Print a Small Size U-Shape-Modified Broadband Slot Antenna on Ceramic Substrate

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Introduction

Recently, slot antennas played an important role in wireless technology, because the slot antennas had the advantages of low cost, light weight, easy realization and reasonably good performance. Therefore, such antennas become good candidates when applied to wireless handheld terminals. The slot antennas had the advantages of large bandwidth (BW value, measured from the -10dB of S_{11} value), good impedance matching, capability for full integration with active or passive components [1, 2], less conductor loss and better isolation between the radiating element and feeding network [3]. However, traditional slot antennas had the shortcoming of larger dimension, for that they were not suitable for WLAN applications. Many novel antenna techniques had been proposed for either size reduction [4] or bandwidth enhancement [5,6]. And in the past, the increase in bandwidth and the decrease in the size of designed antennas were considered as mutually conflicting properties, the improvement of one characteristic normally results in the degradation of the other one.

To further exploit the desirable miniaturization of microstrip antennas, a novel broadband microstrip fed slot antenna geometry was designed on the Al_2O_3 ceramic substrate and proposed in this paper. There were three reasons made us to use Al_2O_3 ceramic as substrate and use printed method to fabricate the designed slot antennas. First, due to the dielectric constant of traditional FR4 substrate was lower (ε_r =4.2), it was not suitable for the fabrication of small size microwave antennas. Using square Al_2O_3 ceramic (the thickness was 0.4 mm, 0.635mm and 1mm) as the substrate, the size of designed slot antenna could be reduced as compared to FR4 based antennas due to the higher dielectric constant of Al_2O_3 ceramic (ε_r=9.8). Second, the printed method was used to form the designed antenna patterns and the Ag/Pd paste was used as the paste. For that the printed method had a lower environmental pollution problem, because this method did not need using the $FeCl_3$ solution to etch the Cu plate from the surfaces of Duroid and the FR4 substrates. And third, the printed method was easy for mass production. In general, the conventional slot antennas fabricated on the ceramic substrate had the characteristics of small size, narrow-band and smaller return loss (S_{11}), because ceramic substrates had higher dielectric constant and lower loss tangent. However, a U-shape disturber was added in the slot and that would improve the characteristics of antennas designed on the Al_2O_3 ceramic substrate. In this paper, a U-shaped modified microstrip-line rectangular slot antenna was successfully designed and fabricated on Al_2O_3 substrate.

Antenna Design and Fabrication

The HFSS fullwave electromagnetic field simulator is used to design the parameters of the ceramic microstrip-line-fed slot antennas on Al_2O_3 ceramic substrates. From the simulated results, we have found that the thickness of Al_2O_3 ceramic has large influence on the characteristics of designed antennas. If the thickness of Al_2O_3 ceramic is equal to 1 mm or 0.635mm, the optimal maximum return loss (S_{11}) is lower -12 dB. The low loss of Al_2O_3

978-1-4244-2642-3/08/$25.00 ©2008 IEEE

ceramic is the reason and the antennas with the characteristics are not suitable for the use of modern communication. If the thickness of Al_2O_3 ceramic is 0.4 mm, the characteristics of designed slot antennas will be critically improved, the designed antennas have the simulated S_{11} values around -18dB and the optimal BW value is smaller than 1.2%. We have found that the Al_2O_3 ceramic with the thickness of 0.4 mm is the better choose to design and fabricate the slot antennas. However, the characteristics of slot antenna are not good for real use because of narrow BW value and smaller S_{11} values. If a U-shaped disturber is added in the slot, the BW values and the S_{11} values have been improved. For that, the proposed U-shaped modified microstrip-line-fed slot antenna is shown in Figure 1.

