Progress In Electromagnetics Research C, Vol. 25, 67–79, 2012

ULTRA-WIDEBAND ANTENNA ARRAY DESIGN FOR TARGET DETECTION

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Abstract—In this paper, a four-element microstrip antenna array is presented. The array is composed of Wilkinson power dividers which act as feed network along with Dolph-Chebyshev distribution and four-identical patch antenna elements. The array elements are properly designed to have a compact size and constant gain against frequency. The simulated results show good agreement with the measured results for the fabricated antenna array. Measurement shows that the array has a peak gain of more than 12 dBi with side-lobe level of −15 dB at 6 GHz. These characteristics make the antenna array suitable for UWB directional uses.

1. INTRODUCTION

The ultra wideband (UWB) radio system has attracted both academic and industrial communities attentions since the Federal Communication Committee (FCC) approval of frequency band between 3.1 to 10.6 GHz for commercial applications in 2002 [1]. Finding a suitable antenna design for the implementation of UWB systems remains a challenge still. Planar antennas are good candidates for UWB radio system integration because of the merits of lightweight, low profile and cost effective. Various antenna geometries presented in the literature [2–6] have been studied for UWB applications.

Having high gain and good directional beam-width in a wide frequency band are essential characteristics of the antennas used for

Received 6 September 2011, Accepted 14 October 2011, Scheduled 4 November 2011
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applications such as target detection, localization systems and cancer screening using microwave radio-systems. However, a typical UWB antenna element has a relatively low gain of order 3 to 5 dBi since they are required to operate at low power in order to minimize the potential interferences within the UWB frequency spectrum. It is therefore desirable to consider the development of UWB antenna array.

Several studies about UWB planar antenna array have been recently proposed [7–10]. However, the feeding structures of the array presented in [7–9] are not embedded with the antennas, thus impose a constraint within the context of integration into devices. In contrast to the above-mentioned works, Chen and Wang [10] developed an array with feed network integrated into the structure of the antennas. But the measurement results were not mentioned in their work to validate the performance of the array. When designing antenna array, problems associated with the integration of antenna element and feeding network such as mutual coupling among antenna elements must be addressed.

In this paper, a four-element planar UWB antenna array is proposed. The characteristics of the proposed array are investigated numerically and validated experimentally. The outline of this paper is as follows. In Section 2, the geometry of the proposed antenna is presented. This compact antenna element is used to compose the UWB antenna array. In Section 3, the design of Wilkinson power divider which is used as feed network for this array is described. Results are presented in Section 4 and the conclusions are summarized in Section 5.

2. ANTENNA ELEMENT DESIGN

The proposed antenna and its geometrical parameters are shown in Figure 1. The antenna is located in the x-y plane and the normal direction is z-axis. It consists of a radiator with a U-shaped rectangular patch combined with a transition step fed by a microstrip line. The proposed antenna is printed on a standard Taconic TLC-30 substrate with a dielectric constant of 3, thickness of 1.575 mm, and a loss tangent of 0.003. The antenna is excited by a 50 Ω microstrip line printed on a partial grounded substrate.

A number of techniques have been proposed and reported to increase the microstrip antenna impedance bandwidth [11]. The authors of this paper applied three techniques to the proposed antenna to obtain a good impedance matching. One is to use step transition in the antenna structure. Another technique is to use a U-shaped radiator. The other type is to apply a partial ground plane. The proposed antenna can be operated within the UWB spectrum by optimizing these parameters.

3. PARAMETRIC STUDY

In order to do antenna optimization, engineers can carry out parametric study. Four parameters are considered in this analysis, namely the feed gap size, notch cut, transition step dimensions, and the ground plane width. The simulation for proposed antenna is carried out using CST Microwave Studio [12].

3.1. Effect of the Feed Gap (f_g)

The feed gap size of the proposed antenna is the first parameter to optimize for the widest bandwidth. This parameter is denoted by 'f_g' in Figure 1. Figure 2(a) shows the calculated return loss curves with various values of f_g when other parameters are kept invariant. As seen in Figure 2(a), the middle and the upper edges of the frequencies are more sensitive to the variation in feed gap sizes. It can be seen that the increase of the feed gap size will result in reductions of the return loss and the bandwidth. From this result, one can conclude that tuning the feed gap size enable us to obtain a wider impedance bandwidth. The optimal feed gap is found to be at $f_g = 1\,\text{mm}$.

