

Miniaturized Microstrip-Fed Tapered-Slot Antenna With Ultrawideband Performance

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Abstract—A method to design a microstrip-fed antipodal tapered-slot antenna, which has ultrawideband (UWB) performance and miniaturized dimensions, is presented. The proposed method modifies the antenna's structure to establish a direct connection between the microstrip feeder and the radiator. That modification, which removes the need to use any transitions and/or baluns in the feeding structure, is the first step in the proposed miniaturization. In the second step of miniaturization, the radiator and ground plane are corrugated to enable further reduction in the antenna's size without jeopardizing its performance. The simulated and measured results confirm the benefits of the adopted method in reducing the surface area of the antenna, while maintaining the ultrawideband performance.

Index Terms—Miniaturization, planar antenna, tapered-slot antenna, ultrawideband (UWB) antenna.

I. INTRODUCTION

TAPERED-SLOT ANTENNAS (TSAs) offer a wide operational bandwidth and high gain. Therefore, they are widely used in radar, remote sensing, and ultrawideband (UWB) communications.

TSAs are designed using different types of tapering, such as linear, constant width, exponential (Vivaldi), broken linear, dual exponential, and elliptical [1]. In its basic configuration, the TSA is fed by a slotline with high input impedance ($\approx 300 \Omega$). To overcome this problem and achieve the required matching with the widely used $50\text{-}\Omega$ microstrip feeder, several types of feeding arrangements that use transitions and/or baluns were developed [1]. However, those feeding structures resulted in a larger size and a lower efficiency due to the additional insertion losses introduced by the utilized feeding configurations.

To minimize the feeding problems of the TSAs, the microstrip-fed antipodal structure was proposed [2]. In the antipodal arrangement, one of the radiating fins is converted to form a transition and a microstrip line, while the other one is shaped to create a tapered ground plane for the microstrip. Design guidelines have recently been proposed to build microstrip-fed antipodal TSAs [3]. However, the utilized feeding structure, which includes slotline-to-microstrip transition and tapered ground, introduces an additional size to the antenna.

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The large dimensions of the TSA represent a serious challenge toward its use in the new generations of highly compact wireless communication systems, which offer a limited space for the RF front-end including the antenna. The relatively large size of the TSA originates from two factors: first, the use of a complicated feeding structure, and second, the design requirement that the width of the taper's opening and its depth should not be less than one wavelength calculated at the lowest frequency of operation [4], [5].

In this letter, the antipodal structure of the TSA is miniaturized following two steps. First, the antenna's configuration is modified to enable direct connection with a microstrip feeder. Second, corrugated structures are utilized in the radiator and ground plane.

II. DESIGN

Configuration of the conventional antipodal TSA is shown in Fig. 1(a). Using the design method of [3], it is possible to find that the most compact overall dimensions for the antenna to achieve an UWB bandwidth (3.1–10.6 GHz) are $l = 60$ mm and $w = 60$ mm. It is assumed that an elliptical tapering is used and Rogers RT6010 (thickness = 0.64 mm, dielectric constant = 10.2) is the substrate.

In the first step of the miniaturization process, the structure is modified by removing the tapered ground plane and the slotline-to-microstrip transition. A microstrip line is connected directly to the top layer in the manner shown in Fig. 1(b), whereas the bottom layer acts as a ground plane. The slot (s) between the top and bottom layer is used to achieve a perfect matching between the microstrip feeder and the radiator. With this modification in the structure, the overall dimensions of the structure become $l = 40$ mm and $w = 60$ mm, which means a reduction in size by 33%. The optimized values for the other design parameters (s and w_o) are 0.3 and 40 mm, respectively.

It is worthwhile to mention that the microstrip feeder in Fig. 1(b) is curved away from edge of the structure to ease the connection of the feeder to the external port using a Subminiature A (SMA) connector and to prevent the unwanted radiation from the microstrip line in case it extends along edge of the structure.

In the second step of the miniaturization process, symmetrical corrugations are made in the radiator and the ground plane in the manner shown in Fig. 1(c). This step helps the designer reduce the length (l) and width (w) of the antenna while maintaining the ultrawideband performance. The depth of the corrugations is chosen to be less than a quarter of the effective wavelength at the lowest frequency of operation (3.1 GHz) so that the corrugations present an inductive reactance to the passing wave [6].