The parameters with the optimal characteristics to design the U-shape-modified slot antennas are ground plane size (L_1 x W_1) = 30 mm x 30 mm, L_2 = 12 mm, W_2 = 15 mm, W_f= 1 mm, L_4 = 10 mm, W_3 = 6 mm, W_4 = 0.5 mm and W_5 = 2.5 mm. As the parameters show, the designed antenna has a small size of 30 mm x 30 mm, which is small than the slot antennas fabricated on a FR4 substrate. Figure 2 shows the influence of the length of microstrip-fed line (L_3) on the characteristics of designed slot antennas. As the length of L_3 increases from 13 mm to 17 mm, the S_{11} values critically increase from -11.2 dB to -34.3 dB, and the resonant frequencies have no apparent change. As the length of L_3 increases from 17 mm to 19.5 mm, the S_{11} values slightly increase from -34.3 dB to -37.0 dB, the resonant frequencies are apparently shifted from 3.43 GHz to lower 3.05 GHz, and the BW values are decreased from 5.3% to 3.8%.

Figure 3 shows the influence of the thickness of Al_2O_3 ceramic substrate on the S_{11} values of proposed antennas, the length of microstrip-fed line is 19.5 mm. As the Figure 3 shows, the S_{11} values critically decreases from -37.0 dB to -14.1 dB and -7.54 dB as the thickness of Al_2O_3 ceramic is increased from the 0.4 mm to 0.635 mm and 1 mm. This is caused that the Al_2O_3 ceramic substrate has the low dielectric loss and high resistance. When the 0.635 mm and 1 mm Al_2O_3 ceramics are used as the substrate, the electromagnetic energy from the microstrip-fed line is hard to penetrate the substrate, and then the S_{11} values will be decreased.

After the parameters of the U-shape-modified slot antennas have been found, the mask is done according to the designed patterns and used to print the Ag/Pd paste on the Al_2O_3 substrate. The printed filters are fired in an oven at 700^{o}C for 15min. Finally, SMA connector is welded as the input, and the characteristics of fabricated antenna are measured using a vector network analyzer and far-field measurement system (Agilent-N5230A).

Results and Discussion

Figure 4 show the measured S_{11} values of the proposed antennas as a function of the thickness of Al_2O_3 ceramic substrate, the length of microstrip-fed line is 19.5 mm. The simulated results show that the S_{11} values critically decrease with the increase of the thickness of Al_2O_3 ceramic. Figure 4 also shows that the measured S_{11} values are smaller than the simulated results and the measured BW values are larger than the simulated results. The proposed dielectric loss of Al_2O_3 ceramic for simulation is 0.0001. These results suggest that the real dielectric loss of Al_2O_3 ceramic at the microwave frequency is larger than the proposed one. For that, the measured BW value will be larger and the S_{11} value will be smaller than the simulated results. For the 0.4mm-Al_2O_3 ceramic, the maximum measured S_{11} value is -28.0 dB at 3.12 GHz and the BW value is 8.9% (275 MHz), respectively.

Figure 5 shows the antenna gain of the proposed slot antenna across the frequency band of 2.95~3.30 GHz. The peak antenna gain is about 2.77 dBi at 3.12 GHz, and the antenna gain variation within the impedance bandwidth (2.98~3.25 GHz) is above 1.50 dBi. The measured far-field radiation patterns for the proposed antenna at the resonant frequency of 3.12 GHz are plotted in Figure 6. The measured radiation patterns are very close to those obtained in the simulation. It is seen that this antenna has the nearly omnidirectional radiation pattern in the x-y plane and monopolelike radiation pattern in the y-z plane. So the radiation patterns are generally omnidirectional over the entire bandwidth.

Conclusions

A microstrip-line-fed U-shaped modified slot antenna is designed and fabricated on Al_2O_3 ceramic substrate using the printing method. The influences of the length of microstrip-fed line and the thickness of Al_2O_3 ceramic on the characteristics of designed antennas are well defined in this study. As compared to other available current designs, the proposed structure of the fabricated antennas would offer the advantages of large bandwidth, large return loss, low profile and easy fabrication. Due to the larger dielectric constant of Al_2O_3 ceramic, the fabricated antenna has a small ground plane size of 30 mm × 30mm, and that is smaller than the slot antennas fabricated on a FR4 substrate. The fabricated slot antenna has a broad bandwidth of 275 MHz/8.9%, a high return loss of −28.0 dB and a maximum gain of 2.77 dBi at 3.12 GHz.

