

Differential Fed Ultra-Wideband Multiple-Mode Antenna Using Uniform Narrow Slot Radiator

Xiu Hua Jin, Xiao Dong Huang*, and Chong Hu Cheng

Abstract—A new ultra-wideband antenna based on a uniform narrow slot is proposed. The slot radiator is fed by a pair of differential microstrip-lines, to implement a balanced and vialess antenna. The multiple-mode resonances of the radiator are excited simultaneously to form an ultra-wideband radiation, by optimizing antenna dimensions and port impedance. Comparing with other ultra-wideband slot antennas, this antenna has improved radiation patterns and low cross polarization due to its symmetry in structure. Antenna samples are designed and fabricated for verification. The measured impedance bandwidth has successfully achieved a fractional bandwidth of 106% ($VSWR < 2.5$). The radiation patterns are also measured and agree well with the prediction.

1. INTRODUCTION

As a fundamental concept in antenna theory [1], multiple-mode resonance (MMR) has been widely used in ultra-wideband (UWB) antenna design. Compared with others, MMR-based UWB antennas attract much attention due to their compact size and good design flexibility. Therefore, numerous designs have been developed in the past decade [2–7]. One of the main drawbacks of those traditional MMR-based UWB antennas [2–5] is high cross polarization, due to their 2D radiation structures [8, 9]. Also, the design procedure relies on cut-and-try method because of complicated radiation mechanism. Recently, several wideband antennas have been reported based on quasi-1D radiators, e.g., narrow straight slot. In such antennas [6–10], the radiation launches from a narrow straight slot, in which the first two or more resonances are merged to form a continuous wide radiation band. In a 1D radiator, the electromagnetic field distributes along one direction, brings convenience in mode prediction and modeling. A 1D radiator can lead to high polarization purity, too. Furthermore, the circuit behavior can be analyzed by using the transmission line model [11, 12]. Of these designs, the most important role is the feeding scheme, because the feeding location dominates the excitation strength for each mode. The feeding is usually implemented by using a section of microstrip-line with short- or open-circuited end, which is arranged over the radiating slot on the ground plane. This configuration can enhance the mutual coupling between feeder and slot.

Figure 1 shows several feeding schemes for microstrip-fed narrow slot antennas. Metallic via (Figure 1(a)) can be widely found in the designs of microstrip-line to slotline transition [13]. With this feeding, the first two modes are excited [6] and then form a wideband antenna of 40% fractional bandwidth (FBW). In [7], an improved scheme is developed, as shown in Figure 1(b). The slot nearby the feeding is narrowed for wideband coupling. As a result, a UWB antenna of $\sim 100\%$ FBW is implemented successfully. The metallic via can be replaced by a section of open-ended line for vialess application [6, 8–10], as shown in (c). However, this replacement only works for narrow FBW that limits its use in UWB applications. In addition, the three feeding schemes are asymmetric along the direction in slot width;

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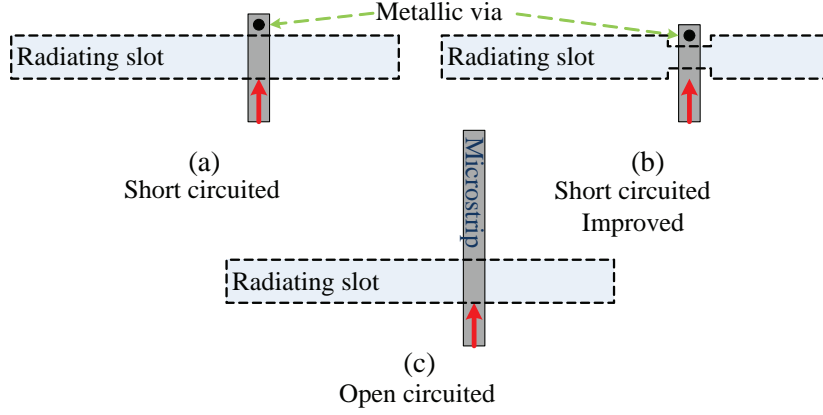


Figure 1. Feeding schemes for microstrip-line to slot radiator.

therefore, the field distribution in this direction will be affected slightly, especially at high frequencies. As a result, the radiation pattern will be influenced, e.g., lobe direction and polarization purity. In the last, the radiating slot in (b) is non-uniform to gain best performance. However, the initial radiation from a uniform slot has been damaged on a certain level.

By employing a differential feeding scheme, a novel UWB antenna based on a uniform narrow slot is studied in this work. The differential feeding can be widely found in high performance antenna designs, including UWB antennas [14]. Compared with the original design [7], the proposed one has three advantages: uniform slot, symmetry (in slot width direction) and vialess. A uniform radiator has minimal number of parameters in geometry, and can be modeled or analyzed more efficiently. Furthermore, the symmetry in a radiating structure always leads to symmetric pattern, which has the lowest cross polarization level. In the last, a vialess structure is simple in fabrication and low in cost. Meanwhile, the UWB radiation behavior is fully retained in this design.

