A Broadband Omni-directional Small Printed Antenna Comprising Symmetrically Arranged Trapezoid Elements

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1. Introduction

The demand for small wireless telecommunications modules that can access the IMT system has increased and their use has proliferated to the remote control of applications such as controlling stock and verifying purchases for vending machines, managing taxi operations, reading of meters, and managing delivery trucks. The IMT system mainly uses the 800 MHz to 2 GHz frequency band. We focus on actualizing an antenna for a small wireless telecommunications module that can operate in the 800 MHz band because utilizing this band poses difficulties in terms of miniaturization and securing the gain.

This paper proposes a new small broadband printed antenna that achieves a fractional bandwidth of 28.9% with the size of $0.160\lambda \times 0.226\lambda$ (@lowest frequency). This antenna is suitable for mass production and is cost efficient due to its printed antenna structure. Its omni-directional pattern allows a wide range of placement possibilities.

The rest of the paper is organized as follows. First, the proposed antenna structure is described in Section 2. The center frequency and bandwidth characteristics are investigated based on the method of moment (MoM) simulation and measurement, and the optimum antenna structure parameters that satisfy a low operating frequency with a wide bandwidth are clarified in Section 3.1. Finally, the current distribution and radiation pattern characteristics are presented in Section 3.2.

2. Proposed Antenna Structure

The antenna structure is shown in Fig. 1. This antenna is designed based on an electromagnetic coupled printed dipole antenna [1] and a printed monopole antenna. The size of the substrate is 60×85 mm^2. In Fig. 1, two symmetrical trapezoid elements are printed on the bottom side of the substrate and are connected to a small ground plane printed on the same side over two strips. The trapezoid elements and the strips are excited in an electromagnetically coupled manner by the monopole element set between the trapezoid elements. The monopole element is printed on the other side (top side) of the substrate.

A simulation of the antenna characteristics is performed using the MoM based IE3D electromagnetic simulator [2]. Based on the antenna parameter investigation, we obtained the following antenna parameters as indicated in Fig. 1 that give the best performance in terms of a low operating frequency and wide fractional bandwidth: $a = 18.7$ mm, $b = 31.2$ mm, $c = 43.8$ mm, $d = 10$ mm, $e = 72.7$ mm, $f = 68.5$ mm, $g = 22.6$ mm, $w_1 = 3$ mm, $w_2 = 2.5$ mm, $t = 1.6$ mm, and $\varepsilon_r = 3.3$. The details regarding the parametric studies are described in the next section.

3. Numerical and Experimental Results

3.1 Parametric Study and Frequency Characteristics of VSWR

In the preliminary investigation mentioned above, we found that the monopole element, vertices A and C, and vertices B and D mainly influence the antenna characteristics, so the influence of these parameters is described in this section.

Fig. 2 shows the influence of the length of the monopole element on the VSWR. Parameter t_1 shown in Fig. 2 represents the moving distance from the edge of the monopole element (EF). When that edge moves in the Y axial direction, it is defined as a positive value. Parameter t_1 is changed from -10 mm to 10 mm in 5 mm steps. In this case, it is understood that the impedance matching can be adjusted by changing t_1 although there is little influence on the center frequency. For $t_1 = 0$ mm, a broad bandwidth is obtained although the lowest VSWR is approximately 1.4. On the other hand, for $t_1 = 5$ mm, a narrow bandwidth is obtained, but the lowest VSWR is approximately 1.0. As indicated in Fig. 2, dual resonance and single resonance characteristics are obtained by changing the length of the monopole element [3]. Thus, we can see that the length of the monopole element is an important parameter to the impedance matching. For $t_1 = -15$ mm or less, favorable impedance matching is not obtained.

