UWB Phased Array Antennas for High Resolution Radars

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Abstract—**In this paper we present a new UWB antenna and its linear phased array. The single UWB element has omnidirectional and stable radiation patterns over a wide-bandwidth that make it suitable for UWB wireless communication. In addition an E-plane phased array design of four proposed UWB antennas has been simulated to achieve beam steering capability which is used in high accuracy phased array radar. Phase of each element applied by the well-known progressive phase shift method. The proposed phased array antenna has a wide beam steering capability of ±30° and an average of -10 dB side lobe level (SLL) in over a wide bandwidth from 3 to 11 GHz. The simulated and measured results of return loss for the single antenna, both single and array Gain, and beam scanning feature will be discussed. The simulation results confirm that the proposed UWB phased array has a stable radiation pattern and perfect cross polar isolation in the entire band of operation for mentioned beam scanning angles.**

I. INTRODUCTION

There is a trend to use Ultra – wide band (UWB) phased array antennas in wireless communication and high accuracy radar system [1]. Because of the low cost and compact size of the planar antennas, they are suitable for UWB applications.

The existing UWB antennas lack high gains and usually satisfy omnidirectional radiation patterns. However, applications such as high resolution radars, target detections, 3D microwave imaging, sensor networks and RFID readers need high gains and narrow beamwidths [2–5]. UWB arrays can be good choices for the purpose of achieving directional radiation patterns. To have beam steering capability phased array design is proposed. This paper will present an electronic beam scaning design that phase of each element controlled by progressive phase shift method.

There are several beam steering methods for UWB antenna are designed, such as piezoelectric transducer controlled phase shifter (PET) [6], true time delay technique [7] and MEMS switched phase shifter [8] which have been reported. In [6], a new beam scanning method has been demonstrated for wide bandwidth operation using a multiline progressive phase shifter, controlled by a low cost PET. A beam scaning of ±16° and ±27° was achieved in a wideband width from 8 to 26.5 GHz for E-plane and H-plane phased array antenna, respectively.

This new method is proposed for UWB phased array antennas. The advantages of this method are a small size and lower power consumption of less than 1mw. Also, has a wider bandwidth in comparison to a true time delay phase shifter. In this paper 1×4 E-plane antenna array, with a beam Steering angle of ±30° from 3 to 11 GHz is proposed. There are several reasons to limit the steering angle of this phased array design. One of them is limitation of the PET phase shifter to supply maximum phase shift. Another one is limitation of the element spacing to reducing the side lobe level. Also, the frequency span limits the steering angle. The proposed design is simulated by CST Microwave Studio commercial software and by using Transient Solver.

This paper organized as follow. Section II presents the geometry of the new UWB antenna and reviews characteristics of it such as S_{11}, antenna gain and radiation pattern. Section III shows the array designing process and also the main features like array gain is studied and in section IV the theory and simulation results of phased array is described. Section V concludes this paper.

II. UWB ANTENNA SINGLE ELEMENT

Fig. 1 shows the original geometry of the proposed antenna. The antenna is designed on TACONIC TLC-30 substrate with a dielectric constant (ϵ_r) of 3 and loss tangent of 0.002. The antenna has a compact volume of 25 mm × 34 mm × 1.58 mm. It is fed by 50 ohm microstrip line. The optimal dimensions of the designed antenna are at Table I. These parameters are optimized by well-known parametric study method using CST Microwave Studio.

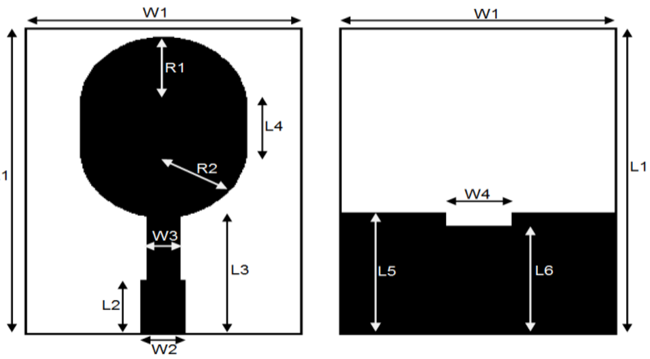


Fig. 1. (a) Top layer, and (b) Bottom Layer

TABLE I

Antenna parameters

Parameters	Size (mm)
L1	34
L2	6
L3	13
L4	5
L5	13.5
L6	12
W1	25
W2	4
W3	3
W4	6
R1, R2	7.5

The photograph of the antenna can be seen in Fig. 2. The reflection coefficient performance of the fabricated prototype was measured by using a HP 8510 network analyzer. The simulated and measured reflection coefficient for this antenna can be seen in Fig. 3. It is observed that the S_{11} of the element is less than -10 dB entire the UWB frequency range for both simulated and measured.

