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Miniature compact microstrip rat-race hybrid ring with continuous suppression of higher harmonics

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A new type of miniature compact rat-race hybrid rings is reported. It has strong and continuous suppression of higher harmonics. The proposed hybrid ring, also, effectively reduces the occupied area to 16 % of the conventional case. All slots and narrow tapes are 0.2 mm or wider and easy for fabrication. The same method can be applied for lower frequencies, including UHF.

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Keywords: Microwaves, Microstrip, Slow-wave effect, Harmonic suppression, Rat-race hybrid ring

1. Introduction

Rat-race hybrid ring is an important structure in microwaves. An often-important task is suppression of higher harmonics. In the case of conventional rat-race hybrid ring, one must add a low-pass filter. Unfortunately, that solution occupies an additional area. Conventional rat-race hybrid ring has, already, problem with a large occupied area due to the ring structure. One of the main goals is to minimize the occupied area [1-10]. According to demand for miniaturization, low-pass filter need to be incorporated into rat-race hybrid ring [8-10]. In ref. [8], rat-race hybrid ring with suppression of higher harmonics has been introduced using electromagnetic bandgap (EBG) structure etched in the ground plane (defected ground structure -DGS). Unfortunately, etching in the ground plane has packaging problems and it is better to use only modification of the microstrip line. Rat-race hybrid ring with suppression of the higher harmonics, but without etching in the ground plane, has been introduced in [9] and [10]. Bandgap for suppression harmonics in [9] and [10] has a ripple between the second and the third harmonic: Suppression is less than 10 dB and S_{11}-parameter in the ripple is below -10 dB (small reflection).

Lay-out of the conventional rat-race hybrid ring is shown in Fig. 1a. It is fabricated on substrate thickness h=0.508 mm and relative dielectric constant ε_r =2.1. S-parameters for the conventional rat-race hybrid, with outer radius 11.2 mm, are presented in Fig.1b. Microstrip ring tape, Fig. 1a, is 70.7 Ω characteristic impedance. The full ring corresponds to 1.5 λ_g . λ_g is wavelength of the central frequency, here 5 GHz, and 15 GHz corresponds to 3 x (1.5 λ_g)= 4.5 λ_g .

Previously published paper in [6] has a very small-occupied area: 11 % of the conventional case. Disadvantage is lack of appropriate suppression of higher harmonics. Simulated results of the structure published in [6], in wider frequency range, are in Fig. 2.

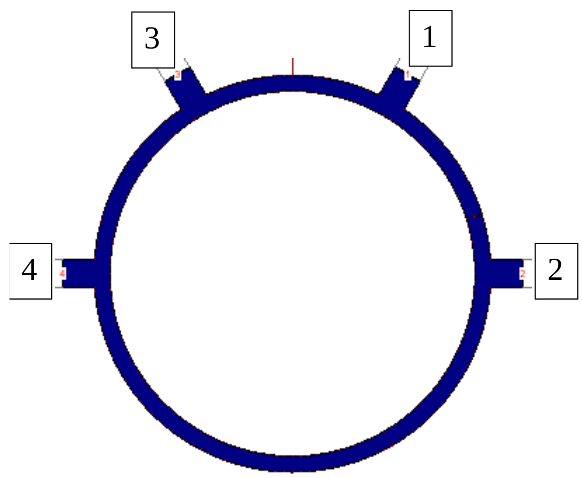


Fig. 1a. Lay-out of the conventional rat-race hybrid ring.

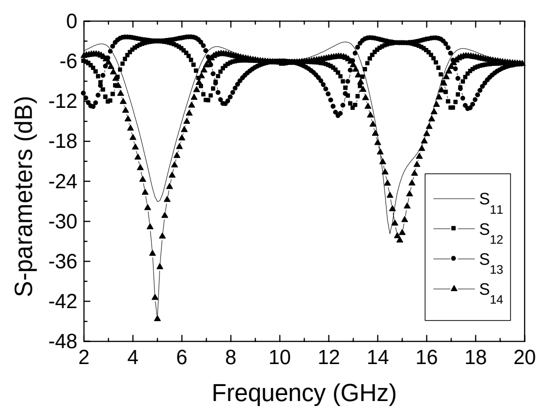


Fig. 1b. S-parameters of the conventional rat-race hybrid ring with the outer radius 11.2 mm.