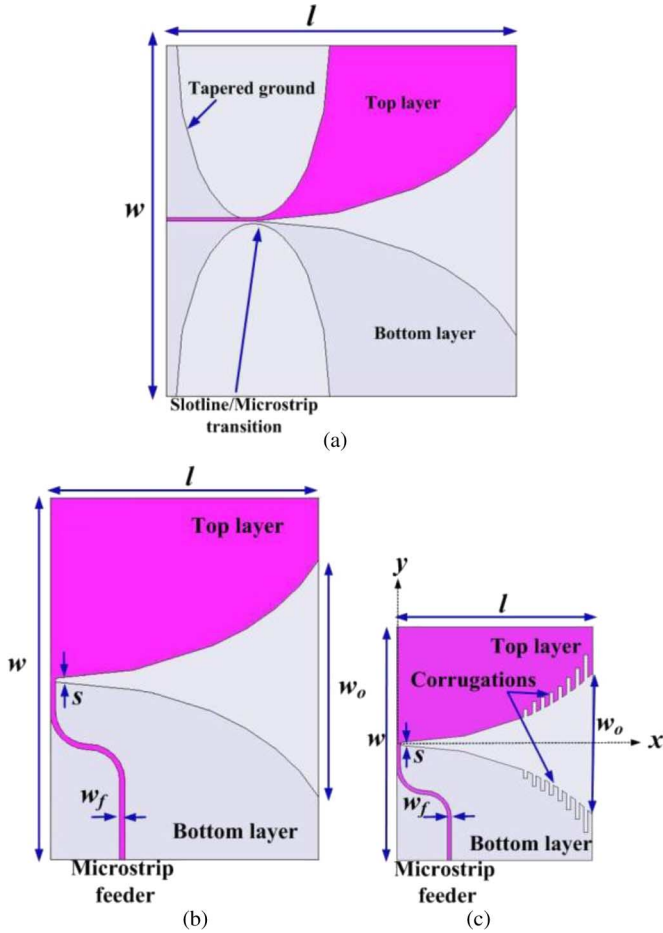


Fig. 1 Configuration of (a) the traditional antipodal TSA, (b) modified structure, and (c) miniaturized structure.

This added inductance increases the electric length of the structure. Therefore, the corrugated antenna's structure resonates at a lower frequency in comparison with a noncorrugated structure having the same dimensions [7]. The initial values for the depth and width of the corrugations are found using the principles mentioned in [7], whereas the final values are found using the optimization capability of CST Microwave Studio.

III. RESULTS AND DISCUSSION

To validate the presented method, the miniaturized antenna's configuration [Fig. 1(c)] was manufactured. A photograph of the manufactured antenna is shown in Fig. 2. Values of the design parameters (l , w , w_f , s , and w_o) obtained after optimization using Microwave Studio are 25, 30, 0.5, 0.3, and 18 mm, respectively. Depth of the corrugations ranges from 1 mm for the inner corrugation to 3 mm for the outer corrugation, while they have uniform width and separation that are equal to 0.5 mm.

It is clear from values of the final design parameters that the overall dimension of the antenna (25 mm \times 30 mm) represents only about 20% of the antenna's surface area designed using the traditional approach for UWB antipodal TSA (60 mm \times 60 mm).

The developed antenna was tested via simulations and measurements. During measurements, the cable connecting

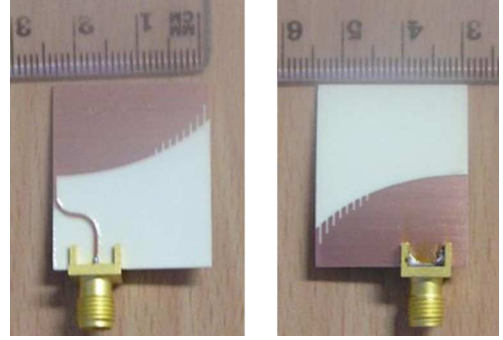


Fig. 2 Photographs of the manufactured antenna. (a) Top view and (b) bottom view.

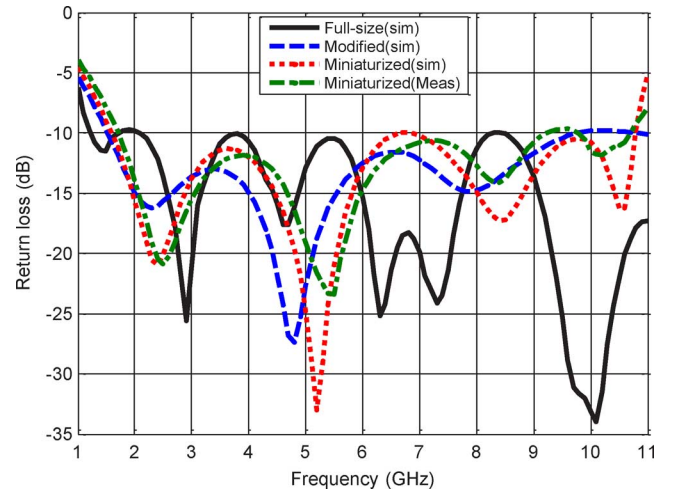


Fig. 3 The return loss of the designed antennas.

the antenna to the measuring instrument was embedded in an absorbing sheet to avoid any interaction between the near-field of the antenna and the cable. The simulated and measured return losses of the miniaturized antenna together with the simulated results for the original full-size structure of Fig. 1(a) and the modified noncorrugated structure of Fig. 1(b) are shown in Fig. 3. The full-size, modified, and miniaturized antennas have UWB performance with bandwidths extending from 1.3 to more than 11 GHz, 1.5 to more than 11 GHz, and 1.8 to 10.8 GHz, respectively, assuming the 10-dB return loss as a reference. This result indicates that despite the huge size reduction, the adopted miniaturization method maintained the UWB performance of the antenna. A good agreement can be seen in Fig. 3 between the simulated and measured results.

