Wideband Planar Folded Dipole Antenna With Self-balanced Impedance Property

Shingo Tanaka, *Member, IEEE*, Yongho Kim, *Student Member, IEEE*, Hisashi Morishita, *Senior Member, IEEE*, Satoru Horiuchi, Yasunori Atsumi, and Yoichi Ido

***Abstract*—A planar folded dipole antenna that exhibits wideband characteristics is proposed. The antenna has simple planar construction without a ground plane and is easy to be assembled. Parameter values are adjusted in order to obtain wideband properties and compactness by using an electromagnetic simulator based on the method of moments. An experimental result centered at 1.7 GHz for 50 Ω impedance matching shows that the antenna has bandwidth over 55% $(\mathrm{VSWR} \leq 2)$. The gains of the antenna are almost constant (2 dBi) in this frequency band and the radiation patterns are very similar to those of a normal dipole antenna. It is also shown that the antenna has a self-balanced impedance property in this frequency band.**

***Index Terms*—Folded dipole antenna, planar antenna, self-balanced antenna, wideband antenna.**

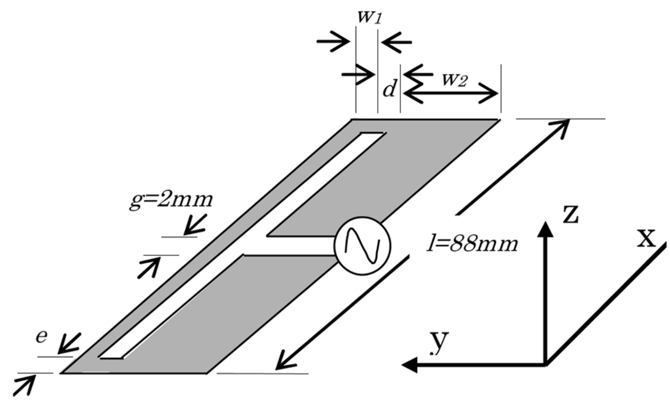

Fig. 1. Antenna structure of the planer folded dipole antenna.

I. Introduction

WITH THE recent progress and rapid increase in radio communication systems, wideband wireless systems are being put into actual use; examples are an ultrawideband system [1], [2] and digital terrestrial television [3], [4]. This emphasizes the importance of designing high performance antennas for small mobile terminals. A key demand is wideband and compact antennas [5], [6].

One interesting candidate for wideband and compact antennas is the folded dipole antenna with folded elements [7], [8]. It is named as folded loop antenna but basically constructed by folding both ends of an approximately $\lambda_C/2$ length folded dipole antenna [9]–[13] (λ_C is the wavelength at the center frequency $\mathrm{f_C}$). This folding parts are important to widen the bandwidth and by adjusting some construction parameters, the antenna exhibits wideband characteristics of more than 50% (VSWR $\leq$ 2, antenna impedance $= 50\Omega$). The antenna is not accompanied by a ground plane so its radiation pattern is similar to the dipole antenna [7], [8].

The aim of this paper is to simplify the antenna configuration of the folded dipole antenna with folded elements, that is, to remove the folding parts at both ends of the element and at the same time to maintain wideband properties. With this modification, the antenna can be planar and is easy to be assembled.

It is normal to apply a balanced feed to a balanced antenna like a dipole antenna. However, a narrow band folded dipole antenna has self balanced properties [12] so an unbalanced feed is also applicable. In this case, no balun is needed so the antenna is cost-effective. Therefore, balanced and unbalanced feeds are evaluated in order to examine the self-balanced properties.

II. Antenna Structure

Fig. 1 shows the structure of the proposed planar folded dipole antenna. The folded dipole antenna [9]–[13] with two $\lambda/2-\mathrm{long}$ elements is constructed 2-dimensionally. Its construction parameters are also indicated in Fig. 1. The length of the elements, l is fixed to 88 mm so $\mathrm{f_C} \approx 1.7$ GHz. The widths of the two strips are w_1 and w_2. The width w_2 is set to be wider than w_1 in order to match the antenna impedance to 50 Ω. The separation width between two strips is d. The end width of the folded portion is e. The gap of the feed point, g is fixed to 2 mm. So we can adjust 4 parameters, w_1, w_2, d, and e. A cupper plate with 0.2 mm thickness is employed to construct the antenna.

