Design of a symmetric open slot antenna for UWB applications

Sheng Zhang¹, Ye Zhong¹a, Yuyu Zhou¹, Ya Guo¹, and Chao Ji¹

Abstract In this paper, an ultra-wideband (UWB) antenna with symmetric open slots is proposed. The symmetric open slots and the U-shaped feeding line are introduced for obtaining the symmetrical radiation property and the lower cross-polarization level. By using the U-shaped feeding line to feed the symmetric open slots in parallel, four resonances are excited by the different effective resonant length of the open slots and form a wideband, which locates at 3.1-10.8GHz. The measured results show that the stable radiation patterns and the low cross-polarization level are obtained in the operating band, which shows that the proposed antenna is a good candidate for UWB applications.

Key words: slot antenna, ultra-wideband(UWB), open slot, symmetrical radiation property

Classification: Microwave and millimeter wave devices, circuits, and hardware

1. Introduction

With the rapid development of wireless communications, wideband antennas with low cost, compact size, and stable radiation patterns are in great demand. For the advantages of low profile, easy integration and wide bandwidth, slot antenna is an attractive candidate for wideband antenna design. In recent years, various methods have been used in closed slot antennas to obtain bandwidth enhancement [1–9]. However, the bandwidth of this type of antennas is limited by their slot width. Thereafter, many wide-slot antennas were proposed to enlarge antenna bandwidth in [10–22]. In [10–14], by employing various slot structures, and in [15], by appropriately choosing slot width, multiple resonances are generated and forms a wide bandwidth. Although have significantly broadened antenna bandwidth and meet the ultra-wideband(UWB) frequency requirements as well, wide-slot antennas have an obvious shortcoming of large size, which does not satisfy the requirement of miniaturization. To achieve wide bandwidth and compact slot size, the open-slot antennas were proposed in [23–33]. The open slot antenna has benefits of compact slot size and easy to obtain a wideband response, which makes it is getting more attention recently. In [23], by employing bent microstrip line to fed the U-shaped open slot, both slot modes and monopole modes are generated and form a wide bandwidth. In [24, 25], by introducing the irregular open slots, such as the J-shaped slot [24] and the stepped slot [25], antenna impedance bandwidths were widened and a UWB bandwidth result was gotten. Moreover, in [26], the open slot loaded substrate integrated waveguide (SIW) structure was proposed and an about 136% relative bandwidth was achieved. However, there are few works of the open slot antennas that possess the symmetrical radiation property and low cross-polarization level, which are desired in communication systems, due to their inherent directional radiation characteristic and asymmetrical current distributions that caused by their asymmetrical structures [34].

In this letter, an ultra-wideband symmetric open slot antenna is proposed for obtaining symmetrical radiation property and low cross-polarization level. By introducing the U-shaped feeding line to feed the symmetric etched open slot in parallel, four resonances are excited by different effective resonant lengths of the open slots. And through properly choosing the open slots length and the U-shaped feeding line parameters, four resonances are tuned and merged into a wide bandwidth. The bandwidth of the proposed antenna is aimed at 3.1-10.8GHz, which satisfy the FCC demands. At last, the proposed symmetric open slot antenna is manufactured and measured, the measured results show the symmetrical radiation patterns and low cross-polarization level, which are in good agreements with simulated ones.

2. Antenna design and analysis

2.1 Antenna design

Fig.1 shows the schematic diagram of the proposed symmetric open slot antenna on a Rogers 5880 substrate with the thickness of 1.575mm and permittivity of 2.2. The proposed antenna mainly consists of two parts, the U-shaped feeding line on the upper side of the substrate, which is referenced in [35], and the ground plane etched a pair of symmetric open slots at the bottom of the substrate. The symmetric open slots are electromagnetically fed by two arms of the U-shaped feeding line in parallel, which is designed to provide the same excitations to slots, in order to realize the symmetrical current distributions. The overall relative planar size of the proposed antenna is \( 0.67\lambda_0\times0.46\lambda_0 \), where \( \lambda_0 \) is the free-space wavelength at the mid operating frequency. The \( l_4 \) that denoted in Fig.1(a) is the length of the
2.2 Antenna analysis

Fig.2 exhibits the measured and simulated $S_{11}$ of the proposed antenna. It can be seen that four resonances are located at the frequencies of 3.28, 4.87, 7.22, and 9.46 GHz, respectively, and an ultra-wideband is obtained by joining these four resonances.

