Printing a Novel Compact Triple-Band Monopole Antenna on Ceramic Substrate

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Abstract

A novel miniaturized monopole antenna was designed on the 0.4mm- thickness Al_2O_3 ceramic substrate and a printed method that generated minimal environmental pollution was used to get the designed pattern. For the proposed triple-band antenna, the compact W-shaped electrode with different length in three arms was used as radiation pattern. Owing to the higher dielectric constant of Al_2O_3, the size of the triple-band antenna was minimized to 30 mm x20 mm. The novel triple-band monopole antenna was proposed to operate at 2.4 (WLAN), 3.5 GHz (WiMAX), and 5.2 GHz (WLAN).

1. Introduction

Recently, monopole antennas play an important role in wireless technology, because the monopole antennas have the advantages of low cost, light weight, easy realization, and novel structure. Owing to the rapid developments in modern communications, wide-band and multi-band operations are the basic demanding in practical applications. The use of a rectangular notch in coplanar waveguide (CPW)-fed antennas could change the surface current path, and hence the monopole antenna with dual-frequency operations was obtained [1]. In Ref. [2], different electric lengths were adopted to reach the multi-band applications. In Ref. [3], the authors used various meandered current paths to reach the multi-band operations of a CPW-fed monopole antenna. The characteristics of the fabricated antennas were not influenced by removing half of the ground plane. In the past, the L-shaped monopole dual-band antennas were fabricated on the FR4 substrates [4].

In this study, there were three reasons for us using Al_2O_3 ceramic as substrate and using printed method to fabricate the designed monopole antennas [5]. First, the FR4 substrate is not suitable for the fabrication of small size microwave antennas because of the lower dielectric constant (ε_r =4.2). Using square Al_2O_3 ceramic (the thickness was 0.4 mm, ε_r=9.8) as the substrate, the size of designed monopole antenna can be reduced due to the higher dielectric constant. Second, the Ag/Pd paste is used as the paste and the printed method is used to get the designed antenna patterns. The printed method has a lower environmental pollution problem, because this method does not need using the $FeCl_3$ solution to etch the Cu plate from the surfaces of Duroid or FR4 substrates. And third, the printed method is easy for mass production. In general, the conventional microstrip-line antennas fabricated on the ceramic substrate have the shortcomings of narrow bandwidth (BW) and smaller return loss (S_{11}), because ceramic substrates have lower loss tangent. However, using a thinner Al_2O_3 ceramic substrate will improve the characteristics of antennas [6]. In this paper, we will show that the W-shaped triple-band (operated at 2.4 GHz, 3.5 GHz, and 5.2 GHz) monopole antennas are successfully designed and fabricated on Al_2O_3 substrate.

2. Design and Fabrication of Triple-Band Monopole Antenna

The HFSS fullwave electromagnetic field simulator was used to find the optimal parameters of microstrip-line-fed W-shaped triple-band monopole antennas (abbreviated as W-shaped antenna) on Al_2O_3 ceramic substrates. When the 0.635 mm and 1 mm Al_2O_3 ceramics were used as the substrate, the electromagnetic energy from the radiation patterns

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were difficult to radiate from the substrate, the S_{11} values were decreased. The low loss of Al_2O_3 ceramic was the reason and the antennas with the characteristics were not suitable for the use of modern communications. We had found that the Al_2O_3 ceramic with the thickness of 0.4 mm was the better choose to fabricate the monopole triple-band antennas, because the characteristics of developed antennas were improved [6].

Even some Rogers Duroid printed boards had the dielectric constant of 10.2 and low dielectric loss, it was indeed too expensive for commercial applications. The Al_2O_3 ceramic substrates had a comparably higher dielectric constant of 9.4, a smaller dielectric loss less than 0.001, and low price. For those reasons, the filter was built on 0.4 mm thickness Al_2O_3 ceramic substrates for pattern minimization. The proposed antenna is shown in Fig.1, and the low environmental pollution of printing method was used to fabricate the proposed triple antenna. The printing method did not need using the $FeCl_3$ solution to etch the Cu plate from the surface of Duroid or FR4 substrates [6]. The printing mask was done according to the designed patterns and used to print the Ag/Pd paste on the Al_2O_3 ceramic substrates. After printing, the pattern was sintered in an oven at 700°C for 15min. Finally, two SMA connectors were welded as the input/output of the fabricated antennas, and the characteristics were measured using a vector network analyzer (Agilent-N5230A) and a far-field measurement system.

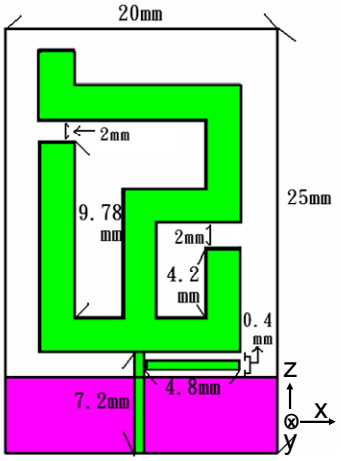

Fig. 1 The proposed triple-band monopole antenna.

