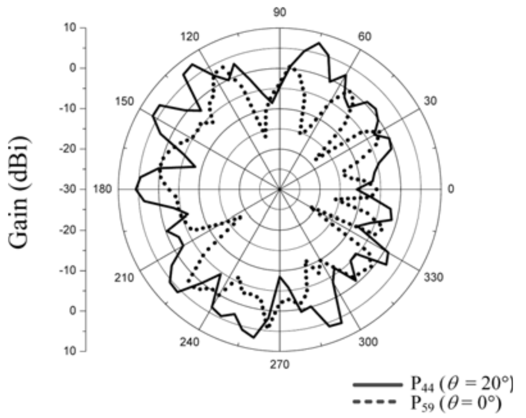


Figure 10. Characteristic of the optimization position and angle compared with the antenna mounted at P_{59}.

improves the radiation characteristics, we observe a gain variation according to the distance between the antenna and a cylindrical platform, as shown in Figure 11. In this observation, it is assumed that the first position (P_1) is located at 10 cm from the platform, and the other positions (P_2, P_3, …, P_{11}) are determined by an equivalent spacing of 5 cm. Figure 12 shows that the average gain is improved as

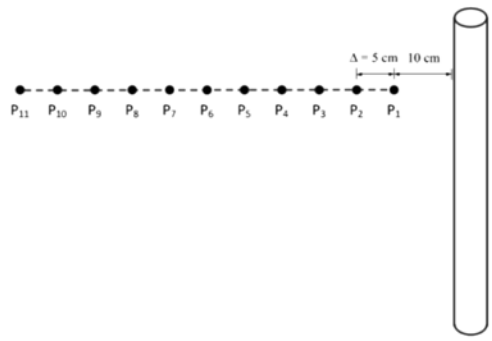


Figure 11. Antenna positions for the simulated average radiation patterns.

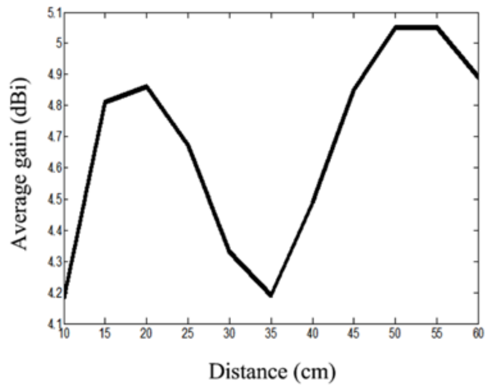


Figure 12. Average azimuth gains of the RKE antenna according to the antenna positions.

the distance becomes greater; however, the result shows a fluctuation according to the distance because of the platform effect. The maximum value is found when the antenna is located at 50 from the platform, which explains that the optimization of the mounting position and angle can improve the radiation characteristic of the antenna by minimizing the platform effect.

4. CONCLUSION

We have investigated optimization of a mounting position and angle for vehicle RKE antennas to achieve the maximum reading distance. In our approach, we evaluated each mounting position and angle with the average and the minimum radiation gain that were obtained from a full-wave FEKO EM simulator. To take the platform effect into consideration, both interior and exterior vehicle structures were re-modeled as piece-wise mesh elements. The optimum placement was found by evaluating all the possible mounting positions and angles with their radiation characteristics, and its average gain and the minimum gain were improved by 4.7 dB and 8.4 dB, respectively, compared to the conventional placement. The results demonstrate that the proposed method is suitable to be used to optimize the radiation characteristics of RKE antennas in commercial vehicles.

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