**BULLETIN OF
SCIENTIFIC RESEARCH**

Design of Rat-Race based Retrodirective Arrays for Backscatter Communications
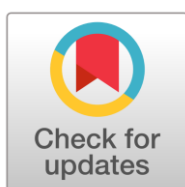
P. Mahalakshmi [a], **A. L. Vallikannu** [a]

[a] Department of ECE Hindustan Institute of Science and Technology, Chennai, Tamil Nadu, India.

* Corresponding Author: mahapearl57@gmail.com DOI: https://doi.org/10.34256/bsr2022

Abstract: Fast beaming tracking and security are important factors for the development of communication technology. A Retrodirective antenna (RDA) technique has been attenuated to one way of improving security. It has the interesting property of automatically responding to an incoming signal location without any prior knowledge of the direction of that source. The purpose of this paper is to design a Rat race coupler which acts as a Retrodirective mode in ANSYS. The resonant frequency of the coupler is 2.4 GHz. The Proposed Rat race 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; Return loss; ANSYS.

1. Introduction

In recent years, interest in wireless communication is increasing due to the development of communication technology. Many RF systems are designed for tracking systems, military communications, radar, and Radiofrequency identification and microwave power transmission [1]. RDA has a simpler structure than a conventional antenna. This high speed and self-tracking process make Retrodirective array useful for RFID and civilian applications by offering automatic maintenance of a high gain link between an interrogator and an RDA.

A Retrodirective array is innately a transponder, as its main function is to wirelessly send a signal response upon being interrogated [2]. Therefore, Retrodirective array is ideal use as passive transponders for a wide range of applications. Battlefield IFF (Identification friend or foe) transponders, and target or project surveillance detection radar

for mobile vehicles, are some scenarios which would benefit from an RDA. Retro directive systems can accelerate the detection of targets and reduce the complexity of systems compared with conventional phased array-based smart antennas.

2. Rerodirective Technology

An RDA is a unique type of phased array where beam scanning is achieved automatically and instantaneously [3,4]. It operates by responding toward a source upon incident interrogation with a directivity based on array theory.

A. Van Atta Array

It consists of a pair of antennas connected by equal lengths of transmission lines creating the symmetric array [2]. The

received signal creates a phase gradient across the elements in the array based on the incoming signal direction. The received signal at each element is reradiated by its conjugated pair, effectively reversing the phase gradient in the transmitting beam directing it back in the same direction as the originating source. Van atta arrays can operate over a wide bandwidth but require that the incoming wave front and the array itself be planar. Besides, for large arrays, the design of the interweaving feed lines can become intricate.
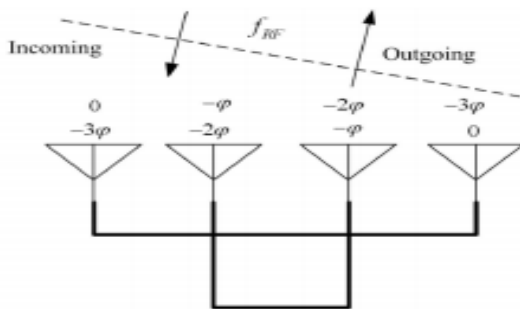

Fig 1. Schematic of Passive van Atta array and the relative phase for transmitted and received signals.

B. Phase Conjugating Array

The most important method to achieve retro directivity by phase conjugation. This implementation is sometimes known as the heterodyne approach achieves the phase reversal effect in an array at each element using phase conjugating mixers since they are power-hungry devices less used in low – power environments.
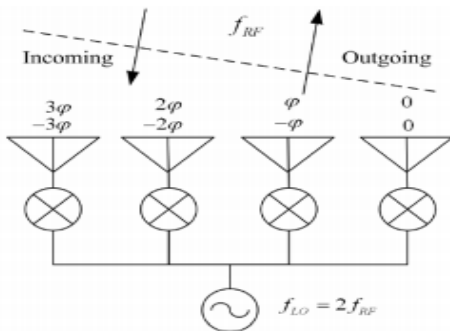

Fig 2. Schematic of phase conjugating or Pon arrays and the relative phase for received and transmitted signals.

3. Rat-Race Couplers

The microwave communication technologies are being miniaturized for development in wireless communication systems. The couplers are used for power dividers /combiners with or without phase shift and with equal and unequal power division [5]. The rat-race coupler is a transmission line device in which output appearing at one port depends on the phase of the signals arriving at the port follows different paths.

