Design and performance of electrically small planar antennas with matching circuit at 2.4GHz band

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1. Introduction

In recent years, the miniaturization of antennas is essential in radio communication devices such as wireless LAN, RF-ID, and MIMO, and extensive studies are made of an electrically small antenna (ESA), i.e., the antenna whose dimension is much smaller than one-wavelength, towards further reduction of the antenna size[1]-[3]. It is widely known that small antenna has an extremely narrow bandwidth, low radiation resistance and large impedance mismatch. So, we must simultaneously implement a broadband impedance matching circuit. Moreover, the small antenna is sensitive to the conductor resistance because of its low radiation resistance, and the decrease of the radiation efficiency often makes serious problem. However, there are almost no reports about the details of the relations between the radiation resistance, realized gain and efficiency of the small antenna.

In this paper, we design some ESAs with impedance matching circuit, which have various gains, and discuss about the relations between peak realized gains and *s* parameters. The substrate has dielectric constant ε_r=4.25 and $tan\delta$=0.015. The thickness of the substrate and copper top metal is 0.8mm and 18μm. By using the impedance matching circuit, we can reduce the total antenna size more than one-wavelength. So, we designed the ESAs at 2.45GHz and fractional bandwidth 3%. Also, we carried out experiments on the ESAs and compared experimental results and simulated results.

2. Design theory of the electrically small antenna (ESA)

We design the ESAs with impedance matching circuit at 2.45GHz, whose antenna size are $0.09\lambda_0$*$0.09\lambda_0$ (ESA1) and $0.24\lambda_0$*$0.16\lambda_0$(ESA2), respectively. Antenna ESA2 has a larger gain. Fig.1 shows the layout of ESA1 with impedance matching circuit. In Fig.1, the impedance matching circuit is composed of admittance (*J*)-inverter and the transmission line from the slot antenna[4]. The input impedance of the ESA is designed to be Z_0=50 Ω for the experiment to be convenient. Fig.2 shows the input impedance

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(Z_{in}) and Fig.3 shows the return loss of ESA1. Simulated Z_{in} is almost 50Ω around 2.45GHz, so that, return loss is –43.3dB at 2.45GHz. The antenna gain of ESA1 is –2.49dBi at 2.45GHz, where the antenna gain includes conductor loss and impedance matching loss. Fig.4 shows the layout of ESA2 with impedance matching circuit. In the ESA, the antenna gain can be controlled by L_{top_metal} (see Fig.5). According to Fig.5, antenna optimization was performed resulting in ESA2 design whose antenna gain is around 0dBi. Fig.6 shows the input impedance (Z_{in}) and Fig.7 shows the return loss. Simulated Z_{in} is almost 50Ω around 2.45GHz, so that, return loss is –37.7dB at 2.45GHz. The antenna gain of ESA2 is –0.62dBi at 2.45GHz.

3.Experimental results

The ESAs are fabricated on FR4 substrate. Fig.8 shows the photographs of ESA1 and ESA2. We measured S-parameters by using a vector network analyzer (VNA) and compared the experimental results with the simulated results of the return loss and antenna gain. Transmitted and received power (P_t and P_r) are given by,

$$P_r = |S_{21}|^2 P_t = \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r P_t \tag{1}$$

, where G_t and G_r is antenna gain, and input power from VNA is 0dBm and distance between antennas(d) is 0.23m. We calculated the experimental results of antenna gain by measured values of S21 [dB] in e.q. (1). Fig.9 and Fig.10 show the comparison of the return loss and antenna gain between the experimental results and simulated results. In Fig.9 (a), it seems that the center frequency shifts 32.5MHz to lower side and the return loss at the center frequency is –26.5dB. The observed disparity between experimental and simulation results is caused by an error of dielectric constant of the FR4 substrate and contact loss between connector and antenna. If ε_r is changed from 4.25 to 4.1, the experimental results and simulation values are matching well. These results are showed in Fig.9 (a). In Fig.9 (b), it seems that the center frequency for simulation and experiment is the same but the return loss at the center frequency is –8.48dB. The observed disparity of experimental result is caused by contact loss of the connection between connector and antenna. In Fig.10, measured antenna gains are near simulated gain in the passband, although the gain without passband is different from simulation.

