A Shared Aperture Dual-Polarization Tightly Coupled Dipole Array

Peiji Yang, Shiwen Yang*, Jianhui Huang, Shi-Wei Qu AND Yikai Chen
School of Electronic Science and Engineering
University of Electronic Science and Technology of China, Chengdu, 611731, P.R. China
E-mail: 18615714927@163.com

***Abstract*—Due to mutual coupling between elements, traditional phased-array antennas are subjected to certain restraints in terms of bandwidth extension, wide-angle scanning and array miniaturization, etc.With the application of ultra-wideband phased-arrays with the tightly coupled dipole arrays and shared aperture have extensive application prospects. In this paper, an electric/magnetic dipole phased array based on enhanced mutual coupling effect was adopted. By intentionally strengthening coupling between the electric/magnetic dipole array elements, low-profile, broadband and wide-angle array scanning was realized. Additionally, broadband dual-polarization properties in the context of small bandwidth were achieved by virtue of a shared aperture technology.The designed antenna has an impedance bandwidth of 5:1 with VSWR＜3.0.It can realize a dual-polarization phased array with ±60° beam scanning range. Its width and height are 0.4 and 0.41 of a high-frequency wavelength respectively to meet electrical performance in the narrow space.**

Intex Terms—phased-arrays; tightly coupled; ultra wide band; shared aperture; electric/magnetic dipole

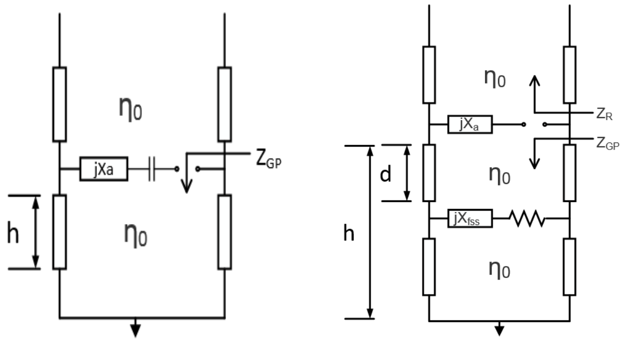
I. INTRODUCTION

Tightly Couple Dipole Arrays(TCDAs) have been shown to provide wide bandwidth with very low profile[1].However use of these antennas as wide-angle scanning arrays implies one or more dielectric slabs placed above the aperture as superstrate. By using one dielectric layer as a superstrate and an integrated folded Marchand's balun [2], 7.4:1 impedance bandwidth with VSWR< 2.7 was achieved when scanning down to 45^0 in all planes [3]. A 2-way Wilkinson's power divider was also employed to excite unit cell elements, causing resistive losses for wide scan angles in the E-plane. Another approach is to use shorting pins instead of a Marchand's balun to provide balanced excitation to the dipoles [4]. By using dielectric loading in substrate and superstrate, 5:1 impedance bandwidth was achieved with VSWR<2.9 and $\pm 45^0$ scanning. Greater scanning range (60^0 in H-plane and $\pm 70^0$ in E-plane with VSWR<2) was achieved by using a different TCDA design with an integrated balun and dielectric superstrate but the bandwidth was only 1.6:1 [5]. By contrast to TCDAs,BAVA arrays [6] do not typically use dielectric loading across the aperture, which results in a light- weight structure.Impedance bandwidth of 10:1 was reported for $\pm 45^0$ scan angle with a very low profile design [6]. However, mismatch efficiency deteriorated (VSWR ≈ 4) when scanning due to lack of wide angle matching. Using interlaced rectangular spiral antenna element is proposed by Volakis [7][8][9],the impedance bandwidth of 10:1 can be achieved when no media is loaded. Moulder puts forward the method of using resistive frequency selective surface to improve impedance bandwidth [10].The impedance bandwidth of 2:1 is realized by the loading square, but the standing wave coefficient and direction patterns of the antenna array scanning are not analyzed.

Based on tightly coupled effect, printed electric/magnetic dipoles were utilized as antenna elements to introduce complementary strong mutual coupling slot (magnetic dipole) array on the account of original strong mutual coupling dipole array to enforce dual-polarization. As demonstrated by preliminary simulation,a dual-polarization phased array with ±60°beam scanning range within a wide frequency band of about 5 octave bandwidths can be realized on the premise of voltage standing wave ratio (VSWR)≤ 3.0 and in-band cross polarization level ≤15 dB. In addition, it was featured with low profile and low broad side dimension.

