A Design Method of an X-band Compact Wideband In-phase Unequal Divider Utilizing a Short-circuited Coupled Transmission Line

Soichiro Usui, Akira Nagasawa, Tadashi Kawai and Akira Enokihara

April 11, 2024

A Design Method of an X-band Compact Wideband In-phase Unequal Divider Utilizing a Short-circuited Coupled Transmission Line

Soichiro Usui† Akira Nagasawa Tadashi Kawai Akira Enokihara
Graduate School of Engineering, University of Hyogo
†ei23f005@guh.u-hyogo.ac.jp

Abstract This paper treats a circuit configuration in which the 3λ/4 transmission line of the conventional rat race circuit is replaced with a λ/4 short-circuited coupled transmission line in order to realize an in-phase divider with broadband characteristics. Electromagnetic field analysis has showed that the proposed circuit can achieve a relative bandwidth of approximately 35% in the X-band.
Keywords : In-phase divider, compact, X-band, coupled transmission line,

I. Introduction

Microwave division circuits are used in balanced amplifiers, mixers, phase shifters, antenna feeding circuits, etc. Unequal division circuits especially are required to feed microwave power to array antenna systems. Targeting the X-band, we are investigating a circuit configuration using a short-circuited coupled transmission line in order to realize a compact in-phase unequal divider with broadband characteristics. The authors have previously reported on the miniaturization and broadband expansion of couplers using open-/short-circuited coupled transmission lines [1], [2]. This paper shows through numerical and electromagnetic field simulations that the circuit treated here is possible to achieve smaller size and wider bandwidth characteristics than conventional rat-race circuits composed of three $\lambda/4$ transmission lines and a $3\lambda/4$ transmission line.

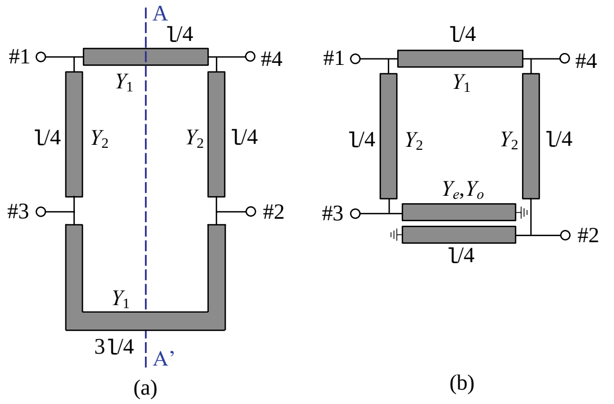


Fig.1 Circuit configuration
(a)prototype rat-race circuit and (b)rat-race circuit with short-circuited coupled transmission lines.

II. Circuit Configuration

The 3-port Wilkinson power divider is often used as microwave dividing/combining circuits. This divider, however, requires an absorption resistor connected between two output ports. In addition, in the case of an unequal divider, the terminal impedance of the output port is different from the standard impedance (50Ω). Therefore, an impedance transformer is required for use in a 50 Ω system. On the other hand, the 4-port rat race circuit shown in Fig.1(a) is also used as an in-phase unequal division circuit, but this circuit occupies large circuit area because the $3\lambda/4$ line is required. Here, in order to solve this problem, we will consider a circuit in which the $3\lambda/4$ line is replaced with a $\lambda/4$ short-circuited coupled transmission line as shown in Fig.1(b) [3]. Fig.2 shows frequency characteristics of the scattering matrix of a circuit with unequal division (power division ratio $R=|S_{31}/S_{41}|^2=4$). Although the reflection characteristics of the input and output ports are smaller than -20 dB near the center frequency, flat division characteristics are obtained over more than

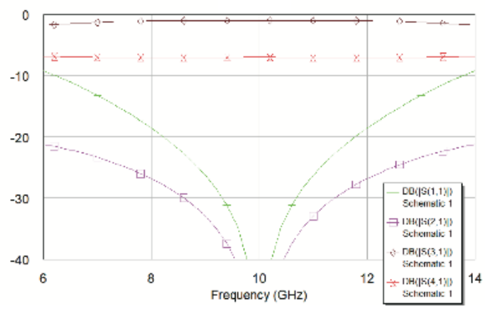
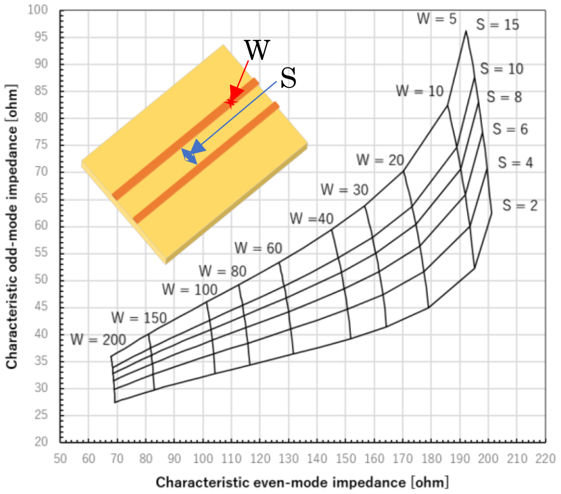