4.Conclusions

In this paper, we designed and tested ESAs with impedance matching circuits having different gain. We succeeded in implementing the circuit which matches the small radiation resistance of ESA to amplifier. Measured results are close to the simulation value. So we proved possibility to design and fabricate ESA with high radiation efficiency.

References

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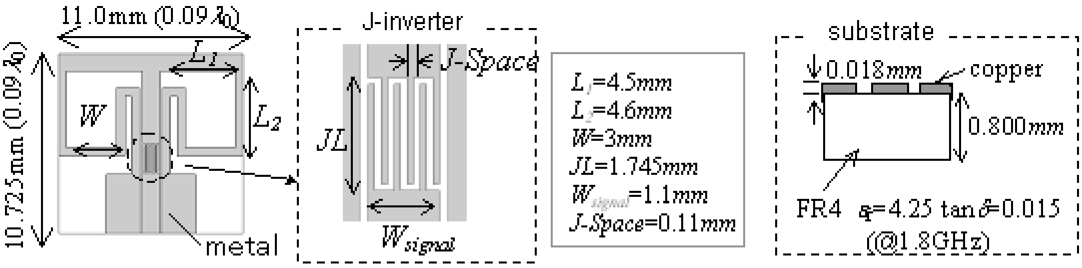


Fig.1 Layout of ESA1.

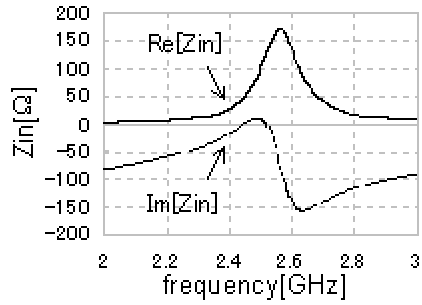


Fig.2 Input impedance (Z_{in}).

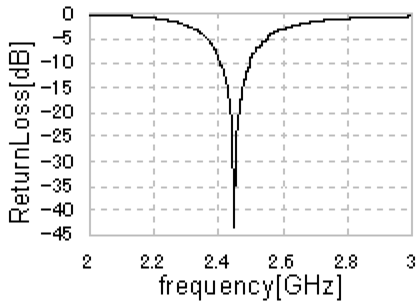


Fig.3 Return loss.

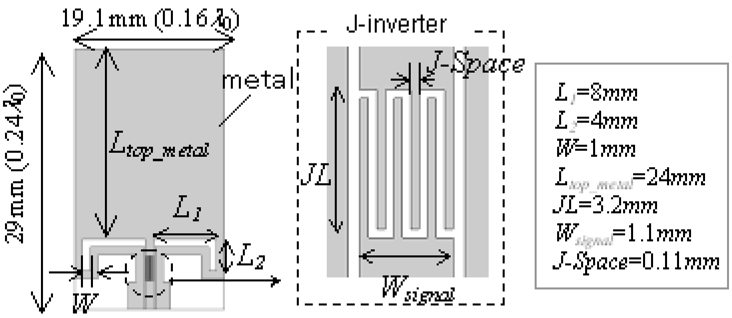


Fig.4 Layout of ESA2.

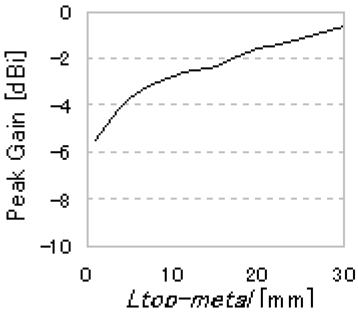


Fig.5 $L_{top\text{-}metal}$ vs. antenna gain

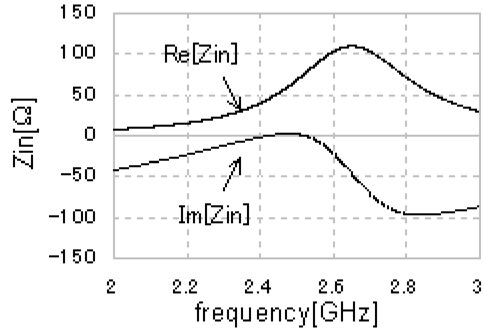


Fig.6 Input impedance (Z_{in}).

