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A NEW KIND OF MILLIMETER WAVE ARRAY FOR DIGITAL RADAR MODULE

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Abstract—A novel circularly polarized array designed for millimeter wave digital radar module was proposed and validated in this paper. The circularly polarized array was designed with single feeding point for easily integrating with front-end module. A new kind of medium filled circular cavity was employed as transition to connect the output of the T/R module and the feeding point of the array. TM_{010} mode was selected as the operating mode of the circular cavity based transition for its special field distribution. Good performance of flexibility, return-loss, axial ratio and radiation pattern were observed.

1. INTRODUCTION

Relative delays among digital T/R modules for the wideband digital array are important for the performance of phased array. Circularly polarized array was usually used in digital T/R modules for its good isolation degree performance when the direction of rotation were opposite between transmitting wave and receiving wave. Circular polarization can be realized with dual/single-feeding point [1]; sequential rotation method was usually used for circularly polarized array design when antenna was fed with single feeding point. In some multi-layer modules, more and more transmission lines are arranged in different layers simultaneously for dimension restriction. Flexible transition structure was needed in these systems for the unanticipated outstretched direction of the transmission lines in different layers. In some T/R modules, microstrip antenna was usually arranged in the back side of the T/R front-end and transition structure was usually employed to connect the RF-output port and the antenna feeding port. Rectangular or other shape air filled aperture located in ground

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of multi-layer modules or metal ground was usually used to couple energy from layer of circuit to microstrip antenna layer [2–5]. In some low frequency modules, coaxial line can be used as transition structure [6]. It is well know that flexibility is a very important aspect that should be considered in design of the transition structure for the unanticipated spreading out direction of transmission lines of different layers. Whereas, flexibility of the rectangular aperture coupled structure was not good enough for its non-revolution-invariant field distribution structure. Misalignment can easily produce for the transition structure in Ref. [4] for there have no locating area in either ground of the substrate or metal ground. Coaxial line can not be used in millimeter wave band for the unacceptable transmission line loss. In this paper, we present a novel vertical transition which based on medium filled circular cavity; this vertical transition takes the advantages of high flexibility, low insertion loss, aligning easily, simple structure, etc, and the transition structure was integrated with the circularly polarized array mentioned above.

2. TRANSITION DESIGN

Figure 1 shows the top view of the single-feeding point left-hand circular polarization (LHCP) array; the right-hand circular polarization (LHCP) array can be acquired by mirror operation. The related dimensions of the four cells millimetre wave array can be found in Table 2.

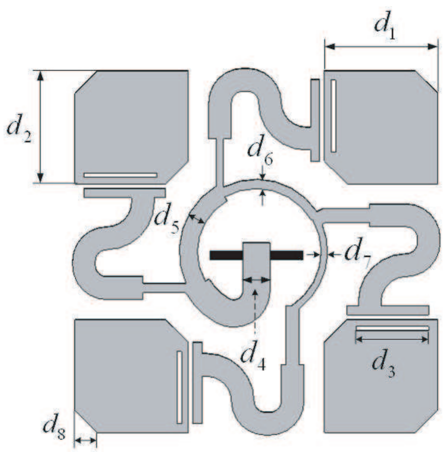

Figure 1. Structure of the millimetre wave array.

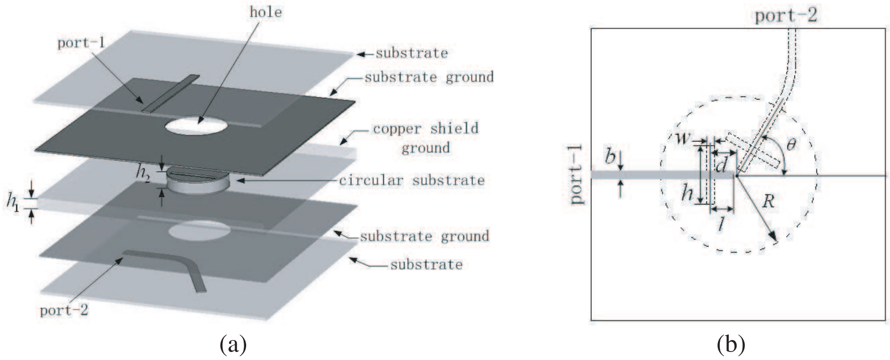

Figure 2. Structure of the circular cavity transition (a) 3D view, (b) top view.

