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The Study of a Novel Patch Antenna Sensor

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Abstract: In order to improve the bandwidth of the traditional patch antenna, a new antenna sensor based on the U-slot antenna was designed in this paper. The electromagnetic simulation software Ansys-HFSS was used to analyze the impact of the antenna parameters, and short circuit loaded half U-slot antenna with a slot ground plane was designed at last. The main bandwidth of the antenna sensor ranges from 670 MHz to 839 MHz, while the dimension of the sensor is small enough. The size of the antenna patch is just 70×42 mm. Although the directivity of the antenna is not good enough, it can be used to detect the ultra high frequency electromagnetic signals emitted from partial discharge sources in the power transformers. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Half-U slot antenna, Ansys-HFSS, Slot ground plane, Ultra high frequency, Power transformer.

1. Introduction

The concept of micro-strip antenna has been proposed since 1950s, however there was just little research about it for the limit of the technical level at that time. When it comes to 1970s, the micro-strip antenna was applied in practice gradually with the rapid development of microwave integrated technology Nowadays the micro-strip antenna has been widely used in many areas, such as satellite communications, radar and telemetry. Although the micro-strip antenna is small, light and can be attached to the objects easily, the bandwidth is too narrow compared to other antennas [1]. For the limit of the bandwidth, the micro-strip can't be applied in the field of broadband. In order to expand the bandwidth of the antenna many technology has been applied, such as antenna loading, surface slotted, changing the substrate, impedance matching etc. [2]. In order to take advantage of the micro-strip antenna, a new half U-slot micro-strip antenna which combines the shorted loading and surface grooving technology is designed in this paper.

2. The Design of Slot Patch Antenna

The slot shape on the antenna can be various, such as L-shaped, E-shaped, U-shaped, cross-shaped, etc. Firstly a U-shaped slot patch antenna which was based on the study of foreign scholars was analyzed in this paper [3-4]. The detail of the antenna can be seen in Fig. 1.

For the U-shaped slot antenna and other slot antennas, the methods to analyze the performance of them are similar. Firstly the transmission line theory is used to analyze the change of equivalent circuit, then the cavity mode theory is applied to study the excitation case of different modes, finally the results are got by considering the actual situations and the empirical formulas can also be created at last. The U-shaped slot designed in this paper is symmetrical and it is located in the central part of the patch antenna. The dimensions of the slot patch can be seen in Table 1. Note that the air is used as the dielectric between the patch and ground plate for the value of h is too large and several slender plastic rods and some glue are used to fix the patch and ground plate.

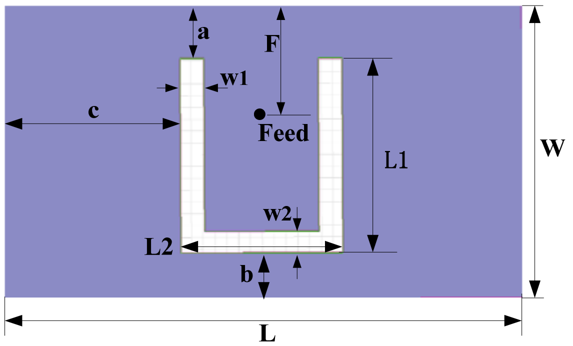


Fig. 1. The schematic diagram of slotted patch antenna.

Table 1. The parameters of U-shaped slot.

Parameter	Value
Length of patch, L	220 mm
Width of patch, W	125 mm
Width of U slot1 W1	10.2 mm
Width of U slot2, W2	12 mm
Length of U slot2, L2	68.6 mm
a	22.9 mm
b	19.4 mm
c	75.6 mm
Length between patch and ground, h	23 mm
Feed position F	76 mm

3. Influence of Parameters Constituting the U-shaped Slot

Although there is a formula to calculate the approximate center frequency of the traditional patch antenna [5], it seems difficult enough to find an appropriate formula to calculate the center frequency of the slot patch antenna after reading the academic literature published recent years. For the U-shaped slot antenna two empirical formulas can be referred to calculate the center frequency [6].

