Near-metal-insensitive antenna for closed space wireless communications

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Abstract: In order to obtain near-metal-insensitive antenna for closed-space wireless communications, the impedance characteristics of U-shaped folded monopole antenna is investigated in detail. In this Letter, the near-metal-insensitive means antenna VSWRs are hardly influenced by the near object, especially metal. The simulated and measured results show that the proposed higher impedance model has stronger near-metal-insensitiveness than the conventional middle impedance model. The simulated and measured results show that the antenna gains of higher impedance models are 3 dB greater at maximum than those of middle impedance models, when metal plane approaches.

Keywords: antennas, U-shaped folded monopole antenna, closed space wireless communications, near-metal-insensitive antenna, robust antenna

Classification: Antennas and Propagation

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1 Introduction

The research and development activities on wireless communication technologies are rapidly growing, not only for open space applications, but also for closed space applications [1, 2, 3]. The propagations and distributions of electric fields in closed space are more complicated than those in open space, but it is expected that those research and development will pioneer novel application fields on wireless communications.

However, the problems for closed space wireless communications are not only electric field propagations, but also antenna characteristics. It is known that the antenna impedances are strongly influenced by the near object (especially metal), so the near-metal-insensitive antennas are strongly required for closed space wireless communications [4, 5].

In this Letter, therefore, we introduce fundamental study on near-metal-insensitive antenna, by employing U-shaped folded monopole antenna (UFMA) with ground plane (GP) [6]. UFMA is a modified folded monopole antenna, so the basic impedance characteristics are depends on step up ratio [7, 8, 9], that will be defined in Section 3.

The impedance characteristics of UFMA are investigated in detail when metal object approaches and step up ratio is controlled in order to enhance near-metal-insensitive characteristics. In addition to simulated results [10], measured results will be shown and compared.

2 Antenna structures

The structure of investigated UFMA is shown in Fig. 1(a). The antenna element is composed of two parallel metal strips with widths $w_{a1}$ and $w_{a2}$. Two strips are short-connected by metal strips with width $w_{a3}$ and length $s_a$, at one side.
At the other side, one strip with width $w_{a1}$ is connected to GP and the other strip with width $w_{a2}$ is connected to feed point. The total length of two metal strips is $l_a + h$, and they are folded to keep low profile antenna with height $h$. The antenna impedance can be changed by step up ratio. The parameter values shown in Fig. 1(a) are selected in order to obtain VSWR $\leq 3$ at 2.4 GHz with bandwidth 10 MHz, when there is no infinite plane.

The antenna element is placed on the GP (50 mm x 80 mm), which models printed circuit board of electronic control unit. Therefore, considering the mounting space and the layout flexibility of electronic components, the placement of the antenna elements is preferably the edge of GP.

We assumed installation image of UFMA is shown in Fig. 1(b). The infinite plane (perfect conductor) of Fig. 1(a), which models metal wall of closed space, is located in parallel to GP. The distance between GP and infinite plane is defined as $h_{gp}$, and changed in order to investigate the near-metal-insensitive characteristics of the antenna.

![Diagram of antenna mounted on ECU and assumed installation image](image)

Fig. 1. UFMA.

### 3 Impedance characteristic [7]

The input impedance characteristics of the UFMA are investigated in this chapter, when $h_{gp}$ values are changed. The simulated results using FEKO simulation, based on method of moment and measured results are shown and compared. For the measurement, Cu plane with size 400 mm x 635 mm is placed near the antenna, instead of infinite plane for simulation. The input impedance of the folded monopole antenna $Z$ is expressed by equation (1).

$$Z = (1 + a)^2 Z_m$$  \hspace{1cm} (1)

Where $Z_m$ is impedance of the monopole antenna ($Z_m = 9.2 \Omega$, in case of Fig. 1(a)), $(1 + a)^2$ is step up ratio. The $a$ value is obtained from (2) and (3).
\[
\begin{align*}
    a &= \frac{\ln\left(4c + 2\sqrt{(2c)^2 - \left(\frac{w_{a2}}{2}\right)^2}\right) - \ln(w_{a2})}{\ln\left(4c + 2\sqrt{(2c)^2 - \left(\frac{w_{a1}}{2}\right)^2}\right) - \ln(w_{a1})} \\
    c &= \frac{\frac{w_{a1} + w_{a2}}{2} + s_a}{2}
\end{align*}
\] (2)

Where the \(w_{a1}, w_{a2},\) and \(s_a\) are indicated in Fig. 1(a). The step up ratio is determined by \(w_{a1}, w_{a2},\) and \(s_a\).

