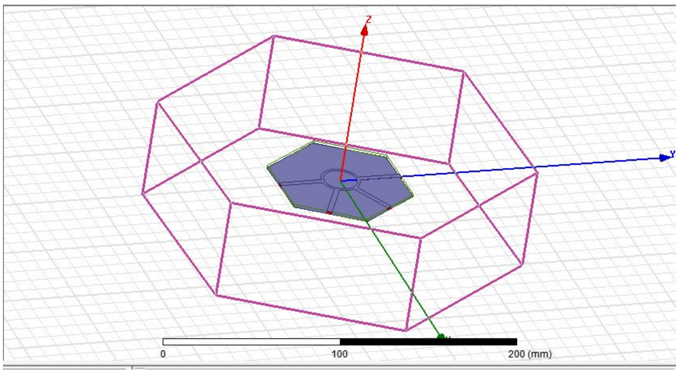
180º Hybrid
Rat-Race Coupler

***Abstract*—Rat-race coupler is one of the essential components used in microwave circuits. This paper includes the in-depth design of a proposed microstrip rat-race coupler for 3.5 Ghz.**

I. Introduction

A rat-race coupler is one of the most essential components used widely in RF and microwave circuits. Its many applications include balance mixtures, balanced amplifiers, power dividers/multipliers and antenna feeding networks. The major advantage of this coupler over 3-ports is its tendency to maintain port-to-port isolation with all of them being matched. while generating an in-phase as wells as an out-of-pose power splitting output. However, the major problem arises from the conventional rat-race coupler is its larger size and reduced bandwidth. The paper includes the design of the proposed conventional microstrip rat-race coupler at a frequency of 3.5GHz. AWR Environment Design is used to simulate the coupler, and then using that design, a rat-race coupler is built on Ansoft HFSS software

II. DESIGN



A. Substrate specifications

The material used in this simulation of the rat-race coupler is an FR4 substrate. FR-4 glass epoxy is a popular and versatile high-pressure thermoset plastic laminate grade with good strength to weight ratios. With near zero water absorption, FR-4 is most commonly used as an electrical insulator possessing considerable mechanical strength. The material is known to retain its high mechanical values and electrical insulating qualities in both dry and humid conditions. These attributes, along with good fabrication characteristics, is the major reason why it would make a viable and good substrate material for the rat-race coupler.

The other specifications include:

Height of the substrate (h)	: 1.6mm
Dielectric loss tangent (tanδ)	: 0.02
Relative Permittivity (εr)	: 4.4
Thickness (t)	: 0.035 mm

B. Designing the Substrate

For optimum performance of a rat-race coupler, we choose a hexagonal polyhedron as our substrate. We place the substrate at the center at a height of 1.6mm, i,e. 0.8mm above and 0.8mm below the origin. .

III. Designing the ring structure

Now we proceed to create the ring-structure on the substrate.

A. Designing the rectangular arms of the ring structure

First, we create a rectangular arm of length equal to the height of an equilateral triangle of side λ(85.7mm as per our assumption) and width equal to thickness of a microstrip line (characteristic impedance $Z_o = 50\Omega$) of substrate specifications as mentioned before. We use the following formula.

$$\frac{W}{d} = \begin{cases} \dfrac{8e^A}{e^{2A}-2} & \text{for } W/d < 2 \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B-1) + \dfrac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B-1) + 0.39 - \dfrac{0.61}{\epsilon_r}\right\}\right] & \text{for } W/d > 2, \end{cases} \quad (3.197)$$

Where

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}.$$

As our Characteristic Impedence (Zo) >44-2εr; we use the first formula (ie, the one where we have to calculate the constant A). From calculation, we obtain a width of 3.0582mm for the arm.

Similarly, we create the other three arms of the ring structure of the rat-race coupler.

We create two concentric circles of which the bigger circle has a radius of 11.483mm which is obtained by the following formula.

$$R=3\lambda/4\Pi \sqrt{\varepsilon e}$$

Where "εe" is calculated from the below formula;

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}}.$$

Now, we create the inner circle with radius of 9.861mm which is the difference between the radius of the outer circle and the thickness of a microstrip line of $Z_o = 70.71\Omega$ and substrate specifications as mentioned before.

Finally, for the finesse, we merge the bigger circle with the arm that were created before and subtract the inner circle from it; which leaves us with the ring structure.

B. Ground Creation

We create a hexagonal polygon of same co-ordinates as that of our substrate but its position is below the substrate.

C. Lumped Port

Now, we look to create lumped ports for our substrate. We switch the axes such that the side of the substrate faces us, then we draw a rectangle which is perpendicular to the rectangular arm. The rectangle has a length equal to the width of the corresponding arm; and the width is equal to the height of the substrate(1.6mm).Similarly, we create the other ports corresponding to the other rectangular arms.

Now, we assign lumped excitation to these ports. Hence, the lumped ports are created.

D. Radiation Box

We choose a hexagonal polyhedron of vacuum material in which the substrate is placed at its center and the top and bottom of the substrate is λ/2 away from the box & sides are a length of λ/4 away from the box. Basically, none of the sides of the substrate should be in contact with the box.

Now we apply Radiation boundary to the box. Hence the Radiation Box is thus, created.

