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An Application of Slow Wave Property to Design of Compact Antenna

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Abstract- In this paper, we propose a new method to design the compact antenna. The shorting and feeding positions are located respectively on both sides of the designed antenna. Furthermore, the different slow wave effect is introduced by etching applicable geometric figures and adjusting considerately on radiator of the antenna. The measurement results show that the significant slow wave effect is introduced, if the etching geometric figure on the radiator of the antenna is placed at the position where the current density is larger current. Then the more obvious slow wave effect introduces the lower relative resonant frequency. So the antenna size can be reduced significantly by the application of slow wave property. Also, modifying the width and height of antenna is alternative way to reduce the size of antenna.

Keywords- compact antenna, slow wave effect

Ⅰ. Introduction

At present, most of consumer electronic products are developing toward miniaturization. So the technology of integrated circuit is widely applied in the field of communication base band module and radio frequency module to make communication products minimized. On the contrary, the technology of integrated circuit is difficult to design compact antenna. Therefore, the design of compact antenna becomes a critical technique to reduce the size of communication products.

PIFA (Planer Inverted F Antenna) is a major structure in compact antenna, and there are detailed discussions in [1][2][3]. Also the PIFA antenna is usually used in the design of dual band antenna [4][5][6] and diversity antenna [7]. The feature of the antenna is its $\lambda/4$ resonant length. This advantage compared to monopole antenna as well as microstrip antenna is planar and no dielectric loss, respectively. The design method of using capacitive load to minimize PIFA antenna is initially discussed in [1].

The main idea of this paper is to use alternative method to design the antenna that performs as well as PIFA antenna. Figure 1 shows the structure of antenna. We adjust feeding position such that the total length of radiator and ground forms the $\lambda/2$ length, then the phase of current on radiator conductor will keep consistent. The length of radiator on antenna is $\lambda/4$ the same as PIFA antenna. This paper also discusses the influence of antenna height and width to the resonant frequency, and find that the more width and height of antenna, the lower resonant frequency. In order to minimize the antenna size, we etch applicable geometric figure on radiator or ground that will induce slow wave effect on the antenna. Figure 2 illustrates the structure of etching geometric figure. Etching geometric figure increases equivalent inductance and capacitance that will decrease phase velocity on antenna to minimize antenna size.

Ⅱ. Antenna module and slow wave effect application

A. Antenna configuration

As shown in figure 3, the antenna transmission module is divided into two segments. One is the upper radiator composed of two conductors, each with one-eighth wavelength. The other is the lower ground with a quarter wave length. Feeding port uses the coaxial feed. The position of feeding port can be placed on one of the two ends. If one side of antenna is the feed position, the other side is short to ground. Figure 4 illustrates the equivalent transmission-line model, the slot between two upper conductors are modeled as the equivalent capacitors C_1, C_2 and C_3. On the short-pin end and feeding port end are modeled as the radiation resistance $R_r/2$ series with the equivalent inductor L_1 and

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radiation resistance $R_r/2$ series with the equivalent inductor L_2, respectively. The radiation resistances and equivalent inductances are produced by upper radiator, short pin and feeding port, respectively. The radiation resistance can transfer the energy to propagate in space when the resonance occurs. In this antenna structure, the lower ground provides the phase delay $(\beta_3+\beta_4)\bullet\lambda/8$, the radiator conductors provide the phase delay $\beta_1\bullet\lambda/8$ and $\beta_2\bullet\lambda/8$ respectively. When the length of each conductor on the upper radiator and ground plane is one eighth wavelength and quarter wavelength, the phase of current on the radiator is inphase to produce the resonant phenomenon. When resonant frequency is at 2.1GHz, the antenna size are L1=L2=18.5mm,Lg=40mm,h=6mm.

