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Design and Performance Analysis of lumped and distributed 6-dB micro strip coupler topologies at S-band

Sanjana.S. Pai[1], Manish Kumar[1], Kamaljeet Singh[2]
[1]Telecommunication Dept., Dayananda Sagar College of Engineering, Bangalore
[2]Systems Engineering group, ISRO Satellite centre, Bangalore

***Abstract*— Present article demonstrates the various approaches for the realization of 6-dB coupler in planar configuration. Distributed topologies such as hybrid coupler, ring coupler, rat-race coupler is designed at S-band in micro strip configuration. Further design of 6-dB coupler using lumped approach is also carried out. A comparative analysis of all these topologies are presented and discussed.**

***Keywords*— Planar coupler, micro strip, lumped topology, coupling**

I. INTRODUCTION

Power dividers are the basic and important component of Radio Frequency systems employed for power division or power combining applications. Power dividers are commonly find its application in balanced mixers, phase shifters, balanced amplifiers, mixers, frequency discriminators, phase shifters and demodulators. Couplers are classified as 3-port or 4-port network which are designed to achieve the desired coupling ratio [1]. Three port networks are Wilkinson power divider, T-junctions; circulators whereas the four port networks are hybrid couplers, directional coupler, magic-tee, having equal or unequal power division at the output ports. The phase difference between the outputs can be either 90° (quadrature) or 180° (rat-race). The main limitation in 3-port network is to achieve lossless transmission, reciprocity and port matching simultaneously but a 4-port network can overcome the above limitations [2]. The main parameters for a coupler are coupling, directivity, isolation, return loss and phase which are evaluated using S-parameters at higher frequency band. Waveguide coupler such as Bethe hole couplers are bulkiest and are employed for high power application, planar directional coupler such as quadrature hybrid, rat-race hybrid is easier to design and is compact in size having ease of implementation in micro-strip topology [3].

The main challenge in planar topology is to achieve tight coupling ratio for which the standard technique of cascading is generally employed. The same can be achieved by single branch line hybrid topology and dimensions can be easily found out using theoretical equations. Parallel coupled topology can also be employed to achieve designed coupling but are prone to fabrication tolerances and interferences apart from having input port and coupled port on the same side. Alternatively lumped implementation of quadrature hybrid [4-5] is also possible at microwave frequencies but becomes sensitive towards the lumped values resulting in more losses and frequency detuning.

This article details, various 4-port coupler topologies in distributed as well as lumped configuration and comparative analysis of the same is presented. Single quadrature hybrid topology, ring hybrid, rat-race topologies are designed for 6-dB at S-band in micro strip configuration whereas lumped coupler topology using inductance and capacitance is designed to achieve the desired performances at S-band for 3-dB and 6-dB coupling. Cascaded and single topology approach for the design for hybrid and lumped are also presented.

II. OVERVIEW OF COUPLER TOPOLOGIES

Distributed coupler topologies having signal and coupled port on different sides are hybrid coupler, ring coupler and rat-race coupler. To achieve tight coupling ratio, the standard approach is to employ cascading of the individual topology whereas quadrature hybrid (in lumped topology also) can provide the same by varying the width. Another disadvantage of cascaded approach is the implementation of only the whole value for coupling whereas any coupling value can be realized with the single topology approach. This section provides the various impedance values for different coupling ratios, theoretical and realization aspects as well as overview of each topology. The distributed approach on micro strip is dependent on the substrate definition and in present article RT Duroid substrate (ε_r=10.2, 10 mils) is taken for the design.

<u>HYBRID COUPLER</u>: A branch line coupler is employed either to equally split an input signal with a resultant 90° phase shift between output ports or to combine two signals. The circuit is electrically symmetrical and reciprocal (Fig 1). Standard topology provide 3-dB coupling by employing the impedances of 50Ω and 35.4Ω respectively [6]. A 6-dB coupler can be constructed by cascading the standard 3-dB branch line coupler but in present case the same is designed by employing single topology by changing the impedances of series and shunt arms from 50Ω and 35.4Ω to 33.35 Ω and 37.04 Ω using the standard equations. This approach provides compactness and eliminates the termination of one extra port.