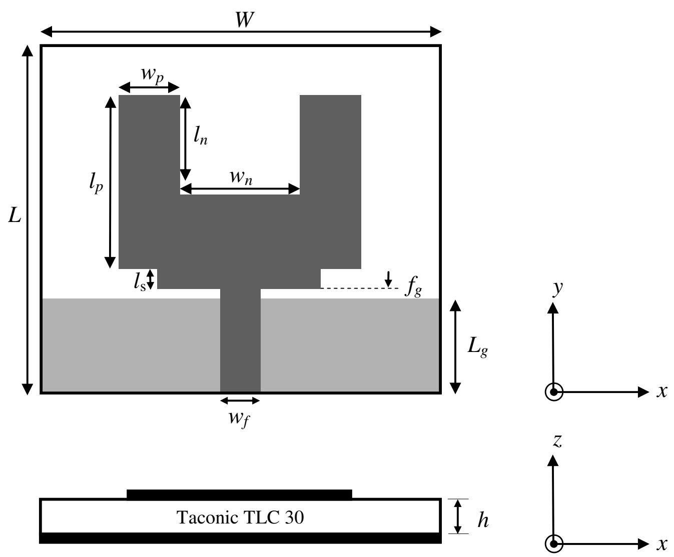

Figure 1. Geometry of the proposed UWB antenna.

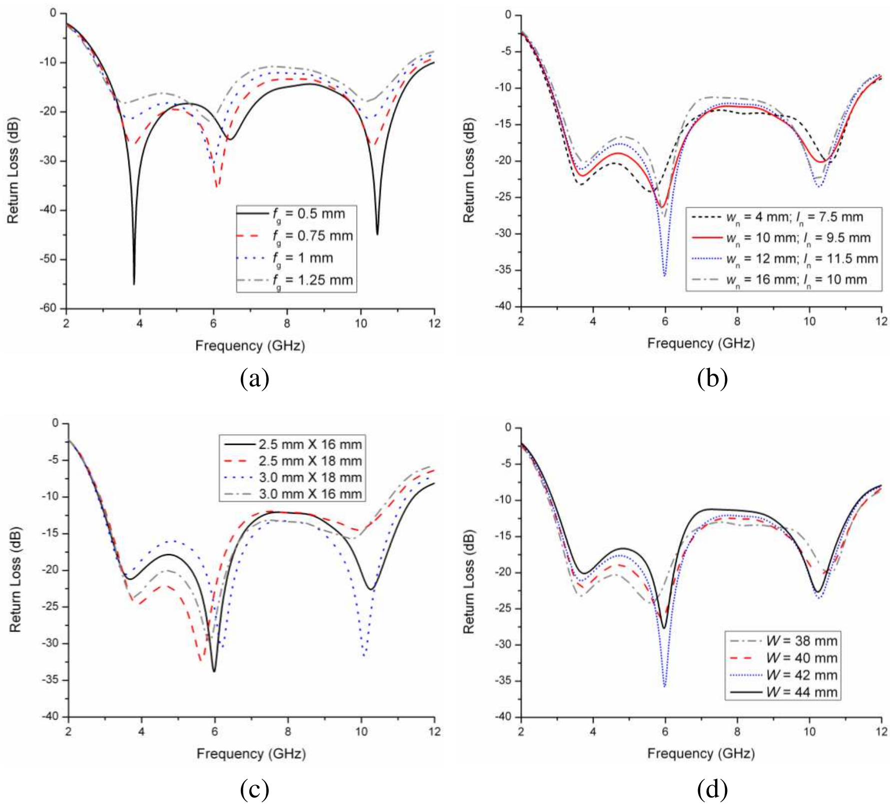

Figure 2. Parametric study. (a) Feed gap size, (b) notch cut, (c) transition step size, and (d) ground plane width.

