Simulations of Radiation from an Antenna contained in a Tire equipped with Carcass

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1. Introduction

In order to ensure driving safety, tire pressure monitoring systems (TPMS) have been introduced in the US and Europe. In Japan, the AIRwatch system has been developed [1] by The Yokohama Rubber Co.,Ltd.. In the AIRwatch system, a very small antenna for the tire pressure sensors was required at the frequency of 315MHz. The antenna gain needed to be high for saving the battery power. Hence, a small normal mode helical antenna (NMHA) was developed [2]. On the other hand, car tires have a variety of configurations. As the electrically severest case, tires with carcass are considered.

In this paper, effects of carcass on radiation characteristics of the NMHA contained in a tire are studied. Radiation patterns of the NMHA are compared to that of a tire-mounted antenna. Moreover, electric field distributions around a tire are calculated. Mechanisms of producing radiation from the carcass tire are clarified.

2. The AIRwatch System

The AIRwatch system is shown in Fig.1. Transmitters connected to tire pressure sensors are mounted on wheels. A receiver unit is placed on a dashboard. A receiving antenna (film antenna) is attached on a windshield. Each of the sensors modulates 315MHz continuous waves with air pressure data by using the FSK scheme. The modulated waves are transmitted from the small loop antenna in the sensor. The receiving antenna collects all the transmitted waves. The pressure levels are indicated on the receiver unit.

3. Simulation Conditions

Fig.2 shows the structure of a tire containing tire carcass. Fundamental metallic parts of the tire are a wheel and a tire belt. The tire belt is composed of thin mesh wires and is modelled as a thin metallic plate. Enforcing wires called tire carcass are contained on both sides of the tire to support heavy weight.

Fig.3 shows the NMHA used as the transmitting antenna. This antenna is well known for having the electric current source (I) and the magnetic current source (J) as indicated in the figure. The size of the NMHA is 12.5mm (0.01 wavelength) in diameter. Since the input impedance is very small, a tap is added to the NMHA in order to achieve impedance matching to 50Ω.

Table 1 shows simulation parameters. A personal computer was used in the simulations. The electromagnetic simulator FEKO was used. In the MoM procedure, metallic surfaces are divided into small segments (mesh). Currents on the meshes are calculated precisely. Mesh sizes are selected adequately depending on the sizes of the metallic parts. The number of wires of tire carcass was set at 288. Although the actual number is several times more than that, this value was selected for reasons of calculation time. The unknown number of the current sources was 14,014. The calculation required nearly 2 hours and the memory usage of 1.47G bytes.

4. Radiation Characteristics

First of all, radiation characteristics of the NMHA are shown in Fig.4. The Eϕ component corresponds to radiation from the magnetic current sources. The Eθ component corresponds to radiation from the electric current sources. In the case of the NMHA in Fig.3, the Eθ component becomes the major radiation element.

Fig.5 shows radiation characteristics of the NMHA contained in a tire without carcass. The Eϕ component becomes the major radiation element. In this case, the electric current sources are suppressed by the effects of surrounding metallic parts. On the other hand, the magnetic current sources are enhanced by the effects of metallic surroundings. About -5.7dBd gain is achieved.

In Fig.6, radiation of with carcass is shown. The Eϕ component is reduced to -21.6dBd. The reduction value is about 16dB. This reduction is attributed to an effect of shielding by carcass. The antenna input impedance of with and without carcass is shown in Fig.7. The effect of carcass is rather small.

5. Electric Field Distributions

Next, the effect of carcass is studied through electric field distributions. In Fig.8, electric field distributions inside a tire are expressed. Around the antenna, electric field vectors are directed towards the radial directions. This direction coincides with the carcass wire. So, radiation from the electric fields near the antenna is suppressed by carcass. On the other hand, at the top and bottom positions, the electric field vectors become perpendicular to carcass wires. So, at the top and bottom positions, radiation from the electric fields is not prevented by carcass wires. As a result, radiation is directed towards top and bottom directions as shown in Fig.6(a).

Finally, electric field distributions around the tire are shown in Fig.9 and Fig.10 in the case of without and with carcass respectively. In Fig.9, electric fields expand towards the horizontal direction. In Fig.10, electric fields expand towards the horizontal and vertical directions. The effect of carcass can be clearly recognized.

6. Conclusions

Effects of carcass on radiation from an antenna contained in a tire are clarified.

·As for radiation intensity, radiation level is decreased by about 16dB by carcass.

·As for electric fields, electric field vectors near the NMHA become parallel to carcass wires. So, radiation towards the horizontal direction is suppressed.

·Electric field vectors at top and bottom positions of a tire become perpendicular to carcass wires. So, radiation towards the vertical direction survives.

·By the near field distribution of electric fields, radiation mechanisms are clearly understood graphically.

References

[1] K.Tanoshita, K.Nakatani, and Y.Yamada, “Electric Field Simulations around a Car of the Tire Pressure Monitoring System”, IEICE TRANS. COMMUN., vol.E90-B, N.9, pp.2416-2422, Sep.2007.

