Compact Folded Line Rat-Race Hybrid Couplers

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***Abstract*—A new, compact folded line configuration for rat-race hybrid couplers is proposed. Simple design equations are presented for the single and double C-section folded line structures. The new configuration exhibits four- to fivefold reduction in footprint as compared to the conventional rat-race configuration. The design is validated both by using the full-wave electromagnetic simulator and with measurement.**

***Index Terms*—Coupled transmission lines, embedded passives, rat-race hybrid couplers.**

I. Introduction

RAT RACE hybrid couplers are extensively used at microwave frequencies for a host of applications including mixers, beam-forming networks, frequency multipliers, amplifiers, etc. In [1], March introduced the hybrid ring configuration with a short circuited $\lambda/4$ coupled line in one of the arms. Subsequently, serveral workers [2]–[6] have reported a variety of configurations for the 180° hybrid coupler.

In recent years, compact design of components has been the focus of attention for several researchers, due to the increased importance of embedded passives and three-dimensional components for radio frequency (RF) and lower microwave applications. Folding the transmission lines in a multilevel and multiconductor environment has been found to be an attractive solution for achieving smaller footprints. An application of the folded line configuration for branch line hybrid coupler design has been recently reported by the authors [7], [8].

This paper presents a new compact design for the rat-race hybrid coupler using the folded line configuration. Simple design equations are given for the hybrid using single and double C-sections in each arm. The paper finally presents validation of the proposed design using a full-wave electromagnetic simulator as well as with measurement.

II. Design Equations

Fig. 1 shows the proposed rat-race hybrid configuration using folded line geometry. Here, the transmission line sections of the conventional rat-race hybrid are replaced by folded line sections connecting through transmission line sections of small length. The folding can be in either edge-coupled (single-level) or broadside-coupled (multilevel) configurations, as described in [7] and [8].

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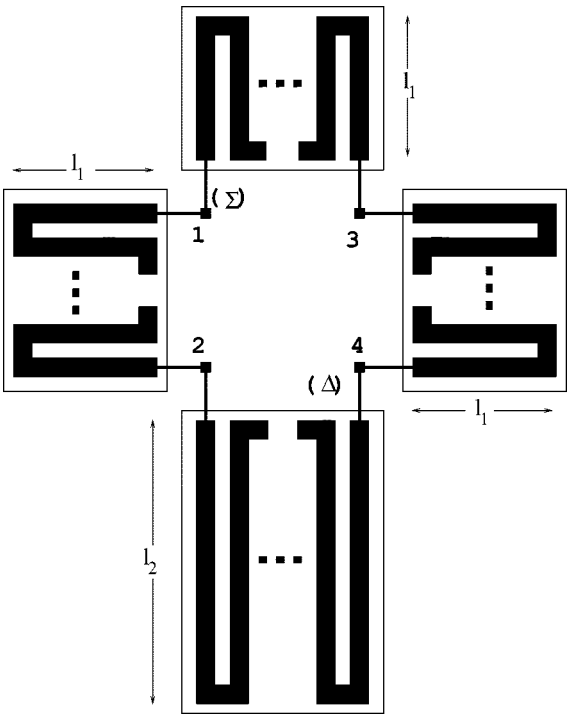

Fig. 1. Rat-race hybrid configuration using folded line geometry.

A. Single C-Section 3-dB Rat-Race Hybrid

We first consider the analysis of the hybrid with one folded line section (C-section) in each arm. Referring to Fig. 1, the even and odd mode analysis can be carried out with excitation at port 1 (Σ port) and port 4 (Δ port), respectively. The four-port scattering parameters of the hybrid can be calculated in terms of the even and odd mode scattering parameters for both excitations. At the center frequency, the scattering parameters can be solved to give a perfect match and equal and in-phase power division between ports 2 and 3 when Σ port is excited, and equal and out-of-phase power division between ports 2 and 3 when Δ port is excited. The design equations are

$$Z_{oe} = \sqrt{2} Z_o \tan\theta_1 \qquad Z_{oo} = \sqrt{2} Z_o \cot\theta_1. \tag{1}$$

The electrical length of the longer arm is given by

$$\theta_2 = \pi - \theta_1. \tag{2}$$

From (1) and (2) it is clear that specifying θ_1 determines the extent of coupling, and hence, we may call it the coupling angle. In the limiting case of $\theta_1 = \pi/4$, θ_2 becomes equal to $3\pi/4$, and the equations reduce to those of the conventional rat-race hybrid using simple strip transmission lines.

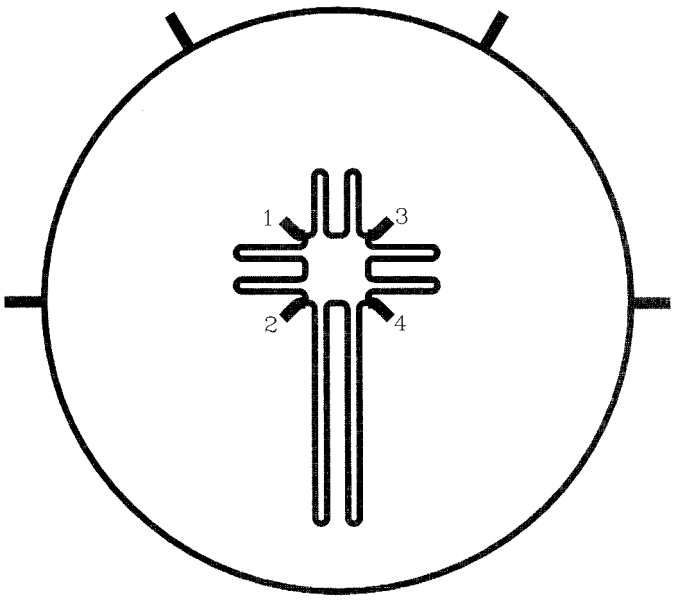

Fig. 2. Footprint comparison for the double C-section hybrid with the conventional design.