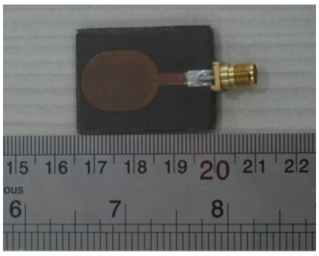


Fig. 2. Single element UWB antenna photograph

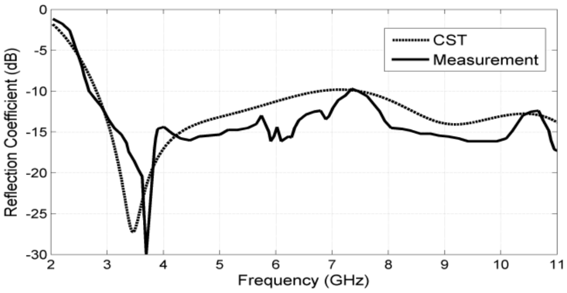
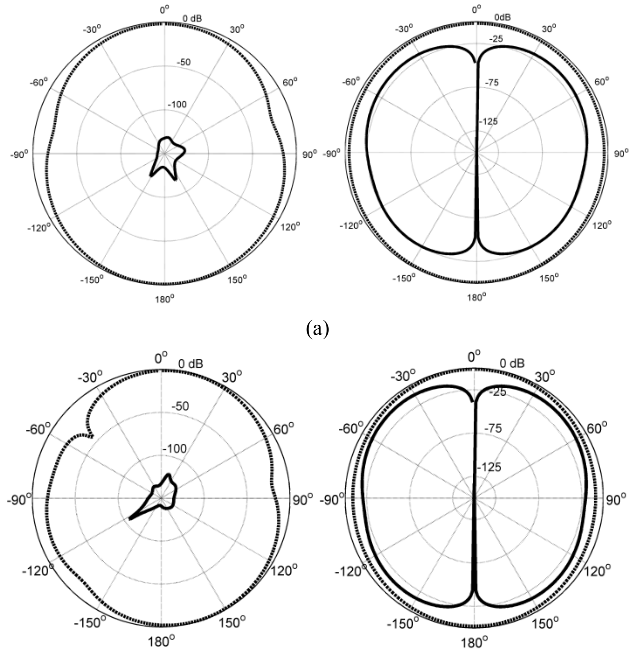


Fig. 3. Simulated and measured S_{11} in dB for the UWB element

The simulated co- and cross-polarized radiation patterns of the single antenna in E-plane (φ=90) and H-plane (φ=0) at 6 GHz and 10 GHz are shown in Fig. 4. It shows that the antenna can give a nearly omnidirectional characteristic in the H-plane and quasi omnidirectional pattern in the E-plane. The antenna exhibits stable radiation patterns and a perfect cross polar isolation. Also, at the high-end frequency near 10.0 GHz, the cross polarization in the H-plane pattern is increased. It is primarily because of the fact that the antenna becomes electrically large at high frequencies and many other high- order resonant modes are excited.



(a)

(b)

Fig. 4. Co (dotted) and Cross (black) polarized pattern of UWB element at (a) 6 GHz and (b) 10 GHz in E-plane (left) and (b) H-plane (right)

III. LINEAR ARRAY DESIGN

Four UWB antennas are placed along the E-plane in uniform linear array configuration as shown in Fig. 5. Because of the simple fabrication and high gain features the E-plane structure is proposed. The spacing between each element is optimized by half wavelength theory to minimize the fading correlation and mutual coupling between each antenna. Also for reducing the grating lobes the element spacing cannot be larger than one wavelength.

