INPUT IMPEDANCE CHARACTERISTICS OF SMALL RECTANGULAR LOOP ANTENNA

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INTRODUCTION

Small rectangular loop antennas are widely used in personal radio equipment (like pagers), because their efficiencies remain high near the human body[1]. Most antennas are about 0.1 to 0.2 wavelengths(λ) in circumference. For such antennas, however, the optimal location of the feed point has not been studied in detail[2][3].

This paper numerically solves the input impedance of rectangular loop antennas 0.2λ in circumference with various aspect ratios. On the basis of the results so obtained, the radiation resistance dependency on the location of the feed point is examined when the antenna is placed in free space and near an infinite perfectly conductive plane. The latter is a rough approximation of the human body. As a result, the best arrangement of the feed point is shown for this type of loop antenna.

Analysis Models

The analysis models are shown in Fig.1. The length of each segment is $3.1\times10^{-3}\lambda$, and the diameter is $2.5\times10^{-4}\lambda$. Each model has a different feed point as follows:

Model (i) The feed point is placed at the center of the short side of the loop antenna in free space.
Model (ii) The feed point is placed at the center of the long side in free space.
Model (iii) The long side of model (i) is parallel to an infinite conductive plane.
Model (iv) The long side of model (ii) is parallel to an infinite conductive plane and the feed point is placed against the plane.
Model (v) The long side of model (iii) is parallel to the plane and the feed point is placed away from the plane.

Impedance characteristics in free space

Figure 2(a) shows the dependency of the input resistance on the aspect ratio. When the aspect ratio increases with a constant circumference, the loop area decreases. The input resistance of a small loop antenna is given by Eq.(1) [1].

$$R_{in}=\frac{320\pi^4}{\lambda^4}A^2, \qquad (1)$$

where **A** is the loop area. The area $\mathbf{A_0}$ of the square loop is equal to $\mathbf{l_0^2}$ ($\mathbf{l_0}$ is the side length). The area $\mathbf{A_n}$ of the rectangular loop at the aspect ratio of **n**, (which is the ratio of the long side length to the short side length), is equal to $\mathbf{nl_a^2}$ ($\mathbf{l_a}$ is the short side length). Since $2l_0$ is equal to $(n+1)l_a$, by substituting A_0 and A_n into Eq.(1), the input resistance R_n (the input resistance at an aspect ratio of n) is given by Eq.(2).

$$R_n = \frac{16n^2}{(n+1)^4} R_0, \tag{2}$$

where R_0 is the resistance of a square antenna.
The dotted line in Fig.2(a) shows the input resistance according to Eq.(2). The resistance of the square loop given by the dotted line was calculated by the moment method. For model (i), the calculated resistances almost agree with Eq.(2). On the other hand, for model (ii), the more the aspect ratio increases, the larger the difference between the calculated resistance and Eq.(2) becomes. The resistance of model (ii) is about twice that of Eq.(2) at the aspect ratio of 4.

Figure 2(b) shows the dependence of the reactances on the aspect ratio. The reactance of a rectangular loop antenna is given by Eq.(3) [1].

$$X_{in} = \frac{\mu_0}{\pi} [\, l_b \ln\{\frac{2A}{a(l_b+l_c)}\} + l_a \ln\{\frac{2A}{a(l_a+l_c)}\} + 2\{\, a + l_c - (\, l_a + l_b)\,\}\,], \tag{3}$$

where $l_c = \sqrt{l_a^2 + l_b^2}$, A is the loop area, l_a and l_b are the long and short side length of the loop antenna, a is the radius of the antenna element.
The dotted line in Fig.2(b) shows the input reactance according to Eq.(3). The reactance of the square loop given by the dotted line was calculated by the moment method. The reactance of model (ii) almost agrees with that of model (i) since the difference is less than 30Ω. There is a 50Ω difference in the reactance given by Eq.(3) and the value calculated by the moment method at the aspect ratio of unity, but as the aspect ratio increases, the difference decreases.

Input impedance characteristics near an infinite conductive plane

Figure 3(a) shows the relationship between the input resistance and the aspect ratio near an infinite conductive plane. The distance between the loop antenna and the conductive plane is 0.01λ (shown in Fig.1). Models (iii) and (iv) have the largest resistances, except at aspect ratios between 1 to 2, but the difference is less than 0.06Ω. Model (v)'s resistance is only half that of models (iii) and (iv). Compared to the resistances of these models in free space, for a square loop, the resistances of model (iii) and model (iv) are almost twice the equivalent value in free space. The resistance of model (v) is only 0.02Ω larger than that calculated for free space. At an aspect ratio of 5, the difference between model (iii) (and model (iv)) and model (ii) is zero. As the aspect ratio is increased, the resistances of models (iii) and (iv) decrease to less than that of model (ii). The resistances of models (iii) and (iv) are twice that of model (i) . The resistance of model (v) is equal to that of model (i) over all aspect ratios considered.

