ARBITRARY TERMINATION IMPEDANCES, ARBITRARY POWER DIVISIONS AND SMALL- SIZED RING HYBRIDS

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Abstract

If a ring hybrid is terminated by arbitrary impedances, design equations can not be derived with conventional methods because symmetry planes for even and/or odd symmetries are not available. Therefore, under these conditions new design equations for ring hybrids have been derived. They can be applied to both ring hybrids with arbitrary termination impedances and arbitrary power division ratios. Also, new design equations for small sized ring hybrids have been developed. They allow that arbitrary power divisions, arbitrary termination impedances and specially small sized ring hybrids can be designed. On the basis of these derived design equations, a simulation of ring hybrids with 4 arc lengths of 75°, arbitrary termination impedances and a power split ratio of 4 dB was performed using ideal CPS crossover

Introduction

Although considered as narrow banded devices, rat race hybrids (ring hybrids) have been found in extensive applications in microwave circuits. In practical cases, hybrids can be used together with other devices. In that case, to obtain the desired performances, additional matching networks are necessary. If hybrids are terminated by arbitrary impedances, there is a good chance to reduce their size. Recently, for the first time, Hee Ran Ahn et al. treated ring hybrids terminated by arbitrary impedances for MMIC application [1]. However, the material in this reference is restricted to hybrids with an equal power split. For arbitrary power divisions, since Chuck Y.Pon [2], several authors dealt with ring hybrids [3 - 5]. But all these analyses were applied to only symmetrical structures (even and odd mode analyses) and the procedures to determine the correct characteristic impedances are somewhat complex.

In this paper, design equations for ring hybrids with both arbitrary termination impedances and arbitrary power division ratios will be described. The method used for their derivation is quite different from the conventional methods. Also, design equations which can be used in the case that the arc lengths are less than $\lambda/4$ have been developed. Again, these design equations can be used for ring hybrids with both arbitrary power divisions and arbitrary termination impedances.

A simulation of ring hybrids with termination impedances of 50 Ω, 45.45 Ω, 55.55 Ω and 38.46 Ω, a power split ratio of 4 dB, and four arcs of 75° electrical length was performed using ideal CPS crossover

Analyses

A general configuration of a ring hybrid is shown in Fig.1. If it is assumed that the ring hybrid is lossless, for the excitation at port ① the condition $|S_{11}|^2 + |S_{21}|^2 + |S_{31}|^2 + |S_{41}|^2 = 1$ is valid.

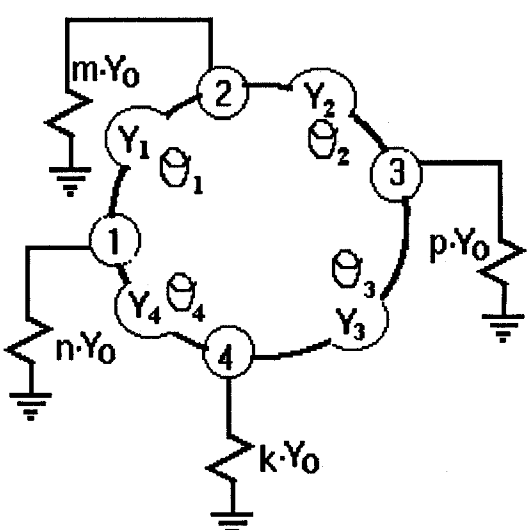

Fig. 1: Ring Hybrid terminated by arbitrary impedances (with arbitrary power divisions).

If the output arms are isolated from each other, and the input impedances are matched looking into any arm (when the other arms are terminated by matched impedances), the condition $|S_{21}|^2 + |S_{41}|^2 = 1$ can be obtained. If $|S_{31}| = 0$ is assumed, excitation at port ① can be interpreted as shown in Fig. 2.

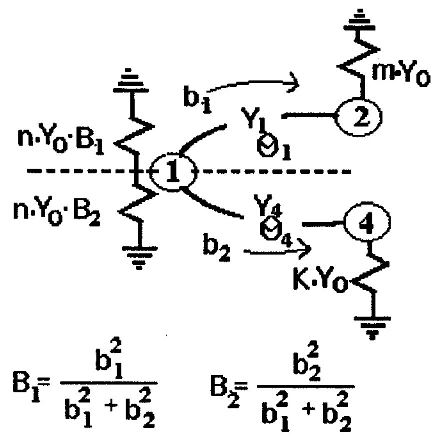

Fig. 2: The excitation for port ①.

