http://dx.doi.org/10.5392/IJoC.2015.11.3.034

Dual CRLH Based Band Stop Filter Using Conductor-Backed Defected Coplanar Waveguide

Doo-Yeong Yang
Department of Telecommunication Engineering
Jeju National University, Jejudaehakro 102, Jeju 690-756, Republic of Korea

Lei Yang
Key Laboratory of Network and Intelligent Information Processing
Hefei University, Hefei 230601, China

ABSTRACT

A band stop filter is proposed with cascading unit cells that are based on a dual composite right/left-handed (D-CRLH) conductor-backed coplanar waveguide. The parameters of the unit cell have been analyzed to confirm the behavior of each component for the equivalent circuit of the cell. We simulated the dispersion characteristics and energy distribution and have determined that the unit cell has a D-CRLH property. The band stop filter was implemented by symmetrically cascading two of the proposed unit cells. The experimental results for the band stop filter revealed a band rejection performance of 32 dB and a return loss of 0.35 dB in the stopband frequency range from 869MHz to 954MHz. Finally, we show that there is a good agreement in the experimental results and those obtained through the simulations.

Key words: *Band Stop Filter, Dual Composite Right/Left-Handed (D-CRLH), Conductor Backed Coplanar Waveguide, Unit Cell.*

1. INTRODUCTION

Band stop filter has been widely concerned as a means to separate an undesired frequency band in microwave systems. For optimal design of the systems, the filters have compact and low loss structures, as well as low-power operation. Recently, a composite right and left-handed (CRLH) transmission line has been used for compact design since it has high frequency selectivity, low loss, wide bandwidth and the capability of planar configuration [1], [2]. The equivalent circuit model using a CRLH transmission line consists of the serial impedance and the parallel admittance. The serial impedance is constituted by a right-handed (RH) inductance in series with a left-handed (LH) capacitance, and the parallel admittance is constituted by a RH capacitance in parallel with a LH inductance [2]-[5]. In [6], a dual composite right/left-handed (D-CRLH) structure was proposed as a dual structure of the conventional CRLH transmission line. The equivalent circuit for a D-CRLH transmission line has a series LC parallel resonant circuit and a shunt LC series resonant circuit, which provides band stop property.

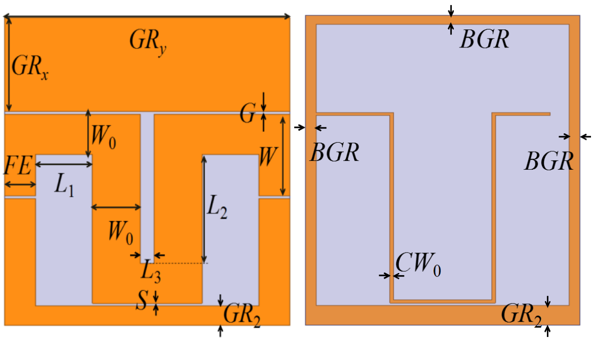
* *Corresponding author, Email: yeongyd@jejunu.ac.kr*
Manuscript received Mar. 31, 2015; revised May. 11, 2015; accepted May. 18, 2015

For filter design in microwave integrated circuits (MICs) or monolithic microwave integrated circuits (MMICs), coplanar waveguide (CPW) is more suitable than conventional microstrip lines because of simple fabrication and weak crosstalk effects between the adjacent lines. Moreover, the size of CPW can be reduced without limit since the characteristic impedance of CPW is dependent on the ratio of the widths of transmission line and ground plane [7]-[8]. As a variant of CPW, a conductor-backed coplanar waveguide (CBCPW) has an extra ground plane on the bottom layer of the dielectric substrate. The bottom ground plane increases mechanical strength of circuits and provides cooling effect for circuits with active devices [7], [9], [10].

In this paper, in order to obtain a band stop filter with a low return loss within the stopband frequency range from 869MHz to 954MHz, a unit cell structure based on a D-CRLH structure using a CBCPW is presented. And a conductor-backed defected ground is attached and etched on the bottom ground plane to have proper band stop characteristics. Then, the equivalent circuit model for the unit cell is extracted to analyze its performance. And the dispersion characteristic and energy distributions of electromagnetic fields are simulated to prove the property of D-CRLH structure. In the end, the band stop filter is fabricated by connecting two proposed unit cells in symmetric series. To prove validity of the proposed filter design, the S-parameter simulation results are compared to the measured results of the band stop filter.

