Design of TCDA Avoiding Half-wavelength Limitation Using PC

Seongjung Kim, Sangwook Nam
School of Electrical and Information Engineering, Seoul National University, Seoul, Korea
sjkim@ael.snu.ac.kr*, snam@snu.ac.kr*

***Abstract*—Low-profile array antennas are important in many defense and commercial communication systems. Although tightly coupled dipole arrays (TCDAs) have several advantages, their bandwidth is limited by their ground plane. The use of resistive frequency-selective surfaces to overcome this limitation generates ohmic losses which then deteriorate the radiation efficiency of the array antenna. In this paper, we propose a 4x4 TCDA with no ohmic loss. The proposed array employs a polarization convertor to overcome bandwidth limitation when antenna height is half the wavelength (λ). The impedance bandwidth for VSWR < 3 covers 0.43–8.06 GHz to broadside radiation (18.7:1), and antenna height is 0.07 λ_{low} at the lowest operating frequency.**

***Index terms:* TCDA, phased array, polarization conversion, ultra-wideband, beam steering.**

I. Introduction

For many wireless electronic systems, low-profile, ultra-wideband, and electrical beam-scannable phased array antennas are in high demand. For example, a Vivaldi antenna is commonly used for its ultra-wideband characteristics [1]. However, since it supports a traveling wave in order to have this high bandwidth, the antenna's height is inevitably increased, and its application is consequently limited.

In an effort to reduce antenna profile but retain bandwidth, the concept of a uniform amplitude current sheet array (CSA) has been proposed [2]. In free space, this type of antenna has infinite impedance bandwidth. In recent years, the tightly coupled dipole array (TCDA), which mimics the CSA, has become representative of wideband, low-profile phased array antennas [3,4]. Although impedance bandwidth can be limited by the TCDA ground plane, it can be relieved if appropriate mutual coupling between the dipoles is implemented.

Since TCDAs have numerous positive features, including their low profile and ultra-wideband, they have received significant attention [5-9]. Nevertheless, the bandwidth of a TCDA is limited by the ground plane when antenna height is half the wavelength (λ). In order to overcome this bandwidth limitation, TCDAs with a resistive frequency-selective surface (FSS) has been proposed [10], although the introduction of an FSS degrades radiation efficiency. Thus, a complimentary superstrate with high dielectric constant is introduced and has been found to reduce ohmic losses to under 1.1–1.4 dB when the relative dielectric constant of the complimentary superstrate is 4. However, such a superstrate with high dielectric constant is not ideal because it has the probable potential to incur surface waves which limit beam scanning [11].

In this paper, we propose a novel approach to overcoming bandwidth limitations at high frequencies without a resistive FSS, resulting in a beam-scannable antenna characterized by low ohmic loss. By introducing a polarization convertor (PC) between ground plane and dipoles, the reflected wave from the former to the latter is decoupled and the bandwidth can be doubled. Indeed, the PC operates selectively when antenna height is 0.5 λ, and it does not affect other frequency bands.

II. Development and Description of the Proposed Antenna

The development of the proposed unit cell antenna will be described, starting with an introduction to conventional TCDA antennas in subsection *A*. As mentioned, impedance bandwidth is limited when antenna height is half the wavelength. In subsection *B*, the proposed PC is presented, having been designed to operate in a narrow band that corresponds to the limited bandwidth in *A*. Finally, the conventional TCDA is combined with the PC in subsection *C*, overcoming the original limitations and doubling the bandwidth.

A. Conventional TCDAs

A conventional TCDA unit cell is defined by a 2x2 dipole array (Fig. 1) in order to be combined with a proper size of PC. A superstrate (Taconic TLY-5; ε_r = 2.2; tanδ = 0.0009) is employed for increased bandwidth, and the board is FR-4 (ε_r = 4.3; tanδ = 0.025). In Figure 1, the overlapped pad behind the dipoles that increases mutual capacitance measures w = 10 mm; $d_e = d_h$ = 37 mm; h_1 = 37 mm; and h_2 = 47 mm. A 100-Ω twin feeding line goes through the ground plane from the dipole and is simply terminated by a 100-Ω discrete port. The bandwidth is limited at f = 4.06 GHz when h_1 is 0.5 λ, as shown in Figure 3, because antenna input impedance is significantly affected by the shorted transmission line with h_1 [8]. When the height (h_1) is 0.5 λ, antenna input impedance is zero.