Fig. 3 shows the dependency of the position of vertices A and C on the center frequency and the bandwidth. Parameter t_2 shown in Fig. 3 is the moving distance of vertices A and C. When those vertices move in the Y axial direction, it is defined as a positive value. The length of the monopole element is adjusted to obtain the maximum bandwidth for each structure. When vertices A and C move in a negative direction, i.e., edges AB and CD are longer, the center frequency shifts to a lower frequency. For instances greater than $t_2 = -5$ mm, the bandwidth exceeds 25%. Discontinuity is observed when t_2 is approximately –5 mm. The bandwidth becomes maximum when two resonance frequencies appear and the difference between the resonant frequencies is fairly close. The bandwidth becomes narrow when t_2 is approximately –5 mm or less because only one resonance frequency appears.

Fig. 4 shows the influence of the position of vertices B and D on the center frequency and the bandwidth. Parameter t_3 shown in Fig. 4 is the moving distance of vertices B and D. When those vertices move in the Y axial direction, it is defined as a positive value. Even here the length of the monopole element is adjusted to obtain the maximum bandwidth for each structure. As shown in Fig. 4, the center frequency shifts to a lower frequency as t_3 increases. For $t_3 = -50$ mm or more, the bandwidth is almost constant and becomes roughly greater than 25%. For $t_3 = -50$ mm or less, the bandwidth becomes narrow. Therefore, to set the center frequency to the target frequency, we need only move vertices B and D. The lowest center frequency and the widest bandwidth can be achieved by using the structure described in Section 2.

To ensure the validity of the numerical results, the VSWR is compared to the experimental results. The antenna is connected to a semi-rigid cable. A ferrite balun is used for the measurement. Fig. 5 shows the frequency characteristics of the VSWR. The VSWR bandwidth (≤ 2) is approximately 28.9%. Broadband impedance matching is achieved. The measured and numerical results are in good agreement.

3.2 Current Distribution and Radiation Patterns

Fig. 6 shows the current distribution at 850 MHz, 950 MHz, and 1050 MHz. The current that passes in the direction of the ground plane from acute angle vertices A and C via vertices B and D is predominant. Nearly the same tendency is exhibited for each frequency. The current is particularly strong for 850 MHz. Arrow head size indicates strength of current in Fig. 6.

Fig. 7 shows the radiation patterns at 850 MHz, 950 MHz, and 1050 MHz. An omni-directional pattern in the ZX plane is obtained in the resonance band. The radiation from the two strips set in the Y axial direction becomes predominant due to the flow of the powerful electric current. Based on Fig. 7, it is thought that there is no radiation from the two trapezoid elements when considering co-polarization.

We conclude the following based on the current distributions shown in Fig. 6 and the radiation patterns shown in Fig. 7. An omni-directional pattern is obtained with a powerful current similar to the case of a printed monopole antenna with two strips. The antenna is operated as a monopole antenna.

4. Conclusions

A broadband omni-directional printed antenna with symmetrical trapezoid elements was proposed. Their characteristics with various antenna parameters were investigated numerically and experimentally. A compact antenna with a VSWR bandwidth (≤2) of 28.9%, low profile, and omni-directional pattern features was achieved. We also clarified that the length of the monopole element that is placed between the trapezoid elements is an important parameter for the impedance matching and the bandwidth, and the positions of vertices A, C, B, and D are important parameters for the center frequency and the bandwidth based on the parametric study.

References

[1] N. Michishita, H. Arai, "A polarization diversity antenna by printed dipole and patch with a hole," IEICE Trans. Commun., Vol. J85-B, No. 3, pp. 391-399, 2002.
[2] Zeland Software, Inc., "IE3D: MoM-Based EM Simulator," http://www.zeland.com/.
[3] T. Hori, "Broadband/multiband printed antennas," IEICE Trans. Commun., Vol. E88-B, No. 5, pp. 1809-1817, 2005.