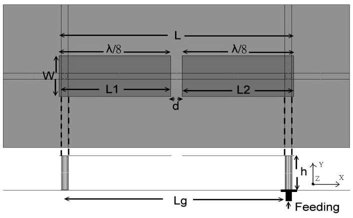

Fig.1. Antenna structure

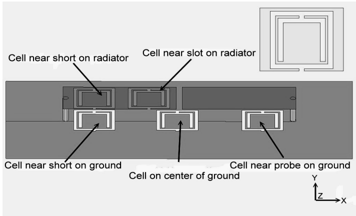

Fig.2. Etching structure and etching position

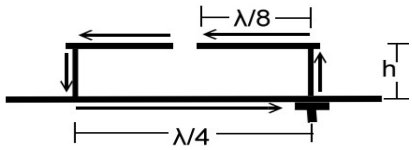

Fig.3. Antenna transmission module

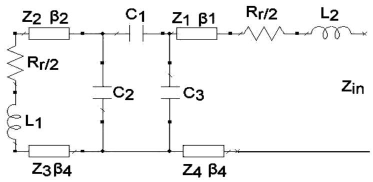

Fig.4. Equivalent transmission line circuit

B. An application of slow wave effect to minimize antenna size

The purpose of slow wave is to reduce the phase velocity. The relationship among phase velocity, capacitance and inductance is

$$v_p = 1/\sqrt{LC} \tag{1}$$

where v_p is phase velocity, L is equivalent inductance. C is equivalent capacitance. Hence, increasing the equivalent inductance and capacitance on resonant route of antenna can decrease the phase velocity. The method of increasing the equivalent inductance and capacitance is to etch applicable geometric figure, which is shown as figure 2, on antenna conductor. The etching part and thin conductor part on the geometric figure increases parallel capacitance effect as well as series inductance effect, respectively. Therefore, it will decrease phase velocity to minimize antenna size. The relationship between phase velocity and wavelength is

$$v_p = f\cdot\lambda \tag{2}$$

where f is resonant frequency, λ is resonant wavelength. At the same resonant frequency, decreasing phase velocity can reduce resonant wavelength.

Ⅲ. Results and discussions

A. Influence of slow wave effect on the antenna

Firstly, we discuss how the etching geometric figure on conductor surface affects the phase delay. The simulation results are shown in figure 5. There are two situations. The thin line shows the case without etching geometric figure on conductor. Phase velocity is about $5.1\times10^6\,m/s$ and is almost independent on frequency. The wide line shows the case with etching geometric figure on antenna. The geometric figure is shown as figure 2. The phase velocity is about $4.1\times10^6\,m/s$ before 4GHz, compare to the case without etching structure on conductor the phase velocity is reduced 20%. At 4.2GHz~4.7GHz, the phase velocity is larger than the case without etching geometric figure. Hence, the etching geometric figure shown as figure 2 can be only used to design the compact antenna of less 4GHz.

Figure 6 is the measured return loss by HP8720C. We discuss the affection of resonant frequency by different etching position with the same height, length and width of the antenna. The antenna size are h=6mm, W=8mm, L1=L2=18.5mm. The following describes the observations from the results shown in figure 6. First, etching geometric figure on radiator provides slow wave effect more than etching geometric figure on ground since there is larger area on the ground that causes smaller current density on the antenna resonant route. Second, the current distribution on antenna conductor is not uniform, and near short end of the antenna provides larger current distribution, hence, etching geometric figure on near short conductor of the antenna can obtain more effect of slow wave.

B. The influence of antenna size

Figure 7 illustrates antenna size to influence resonant frequency. When the antenna size is set as h=6mm, L1=L2=18.5mm and different width W=13mm, 8mm or 5mm, respectively. The measurement results shown in figure 7 could be concluded that wider width of the antenna provides lower resonant frequency. This is because increasing radiator width can increase capacitance effect that decreases phase velocity. On the other hand, for the same length and same width of radiator, it adjusts height of the antenna from h=6mm to h=3.5mm. According to measurement results, the height of antenna can also affect resonant frequency. To reduce antenna height can increase antenna resonant frequency. That is because lower antenna height causes shorter resonant length, and then smaller equivalent inductance.