III. Impedance Characteristics

In this section, the input impedance of the planar folded dipole antenna shown in Fig. 1 is investigated. In Subsection III-A, impedance changes due to 4 construction parameters are discussed. In Subsection III-B, the bandwidth $(\mathrm{VSWR} \leq 2)$ and $\mathrm{f_C}$ changes due to 3 active parameters are investigated in detail together with the standpoint of compactness. In these subsections, the electromagnetic simulator based on the method of moments [14] is used. Only balanced feed is considered in the simulations. In Subsection III-C,

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experimental results with balanced and unbalanced feeds, and simulated results are compared and discussed.

A. Impedance Changes by the Parameters

Fig. 2 shows the impedance characteristics of the planar folded dipole antenna, when 4 parameter values, w_1, w_2, e, and d is changed. The starting values of these parameters are $w_1 = 4$ mm, $w_2 = 28$ mm, $d = 2$ mm and $e = 2$ mm, as those are used in [7], [8]. As shown in Fig. 2(a), rounded curves on the Smith chart (with two resonance frequencies) go to higher impedance when w_2 is decreased under 32 mm. When w_2 is increased over 32 mm, the rounded curve goes to higher reactance. $w_2 = 32$ mm is the best value for wideband impedance matching around 50 Ω. So we changed w_2 from 28 mm to 32 mm for the next studies.

Fig. 2(b) shows that imaginary part of the impedance decreases when w_1 increases. However, the change caused by w_1 has less impact than that by w_2. Fig. 2(c) shows that the real part of the impedance increases when e increases. So wideband properties cannot be obtained when $e > 16$ mm if 50 Ω matching is desired. As shown in Fig. 2(d), little impedance change is observed when d is changed. Wavelength λ_{HRF} at 2 GHz (higher resonance frequency; refer to Fig. 6) is 150 mm, so $\mathrm{d} = 2$ mm is 0.013 λ_{HRF} and $\mathrm{d} = 16$ mm is 0.107 λ_{HRF}, respectively. According to [10], d is better to be less than 0.01 λ, however, this limit is not so strict. So the impedance is almost constant when d is changed from 2 to 16 mm.

B. Bandwidth $(\mathrm{VSWR} \leq 2)$ Changes by the Parameters

As is shown in the former subsection, construction parameters w_1, w_2, and e have an important role in a planar folded dipole antenna. So we are going to change these parameters simultaneously in order to find the optimum parameter sets for wideband properties. Fig. 3 shows the simulated bandwidth when parameters w_2 and e are simultaneously varied while $w_1 = 4$ mm and $d = 2$ mm are fixed. Fig. 3 illustrates the area of w_2 and e to obtain the bandwidth over 50%. For the bandwidth more than 50%, w_2 shall be 32 mm for small e and w_2 shall be 40 mm for large e. So for the compactness of the planar folded dipole antenna, small e is desirable.

Fig. 4 shows the simulated bandwidth when parameter w_2 and w_1 are simultaneously varied while $d = 2$ mm are fixed. Fig. 4(a), (b), and (c) are for $e = 2$, 8, and 16 mm, respectively. When e is small as shown in Fig. 4(a), $w_2 \approx 32$ mm and small w_1 values are the best for wideband properties. However, as shown in Fig. 4(b) and (c), w_2 and w_1 values for the bandwidth over 50% is increased when e is increased. Therefore, e shall be kept small to obtain a compact antenna that is the same as indicated in Fig. 3.

In Fig. 4(b) and (c), tendencies such as the tradeoff between w_2 and w_1 are observed. For example, both $w_2 = 40$ mm and $w_1 = 4$ mm or $w_2 = 36$ mm and $w_1 = 8$ mm are the conditions for the bandwidth over 50% in Fig. 4(c). In both cases, $w_2 + w_1$ is almost constant (44 mm). For the wideband properties, w_2 shall be increased when w_1 is decreased and vice versa, in these conditions.