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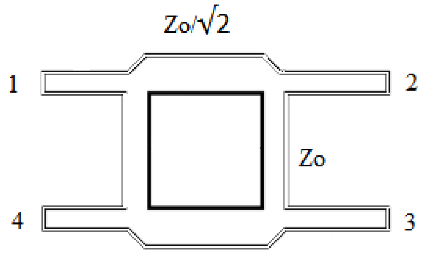

Fig 1. Hybrid coupler schematic

The design is carried out for Z_0=50Ω and values are calculated using the below equations:

$6.0 = -20 \log S_{31}$ ………… (1)

$(S_{12})^2 + (S_{13})^2 = 1$…………(2)

RING COUPLER: This is another form of hybrid coupler and also provides the 90° phase shift at the output ports. Both cascaded and single topology approach can be used to achieve 6-dB coupling at the output ports 2 and 3 respectively.

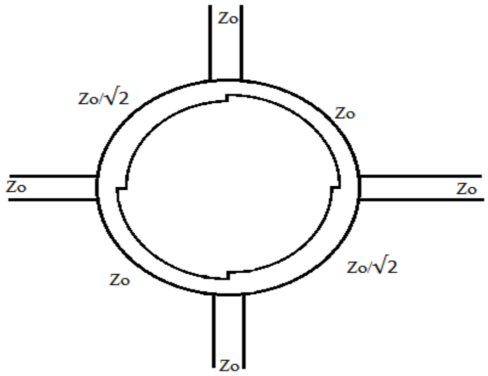

Fig 2. Ring coupler schematic

RAT-RACE: **A Rat-race coupler is a** hybrid ring to alternately provide equally-split but 180-degree phase shift between the output signals. The impedances of the inner ring are 70.7 Ωfor a 50Ω system.

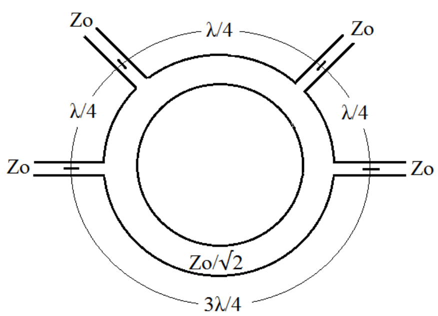

Fig 3. Rat race coupler schematic

LUMPED TOPOLOGY: Branch line coupler can be realized using a pair of shunt capacitors of equal value separated by a series inductor to realize quarter-wave transmission line [4-5]. Both cascaded and single structure topology can be employed for realizing the desired coupling values. The lumped element design has a narrower bandwidth than the transmission line coupler. The equation 1 and 2 represents the inductance and capacitance value used for the design of the lumped coupler.

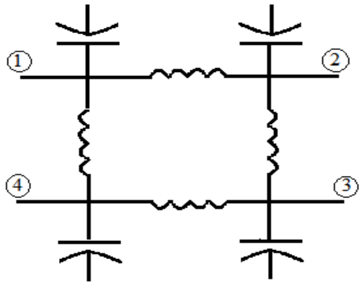

Fig 4. Schematic representation of lumped element coupler

The 3-dB design of a coupler at 2.2 GHz is based on the following design equations.

$L = \frac{Zo}{2\pi f}$

L= 2.5 nH.........………………. (3)

$C = \frac{1}{Zo 2\pi f}$

C=1.8 pF……………………… (4)

III. SIMULATION STUDIES

The above mentioned coupler topologies are simulated using linear and electromagnetic simulation for the center frequency of 2.2 GHz and the results are plotted in Fig 5 to Fig 7.

In case of lumped approach, the effect of inductance and capacitance on various parameters are plotted. The coupling error starts increasing gradually shifting towards higher frequencies for the enhanced inductance value whereas for decrease in the inductance value the coupling error increases linearly resulting in shifting center frequency to lower values. Apart from inductance, variation in capacitance also shows similar behavior coupling performances. The comparison of output results of the designed couplers is shown in the table-1. Cascaded approaches of all the topologies are taken for comparison purpose.

