Impedance-transforming, coupled-line 180° hybrid rings with frequency independent characteristics

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Abstract — **A new impedance-transforming, 180° hybrid-ring using coupled-lines is presented. Its amplitude and phase balances as well as isolation between diagonal ports are theoretically perfect and frequency independent. This was achieved without using physical phase inverters on uniplanar structures. Instead, the ideal phase inversion between coupled-line structures is exploited. Simple design equations will be derived and validated by experimental results.**

I. INTRODUCTION

The 180° hybrid-ring is a fundamental component in microwave circuits. It performs the important function of in-phase and out-of-phase power splitting while maintaining perfectly matched ports. Compared to the 90° branch-line coupler, it has broader bandwidth and the isolation between the input ports may be independent of the output termination impedances. Therefore, the 180° hybrid-ring is extensively used for isolated power splitting in balanced mixers, multipliers, power amplifiers and antenna feed networks.

The conventional 180° hybrid-ring, as shown in Fig. 1, has a phase inverter in the form of a $\lambda/2$ line within the $3\lambda/4$ line section. This $\lambda/2$ line phase inverter provides 180° phase shift only at a single frequency. This results in narrow-band characteristics where perfect phase balance is only obtained at the centre frequency. Consequently, March [1] replaced the $3\lambda/4$ section with a $\lambda/4$ coupled line section, which has broad-band phase inversion characteristics, as shown in Fig. 2. However, the phase inversion is not frequency independent and the even-mode impedance required for the coupled line section is too high to be realised on commonly used microstrip circuits. Subsequently, many efforts have been directed towards achieving frequency independent phase inversion within the hybrid ring, as illustrated in Fig. 3. These include exploiting the anti-phase power splitting characteristics of slotline T-junctions and implementing physical phase inverters using cross-overs in coplanar strips (CPS) and coplanar waveguides (CPW) [2].

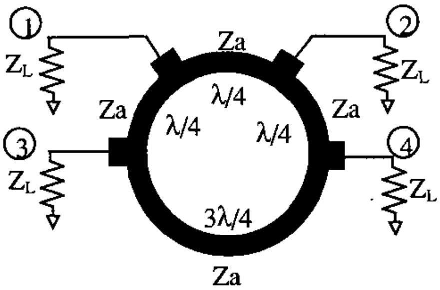

Fig. 1: Conventional 180° hybrid ring.

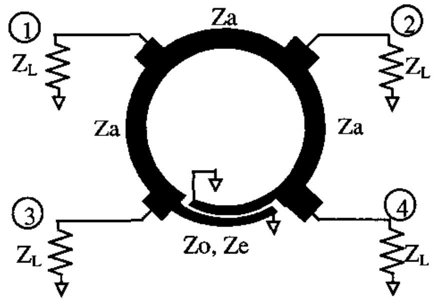

Fig. 2: Modified hybrid ring proposed by March [1].

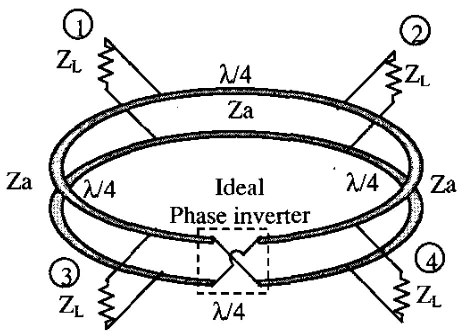

Fig. 3: Transmission line representation of hybrid ring with ideal phase inverters.