2. ANTENNA DESIGN

Figure 2 depicts the configuration of the proposed UWB antenna with a differential feeder. The radiating slot is constructed on the back of a microstrip substrate, with dimensions of W (width) and L (length). On the front side, a short section of microstrip-line is arranged across the slot in right angle, with dimensions of f (width) and W (length). Similar to other MMR narrow slot antennas [6–10], the feeding location (t) is offset from center in x -direction. At the two edges of the microstrip-line, two ports/excitations are added in odd mode. This scheme is so-called differential feeding, which is popular in differential circuit/antenna design [14]. In fact, with the knowledge of electromagnetic, a structure excited in odd mode can be treated as if there is an electric wall in the central symmetric plane. This virtual electric wall simplifies the field analysis and guarantees the polarization purity in the symmetric

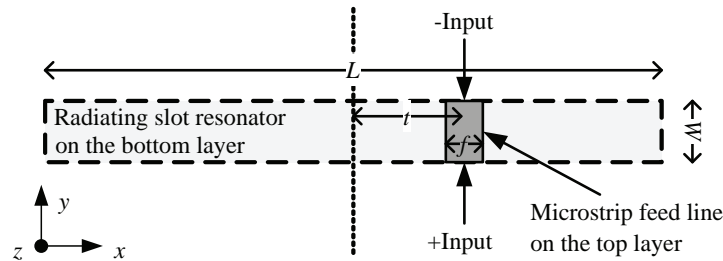


Figure 2. Configuration of proposed differential-fed narrow slot antenna that is fed at an offset distance (t).

plane (H -plane or xoz -plane in this case). The last parameter is the port impedance, Z_{port} .

The optimization on the parameters of W , L , f , t , and Z_{port} is executed using the Zeland IE3D package. The optimization procedure is the same as that in [7], with fewer parameters. On the same substrate of [7] (relative permittivity: 2.94 and height: 0.762 mm), the slot parameters are kept unchanged in optimization, e.g., $L = 40.0$ mm and $W = 7.0$ mm, to make sure antenna works in UWB band. After the optimization ($|S_{11}| < -10$ dB from 3.1 to 10.6 GHz), a set of parameters is derived as $L = 40.0$ mm, $W = 7.0$ mm, $f = 2.3$ mm and $t = 5.5$ mm.

The main objective of this work is to demonstrate the effect of a differential feeder. Therefore, the details of the optimization and parametric studies are not given. As has been extensively studied in [6, 7], the selection of port impedance is very important. Figure 3 depicts the simulated VSWR with varied port impedance under the optimized antenna dimension. From the figure, it may be found that with port impedance of 110 Ohm, the VSWR curve has the widest bandwidth below 2.0 from 3.1 GHz to 10.6 GHz, except for a protruding up to 2.2 around 5.0 GHz. It can also found that there are four reflection minima within the operating band; these are 3.5, 6.0, 8.3 and 9.7 GHz, respectively.

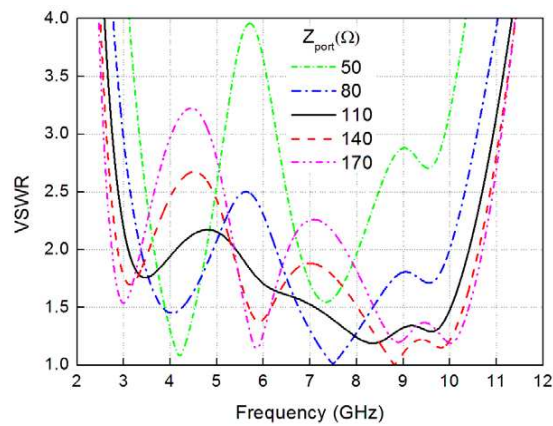


Figure 3. VSWR versus frequency under varied port impedance.

3. EXPERIMENTAL VERIFICATION

Figure 4 shows the front and back views of a fabricated antenna. From the photos, one may find that a pair of tapered-line transformers is added. The purpose is to transform the optimized local port impedance $110\ \Omega$ to the standard $50\ \Omega$ test equipment. Also, the finite ground effect should be considered in practical fabrication. Figure 5 plots the simulated VSWR of this actual $50\ \Omega$ fed antenna with finite ground, compared to that of the initial ideal $110\ \Omega$ fed antenna. As the transformers and finite ground effect are taken into account, the operating band keeps almost unchanged except for a small shift of the raising part near 5.0 GHz.