Figure 2 were the 3D and top view of the proposed transition structure, which consists of a circular-shaped substrate and two apertures in top and bottom of its ground; a metal shield ground with a hole used to fix the circular-shaped substrate and a pair of microstrip line with an arbitrary angle of θ located on top layer of the substrate which located in two side of the shield ground, the microstrip line cross at right angles with the corresponding aperture. The medium filled circular cavity was composed by the substrate and lateral wall of the hole in the shield ground. The corresponding area of the substrate ground which touched with the shield ground is etched to couple energy in/out of the circular cavity. The TM_{010} mode is selected as operating mode; it is characterized with revolution invariant and z-axis irrespective if $z < 2.1R$ and had more flexibility than rectangular cavity in application.

It is well known that the resonant frequency (unloaded) of TM_{010} mode for circular cavities with solid wall can be calculated by:

$$f_{mnp} = \begin{cases} \frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{\mu'_{mn}}{R}\right)^2 + \left(\frac{p\pi}{z}\right)^2} & TE_{mnp} \text{ mode} \\ \frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{\mu_{mn}}{R}\right)^2 + \left(\frac{p\pi}{z}\right)^2} & TM_{mnp} \text{ mode} \end{cases} \quad (1)$$

For TM_{010} mode we have:

$$f_{010} = \frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}} \cdot \frac{2.405}{R} = \frac{0.383c}{R\sqrt{\mu_r\varepsilon_r}} \quad (2)$$

where μ_r and ε_r are relative permeability and permittivity of the substrate, μ'_{mn} and μ_{mn} is the nth roots of mth Bessel function of the first kind and its derivative, R is the radius of the circular cavity,

c is the speed of light in free space. Once the resonant frequency is given, the radius of the circular cavity can be calculated by (2).

The transition structure is optimized firstly and then it is simulated with the millimeter wave array together. To validate the circularly polarized array with transition structure, a medium filled circular cavity transition which operated in 35 GHz is simulated with ANSOFT HFSS. Permittivity and loss tangent of the medium are selected to be 2.2 and $\tan\delta = 0.002$ respectively. The metal shield ground is designed to be a little small than the thickness of the circular substrate to ensure the ground touching with the etched area of the circuit/antenna substrate accurately. The initial radius of the circular cavity $R = 2.213$ mm can be acquired by (2). As shown in Fig. 2, the distance between centre line of the aperture and circle centre d; the length of the stub l; the radius of the circular cavity R; the length and width of aperture h, w are optimized for $\theta = 0°$ with 3D full-wave simulation tool HFSS. The initial values of above parameters are $d_0 = 1$ mm, $l_0 = 1.35$ mm (approximately $\lambda_g/4$), $h_0 = 2$ mm, $w_0 = 0.2$ mm, $R_0 = 2.21$ mm. Table 1 shows the final optimum results of the transition dimensions.

Table 1. Dimension of the circular cavity transition.

d	l	h	w
1 mm	1 mm	2 mm	0.2 mm
R	b	h_1	h_2
2.2 mm	0.78 mm	1 mm	1.1 mm

Table 2. Dimension of the array.

d_1	d_2	d_3	d_4
2.5 mm	2.5 mm	1.6 mm	0.5 mm
d_5	d_6	d_7	d_8
0.3 mm	0.2 mm	0.1 mm	0.5 mm