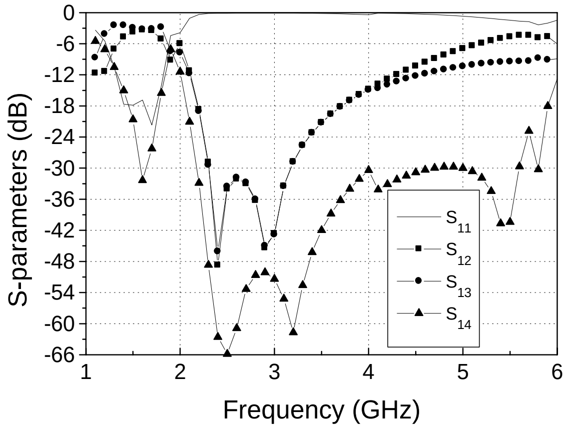
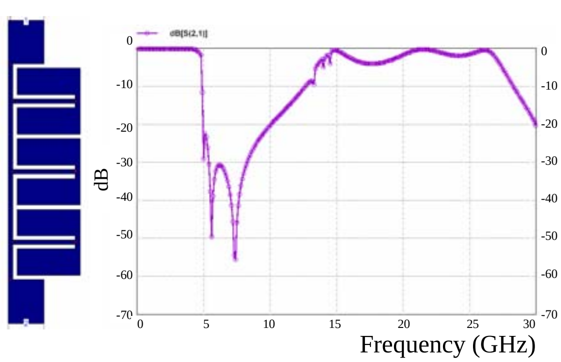


Fig. 2. Simulated results of the rat-race hybrid ring published in [6] in wider frequency range Substrate thickness h = 0.508 mm, relative dielectric constant ε_r =2.1 and outer radius 11.2 mm.

In this paper, a new type of rat-race hybrid ring is introduced. It has strong and continuous suppression of higher harmonics (without ripples). The proposed hybrid ring, also, effectively reduces the occupied area to 16% of the conventional case.

Design of the proposed rat-race hybrid ring

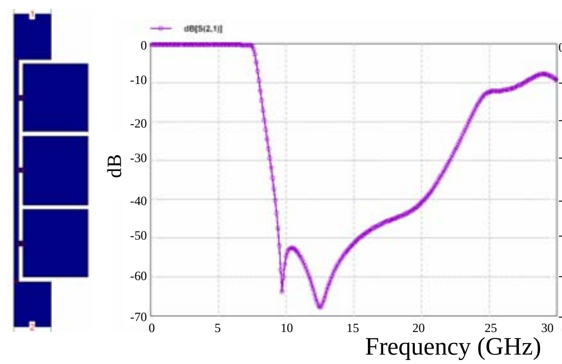
Rat-race hybrid ring previously published in paper [6] is based on structure in Fig. 3a. The substrate is: thickness h=0.508 mm and relative dielectric constant ε_r =2.1. All narrow slots and tapes are 0.2 mm. Dimension of each cell is 2.8 mm wide and 3 mm long. S_{21}-parameters for such lowpass filter are shown in Fig. 3b. As can be seen, bandgap of the corresponding low-pass filter is relatively narrow. To obtain wider bandgap, another type of the resonant cell needs to be used.



a) lay-out b) S_{21}-parameters

Fig. 3. An example of low-pass filter with the same cell shape as published in [6].

A new type of cell with the same total dimensions is introduced in Fig. 4a. S_{21}-parameters are shown in Fig. 4b. As can be seen, bandgap for the proposed type of cells is much wider. It can be used for suppression of higher harmonics.



a) lay-out b) S_{21}-parameters

Fig. 4. An example of low-pass filter with the proposed cell shape.