Fig.2 Frequency response of the scattering matrix of designed coupler with Y_1=0.45, Y_2=0.89, Y_e=0.71, Y_o=1.61.

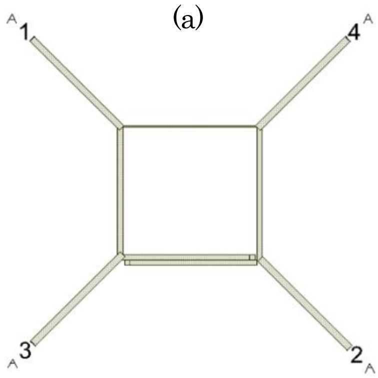
50% of the relative bandwidth. The relative bandwidth that provides directivity of 10 dB or more is also over 40%.

III. Electromagnetic field simulation

An electromagnetic field analysis of the circuit obtained in section II was performed for the prototype experiment. The circuit pattern was designed using a microstrip line configuration with a dielectric substrate thickness of 0.1 mm and a relative permittivity of 3. Fig.3(a) shows the design chart for the coupled transmission lines [4]. This determined line width and gap of the coupled line achieves the desired even and odd mode characteristic impedances. Fig.3(b) shows the pattern of a rat-race circuit with the short-circuited coupled lines. Fig.4 shows the results of analyzing this pattern by an electromagnetic field simulator (AWR AXIEM), which are in good agreement with the results shown in Fig.2. The output phase difference characteristics are also found to be in-phase over a wide bandwidth.



(a)

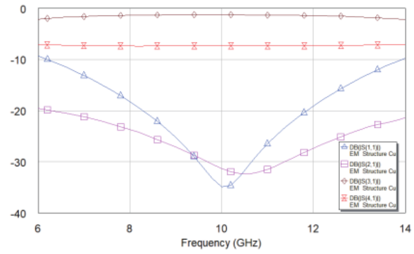


(b)

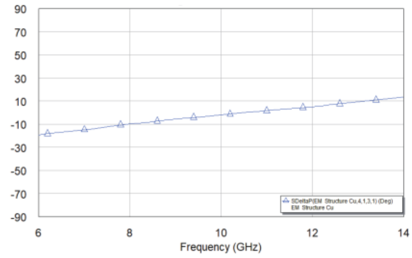
Fig.3 (a)Coupled line design chart and (b) simulation circuit pattern.

IV. Conclusion

An unequal division rat race circuit using a short-circuited coupled transmission line instead of a 3/4-wavelength line was handled, and it was confirmed by circuit and electromagnetic field simulations that in-phase division is possible over a wideband frequency region. We plan to conduct prototype experiments and also to design different degrees of coupling circuit.



(a)



(b)

Fig.4 Simulation results.
(a) Magnitude and (b)output phase difference.

References

[1] T. Kawai, T. Matsuda, and A. Enokihara, “Design of Parallel Ring-Line Rat-Race Circuit with Very Loose,” IEICE Trans. Electron., vol. J102-C, no. 2, pp. 9-12, Feb. 2019.

[2] Y. Haoka, T. Kawai, and A. Enokihara, “X-Band Broadband Branch-Line Coupler with Loose Coupling Utilizing Short-/Open-Circuited Coupled-Transmission Lines,” IEICE Trans. Electron., vol. J103-C, no. 1, pp. 17-23, Jan. 2020.

[3] J. L. B. Walker, “Improvements to the design of the 0-180◦ rat race coupler and its application to the design of balanced mixers with high LO to RF isolation,” IEEE MTT-S Int. Microw. Symp. Dig., pp. 747–750, June 1997.

[4] B. C. Wadell, Transmission Line Design Handbook, pp. 199–207, Artech House, Boston, 1991.