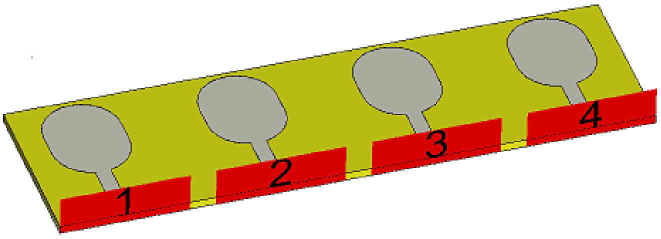


Fig. 5. Array Configuration

Fig. 6 shows the array gain for three different element spacing values and the single element in the UWB frequency range. In most of frequencies, the gain of the array is about 6 dBi more than the gain of the single element. Array theory proves that the array gain is increased by increasing element spacing value until a grating lobe is produced. Grating lobes usually occur around d= λ. By increasing the frequency, the element spacing becomes electrically large with respect to wavelength, and hence the effect of mutual coupling decreases, which results in gain enhancement. The results in Fig. 6 confirm that our proposed array follows this rule. The value of λ at 10 GHz is 30 mm. Consequently, for d= 30 mm, 35 mm, and more, grating lobe appears in lower frequencies in comparison to the case d= 25 mm is used. This phenomenon results in gain decrease at lower frequencies for d> 30 mm. The array gain for d= 25 mm is stable through the bandwidth and also has an approximately linear increasing curve. This optimal spacing is $0.25\lambda_\circ$ at 3 GHz and $0.91\lambda_\circ$ at 11 GHz. The overall size of the antenna array is 34 mm × 100 mm.

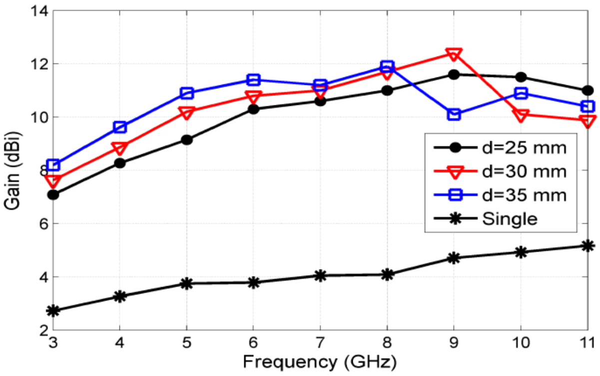


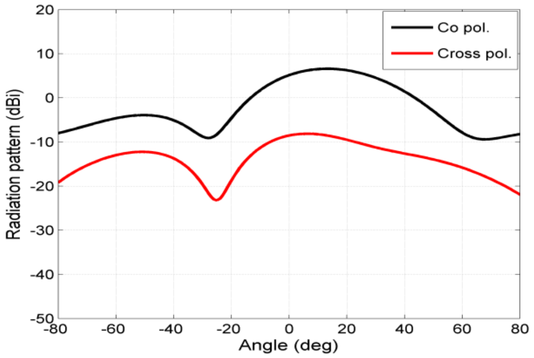
Fig. 6. Gain for Array and Single Element Structures

IV. UWB PHASED ARRAY THEORY AND SIMULATION

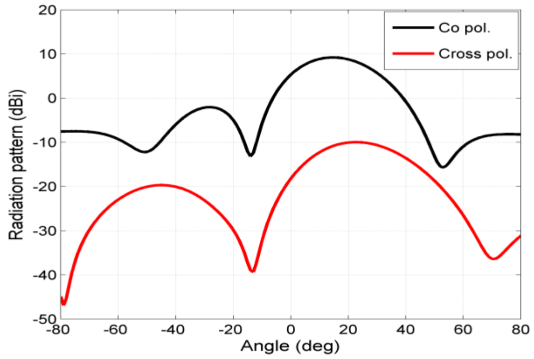
After d optimization in array design, phase of each element is applied by progressive phase shift method to have beam scaning capability. The following equation gives the beam scaning angle of the phased array using by this method [6].

$$\theta_\circ = \sin^{-1}\left(\frac{\varphi}{k_\circ \cdot d}\right) \qquad (1)$$

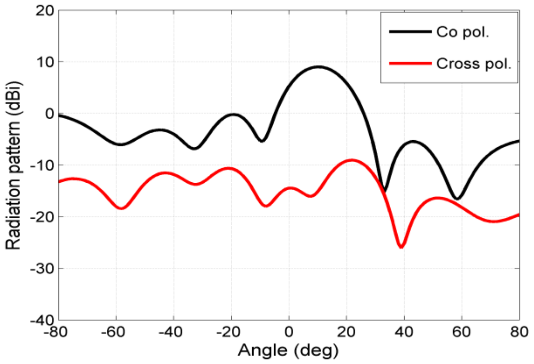
In (1) φ is progressive phase shift, d is element spacing in array design which was achieved in last section and k is propagation constant in free space that is changing by frequency in UWB range. This problem is solved by the proposed PET phase shifter. As mentioned, the highest operational beam scaning angle overall UWB band is limited by element spacing in array, frequency span and achievable maximum phase shift by PET. By applying these limitations in above equation, the maxim beam scaning of 30˚ can be achieved for UWB range. The following results show the proposed phased array has good radiation characteristics from -30˚ to 30˚ beam scaning angles.