Design of the proposed rat-race hybrid ring is presented in Fig. 5. The proposed rat-race hybrid has six compact microstrip resonant cells located in free area inside the ring. Each cell corresponds to λ_g /4, where λ_g is the wavelength of the central frequency. Each port has its correspondent cell symmetrically arranged around the port. The angle covered by each cell is 55^0 and the slots between them are 5^0. It is fabricated on substrate thickness h=0.508 mm and relative dielectric constant ε_r =2.1. The inner radius is R_1 =5.5 mm and outer radius is R_2 =11.2 mm. All slots and narrow tapes are 0.2 mm or wider and easy for fabrication.

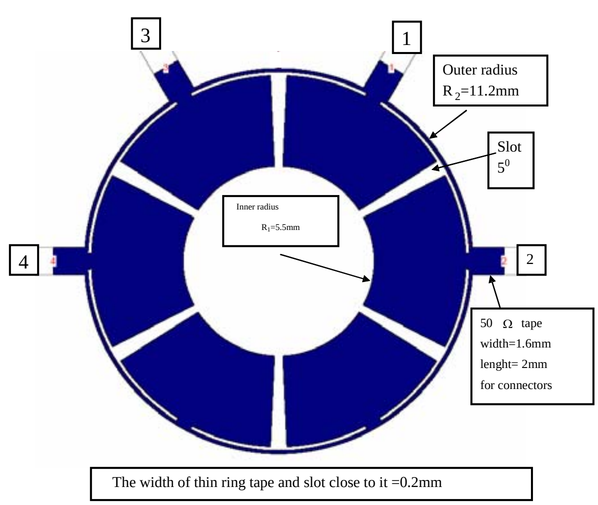


Fig. 5. Lay-out of the proposed rat-race hybrid ring (angles between neighbouring ports are 60^0).

Simulation

Simulation is done using program IE3D Version 10. Simulated S-parameters are presented in diagram in Fig. 6.

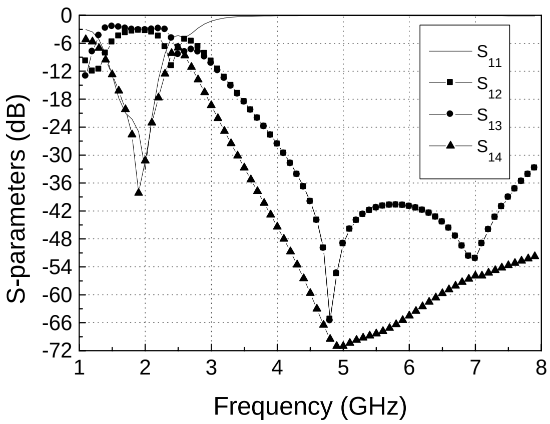
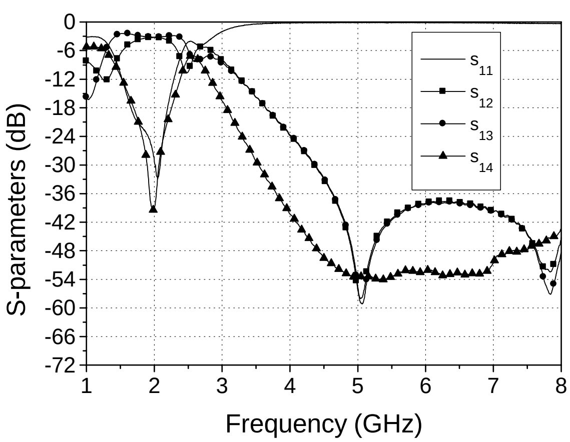


Fig. 6. Simulated results of the proposed rat-race hybrid ring in wide frequency range.