3.2. Effect of the Notch Cut

The dimensions of the notch cut are denoted in Figure 1 by 'w_n' and 'l_n'. The effect of notch cut dimensions on the input impedance bandwidth of the antenna is shown in Figure 2(b). It can be seen that the second and third resonance frequencies shift slightly with an increase in w_n and l_n whereas the first resonance mode remains stationary. The return loss curves are still less than 10 dB over a wide spectrum. The optimum values of w_n and l_n are 12 and 10 mm, respectively.

3.3. Effect of the Transition Step

The size of the transition step was varied from 2.5 mm × 16 mm to 3.0 mm × 18 mm. The results are presented in Figure 2(c). When the transition step dimensions increases, significant effect has been observed at the higher frequencies whereas the lower edge frequency is almost unaffected. It is also noticed that when the transition step dimensions are increased, the third resonance frequency is eliminated gradually and it results in a smaller impedance bandwidth. It is clear that the dimensions of the transition step affect the impedance bandwidth.

3.4. Effect of the Ground Plane Width

The width of the ground plane is another critical design parameter influencing the antenna characteristic. It is denoted with 'W' in Figure 1. Figure 2(d) shows the return loss curves for various values of W. In Figure 2(d), it is observed that the change in the ground plane width shifts the resonance frequencies. When the width of the ground plane is decreased, the second resonance frequency changes significantly compared to the lower and upper band frequencies. The width W of 40 mm was found to provide the optimum response for UWB impedance matching.

In summary, the operating band of the proposed planar UWB antenna is mainly determined by the feed gap size and the step transition size of the antenna. Other parameters show slight effect on the impedance bandwidth. The final optimized values of the antenna parameters are listed in Table 1. Figure 3 shows the fabricated antenna element using the optimal values.

The simulated and measured return loss curves of the antenna

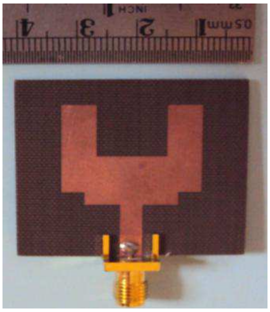

Figure 3. Fabricated antenna.

Table 1. Optimal antenna dimensions.

Parameter	Value (mm)
W	40
L	35
L_g	9.5
l_n	10
l_p	17
l_s	2.5
w_f	3.9
w_n	12
f_g	1
h	1.575

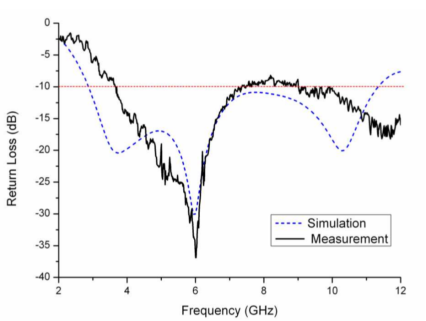

Figure 4. Measured and simulated return loss of the proposed antenna.

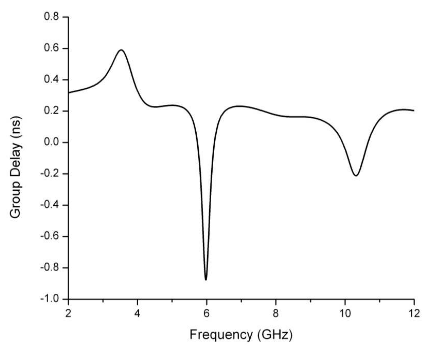

Figure 5. Group delay of the optimized proposed antenna.

prototype are shown in Figure 4. The measured result of the antenna element reveals a return loss curve lower than -10 dB from 3.6 to 12 GHz. In Figure 4, the experimental curve has shifted slightly compared to the calculated ones. This deviation is probably caused by the effect of imperfect soldering of subminiature version A (SMA) connector. The simulated group delay is shown in Figure 5. It clearly shows that the group delay variation is less than 0.6 ns.

Investigation was carried out on the far-field radiation characteristics of the proposed antenna. Figure 6 shows the simulated radiation pattern in E-plane (yz-plane) and H-plane (xz-plane) at several frequencies. The proposed antenna exhibits an omnidirectional pattern in the H-plane and a quasi-omnidirectional pattern in the E-plane.