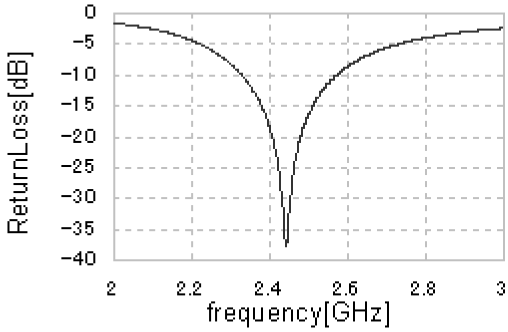
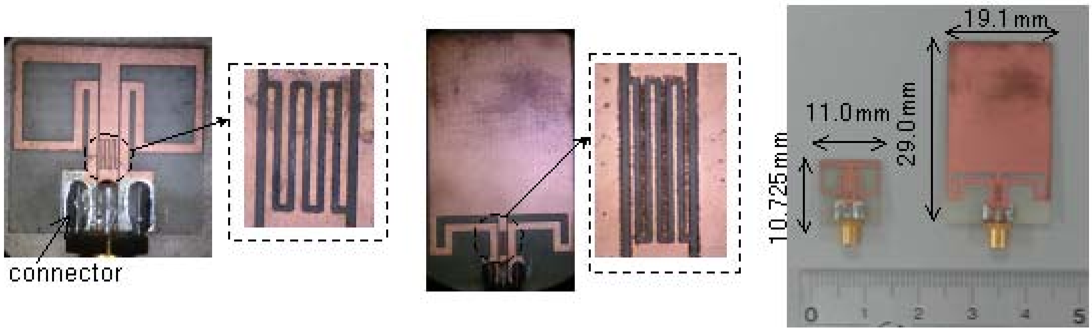
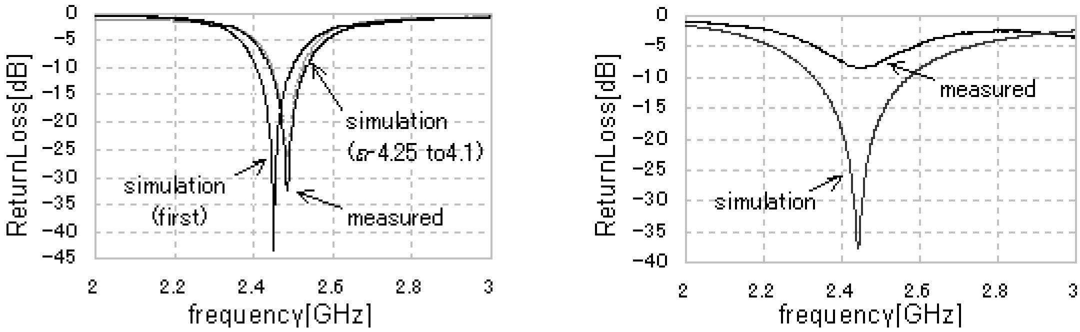


Fig.7 Return loss.



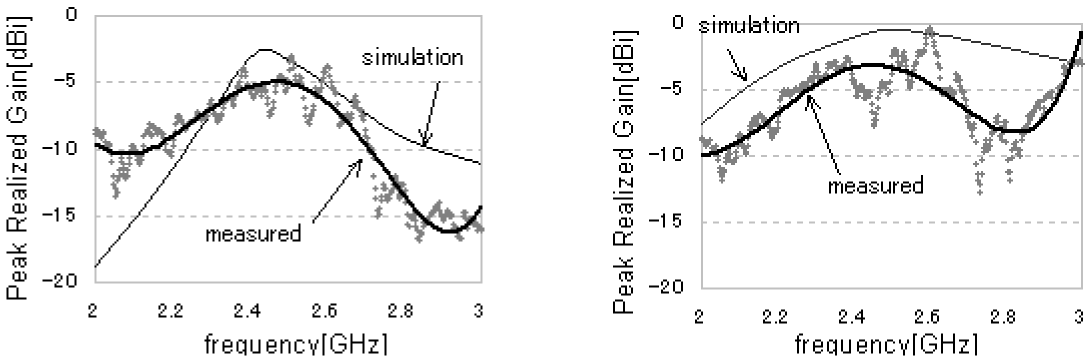
(a) ESA1 (b) ESA2 (c) ESA1 and ESA2

Fig.8 photographs of ESA1 and ESA2.



(a) ESA1 (b) ESA2

Fig.9 Comparison of the return loss between the experimental results and simulated results.



(a) ESA1 (b) ESA2

Fig.10 Comparison of the antenna gain between the experimental results and simulated results.