Bent Coplanar Waveguide Feeds for Balanced Planar Antennas and Arrays

Xianyang Lv[1,2], Yongwei Zhang[1]✉, Yanwei Fu[1], Quan Shi[1], Ahmed El-Makadema[3]

[1] *School of Transportation, Nantong University, Nantong, Jiangsu Province, 226019, China*
[2] *School of Information Science and Technology, Nantong University, Nantong, Jiangsu Province, China*
[3] *Department of Electrical and Electronic Engineering, The University of Manchester, Oxford Road, Manchester, M13 9PL, UK*

✉ *david.y.zhang@ntu.edu.cn*

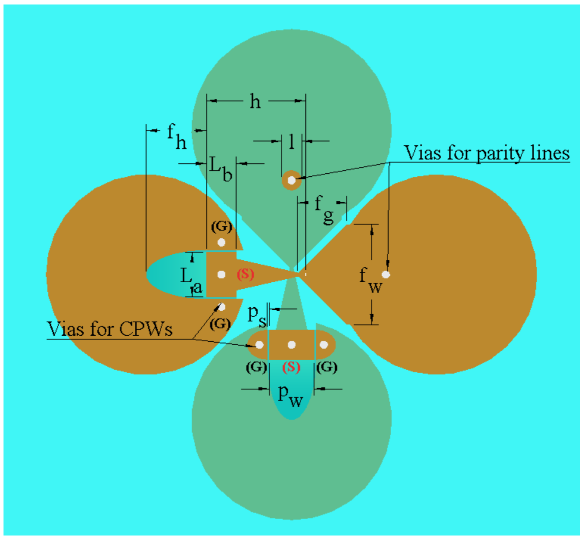
Planar antenna arrays of a balanced structure are of great importance in many applications due to their features including low-profile, wideband and high polarisation purity. However, feeding such antennas adds great complexity in terms of manufacturing and reduces the performance due to production of common mode propagation. A method for feeding such antennas using coplanar waveguide on a thin substrate is proposed. Not only does it terminate the antenna of a balanced structure with a single-ended feed but it also enables impedance transformation. The design was an attempt towards a completely printed front-end that incorporates the antenna elements and their feeding circuits on bendable substrates. The electromagnetic performance has been validated with a dual polarized prototype and its prospect for ultrawideband arrays e.g., 5G sub-6 GHz or square kilometre array, was explored.

Introduction: Wideband planar arrays have been drawing considerable attentions in many applications [1–5]. In particular, flexible phased array that can be readily deployed as rollable sheets will enable rapid and broad utilization of phased arrays to overcome many challenges e.g., size, cost, weight, and complexity of the system as the number of elements grows [6]. Conformal arrays evolved from planar structure have the potential for a cost effective system [7]. However, for planar arrays formed by elements with balanced structures and backed by a reflective ground plane, the common mode propagation produced within balanced feedlines for these types of array is widely considered as a challenging problem [8–10]. In particular, the cross polarisation performance is degraded significantly in addition to resonances in the band which is attributable to the presence of common mode current [11, 12].

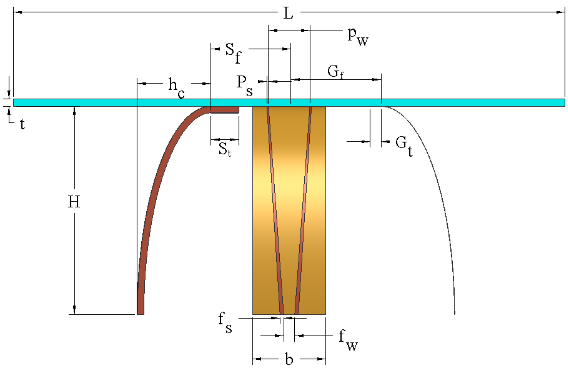
Printed Circuit Board (PCB) based solutions have been reported to feed planar arrays while rejecting the common-mode resonances due to the feedlines [13–16]. In [17], a co-planar strip (CPS) to a microstrip (MS) transformer is used to remove the effect from the feedlines in the integrated balanced antenna structure. Since 180° phase shift between the balanced line needs to be maintained for antenna feeding, but they are "hardwired" as a microstrip. Hence, the bandwidth is limited. A PCB based symmetrical wideband microstrip slot-line transition to cancel out common-mode signals is reported in [18]. It produces an excellent common-mode rejection ratio (CMRR). However, this comes at the expense of a significant loss.

In this paper, CPW based on a flexible substrate is developed to feed the planar antenna with a balanced structure. The CPW serves as a transformer and matching network at the same time. The flexible CPW is bent and attached to the antenna feed terminals at one end and the other end is extended to the ground plane. A conductive parity strip is introduced to mitigate impact of the inserted feedlines on impedance matching.