[2] Nguyen Quoc Dinh, N.Michishita, Y.Yamada and K.Nakatani, “Development of a Very Small Normal Mode Helical Antenna for the Tire Pressure Sensor of TPMS”, ISAP2008, No.1645313, Oct.2008.

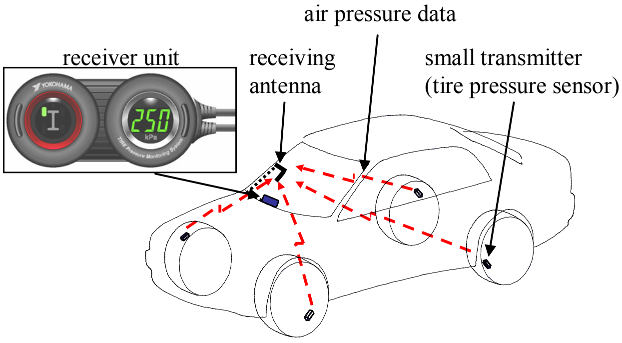


Figure 1. The AIRwatch system

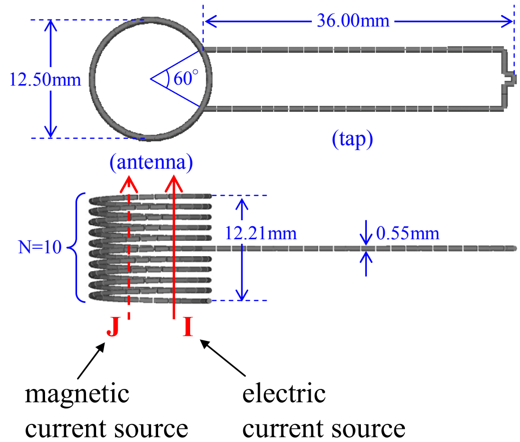
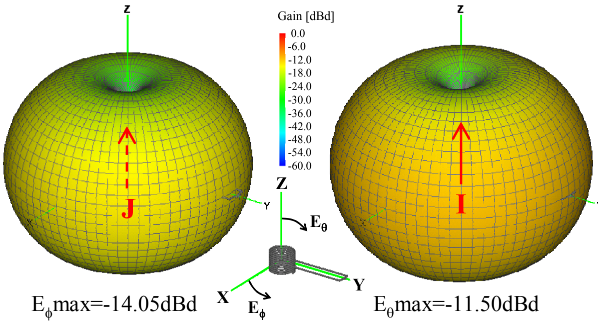
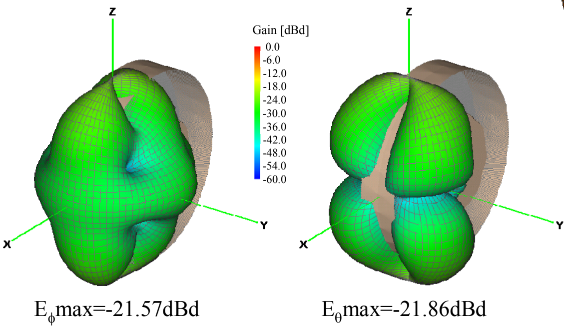