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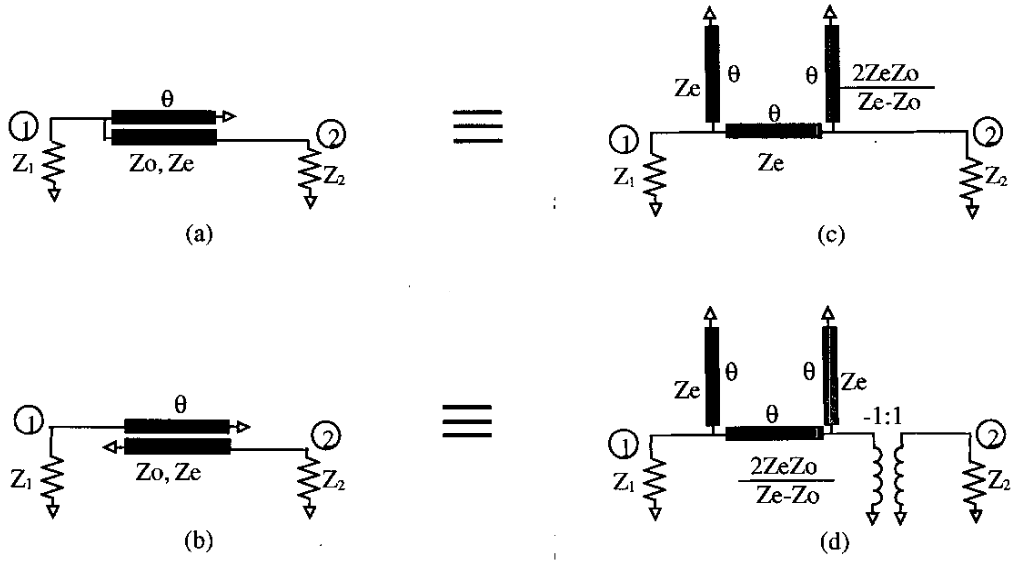

Fig. 4: Coupled line structures and their equivalent circuits

Besides having a broad passband in the amplitude response, these phase inverter hybrid-rings also exhibit various characteristics that are theoretically frequency independent [2]. These include perfect amplitude and phase balance between the output ports and isolation between diagonal ports. These properties are highly desirable in balanced mixer and multiplier applications where amplitude and phase balance beyond the passband enhance signal isolations and spurious suppressions. However, these ideal phase inversions have been realised using uniplanar structures like slotlines, CPS and CPW and cannot be implemented on more widely used microstrip or stripline circuits. Moreover, these designs often involve full-wave electromagnetic simulations.

In this paper, a technique for achieving ideal phase inversion using simple coupled lines is presented. As it is based on the phase inversion between coupled lines, it can be implemented on any transmission line medium, including microstrips and striplines. This also results in a simpler design involving only coupled line parameters. In addition, impedance transformation between the source and load can be readily included in the design. The development and performance of these impedance-transforming coupled-line hybrid rings will be presented in this paper.

II. THEORY

Figs. 4(a) and (b) show the two coupled-line structures employed in the coupled-line hybrid ring. Z_o and Z_e are respectively the odd and even mode impedances of the coupled lines with electrical length θ. The source termination Z_1, is in general different from the load termination, Z_2. In Fig. 4(a), the coupled lines are connected at the source terminal and shorted at one end at the load terminal while in Fig. 4(b), the diagonal ends of the coupled line are shorted. The corresponding equivalent circuits [3] of these coupled line structures are shown in Figs. 4(c) and (d). The two equivalent circuits can be made identical, except for the ideal −1:1 transformer in Fig. 4(d), by setting:

$$Zo = \frac{Ze}{3} \tag{1}$$

When eqn. (1) is satisfied, the two coupled-line structures will exhibit transmission characteristics that are equal in amplitude and opposite in phase for all frequencies. In addition, impedance matching between the source and load can be achieved at the centre frequency where $\theta = \lambda/4$ by setting:

$$Ze = \sqrt{Z_1 Z_2} \tag{2}$$

Therefore, the two coupled-line sections can be connected directly in parallel to form a balun with perfect and frequency independent amplitude and phase balance. This is illustrated in Fig. 5 where the source impedance is now $Z_1/2$.

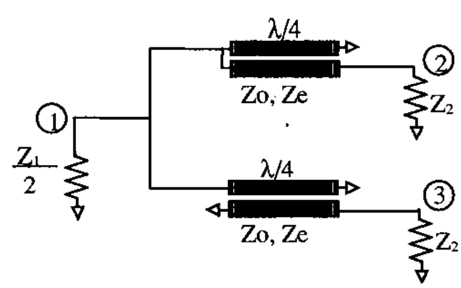

Fig. 5: Balun obtained by parallel connection of coupled line structures in Fig. 4(a) and 4(b).

The balun in Fig. 5 can then be converted to a 180° hybrid by adding an in-phase power divider [4]. Coupled-line power dividers employing the coupled-line structures in Fig. 4(a) or (b) may be used. The resulting 180° hybrid are shown respectively in Fig. 6(a) and (b). These 180° hybrids exhibit theoretically perfect and frequency independent amplitude and phase balance as well as isolation between diagonal ports. Although simple λ/4 transmission line power dividers may be used, frequency independent isolations between ports 2 and 3 as well as balance between S24/S21 and S34/S31 would not have been achieved. This is due to the difference in transmission characteristics between the transmission line power divider and the coupled-line balun. These are also limitations of the 180° hybrids in [4].