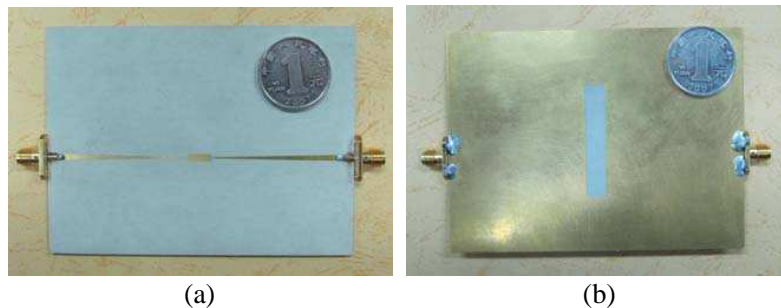


Figure 4. Photographs of the fabricated UWB antenna. (a) Top view. (b) Bottom view.

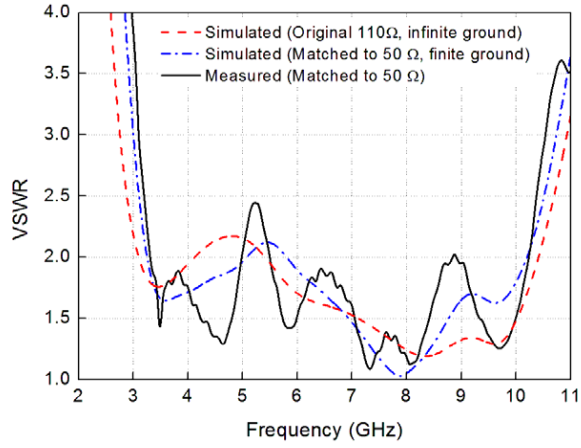


Figure 5. Simulated and measured VSWR of proposed antenna.

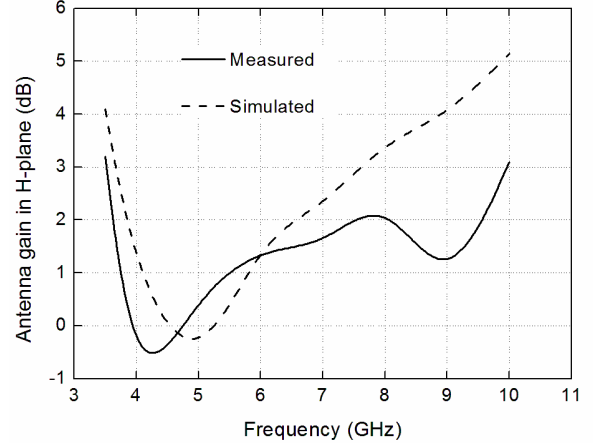


Figure 6. Simulated and measured antenna gain in H -plane (xoz plane) of proposed antenna.

