Area optimization of In-Phase Hybrid Ring Equal Power Divider using Top offset H-shape EBG

Pranavi Nikam[1] and Shivangi Agarwal[2*]

[1]Department of Electronics and Telecommunication, SIES Graduate school of Technology, Nerul, Navi Mumbai, 400706, Maharashtra, India .
[2]Department of Electronics Engineering, Ramrao Adik Institute of Technology, DY Patil Deemed to be University, Navi Mumbai, 400706, Maharashtra, India.

*Corresponding author(s). E-mail(s): shivangi.agarwal@rait.ac.in;
Contributing authors: pranavimhatre12@gmail.com;

Abstract

In the field of microwave, a significant amount of research has been done recently in device downsizing. Low material requirement and prices, increased production output, and possibly quicker operation are advantages of miniaturization. Different methods, including "Defected Ground Structure" (DGS), "Electromagnetic Bandgap" (EBG), etc. can be used to accomplish it. This research proposes a small-scale equal power divider using in phase hybrid ring operating at 4 GHz. "Top offset H shape EBG" structure, a novel sort of EBG structure, was used to create the power divider. For comparison, at 4 GHZ a traditional Equal power divider using Hybrid Ring has also been designed. The proposed method reduces the size of a traditional power divider by 18.03 percent. The bandwidth of traditional power divider is 104 MHz and proposed Top offset H shape EBG structured power divider is 336 MHz.

Keywords: Meta-material, Power divider, Electromagnetic Bandgap, Top Offset H-Shape EBG, RF circuit miniaturization

1 Introduction

One of the essential parts of microwave circuits are the power dividers. Power dividers enable the usage of the signal in another circuit by coupling a certain portion of the electromagnetic energy in a transmission line to a port. The fact that directional couplers only couple power flowing in one direction is a crucial component. The size of the power divider can be reduced with the use of methods like EBG. Designing comprehensive compact microwave systems involves taking into account miniaturization. Power dividers are commutual devices and hence also can be used to combine power from output ports into the input port[1–3].

When choosing a power dividers, we need to consider frequency Range (Hz), Voltage standing wave ratio, Insertion loss, Coupling factor, Isolation, Amplitude tracking, Phase tracking.[4, 5]

Published on: November, 2024

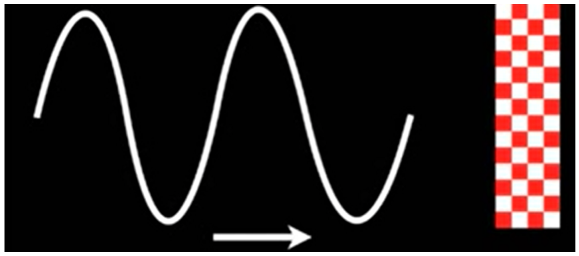

Fig. 1 Comparison of wavelength of electromagnetic radiation to the dimensions of the metamaterial periodic nanostructures

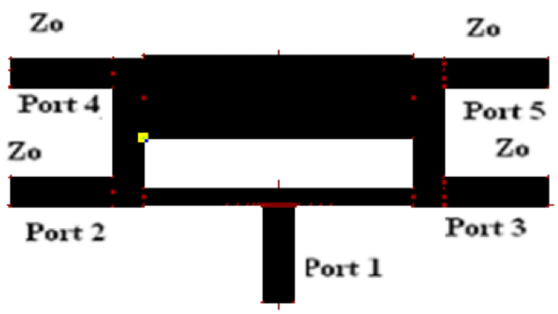

Fig. 2 Designed traditional In Phase Hybrid Ring at thickness 1.6mm and permittivity 4.4[19]

To design a power divider using microstrip technology, the propagation constant, phase velocity, wavelength, and conductor width must be determined. The phase velocity and propagation constant β for the microstrip line are given in Eq. (1,2) as:

$$v_p = \frac{c}{\sqrt{\epsilon_{\text{eff}}}} \tag{1}$$

$$\beta = \frac{2\pi}{\lambda_{\text{eff}}} \tag{2}$$

The relationship between the effective dielectric constant and the substrate's relative permittivity, thickness, and conductor width can be calculated using,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} * \left(\frac{1}{\sqrt{1 + 12D/W}} \right) \tag{3}$$