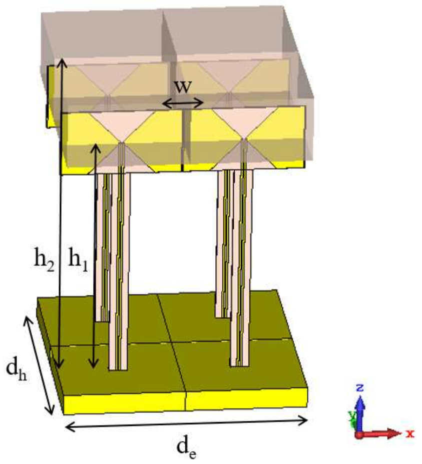
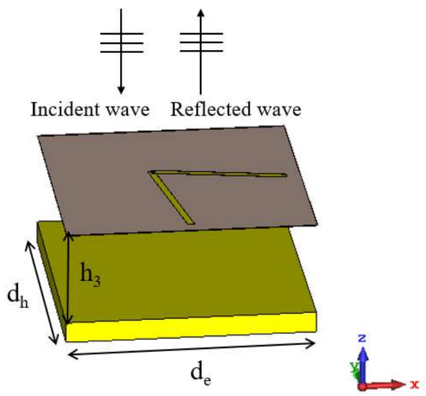


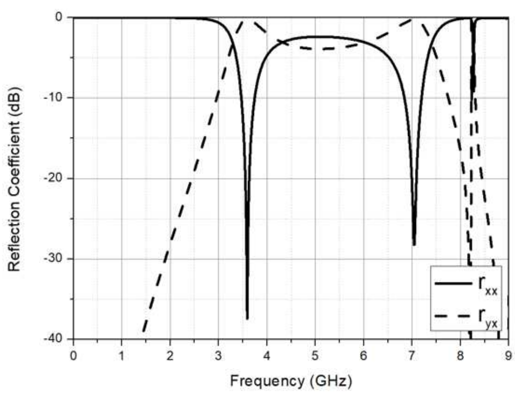
Fig. 1. A TCDA 2x2 dipole array which is periodic on the x-y plane.

B. PC Configuration

Polarization of the incident plane wave can be rotated by 90º [12]. In this study, we employed a V-shaped conductor and ground plane. The x-polarized incident wave is thereby rotated to a y-polarized reflected wave, as shown in Figure 2(a). In Figure 2(b), r_{xx} is the reflection coefficient of the x-polarized wave and r_{yx} is that of the rotated y-polarized wave. Since it operates near 4 GHz, it is expected to overcome the TCDA limitations and only minimally affect other frequency bands.



(a)



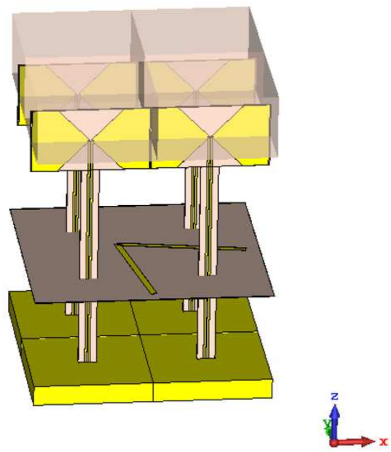
(b)

Fig. 2. (a) PC unit with width equal to that of the conventional TCDA; (b) The reflection coefficients when the incident wave is reflected by the PC.

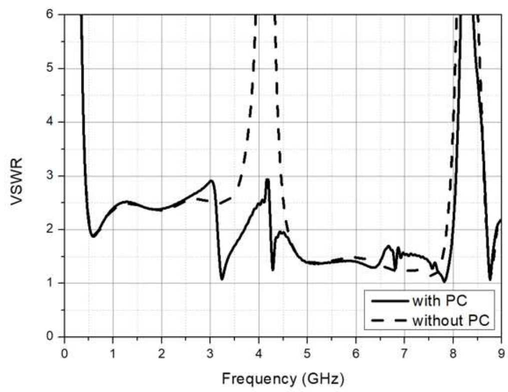
C. TCDA with PC

In the final step, the structures depicted in Figures 1 and 2(a) are combined, as shown in Figure 3(a). Figure 3(b) shows that the conventional limitations are avoided, and the bandwidth is doubled as expected because the reflected wave is decoupled from the dipole. Thus, the ground plane effect seems to be absent at the PC operating frequency. The results show that the impedance bandwidths for VSWR < 3 is 0.43–3.64 GHz (8.47:1) without the PC and 0.43–8.06 GHz (18.7:1) with the PC.

It should be noted that the feeding line must be aligned in parallel with the E-plane (in this case, the x-axis). In cases where twin feeding lines are aligned orthogonally to the E-plane [9], the rotated reflected wave can couple to the dipole and bandwidth limitations remain.



(a)



(b)

Fig. 3. (a) The combined TCDA and PC array; (b) VSWR of the TCDA with and without the PC.