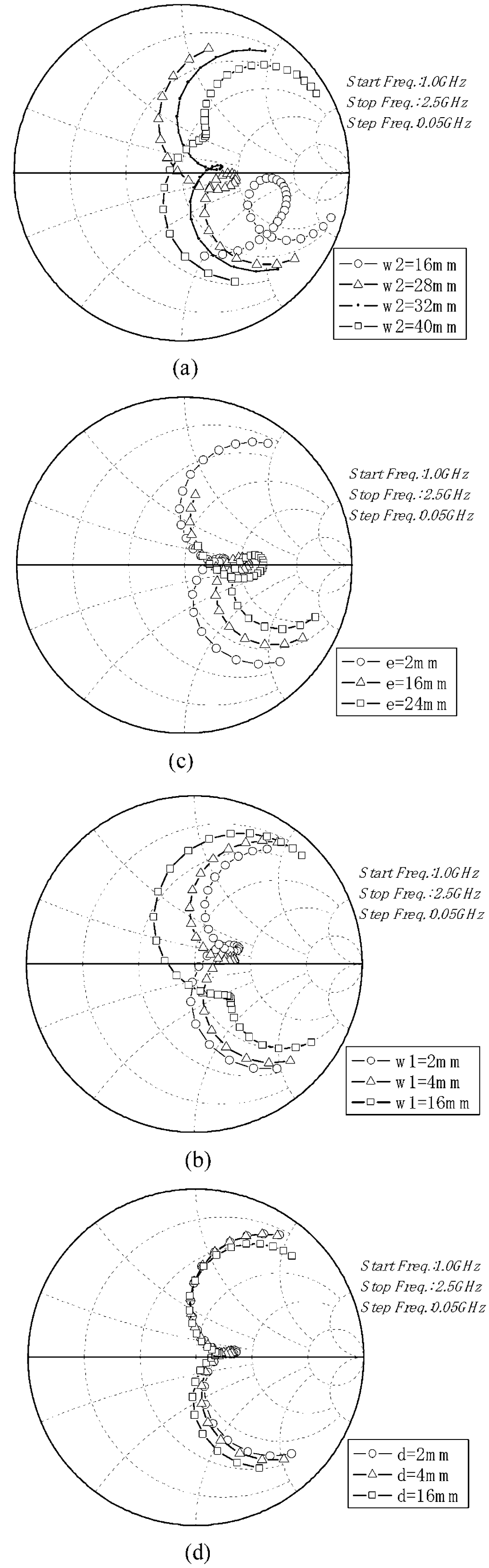

Fig. 2. Simulated input impedance characteristics of a planar folded dipole antenna with the variation of (a) w_2 ($\mathrm{w}_1 = 4$ mm, $\mathrm{d} = 2$ mm, $\mathrm{e} = 2$ mm), (b) w_1 ($\mathrm{w}_1 = 32$ mm, $\mathrm{d} = 2$ mm, $\mathrm{e} = 2$ mm), (c) e ($\mathrm{w}_1 = 32$ mm, $\mathrm{w}_1 = 4$ mm, $\mathrm{d} = 2$ mm) and (d) d ($\mathrm{w}_1 = 32$ mm, $\mathrm{w}_1 = 4$ mm, $\mathrm{e} = 2$ mm).

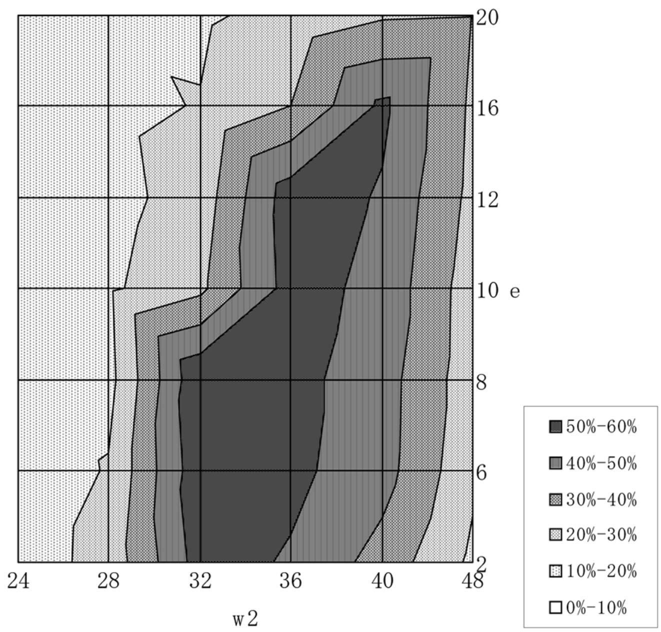

Fig. 3. Simulated bandwidth (in %) of a planar folded dipole antenna with the variation of w_2 and e ($w_1 = 4$ mm, $d = 2$ mm).

