1. Introduction

For a long time, many types of antenna which have folded structure, have been introduced and investigated. In this paper, by investigating some kinds of antenna with folded structure through our previous researches, we discuss theoretically about folded structure and confirm its utility. Firstly, as a motive argument, we investigate the feeding method of folded dipole antenna (FDA) on a ground plane, and then signify its two-resonances and broadband characteristic. Next, by focusing on planar folded dipole antenna (PFDA) and bow-tie antenna (BTA), we show the effectiveness of folded structure in each case from two aspects of impedance adjustment and current pathway changing.

2. Motivation of Folded Structure

Figure 1 shows configurations of folded dipole antenna (FDA) [3] placed on a ground plane (GP), and two feeding methods of FDA. Since it is possible in changing the impedance transformation ratio by using two folded elements of FDA as shown in Fig. 1(a), FDA itself has radiation resistance not to become lower, and then it is good for impedance matching even though FDA is placed closely to GP.

Figure 1(b) shows both calculated model and measured model of balanced feed and unbalanced feed of FDA. In the case of calculated balanced feed model, a small gap is set up at the feed point of FDA, and balanced feed is simulated by a gap feed. In the case of measured balanced feed model, a balun is used to feed the antenna from a coaxial cable connected to GP. On the other hand, in the case of calculated unbalanced feed model, a gap feed is also set up, but the right edge of the gap is connected to GP by a short strip, which simulates the coaxial cable from GP to the antenna. As indicated in Smith chart in Fig. 1(c), all of these models have the same impedance characteristic, meaning that the problem of conventional balanced feed antenna in impedance matching is improved by folded structure of FDA. Moreover, here, the effectiveness of unbalanced feed method is also confirmed.

3. Folded Structure from Viewpoint of Input Impedance
FDA is different from dipole antenna (DA), since the possibility of FDA in transforming impedance. Here, we discuss the operating principle of folded structure by comparing its input impedance characteristic to that of basic DA.

3.1 Input Impedance Characteristics by Width Ratio

Figure 2(a) shows the structure of FDA with two different widths $r_1$ and $r_2$. This structure of FDA can be considered as a combination of an antenna mode and a transmission line mode as in Fig. 2(b) and (c).

![Figure 2](image)

If $a_r=a_f=a$, the impedance $Z$ of FDA will be calculated as

$$Z = (1 + a)^2 Z_r$$

where $Z_r$ is the impedance of DA. $(1+a)^2$ is called step up ratio, and formulation to calculate $a$ is

$$a = \frac{\ln \nu - \ln \mu}{\cosh^{-1} \left( \frac{\nu^2 - \mu^2 + 1}{2\nu} \right)}$$

with $r_2 = \mu r_1$, $d = \nu r_1$ [1], [2]. It is confirmed that impedance of FDA is decided by two widths $r_1$, $r_2$ and the spacing $d$ with the transformation ratio larger than 1. Furthermore, impedance of FDA is always larger than DA, and in the case $r_1 = r_2 = 1$, $(1+a)^2$ becomes 4, FDA has a high impedance about $300 \, \Omega$.

3.2 Folded Dipole Antenna with a Feed Line

Figure 3(a) shows the model of a basic FDA with a feed line [4] which has the length $lf$. Impedance characteristic of FDA with a feed line is shown in Fig. 3(b) and (c), where we can observe that by loading the feed line, two resonant frequencies appear, and adjusting $lf$ to $\lambda/4$ makes two resonances move closely to each other with good matching. This impedance transformation
effect with two resonances done by a feed line is also confirmed in the case of DA or loop antenna (LA), but only FDA can get the good impedance matching at 50 Ω. This is because FDA has the high impedance characteristic before loading the feed line to it.

4. Folded Structure from Viewpoint of Current Pathway

Effect of folded structure can also be considered by changing the pathway of current on the antenna. We discuss here the effect of current pathway changing in two cases of planar folded dipole antenna (PFDA) and folded bow-tie antenna (FBTA).

4.1 Planar Folded Dipole Antenna

![Figure 4: Change of Current Distribution by Folded Structure (1.35 GHz)](image)

Structure of PFDA is shown in Fig. 4(a), and with this structure, PFDA can be equal to a planar dipole antenna (PDA) shown in Fig. 5(a) with a folded element [5]. Current distribution of PDA and PFDA at 1.35 GHz is indicated in Fig. 4(b) and (c), where we can see that by loading the folded element to PDA, the currents at the upper edges of PDA increase strongly. This change of current pathway makes clear that it is possible to consider PFDA having two modes of PDA and FDA as in Fig. 5(a) and (b). Comparison of VSWR characteristics of PFDA, DA, and FDA is shown in Fig. 5(c), where it is easy to confirm that the first resonance is the resonance of DA, and the second resonance is the resonance of FDA. This means that, impedance characteristic is controlled by the changing of current pathway at the edges of folded structure.

4.2 Folded Bow-tie Antenna

Next, we discuss about the case of bow-tie antenna (BTA) [6], [7]. Conventional BTA and BTA with two folded elements (FBTA2) have the respective structures as shown in Fig. 6(a) and (b). BTA is designed to operate at the lowest operating frequency 540 MHz for VSWR≤2. VSWR characteristics of BTA, FBTA2 and BTW with one folded element (FBTA1) are normalized to 200 Ω and shown in Fig. 6(c).
Comparing to BTA, FBTA2 has the lowest operating frequency as 300 MHz, which means that it is possible in miniaturizing the entire physical area of BTA to only 31%. This is considered as a result of the changing of the current pathway at the edges after loading folded element to BTA. Current distributions of BTA and FBTA2 at 300 MHz are indicated in Fig. 6(c). Similar to the case of PFDA in subsection 4.1, it is obvious to see that impedance of FBTA2 is controlled by the changing of the current pathway on the antenna.

5. Conclusion

In this study, we discuss about some types of antenna with the folded structure, and the effects of folded structure on antenna characteristics from two viewpoints of input impedance and current pathway. In the future work, we will investigate more specifically these effects in the cases of some other kinds of antenna with folded structure.

References