New 2.5 Ghz Circularly Polarized Retrodirective Arrays For Autonomous Cars.

[1]P.Mahalakshmi, [2]R.Vallikannu

[1]Research Scholar
Department of ECE
Hindustan Institute of Technology and Science
mahapearl57@gmail.com

[2]Associate Professor
Department of ECE
Hindustan Institute of Technology and Science
vallikannu@hindustanuniv.ac.in

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 10 May 2021

Abstract—For the development of wireless communication technology beam tracking and security are the most important factor. Retrodirective analysis works as it automatically responding to an incoming signal location without any prior information of the source direction. The passive feed structure is used for designing MIMO antenna array systems due to its mow profile and its miniaturization Whereas the circularly polarized arrays is applied in the MIMO system to provide power division. The purpose of this paper is to design a circularly polarized couplers which works in Retrodirective mode. The resonant frequency of the coupler is 2.5 GHz. The Proposed couplers have been devised using the Glass Epoxy substrate (FR4) with dielectric constant (εr = 4.4). S parameters, radiation pattern, insertion and isolation losses are obtained from ANSYS software.

Keywords- Retrodirective array; Rat-race couplers; Returnloss; ANSYS

I. INTRODUCTION

In recent years, research in wireless communication technology is increased. RF systems are designed mainly for tracking systems, military communications, radar, and Radiofrequency identification (RFID) and microwave power transmission. Retrodirective antenna has a simpler structure than a conventional smart antenna. Due to its high speed and self-tracking process make RDA useful for RFID and other civilian applications by providing high gain link between an interrogator and an RDA.

A Retrodirective array is basically a transponder, its main function is to wirelessly send a signal response upon being interrogated. RDA array is used as passive transponders for a wide range of applications such as battlefield IFF (Identification friend or foe) transponders, and target or project surveillance detection radar for mobile vehicles. It can accelerate the detection of targets and reduce the complexity of systems compared with smart antennas or conventional phased array antennas.

II. FOUR PORT NETWORK

An RDA is a special type of phased array where beam scanning is achieved automatically and instantaneously. The S- matrix parameters of a four-port network can be expressed as below

$$[S] = \begin{bmatrix} S11 & S12 & S13 & S14 \\ S21 & S22 & S23 & S24 \\ S31 & S32 & S33 & S34 \\ S41 & S42 & S43 & S44 \end{bmatrix} \qquad [1]$$

Due to the symmetric property, we can obtain that $S_{ij}= S_{ji}$. If the ports are well matched with the load, then S_{ij} =0. Thus the matrix can be rewritten as

$$[S] = \begin{bmatrix} 0 & S12 & S13 & S14 \\ S21 & 0 & S23 & S24 \\ S31 & S32 & 0 & S34 \\ S41 & S42 & S43 & 0 \end{bmatrix} \quad [2]$$

Because of unitarity of the port network, multiplication of row 1, 2 and row 3, 4 can be performed

$S^*_{13} S_{23} + S^*_{14} S_{24} = 0$ [3]

$S^*_{14} S_{13} + S^*_{24} S_{23} = 0$ [4]

Multiply eq [3] and eq [4] separately using S^*_{24} and S^*_{13} and then subtract, we obtain

$S^*_{14}(|S_{13}|^2 - |S_{24}|^2) = 0$ [5]

Similar process on row 1, 3 and row 2, 4 gives

$S^*_{23}(|S_{12}|^2 - |S_{34}|^2) = 0$ [6]

Assume that $S_{14} = S_{23} = 0$, then S-matrix can be rewritten as

$$[S] = \begin{bmatrix} 0 & S12 & S13 & 0 \\ S12 & 0 & 0 & S24 \\ S13 & 0 & 0 & S34 \\ 0 & S24 & S34 & 0 \end{bmatrix} \quad [7]$$

Using unitary rule in each row to obtain that

$|S_{12}|^2 + |S_{13}|^2 = 1$ [8]

$|S_{12}|^2 + |S_{24}|^2 = 1$ [9]

$|S_{13}|^2 + |S_{34}|^2 = 1$ [10]

$|S_{24}|^2 + |S_{34}|^2 = 1$ [11]

From the above statements, it is obvious that $|S_{13}| = |S_{24}|$ and $|S_{12}| = |S_{34}|$. The following parameters are used to verify the performance of the coupler. The section of input power coupled to the output port is termed as coupling loss. Directivity is defined as the ratio of the coupled port to isolated port. The isolation loss measures the unwanted power delivered to uncoupled port. The insertion loss can be defined as the transmission factor between the input and through port.