III. A 4X4 ANTENNA ARRAY

In order to compensate for the mutual coupling of the edge elements, conducting walls were employed on each side [9]. The resulting 4x4 array structure, with extended ground plane measuring 18.5 mm, is shown in Figure 4, and the active VSWR of the center element is shown in Figure 5. The VSWR of the full array to broadside direction is similar with that of the unit cell. When scanning to 30º on the E, D and H-planes, VSWR is preserved over wideband except for partial bands. The array's gain is shown in Figure 6 where it can be seen that cross polarization grows at around 4 GHz but is low at other frequencies. Finally, the gain pattern at 4 GHz is shown in Figure 7. Employing a PC within the TCDA produced no unexpected phenomena in the beam-scanning pattern.

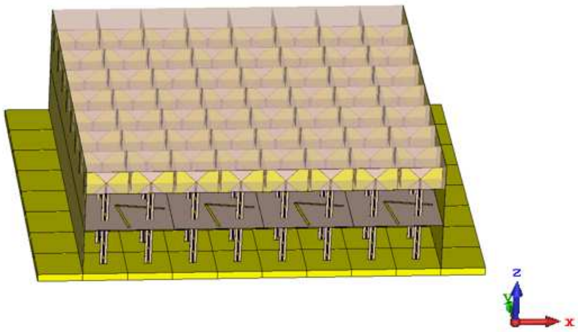


Fig. 4. Proposed 4x4 antenna array.

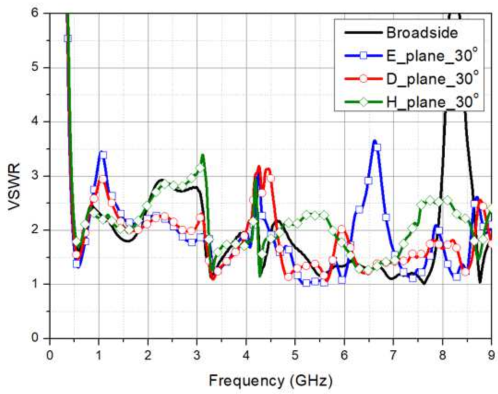
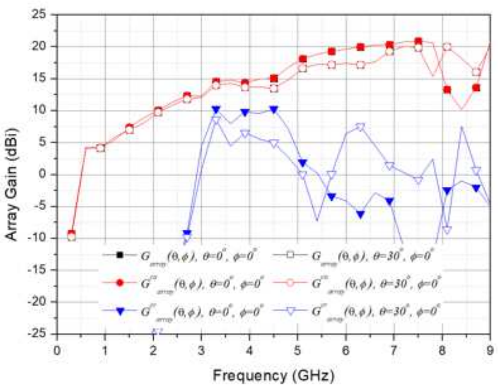
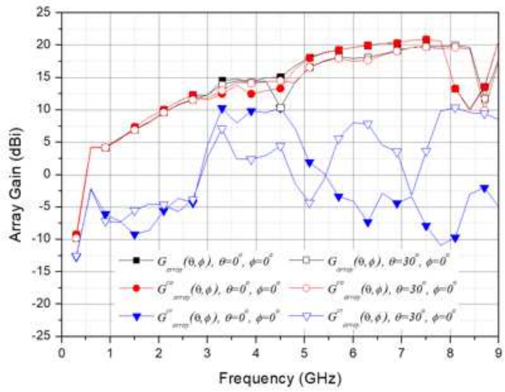


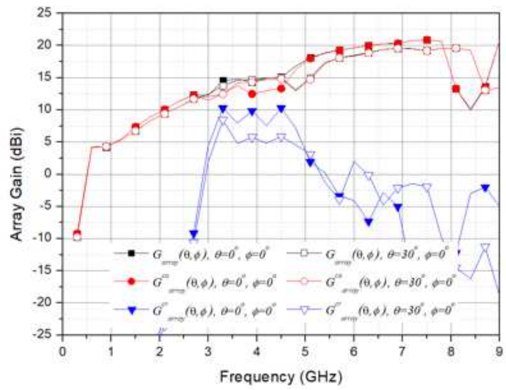
Fig. 5. Active VSWR of center element as scanning the beam.