To verify the UWB operation of the proposed antenna, the simulated surface current distributions at different frequencies are depicted in Fig.3. It is observed in Fig.3(a) that the current mainly accumulates around the entire open slot and the slot is denoted as $L_1$ at 3.28GHz. In Fig.3(b), when the antenna operates at the intermediate resonant frequency, i.e. 4.87GHz, it is observed that the strong current is mainly distributed on the central part of the open slots $L_2$, which are at the corresponding position of the U-shaped feeding line on the ground plane. Moreover, the surface current distribution of the third resonant mode, i.e. 7.22GHz, is depicted in Fig.3(c). The strong current is mainly concentrated on the outside of the open slots $L_3$, which are the counterpart of two sides of the U-shaped feed line. From Fig.3(a), (b), (c), it is concluded that the three resonances are generated by the different effective resonant length of the open slots and the frequencies are related to its corresponding effective resonant length $L_1$, $L_2$ and $L_3$ respectively. It worth mentioning that in Fig.3(b), (c) the distributed current length $L_3$ is longer than $L_2$ while the third resonance frequency is higher. This is because the current cannot wrap around the open slot in case of $L_3$, which leads a shorter effective resonant length.

Moreover, the surface current distributions of the highest resonant frequency, e.g. 9.46GHz, is shown in Fig.3(d). From the distributions, it is observed that the resonance is generated by the high-order mode and radiates from the open slot too. Although not shown here for brevity, the U-shaped feeding line is also responsible for some radiation, especially at high frequencies, which is demonstrated in [36].

3. Simulated results and experimental verification

A prototype of the proposed antenna was fabricated and measured according to the final optimized dimensions. In Fig.2, The measured impedance bandwidth for $S_{11} < -10dB$ is 108% ranging from 3.15 to 10.55 GHz, which corresponds with the simulated bandwidth (3.1-10.8 GHz). Fig.4 exhibits the simulated and measured radiation patterns at 4.0, 6.0,
Fig. 4. Simulated and measured radiation patterns for \(yz\) plane and \(xy\) plane of the proposed symmetric open slot antenna for four different frequencies. (a) 4GHz, (b) 6GHz, (c) 8GHz and (d) 10GHz.

8.0, 10.0 GHz, respectively. It is observed that the symmetrical radiation patterns and the low cross-polarization level are obtained in most of the operating frequencies, except for a slight asymmetry radiation patterns in the low-frequency band, which is mainly caused by polarization direction deviating from the \(xoy\) (\(phi\)) plane. The measured peak gain of the proposed antenna varies 3.9 to 5.7 dBi in the concerned band (3.1-10.6GHz) is depicted in Fig.5, which shows that the gain curve is relatively stable with a floating of no more than 2dBi. The difference between the simulated and measured results is mainly caused by processing precision and measurement errors.

4. Conclusion

In this letter, a symmetric open slot antenna is proposed for UWB applications. Through introducing the symmetrical open slots and fed by two arms of the U-shaped feeding line, symmetrical current distributions and radiation patterns are obtained. Meantime, a wide bandwidth covering the UWB frequency band is achieved by combining the four resonances, which are generated by different resonant lengths of the open slots. The proposed symmetric open slot antenna has a compact and simple structure, which makes it a good candidate for UWB applications.

Fig. 5. Simulated and measured peak gain against frequency of the proposed symmetric open slot antenna.

Acknowledgments

This work is supported by the Fundamental Research Funds for the Central Universities (2019GF12).

