Development of a One-Sided Directional Thin Planar Antenna with Quarter Wavelength Top Metal

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***Abstract* — This paper presents the design of thin planar one-sided directional slot antenna on patterned circuit board. Our proposed planar antenna has the matching circuit composed of coplanar waveguide (CPW) transmission line, interdigital gap, a top metal layer and a bottom floating metal layer. In order to realize the one-sided directional properties, the length of the top metal layer is adjusted, and at that time, the bottom metal layer is adjusted to the length that doesn't resonate. The final antenna size of the 300MHz specified low power wireless receiver is 137mm x 61 mm. We also fabricated the one-sided directional slot antenna using FR4, and measured the radiation pattern.**

***Index Terms* — planar antenna, one-sided directional slot antenna, specified low power wireless receiver.**

I. INTRODUCTION

In the recent specified low power radio station, 300MHz-400MHz bands are the most suitable for wireless sensor node such as RFID, medical and industrial telemeter because of the license free base station.

Antennas in the 300MHz band are considered to be the largest components of such wireless devices, so that, it is necessary to miniaturize small size and low profile antennas. Planar printed antennas such as slot antenna and microstrip antenna are attractive for their use in mobile and wireless communication systems due to their low profile compact size [1, 2].

However, for size reduction, another problem occurs. Namely, omni directional antennas such as the slot antennas are remarkably deteriorated if metal blocks like a ground plane of circuit board or body of a car approaches on the back of antenna because of the electro-magnetic interference. Patch antenna, which has large bottom ground plane, is one of the solutions to overcome these problems [3-5]. However, antenna size is decided depending on the frequency, and radiation efficiency and bandwidth of a patch antenna decreases rapidly as the thickness of the substrate decreases; therefore, miniaturization of the patch antenna is usually carried out at the cost of the substrate area and thickness.

In our previous works, we presented the design method of the one-sided directional electrically small antenna (ESA) [6, 7], whose dimension is much smaller than one-wavelength, for narrow band IMS (@2.4GHz) application with attaching floating metal layer on the bottom side and controlling the length of the λ/2 open-end top metal layer [8, 9].

In this paper, we design the one-sided directional slot antenna with λ/4 top metal layer, which is connected on the bottom metal layer, for 300MHz-band specified low power wireless application. By using the two resonances appeared from the slot and λ/4 top metal, we can realize the one-sided directional radiation. We designed and simulated by using the commercial electro-magnetic (EM) field simulator (Ansoft; HFSS, ver.10). We also carried out experiments on this antenna by using FR4 printed circuit board.

II. DESIGN OF THE ONE-SIDED DIRECTIONAL SLOT ANTENNA

Fig. 1(a) shows the layout of the conventional one-wavelength center-feed slot antenna and cross sectional view of the substrate. The substrate has dielectric constant ε_r=4.25 and tanδ = 0.015. The thickness of the substrate and copper top metal is 3.2 mm and 18 μm, respectively. Three-dimensional EM simulator simulates the RF properties. The simulated electric field distribution is also shown. Fig. 1(b) shows the simulated radiation pattern of the conventional slot antenna. This antenna has a omni-directional radiation pattern.

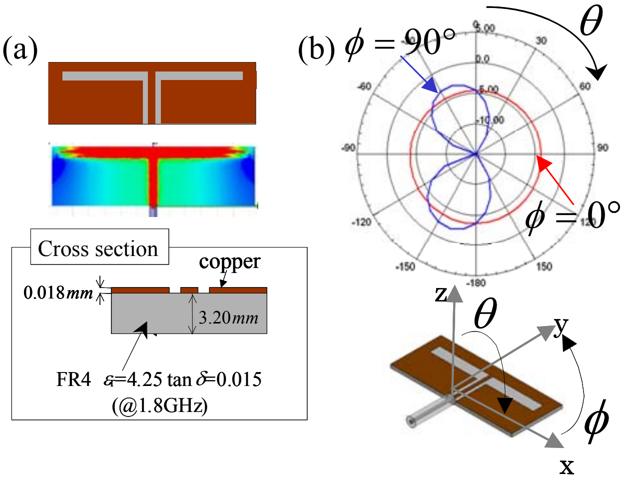

Fig. 1. Layout, electric field distribution and cross sectional view (a), and simulated radiation pattern (b) of the conventional slot antenna.

Fig. 2(a) shows the layout of the one-sided directional slot antenna with one-wavelength center feed line. Cross sectional view of the substrate is also shown. This antenna has a conductor-baked configuration. The simulated electric field distribution of top and bottom floating metal layer are also shown, respectively in Fig. 2(b). The top layer resonates, on the other hand the bottom layer doesn't resonate. So this floating conductor can suppress the radiation of the backward radiation. Fig. 2(c) shows the simulated radiation pattern of the one-sided directional antenna. The directivity for forward direction is larger than that of backward direction.