For given characteristic impedance and relative permittivity, it is more practical to compute the ratio of conductor width to dielectric thickness by utilising the formulae provided in [1]:

$$\frac{W}{D} = \frac{8e^A}{e^{2A} - 2}, \quad \text{for } \frac{W}{D} < 2 \tag{4}$$

$$\frac{W}{D} = \frac{2}{\pi} \left[B - 1 - ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} ln(B - 1)_0.39 - \frac{0.61}{\epsilon_r} \right] \tag{5}$$

Where,

$$A = \frac{z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} + \left(0.23 + \frac{0.11}{\epsilon_r} \right)$$

$$B = \frac{377\pi}{2z_0\sqrt{\epsilon_r}}$$

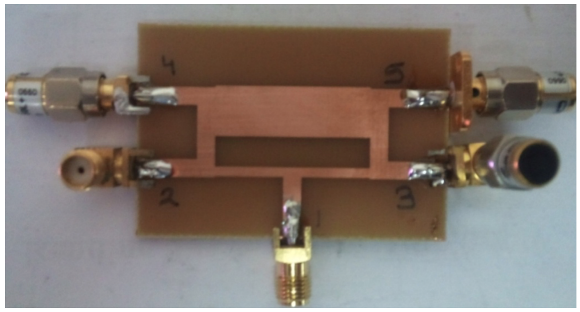

Fig. 3 Fabricated traditional hybrid ring power divider

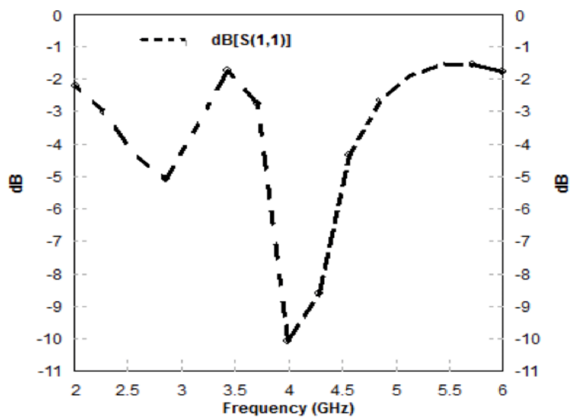

Fig. 4 Simulated S11 of traditional power divider using hybrid ring

1.1 Hybrid Ring

Simple T-junctions, which were the initial transmission line power dividers, had very poor output port isolation. The majority of the electricity that is reflected back from port 2 enters port 3 from port 2. Poor isolation is inevitable and it was not conceivable to concurrently correspond to all three ports of a lossless, passive three port splitter[6]. However, four-port devices make this conceivable, and this is the main justification for using them to construct three port power dividers. Four port devices can be created so that, in the ideal scenario, no power flows through port 3 and instead is divided between port 1 and port 4. The phrase "hybrid coupler" was first used to refer to 3 dB coupled line directional couplers with two outputs that are each half as powerful as the input. Quadrature 3 dB coupler with outputs that are 90 degrees out of phase known as hybrid coupler. The term "hybrid" or "hybrid coupler" now refers to matched 4-port with isolated arms and equal power division. Different phase interactions can exist between other types[6, 7].

1.2 Electromagnetic Bandgap structure (EBG)

Microwave band gap structures are made up of periodic arrangements of magnetic or dielectric materials that cause a stop band to form in the microwave frequency range. These structures are commonly known as photonic band gap or electromagnetic band gap structures. Similar to the periodic potential energy of an electron in an atomic crystal, such stop band is brought on by the periodic fluctuation of dielectric permittivity or magnetic permeability that electromagnetic waves travelling through such structures meet. Thus, bands and gaps the frequency ranges within which photons are allowed or disallowed, accordingly, to pass through the medium can be formed in the optical state of a photonic crystal. Similar classifications can be made for the electrical state of an atomic crystal in this manner. Electromagnetic waves that are reflected by the materials produce

