An Open Terminated Folded Inverted-L Antenna with Slits

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***Abstract* - An open terminated folded inverted-L antenna (FILA) is investigated for the theoretical limitation based on the product of bandwidth and radiation efficiency ($B\eta$ product). The FILA consists of two strips without connecting point and two slits on the strips are employed to miniaturize. Aspect ratio of the FILA is chosen as 1 : 2 that the horizontal arm has double the length of the vertical strip. Electrical radius of the surrounding sphere of the FILA became 0.59, and $B\eta$ product of 0.12 was obtained. Both of the size and performance of the proposed FILA were improved compared with conventional FILA.**

***Index Terms* — Folded structure, inverted-L antenna, small antenna, theoretical limitation.**

1. Introduction

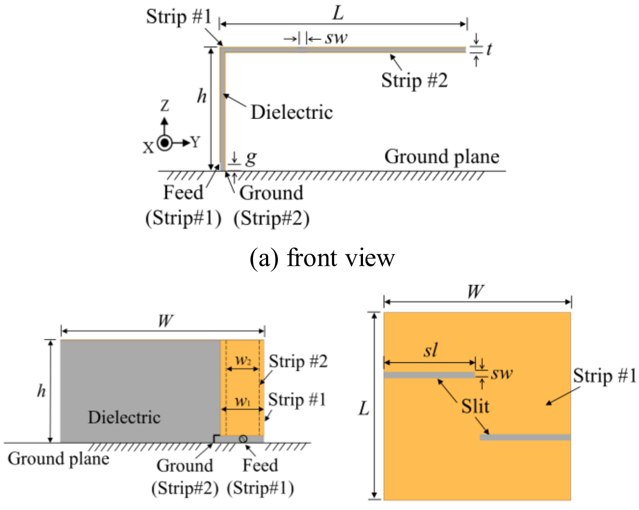
Small antennas with folded structure have good performances since wideband characteristics are realized with simple way. We have proposed small antennas with folded structure such as a folded inverted-L antenna (FILA), a folded meander line antenna and a folded normal mode helical antenna [1]-[3]. Though the folded small antennas have wideband characteristics, miniaturization method and comparison with theoretical limitation are not sufficient.

This paper proposes an open terminated FILA with slits that has no connecting point between strips due to high dielectric constant substrate. As the FILA is designed following with the design guideline of small antenna [4], the aspect ratio of 1 : 2 is selected for the length of horizontal and vertical strips. After characteristics of the FILA is simulated and measured, product of bandwidth and radiation efficiency is investigated.

2. Proposed FILA

Our proposed open terminated FILA with slits is shown in Fig.1. The antenna consists of two strips #1 and #2 printed on a dielectric substrate. Strip #1 is fed at the bottom, while strip #2 is grounded at the bottom for making folded structure. In order to obtain stable impedance characteristics, the FILA has no connecting point between strips. Vertical strips have different width for step-up impedance as shown in Fig.1 (b), horizontal strips are with two slits as shown in Fig.1 (c). Dielectric substrate is laminated fluoroplastic film produced by Chukoh flo (CGK-500, $\varepsilon_r = 5.0$, $\tan\delta = 0.004$).

The FILA is designed basically with following equations.



(a) front view

(b) side view (c) top view

Fig.1 Proposed open terminated FILA with slits.

$$Z_r = R + jRQ\left(\frac{f}{f_0} - \frac{f_0}{f}\right) \tag{1}$$

$$Z_b = -jZ_c \cot \beta\ell \tag{2}$$

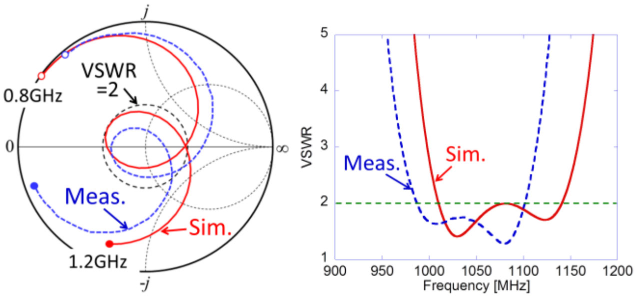
$$Z_{in} = \frac{2n^2 Z_r Z_b}{n^2 Z_r + 2Z_b} \tag{3}$$

In (1), Z_r, R, Q and f_0 are radiation impedance, radiation resistance, quality factor and resonant frequency, respectively. In (2), Z_b, Z_c, β and ℓ represent transmission line impedance, characteristic impedance, phase constant and line length between feed and open terminated strip. Input impedance Z_{in} includes Z_r, Z_b and impedance step up ratio n^2.