For a ring hybrid, the power split ratio is proportional to the square of the admittance ratio of the two variable admittances in the ring [2-3]. Therefore, the input impedances of port ① can be divided as shown in Fig. 2, depending on the power delivered at port ② and port ④. In Fig.2, b_1:b_2 is the scattered wave ratio at the two output arms. If the length of the two arcs shown in Fig.2 is λ/4, the characteristic admittances are:

$$Y_1 = \sqrt{mn}\sqrt{b_1^2 / (b_1^2 + b_2^2)}\, Y_0,$$

$$Y_4 = \sqrt{kn}\sqrt{b_2^2 / (b_1^2 + b_2^2)}\, Y_0. \qquad (1)$$

In eq. (1), m, n, and k are constant values determined by the termination impedances. b_1 and b_2 are calculated according to the power division. Under the assumption of $|S_{31}| = 0$, the characteristic admittances, Y_1 and Y_4, can be determined from Fig. 2. To fulfill the assumption, the remainder arms can be drawn like in Fig.3. Because the circuit is passive, it is also reciprocal. Therefore, we can also consider this circuit as being excited at port ③. In case of a Y junction such as Wilkinson power divider, there is an isolation resistor between the two output arms [7]. Instead of the isolation resistor, for the ring hybrid shown in Fig. 1, the dummy arms of admittances Y_2 and Y_3 are connected with the two output ports ② and ④ to make these two output ports isolated. Therefore, almost the amount of power reached at port ② can be delivered to the load at port ②. If the isolation is not ideal, an extremely small amount of the power flows forward to port ③. Likewise, the amount of power reached at port ④ can be delivered to the load at port ④ and an extremely small amount of this power flows forward to port ③.

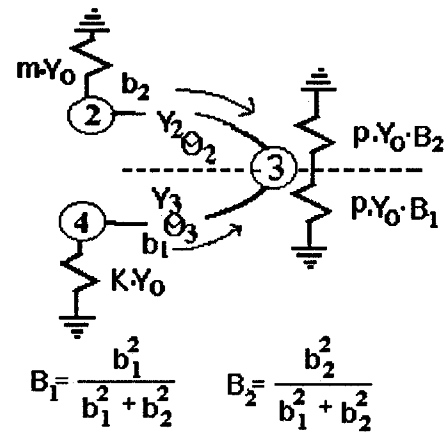

Fig. 3: The excitation of port ③.

For these two waves to be isolated from port ①, two conditions must be satisfied :

1) the two waves must have a phase shift of 180° against each other,

2) the wave ratio must be b_2: b_1 as shown in Fig. 3.

As the lengths of the arcs (Y_1, Y_4) are λ/4, one of the two remainder arcs (Y_2, Y_3) must be λ/4, the other one 3λ/4 long, to satisfy condition 1). So the characteristic admittances are :

$$Y_2 = \sqrt{mp}\sqrt{b_2^2 / (b_1^2 + b_2^2)}\, Y_0,$$

$$Y_3 = \sqrt{kp}\sqrt{b_1^2 / (b_1^2 + b_2^2)}\, Y_0. \qquad (2)$$

From eq. (1) and eq. (2), in the case that m = n = p = k the results are equal to those given by Pon [2]. If b_2: b_1 = 1:1, the result is in agreement with that of Hee Ran Ahn et al. [1]. If m = n = p = k and additionally b_2: b_1 = 1:1, the admittances for the well-known 3-dB ring hybrid are found.

On the basis of the derived design equations, a simulation for the example n = 1, m = 1.1, p = 0.7 and k = 0.8, and a power split ratio of 2 dB (which means $20*\log(b_1/b_2)= 2$ dB) was performed. For the analysis of the resulting ring hybrid, EEsof Libra software was used as a simulator.

The simulation results in Fig. 4a) show that the power ratio is really 2 dB with $|S_{21}| = -2.124$ dB, $|S_{41}| = -4.124$ dB, $|S_{43}| = -2.124$ dB and $|S_{23}| = -4.124$ dB. The simulation results in Fig. 4b) show that the power at the isolated ports ($|S_{31}| = -158.656$ dB and $|S_{42}| = -160.656$ dB) is theoretically zero at the center frequency. All input reflection coefficients are shown in Fig. 4c). The value $|S_{21}| = -2.124$ dB can be obtained by $10*\log[b_1^2/(b_1^2+b_2^2)]$.