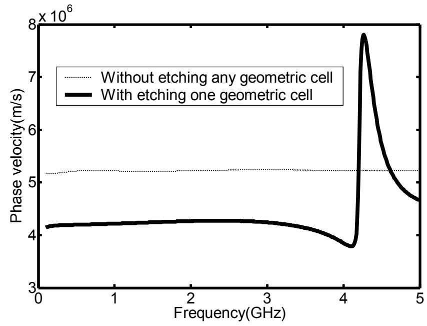

Fig.5. phase velocity with and without etching structure.

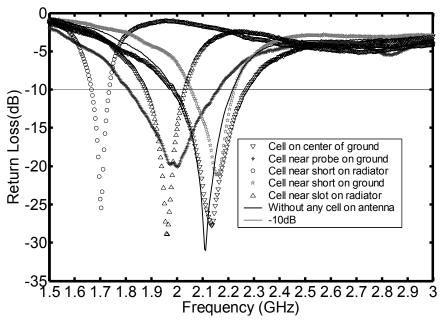

Fig.6. Return loss for etching geometric on different position.

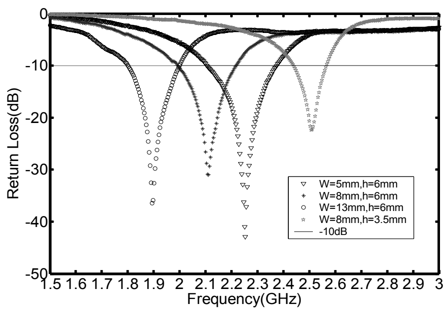

Fig.7. Return loss for different antenna width and height

Position of etching cell on antenna	Gain (dBi)	Antenna geometric parameter (without etching any cell)	Gain (dBi)
Cell near slot on radiator	2.93	W=5mm，h=6mm	2.9
Cell near short on radiator	2.1	W=8mm，h=6mm	3.41
Cell near probe on ground	2		
Cell on center of ground	3	W=13mm，h=6mm	1.57
Cell near short on ground	2.37	W=8mm，h=3.5mm	2.6

Table1. Antenna gain with different configuration

C. Results for antenna pattern and gain

Table 1 shows the gains of all antennas and is divided into two parts. The upper is classified according to the position of etching on the radiator. The lower is classified according to the different width and height. The maximum gain of the antenna is 3.41dBi without etching geometric figure on the antenna with size w=8mm and h=6mm. Figure 8 plots the radiation patterns in sequence the same as table 1. The asymmetry of the antenna radiation pattern is due to single-end feed. To compare the results without and with etching, the cross polarization of the H-plane will increase about 10 dB. This is because the etching structure on the antenna will destroy the direction of the current on the conductor, and hence the cross polarization increases. Although the amount of cross polarization is increased, the difference between co-polarization and cross-polarization is still over 10dB. As far as co-polarization is concerned, etching does not effect the magnitude of the radiation pattern. The previous analysis shows that reduction of antenna size, i.e. the lower resonant frequency could be obtained by wider width, higher height of antenna or locating the etching geometric figure on the positions which has larger current distribution. The advantage is got from the expense of little reduction of antenna gains.