II. TCDA THEORY

Considering the effect of the ground plane on the antenna, Fig. 1(a) is the equivalent circuit model of dipole element.jXa is the equivalent inductance between dipoles.The coupling effect between antennas can be replaced by a capacitor. Z_{GP} is the input impedance of the feed point of the dipole cell.When $h < 1/4\lambda$, Z_{GP} is inductive and the coupling capacitance between the antennas can be offset by Z_{GP}, so that the reactance is kept near 0 in the lower band, thus extending the bandwidth to the low frequency.When $h > 1/4\lambda$, Z_{GP} is capacitive.The coupling capacitance between the antennas can be superimposed with Z_{GP} ,so that the impedance can accelerate the mismatch at high frequency, and the high frequency cutoff frequency is reduced.As the frequency goes up,when $h=1/2\lambda$, $Z_{GP}=0$.At this time the antenna element is short by the ground plane,will not have the energy to radiate out.And when the frequency goes up further, $Z_{GP} \neq 0$.It radiates energy into space.Therefore, in order to broaden the bandwidth ,consider adding resistive material between the antenna and the to make up for the frequency of the short of the floor.Now,the equivalent circuit is shown in Fig. 1(b).It can be seen that by increasing Z_R, energy can be further directed to the radiation resistance.In the simulation, the resistive material is adopted in the form of the thin film resistance.



(a) (b)

Fig. 1.The equivalent circuit of TCDA element in an infinite array

III. Dual-Polarized TCDA

The designed antenna element model has been presented in Fig. 2,which is composed of electric dipole antenna, magnetic dipole antenna, Balun and lumped resistance ring. Its width and height are 0.4 and 0.41 of a high-frequency wavelength respectively. While periodic boundaries are in the front and the rear of it, its periphery is deemed as PML. Among them, the lumped resistance ring is constituted by several 100Ω lumped resistances connected in series but not directly connected to the antenna. Both antennas described above are located above dielectric-slab FR4 and the resistance ring below it. 50Ω-100Ω hyperbolic gradient Balun is selected for electric dipole elements; in comparison, resistance of the hyperbolic gradient Balun used for magnetic dipole elements ranges from 50Ω to 150Ω. Accordingly, Balun dielectric-slabs utilized are Rogers RO4003 and Roger TMM 10i for the former and the latter successively.

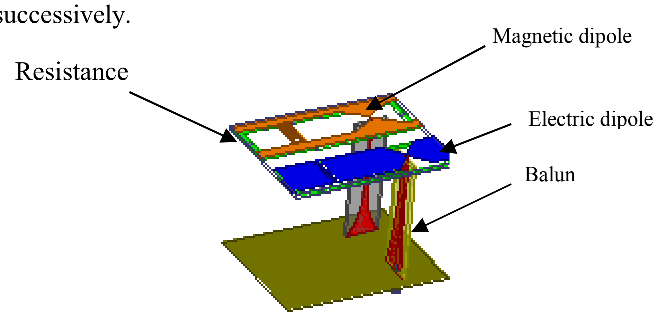


Fig. 2.HFSS simulation model

IV. Array Permormance

A. Active VSWR

Standing-wave properties of two different polarized antennas were given in a context of one-dimensional infinite major cycle in Fig. 3 and Fig. 4. Subjected to a condition of impedance bandwidth of 5:1, VSWR is less than 3.0 at the time of scanning in the E-Plane with a scanning angle between $0^0$and 60^0. As for individual frequency points, they still satisfy the requirement of VSWR＜3.5 in spite of being slightly higher.f_p represents the lowest working frequency.