4. ANTENNA ARRAY DESIGN

The simulated far-field radiation patterns of a single antenna on E and H planes at 3, 6 and 9 GHz are presented in Figure 6. It is noted that

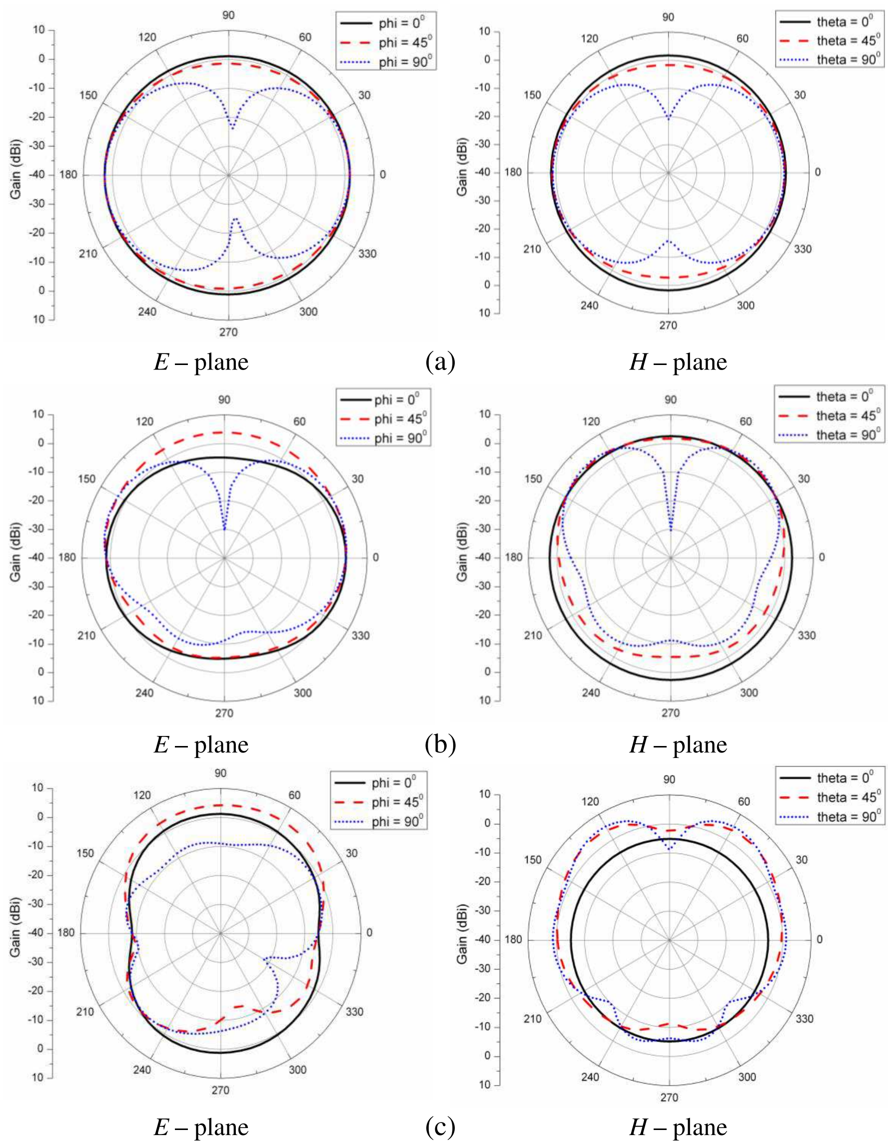

Figure 6. Simulated E-plane and H-plane radiation patterns for the proposed antenna at (a) 3 GHz, (b) 6 GHz, and (c) 9 GHz.

the antenna shows a stable radiation patterns over the UWB spectrum. However, the proposed antenna element has relatively low gain of order 3 to 6 dBi. Therefore, in order to enhance gain and to achieve beam steering capability, the investigation of antenna array design must be carried out. While constructing the UWB arrays, it is imperative to consider the feeding network design because it modifies the radiation pattern of the array by controlling the radiators excitation currents.

According to [13], the feeding network based on Wilkinson power divider (WPD) design exhibits a better return loss characteristic compared to the structure employing T-junction. Nonetheless, when applied to UWB frequency range, the traditional WPD suffers from narrow impedance bandwidth. For this reason, several publications have discussed modified WPD designs for UWB applications [14–18]. Typical ones are the applications of multiple quarter wave transformers [14–16], open radial stub [17], and delta stub [18].