The coupler is a four-port structure; it can be used as a power combiner or divider. It is a 3 dB coupler with impedance $\sqrt{2}Z0$. There are four ports with impedance Z0. It has transmission length of one port has $3\lambda/4$ and three with lengths of $\lambda/4$.
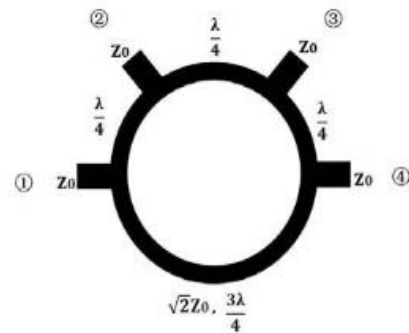

Fig 3. Schematic of Rat-Race Coupler

When port 2 is used as an input port this signal is equally divided into two parts travelling clockwise and anti-clockwise. The distance travelled by the signal from port2 to port 1 is $5\lambda/4$ and the distance travelled from port 2 to port 3 is $\lambda/4$. Output at port 2 and port 3 are in phase [6]. The signals travelling to port 4 have the path difference of $\lambda/2$ and due to this 180° phase difference, no output appears at this port and port being isolated port. If power is applied at port 4, it divides into two out of phase equal signals between ports 1 and 3, port 2 being an isolated port. When the device is used as a power combiner, the two inputs are applied at ports 1 and 3 the output appears at port 2 as the summation of these two inputs

and the difference will appear at port 4. Due to this behavior of the coupler port 2 is called the sum port while port 4 as difference port. This coupler can divide 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 the following:

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

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

4. Design and Evaluation

A. Rat-Race coupler as Retrodirective Array

Therat-race coupler is Retrodirective 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 advantages of using this structure over other techniques such as van atta array are its compatibility and low power consumption. Since Rat –race couplers [7] have a wider bandwidth than other couplers, which is used for high-frequency applications. It is also immune to signal degradation.
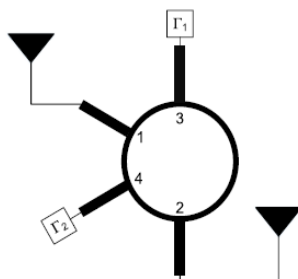

Fig 4. A Rat-Race coupler in which Ports 1 and Ports 2 are connected to antennas and Port 3 and Port 4 is terminated with loads of specific reflection co-efficient.

A passive Retrodirective antenna array overcomes propagation losses and requires no power to scan multiple angles. The phase reversal property can be derived from the scattering matrix. As

$$
[S] = \frac{1}{\sqrt{2}}
\begin{bmatrix}
0 & 0 & e^{-j\frac{\pi}{2}} & e^{-j\frac{\pi}{2}} \\
0 & 0 & e^{-j\frac{3\pi}{2}} & e^{-j\frac{\pi}{2}} \\
e^{-j\frac{\pi}{2}} & e^{-j\frac{3\pi}{2}} & 0 & 0 \\
e^{-j\frac{\pi}{2}} & e^{-j\frac{\pi}{2}} & 0 & 0
\end{bmatrix}.
$$

The output waves (b3 and b4) at port 3 and port 4 are the input waves (a1 and a2) at port 1 and port 2 are

$$
b_3 = \frac{1}{\sqrt{2}}\left(a_1 e^{-\frac{j\pi}{2}} + a_2\, e^{-\frac{j3\pi}{2}}\right)
$$

$$
b_4 = \frac{1}{\sqrt{2}}\left(a_1 e^{-\frac{j\pi}{2}} + a_2\, e^{-\frac{j\pi}{2}}\right)
$$

$$
a_3 = \Gamma_1 b_3
$$

$$
a_4 = \Gamma_2 b_4
$$

By setting the condition $\Gamma_2 = -\Gamma_1$, we obtained the Retrodirective condition in rat-race couplers [8]. By comparing the phase difference of the input waves to that of the output waves, the phase of the output is negative concerning input. Thus, the rat-race couplers reverse the incoming phase and act as Retrodirective.

B. Coupler Design

This proposed model presents a comprehensive description to model Rat-race couplers. Figure 5 is shown the configuration of the Rat-race coupler. The dielectric material is Glass epoxy substrate fr4 (ε_r=4.4) and the height is h=1.58mm for the operating frequency of 2.4 GHz.