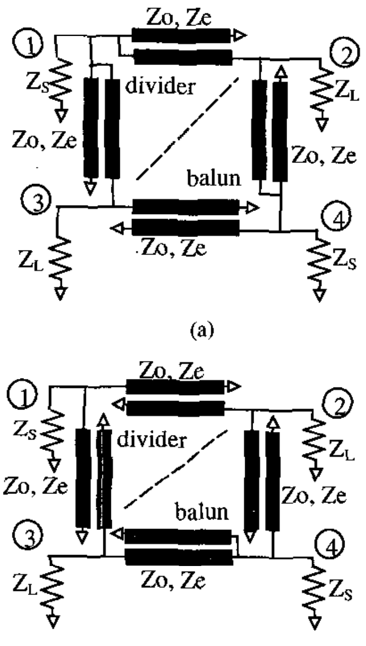

Fig. 6: Coupled line hybrid rings obtained by employing the balun in Fig. 5

The design equations for these impedance transforming coupled-line hybrids are obtained by simply replacing $Z_1/2$ by Z_S and Z_2 by Z_L in eqns. (1) and (2):

$$Ze = \sqrt{2Z_S Z_L} \qquad (3)$$

$$Zo = \frac{\sqrt{2Z_S Z_L}}{3} \qquad (4)$$

For the case where $Z_S = Z_L = 50\Omega$, the required even- and odd-mode impedances are $Z_e = 70.7\Omega$ and $Z_o = 23.6\Omega$. Compared to the $Z_e = 170.7\Omega$ and $Z_o = 29.3\Omega$, required by the modified hybrid ring in Fig. 2, these values are more realizable in microstrip coupled lines.

III EXPERIMENTAL RESULTS

To evaluate the proposed 180° hybrid-ring and validate the analytical results, a microstrip coupled-line 180° hybrid-ring based on Fig. 6(a) was designed for a 50Ω system. A photograph of the fabricated circuit is shown in Fig. 7. The circuit was fabricated on a low-cost FR-4 board with a dielectric constant of 4.5 and thickness of 1.5mm. The coupled line sections were realised using three-conductor coupled lines [4]. The conductor widths for the centre conductor and the two side conductors are respectively, 1.4 and 0.7mm, while the gaps between them are 0.2mm. Quarter-wavelength for the design frequency of 1GHz is about 40mm. The microstrip tracess are defined by a T-tech PCB router. The short-circuits for the coupled lines were obtained by copper wires through grounded vias. The overall circuit measures about 5.5x5.5 cm^2.

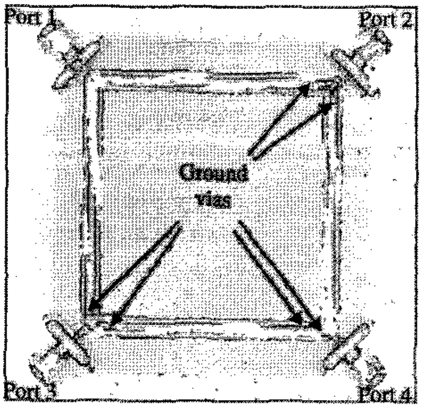

Fig. 7: Photograph of the fabricated hybrid ring

Fig. 8(a) shows the theoretical and measured transmission coefficients of the 180° hybrid-ring. Theoretically, all these S parameters have identical passbands resulting in perfect amplitude balance. Practically, the measured responses track each other within 0.5dB until the high frequency end of the passband. This increasing amplitude imbalance at high frequencies can be attributed to the unequal even- and odd-mode phase velocities in the non-homogeneous microstrip coupled lines.