III. RAT-RACE COUPLER

The hybrid or rat race ring is also named as 180-degree coupler. It consists of four-port which provides 180-degree phase shift between two output ports. Figure 1 gives the structure of the hybrid couplers, where four ports are located on the ring with the distance of $3\lambda_g/4$ between port1 and port 4 and $\lambda g/4$ between the other ports. Where λ_g refers to the guided wavelength of the material. The four ports are well matched with Z_0 and the impedance of the coupler is $\sqrt{2}\, Z_0$.

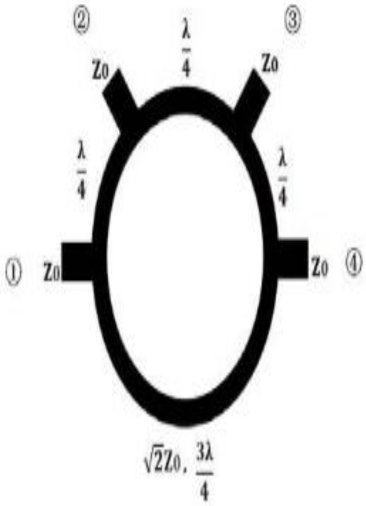

Fig 1: Schematic of Rat-Race Coupler.

When port 1 is excited, the signal is divided into two directions such as clockwise and anti-clockwise direction. The wave incidents in port 1 divides power into port 2 and port 4 but not into port 3. The distance travelled by the signal from port 1 to port 2 is λ/4 and port 1 to port 4 is 3λ/4 and the phase shift obtained between these two are 180 – degree. The wave incidents in port 3 divides power into port 2 and port 4 but not into port 1. The distance travelled by the signal from port 3 to port 2 is λ/4 and port 3 to port 4 is λ/4 and the phase shift obtained between these ports are in-phase signals. The coupler can act as power divider as it divides the input power into halves but the output powers are in 0 or 180-degree phase difference.

The S- parameter matrix of the coupler is following:

$$\begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

$$\frac{-i}{\sqrt{2}} \begin{pmatrix} 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ -1 & 0 & 1 & 0 \end{pmatrix}$$

IV. RETRO-DIRECTIVE ANALYSIS

Retrodirective antenna array has unique feature as beam scanning is achieved beam automatically. It is special type of phased array [3]. Based on array theory it responds toward source direction automatically. The two important methods to achieve retrodirecitivity are van-atta array and phase conjugation array.

Van-atta array consists of a pair of antennas connected by equal lengths of transmission lines creating the symmetric array [2]. Based on the incoming signal direction the phase gradient is obtained across the elements. It works as reversing the phase gradient in the transmitting beam directing it back in the source direction. It can operate over a wide bandwidth but it can be realized as planar structure alone. The design of the interweaving feed lines can become intricate when used for large arrays.

Phase conjugating array is also known as heterodyne approach. The phase reversal property is achieved at each element using phase conjugating mixers. The major disadvantage is high power consumption when they are used in low – power environments.

V. DESIGN AND EVALUATION

A. Coupler design

This proposed model presents comprehensive description to model Rat-race couplers. Figure 1 represents the schematic of coupler. The dielectric material is Glass epoxy substrate fr4 (ε_r=4.4) and the height is h=1.58mm for the operating frequency 2.5 GHz.