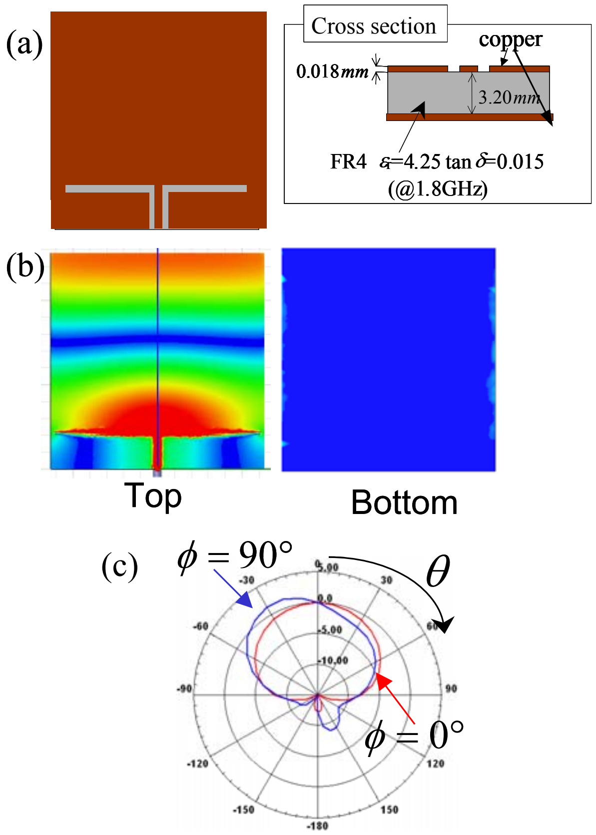

Fig. 2. Layout and cross sectional view (a), electric field distribution (b), and simulated radiation pattern (c) of the one-sided directional slot antenna.

III. DESIGN OF THE ONE-SIDED DIRECTIONAL SLOT ANTENNA WITH IMPEDANCE MATCHING CIRCUIT

For size reduction, we can adopt the design theory the electrically small antenna (ESA), namely the length of the antenna is smaller than $\lambda/4$ [6, 7]. Fig. 3 shows the equivalent circuit model for the ESA with impedance matching circuit. In this figure, Z_a denotes the input impedance of ESA and Z_L represents the input impedance of LNA or the output impedance of PA. Z_{01} and θ_i are the characteristic impedance and electrical length of the transition line. *L*-type admittance inverter (*J* inverter) is composed of two capacitors C_m and $-C_n$. C_m is realized by using the interdigital gap. To realize the minus capacitance ($-C_n$.), we shorten the feed line (electrical length ($-\theta_{02}$)) of the antenna. In this situation, we can realize the impedance matching of complex impedance.

Fig.4 shows the layout of the one-sided directional antenna with impedance matching circuit. Close up of the *J* inverter is also shown. The size of this antenna is 295mm x 130.4mm. The size of the longer side is almost the same as half wavelength in waveguide. Fig. 5 shows the input impedance (Z_{in}), which is the impedance for looking the antenna from A-A' in Fig. 3.

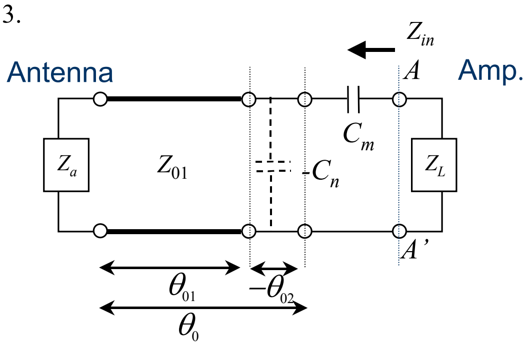

Fig. 3. Circuit model of the ESA with impedance matching circuit.

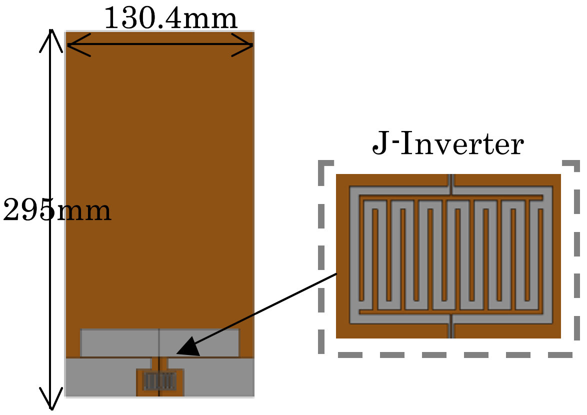

Fig. 4. Layout of the one-sided directional ESA with λ/2 top metal.