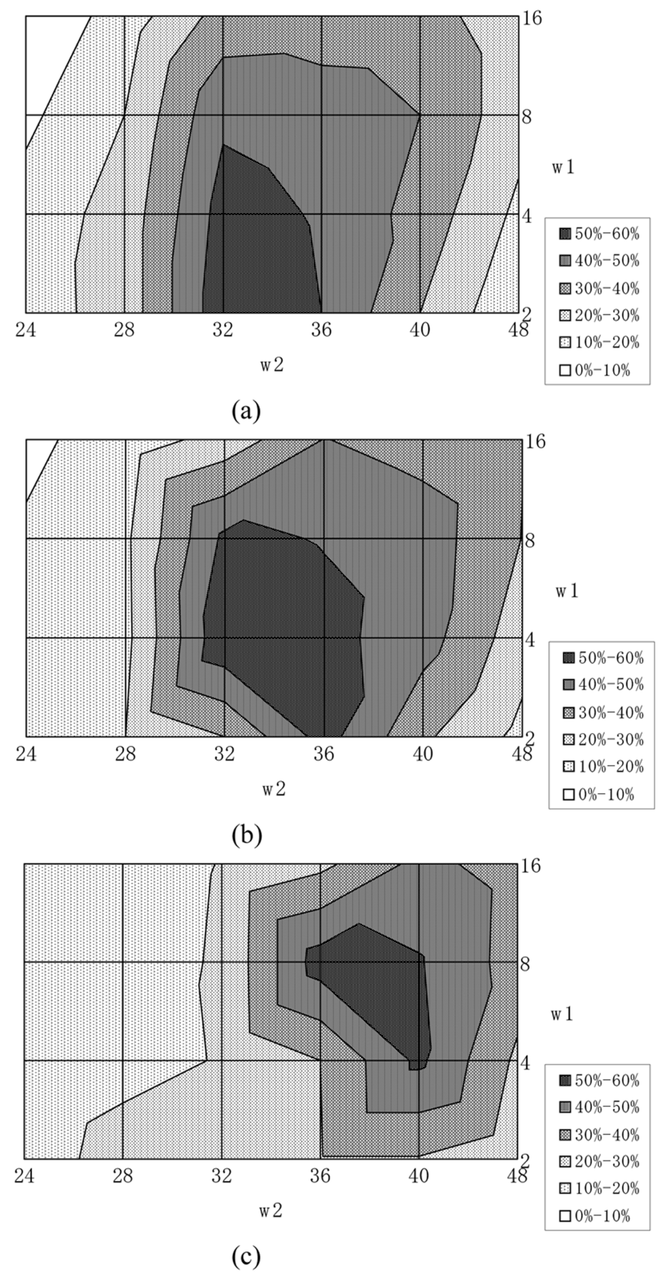

Fig. 4. Simulated bandwidth (in %) of a planar folded dipole antenna with the variation of w_2 and w_1 (a) $e = 2$ mm, (b) $e = 8$ mm, and (c) $e = 16$ mm ($d = 2$ mm for all).

C. *Experimental Results*

In consideration of the studies in the former subsections, we selected construction parameters $w_1 = 4$ mm, $w_2 = 32$ mm, $d = 2$ mm and $e = 2$ mm for the compact and wideband properties. We made two prototypes of planar folded dipole antennas for the impedance measurement. The one has the structure shown in Fig. 1 (hereinafter referred to as the normal structure) used for the radiation pattern measurement. In this case, the antenna is fed by a coaxial cable without a balun, so an unbalanced feed is used here.

The other has the antenna structure with a ground plane for the balanced feed shown in Fig. 5. In this case, due to the symmetry of the dipole antenna shown in Fig. 1 the half portion of the antenna is made on the ground plane as shown in Fig. 5. The size of the ground plane is around 300 mm $\times$ 300 mm and the antenna is attached at the center. The measured impedance is doubled for the compensation so the model is equivalent to the antenna with a wideband balun.