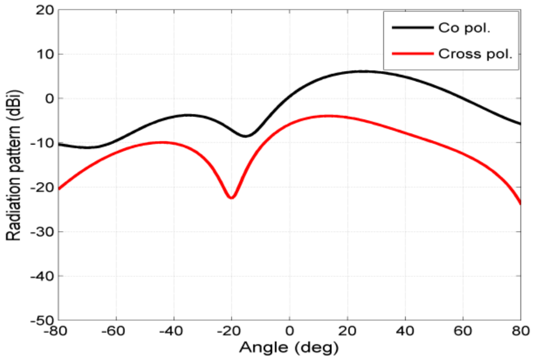
(a) At 4 GHz for 15˚ beam angle



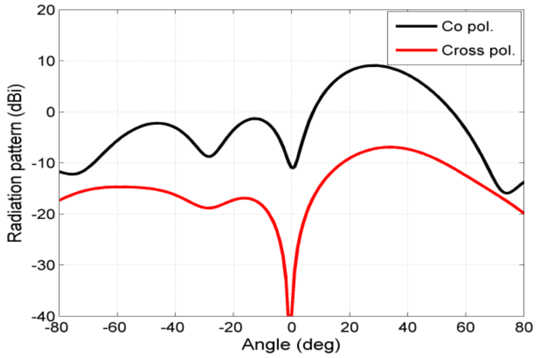
(b) At 6 GHz for 15˚ beam angle



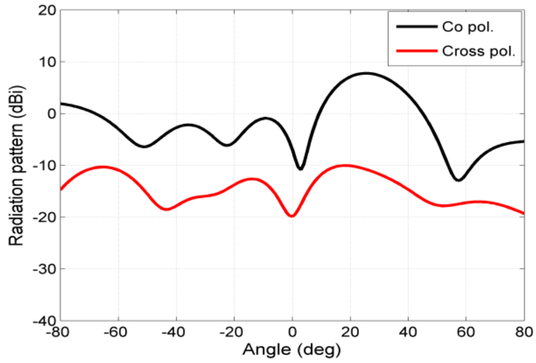
(c) At 8 GHz for 15˚ beam angle



(d) At 4 GHz for 30˚ beam angle



(e) At 6 GHz for 30° beam angle



(f) At 8 GHz for 30° beam angle

Fig. 7. The H-plane co- and cross- polarized radiation pattern in dBi
(a) - (c) for 15° beam angle at 4, 6 and 8 GHz
And (d) - (f) for 30° beam angle at 4, 6 and 8 GHz

Fig. 7 (a – f) display the co- and cross- polarized radiation pattern of the proposed phased array in H-plane for scaning angle of 15° and 30° at three frequencies of 4 GHz, 6 GHz and 8 GHz ,respectively. It is observed that the array has good radiation pattern with low SLL nearly less than -10 dB for UWB frequency span. It is also achieved that this design has a prefect cross polar isolation during the beam scaning. The following equation [9] states that the half power beamwidth of a linear array for a beam scanned at $\theta_\circ$, decreases in case of increasing frequency (decreasing λ) in a special beam angle, for a fixed number of elements and a fixed element spacing value:

$$\mathrm{HPBW} = \sin^{-1}\left(\sin\theta_0 + 0.4429\,\frac{\lambda N}{d}\right) - \sin^{-1}\left(\sin\theta_0 - 0.4429\,\frac{\lambda N}{d}\right) \qquad (2)$$

Where λ is wavelength, N is the number of array elements, and d is the element spacing value. Also Fig. 7 verifies that sharper beamwidths are achieved by increasing frequency. Using the optimization algorithms to optimize the amplitude of each UWB antenna element causes the reduction of the SLL. It is also helps the phased array design to has a better capability of scaning angles. It will be our future work to modify this paper.

The progressive phase shifts for three beam scaning angles and two frequencies is represented at Table II. A reverse angle scaning is easily accessible by inversing phase distribution.

TABLE II

Progressive phase values for two beam scaning angles of 15°and 30° and three frequencies of 4, 6 and 8GHz

	F=4 GHz	**F=6 GHz**	**F= 8GHz**
θ=15°	31.05°	46.58°	62.11°
θ=30°	60°	90°	120°

V. CONCLUSION

In this paper a new UWB antenna and its four elements phased array have been designed. Phase of each element applied by progressive phase shifter method. A well-known piezoelectric transducer phase shifter (PET) with maximum phase shift of 480° and low loss system is suitable for the proposed UWB phased array design. The array design has a good beam steering property from -30 to +30 and also, has low SLL nearly less than -10 dB for UWB frequency span. Low cost and easy fabrication are the other good characteristics of this array design for high resolution radars and target detection applications. This progressive phase shifters can replace true time delay elements in UWB phased array applications. Our future work will be reduces the SLL of the phased array pattern by the well-known evolutionary optimization algorithms to achieve better beam steering capability.

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