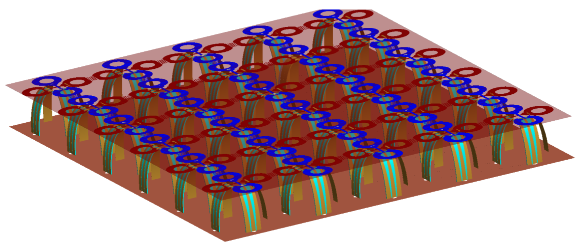
The dual-functional CPW design: The balanced antenna considered consists of two pairs of disks on the opposite side of the same board. They are orthogonal to each other for dual polarisation. The antenna is proposed to be fed by a flexible CPW, and a parity line accompanying each CPW line is inserted to suppress the common mode. The configuration of the dual polarized planar antenna and the corresponding feed lines are illustrated in Fig. 1. The substrate of the CPW has to be thin enough to make it bendable. Cavity is carved on one disk and a strip is extended from the other disk in order to make the antenna suitable for CPW feeding. The CPW line extends the feed point from the plane of antenna to the level of ground plane.



(a)



(b)



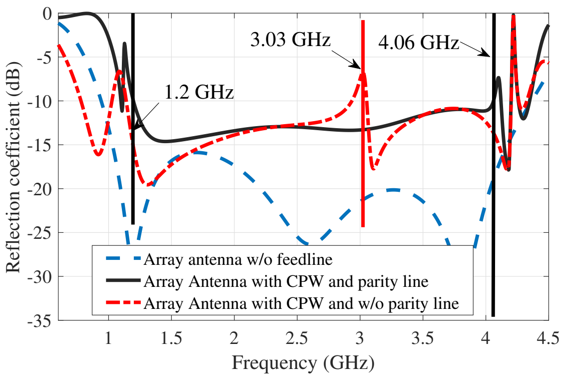
(c)

Fig. 1: The bent CPW design for feeding dual polarized planar balanced antennas or arrays, two copper layers are on the opposite side of the same board for dual polarisation, (a) the top layer for one polarisation, (b) the bent CPW feed design for dual-polarized planar antenna in azimuth plane, the conductive parity line is on the opposite side of CPW, (c) The bent CPWs for feeding the planar array of tightly coupled crossed disk antennas of balanced structures

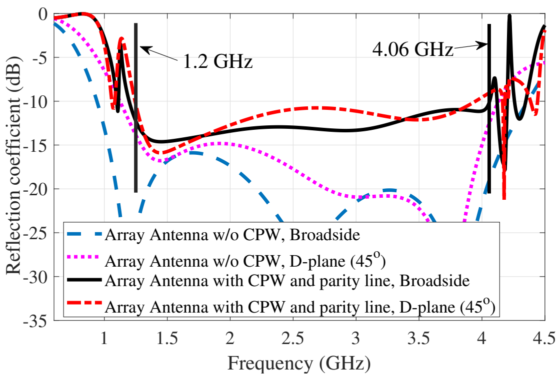
CPW design for feeding a single antenna: The characteristic impedance of a CPW is decided by four parameters: the dielectric permittivity of the substrate and its thickness, the width of the trace for signal and the separation to ground plane. The parameters for the CPW at both ends are optimized, thus, the impedance is 50 Ohm at output side, connected to a sub-miniature version A (SMA) connector, and 25 Ohm on the antenna side which is the characteristic input impedance of the disk dipole antenna above a ground plane. It is essential for CPW to be bendable to make it flexible enough to be connected with antenna in azimuth plane and reach the ground plane at the same time. The antenna on the top of the substrate is excited by one CPW via three plated holes, the middle hole is connected to the signal trace of CPW, and the other two joined to the ground traces of CPW. Antenna on the bottom side of the substrate is fed by a CPW in a similar fashion. In order to ensure a good impedance matching and

Table 1: Design parameters for the bent CPW Feed

Parameter	Size (mm)	Description
d	20	disk diameter
l	2	diameter of via for parity line
L_a	4.5	tap width for CPW signal trace
L_b	3	tap length for CPW signal trace
f_h	6	major axis of ellipse cavity
h	10	extension of CPW signal trace
b	8	width of CPW
f_w, f_s	4.5,0.18	CPW size at antenna side
f_w, f_s	1.2,0.4	CPW size at receiver side
p_w, p_s	4.5,0.18	Soldering tap for P2



(a)



(b)

Fig. 2: Reflection coefficient of the elements in an infinite array of three configurations: planar elements only in tightly coupled disk dipole array, elements with CPW feeds, or elements with CPW feeds and parity lines, (a) broadside scan for three configurations, (b) scan performance at broadside and 45° in the D-plane, with and without the proposed complete feed structures

assembly easiness for the antenna on the bottom side, three soldering taps are added on the top with plated holes and they are connected to the CPW traces through vias. The connection between the CPW feedline and the balanced antenna in the azimuth plane is illustrated in Fig. 1(b). The optimized physical dimensions of the CPW design and the planar differential antenna utilized for investigating the effect of CPW feed are summarized in Table 1.