2. D-CRLH CBCPW BASED UNIT CELL

The unit cell for band stop filter design is proposed and based on D-CRLH CBCPW as shown in Fig. 1. The geometry of the cell consists of a dielectric substrate between two metallic layers and a conductor-backed defected ground (CBDG) structure which is etched on the bottom metallic plane. The signal line on the top metallic layer is transformed into a U-shaped structure for size reduction. In order to obtain a band rejection property, the CBDG structure on the bottom layer is transformed into the same U-shaped structure with the signal line on the top layer. One port of the CBDG structure is shorted to the bottom ground plane and the other is opened. Thus, the two U-shaped structures result in a coupled resonator. In an attempt to simulate and test the unit cell, characteristic impedance of input and output port for the substrate with 0.787 mm thickness is 50 Ω and the relative dielectric constant ε_r of 2.5 is used for all cases.



(a) Top view (b) Bottom view

Fig. 1. Physical geometry of the proposed unit cell

As shown in Fig. 1, when the input signal transmits along the transmission line, the equivalent series RLC parallel resonant circuit component L_R is distributed on the signal line and the component C_L is generated in proportion to the coupling area of the resonator. On the other hand, the equivalent parallel GLC series resonant circuit components L_L and C_R are created on the CBDG structure. Since one port of the CBDG structure connects with the bottom ground plane, the inductance L_L and the capacitance C_R can be generated at the resonant condition when the length of the CBDG structure is set to a quarter of the wavelength. Therefore, the equivalent circuit model for the unit cell can be depicted as Fig. 2. The values of the components (L_R, C_R, L_L, C_L) in the unit cell transmission line can be changed by adjusting the main parameters W_0, CW_0, L_1, L_2, L_3 and S.

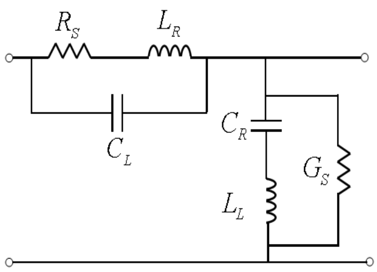


Fig. 2. Equivalent circuit model for the proposed unit cell

Consequently, the equivalent impedance Z, the admittance Y, the series and shunt resonance can be calculated as follows:

$$Z = \frac{(R_S + j\omega L_R)\{1-(\omega/\omega_{se})^2 - j\omega R_S C_L\}}{\{1-(\omega/\omega_{se})^2\}^2 + (\omega R_S C_L)^2} \quad (1)$$

$$Y = \frac{G_S\{1-(\omega/\omega_{sh})^2\} + j\omega C_R}{1-(\omega/\omega_{sh})^2} \quad (2)$$

where $\omega_{se} = \frac{1}{\sqrt{L_R C_L}}$, $\omega_{sh} = \frac{1}{\sqrt{L_L C_R}}$.

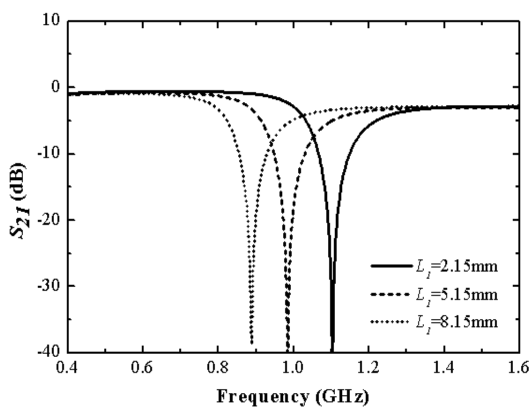
And also the propagation constant, attenuation constant and phase constant of the equivalent circuit can be computed from the transmission parameter.

$$\gamma = \alpha + j\beta = \sqrt{ZY} = -\frac{1}{l}\{\ln(|S_{21}|) + j\varphi(S_{21})\} \quad (3)$$

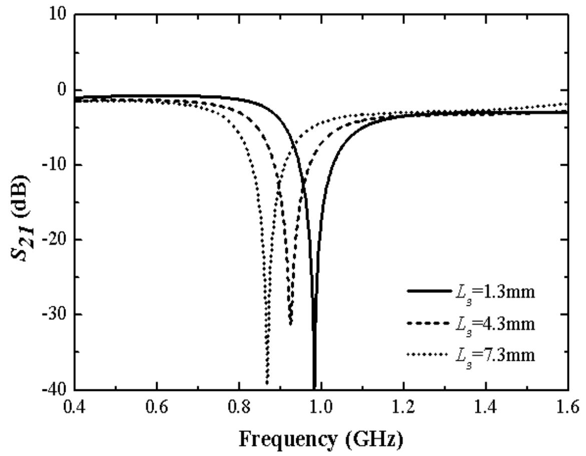
The dispersion characteristics of β generally appears a continuous function of frequency as a curve varying within $|\beta| \le \pi$. And l and $\varphi(S_{21})$ represent the physical length of the unit cell in a specific implementation and the phase of S_{21}, respectively.