B. Double C-Section 3-dB Rat-Race Hybrid

The analysis for the double C-section rat-race coupler can be carried out by treating the double C-section in each arm as two cascaded C-sections which are sufficiently far apart. For this case, the design equations are found to be

$$Z_{oe} = Z_o \tan\theta_1 (2+\sqrt{2}) \qquad Z_{oo} = Z_o \cot\theta_1 (2-\sqrt{2}) \quad (3)$$

and

$$\theta_2 = \tan^{-1}\left(\frac{(2+\sqrt{2})Z_o}{Z_{oo}}\right). \quad (4)$$

Again, it can be seen that for $\theta_1 = \pi/8$, the equations reduce to those of the conventional rat-race hybrid using single strip transmission lines, with $\theta_2 = 3\pi/8$ from (4). When coupling between all the lines is considered, the structure can be analyzed using the network approach for muliple-coupled folded lines given in [8], and optimized for desired performance.

III. Experiment

To validate the new topology, a 3-dB double C-section rat-race hybrid is designed in the homogeneous edge-coupled stripline configuration with $\epsilon_r = 2.2$ and a ground plane separation of 62 mil. For a coupling angle of $\theta_1 = 25^\circ$ at $f_o = 1.5$ GHz, the even- and odd-mode characteristic impedances can be quickly determined from the design equations given in (1)–(4). The physical dimensions for the structure are then obtained as $w = 0.72$ mm, $s = 0.60$ mm, and lengths of the smaller and longer arms, $l_1 = 9.36$ mm and $l_2 = 26.14$ mm, respectively. The separation between the two C-sections is kept as 1 mm for both series and shunt arms. Appropriate curved line sections have been introduced connecting the coupled lines, and the electrical delays associated with the additional lengths have been taken into account while determining the final lengths of the coupled line sections. The design has been analyzed using the full wave electromagnetic simulator HP Momentum. To further validate the design, the coupler was fabricated using an RT-5880 duroid substrate and tested on an HP 8722c network analyzer. The layout of the proposed hybrid and that of the conventional rat-race hybrid are shown in Fig. 2. A four- to fivefold footprint reduction over the conventional geometry is

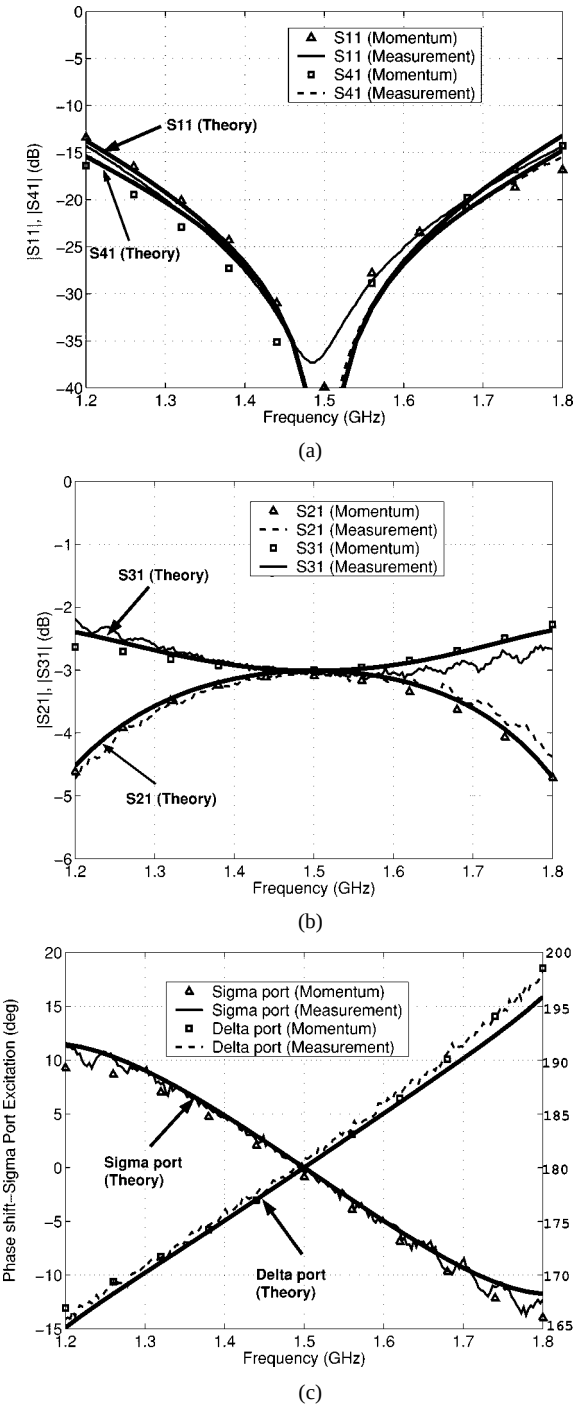

Fig. 3. Computed and measured scattering parameters for the 3-dB double C-section rat-race hybrid on a homogeneous edge-coupled stripline configuration with $\epsilon_r = 2.2$ and $Z_o = 50\ \Omega$.

observed in the layout using the present design. Fig. 3 shows the response using the present design and the measured data as well as the results from Momentum. The three results show very good agreement.

IV. Conclusion

A new configuration for the design of compact folded coupled line rat-race hybrid coupler has been presented. Design equations are given for hybrid design using single and double C-sections in each arm. The proposed topology is validated using the full wave EM simuator HP Momentum, as well as by comparison with measurements. The new folded line designs exhibit a considerable reduction in footprint opening up a variety of possible applications for embedded passive components for RF and mixed signal modules.

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