3.1 Middle impedance model

The UFMA with parameter values shown in Fig. 1(a) is referred to as middle impedance model (MIM), as it is designed to obtain 37 \(\Omega\) at 2.4 GHz when there is no infinite plane \((hgp = \infty)\). In MIM, the step up ratio value calculated from equations (1)–(3) is 4 [7]. The simulated and measured VSWRs of MIM are shown in Fig. 2(a) and (b). The relevant Smith Charts are also shown inset. Fig. 2(a) shows that VSWR \(\leq 3\) is satisfied at 2.4 GHz when \(hgp = 16\) mm. However, as are shown Fig. 2(b), VSWR \(\leq 3\) cannot be satisfied at 2.4 GHz when \(hgp = 4\) mm. We can say that the measured VSWR values agree well with simulated VSWR values.

The Smith Charts in Fig. 2(a) and (b) indicate that the larger VSWRs with \(hgp = 4\) mm is caused by lower antenna impedances that those with \(hgp = 16\) mm. So we can say that this is the influence of the infinite plane coming close to parallel with the horizontal element of length \(l_a\) and the radiation resistance is reduced due to the generation of the image current. Therefore, we expect that, if we can obtain higher antenna impedance by adjusting step up ratio, the reduced impedance will be cancelled and the antenna will be more near-metal-insensitive than MIM.

3.2 High impedance model

In order to obtain higher antenna impedance, we changed parameters shown in Fig. 1(a). \(w_{a1} = 2\) mm and \(w_{a2} = 0.2\) mm are selected to obtain higher step up ratio. \(l_a = 26\) mm is selected for frequency adjustment, but other parameters are not changed from Fig. 1(a), and the antenna is referred to as higher impedance model (HIM). In HIM, the step up ratio value calculated from equations (1)–(3) is 13.8 [7], and the impedance value is 126 \(\Omega\) at 2.4 GHz when there is no infinite plane \((hgp = \infty)\). Fig. 2(c) and (d) show the VSWRs and Smith Charts of simulated and measured of HIM. Fig. 2(c) shows that the antenna impedance of HIM is higher than that of MIM, but VSWR \(\leq 3\) is satisfied when \(hgp = 16\) mm. Fig. 2(d) shows that antenna impedance with \(hgp = 4\) mm is lower than that with \(hgp = 16\) mm, as are observed in Fig. 2(a) and (b). However, due to higher impedance with \(hgp = \infty\), VSWR \(\leq 3\) is satisfied even when \(hgp = 4\) mm. Regarding the bandwidth, HIM became narrower than that of MIM.

The simulated and measured VSWR values vs. \(hgp\) values at 2.4 GHz are summarized in Fig. 2(e). We can say that, in order to obtain VSWR \(\leq 3\), \(hgp \geq\)
5 mm is necessary for MIM. However, $h_{gp} \geq 2$ mm is acceptable for HIM. HIM is more robust against nearby metal than MIM.

4 Radiation characteristics

The simulated and measured radiation patterns of UFMAs in H-plane at 2.4 GHz, when $h_{gp} = 4$ mm, 16 mm are shown in Fig. 3. Fig. 3(a) and (b) is xz-plane radiation patterns for MIM and Fig. 3(c) and (d) is xz-plane radiation patterns for HIM, respectively. The definitions of $x/y/z$ axes are shown inset, and maximum radiation is observed toward 0 or $+30$ degree.

Fig. 3(e) shows the simulated and measured antenna gains of maximum radiation direction vs. $h_{gp}$ values at 2.4 GHz. We can say that the antenna gain of HIM is greater than that of MIM in $h_{gp} \leq 6$ mm. The difference of antenna gain between MIM and HIM is the 3 dB at maximum in $h_{gp} \leq 6$ mm.
5 Conclusion

We investigated impedance characteristics of UFMA, in order to obtain near-metal-insensitive antenna for closed-space wireless communications. The simulated and measured results show that the antenna impedance changes to small value when metal plane approaches. To encounter this problem, we proposed higher impedance model by selecting step up ratio. The limitation value in order to obtain $\text{VSWR} \leq 3$ is $5\text{ mm}$ for the conventional MIM and $2\text{ mm}$ for the proposed HIM, respectively.

The simulated and measured results show that the antenna gains of HIM are $3\text{ dB}$ greater at maximum than those of MIM.

Fig. 3. Simulated and measured radiation characteristics of UFMAs at 2.4 GHz.