Figure 3(b) shows the relationship between the input reactance and the aspect ratio. The dependence of the reactance characteristic on the aspect ratio is almost the same for models (iii) and (iv), the difference is less than 20Ω. These reactances also agree with the values calculated for free space (models (i) and (ii)). The reactance of model (v) is about 100Ω less than those of the other models. The dependency of the reactance on aspect ratio is almost the same for all models.

Input resistance for aspect ratio and feed point.

The calculated resistances express the radiation resistances of the antennas. The antenna efficiency η is given by Eq.(4)[1].

$$\eta = \frac{R_r}{R_r + R_{loss}}, \quad (4)$$

where R_r is the radiation resistance and R_{loss} is the ohmic loss.

Since R_{loss} is constant because the circumferential length is constant, the more the input resistance increases, the more the radiation efficiency increases. As a result of the above discussion, the resistance of model (ii) is larger than that of model (i) in free space. Near an infinite conductive plane, the resistances of model (iii) and (iv) are larger than that of model (v). Therefore, the feed point of a small rectangular loop antenna should be placed at the center of the long side, it is also found that when the antenna is placed near an infinite conductive plane, the feed point should be placed against the conductive plane. With this arrangement, the antenna efficiency near an infinite conductive plane increases than over that in free space at aspect ratios less than 5; however, this situation is reversed if the aspect ratio exceeds 5.

Conclusion

The relationship between the feed point location and the input impedance was analyzed for small rectangular loop antennas in free space and placed near an infinite perfect conductive plane. It was found that the optimum antenna feed point location is placed at the center of the long side. Moreover, when the antenna is placed near an infinite conductive plane, the optimum feed point location is at the center of the long side next to the conductive plane, i.e.,model (iv). With this arrangement, antenna efficiency is increased by the presence of an infinite conductive plane at aspect ratios less than 5. However, efficiency is decreased by the same presence if the aspect ratio exceeds 5.

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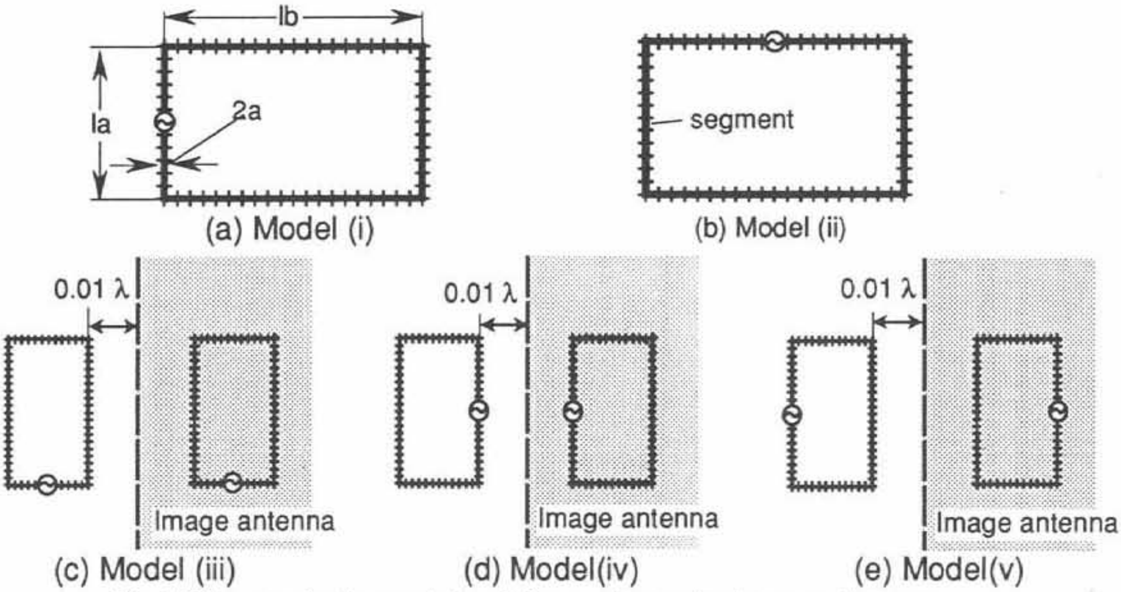

Fig.1 The analysis models of the rectangular loop antennas.
((a) and (b) are in free space , (c),(d) and (e) are near an infinite conductive plane.)