(a)

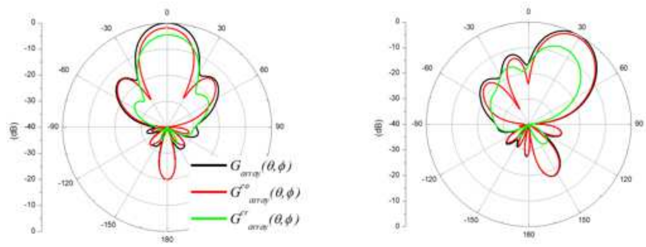


(b)

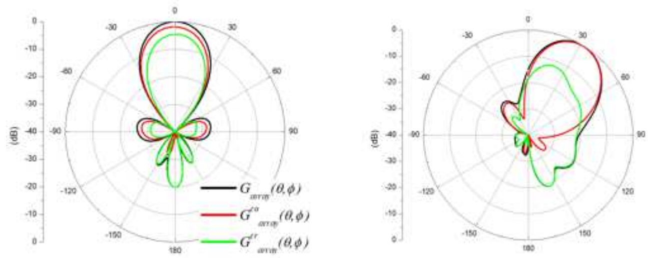


(c)

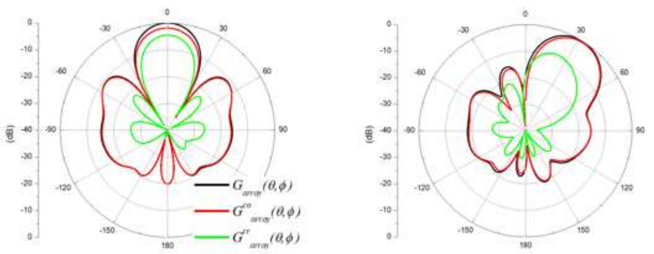
Fig. 6. The gain of the 4x4 array on the (a) E-plane, (b) D-plane, and (c) H-plane.



(a)



(b)



(c)

Fig. 7. The gain pattern of the 4x4 array at 4 GHz on the (a) E-plane, (b) D-plane, and (c) H-plane, normalized by absolute gain value.

IV. Conclusion

In this paper, a wideband and beam-scannable TCDA with PC is proposed. By introducing the PC to the TCDA, conventional limitations in the highest frequency bands can be avoided and impedance bandwidth can be doubled to 18.7:1. Although polarization is mixed at the PC operating frequency band, introducing the PC does not generate any ohmic losses. This approach is therefore expected to have wide application in ultra-wideband polarization insensible systems.

Acknowledgments

This work was supported by the Brain Korea 21 Plus Project in 2018.

References

[1] D.-L. Wen, D.-Z. Zheng, Q.-X. Chu, “A dual-polarized planar antenna using four folded dipoles and its array for base stations,” *IEEE Trans. Antennas Propag.*, vol. 64, pp. 5536–5542, 2016.

[2] H. Wheeler, “Simple relations derived from a phased-array antenna made of an infinite current sheet,” *IEEE Trans. Antennas Propag.*, vol. 13, pp. 506–514, 1965.

[3] B. A. Munk, *Finite antenna arrays and FSS*. John Wiley & Sons, 2003.

[4] J. L. Volakis, K. Sertel, “Narrowband and wideband metamaterial antennas based on degenerate band edge and magnetic photonic crystals,” *Proc. IEEE*, vol. 99, pp. 1732–1745, 2011.

[5] J. P. Doane, K. Sertel, J. L. Volakis, “A wideband, wide scanning tightly coupled dipole array with integrated balun (TCDA-IB),” *IEEE Trans. Antennas Propag.*, vol. 61, pp. 4538–4548, 2013.

[6] E. Yetisir, N. Ghalichechian, J. L. Volakis, “Ultrawideband array with 70° scanning using FSS superstrate,” *IEEE Trans. Antennas Propag.*, vol. 64, pp. 4256–4265, 2016.

[7] H. Lee, S. Nam, “A dual-polarized 1-D tightly coupled dipole array antenna,” *IEEE Trans. Antennas Propag.*, vol. 65, pp. 4511–4518, 2017.

[8] S. Kim, S. Nam, “Bandwidth extension of dual-polarized 1-D TCDA antenna using VMS,” *IEEE Trans. Antennas Propag.,* forthcoming.

[9] S. Kim, S. Nam. “A Compact and Wideband Linear Array Antenna With Low Mutual Coupling,” *IEEE Trans. Antennas Propag.*, vol. 67, pp. 5695–5699, 2019.

[10] W. F. Moulder, K. Sertel, J. L. Volakis, “Superstrate-enhanced ultrawideband tightly coupled array with resistive FSS,” *IEEE Trans. Antennas Propag.*, vol. 60, pp. 4166–4172, 2012.

[11] W. H. Syed, A. Neto, “Front-to-back ratio enhancement of planar printed antennas by means of artificial dielectric layers,” *IEEE Trans. Antennas Propag.*, vol. 61, pp. 5408–5416, 2013.

[12] N. Yu et al., “Light propagation with phase discontinuities: generalized laws of reflection and refraction,” *Science*, vol. 334.6054, pp. 333–337, 2011.