References

[1] N. Behdad, et al.: "A wide-band slot antenna design employing a fictitious short circuit concept", IEEE Transactions on Antennas and Propagation, vol.53, no.1, pp. 475-482, Jan 2005 (DOI:10.1109/tap.2004.838778).
[2] Hu, H. T, et al.: "Novel Broadband Filtering Slotline Antennas Excited by Multimode Resonators" IEEE Antennas and Wireless Propagation Letters (2017) (DOI:10.1109/lawp.2016.2585524) (DOI:10.1109/lawp.2016.2585524).
[3] L. Zhu, et al.: "A novel broadband microstrip-fed wide slot antenna with double rejection zeros", IEEE Antennas and Wireless Propagation Letters, vol.2, pp. 194-196, 2003 2003 (DOI:10.1109/lawp.2003.819689).
[4] N. Behdad, et al.: "A multiresonant single-element wideband slot antenna", IEEE Antennas and Wireless Propagation Letters, vol.5, pp. 5-8, 2004 2004 (DOI:10.1109/lawp.2004.825093).
[5] X. K. Bi, et al.: "Design of wideband and high-gain slotline antenna using multi-mode radiator", IEEE Access, vol.7, pp. 54252-54260 2019 (DOI:10.1109/access.2019.2911329).
[6] C. R. Guo, et al.: "Wideband non-traveling-wave triple-mode slotline antenna", IET Microwaves Antennas & Propagation, vol.11, no.6, pp. 886-891, May 2017 (DOI:10.1049/iet-map.2016.0607).
[7] W. J. Lu, et al.: "Planar dual-mode wideband antenna using short-circuited-strips loaded slotline radiator: Operation principle, design, and validation", International Journal of RF and Microwave Computer-Aided Engineering, vol.25, no.7, pp. 573-581, Sep 2015 (DOI:10.1002/mmce.20895).
[8] W. J. Lu and L. Zhu, "Wideband sub-loaded slotline antennas under multi-mode resonance operation", IEEE Transactions on Antennas and Propagation, vol.63, no.2, pp. 818-823, Feb 2015 (DOI:10.1109/tap.2014.2379921).
M. Gopikrishna, W. Sun, A. Wu, P. Li, W.-L. M. Sonkki, C.-J. Wang, H. T. Hu, Y. F. Liu, G. Pan, R. Azim, M. T. Islam and N. Misran, “Compact tapered-shaped slot antennas fed by CPW and microstrip line”, IEEE Antennas and Propagation, vol.58, no.4, pp. 1057-1060, 2010 (DOI:10.1109/lapwp.2010.5485446).

A. A. R. Saad, C. S. Y. Li, S. A. Rezaeieh, A. K. Arya, A. Dastranj, G. Srivastava, J. Y. Jan, W. J. Lu, “Planar ultra-wideband printed slot antennas for UWB applications”, IEEE Antennas and Wireless Propagation Letters, vol.3, pp. 273-275, 2004 (DOI:10.1109/lapwp.2004.837510).

A. Wu, et al., “A shape blending based design of printed slot antennas for various wideband applications”, Microwave and Optical Technology Letters, vol.61, no.2, pp. 374-380, Feb 2019 (DOI:10.1002/mop.31572).

S. A. Rezaeieh, et al., “3-d wideband antenna for head-imaging system with performance verification in brain tumor detection”, IEEE Antennas and Wireless Propagation Letters, vol.14, pp. 910-914, 2015 (DOI:10.1109/lapwp.2015.2486506).

Y. F. Liu, et al., “Experimental studies of printed wide-slot antenna for wide-band applications”, IEEE Antennas and Wireless Propagation Letters, vol.3, pp. 273-275, 2004 (DOI:10.1109/lapwp.2004.837510).

X. L. Liang, et al., “Printed binominal-curved slot antennas for various wideband applications”, IEEE Transactions on Microwave Theory and Techniques, vol.59, no.4, pp. 1058-1065, Apr 2011 (DOI:10.1109/tmtt.2011.2113990).

J. Y. Jan, et al., “Bandwidth enhancement of a printed wide-slot antenna with a rotated slot”, IEEE Transactions on Antennas and Propagation, vol.53, no.6, pp. 2111-2114, Jun 2005 (DOI:10.1109/tap.2005.848518).