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

$$
R = \frac{3\,\lambda_g}{4\pi}
$$

$$
Inner\ radius\ of\ the\ ring\ r_1 = \left(r - \frac{w}{2}\right)
$$

$outer\ radius\ of\ the\ ring\ r_2 = \left(r + \dfrac{w}{2} \right)$

- The wavelength of the coupler is calculated with the velocity of light C=3x108 m/s and the operating frequency f = 2.4Ghz.

$$\lambda_0 = \frac{c}{f}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff2}}}$$

- The effective dielectric constant εeff1 and εeff2 is calculated using

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\dfrac{h}{w}}} \right)$$

- The width for the port input and width for the branches are calculated using the formula

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

$$where, A = \frac{z}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r} \right)$$

The equivalent circuit of the rat- race couplers of 2.4 GHz is simulated using HFSS EM simulation software [9]. This software is employed to simulate the microstrip patch antenna design. The simulation parameters utilized in the look of rat-race couplers is illustrated in Table 1:

Table1. Parameters for Rat-Race Couplers.

Parameters	Value (mm)
Inner radius (r1)	17.56mm
Outer radius (r2)	16.46mm
Length of the feed line	3mm
Width of the feed line	9.36mm
Thickness of the substrate	1.58mm

The above figure 6: shows the conventional circuit for the rat- race couplers. For high gain, the intention is to suit the value

of the return loss (S11) parameter at -15dB at resonant frequency 2.4 GHz.
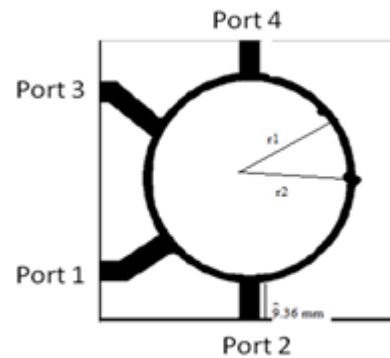

Fig 6. Conventional Rat-Race Coupler

C. Simulation Results

The simulated Coupler ring frequency versus magnitude response and phase response are shown in figure 7(a) and 7(b) respectively, its return loss is less than 15dB, insertion loss between 3dB to 3.5dB and isolation loss less than 20dB respectively.
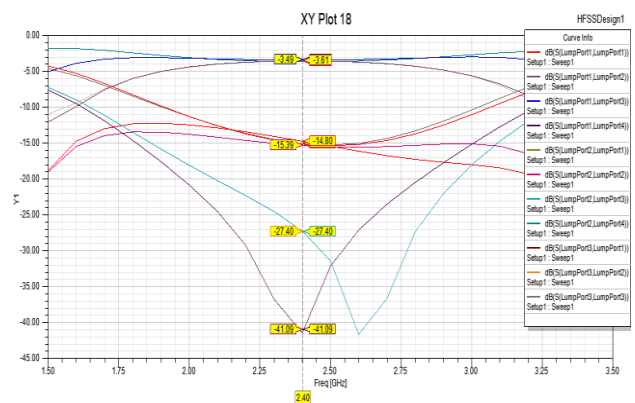

Fig 7(a). Frequency vs. Magnitude response of Hybrid coupler

The phase difference between input and output ports is 179.3 degrees as shown in fig 7(b). The coupler is a four-port device, which divides the signal (port 4) into two equal splits (3 dB) and in phase between output ports 1 and 2, port 3 will be isolated [10]. 50-ohm inputs and output ports are excited with three λg/4 lines and port 2 to port 3 lengths will be3 λg/4; its impedance is 70.7 ohm as shown in figure 3. The phase difference between port 4 to port 1 and port 2 is 90◦
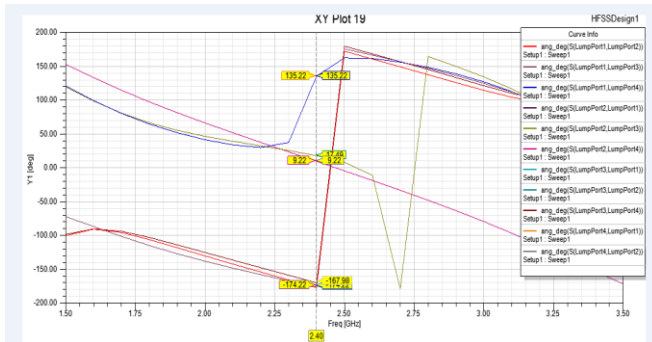
Fig 7(b). Frequency vs. Phase response of Hybrid coupler

5. Conclusion

The rat-race coupler is designed and simulated using HFSS EM simulation software. From observing simulation results the return loss and angular phase of s-parameters were obtained. As an extension of the current work, we plan to design Retrodirective RFID mm-wave backscatter tags with the rat-race coupler as the feeding network. The feeding network is described clearly how the rat race coupler work in Retrodirective and non-retro-directive mode and simulation and fabrication process is going on. Besides, we plan to include arrays along with rat-race coupler to improve the efficiency of the retro-directive designs and compare their performance.

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