3. SIMULATION RESULTS

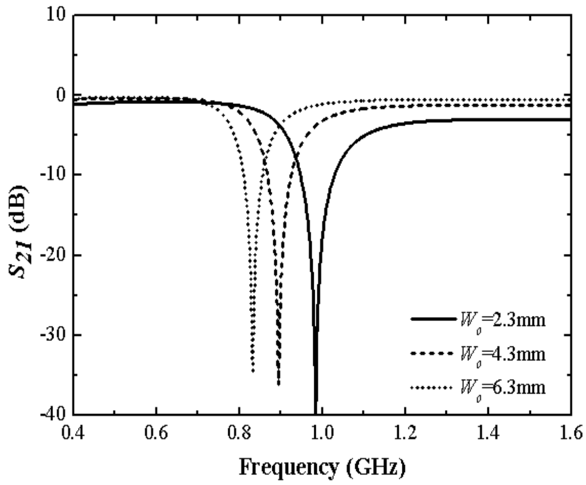
The influences of the parameters L_1, L_3, W_0 and CW_0 are investigated. For the simulation, other parameters except them are used on Table 1. Fig. 3 is the simulated insertion loss by HFSS. As L_1 and L_3 increase doubled or quadrupled in Fig. 3(a) and (b), the resonant frequency decreases according as the length of the signal line and the coupling area of the resonator get enlarger. Therefore, the components of L_R, L_L and C_R increase. Additionally, the resonant frequency decreases as W_0 of Fig. 3(c) increases, but increases as CW_0 of Fig. 3(d) increases. The reason is that the value of the inherent capacitance of the TL depends on the widths of the U-shaped lines. And the interaction between the inherent capacitance and the coupling capacitance makes a special result.



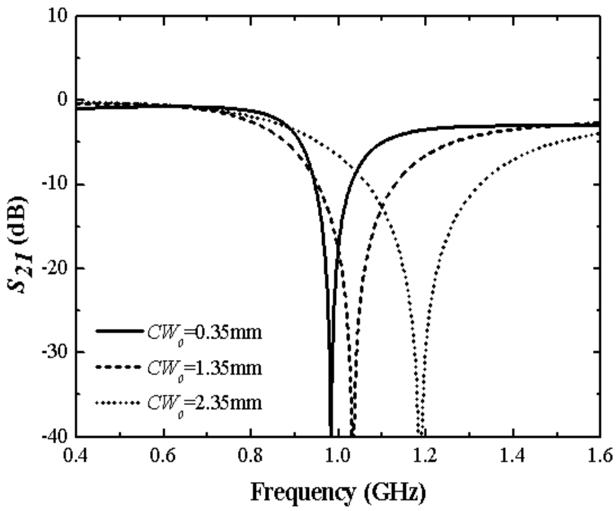
(a) L_1



(b) L_3



(c) W_0



(d) CW_0

Fig. 3. S_{21} (dB) characteristics as a function of the geometrical parameters

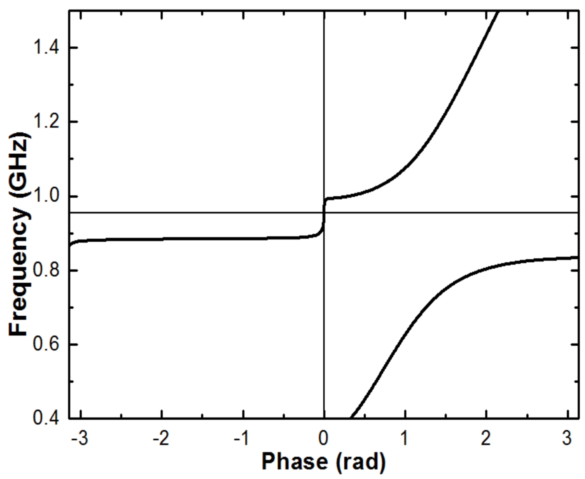
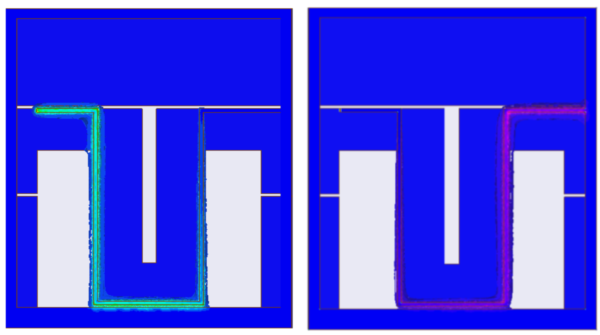