$$f_1 = \frac{c}{2(\frac{L2}{4} + \frac{L}{4} + W - \frac{b}{2})\sqrt{\varepsilon_e}}, \quad (1)$$

$$f_2 = \frac{c}{2(L1 - W + \frac{L2}{4} + 2F + b + \frac{W1}{2})\sqrt{\varepsilon_e}}, \quad (2)$$

where f_1 is the low resonance frequency, f_2 is the high resonance frequency, F is the distance between the feed point and the upper edge of patch, ε_e is the effective dielectric constant [5].

It should be noted that the U-shaped slot can inspire another cavity mode on the micro-strip line, two resonance frequency can exist at last (here we set $f_1 < f_2$). We can get the relationship between the antenna return loss and frequency as shown in Fig. 2 after using the electromagnetic simulation software Ansys HFSS. It can be seen from Fig. 2, there are two effective bands existing: 780 MHz ~ 827 MHz and 1.02 GHz ~ 1.12 GHz, two resonance frequencies can also be seen obviously. What's more, the bandwidth of the antenna is wider than the traditional one. If we put the data listed in Table 1 into expression (1) and expression (2), the resonance frequency f_1 can be 800.21 MHz, and another resonance frequency f_2 can be 991.28 MHz. These two calculated resonance frequencies seem similar to the simulation results showed in Fig. 2, so expression (1)~(2) can be used to estimate the center frequency of the U shaped slot patch antenna. The 3D gain pattern of the antenna at 1 GHz can be seen in Fig. 3. It is obvious that the normal direction of the antenna patch gets the largest radiation and the maximum gain is 10.357 dB.

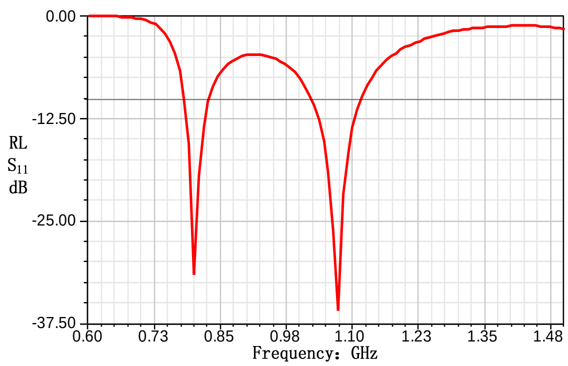


Fig. 2. The relationship between the antenna return loss and frequency.

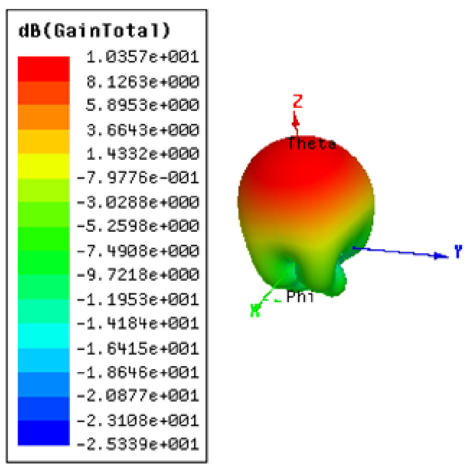


Fig. 3. The 3D gain pattern of the antenna.

In order to study the relationship between the antenna structure and the antenna performance, we set the key parameter W2 as an example. The value of the W2 ranges from 6mm to 18 mm with the length of each step is 2 mm. The parameter scan function which is built in the HFSS software can be used to get the S-parameter curves under different values of W2. The main result is shown in Fig. 4. It can be seen from Fig. 4, with the increase of W2, the f_1 and f_2 also increases (it is caused by the decrease length of U shaped slot [7]). It should be noted that if we keep other parameters of the antenna unchanged there is a optimal value of W2. The optimal value seems to be about 12 mm according to the simulation result.