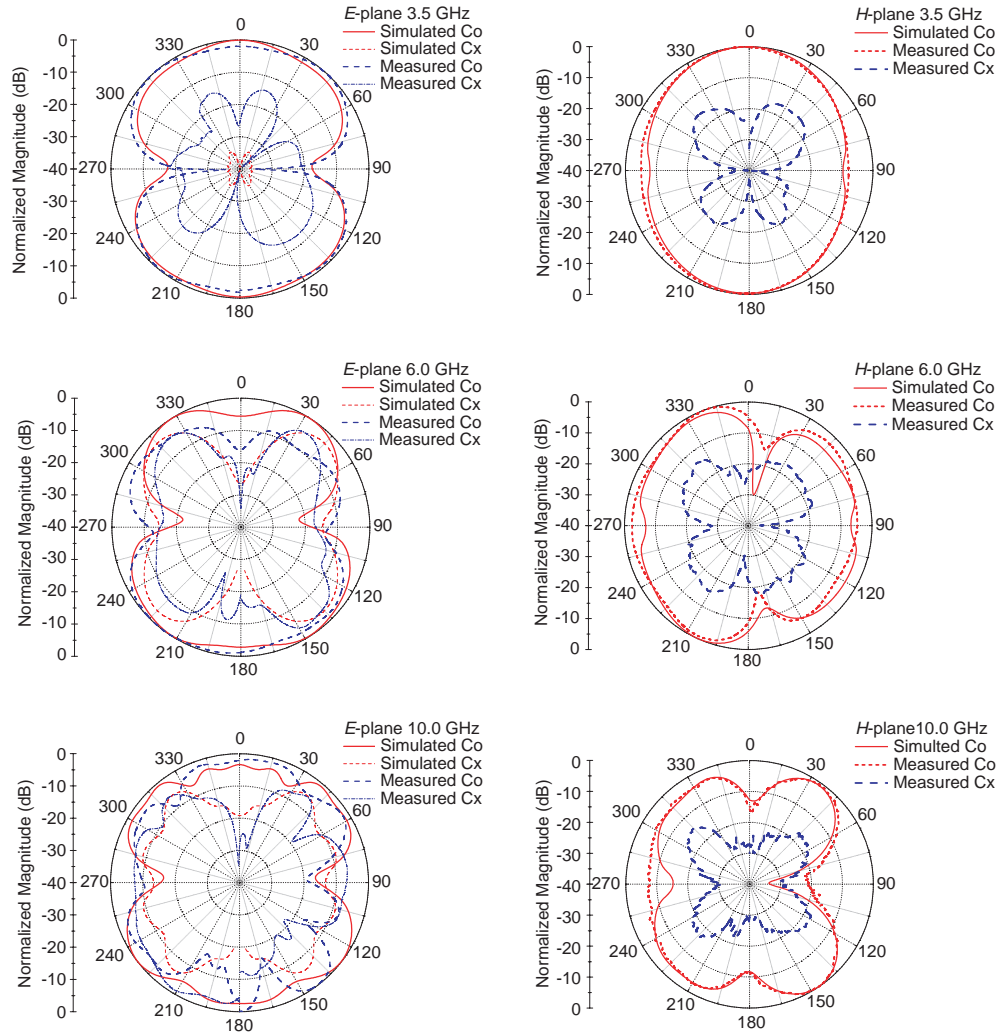


Figure 7. Measured and simulated radiation patterns at different frequencies of proposed antenna.

The $VSWR/|S_{11}|$ test is carried out via an Agilent VNA (5230A with two channels). Because the differential measurement is not supported directly on our VNA, a post-processing is needed after the test on equipment. The measured scattering parameters of the two-port antenna sample are S_{11} , S_{12} , S_{22} and S_{21} , respectively. In ideal case, S_{11} and S_{22} have the same value due to symmetry, as well as S_{12} and S_{21} . In practical, there exist differences between them as a result of the fabrication tolerance and other uncertainties. To improve the stability in measurement, the averaged reflection and transmission coefficients can be obtained as,

$$\begin{cases} S_{11}^{avg} = (S_{11} + S_{22})/2 \\ S_{21}^{avg} = (S_{12} + S_{21})/2 \end{cases}$$

Then, the equivalent differential reflection coefficient can be written as,

$$S_{11}^{diff} = S_{11}^{avg} - S_{21}^{avg}$$

Finally, the measured differential VSWR can be obtained and plotted in Figure 5 against the predicted results. Over the realized band of 3.2 to 10.4 GHz, the measured VSWR is less than 2.5 and slightly higher than 2.2 obtained in simulation. This small discrepancy is mainly attributed by the uncertainty of substrate and the fabrication tolerance.

The simulated and measured antenna peak gains in H -plane (xoz plane) is plotted in Figure 6 versus frequency. The peak gain in H -plane varies from -0.5 to 3.0 dB in the realized impedance bandwidth. At some frequencies, the gain in dB is negative, because the beams with maximum radiation are out of H -plane. In pattern measurement, the differential feeding is hard to be implemented directly in our microwave chamber, thus the patterns are measured on the three frequencies only, e.g., 3.5, 6.0, 10.0 GHz, by using three different 180° rat-race hybrids. Each hybrid offers acceptable differential output at a sample frequency. Figure 7 plots the simulated and measured radiation patterns at three frequencies, i.e., 3.5, 6.0 and 10.0 GHz, and they are in good agreement with each other.

At the high-end frequency near 10.0 GHz, the H -plane (xoz plane) radiation pattern is split into a few lobes and the cross polarization in the E -plane ($yo z$ plane) pattern is increased, as can be found in [7]. The cross polarization can be decreased at high frequencies by narrowing the radiating slot at the cost of narrow impedance bandwidth. In H -plane, the simulated cross polarization is zero, because there is an equivalent electric wall in this plane, as a result of the symmetry in geometry and differential feeding scheme. In E -plane, the simulated cross polarization is very low but none zero, since the offset-feeding nature. In measurement, the cross polarization raised up due to the fabrication tolerance and the unwanted magnitude/phase unbalance between the inputs from the two ports. The measured patterns are in high symmetry as designed.

4. CONCLUSION

An MMR UWB slot antenna under differential feeding has been studied. The proposed antenna is based on a uniform narrow slot, fed by a pair of differential microstrip line. Therefore, the overall structure is symmetric. When the dimensions and reference port impedance are properly selected, an UWB antenna can be developed by using the first four resonances of the slot radiator. In measurement, tapered-line impedance transformers are inserted between the antenna and test equipment, for matching the optimized port impedance (110Ω) to the standard 50Ω . Measured results are in good agreement with the predictions. The measured radiation patterns are symmetric due to the differential feeding scheme. The realized FBW of the antenna is 106%, over which the VSWR is less than 2.5, and the antenna gain in H -plane varies from -0.5 to 3.0 dB.

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