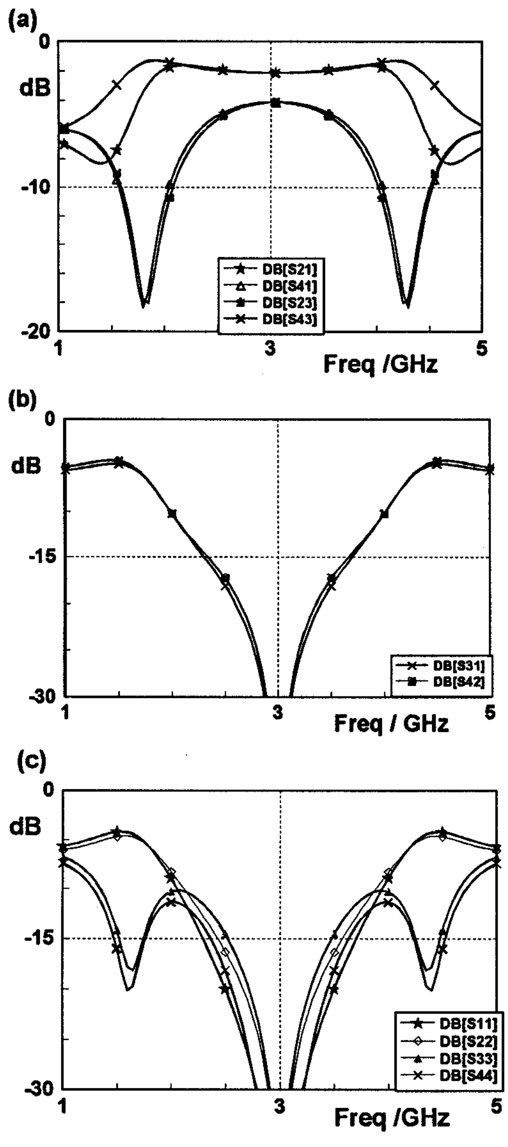

Fig. 4: Simulation results for n = 1, m = 1.1, p = 0.7 and k = 0.8, power split ratio = 2 dB.
(a) [S]-parameters for power divisions,
(b) [S]-parameters for isolations,
(c) [S]-parameters for matching.

Arbitrary Power Division, Arbitrary Termination Impedances, Reduced-Sized and Wide Bandwidth Ring Hybrid

The voltages in the two output arms are either in phase or 180° out of phase, depending on the input arms chosen. Conventional ring hybrids use arc lengths of $\lambda/4$ or $3\lambda/4$. To reduce the ring hybrid's size, lengths of $\lambda/8$ or $\lambda/6$ may be used [8-9]. Another approach described in the literature was the application of $\lambda/5$ arc lengths [6].

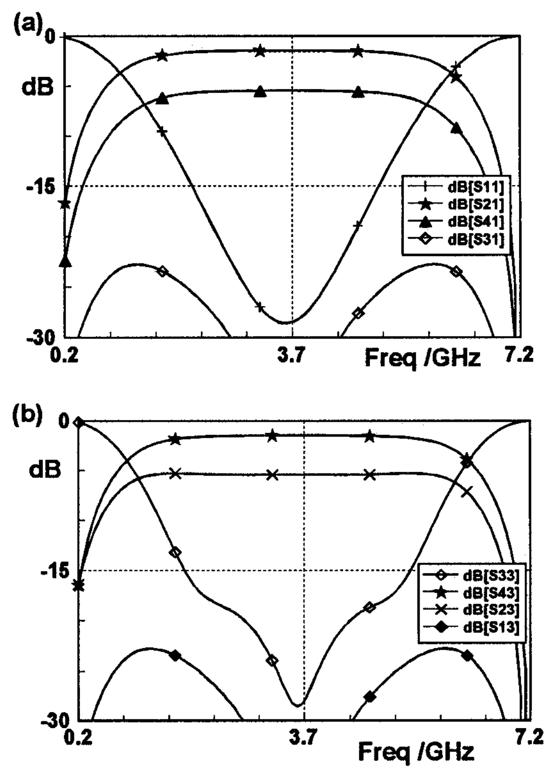

Fig.5: The calculated responses of a wide bandwidth ring hybrid which is terminated by arbitrary impedances, 50 Ω, 45.45 Ω, 55.55 Ω and 38.46 Ω.
(a) In the case of port ① excitation,
(b) in the case of port ③ excitation.

In any cases, three of the ring arcs are of equal length and the other arc must provide a ±180° phase shift compared to the three other arcs. If the arc lengths are not λ/4 or 3λ/4, the characteristic impedances are changed in proportion to the arc lengths [6,9]. So the characteristic admittances can be derived as:

$$Y_1 = \sqrt{mn}\sqrt{\frac{b_1^2}{(b_1^2+b_2^2)\,(1-\cot^2\theta_1)}}\,Y_0\,,$$

$$Y_2 = \sqrt{mp}\sqrt{\frac{b_2^2}{(b_1^2+b_2^2)\,(1-\cot^2\theta_2)}}\,Y_0\,,$$

$$Y_3 = \sqrt{kp}\sqrt{\frac{b_1^2}{(b_1^2+b_2^2)\,(1-\cot^2\theta_3)}}\,Y_0\,,$$

$$Y_4 = \sqrt{kn}\sqrt{\frac{b_2^2}{(b_1^2+b_2^2)\,(1-\cot^2\theta_4)}}\,Y_0\,. \qquad (3)$$

A simulation of a hybrid ring with termination impedances: 50 Ω, 45.45 Ω, 55.55 Ω and 38.46 Ω and a power split ratio of 4 dB, with four arcs of 75° electrical length was performed using an ideal 180° CPS crossover. Fig. 5 shows, this design was made at a center frequency of 3.7 GHz and the frequency responses of this ring hybrid show quite wide bandwidths.

Conclusion

In this paper, new equations for the design of ring hybrids terminated by arbitrary impedances are presented. These design equations can be applied in the case of arbitrary power divisions, arbitrary lengths of arcs and arbitrary termination impedances. So, there are big advantages by reducing the size of ring hybrids for application in microwave circuits when using these design equations.

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