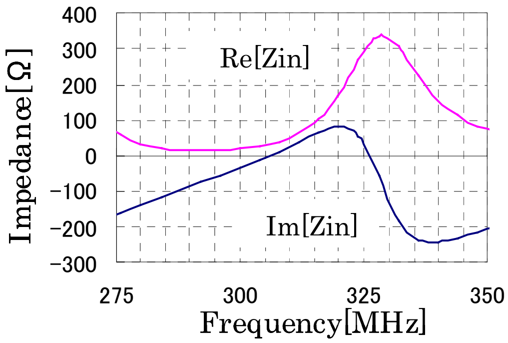

Fig. 5. Input impedance of the one-sided directional antenna with matching circuit.

Fig. 6 shows the return loss of the one-sided directional ESA with CPW matching circuit. Z_{in} is almost 50Ω around 305 MHz, so that, we can realize the impedance matching circuit. Fig. 7 shows the simulated electric field distribution of top and bottom floating metal layer, respectively. Fig. 8 shows the simulated radiation pattern of the one-sided directional ESA with CPW matching circuit. The directivity for forward direction is larger than that of backward direction, and front to back ratio (F/B ratio) is approximately 8dB.

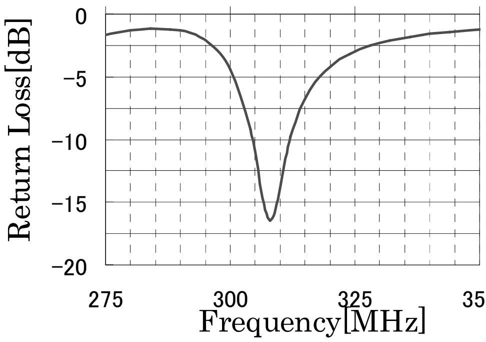

Fig. 6. Return loss of the one-sided directional antenna with matching circuit.

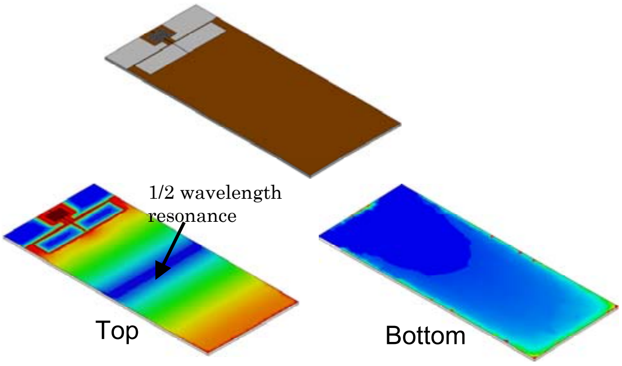

Fig. 7. Simulated electric field distribution of the one-sided directional antenna with λ/2 top metal.

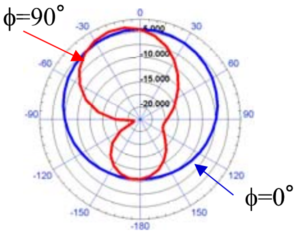

Fig. 8. Simulated radiation pattern of the one-sided directional antenna

IV. DESIGN OF THE MINIATURIZED ONE-SIDED DIRECTIONAL SLOT ANTENNA

As shown in Fig. 7, both edges of the top metal layer have open ends, on the other hand, the center of the top metal layer has a short region. So, we can realize λ/4 resonance by cutting off the half of the top metal and connecting the bottom metal layer. Fig. 9(a) and (b) show the layout and simulated electric field distribution of top and bottom metal layer of the λ/4-type one-sided directional antenna. Short end of the antenna is connected to the bottom conductor, as shown in the close up section. Fig. 10 shows the radiation pattern, respectively. F/B ratio is approximately 8dB for EM simulation.

For size reduction, we modified the slot and CPW feed line, and Fig. 11 shows the final layout of the miniaturized one-sided directional ESA with λ/4 top metal. The size is 137mm x 61mm. Fig. 12 (a) and (b) show radiation pattern and return loss of the proposed antenna. F/B ratio is approximately 10dB at 305MHz.

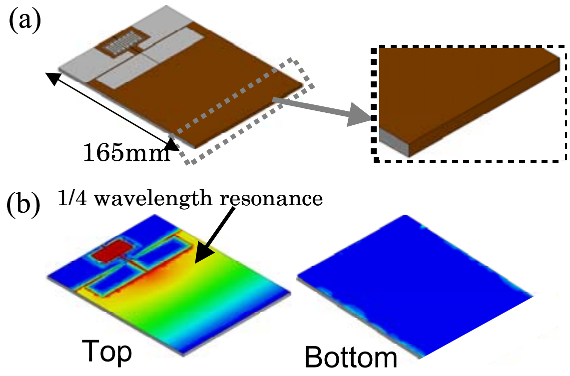

Fig. 9. Layout (a) and simulated electric field distribution (b) of the one-sided directional antenna with λ/4 top metal.