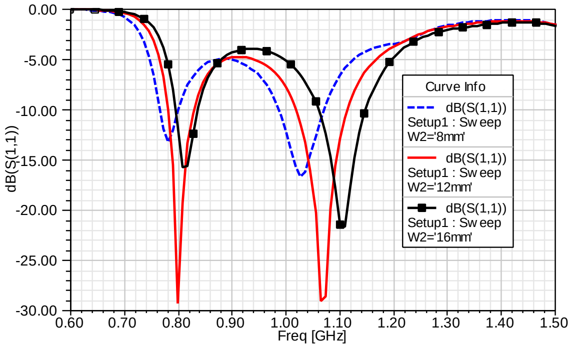


Fig. 4. The relationship between the antenna return loss and frequency with different W2.

It can be found that with the increase value of W and L, the low resonance frequency f_1 decreases while the high resonance frequency f_2 changes a little after many simulations. The simulation results also show that the change of L1 and L2 can influence the f_2 significantly while the f_2 seems insensitive relatively. However it is hard to find a clear relationship between the value of S parameter and the design parameters of the U-shaped slot patch antenna. Finally it should be noted that each parameter should be arranged properly to make the S parameter be good enough. The parameter values mentioned in Table 1 may not be the best, but they are obtained after many simulations and the antenna is suitable for measuring UHF signals.

4. Design of the Short Circuit Loaded Hall U Slot Antenna

Although it is possible to simply apply opening slots for the purpose of increasing bandwidth, this approach also leads to the problem of larger demanded antenna size. Therefore, it is required to consider additional measures to increase the bandwidth on the basis of without increasing the antenna area. In this paper, in order to reduce the size of the antenna, the optimization methods of load short-circuit and half U-slot are used, constituting a micro strip patch antenna structure which is similar with a dual-band PIFA (Planar Inverted-F Antennas) [8-9]. For further improving of the antenna's performance, it is slotted in the grounding plane [10].

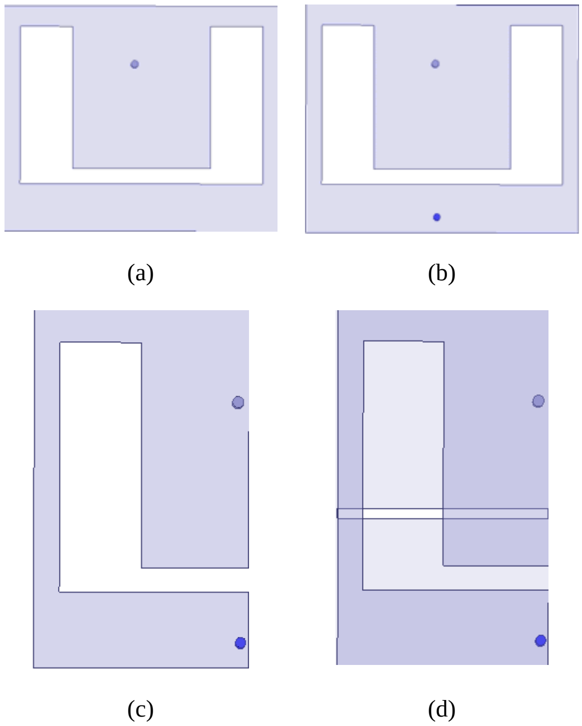


Fig. 5. Design ideas:
(a) U-shaped slot patch; (b) short-circuit loaded;
(c) half U slot patch; (d) slot in the ground plate.

A new slot patch antenna which contains a slot ground plate and a short-circuit pin is proposed in this paper. After a series of optimization, the final structure and size parameters of the antenna are shown in Table 2 and Fig. 6, Fig. 7, respectively.