E. Applying Boundary

- For the ground plane, we apply the Perfect-E boundary.
- For the ring structure, we apply Perfect-E as well.

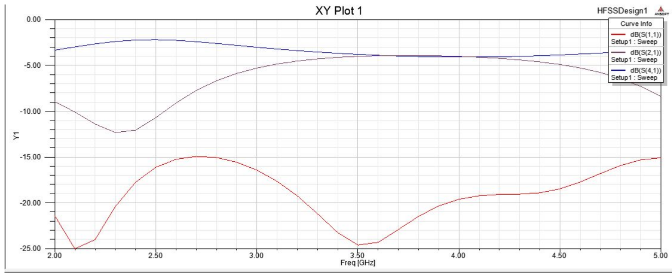
F. Applying mesh

Now we apply mesh, length-based, inside the radiation box. We use maximum length of elements as λ/10 (8.57mm) and maximum number of elements as 10000 (can be any arbitrary value)..

G. Analytical Setup

We create an analytical setup of operational frequency 3.5GHz and accordingly assign the frequency sweep for our design. prescribed.

H. Results and Graphs



The above plot depicts the Insertion loss at different frequencies using S-Parameters. We have taken our input port as 1 and therefore, by our design, the output ports automatically become ports 2 and 4 whereas port 3 is isolated. It shows that the Insertion loss is the least at the operational frequency, ie, 3.5GHz, which is expected.

	Freq [GHz]	ang_deg(S(1,1)) [deg] Setup1 : Sweep	dB(S(1,1)) Setup1 : Sweep	ang_deg(S(2,1)) [deg] Setup1 : Sweep	dB(S(2,1)) Setup1 : Sweep	ang_deg(S(4,1)) [deg] Setup1 : Sweep	dB(S(4,1)) Setup1 : Sweep
7	2.600000	-153.959064	-15.219627	39.677488	-9.106118	-110.130598	-2.274066
8	2.700000	-175.431996	-14.904541	26.025303	-7.738136	-130.550186	-2.421355
9	2.800000	164.045533	-15.034791	10.314971	-6.677906	-150.499324	-2.613554
10	2.900000	144.877702	-15.542907	-6.301756	-5.882665	-170.001737	-2.822543
11	3.000000	127.386954	-16.402359	-23.253095	-5.291473	170.870261	-3.029100
12	3.100000	112.010294	-17.617442	-40.271816	-4.853076	152.031838	-3.222196
13	3.200000	99.542459	-19.206380	-57.240690	-4.529553	133.405664	-3.396743
14	3.300000	91.510314	-21.149433	-74.114117	-4.293987	114.929932	-3.551290
15	3.400000	90.454696	-23.207906	-90.879847	-4.127402	96.559382	-3.686194
16	3.500000	97.847350	-24.557396	-107.541130	-4.016236	78.262756	-3.802317
17	3.600000	107.603285	-24.263685	-124.109152	-3.950572	60.018486	-3.900216
18	3.700000	111.181550	-22.875905	-140.600607	-3.923032	41.809818	-3.979757
19	3.800000	108.267090	-21.422774	-157.037490	-3.928239	23.620249	-4.040097
20	3.900000	101.720178	-20.305425	-173.447374	-3.962707	5.430052	-4.079954
21	4.000000	93.698185	-19.577910	170.136867	-4.025029	-12.785583	-4.098052
22	4.100000	85.582082	-19.191503	153.678455	-4.116273	-31.056610	-4.093595
23	4.200000	78.341069	-19.052221	137.139514	-4.240482	-49.416634	-4.066633
24	4.300000	72.612296	-19.013270	120.485449	-4.405239	-67.900617	-4.018223
25	4.400000	68.420793	-18.872354	103.691179	-4.622306	-86.542866	-3.950335
26	4.500000	64.778158	-18.442104	86.750020	-4.908371	-105.376580	-3.865593

The above table depicts the insertion loss between different ports and the angles at the ports (in degrees). As we can see in the highlighted segment, at our operational frequency, ie, 3.5GHz, the Insertion Loss at port 1 is about -24.5db. Also the phase difference between Port 1 & Port 4 is 185.803886 which is approximately equal to the expected phase difference, ie, 180^o.

Also, from the table, we see that

The figure below further shows the phase difference of 180^o between output ports 2 and 4.

In AWR

Schematic:

Graph:

In AWR, we consider the input port as 4. For the circuit built in the schematic, the output ports are 2 and 3 while port 1 acts as n isolated port. The graph shows the insertion loss (in db) according to the S-Parameters across different frequencies. As we can infer from the below Data table, the phase difference between the output ports is 180^{0}. at the operating frequency.

APPLICATIONS

With the growing technology and in keeping with par with the growing need of faster data transmission of large information over an instant of time, the need for something other than Wi-Fi was immensely felt. Thus, LTE a.k.a was born. In order to implement this, a different band of frequencies were to be selected so that these bands don't clash with that of the Wi-Fi. This issue has always been a bone of contention between Wi-Fi users and selective telecom service providers in countries like USA that make use of unlicensed LTE at a frequency of 3.5GHz spectrum band. Our main objective of this project was to implement this coupler in various wireless communication devices at the same frequency band so that it could it could help us in dividing the band judiciously between both Wi-Fi and LTE applications.

ACKNOWLEDGMENT

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