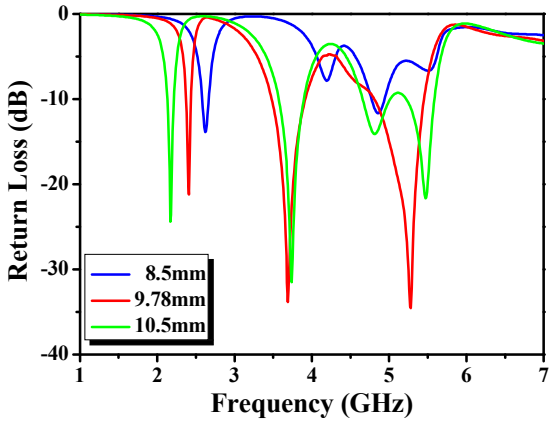

Fig. 2 The simulated responses of proposed triple-band antenna.

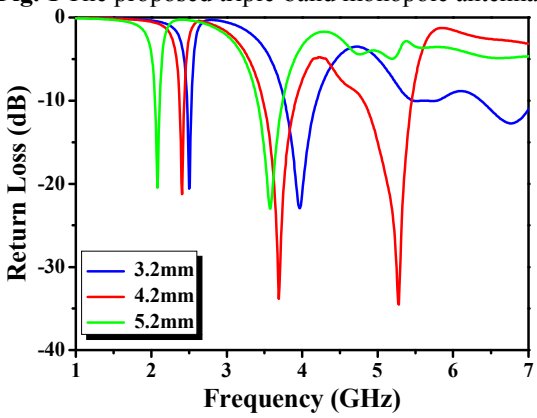

Fig. 3 The simulated responses of proposed triple-band antenna.

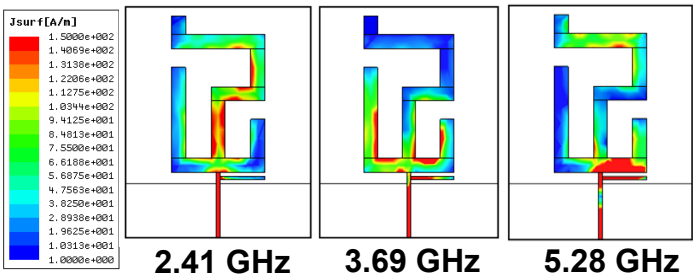

Fig. 4 Equivalent magnetic current distributions of W-shaped antenna

3. Simulated and Measured Results

Figs. 2-3 show the simulated results of the designed antenna as a function of left arm (for 3.5 GHz band) and right arm (for 5.2 GHz band), respectively. As the results in Fig.2 and Fig.3 show, if the lengths of left arm and right arm were not well selected, the designed antenna revealed the characteristic of dual-band rather than that of triple-band. However, the bandwidth of 2.4 GHz band in the simulated results of Fig.2 and Fig.3 was narrow. The optimal parameters for the proposed triple-band antenna are also shown in Fig.1. The resonant-mode magnetic current distributions in the W-shaped antenna are demonstrated in Fig.4. The magnetic current distributions for the W-shaped antenna were very complicated because there were three different current paths in this antenna. Due to the use of W-shaped electrode, a new resonant mode with shorter efficient length was excited and operated at higher frequency. As

Fig. 4 shows, the magnetic current distribution length of half-guided-wavelength route for 5.28 GHz at the microstrip line (the right arm) of W-shaped antenna was shorter than those of the 2.41 GHz and 3.69 GHz. Hence, the third resonant-band center frequency of the W-shaped antenna was higher than those of the L-shaped antenna published before [5, 6]. Similarly, the half guide-wavelength route of resonant frequency 2.41 GHz (3.54 GHz) was equal to the full length of microstrip feed line and central-arm (left-arm) of W-shaped electrode.

The simulated and measured results of the W-shaped antenna are compared in Fig.5. Apparently, the W-shaped antenna has the triple-band characteristics. The simulated results of the appropriate resonant frequencies are 2.41 GHz, 3.69 GHz, and 5.28 GHz with the S_{11} values of 21.2 dB, 33.9 dB, and 34.5 dB. The BW values are 2.90 % (70 MHz, 2.37 GHz~2.44 GHz), 11.7% (430 MHz, 3.48 GHz~3.91 GHz), and 12.1% (640 MHz, 4.81 GHz~5.45 GHz). However, as Fig.5 shows, the measured results for the W-shaped antenna really offered the advantages of triple-band. The measured results of the appropriate resonant frequencies are 2.34 GHz, 3.63 GHz, and 5.14 GHz with the S_{11} values of 24.5 dB, 21.8 dB, and 35.5 dB. The BW values are 11.1% (260 MHz, 2.20 GHz~2.46 GHz), 12.4% (450 MHz, 3.43 GHz~3.88 GHz), and 15.2% (780 MHz, 4.66 GHz~5.44 GHz), respectively.