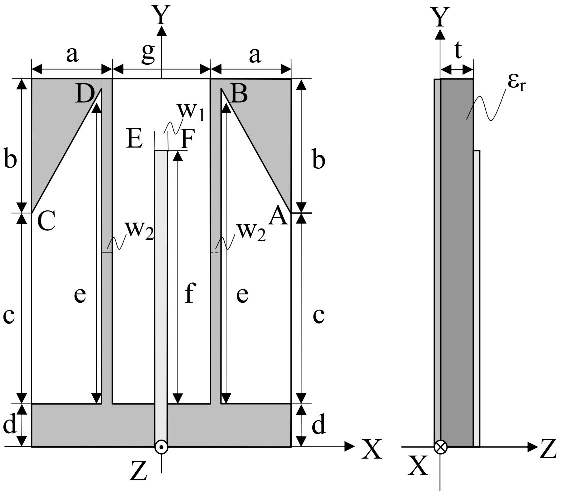


Figure 1: Antenna Structure

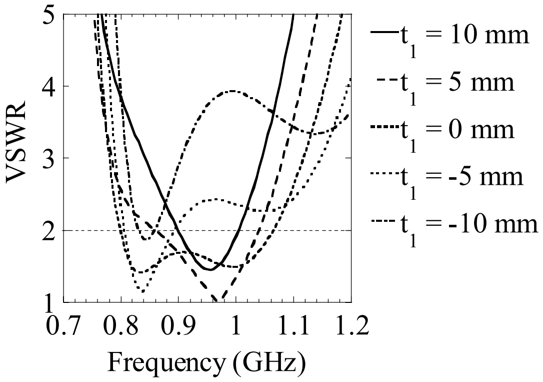


Figure 2: Effects of Monopole Element Length

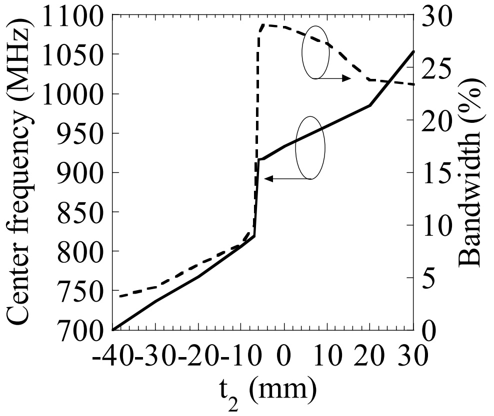


Figure 3: Effects of Position of Vertices A and C

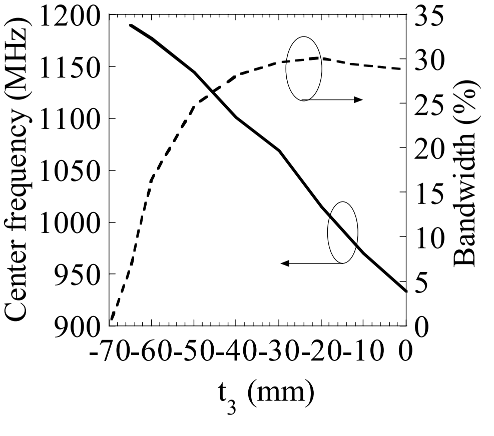


Figure 4: Effects of Position of the Vertices B and D

