Fully Integrated Unequal Wilkinson Power Divider With EBG CPW

Young-Joon Ko, Jae-Yeong Park, and Jong-Uk Bu

***Abstract*—In this paper, a CPW with electromagnetic bandgap (EBG CPW) is newly proposed for designing a transmission line with high impedance. After designing, fabricating, and evaluating the characteristic impedance of the proposed EBG CPW transmission line, it will be applied for an integrated Unequal Wilkinson Power Divider. In the EM simulation, the EBG-CPW transmission line with 10 μm in line width has the same characteristic impedance as a CPW with a line width of 2.5 um. The insertion and return losses of the fabricated power divider with a power ratio of 1 to 3 are less than -0.7 dB and -15 dB, respectively. It also has excellent isolation characteristics with more than -20 dB. The experimental results are good agreement with the simulation.**

***Index Terms*—Electromagnetic bandgap (EBG) CPW, transmission line with high impedance, unequal Wilkinson power divider.**

I. Introduction

The photonic bandgap (PBG) structure is utilized to prevent electromagnetic propagation and change wave impedance and phase. Most of PBG applications were reported for constructing microstrip lines in antennas, resonators, and filters but little for CPW transmission line [1]–[2]. Recently, etched rectangular holes in the ground line following periodic patterns were proposed for the PBG CPW structures [3]–[4]. The periodic rectangular etched holes reported in [3] can be expressed as parallel LC-circuit and then make stop band. But the etched rectangular holes are not suitable if they are utilized to change wave impedance, that is, increase the characteristic impedance of transmission line.

Generally, a transmission line with high impedance is useful for changing the power ratio of the power dividers. But it is not easy to apply for microwave and millimeter wave passive circuits due to the difficulty of design and fabrication. This phenomenon is more evident at the higher frequencies. Thus, a microstrip line with defected ground structure (DGS) was proposed for an unequal power divider [5]. In this paper, a CPW with electromagnetic bandgap (EBG CPW) is newly proposed to design a transmission line with high impedance. In the proposed EBG CPW, the spacing distance between two narrow slots is optimized for obtaining high impedance and four rectangular holes are arranged symmetrically. After fabricating and evaluating the characteristic impedance of the EBG CPW, it will be applied for a CPW Unequal Wilkinson Power Divider with a power ratio of 1 to 3.

Manuscript received October 17, 2002; revised December 18, 2002. This work was supported by Ministry of the Ministry of Science & Technology under the 21st Frontier Intelligent Microsystem Project. Fabrication and measurement were carried out at the LG Electronics Institute of Technology. The review of this letter was arranged by Associate Editor Dr. Shigeo Kawasaki.

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Digital Object Identifier 10.1109/LMWC.2003.814597

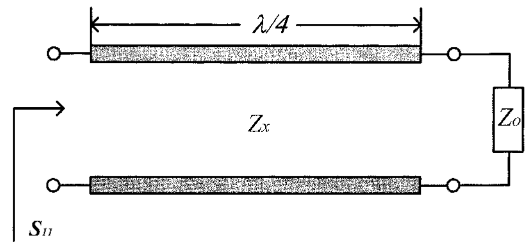


Fig. 1. A transmission line terminated with Zo.

II. Design and Simulation

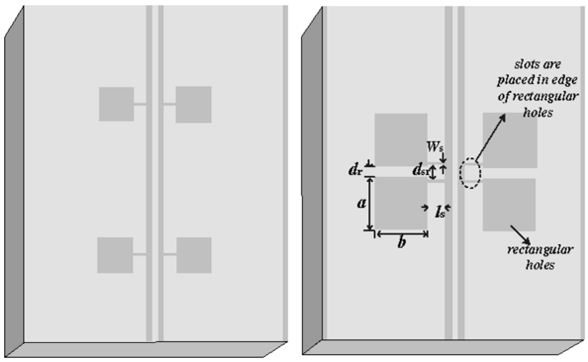
A. EBG CPW Transmission Line With High Impedance