R. Azizn, M. T. Islam and N. Misran, “Compact tapered-shape slot antenna for UWB applications”, IEEE Antennas and Wireless Propagation Letters, vol.10, pp. 1190-1193, 2011 (DOI:10.1109/lapwp.2011.2172181).

A. K. Arya, et al., “Planar ultra-wideband printed wide-slot antenna using fork-like tuning stub”, Electronics Letters, vol.51, no.7, pp. 550-U107, Apr 2 2015 (DOI:10.1049/el.2015.0428).

H. T. Hu, et al., “A wideband u-shaped slot antenna and its application in mimo terminals”, IEEE Antennas and Wireless Propagation Letters, vol.15, pp. 508-511 2016 (DOI:10.1109/lapwp.2015.2455237).

M. Gopikrishna, et al., “A novel j slot antenna for uwb wimedia”, in Proceedings of the 6th international conference on advances in computing and communications, eds. J. Mathew, D. DasKrishna and J. Jose, pp. 89-93, 2016 (DOI:10.1016/j.procs.2016.07.186).

G. Srivastava, et al., “Compact MIMO slot antenna for uwb applications”, IEEE Antennas & Wireless Propagation Letters, vol.15, pp. 1057-1060 2016 (DOI:10.1109/lapwp.2015.2491968).

A. A. R. Saad, et al., “Bandwidth enlargement of a low-profile open-ring slot antenna based on siw structure”, IEEE Antennas and Wireless Propagation Letters, vol.16, pp. 2885-2888, 2017 (DOI:10.1109/lapwp.2017.2751247).

C. S. Y. Li, et al., “High-Isolation 3.5-GHz 8-Antenna MIMO Array Using Balanced Open Slot Antenna Element for 5G Smartphones”, IEEE Transactions on Antennas and Propagation 2019 (DOI:10.1109/TAP.2019.2902751).

C.-J. Wang, et al., “Microstrip open-slot antenna with broadband circular polarization and impedance bandwidth”, IEEE Transactions on Antennas and Propagation, vol.64, no.9, pp. 4095-4098, Sep 2016 (DOI:10.1109/tap.2016.2583459).

C.-J. Wang, et al., “A wideband open-slot antenna with dual-band-circular polarization”, vol.14, pp. 1306-1309 2015 (DOI:10.1109/lapwp.2015.2403572).

M. Stanley, et al., “A novel reconfigurable metal rim integrated open slot antenna for octa-band smartphone applications”, IEEE Transactions on Antennas and Propagation, vol.65, no.7, pp. 3352-3363, Jul 2017 (DOI:10.1109/tap.2017.2700084).

M. Sonkki, et al., “Wideband planar four-element linear antenna array”, IEEE Antennas and Wireless Propagation Letters, vol.13, 2014 2014 (DOI:10.1109/lapwp.2014.2350259).

H. T. Hu, et al., “A compact directional slot antenna and its application in mimo array”, IEEE Transactions on Antennas and Propagation, vol.64, no.12, pp. 5513-5517, Dec 2016 (DOI:10.1109/tap.2016.2621021).

M. Gopikrishna, et al., “Design of a microstrip fed step slot antenna for uwb communication”, Microwave and Optical Technology Letters, vol.51, no.4, pp. 1126-1129, Apr 2009 (DOI:10.1002/mop.24262).

W. Sun, et al., “Low-profile and wideband microstrip antenna using quasi-periodic aperture and slot-to-cpw transition”, IEEE Transactions on Antennas and Propagation, vol.67, no.1, pp. 632-637, Jan 2019 (DOI:10.1109/tap.2018.2874801).

S. W. Wong, et al., “Broadband dual-polarization and stable-beamwidth slot antenna fed by u-shape microstrip line”, Ieee Transactions on Antennas and Propagation, vol.64, no.10, pp. 4477-4481, Oct 2016 (DOI:10.1109/tap.2016.2586493).

M. A. Antoniades, et al., “Planar antennas for compact multiband transceivers using a microstrip feedline and multiple open-ended ground slots”, Journal of Microwaves Antennas & Propagation, vol.9, no.5, pp. 486-494, Apr 13 2015 (DOI:10.1049/jet-map.2014.0365).