Helmet-Mounted Inverted-F Antenna at VHF Band

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Abstract. A helmet for disaster prevention must be worn to prevent secondary disasters in rescue and evacuation activities when a disaster occurs. Helmet antennas have been widely developed as wearable antennas. In this paper, we investigated the effect of ohmic loss due to the material of the hemispherical conductor. In addition, the validity of the simulation results was verified through experiment. The loading position of the antenna element was examined to further improve the gain. As a result, the maximum gain of −2.6 dBi and the local specific absorption rate value of 0.07 W/kg was achieved at 150 MHz.

Keywords: Inverted-F antenna, Helmet antenna, Wearable antenna, Very high frequency band, Ohmic loss, Specific absorption rate

1. Introduction

A helmet for disaster prevention must be worn to prevent secondary disasters in rescue and evacuation activities when a disaster occurs. Since most of the disaster prevention radios at a very high frequency (VHF) band are transceiver type, rescue activities are greatly limited because one hand is blocked by using the disaster prevention radio. Therefore, the antenna, transceiver, earphone, microphone, etc. need to be integrated on the disaster prevention helmet. The power consumption can be saved when the antenna gain becomes high. The maximum value of the 10 g average local specific absorption rate (SAR) must be lower than the specified value of 2 W/kg [1].

The broadband and high gain antennas are required for the helmet antennas. For broadband operation, a conformal helmet antenna composed of three antennas have been developed [2]. As the single antenna at an ultra high frequency band, a microstrip antenna on the top of the helmet composed of the metal [3] and a semi-circular loop antenna on a visor [4] have been
proposed at 1.35 GHz and 449 MHz, respectively. To operate at the VHF band, a curved folded dipole antenna [5] has been proposed at 150 MHz. To enhance the antenna gain, the gain reduction due to the high dielectric loss of human head should be suppressed. An inverted-L antenna operated at 150 MHz on the metal helmet has been examined including the human head effect, and the maximum gain of −4 dBi was achieved [6]. To further enhance the gain, the arrangement and the feeding directions of the inverted-F antenna on the hemispherical metal ground plane were examined in detail through electromagnetic simulation [7]. As a result, the gain of −3 dBi was achieved in proximity to the human head.

In this paper, we investigate the effect of ohmic loss due to the material of the hemispherical conductor in [7]. In addition, the validity of the simulation results is verified through experiment. The loading position of the antenna element is examined to further improve the gain. The CST Microwave studio ver.2014 was used for electromagnetic simulation.

2. Antenna configuration

Figure 1 shows the inverted-F antenna on the hemispherical conductor and the human head model with the relative permittivity of 52.3 and the conductivity of 0.76 S/m. The hemispherical conductor has a radius of 125 mm and a thickness of 0.2 mm. An antenna element length is 460 mm, as shown in Fig. 1(a). Since the inverted-F antenna has a very low profile and operates at the VHF band, the arrangement and the feeding direction of the inverted-F antenna affect the antenna characteristics. Based on the examination in [6], the antenna configuration as shown in Fig. 1(b) is selected. The distance from the hemispherical conductor to the antenna element is 10 mm, and the distance between the antenna feed part and the short-circuit element is \( l_o = 20 \) mm. The angle of the feed position is \( \phi = 262 \text{ deg} \). The antenna element width is 3.0 mm, and the feed line spacing is 1.0 mm. To consider the fabrication of the antenna, the cylindrical rim with a radius of 2.5 mm is attached to the hemispherical conductor, as shown in Fig. 1(c). Since the antenna element is made of refined copper (pure copper), the conductivity of the antenna element in the simulation is \( 5.8 \times 10^7 \) S/m. The hemispherical conductor is made of copper alloy.
3. Effect on conductivity to antenna characteristics

Figure 2 shows the voltage standing wave ratio (VSWR) characteristics when the conductivity $\sigma$ of copper alloy composed of the hemispherical conductor is varied. The conductivities of $5.8 \times 10^7$, $5.8 \times 10^6$, and $5.8 \times 10^5$ S/m are examined. As shown in Fig. 2, the resonant frequency decreases as the conductivity decreases. The relative bandwidths at VSWR ≤ 3 with $5.8 \times 10^7$, $5.8 \times 10^6$, and $5.8 \times 10^5$ S/m are 0.41%, 0.62%, and 0.77%, respectively.