In general, characteristic impedance of transmission line with $\lambda/4$ in length corresponds to the maximum reflection coefficient of the transmission line, S_{11} and is commonly used for calculating a line width of a transmission line [5]. Fig. 1 shows a transmission line with the characteristic impedance, Zx. The characteristic impedance of the transmission line can be expressed by the reflection coefficient of the transmission line as shown in (1). A 2.5 μm in line width and 150 μm in spacing from signal line to ground can be calculated to the characteristic impedance of 132 Ω in a CPW, which correspond to reflection coefficient, -2.4 dB by using the (1). The characteristic impedance of the transmission line will be applied for fabricating the unequal Wilkinson Power Divider with a power ratio of 1 to 3. However, the transmission line with a 2.5 μm in line width and a 3 μm in thickness is not easy to be realized due to the difficulty of its fabrication. Thus, a EBG CPW with a line width of 10 μm is utilized for fabricating the unequal power divider instead of the CPW with 2.5 μm in line width, which has the same the characteristic impedance of 132 Ω

$$Zx = Zo^{*}\sqrt{\frac{1+10^{0.05^{*}S_{11}}}{1-10^{0.05^{*}S_{11}}}}\,[\Omega] \quad (1)$$

where S_{11} is the magnitude of the reflection coefficient in decibels.

The novel PBG CPW was reported in the form of periodic etched rectangular holes in the ground plane [3]. The reported PBG CPW structure is suitable to obtain a stop band, but not to design the transmission line with high impedance. Thus, the PBG CPW structure needs to be modified for forming the transmission line with high impedance. Fig. 2 shows the conventional PBG CPW and the proposed EBG CPW structure as the modified PBG structure. The rectangular holes with 1400×500 μm



(a) (b)

Fig. 2. Comparison of the conventional PBG and proposed EBG CPW structures. (a) A conventional periodic loaded CPW structure. (b) A proposed EBG CPW structure for transmission line with high impedance.

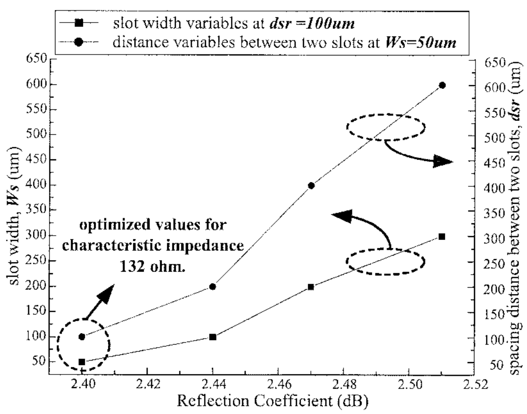


Fig. 3. Reflection coefficient characteristic of EBG CPW by varying slot width at $dsr = 100$ um and spacing distance between two slots (dsr) at $Ws = 50$ um.

are formed in the ground plane on both sides of a CPW signal line and connected with the signal line through the slots with 50 $\times$ 90 μm as shown in Fig. 2(b). The characteristic impedance of the proposed EBG CPW can be calculated by several design parameters which are a size of rectangular hole $(a \times b)$, slot width of Ws, slot length of ls, spacing distance between the rectangular holes of dr, and spacing distance between the slots of dsr. The spacing distance between the slots, dsr, is the main design parameter for increasing the characteristic impedance of the CPW transmission line. The characteristic impedance can be increased by decreasing both dsr and Ws, as shown in Fig. 3. The optimized spacing distance between the slots and the width of slots are 100 μm and 50 μm, respectively. Fig. 4 shows the characteristic impedance of CPW with and without the proposed EBG structure, which is varying from 104 Ω to 132 Ω. In EM simulation, a EBG CPW with a line width of 10 μm has the same characteristic impedance as a CPW with a line width of 2.5 μm.