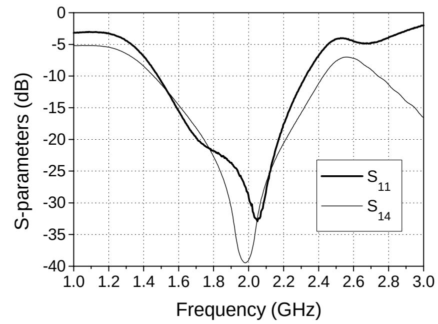
Measurement

Measured S-parameters are presented in diagram in Fig. 7.

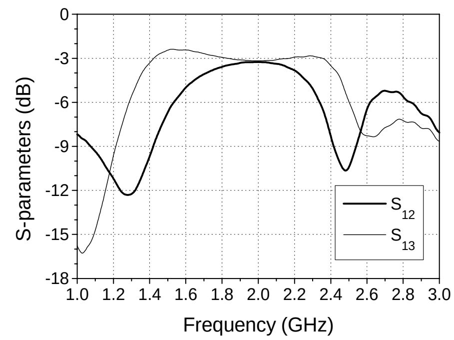


Sl. 7. Measured results of the proposed rat-race hybrid ring in wide frequency range.

Central frequency is close to 2 GHz. Measured results around the central frequency (1 GHz-3 GHz) are presented in Figs. 8a and 8b. Phase difference is presented in Fig. 9.

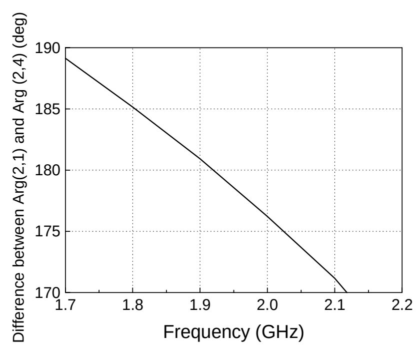


a) Measured S_{11} and S_{14} parameters

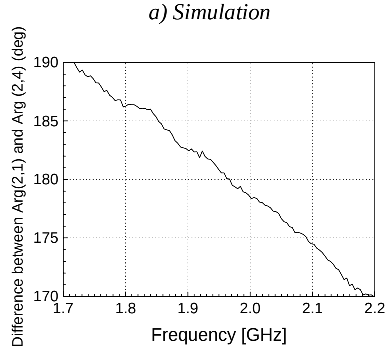


b) Measured S_{12} and S_{13} parameters

Fig. 8. Measured results of the proposed rat-race hybrid ring around the central frequency.



a) Simulation



b) Measurement

Fig. 9. Phase difference between Arg(2,1) and Arg(2,4) of the proposed rat-race hybrid ring (optimum 180^0).

Suppression of the higher harmonics, around 4 GHz and around 6 GHz, is high. Suppression is continuous, without ripples, and appropriate S_{11}-parameter in the bandgap is practically 0 dB above 3.5 GHz. Central frequency, 2 GHz, is 40 % of the central frequency (5 GHz) of the conventional rat-race hybrid ring with the same outer radius, Fig. 1. It means that the occupied area is only $(2/5)^2$ =16 % of the conventional rat-race hybrid ring for the same frequency.

There is continuous suppression in high frequency range. There are no ripples between the second and the third harmonic. The proposed structure has, also, higher reduction of the occupied area than rat-race hybrid rings reported in refs. [9] and [10].

Agreement between simulation and measurement is very good. The simulation results are slightly shifted to the lower frequencies but follow the curves of the measured values. S_{14}-parameters for higher frequencies are something lower in the simulation diagram. The reason for both deviations can be tolerances in fabrication.

2. Conclusion

Reported rat-race hybrid has six compact micostrip resonant cells located in free area inside the ring. The structure has a strong and continuous supression of higher harmonics (without ripples). Appropriate S_{11}-parameter in the bandgap is practically 0 dB above 3.5 GHz. The proposed structure has, also, higher slow-wave effect. Occupied area is only 16 % of the conventional rat-race hybrid ring for the same frequency. All slots and narrow tapes are 0.2 mm or wider and easy for fabrication. The same method can be applied for lower frequencies, including UHF.

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