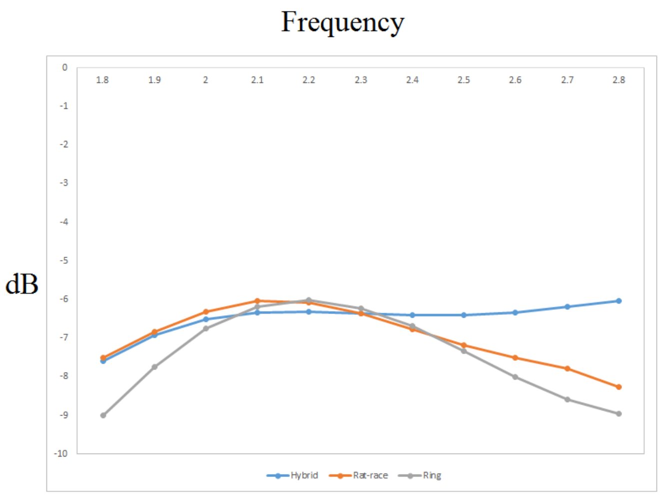

Fig 5. Coupling loss plots

Table-2 shows the design values of the various impedances and lumped values require to achieve the desired coupling.

Topology	*Phase Difference*	*Return Loss (dB)*	*Coupling error (dB)*	*Isolation (dB)*	*Dimensions (mm)*
Lumped hybrid	88.9°	-12.12	±0.08	-11.9	-
Quadrature hybrid	89.3°	-38	±0.2	-51.63	Length=36.4 Breath=27.17
Ring coupler	87.9°	-38	±0.0	-34.63	Length=37.692 Breath=19.48
Rat-Race	176.6°	-39	±0.2	-74.85	Length=59.11 Breath=27.11

Table-1: Comparison table for different couplers (cascaded)

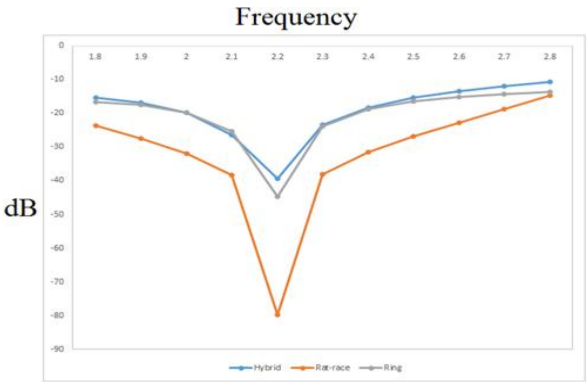

Fig 6. Isolation plots

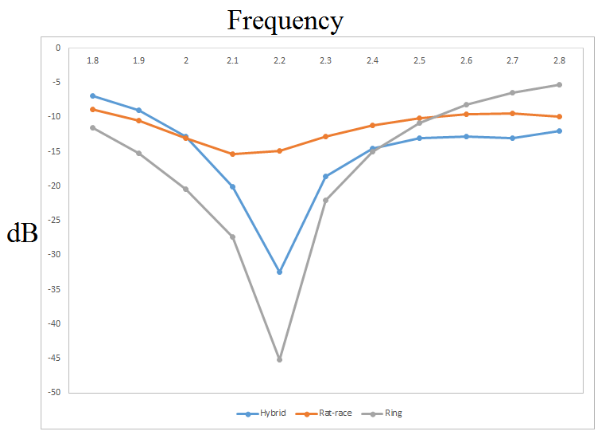

Fig 7. Return loss plots

Table-2: Impedances and lumped values for 3- and 6-dB coupling

Topologies	**3dB coupling**		**6 dB coupling**	
Rat-Race	port	50Ω	port	-
	line	70.7Ω	line	-
Hybrid branch-Line	series	50 Ω	series	37.040Ω
	shunt	35.3Ω	shunt	33.585Ω
Lumped	Series	2.574nH	series	0.051nH
	shunt	3.3nH	shunt	0.046nH
Ring	series	50Ω	series	37.040Ω
	Shunt	35.55Ω	Shunt	33.585Ω

As seen from table-1, the lumped approach is having poor isolation and losses at higher frequencies. The quadrature hybrid topology is having 90° phase shift whereas rat-race hybrid provides 180° phase shift compared to other topologies [7-8].

IV. Conclusion

The comparative analysis of various planar and lumped hybrid couplers is carried out at S-band. Lumped approaches at higher frequencies are prone to vary performances with small deviation in component values whereas in planar approach is having bigger footprint. This article studied various 4-port coupler topologies and analysis of circuit parameters are carried out. A comprehensive approach to realize higher coupling with single and cascaded approach is presented. Authors believe that this analysis will be useful for the selection of the topology based on the applications keeping into consideration various aspects associated with each one.

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