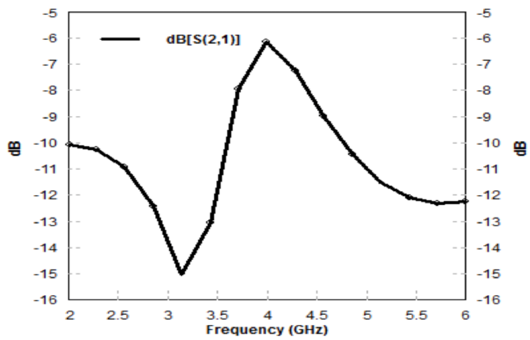

Fig. 5 Simulated S21 of traditional power divider using hybrid ring

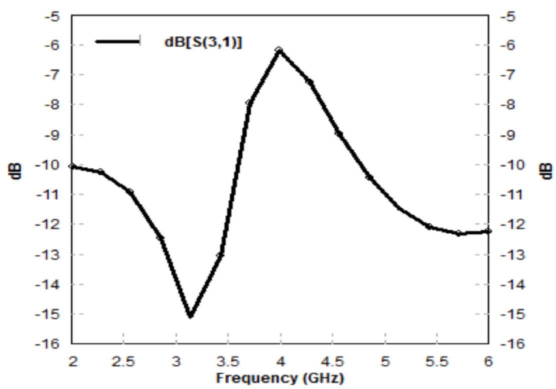

Fig. 6 Simulated S31 of traditional power divider using hybrid ring

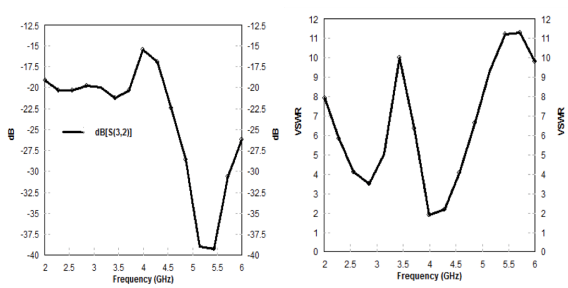

Fig. 7 (a) Simulated S32 of traditional power divider using hybrid ring (b) Simulated VSWR of traditional power divider using hybrid ring

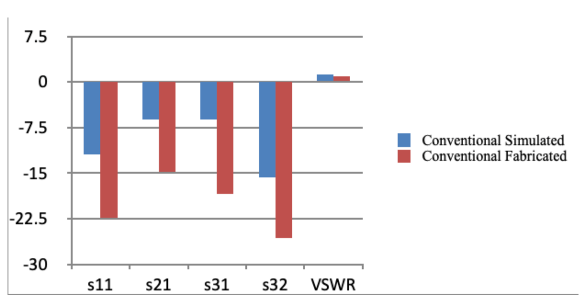

Fig. 8 Graph showing comparison of Simulated and fabricated result traditional design

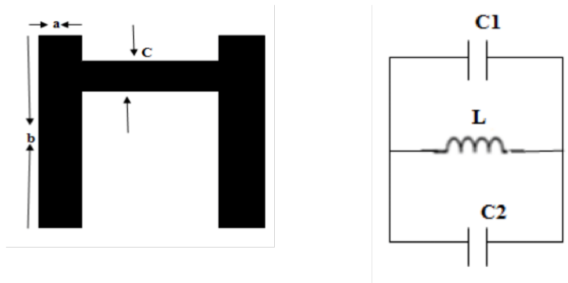

Fig. 9 Unit cell representation of Top Offset H shape EBG with equivalent electrical model

