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Design of Low Profile and Small Print Antennas

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1. Introduction

Small and low profile antennas have been required for a many kinds of applications such as radio frequency identification (RFID) tags[1], mobile terminals and on-body communication etc. In these technologies, such antennas are expected to install above a ground plane or metallic back conductor to reduce electrical effect on the antenna characteristics from backing circuits or material.

Many papers like ref. [2][3] have reported on low profile linear antennas with back conductor. However, as the distance between a linear antenna and a back conductor gets smaller than quarter wavelength, the real part of the input impedance, as the radiation resistance, approaches zero on most part of frequency other than parallel resonance frequencies which can be characterized by a steep transition from very large positive value of imaginary part to large negative. Usually it is difficult to operate the antenna at parallel frequency, however, the resonance frequency, at which the imaginary part of impedance changes from negative to positive, is used as serial resonance frequency of linear antennas.

On the other, electrically small antennas have been studied by many researchers. As the size is miniaturized, the radiation residence approaches zero similarly as the case of low profile antennas. Using meander line is a typical method to miniaturizing antennas to obtain larger radiation residence keeping the small size. In this paper, the authors discuss a design method for a low profile linear antenna. Furthermore, some examples of linear antenna with 0.02λ length element.

2. Low profile linear antenna with reflector

Fig. 1 shows an offset-fed dipole antenna with reflector (160×160 (mm)). In usual cases, the feeding point should be put at the center of linear antenna with $d_x=0$ and the h between the antenna and the reflector should be chosen as $\lambda/4$. The linear element is planar linear element in the x-y with 0 thickness. The length L is 142.5 mm in the x direction and the width 0.5mm in the y direction. The element and the reflector are perfect conductor (PEC). In this paper, we report, at first, the variation in input impedance with the h or d_x .

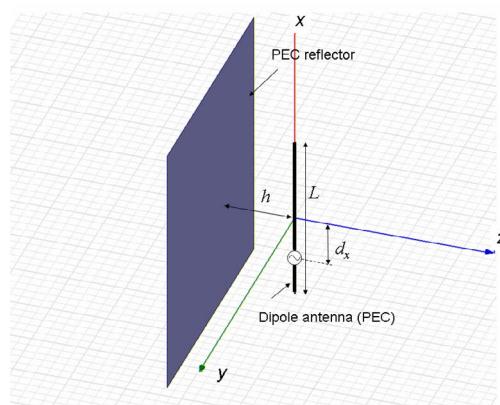


Fig. 1 Offset-fed dipole antenna with metallic reflector

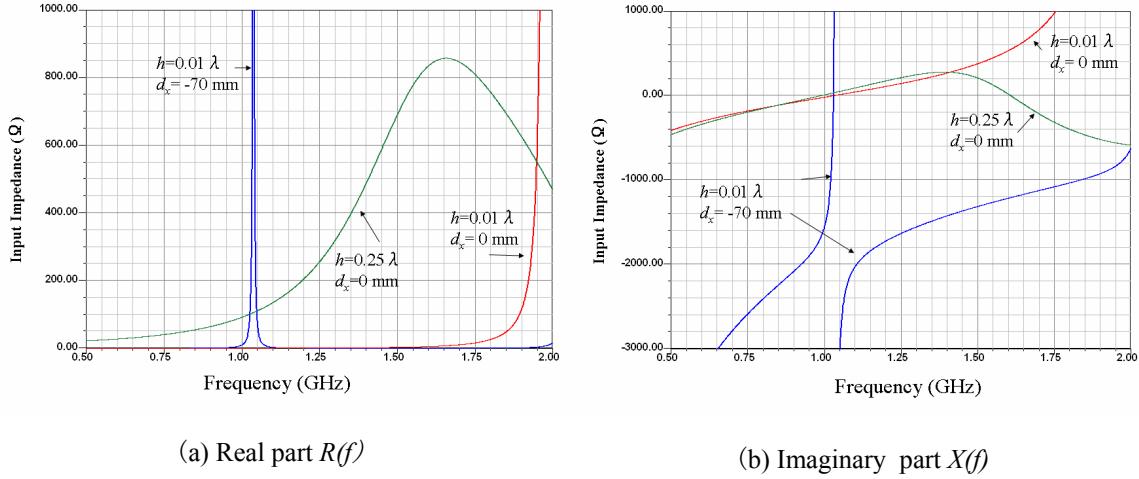


Fig. 2 Input impedance of the dipole antenna as a function of h and d_x

Fig. 2 shows input impedance characteristics of the dipole antenna by Ansoft HFSS. When $h = 0.25\lambda$ and $d_x = 0\text{ mm}$ (center), $R(f)$ is approximately 90 Ω and $X(f)$ is 0 Ω respectively at 1.0 GHz. This is the serial resonance ($X(f)=0$ and $X'(f)>0$) at this frequency. When the h is reduced to 0.01 λ (d_x is still 0 mm), $R(f)$ approaches 0 over the frequency up to 1.5 GHz. However, $R(f)$ increases to about 1000 Ω at maximum when $f > 1.5\text{GHz}$. In this case, the $R(f)$ is 50 Ω at 1.85 GHz, but $X(f)$ is very large (more than +1000 Ω) as shown in fig.2(b).