(i)The inner and outer radius of the Rat-Race coupler is calculated using

$$R = \frac{3\,\lambda g}{4\pi} \quad [12]$$

Inner radius of the ring (r_1) = (r - w/2) [13]

Outer radius of the ring (r_2) = (r + w/2) [14]

(ii) The wavelength of the coupler is calculated with the velocity of light C=3x10^8 m/s and the operating frequency f = 2.4 GHz.

$$\lambda 0 = \frac{c}{f} \quad [15]$$

$$\lambda g = \frac{\lambda 0}{\sqrt{\varepsilon eff2}} \quad [16]$$

(iii) The effective dielectric constant ε_{eff1} and ε_{eff2} is calculated using

$$\varepsilon eff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{w}}}\right) \quad [17]$$

(iv) The width for the port input and width for the branches are calculated using the formula

$$\frac{w}{h} = \frac{8e^A}{e^{2A}-2} \quad for\ \frac{w}{d} < 2 \quad [18]$$

$$where, A =; \frac{z}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \frac{\varepsilon r-1}{\varepsilon r+1}\left(0.23 + \frac{0.11}{\varepsilon r}\right) \quad [19]$$

The calculated parameters to design Rat-race couplers at resonant frequency 2.4 GHz is listed in the table given below.

Parameters	**Value (mm)**
70.7Ω (50√2) Transmission line width	1.1mm
50 Ω Transmission line width	3mm
Thickness of the substrate	1.58mm

Table1: Design parameters

B. Rat-Race coupler as Retrodirective array

The rat-race coupler will act as Retrodirective mode if the port 1 and port 2 are connected to the antenna while port 3 and port 4 are terminated with reflection co-efficient. The main advantages are low power consumption and its compatibility. It is used mainly for high frequency applications [7] because of its wider bandwidth features. It is also immune to signal degradation. To overcome propagation losses, a passive retrodirective antenna array is used. The phase reversal property can be derived from the scattering matrix.

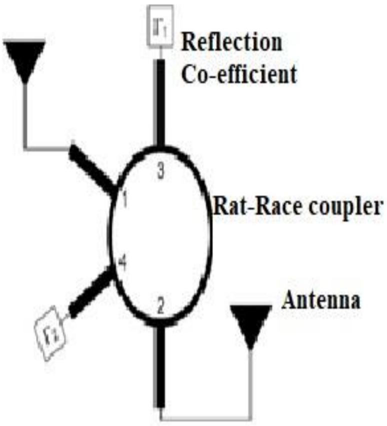

Fig 2: Rat race coupler as retro-directive array

VI. Results and discussion

A. Magnitude Measurements

A 50Ω transmission line and FR-4 substrate are used in this coupler design. The geometry of the rat race ring shown below in figure 3 is obtained using ANSYS software tool.

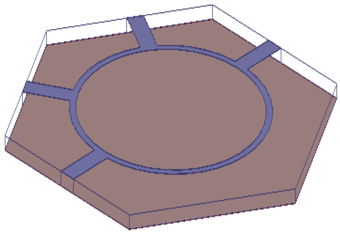

Fig 3: Geometry of Rat-Race ring

The coupler works at a resonant frequency of 2.5 GHz and from the figure 4 very low return losses are observed nearly as -42dB and from the below results port 1 and port 2 get -3.6dB and -3.91dB power respectively.