Fig. 6 shows the measured and simulated voltage standing wave ratio (VSWR). The measured and simulated results are in good agreement and exhibit wideband properties. The measured results by the balanced feed and the unbalanced feed agree well so we suppose that the antenna is self-balanced in the wide frequency band. The resonance frequencies of the unbalanced feed structure have a tendency to be lower than those of the balanced one. We think that this is caused by the parallel feed lines of approximately 5 mm length with the unbalance feed (no ground plane). The frequency ranges for VSWR ≤ 2 are from 1.2–2.23 GHz for the balanced feed and 1.16–2.09 GHz for the unbalanced feed, respectively. The bandwidths are 60% and 57% for the balanced and the unbalanced feed, respectively. The simulated bandwidth is 55% where the antenna feed is assumed a balanced one.

IV. Radiation Pattern

Fig. 7 shows the radiation patterns of the planar folded dipole (normal structure) antenna at three frequencies. The construction parameters are the same as described in Section III-C so the frequencies 1.25, 1.65, and 2.10 GHz are selected in the band with VSWR ≤ 2 (Fig. 6). Simulated (a balanced feed), and measured (with and without a balun) results are plotted together for comparison. The intensity level is indicated with respect to the antenna gain in dBi.

In the x-z plane, the simulated and measured main polarization components (E_θ) are in good agreement, both with and without a balun. However, for the cross polarization component (E_ϕ), the measured results without a balun are stronger

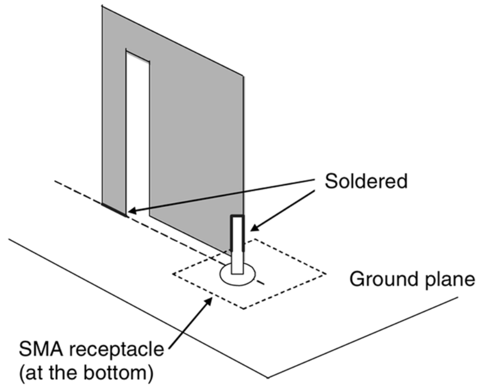

Fig. 5. An antenna structure with a ground plane for the impedance measurement (balanced feed).

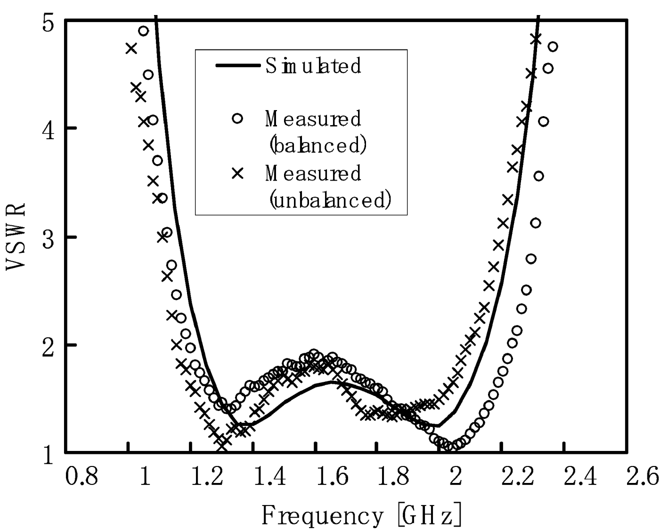

Fig. 6. Measured and simulated VSWR of a planar folded dipole antenna.

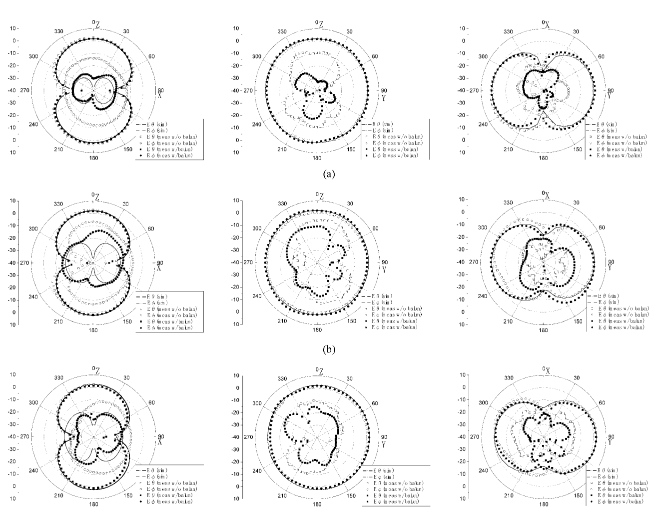

Fig. 7. Measured and simulated radiation patterns of a planar folded dipole antenna at (a) 1.25 GHz, (b) 1.65 GHz, and (c) 2.10 GHz.