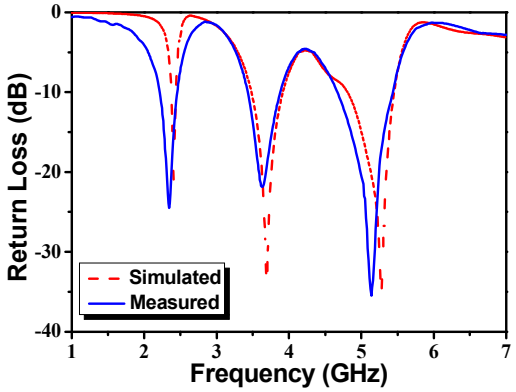

Fig. 5 Comparison of simulated and measured return loss characteristics for the triple-band proposed antennas.

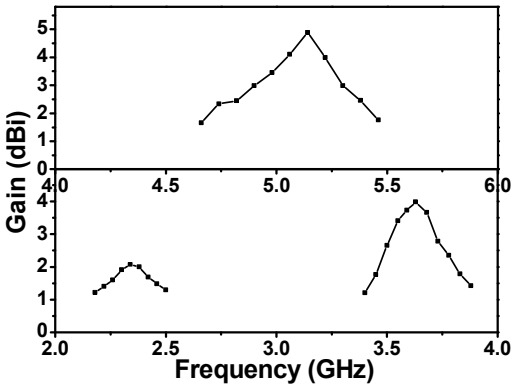

Fig. 6 Gains of the fabricated triple-band monopole antenna.

Figure 6 shows the antenna gains of W-shaped antenna across the different bands. The three peak antenna gains are 2.08 dBi, 3.99 dBi, and 4.88 dBi at 2.34 GHz, 3.63 GHz, and 5.14 GHz. The antenna gains within the 10 dB impedance bandwidths of 2.20 GHz~2.46 GHz, 3.43 GHz~3.88 GHz, and 4.66 GHz~5.44 GHz are larger than 1.30 dBi, 1.42 dBi, and 1.66 dBi, respectively. The measured far-field radiation patterns for the W-shaped antenna at different resonant frequencies are plotted in Fig.7. The W-shaped antenna also has the nearly omnidirectional radiation patterns in the E-plane and monopole like radiation patterns in the H-plane. This paper also proposed an important result that by properly designing the shapes of radiation electrode and using Al_2O_3 ceramic as substrate, a novel printed triple-band monopole antenna with compact size, wide impedance bandwidth, and good radiation characteristics suitable for different operations were achieved.

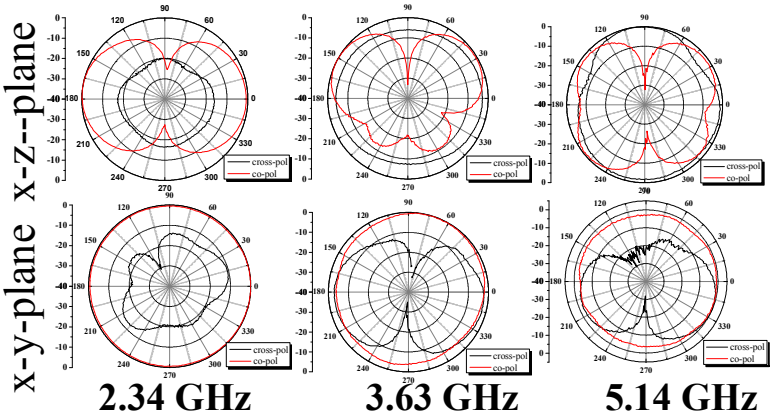

Fig. 7 Measured far-field radiation patterns at 2.34 GHz, 3.63 GHz, and 5.14 GHz for the proposed triple-band monopole antenna.

4. Conclusion

In this study, triple-band W-shaped monopole antenna was designed and fabricated on Al_2O_3 ceramic substrate using the printing method. As compared to other available current designs, the proposed triple-band W-shaped monopole antenna had offered the advantages of easy fabrication, large bandwidth, large return loss, low profile, and small size. As the measured results showed that the designed triple-band antenna had a small size of 30 mm x 20 mm because we used the structure of meandered current path. The W-shaped antenna was excited at 2.34 GHz (BW = 260 MHz/11.1 %), 3.63 GHz (BW = 450 MHz/12.4 %), and 5.14 GHz (BW = 780 MHz/15.2 %). The peak gains of this antenna were 2.08 dBi, 3.99 dBi, and 4.88 dBi at 2.34 GHz, 3.63 GHz, and 5.14 GHz, respectively.

5. Acknowledgment

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