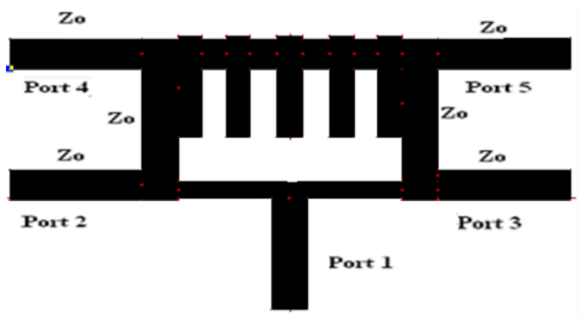

Fig. 10 Proposed Top Offset H shape EBG structure

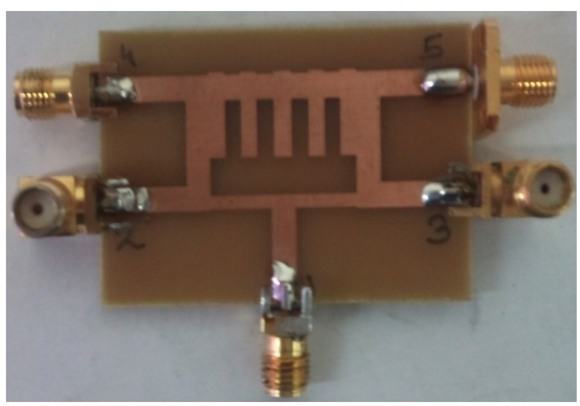

Fig. 11 Fabricated Top offset H shape EBG

secondary sources. For a specific frequency range, the waves from these secondary sources interact destructively at the receiving antenna. One of the characteristics of metamaterials is the ability to stop electromagnetic waves from propagating in a specific frequency band. Unit cells made of conductors and dielectrics are assembled in a single row or columns of many cells to form the device's structure. The ability of EBG structure to block electromagnetic waves in a specific frequency band can be used in many applications[4]-[6],[8].

1.3 Metamaterial

The term 'Meta' means 'beyond'. Hence, the term Metamaterial means material beyond nature. Materials in nature derive their properties from the composition of sub atomic particles like neutrons, electrons and protons. However, properties of Metamaterials are derived from the periodic

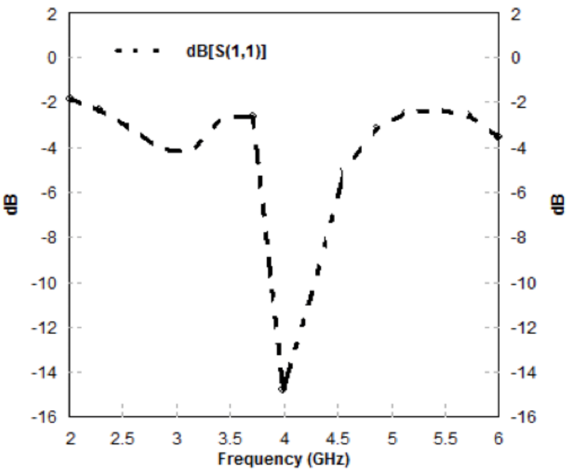

Fig. 12 Simulated S11 of Top offset H shape EBG

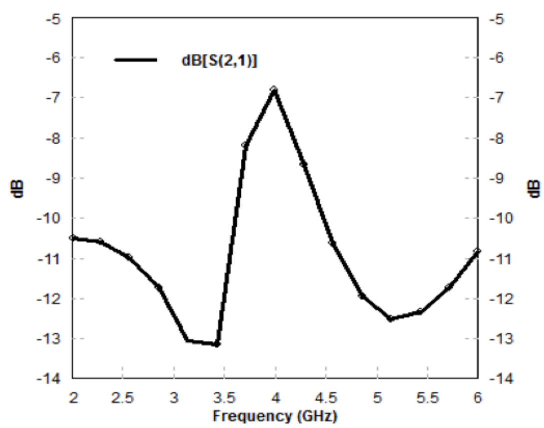

Fig. 13 Simulated S21 of Top offset H shape EBG

nanostructure. Small in homogenities are created to form the periodic nanostructure. These structures are much smaller than the wavelength of electromagnetic radiation. These artificially designed structures act as artificial atoms[8–12].

2 Design of In Phase Hybrid Ring power divider at permittivity 4.4 & substrate thickness 1.6mm

Using IE3D software, design is constructed on substrate material FR4. Figures 2 and 3 depict the traditional Power Divider using hybrid ring structure at 4 GHz with thickness of substrate 1.6 mm and permittivity of substrate material 4.4. The input port is port 1, thus. Equal power signal is provided through ports 2 and 3. The termination ports for matching are ports 4 and 5. The power divider is 32 mm x 15.1 mm, or 483.2mm^2.