Fig. 4. Dispersion characteristics of the proposed unit cell



(a) Electric energy and cell (b) magnetic energy

Fig. 5. Energy distributions of the proposed unit

The dispersion characteristic to confirm the D-CRLH structure is shown in Fig. 4. At both low frequency ranges below the series resonant frequency of 850MHz and high frequencies above the shunt resonant frequency of 961MHz, there are forward propagating waves. In this frequency ranges, the right-handed effect occurs. Otherwise, over the range between the series and shunt resonant frequencies, backward propagating waves are generated. It means that the left-handed effect occurs. Thus, the proposed unit cell provides the D-CRLH characteristics.

The energy distribution of electric fields corresponds to the accumulated energy distribution of the capacitance C_L is generated in the resonator, and the capacitance C_R is distributed on the CBDG structure. As shown in Fig. 5(a), the energy is generated dominantly at the coupling area over the CBDG structure. As time elapses, the electric energy turns to be the magnetic energy. On the other hand, the energy distribution of magnetic fields corresponds to the accumulated energy distribution of the inductance L_L, which is also created at the area on the CBDG structure as shown in Fig. 5(b). This process is repeated while the signal energy transmits from the input to the output ports. Therefore, the transference and the suppression of the input signal energy are achieved through the inductances and the capacitances modeled into equivalent circuit.

4. FABRICATION AND MEASUREMENTS

The unit cell is fabricated as the physical dimensions shown in Table 1. Fig. 6 shows the S-parameter simulation and measurement results. The fabricated unit cell exhibits good band rejection characteristics, which is simulated by HFSS. The simulated resonant frequency of the unit cell is 885 MHz and the measured resonant frequency is 883 MHz. Therefore, the error rate of the resonant frequency is 0.23 %. The measurement shows that the return loss is below 0.6 dB and the band rejection property of S_{21} is below -16 dB in the stopband from 869 to 894 MHz.

From above results, the proposed unit cell can be used for band stop filter design. In order to obtain the desired passband and the sufficient suppression in the stopband, two unit cells are cascaded in symmetric series, as shown in Fig. 7 and 8. The physical dimensions of the band stop filter are shown in Table 2. The S-parameter simulation and the measurement results of the proposed band stop filter are compared in Fig. 9. The results of the simulation are agreed well with those of the measurement. The filter has good properties in both the passband and stopband. The measured return loss is below 0.35dB and the S_{21} has a good property as 32dB rejection in the range of 869 ~ 954 MHz.

Table 1. Physical dimensions of the proposed unit cell

Parameters	GR_x	GR_y	G	W	FE	W_0	L_1
Values (mm)	10	25.8	0.3	8.74	2.8	4.3	5.15
Parameters	L_2	L_3	S	GR_2	BGR	CW_0	
Values (mm)	11.6	1.3	0.3	2.1	1	0.35	

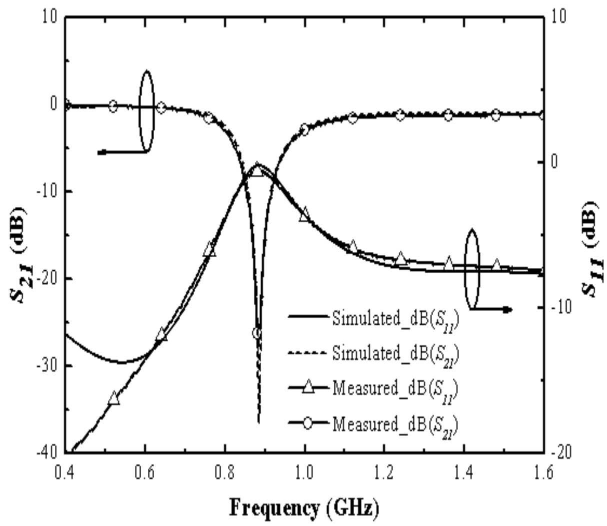
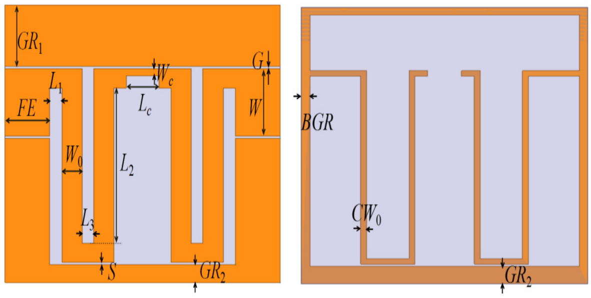
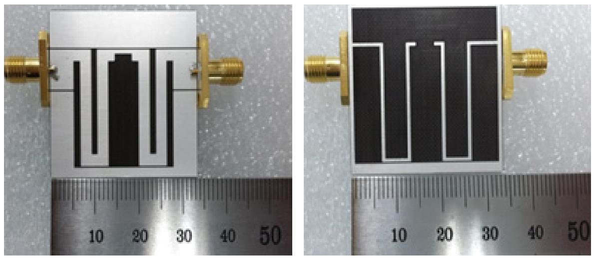