Simulated return loss and insertion loss for $\theta = 0°$, $\theta = 30°$ and $\theta = 60°$ are shown in Fig. 3. Return loss better than -25 dB and Insertion loss less than 0.7 dB can be observed at the operating frequency 35 GHz. The simulated 10-dB return loss bandwidth is found to be approximately 1 GHz for both simulation tools, that's from 34.3 GHz to 35.3 GHz, the corresponding insertion loss is less than 1 dB. Fig. 4 shows the simulated return loss and insertion loss for $\theta = 90°$, $\theta = 120°$ and $\theta = 150°$, return loss better than -27 dB and Insertion loss less than 0.6 dB can be observed at the operating frequency 35 GHz. The simulated 10-dB return loss bandwidth is found to be also about 1 GHz, that's from 34.5 GHz to 35.5 GHz for $\theta = 90°$ and $\theta = 150°$; from 34.7 GHz to 35.7 GHz for $\theta = 120°$. Compared with the corresponding results for $\theta = 90°$ and $\theta = 150°$, the deterioration for $\theta = 120°$ is most likely attributed to the appearance of high order modes which introduced by the crossing area of two apertures located on the top and bottom of the circular substrate. The corresponding insertion loss is less than 1 dB in the 10-dB return loss bandwidth.

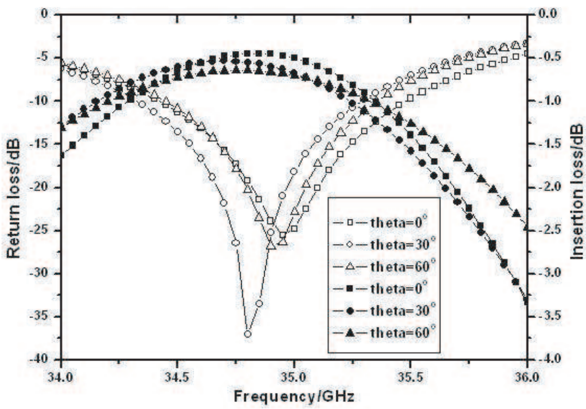

Figure 3. Simulated S parameters for $\theta < 90°$.

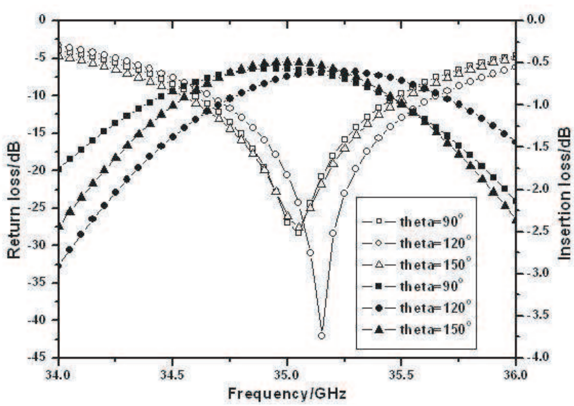

Figure 4. Simulated S parameters for $\theta \geq 90°$.

Simulated results for different θ angles show good agreement with each other; the predicted flexibility characteristic of the transition structure is validated. The flexible transition structure grants permission to design the millimetre array with high flexible structure.

3. MILLIMETER WAVE ARRAY WITH TRANSITION DESIGN

The circularly polarized millimetre wave array with circular cavity transition is modeled and simulated in CST MICROWAVE STUDIO and ANSOFT HFSS simultaneously for comparing with each other to

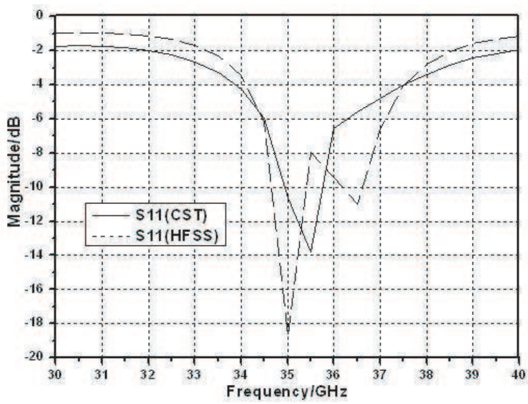

Figure 5. Return loss of the array with transition.

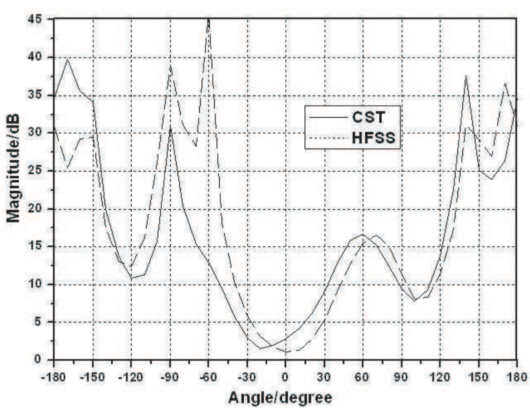

Figure 6. Axial ratio of the array with transition.