On the other hand, when d_x is shifted to -70 mm keeping $h=0.01\lambda$, we can see the parallel resonance at around 1.04 GHz. Note that the parallel resonance frequency having a peak of real part approaches to the serial resonance frequency of 1.0 GHz. As the result of fig.2 (a) and (b), the serial resonance ($X(f)=0$, $X'(f)>0$) exists at 1.02 GHz under the foot of real part of the parallel resonance peak. This result means that we could fabricate a low profile linear antenna using the serial resonance frequency and the foot of the parallel resonance of real part curve as radiation resistance at around 1.02 GHz. However, due to the keen peak of parallel resonance, we should note that the bandwidth become narrow as compared to the conventional dipole case of $h=0.25\lambda$ and $d_x=0\text{ mm}$.

At the serial resonance frequency of 1.02 GHz mentioned above, the real part of input impedance is about 50 Ω corresponding to the radiation resistance R_r . This is a good value for 50 Ω transmission line or circuit. However, in usual case, metallic resistance R_l is added to the radiation resistance, resulting in lower radiation efficiency η following

$$\eta = \frac{R_r}{R_r + R_l} \quad (1)$$

As a practical problem, we should consider to match a input circuit with the input impedance of $R_r + R_l$. Therefore, we may have to add some inductivity to adopt this situation with an additional stub at the element end that is closer to the feed point. This stub may form a T character with the antenna element. The structure and the application will be mentioned in next section. Using this structure, we can fabricate low profile and small linear antenna using folded structures.

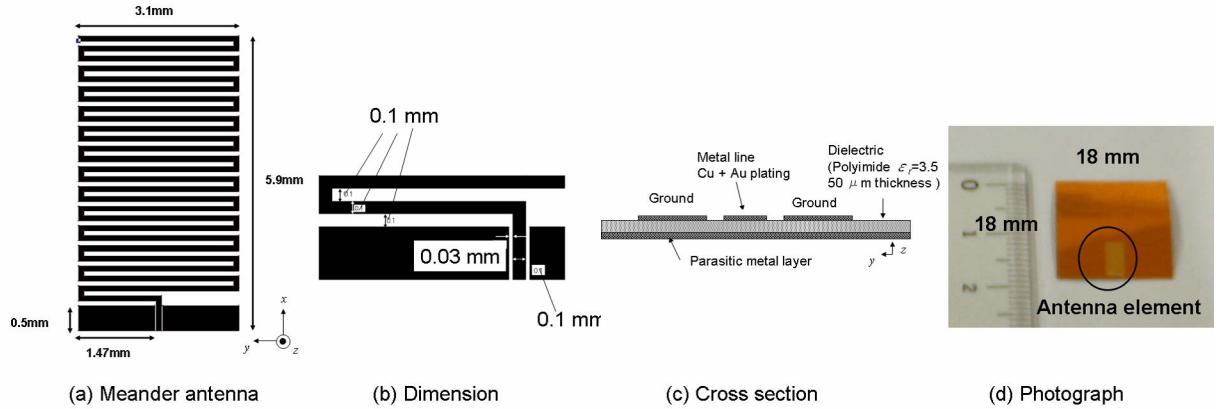


Fig. 3 Fabricated low profile meander antenna.