than the simulated results, although the measured results with a balun agreed well with the simulated results. The antenna has a self-balanced property because of wideband impedance matching for 50 Ω, as described in Section III-C. However, as described above, the self-balanced impedance property does not reduce the cross polarization component without a balun. The E_{ϕ}s without balun are mainly created by currents flowing on the outside of coaxial cable, so the measured value can be changed by realigning coaxial cable. The balun used here has a insertion loss of around 1 dB, so the measured E_{θ}s with the bulun are a little bit smaller than the measured E_{θ}s without the bulun.

In the cases of the y-z and x-y plane patterns, the main polarization components (E_{ϕ}) measured with and without the balun agreed well with those simulated. However, in these cases, the differences between the three results are much bigger than those in the case of the x-z plane pattern. This is because the antenna feeding coaxial cable is laid along the y axis and has effects on the radiated electromagnetic field including the y axis. As the coaxial cable is located along the $-y$ axis direction as shown in Fig. 1, the differences between the simulated and the measured results have tendencies to be larger in the $-y$ region than in the $+y$ region. The simulated cross polarization components (E_{θ}) for the y-z and x-y plane are not appeared in Fig. 7 since they are less than -40 dBi. However, in the y-z plane, the E_{θ}s with the balun are much smaller than E_{θ}s without the balun.

As a whole, as shown in Fig. 7, the planar folded dipole antenna has radiation patterns similar to those of a normal dipole antenna in the wide frequency range except the cross polarization component. The simulated and measured (without the balun) antenna gain for the E_{θ}s in the x-z plane are summarized in Table I.

TABLE I
ANTENNA GAIN OF A PLANAR FOLDED DIPOLE ANTENNA

Frequency [GHz]	1.25	1.65	2.1
Simulated [dBi]	1.9	2.2	2.5
Measured w/o balun[dBi]	2.5	2.7	2.2

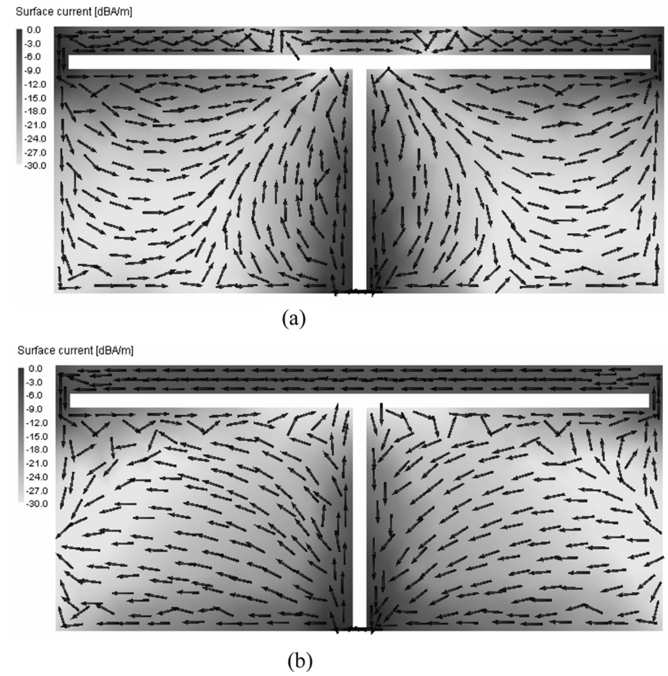

Fig. 8. Simulated current distribution on a planar folded dipole antenna.