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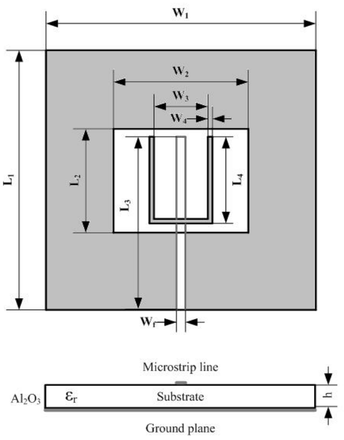

Figure 1. The geometry of designed antenna.

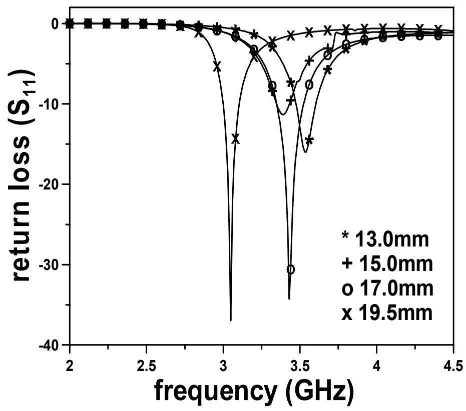

Figure 2. Simulated return loss characteristics of the proposed antennas as a function of L_1.

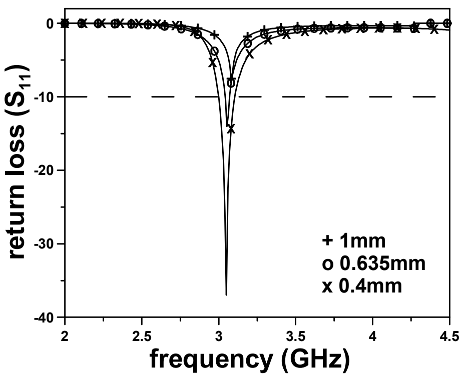

Figure 3. Simulated return loss characteristics of the proposed antennas as a function of the thickness of Al_2O_3 ceramic substrate, L_1=19.5mm.

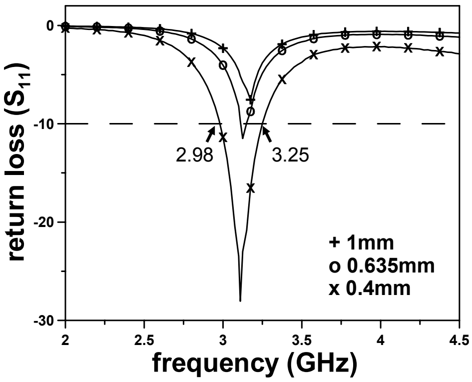

Figure 4. Measured return loss characteristics of the proposed antennas as a function of the thickness of Al_2O_3 ceramic substrate, L_1=19.5mm.

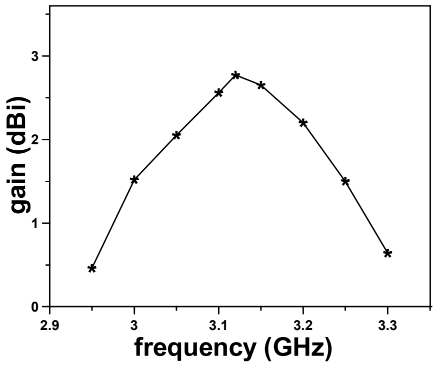

Figure 5. The gain of the fabricated slot antenna.

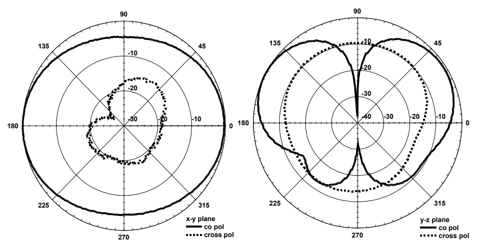

Figure 6. Measured far-field radiation patterns at 3.1 GHz for the proposed antenna.