B. Unequal Wilkinson Power Divider With a Proposed EBG CPW

Fig. 5 shows a conventional Unequal Wilkinson Power Divider. In general, characteristic impedance of transmission line of a power divider can be calculated by using the following equations. If incident power to Port1 is divided into Port2 and

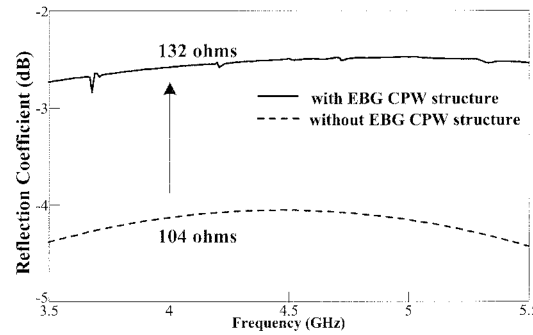


Fig. 4. Simulated reflection coefficient characteristic of a CPW with and without a EBG.

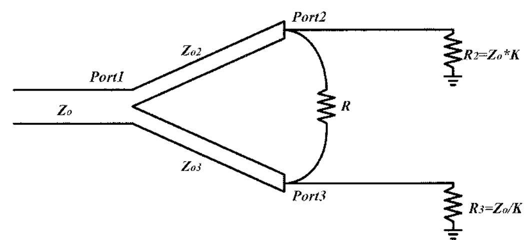


Fig. 5. A schematic drawing of an Unequal Wilkinson Power Divider.

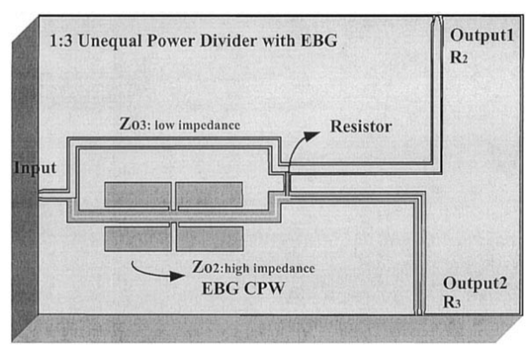


Fig. 6. A schematic drawing of the proposed 1:3 Unequal Wilkinson Power Divider with the EBG CPW.

Port3, the divided powers are defined as P2 and P3, respectively. The ratio of divided powers, k, is also defined as a sqrt(P3/P2)

$$Z_{o3} = Z_o * \sqrt{\frac{(1+k^2)}{k^3}} \tag{2}$$

$$Z_{o2} = k^2 * Z_{o3} \tag{3}$$

$$R = Z_o * \left(k + \frac{1}{k}\right) \tag{4}$$

where Z_{o2} and Z_{o3} are the characteristic impedances of the transmission line for dividing input power to Port 2 and port 3 and R is the resistance for isolation between the output ports. In this paper, the EBG CPW proposed in Section II-A is utilized for realizing the Unequal Wilkinson Power Divider with a power ratio of 1 to 3. Z_{o2}, Z_{o3}, and R are 44 Ω, 132 Ω, and 115 Ω, respectively. Fig. 6 shows a schematic drawing of the proposed Unequal Wilkinson Power Divider with the proposed EBG CPW. A GaAs substrate is utilized with a relative dielectric constant of 12.9 and a thickness of 625 μm. The line widths and air gaps between the signal line and ground plane

TABLE I
DESIGN PARAMETERS OF THE PROPOSED UNEQUAL WILKINSON POWER DIVIDER WITH THE EBG CPW

	Zo	Zo2	Zo3	R2	R3
Characteristic impedance(Zo) & termination (R) (ohms)	50	132	44	87	29
Width of CPW (um)	110	10+EBG	136	166	58

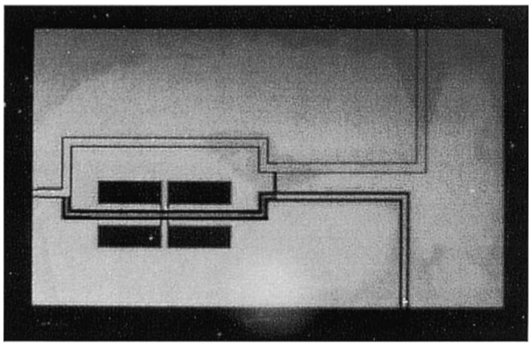


Fig. 7. Photomicrograph of the fabricated Unequal Wilkinson Power Divider with the EBG CPW.