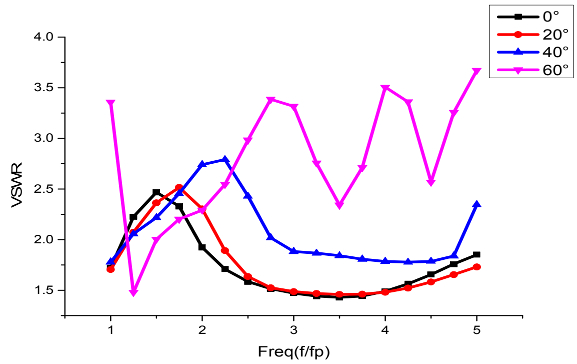


Fig. 3.VSWR of the electric dipole between 0^0 and 60^0 scanning

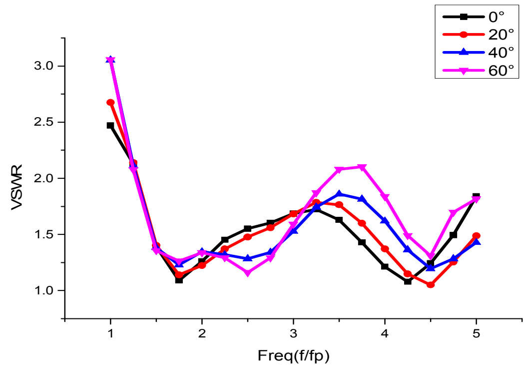


Fig. 4.VSWR of magnetic dipole between 0^0 and 60^0 scanning

B. Active Element Patterns

Element radiation patterns for both antennas at f_p **Error! Reference source not found.**and $5f_p$ are presented from Fig. 5 to Fig. 8. Clearly, no phenomena of beam split or distortion can be found in two polarized directional diagrams during in-band scanning. Meanwhile, such two polarized element radiation patterns are rather stable and cover 60^0 of a spatial scanning range. Maximum and minimum values of in-band cross polarization component reach 40 dB and 13 dB separately. Moreover, they are basically kept at 20 dB approximately,indicating excellent wide-scan capability of the proposed TCDA.