Concerning the radiation pattern of the antenna, the measured results at the two main planes (xz and xy) and different frequencies depicted in Fig. 4 indicate a directive performance. The antenna has end-fire properties as the main beam is in the axial direction of the tapered slot (x -axis), i.e., at $\theta = 90^\circ$ as shown in the xz -plane and $\varphi = 0^\circ$ as shown in the xy -plane. The cross-polarized field was also measured and found to be less than the copolarized field by more than 10 dB across the whole band of operation and angles of radiation. The measured gain of the antenna confirms its directive properties. The results shown in Fig. 5 reveal a gain that is between 2.7 and 8 dBi across the

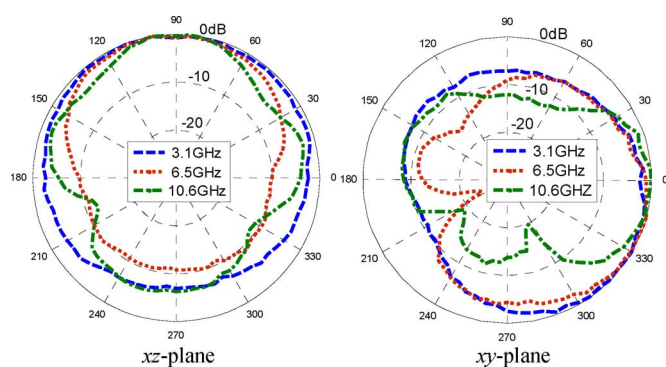


Fig. 4 The measured radiation pattern at two planes and different frequencies.

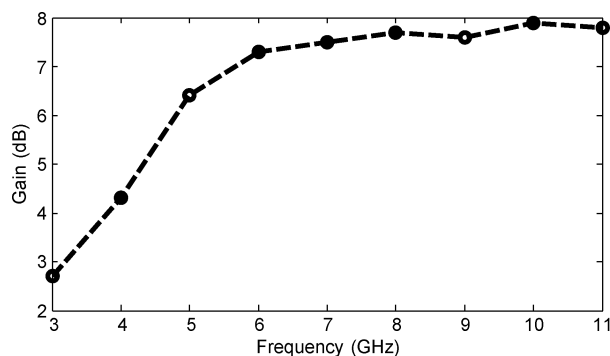


Fig. 5 Variation of the measured gain with frequency.

ultrawideband. It is to be noted that the huge size reduction of the antenna due to miniaturization has only resulted in a modest reduction of 1 dB in the gain compared to the measured gain for the traditional antipodal TSA [3].

The other important parameter for the UWB antennas, especially when used to send/receive pulsed signals, is the time domain response. For this purpose, two miniaturized antennas were put at a distance of 30 cm such that their tapered slots face each other. A UWB pulse synthesized in the vector network analyzer to cover the band 3.1–10.6 GHz was transmitted from the first antenna, and the received pulse by the second antenna was measured. The result is shown in Fig. 6, where amplitudes of the transmitted and received pulses were normalized to have a peak equal to 1. It is clear that the antenna is efficient since the received pulse has low levels of distortion and ringing. The low-distortion time domain performance of the miniaturized antenna was also confirmed by calculating the fidelity factor of the antenna using the method presented in [8]. It was found to be larger than 95% for the face-to-face operation, which is the normal case for directive antennas.

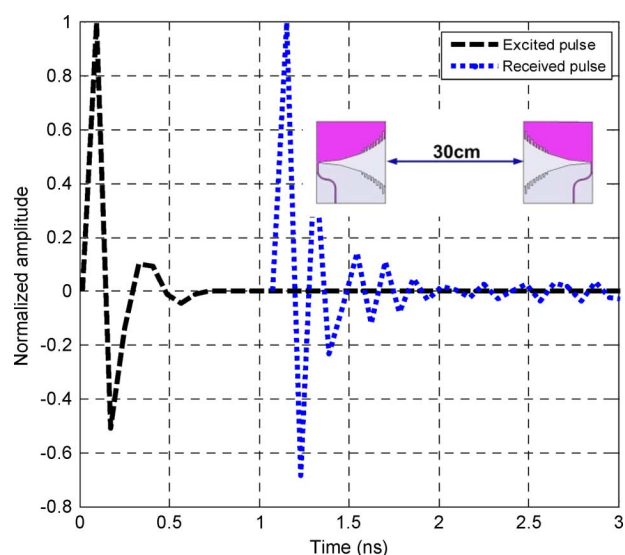


Fig. 6 The measured time domain response of the antenna.

IV. CONCLUSION

A method has been presented to design miniaturized antipodal tapered-slot antennas with ultrawideband performance. The proposed miniaturization process includes two steps. First, the antenna's structure is modified to enable a direct connection to a microstrip feeder, and second, corrugated structures are used in the top and bottom layers of the antenna. The simulated and measured results in the frequency and time domain have confirmed the success of the proposed design approach.

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