in Fig. 6 are 136 μm and 52 μm for obtaining the characteristic impedance(Zo_3) of 44 Ω, and 10 μm and 115 μm for characteristic impedance(Zo_2) of 132 Ω, respectively. Table I shows the design parameters for fabricating the proposed Unequal Wilkinson Power Divider with the proposed EBG CPW. The termination resistors, R2 and R3, are replaced by $\lambda/4$ transformers and load impedance of 50 Ω for easy measurement. The size of the fabricated circuit is 6 $\times$ 8(mm). Before fabricating the proposed power divider, simulation was performed by using EM simulator. Simulated insertion and return losses are -0.7 dB and min. -15 dB, and isolation characteristics is -20 dB over 3.5 GHz $\sim$ 5.5 GHz of frequency band, respectively. The simulated power ratio between the output ports is 1 to 3. The simulated results show the validity of the proposed EBG CPW structure.

III. FABRICATION AND MEASUREMENT

The proposed Unequal Wilkinson Power Divider is fabricated by using 3 μm-thick Au metal on a GaAs substrate with a thickness of 625 μm. Nichrome resistor is formed by using photolithography and lift off techniques for obtaining an isolation characteristics between the output ports. And the EBG CPW line is is formed by using electroplated Au. Fig. 7 shows the fabricated Unequal Wilkinson Power Divider. To remove other modes except CPW mode, bonded wire is implemented in the discontinuous line structures.

The fabricated Power Divider was measured and characterized by using a HP 8510C vector network analyzer (VNA). The measured insertion loss and return loss are less than -0.7 dB and -15 dB, respectively. The measured power ratio between the output ports is 1 to 2.7. It has excellent isolation characteristics with more than -20 dB as shown in Fig. 8. As shown in Table II, the measured results are well matched with the simulated ones.

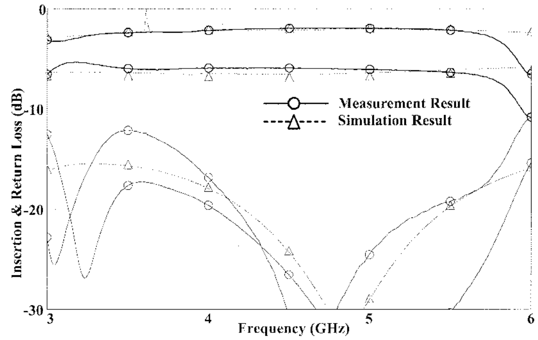


Fig. 8. Simulated and measured performance characteristics of the fabricated Unequal Wilkinson Power Divider.

TABLE II
COMPARISON OF SIMULATION AND MEASUREMENT RESULTS OF THE PROPOSED UNEQUAL WILKINSON POWER DIVIDER

	Simulation Result	Measurement Result
Insertion loss	- 0.7dB	-0.7dB
Return Loss	Min. -15dB	Min. 15dB
Power Ratio	1:3	1:2.7
Isolation	avg. -20dB	avg. -20dB

IV. CONCLUSION

In this paper, the CPW with electromagnetic bandgap is proposed, designed, and simulated for constructing a high impedance transmission line. In EM simulation, the proposed EBG-CPW with a line width of 10 μm has the same characteristic impedance of 132 Ω as a CPW with a line width of 2.5 μm.

To verify the advantage of the proposed EBG CPW transmission with the high impedance, an Unequal Wilkinson Power Divider with a power ratio of 1 to 3 has been designed, fabricated, measured, and characterized on the GaAs substrate. The measured insertion loss and return loss are less than -0.7 dB and -15 dB, respectively. An excellent isolation characteristics of more than avg. -20 dB is also achieved. The measured results are also well matched with the simulated ones. In addition to the unequal power divider application, the proposed electromagnetic bandgap CPW can be applied for integrated phase shifters and filters.

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