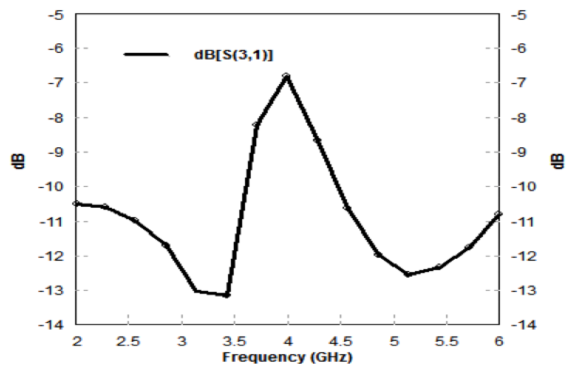

Fig. 14 Simulated S21 of Top of Simulated S31 of Top offset H shape EBG

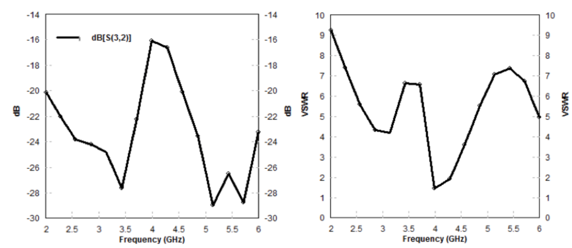

Fig. 15 a) Simulated S32 of Top offset H shape EBG b) Simulated VSWR of Top offset H shape EBG

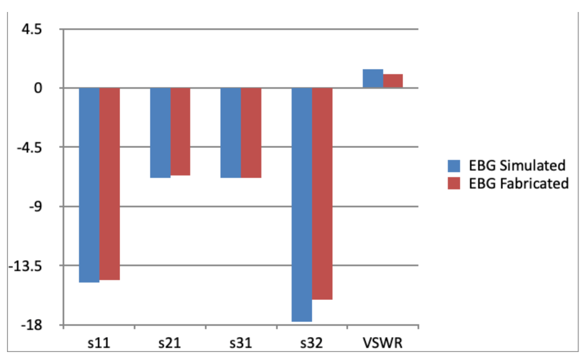

Fig. 16 Graph showing comparison of simulated and fabricated results of EBG structure

3 Simulated results of traditional structure

The simulated outcomes of a traditional in phase hybrid ring are shown in Figures 4, 5, and 6. S11 return loss is -11.96dB. At 4 GHz, S21 and S31 are -6.270 dB. As a result, at 4 GHz ports 2 and 3 get equal power.

The isolation between ports 2 and 3 is illustrated in figure 7(a). S32 is -15.49 dB at 4 GHz. So, ports 2 and 3 are separated. The VSWR is shown in figure 7b. The traditional power divider's bandwidth is 104MHz.

4 Top offset H Shape EBG

Figure 9 shows the unit cell representation of Top offset H Shape EBG. Length 'b' in upper rectangle in changed to obtain the results at 4 GHz and dimensions are a= 2mm, b=10.1mm, c=3mm. With increasing offset operating frequency is lowered. The size of the power divider is 24.6 mm x 16.1 mm

Table 1 Summary of parameter for traditional power divider using hybrid ring

Parameters	Value (Simulated)	Value (Fabricated)
Software	IE3D	-
Frequency	4 GHz	4 GHz
Permittivity	4.4	4.4
Thickness	1.6 mm	1.6 mm
Area	483 mm^2	483 mm^2
S_{11}	-11.96 dB	-22.42 dB
S_{21}	-6.22 dB	-14.74 dB
S_{31}	-6.22 dB	-18.44 dB
S_{32}	-15.57 dB	-25.65 dB
VSWR	1.287	1.01
Bandwidth	104 MHz	480 MHz

= 396 mm2 .Total size reduction is 18.03%. Figure 10 and 11 shows the designed and fabricated Top offset H shape EBG.

5 Simulated results of Top offset H shape EBG structure

Figure 12, 13,14 shows the simulated S parameters results of the proposed Top offset H shape EBG structure The proposed design meets all the specifications with the reduced component size. Return loss S11 is -14.77dB .S21 and S31 is -6.81 dB at 4 GHz. Thus equal power division at port 2 and 3 at 4 GHz. The isolation between ports 2 and 3 is shown in figure 15 a) S32 is -16.11 dB .VSWR illustrated in figure 15 b).The proposed power divider has a 336 MHz bandwidth compared to a 104 MHz bandwidth for traditional power divider.