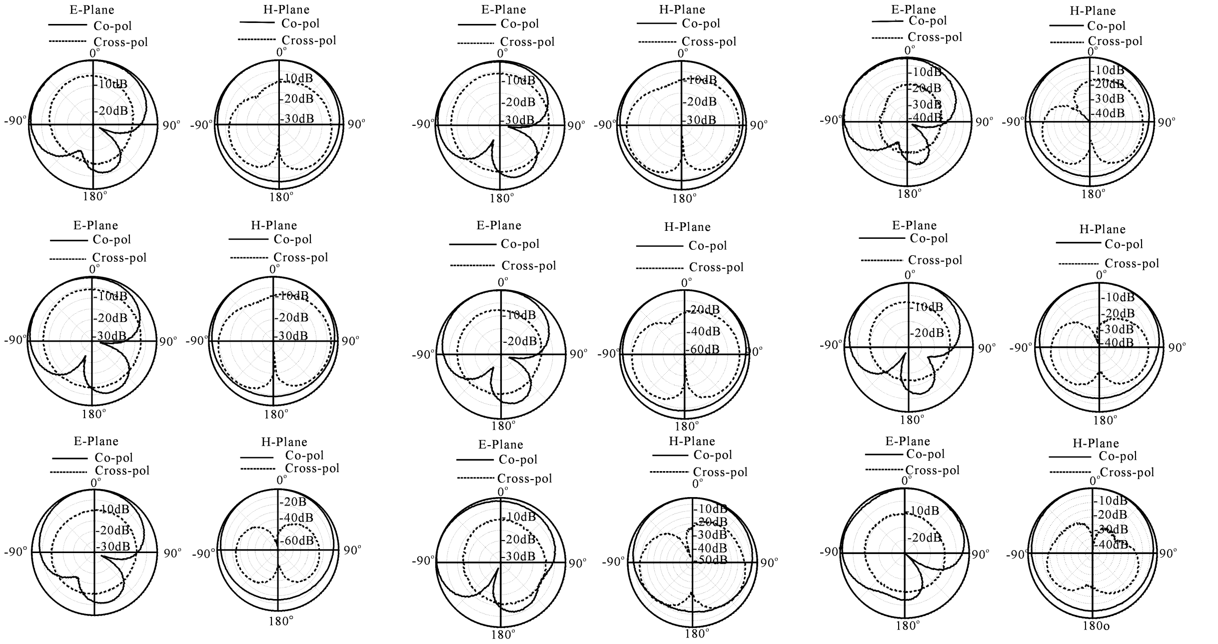

Fig.8. Measured antenna patterns.

Ⅳ. Conclusions

In this paper, the length of the antenna is designed for a quarter wavelengths. The design for feeding, which is different from the conventional PIFA, is an innovative conception designing for plane or conceal antenna. Due to no dielectric loss, this antenna structure could be useful. If we etch applicable geometry structure on proper position of the antenna, the slow wave effect can be measured graduate significantly. Moreover, the etching geometric figure is located at the position where the current density is larger. The significant effect of slow wave will be introduced. The more effect of slow wave will reduce the resonant frequency, and hence reduce the length of the antenna. Putting slow wave structure and increasing the width of radiator are alternatives to reduce the antenna dimension.

Ⅴ. Reference

[1] Rowell C.R., Murch R.D., “A capacitively loaded PIFA for compact mobile telephone handsets,” Antennas and Propagation, IEEE Transactions on , Volume: 45 , Issue: 5 , May 1997

[2] Virga K.L. Rahmat-Samii Y., “Low-profile enhanced-bandwidth PIFA antennas for wireless communications packaging,” Microwave Theory and Techniques, IEEE Transactions on , Volume: 45 , Issue: 10 , Oct. 1997

[3] Panayi P.K., Al-Nuaimi M.O., and Ivrissimtzis I.P., “Tuning techniques for planar inverted-F antenna,” Electronics Letters , Volume: 37 , Issue: 16 , 2 Aug. 2001

[4] Karmakar N.C., “Shorting strap tunable single feed dual-band stacked patch PIFA.,” Antennas and Wireless Propagation Letters , Volume: 2 , Issue: 2 , 2003

[5] Karmakar N.C., “Shorting strap tunable dual-band stacked PIFA,” Antennas and Propagation Society International Symposium, 2003. IEEE , Volume: 3 , June 22-27, 2003

[6] Fu-Ren Hsiao, Wen-Shyang Chen, Kin-Lu Wong, “Dual-frequency PIFA with a rolled radiating arm for GSM/DCS operation,” Antennas and Propagation Society International Symposium, 2003. IEEE , Volume: 3 , June 22-27, 2003

[7] Kin-Lu Wong, An-Chia Chen, Yen-Liang Kuo, “Diversity metal-plate planar inverted-F antenna for WLAN operation,” Electronics Letters, Volume: 39 , Issue: 7 , 3 April 2003

[8] Caloz C. and Itoh, T., “Multilayer and anisotropic planar compact PBG structures for microstrip applications,” Microwave Theory and Techniques, IEEE Transactions on , Volume: 50 , Issue: 9 , Sept. 2002