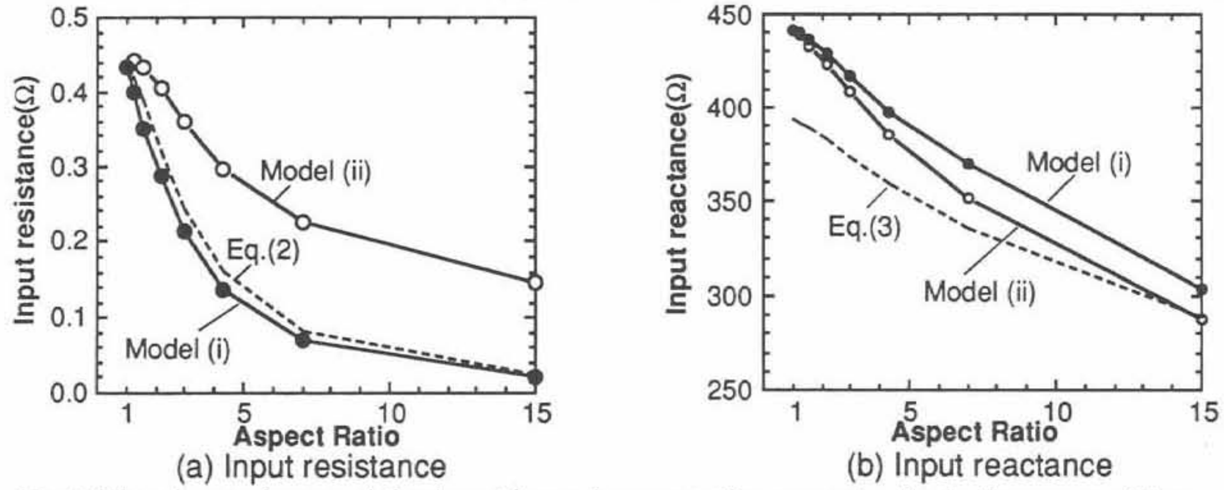

Fig.2 The dependence of the input impedance on the aspect ratio in the case of the rectangular loop antenna in free space.(0.2 λ in circumference, $2a=2.5\times10^{-4}\lambda$)

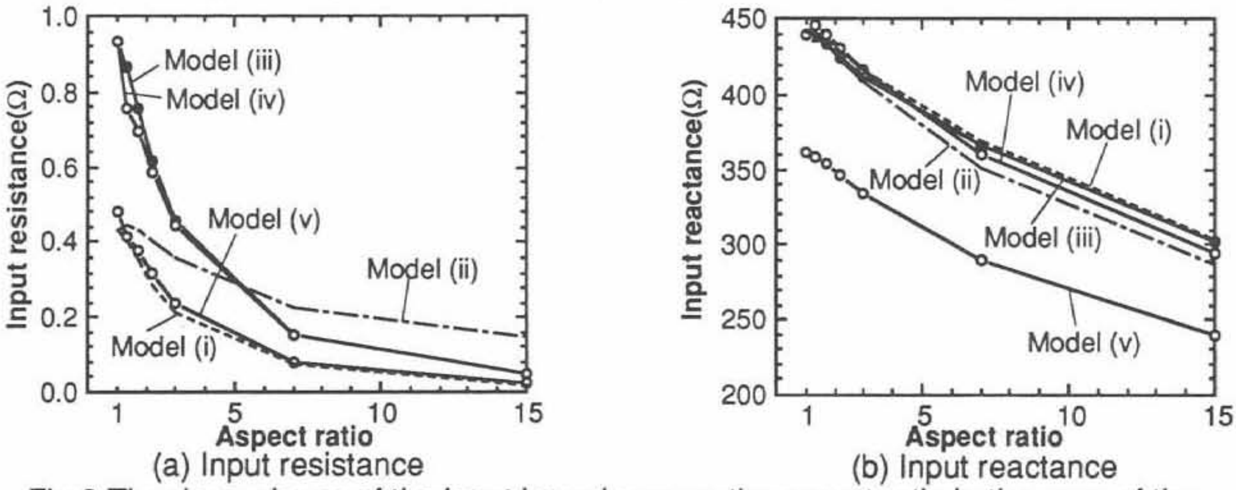

Fig.3 The dependence of the input impedance on the aspect ratio in the case of the rectangular loop antenna near an infinite conductive plane.