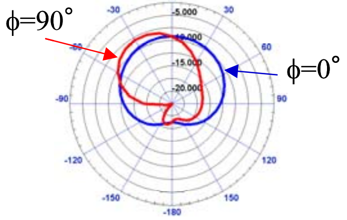

Fig. 10. Simulated radiation pattern of the one-sided directional antenna with λ/4 top metal.

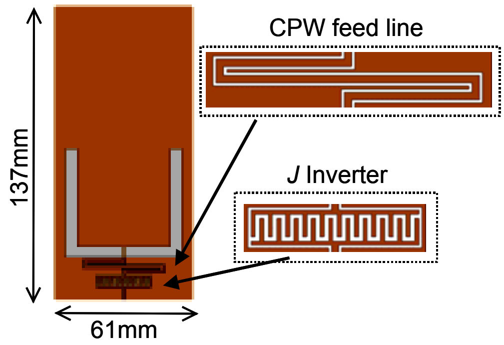

Fig. 11. Final layout of the miniaturized one-sided directional ESA with l/4 top metal.

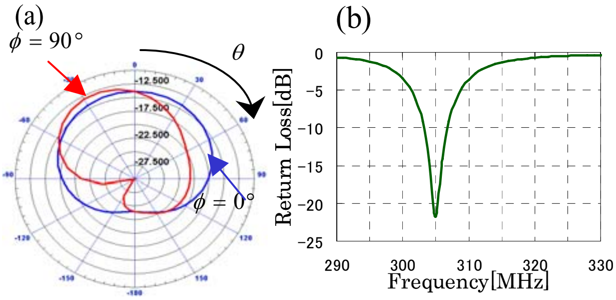

Fig. 12. Radiation pattern (a) and return loss (b) of the proposed antenna.

V. EXPERIMENTALS AND RESULTS

The proposed antenna was fabricated on FR4 substrate by using board making equipment (MITS; FP-21T model 40).

Fig.13 shows the photograph of the proposed one-sided directional antenna. The top and bottom layer is connected by using the copper tape and is soldered on the edge.

Fig.14 shows the experimental set up for measuring the radiation pattern. Fig. 15 shows the radiation pattern of the proposed antenna. We can obtain that the F/B ratio is approximately 7dB. The size of this antenna is 78% smaller than that of λ/2 type.

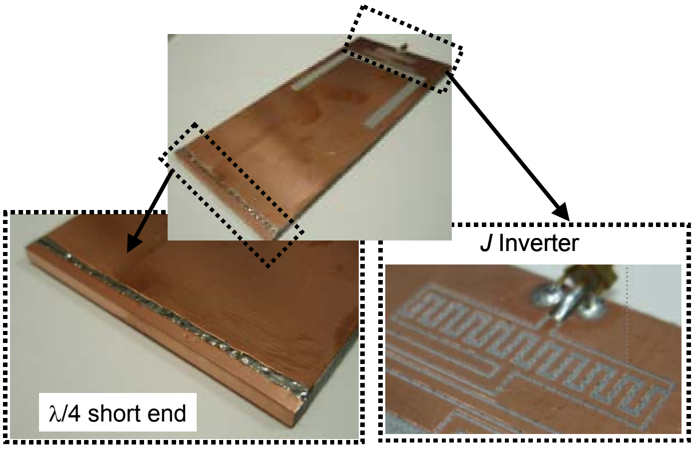

Fig. 13. Photograph of the proposed antenna.

Fig. 14. Photograph of the measurement system.

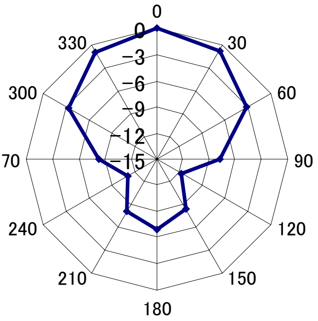

Fig. 15. Experimental result of the radiation pattern of proposed antenna (ϕ=0°).

VI. CONCLUSION

In this paper, we designed and tested the one-sided directional thin planar antenna with quarter wavelength top metal. In order to realize the one-sided directional radiation, the length of the top metal layer is adjusted. Also, for side reduction, design theory of the ESA with impedance matching circuit was adopted. The size is 137mm x 61mm and F/B ratio is approximately 7 dB. Moreover, the size of proposed antenna is 78% smaller than that of λ/2 type.

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