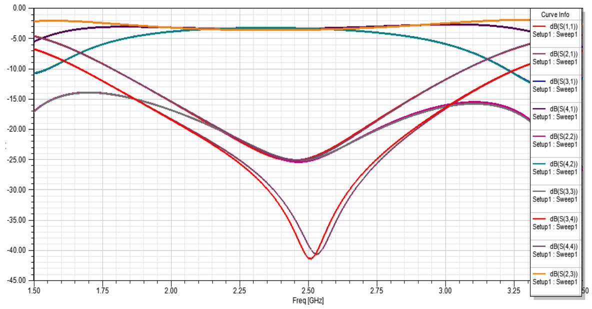

Fig 4: Magnitude Vs Frequency

B. Phase measurement

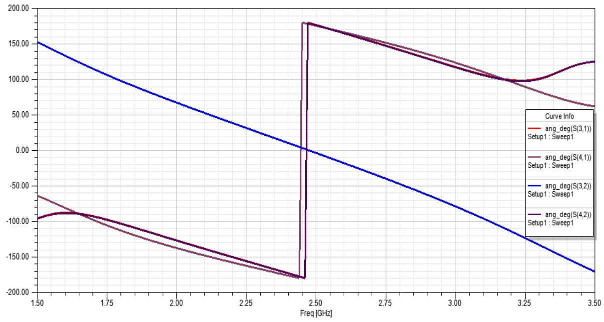

Fig 5: Phase Vs Frequency

It can be seen that the port 1 and port 2 get – 3.6dB and -3.91dB; input power with the phase of 178.45◦ and -0.44◦, the total phase difference is around 178.45- (-0.44◦) =179◦. Retrodirective condition can be achieved from the total phase difference.

VII. CONCLUSION

A novel based circularly polarized coupler is reported in detail. The unique feature of 180-degree hybrid couplers is mostly used in RF circuits such as mixers, phase shifters and power dividers. Due to the advantage of highly integration, the couplers are widely used for MIMO (multiple inputs and multiple outputs) research. The Retrodirective based rat race coupler is connected along with antennas could give multiple outputs with phase control, which is required in MIMO antenna array in 5G technology. This planar integrated antenna with couplers is done with low cost, low loss and small size.

REFERENCES

1. Lin Zong., Jan-Dong., Binshu Wu And Jhih Min Li.: Hybrid Type Rat-Race Coupler Designs, APMEC(2015)
2. Chiou, Y.C., Kuo, J.T., Chan, C.H.: New Miniature Dual Band Rat-Race Coupler With Microwave C-Sections, IEEE MIT-S Int. Microwave Sympo. Dig, Pp. 701-704(2009)
3. Pon, C.Y.: Hybrid-Ring Directional Couplers For Arbitarary Power Divisions,IRE. Trans.Microw.Theory Techn,Vol. 9,No.6,Pp. 529-535,(1961)
4. Van Atta,L.C.: Electromagnetic Reflector,U.S. Patent 2908002 Oct 6,1959.
5. Haoxiang., Wang., Quot.: Trust Management Of Communication Architectures Of Internet Of Things. &Quot: Journal Of Trends In Computer Science And Smart Technology (TCSST) 1, No. 02 (2019).
6. David, M.: Microwave Engineering, John Willey And Sons Inc. Publication, Third Edition (2005)
7. Walker, J.L.B., Improvements To The Design Of The 180 Rat Race Coupler And Its Applications To The Design Of Balanced Mixers With High LO To RF Isolation, IEEE MMT-S Digest,1997, Vol-2, Pp. 747-750.
8. Ecclestion,K.W., Ong,S.H.M.: Compact Planar Microstrip Line Branch-Line And Rat-Race Couplers, IEEE Trans.Microw.Theory Tech,2003,Pp. 2119-2125.
9. Ghali,H., Moshelhy, T.A.: Miniaturized Fractal Rat-Race , Branch-Line And Coupled-Line Hybrids,IEEE Trans.Microw.Theory Tech.,2004,Pp.2513-2520
10. Alhassoun, F.Amato, And G.Durgin,.: "A Multi-Modulation Retrodirective Feed Network For Backscatter Communications," İn Proc. IEEE Int. Symp. Pers. Indoor Mobile Radio Commun.,Oct 2017,Pp-1-5.
11. Pon, C.Y.: Retrodirective Array Using The Heterodyne Technique,IEEE Trans.Antennas Propagation, Vol 12, Pp 176-180, March 1964.
12. E.D.Nielsen.: Square Van Atta Reflector With Conducting Mounting Plane, IEEE Trans. Antennas Propagation, Vol AP-18,Pp 48-54, Jan 1970.
13. Y.-J Ren,K.Chang.: New 5.8-Ghz Circularly Polarized Retrodirective Rectenna Arrays For Wireless Power Transmissions,IEEE Trans. Microw. Theory Techn, Vol.54, No-7, Pp 2970-2976, Jul 2006.

.