CPW design to feed array antenna: The flexible CPW design can also be used to feed a planar array of tightly coupled disk dipoles. In an infinite array environment, the unit cell used to construct the array has been studied under two conditions of with and without the CPW feed integrated. Take an example when the element separation is 40 mm, which is equal to the wavelength at 3.75 GHz, the optimum distance between the antenna plane and the ground plane is 29 mm. Interdigital capacitor of 0.35 pF is placed between the elements for a wider bandwidth. The reflection coefficient of the unit cell element in an infinite array for broadside scan is shown in Fig. 2. It is observed that a resonance occurs at the frequency of 3.03 GHz when the CPW is present alone. When a parity line is added, the resonance can be shifted to outside the operational frequency band. The active reflection

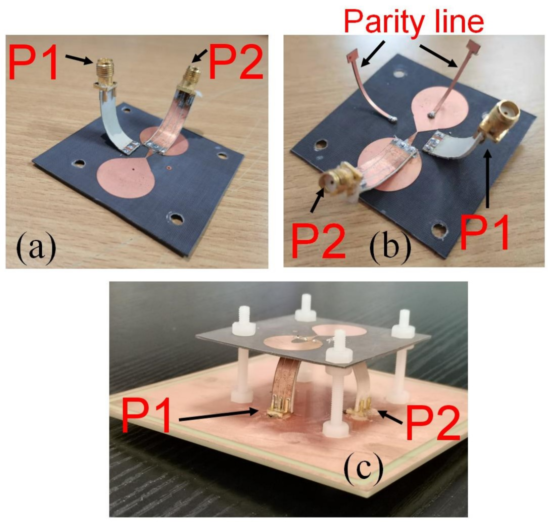


Fig. 3: The prototype of the dual polarized planar antenna fed via flexible CPWs, where P1 and P2 refer to polarisation 1 and polarisation 2, and P2 is on the bottom side of the board, (a) the view from the ground plane side, (b) the view from a side perspective, (c) the complete prototype

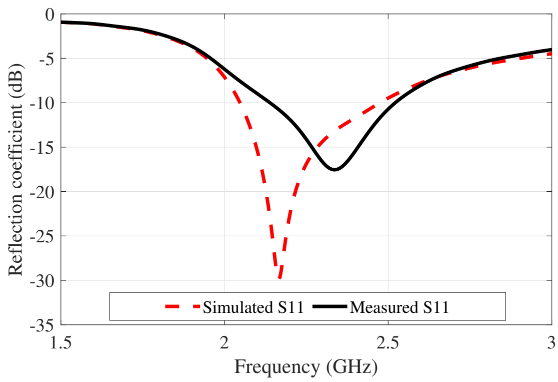


Fig. 4: The reflection coefficient of the dual polarised planar antenna prototype of balanced structure fed through the bent CPW

coefficients for the elements in an infinite array with CPW and parity lines for feed are shown in Fig. 1(c).

Manufacturing and Assembly: A prototype of the dual-polarized planar antenna and the proposed CPW feed were fabricated. The substrate for the antenna is Teflon woven glass fabric based board F_4BM-2-A255, with the relative permittivity of 2.55 and the thickness of 0.762 mm. The CPWs are manufactured by using the material of TP-1/2 ($\varepsilon_r = 10.2$) with the thickness of 0.762 mm. The dual polarized planar antenna, the CPWs for feed, the parity lines and the assembly process are illustrated in Fig. 3, where the element P1 is on the top surface of the board, and P2 is on the bottom side of the same board. They are both connected to CPWs through three vias—the middle one for the signal trace and the other two at sides for the traces of CPW ground.

Results and Discussion: The reflection coefficient of the single antenna of balanced structure with the proposed CPW feed is shown in Fig. 4. The same operational frequency bandwidth was observed from the measured and the simulated results. This validated the effectiveness of proposed feeding mechanism for this type of antenna. Although the bandwidth is limited for the single antenna scenario, but the method can be applied on an array with a similar structure where a wider bandwidth will be yielded when enhanced coupling is present between the elements.

Conclusion: This paper presents a flexible CPW design for feeding dual polarised broad band antennas of balanced structures. The design allows a value controlled impedance transformation into single-ended feed. In addition, the design provides an effective common mode rejection often associated with such antenna type. The flexible CPW design allows for easier integration with the antenna without effecting the performance. The results are demonstrated in simulation and verified through measurements with a good agreement. It showed a prospect in large-scale applications such as Square Kilometre Array (SKA) where low-cost production is one of the key questions.