Table 2 Summary of parameter for proposed In phase Hybrid Ring using Top offset H shape EBG

Parameters	Value (Simulated)	Value (Measured)
Software	IE3D	-
Frequency	4 GHz	4 GHz
Permittivity	4.4	4.4
Thickness	1.6 mm	1.6 mm
Area	396.06 mm^2	396.06 mm^2
S_{11}	-14.77 dB	-14.63 dB
S_{21}	-6.81 dB	-6.626 dB
S_{31}	-6.81 dB	-6.835 dB
S_{32}	-16.11 dB	-17.79 dB
VSWR	1.45	1.07
Bandwidth	336 MHz	480 MHz

6 Conclusion

Miniaturized In phase hybrid power divider using Top offset H EBG structure designed at 4 GHz,achieved size reduction of 18.03% as compared to the traditional Hybrid ring power divider designed using the same input specifications. S21 at ports 2 and 3 is -6.81 db. Hence power is equally divided at ports 2 and 3.Return loss S11 is -14.77 dB. Isolation S32 is -16.11 dB. Thus port 2 and 3 are well isolated.The bandwidth of traditional power divider is 104 MHz and that of proposed power divider is 336 MHz. EBG, one of the metamaterial, provides better control over electromagnetic waves leading to better radiation characteristics at reduced dimensions of the microwave device. A compromise has to be achieved between stopband frequency and size of the cell for design of the microwave device. EBG models are generally iterative. An effect to mathematically model the developed EBG structure so as to make them generic can be made. Electrically modelling the EBG based structure and simulating the structure could make this technology more of an absolute science rather than a relative one.

Declarations

- The authors received no specific funding for this study.
- The authors declare that they have no conflicts of interest to report regarding the present study.
- No Human subject or animals are involved in the research.
- All authors have mutually consented to participate.
- All the authors have consented the Journal to publish this paper.
- Authors declare that all the data being used in the design and production cum layout of the manuscript is declared in the manuscript.

References

[1] Pozar, D.M.: Microwave Engineering, 3rd edition edn. Wiley, New York (2005)

[2] Nesie, D.: A brief review of microwave photonic bandgap (pbg) structures. Microwave Review, 18–24 (2001)

[3] Jun He, D.C., Wang, B.-Z.: Miniaturized microstrip wilkinson power divider with ebg structure. In: International Conference on Microwave and Millimeter Wave Technology (ICMMT), pp. 4673–4675 (2012)

[4] Chih-Ming Lin, J.-C.C. Hsuan-Hung Su, Wang, Y.-H.: Wilkinson power divider using microstrip ebg cells for the suppression of harmonics. Microwave and Wireless Components Letters, IEEE **17**(10), 700–702 (2007)

[5] Chen, H.-H., Pang, Y.-H.: A dual-band wilkinson power divider utilizing ebg structure. In: PIERS Proceedings, Marrakesh, MOROCCO, pp. 1018–1020 (2011)

[6] Ooi, B.-L.: Compact ebg in-phase hybrid ring equal power divider. IEEE Transactions On Microwave Theory And Techniques **53**(7), 2329–2334 (2005)

[7] Chien-Hsun Ho, K.C. Lu Fan: Broadband uniplanar hybrid ring and branch line coupler. IEEE Transactions On Microwave Theory And Techniques **41**(12), 2116–2125 (1993)

[8] Jun Kamiya, T.Y. Kenichi Shirota, Nakazawa, T.: Study of ebg structures using metamaterial technology. OKI Technical Review **79**(1) (2012). Issue 219

[9] Mikucki, G., Agarwal, A.: A broad band printed circuit hybrid ring power divider. IEEE Transactions On Microwave Theory And Techniques **37**(1), 112–117 (1989)

[10] Ban-Leong Ooi, W.P., Leong, M.S.: Broad banding technique for in-phase hybrid ring equal power divider. IEEE Transactions On Microwave Theory And Techniques **50**(7), 1790–1794 (2002)

[11] Kim, D.T., Y, N.: Broad-band design of improved hybrid-ring 3-db directional couplers. IEEE Transactions On Microwave Theory And Techniques **30**(11), 2040–2046 (1982)

[12] Pendry, J.B.: Metamaterials and the control of electromagnetic fields. Optical Society of America (2007)