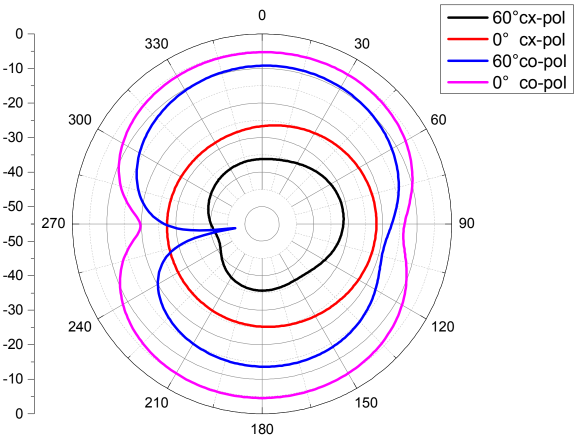


Fig. 5.Electric dipole antenna radiation pattern at f_p

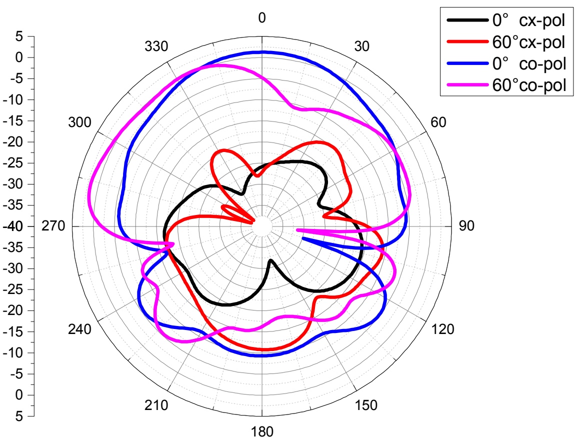


Fig. 6.Electric dipole antenna radiation pattern at $5f_p$

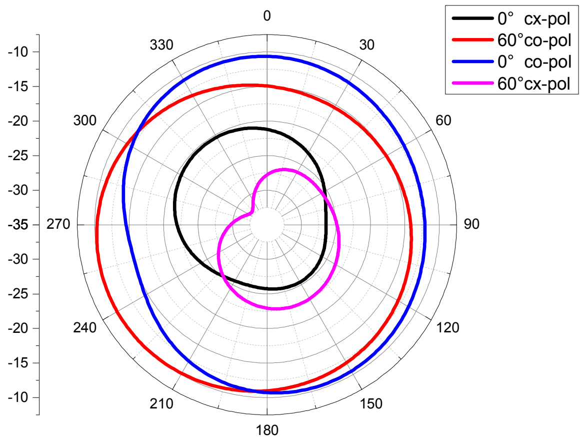


Fig. 7.Magnetic dipole antenna radiation pattern at f_p

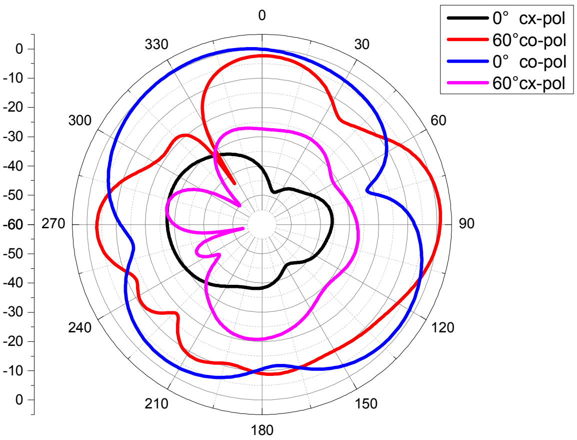


Fig. 8.Magnetic dipole antenna radiation pattern at $5f_p$

V. CONCLUSION

Previously designed low-profile dual-polarized TCDA arrays were utilized to simulate an area array by simulation in a two-dimensional infinitely great cycle environment by virtue of orthogonally arranged dipole elements. As a consequence, it is inapplicable to narrow space. However, as proposed in this paper, magnetic dipole (slot) elements were selected to implement dual polarization. Besides, it was combined with electric dipole elements to form a linear array, which substantially reduced dimension of the array broadside and was thus suitable for phased array radar in narrow space such as wings of aircraft. $\pm 60^0$scanning independent of impedance bandwidth defined to be 5:1 for a wide-angle impedance matching layer. The in-band VSWR below 3.0 signified that relevant gain and cross polarization properties were satisfactory. The antenna element is featured with not only an Ultra Wide Band (UWB) property, but also a compact structure and low profile. Therefore, it conforms to UWB wide-angle phased-array antenna application demands.

REFERENCES

[1] B.A.Munk, Finite Antenna Arrays and FSS New York: John Wiley, 2003.

[2] N.Marchand, Transmission-lion conversion, transformers, Eletronics,vol.17, no.12, pp.142-145, 1994.

[3] 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, no.9, pp.4538-4548, Sept.2013.

[4] S.S.Holland and M.N.Vouvakis, “The planar ultrawideband modular antenna(PUMA)array,” *IEEE Trans.Antennas Propag*., vol.60, no.1, pp.130140, Jan.2012.

[5] J.A.Kasemodel, C.C.Chen, J.L.Volakis, “Wideband Planar Array With Integrated Feed and Matching Network for Wide-Angle Scanning,” *IEEE Trans.Antennas Propag*., vol.61, no.9, pp.4528-4537, Sept.2013.

[6] M.W.Elsallal and J.C.Mather, “An ultra-thin, decade (10:10) bandwidth, modular BAVA array with low cross-polarization,” *IEEE Antennas Propag.Soc.Int.Symp.(APSURSI).IEEE*, Jul.2011, pp.1980-1983.

[7] Tzadidis I, Septel K, Volakis J L.Interwoven spiral array with 10:1 bandwidth on a ground plane[J].*IEEE Antennas and Wireless Propagation Letters*, 2011, 10:115-118.

[8] Volakis J L, Sertel K.Narrowband and wideband matamaterial antenna based on degenerate band edge and magnetic photonic crystals[J]. *IEEE Proceedings*, 2011, 99(10):1732-1745.

[9] Tzandis I, Sertel K, Volakis J L.Characteristic excitation taper for ultra-wideband tightly coupled antenna array[J]. *IEEE Trans on Antennas and Propagation*, 2012, 58(11):1777-1784.

[10] Moulder W F, Sertel K, Volakis J L.Superstrate-enhanced ultrawideband tightly coupled antenna array with resistive FSS[J]. *IEEE Trans on Anennas and Propagation*, 2012, 60(9):4166-4172.