Acknowledgment: This work has been supported by the NSFC (62174091), in part by the Postgraduate Research and Practice Innovation Program of Jiangsu Province under Grant (KYCX20-2792)

References

1 Zhou, W., Chen, Y., Yang S.: Dual-Polarized Tightly Coupled Dipole Array for UHF–X-Band Satellite Applications. *IEEE Antennas Wirel. Propag. Lett.* **18**(3), 467-471(2019)

2 Yetisir, E., Ghalichechian, N., Volakis, J.L.: Ultrawideband Array With 70° Scanning Using FSS Superstrate, *IEEE Trans. Antennas Propag.* **64**(10), 4256-4265(2016)

3 Zhang, Y., Brown, A.K.: A Wideband Planar Aperture Array Using Interconnected Crossed Rings. *IEEE Trans. Antennas Propag.* **67**(2), 945-950(2019)

4 Zhang, H., Yang, S., Chen, Y., et al.: Wideband dual-polarized linear array of tightly coupled elements. *IEEE Trans. Antennas Propag.*, **66**(1), 476–480(2018)

5 Logan, J.T., Kindt, R.W., Lee M.Y., et al.: A New Class of Planar Ultrawideband Modular Antenna Arrays With Improved Bandwidth. *IEEE Trans. Antennas Propag.* **66**(2), 692-701(2018)

6 Hashemi, M., Fikes, A.C. Gal-Katziri, M., et al.: A flexible phased array system with low areal mass density. *Nat. Electron.* **2**(5), 195-205(2019)

7 Meredov, A., Klionovski,K., Shamim, A.: Screen-Printed, Flexible, Parasitic Beam-Switching Millimeter-Wave Antenna Array for Wearable Applications. *IEEE Open Journal of Antennas and Propagation.* **1**, 2-10(2020)

8 Hay, S.G., O'Sullivan, J.D.: Analysis of common-mode effects in a dual-polarized planar connected-array antenna. *Radio Sci*. **43**(6), 1-9(2008)

9 Bolt, R.J., Cavallo, D., Gerini,G., et al.: Characterization of a Dual-Polarized Connected-Dipole Array for Ku-Band Mobile Terminals. *IEEE Trans. Antennas Propag.* **64**(2), 591-598(2016)

10 Zhong, J., Johnson, A., Alwan, E.A., et al.: Dual-Linear Polarized Phased Array With 9:1 Bandwidth and 60° Scanning Off Broadside.*IEEE Trans. Antennas Propag.* **67**(3), 1996-2001(2019)

11 Cavallo, D., Neto, A., Gerini, G., et al.: A 3- to 5-GHz Wideband Array of Connected Dipoles With Low Cross polarisation and Wide-Scan Capability. *IEEE Trans. Antennas Propag.* **61**(3), 1148-1154(2013)

12 Cavallo, D., Syed, W.H., Neto, A.: Equivalent transmission line models for the analysis of edge effects in finite connected and tightly coupled arrays. *IEEE Trans. Antennas Propag.* **65**(4), 1788–1796(2017)

13 Tzanidis, I., Sertel, K., Volakis, J.L.: UWB Low-Profile Tightly Coupled Dipole Array With Integrated Balun and Edge Terminations. *IEEE Trans. Antennas Propag.* **61**(6), 3017-3025(2013)

14 Kasemodel, J.A., Chen, C., Volakis, J.L.: Wideband Planar Array With Integrated Feed and Matching Network for Wide-Angle Scanning. *IEEE Trans. Antennas Propag.* **61**(9), 4528-4537(2013)

15 Li, W., Tu, Z., Chu, Q., et al.: Differential Stepped-Slot UWB Antenna With Common-Mode Suppression and Dual Sharp-Selectivity Notched Bands. *IEEE Antennas Wirel. Propag. Lett.*, **15**, 1120-1123(2016)

16 Tang, Z., Liu, J., Lian, R., Li, Y., et al.: Wideband Differentially Fed Dual-Polarized Planar Antenna and Its Array With High Common-Mode Suppression. *IEEE Trans. Antennas Propag.* **67**(1), 131-139(2019)

17 Cavallo, D., Neto, A., Gerini, G.: PCB Slot Based Transformers to Avoid Common-Mode Resonances in Connected Arrays of Dipoles. *IEEE Trans. Antennas Propag.* **58**(8), 2767-2771(2010)

18 Gilmore, J., Davidson, D.B.: Suppressing Undesired Common-Mode Resonances in Connected Antenna Arrays. *IEEE Trans. Antennas Propag.* **63**(11), 5245-5250(2015)