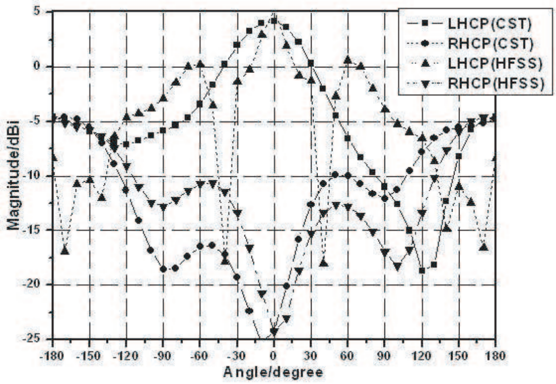

Figure 7. Radiation pattern for $\varphi = 0°$ of the array with transition.

validate the structure and design method. The simulated return loss and axial ratio are shown in Fig. 5 and Fig. 6 respectively; we can see that axial ratio less than 2 dB is observed in normal direction. Left hand and right hand radiation pattern of $\varphi = 90°$ is shown in Fig. 7 for both simulation tools. We can see that the gain of Light-hand CP (LHCP) wave is about 5 dBi, while the gain of Right-hand CP (RH) wave is about -25 dBi.

4. CONCLUSION

A novel circularly polarized millimetre wave array with circular cavity transition structure based on circular cavity is proposed in this paper. Design method is presented for design and optimization of this array with transition structure. The transition structure is optimized firstly and then it is inserted into the array as connection part between the T/R module and the antenna feeding point. Good performance of return loss and insertion loss are observed for the transition from the simulated results. Flexibility of the transition is validated by good simulated results acquired from different θ angles. The characteristic of the millimetre wave array are validated finally by two different simulation tools. The circularly polarized millimetre wave array is characterized with high design flexibility, low axial ratio and compact structure; it can be used in microwave and millimeter-wave modules.

REFERENCES

1. Pozar, D. M. and D. H. Schaubert, *The Analysis and Design of Microstrip Antennas and Arrays*, 136–139, IEEE Press, 1995.
2. Li, E. S., J.-C. Cheng, and C. C. Lai, "Designs for broadband microstrip vertical transitions using cavity couplers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 1, 464–472, Jan. 2006.
3. Chen, C., M.-J. Tsai, and N. G. Alexopoulos, "Optimization of aperture transitions for multiport microstrip circuits," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 44, No. 12, 2457–2465, Part 2, Dec. 1996.
4. Li, E. S. and C. C. Lai, "A comprehensive study on the bandwidth of broad-band slot-coupled and cavity-coupled vertical transitions," *Antennas and Propagation International Symposium, 2007 IEEE*, 3109–3112, Jun. 9–15, 2007.
5. Nedil, M., T. A. Denidni, and A. Djaiz, "Ultra-wideband microstrip to CB-CPW transition applied to broadband filter," *Electronics Letters*, Vol. 43, No. 8, 464–466, Apr. 12, 2007.
6. Lee, J.-H., Y.-T. Im, and S.-O. Park, "Doppler radar sensing system of respiration and heart rate," *The 8th International Symposium on Antennas, Propagation and EM Theory*, 976–978, 2008.
7. Wu, D. and K. Seo, "Waveguide to microstrip line transition and power divider," *Electronics Letters*, Vol. 43, 169–170, 2007.
8. Wu, Y., Y. Liu, and S. Li, "A new dual-frequency wilkinson power divider," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 4, 483–492, 2009.
9. Ruiz-Cruz, J. A., J. R. Montejo-Garai, J. M. Rebollar, and S. Sobrino, "Compact full Ku-band triplexer with improved E-plane power divide," *Progress In Electromagnetics Research*, PIER 86, 39–51, 2008.
10. Chen, H. and Y. Zhang, "A novel compact planar six-way power divide using folded and hybrid-expanded coupled lines," *Progress In Electromagnetics Research*, PIER 76, 243–252, 2007.