Figure 3. The NMHA used as the transmitting antenna



(a) E_ϕ component (b) E_θ component

Figure 4. Radiation characteristics of the NMHA



(a) E_ϕ component (b) E_θ component

Figure 6. Radiation of with carcass

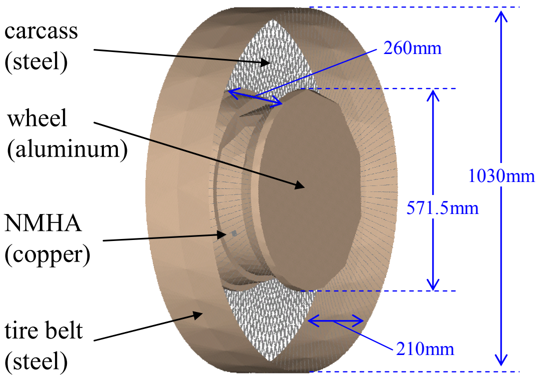


Figure 2. The structure of a tire containing tire carcass

Table 1. Simulation parameters

<table>
<tr><td>CPU clock</td><td colspan="2">Intel® Xeon® CPU 2.80 GHz</td></tr>
<tr><td>CPU memory</td><td colspan="2">8.0 GB RAM</td></tr>
<tr><td>simulator</td><td colspan="2">FEKO (MoM)</td></tr>
<tr><td>frequency</td><td colspan="2">314.932 MHz</td></tr>
<tr><td rowspan="5">mesh size</td><td>antenna</td><td>1/600 wavelength</td></tr>
<tr><td rowspan="2">wheel</td><td>1/100 wavelength (near antenna)</td></tr>
<tr><td rowspan="2">1/5 wavelength</td></tr>
<tr><td>tire belt</td></tr>
<tr><td>carcass:288</td><td>1/50 wavelength</td></tr>
<tr><td>total cell number</td><td colspan="2">11,750</td></tr>
<tr><td>unknown</td><td colspan="2">14,014</td></tr>
<tr><td>memory usage</td><td colspan="2">1.47G bytes</td></tr>
<tr><td>calculation time</td><td colspan="2">7,034 seconds</td></tr>
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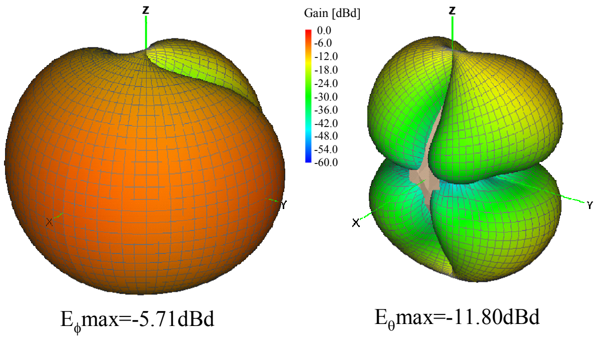

(a) E_ϕ component (b) E_θ component

Figure 5. Radiation characteristics of the NMHA contained in a tire without carcass

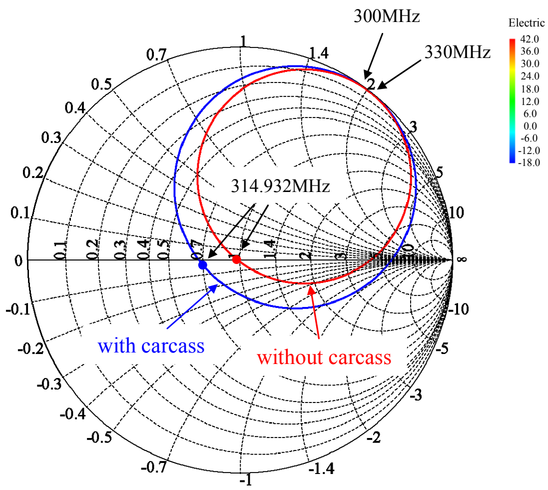

Figure 7. The antenna input impedance of with and without carcass

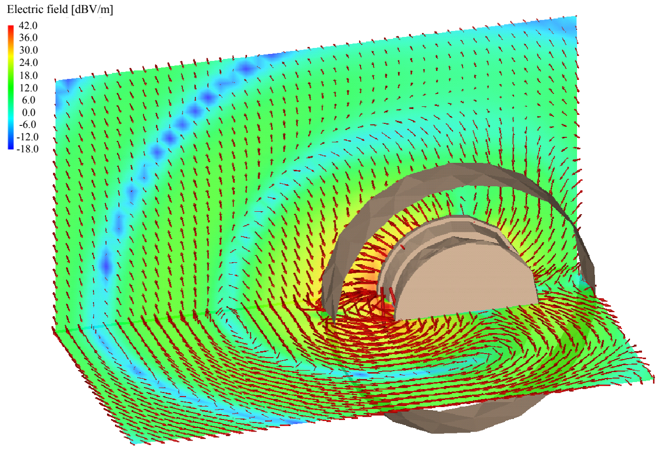

Figure 9. Electric field distributions around the tire without carcass

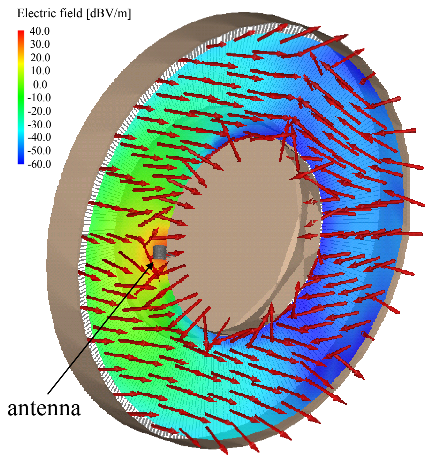

Figure 8. Electric field distributions inside a tire

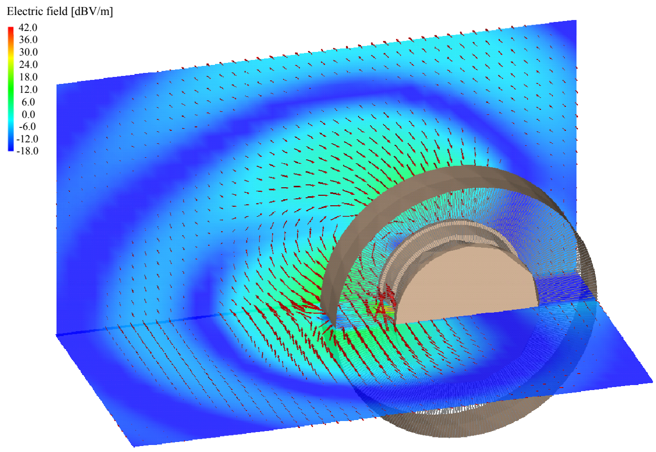

Figure 10. Electric field distributions around the tire with carcass