![Figure 2: VSWR characteristics](image)

![Figure 3: Radiation patterns](image)

(a) zx-plane ($\phi = 0^\circ$)  (b) xy-plane ($\theta = 90^\circ$)  (c) yz-plane ($\phi = 90^\circ$)
Figure 3 shows the radiation patterns when the conductivity of hemispherical conductor is varied. The $E_\theta$ and $E_\phi$ are the $\theta$ and $\phi$ components of the gain. The gain at $5.8 \times 10^7$, $5.8 \times 10^6$, and $5.8 \times 10^5$ S/m are $-4.4$ dBi, $-4.6$ dBi, and $-5.4$ dBi, respectively. Figure 4 shows the 10 g average local SAR distributions when the conductivity of the hemispherical conductor is varied. The input power is 0.5 W, which is the same value used in disaster prevention radios. The maximum SAR values at $5.8 \times 10^7$, $5.8 \times 10^6$, and $5.8 \times 10^5$ S/m are $0.498$ W/kg, $0.364$ W/kg, and $0.243$ W/kg, respectively.

4. Experiment

Figure 5 shows the photograph of the fabricated antenna. The antenna configuration is the same as the simulation. The head phantom is employed for experiment. Figure 6 shows the measurement setup of the open site at the National Institute of Advanced Industrial Science and Technology to measure the radiation patterns of the prototype antenna. A biconical antenna is used as the receiving antenna, and the distance between the prototype antenna and the biconical antenna is 4.70 m, and the height of the antenna is 1.50 m. Moreover, in order to reduce the influence of the reflected wave from the floor, ferrite and absorber are installed on the floor near the center between the prototype antenna and the biconical antenna.
Figure 5: Photograph of fabricated antenna

Figure 6: Measurement setup
Figure 7 shows the VSWR characteristics. The relative bandwidth of the simulated and the measured results agree well when the conductivity of the hemispherical conductor was $5.8 \times 10^5$ S/m, and the validity of the simulated result was verified. Figure 8 shows the radiation patterns. Note that the simulated $E_\theta$ component on the $xy$ plane is less than $-20$ dBi. The simulated results are in good agreement with the measured results, but the measured gain of the $E_\phi$ component on the $zx$ plane is higher than that of the simulation. The reason of this discrepancy might be the small differences of the conductivity of the hemispherical conductor and a change of a calibration state due to the passage of time. The maximum gain of $-4.1$ dBi is confirmed.
5. Improvement of antenna gain

Figure 9 shows the antenna configuration when the installation position of the antenna is varied. As shown in Fig. 9, the height $h$ is the distance from the bottom end of the hemispherical conductor to the antenna element. Figure 10 shows the VSWR characteristics at 150 MHz when the antenna height $h$ is varied from 0 mm to 80 mm. The antenna element length and the distance between the antenna feed part and the short-circuit element is adjusted to achieve the impedance matching at 150 MHz. The VSWR values at each $h$ become less than 2.
Figure 11 shows the maximum gain of the $E_\phi$ component on $xy$-plane at 150 MHz when the antenna height $h$ is varied. The gain was improved by changing the height, and the maximum gain of $-2.6$ dBi was obtained when the antenna height was 40 mm. The gain enhancement of 0.4 dB is confirmed in comparison with the [6].

Figure 12 shows the simulation results of the maximum local SAR values when the antenna height $h$ is varied. In comparison with $h = 0$ mm as shown in Fig. 4, the SAR value in the head was reduced. Since the distance between the human head and the antenna element was increased by increasing the position of the antenna element, the influence in the head direction was reduced. The maximum local SAR value was 0.07 W/kg when $h = 40$ mm. This value
satisfies the requirement of the regulation in Japan [1].

6. Conclusion

In this paper, the effect of ohmic loss due to the material of the hemispherical conductor was investigated. The validity of the simulation results was verified through experiment. The loading position of the antenna element was examined to further improve the gain. As a result, the maximum gain of −2.6 dBi and the local SAR value of 0.07 W/kg was achieved at 150 MHz.

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