Conventional antenna array can achieve a narrow main beam by increasing the array size. And this can be done by either increasing the number of array elements or the inter-element spacing. However, in the case of former it will result in larger array and complex fabrication process. On the other hand, in case of later secondary lobes will be generated. To overcome this problem, many researchers have suggested the usage of tapered amplitude distribution in antenna arrays. Common tapered distributions are binomial, triangular, Taylor and Dolph-Chebyshev [19]. Depending upon the applications, the antenna engineers have to compromise between the beam width and the side lobe level of the designed structure.

Figure 7 shows the geometry of the proposed antenna array. This structure is composed of four identical radiating elements, as shown in Figure 1 and connected by a feeding network. The Dolph-Chebyshev distribution with a side lobe level of −20 dB has been chosen for this

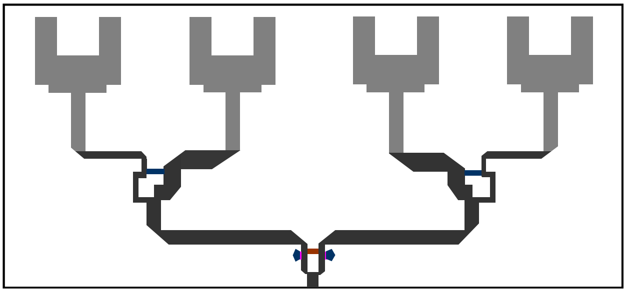

Figure 7. Geometry of the array.

study. Accordingly, the elements' coefficients are (0.58–1–1–0.58). As seen in Figure 7, the feeding network consists of two parts: (1) an equal WPD used to obtain the -3 dB split ratio and (2) two unequal WPDs to feed the individual patches with tapered signals. The -3 dB stage of the feed network is designed based on the work presented in [17] at 6 GHz.

The unequal WPDs dimensions are derived from several resources such as [20, 21]. Distances between the patches are $0.88\lambda_0$ at 6 GHz. The area of the proposed array is $80 \times 172\,\text{mm}^2$.

5. SIMULATION AND MEASUREMENT RESULTS

The proposed antenna array was fabricated and studied. Figure 8 shows the fabricated antenna array. The simulated and measured return loss curves of the four-element array are depicted in Figure 9. The simulated return loss of the feed network is shown in Figure 9 for comparison. It is observed that, the calculated return loss curve is less than -10 dB across most of the UWB frequency band. Meanwhile, the measured -10 dB bandwidth of the antenna array spans 9 GHz, from 3.3 to 12 GHz. The simulated results agree with the measured ones. The little difference between the curves can be attributed to fabrication defects.

Figure 10 illustrates the normalized array's radiation pattern in the H-plane at 6 GHz. From this figure it can be deduced that the proposed array has good directional pattern with the first and second side lobes suppression of 15 dB and 17 dB, respectively. The 3 dB half power beam-width adds up to 18°. The peak gain of the four-element array compared to that of the single antenna element is measured and plotted in Figure 11. It is observed that the array gain steadily increases with frequency and attains a peak of more than 12 dBi at 6 GHz. Thereafter the gain decreases drastically to 7 dBi due to undesired coupling among feed lines.

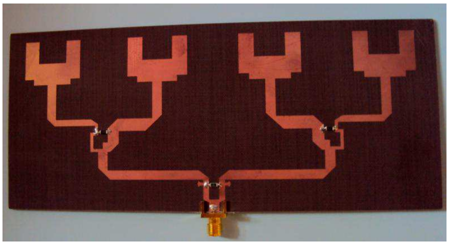

Figure 8. Fabricated antenna array.

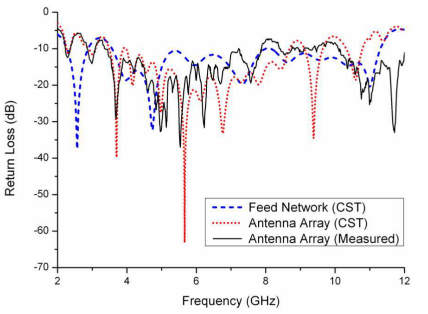

Figure 9. Return loss of feed network and array.