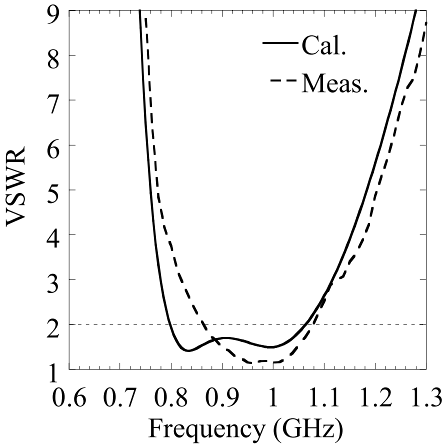
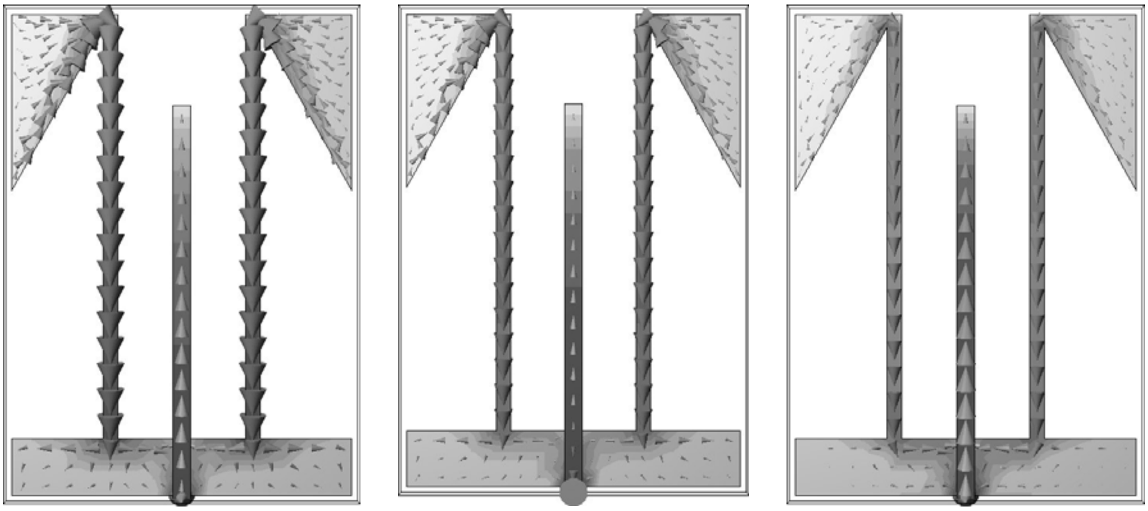


Figure 5: VSWR Frequency Characteristics



850 MHz 950 MHz 1050 MHz

Figure 6: Current Distribution at 850 MHz, 950 MHz, and 1050 MHz

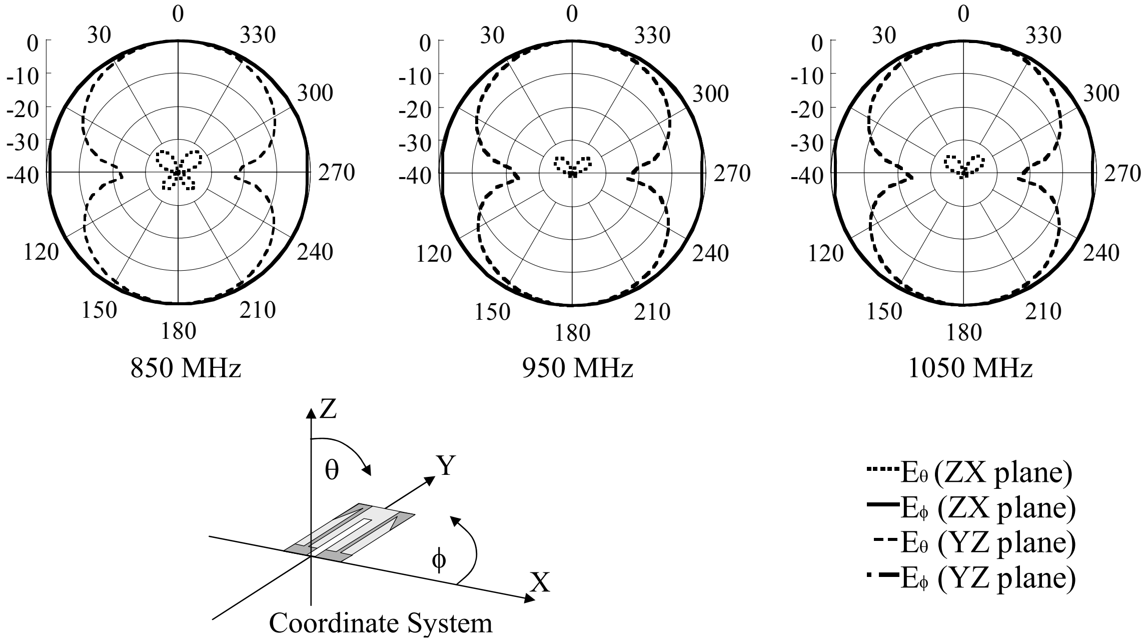


Figure 7: Radiation Patterns at 850 MHz, 950 MHz, and 1050 MHz