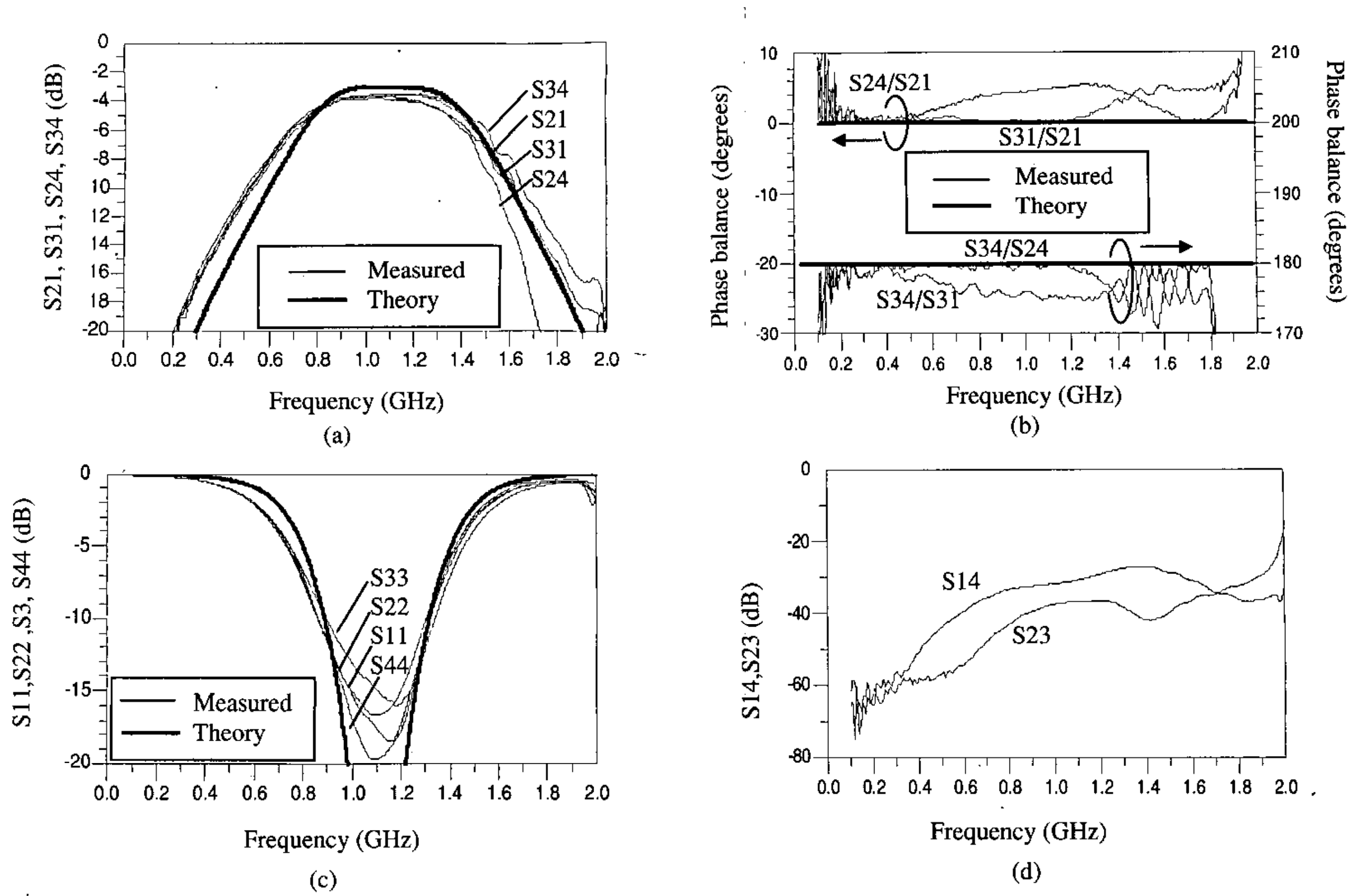

Fig. 8: Theoretical and measured results: (a) transmission passbands (b) phase balance (c) return loss (d) isolations

Fig. 8(b) shows the phase balances of the 180° hybrid-ring. The theoretical phase balances are perfect for all frequencies. The measured phase balances are within 5° from 0.2GHz to 1.8GHz. The theoretical and measured return losses of the four ports are in good agreement as shown in Fig. 8(c). The isolations between diagonal ports are theoretically perfect for all frequencies while the measured results in Fig. 8(d) achieve better than 30dB isolation for most of the measurement frequency range. The discrepancies between the theoretical and measurement results in Fig. 8 can be further abridged with the use of homogeneous mediums like stripline and better fabrication tolerances. Except for the reduced passbands, these results are comparable to hybrid rings using unipalnar phase inverters.

IV. CONCLUSION

Previously, 180° hybrid-rings with theoretically perfect and frequency independent isolation, amplitude and phase balance were obtained using physical phase inverters on slotline, CPS or CPW. This paper has demonstrated that ideal phase inversion can also be obtained from simple coupled line structures, which can be implemented on microstrips and striplines. These impedance-transforming coupled-line hybrid rings will enhance signal isolations and spurious suppressions for balanced mixer and multiplier applications.

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