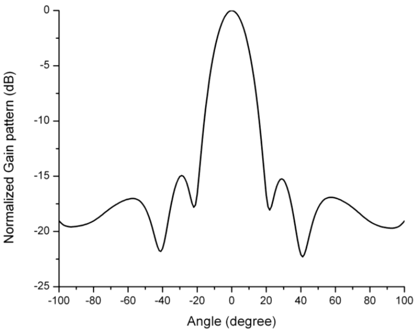

Figure 10. Calculated radiation pattern of the antenna array in H-plane at 6 GHz.

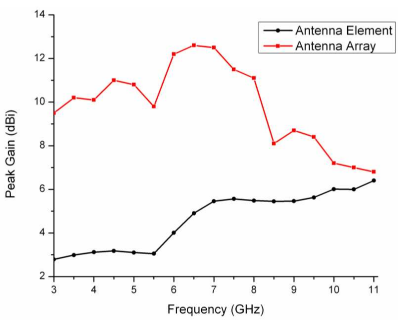

Figure 11. Measured gains of single element and arrays.

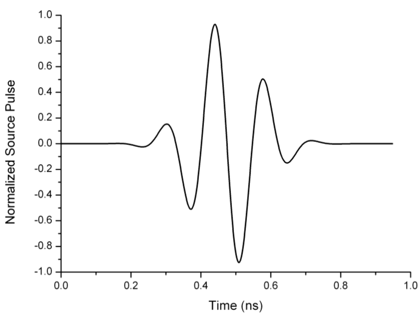

Figure 12. Source pulse waveform.

In the time domain UWB radio system transmits data using narrow pulses to achieve multipath immunity. Antennas designed for UWB system should therefore transmit the UWB pulse without introducing dispersion effect. In this study, the effect of radiated signal is obtained by virtually placing a probe in the far field of the antenna. The authors used a Gaussian pulse within the frequency range of 3.1 to 10.6 GHz as the simulation input signal. The signal is shown in Figure 12.

The array is fixed at azimuth angle ϕ of 90°, and the probe is placed at several angular locations for θ of 0°, 45° and 90°. Figure 13 shows the simulated radiated pulse waveforms in different directions. The curves have already been normalized to their respective maximum values. It is observed that the radiated pulses waveforms are little

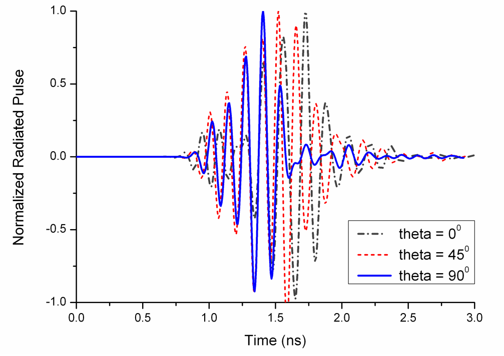

Figure 13. Comparison of the radiated pulses by the antenna array.

distorted as compared to the source pulse. This distortion is termed as 'ringing' and it is due to the derivative relationship between the transmitting and receiving antenna array characteristics.

6. CONCLUSION

This paper starts from a compact microstrip antenna element design for UWB applications. The antenna has a total size equal to $40 \times 35 \times 1.575\,\text{mm}^3$ and is capable of achieving an input impedance bandwidth from 3.6 to 12 GHz experimentally. Then, four identical antenna elements and feeding network based on Wilkinson power dividers were employed to compose the linear array. The power distribution among the radiating elements is realized using appropriate Dolph-Chebyshev coefficients. A prototype of the proposed array was fabricated and measured over the UWB frequency range. The measured array gain is increased by more than 5 dBi between 3 and 8 GHz compared to that of an antenna element. Thereafter, the gain decreases significantly at higher frequencies due to increased losses within the feed network. Besides, the time domain analysis of the antenna array was also carried out. The proposed antenna array is suitable for applications where a directional UWB antenna is required.

ACKNOWLEDGMENT

The authors would like to record their appreciations to Taconic Corporation for providing microwave substrate sample used in this project. Special thanks for Mr. Fauzi Kadir for his assistance in the fabrication of the antennas.

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