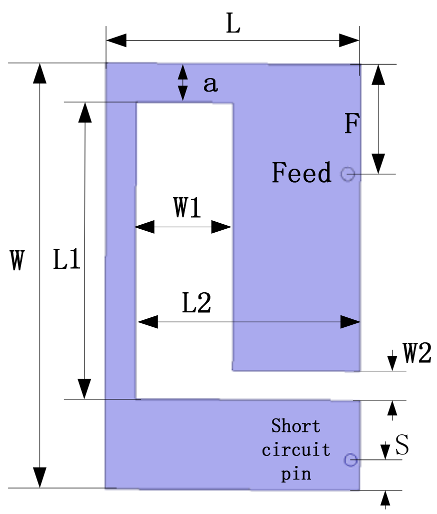


Fig. 6. The schematic diagram of antenna patch.

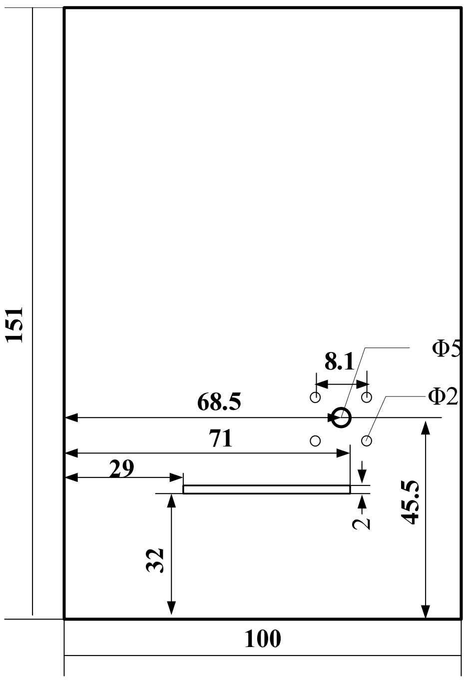


Fig. 7. The schematic diagram of antenna ground plate.

Table 2. The parameters of the designed antenna.

Parameter	Value
L	42 mm
W	70 mm
W1	16 mm
L1	48.7 mm
W2	4.8 mm
L2	37 mm
a	6.2 mm
h	32 mm
F	20 mm
S	5 mm
Radius of coaxial core	0.62 mm
Radius of shorted pin	0.5 mm

5. The Performance of the Antenna

After determining each parameter of the antenna, the sensor performance was simulated by using Ansys HFSS, and we got the relationship between the antenna return loss and frequency as shown in Fig. 8. It can be seen from the Fig. 8, when the frequency ranges from 670 MHz ~ 839 MHz and 936 MHz ~ 968 MHz, the return loss S_{11} is less than -10 dB. So the absolute bandwidth can be more than 200 MHz, which is much wider than the bandwidth of traditional slot antenna. If we compare Fig. 8 with Fig. 2, we can find that not only the bandwidth of the antenna but also the S_{11} value at the resonance frequency changes a lot. The antenna performance at f_1 improves a lot while the performance at f_2 degenerates. The patch surface current distribution which contributes to the antenna performance at resonance frequency can be changed by adjusting the position of the feed point, and the size of the slot. However it seems impossible to make the S_{11} at the two resonance frequencies be better at the same time. When the antenna performance at f_1 becomes better the other one at f_2 becomes worse, and if the antenna performance at f_2 becomes better the antenna performance at f_1 will also become worse. In order to meet the partial discharge measurement requirement for power transformers, we are focused on optimizing the performance at the low frequency. Therefore the performance degeneration at f_2 appears at Fig. 7 can be explained.