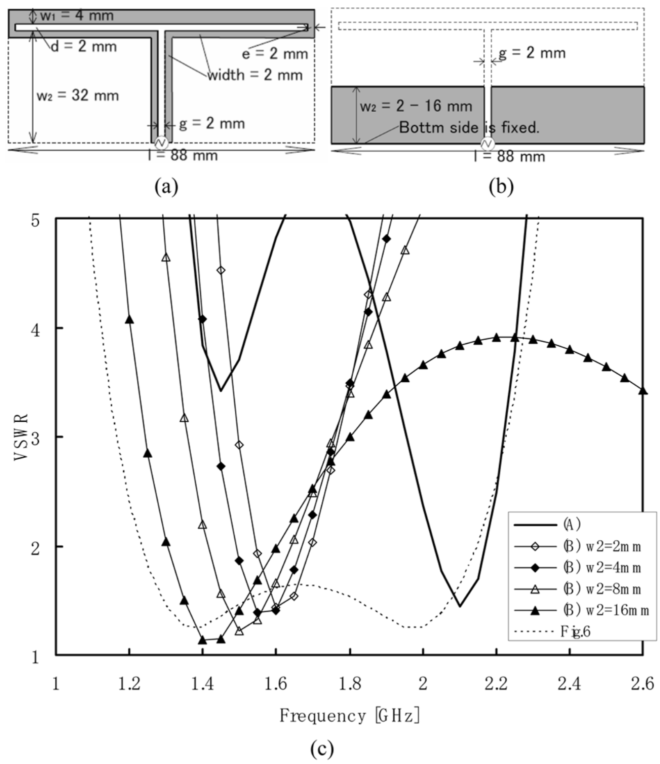

Fig. 9. Decomposition of a planar folded dipole antenna to (a) construction A and (b) construction B, and (c) their simulated VSWRs.

V. Current Distribution and Studies on Wideband Mechanism

Fig. 8 shows simulated current distributions on the planar folded dipole antenna. Fig. 8(a) is for 2.00 GHz and Fig. 8(b) is for 1.35 GHz. As is found from Fig. 6, the minimum VSWRs are obtained at these frequencies. The arrows show the vector of the current flow. As shown in Fig. 8(a) at 2.00 GHz, the current is dominant along the T-shaped slit edges of the antenna. The directions of the currents are anti-parallel in the narrow strip $(\mathrm{width} = w_1)$ and in the wide strip $(\mathrm{width} = w_2)$ along slit, so the antenna is in transmission line mode at 2 GHz. However, as is shown in Fig. 7(c), the antenna radiates. So the radiation mechanism at this frequency is considered to be different from folded dipole antenna. As shown in Fig. 8(b) at 1.35 GHz the main current flows along the bottom side of in the wide strip and the narrow strip. The directions of the currents are same in the narrow strip and in most of the wide strip (mainly at the bottom portion), so we can say that the folded dipole antenna is in antenna mode at this frequency.

In order to investigate these current distributions in detail, we simulated two antenna elements named construction A and construction B. The antenna constructions A and B are shown in Fig. 9(a) and Fig. 9(b), respectively. The simulated VSWRS of these antenna elements are shown in Fig. 9(c). It is shown that construction A has resonance at 2.1 GHz. So we can say that the higher order resonance at 2.00 GHz is mainly caused by the construction A. For construction B, bandwidth is increased when dipole width w_2 is increased. It is found that the resonance frequency is 1.4 GHz when $\mathrm{w}_2 = 16$ mm. So we can say that the lower order resonance at 1.35 GHz is mainly caused by the antenna mode shown in Fig. 8(b), that is based on the dipole antenna shown in the construction B. It is considered that the mechanism of the wideband operation of this folded dipole antenna is caused by the combination of these two constructions. The VSWR of the folded dipole antenna shown in Fig. 6 is also plotted in Fig. 9 as a reference.

VI. Conclusion

A planer folded dipole antenna with wideband characteristics is proposed. The antenna has simple planar construction without a ground plane and is easy to be assembled. Parameters for wideband and compact properties are found by using an electromagnetic simulator based on the method of moments. Experimental results centered at 1.7 GHz for 50 Ω impedance matching show that the antenna has the bandwidth of more than 55% $(\mathrm{VSWR} \leq 2)$. The simulated and experimental results are in good agreement, and the gains of the antenna are almost constant (around 2 dBi) in this frequency band. The radiation patterns are very similar to a normal dipole antenna except cross polarization components, and it is also found that the antenna has a self-balanced impedance property in this frequency band. The antenna is expected to be the powerful solution for the wideband wireless communication systems.

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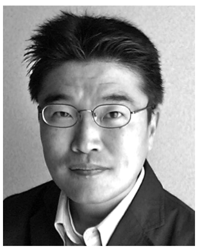

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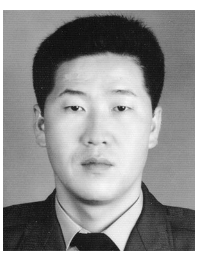

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