3. Simulated and measured results

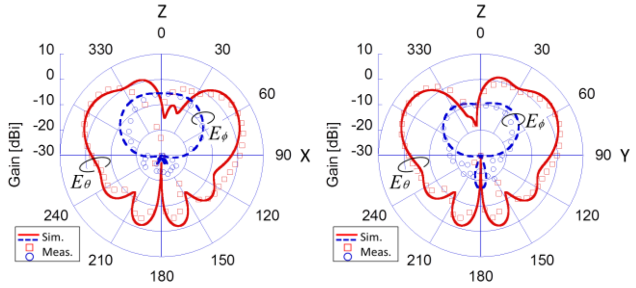
After design the FILA theoretically, simulation was implemented for detail parameters. We used EM Pro that is a 3D structure EM simulator based on FEM produced by Keysight Technologies. Antenna parameters were selected as antenna length and width $L = W = 30.0$ mm, height $h = 15.0$ mm, strip width of #1 $w_1 = 6.4$ mm, width of #2 $w_2 = 6.1$ mm, slit length $sl = 14.6$ mm, slit width $sw = 1$ mm and thickness of substrate $t = 0.5$ mm. Following the design guideline [4], we select the ratio $h : L$ as 1 : 2.

Impedance and VSWR characteristics are shown in Fig. 2. As shown in Fig. 2 (a), kink of impedance locus is located at the center of the Smith chart. The kink is generated due to the cancelation of radiation impedance and transmission line



(a) impedance (b) VSWR

Fig.2 Impedance and VSWR of FILA.



(a) *zx* plane (b) *yz* plane

Fig.3 Radiation pattern of FILA.

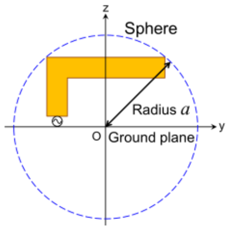


Fig.4 Surrounding sphere of FILA.

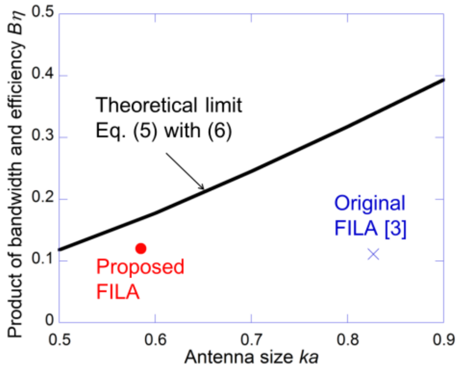


Fig.5 $B\eta$ product of FILA.

impedance each other. Measured results are slightly different from simulated results because of fabrication errors of the prototype FILA. VSWR shows wideband characteristics with center frequency of 1066 MHz and 12.2 % bandwidth for VSWR=2 criterion in simulated results. The bandwidth coincides with theoretical bandwidth B evaluated with the following equation.

$$B = \frac{\sqrt{\rho^2 - 1}}{Q} \quad (4)$$

Where, ρ represents the allowable VSWR. Since the FILA has Q of 14.6 obtained with simultaneous feeding two strip ILA by using same parameters with the FILA, theoretical bandwidth becomes 11.9 %.

Radiation characteristics were investigated and the results in simulation and measurement are shown in Fig. 3. A circular ground plane with radius of 300 mm (one wavelength of 1 GHz) was used for simulation and measurement. As shown in Fig. 3, the FILA has similar radiation pattern with that of conventional inverted-L antenna.

4. Evaluation of $B\eta$ product

In order to evaluate miniaturization factor of the FILA, we used $B\eta$ product with the following relationship [4].

$$B\eta = \frac{\eta}{\sqrt{2}Q} \quad (5)$$

Since the radiation efficiency η of the FILA was evaluated as 98.5 % in simulation, the value of $B\eta$ becomes 0.12. As evaluation of the miniaturization factor, lower bound of quality factor Q_{lb} is expressed as the following equation.

$$Q_{lb} = \frac{1}{ka} + \frac{1}{2(ka)^3} \quad (6)$$

In (6), k and a represent wave number and radius of surrounding sphere as shown in Fig. 4, hence, ka means electrical size of an antenna. As the FILA has ka = 0.585, Q_{lb} is 4.2 calculated with (6). If η = 100 %, $B\eta$ becomes 0.168 with (5). Proposed FILA approaches until 71.4 % of the theoretical limitation of $B\eta$.

Fig. 5 illustrates $B\eta$ product versus electrical antenna size ka. For comparison, $B\eta$ of the original FILA as shown in [3] is plotted. Proposed FILA is approaching to the theoretical limitation compared with the original FILA but the antenna size ka is smaller than that of the original FILA.

5. Conclusion

We proposed an open terminated FILA with slits and designed the FILA along with guide line of small antenna. $B\eta$ product as a miniaturization factor was evaluated and the proposed FILA approached until 71.4 % of the theoretical limitation.

Acknowledgment

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