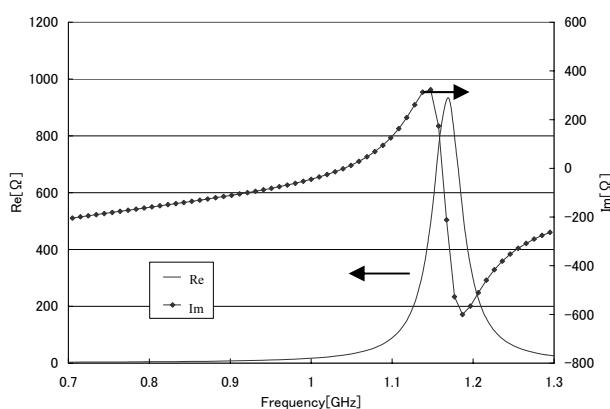


Fig. 4 Simulated input impedance characteristics

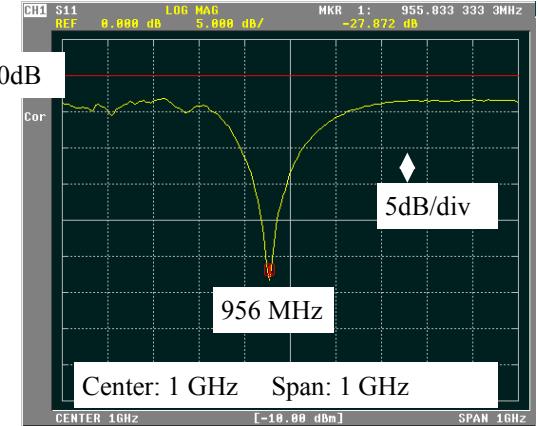


Fig. 5 Measured S11 characteristics

3. Fabrication of low profile and small antennas

Fig. 3 shows a structure of the meander antenna, which is fabricated on the 18×18 (mm) square polyimide substrate with $50 \mu\text{m}$ thickness. A meander-shaped element is fed through a coplanar waveguide structure with 50Ω as shown in the figure. The meander element consists a metallic line with 0.1mm width and forms 0.1 mm spaces between neighboring lines. This structure corresponds to the structure discussed in the previous section, the feed point is offset from the center of the line, and the ground planes of the coplanar line works as stubs to add some inductance for the discussion of metallic resistance in the previous section. When the length of the ground plane is extended in the y direction, the impedance will be more inductive.

Fig. 4 shows the simulated input impedance characteristics, where every loss ($\sigma=5.8 \times 10^7 \text{ S/m}$, $\tan\delta=0.01$) are considered. Therefore, this impedance includes both radiation and metallic resistance. A serial resonance exists under the foot of parallel resonance resulting in good matching with 50Ω . Fig 5 shows the measured S11 characteristics of the antenna, that is fed with 3 needles of GSG-structure installed at the end of 14 cm coaxial cable. The other end to the antenna is put on a probe stage and connected to a network analyzer through a conventional coaxial cable. This figure shows that the operating frequency is about 956MHz, that is lower from the simulation by about 40 MHz. Furthermore, the radiation efficiency was about 8%.

The authors have show some results of the meander antenna using a back conductor. The dimension of element has very small length(0.02λ) and satisfied the condition of electrically small antennas. ($ka=0.3 < 0.5$, $2a$:longest dimention, k :wave number)[4] including the substrate. However, the radia-

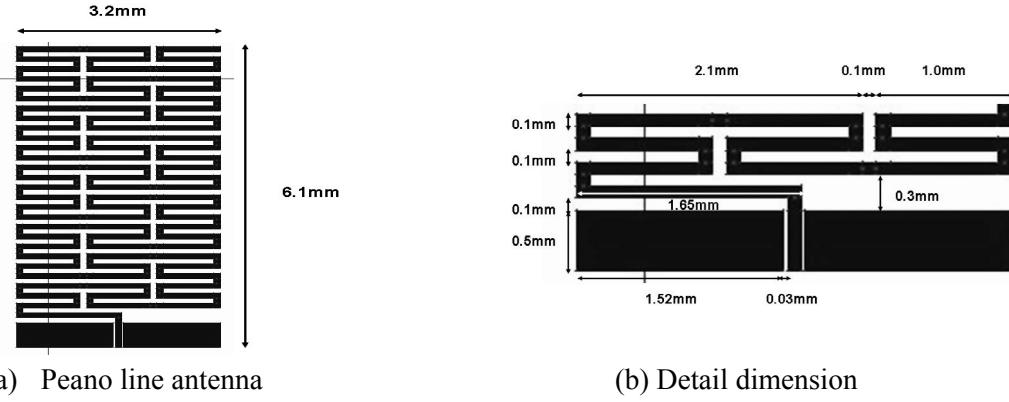


Fig. 6 Peano line antennas



Fig. 7 Gain characteristics of meander and Peano line antenna

tion efficiency was also very small. To overcome the demerit, the authors fabricated a small antenna using the Peano line[6] structure and tried a comparative study for the same frequency.

Fig. 6 (a) and (b) show the fabricated Peano antenna. The element size is almost the same as the meander antenna, and the substrate is the same; relative permittivity is 3.5 with 0.05 mm thickness polyimide with back conductor. Fig. 7 shows the radiation characteristics of both meander and Peano antenna. We have measured these characteristics using a horn antenna that is put 60 cm away from these antennas. From this results, we can confirmed that the antenna gain of the Peano antenna is larger by 3.5dB than that of the meander antennas. Furthermore the radiation efficiency of the Peano antenna was measured using the Wheeler method and the result was about 15%, that is also about twice as much as meander antenna, showing the 3.5dB difference of gain. Finally, we tried to cut the substrate for miniaturizing, however there were little effect on the S11 characteristics.

4. Conclusion

Low profile and small print antennas with $ka=0.3$ were fabricated. Furthermore, we have confirmed the merit of the Peano line structure for larger radiation efficiency of small antennas. As a result, we have obtained 15% of radiation efficiency for the 0.02λ antenna element.

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