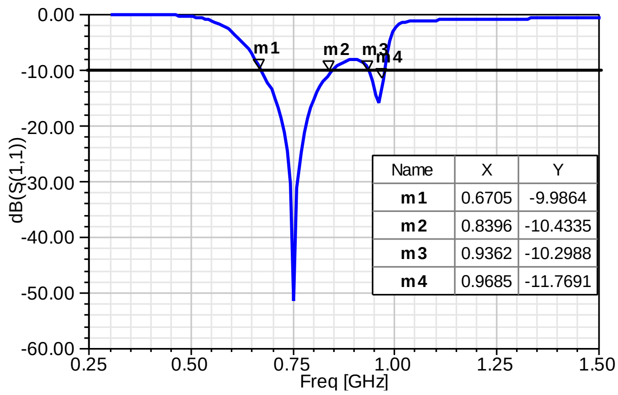
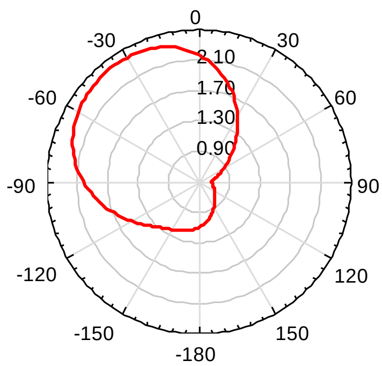
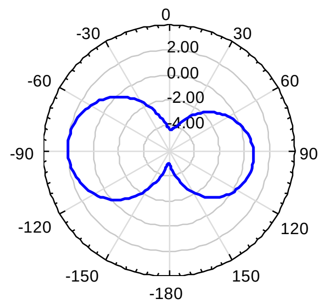


Fig. 8. The return loss figure of improved U slot antenna.

The antenna radiation pattern at xoy and yoz plane can be seen in Fig. 9.



(a) The radiation pattern at yoz plane.



(b) The radiation pattern at xoy plane.

Fig. 9. The radiation pattern of antenna.

It can be seen clear that the horizontal radiation pattern of the antenna is no longer omnidirectional, the vertical radiation pattern is not symmetrical either at the same time, and the maximum radiation direction is replaced by the oblique direction. This kind of antenna is obviously not suitable for the use of precise positioning for the bad radiation pattern, but if it is applied in the field of power transformer partial discharge detection of ultra-high-frequency signal, the radiation pattern may be ignored based on the fact that the antennas used in the power transformer are just required to detect the ultra high frequency signal.

In order to compare with the antenna referred in this paper several common antennas used for partial discharge detection are list in Table 3.

Table 3. The parameter comparison of partial discharge detection sensors.

Antenna Type	Size	bandwidth
Disk antenna [11]	Diameter 28 cm	300 MHz-3 GHz
Rod antenna [12]	Length 20 cm	250 MHz-1 GHz
Archimedes spiral antenna	Length 15 cm	800 MHz-4 GHz
Antenna in this paper	Patch Length 7 cm	670 MHz-839 MHz

The bandwidths of the disk antenna and the rod antenna are able to fulfill the requirement to collect enough amounts of data. The disadvantage for both antennas is the relative bulky size. Although the size of the Archimedes antenna is relative small in comparison with above mentioned two types of antenna, it also holds the drawback of complexity of control with its maximum frequency, which leads to problem of interference from the collected high frequency signals. In addition, for the Archimedes antenna, it is required to configure the feed balun. A compact size for the antenna designed in this paper is achieved at the expense of sacrificing the bandwidth to some degree. The area of the novel antenna is reduced by 90 % and 60 %, compared with the disk and the rod antenna respectively.

6. Conclusions

In this paper, a novel compact antenna for the ultra-high frequency partial discharge monitoring in transformer is designed, based on the structure of U-shaped slot micro strip antenna. Main conclusions are presented as following:

1) The size of the micro strip antenna can be reduced to some extent by using open slot and loaded short circuit. In the meantime, the bandwidth of the antenna is also increase at the expense of the antenna’s gain and the characteristics of direction being affected.

2) The size of the antenna can be reduced further by folding the open slot structure. The bandwidth of the folded antenna can be the same as or even beyond that of the unprocessed antenna, as long as the parameters of the antenna are set properly.

3) The overall performance of the half U-shaped micro strip antenna with short circuit pin loaded is influenced by many factors. In order to pursue the optimal performance, it is required to conduct lots of optimizations. The antenna designed in this paper is not the optimized solution of this type of antenna but its performance is improved to some degree in comparison with conventional micro strip antenna.

Acknowledgements

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