Fig. 6. *S*-parameter simulation and measurement results of the proposed unit cell



(a) Top view (b) bottom view

Fig. 7. Simulated layout geometry of the band stop filter



(a) Top view (b) bottom view

Fig. 8. Fabricated physical geometry of the band stop filter

Table 2. Physical dimensions of the proposed band stop filter

Parameters	GR_1	G	W	W_0	W_c	FE	L_1
Values (mm)	8	0.3	8.74	2.5	0.9	5.5	1.5
Parameters	L_2	L_3	L_c	S	GR_2	BGR	CW_0
Values (mm)	20.2	1.4	4	0.3	2.3	1	0.7

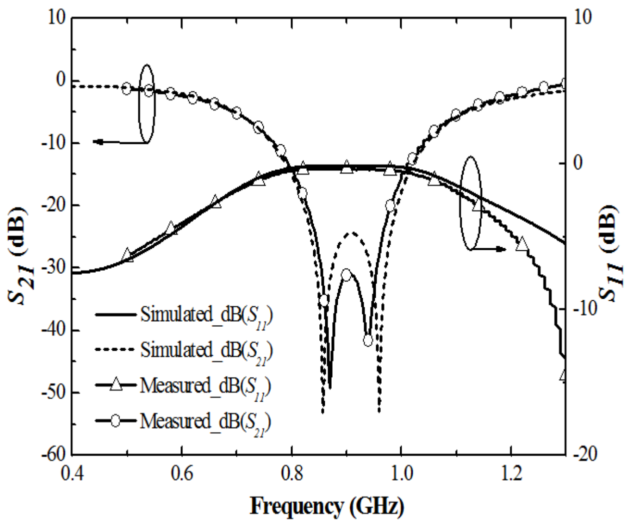


Fig. 9. *S*-parameter simulation and measurement results of the band stop filter

5. CONCLUSIONS

In summary, the unit cell with band rejection property was designed on D-CRLH CBCPW with a CBDG structure. The equivalent circuit for the unit cell has been extracted. In addition, the parameters of the unit cell were investigated to analyze the behavior of each parameter. The D-CRLH dispersion characteristic according to the unit cell has been confirmed through the simulation. We applied a good band rejection property of the proposed unit cell to design the band stop filter. The filter has been implemented by cascading two proposed unit cells serially. In the simulation and the measurement results, we show that the filter has the band rejection performance of 32 dB and return loss of 0.35 dB over the stopband frequency range of 869 MHz ~ 954 MHz and the results of the simulation have a good agreement with those of the measurement.

ACKNOWLEDGMENT

This research was supported by the 2015 scientific promotion program funded by Jeju National University.

REFERENCES

[1] C. Caloz and T. Itoh, "Application of the transmission line theory of left-handed (LH) materials to the realization of a microstrip LH transmission line," Proc. IEEE AP-S USNC/URSI National Radio Science Meeting, vol. 2, Jun. 2002, pp. 412-415.

[2] C. Caloz and T. Itoh, *Electromagnetic metamaterials: transmission line theory and microwave applications*, John Wiley & Sons, 2006. pp. 83-84.

[3] C. Caloz and T. Itoh, "Novel microwave devices and structures based on the transmission line approach of meta-materials," Proc. IEEE MTT-S International Symposium, vol. 1, Jun. 2003, pp. 195-198.

[4] A. Lai, T. Itoh, and C. Caloz, "Composite right/left-handed transmission line metamaterials," IEEE Microwave Magazine, Sep. 2004, pp. 34-50.

[5] Q. Zhu and S. J Xu, "Composite right/left handed transmission line metamaterials and applications," Proc. Meta. 2008 International workshop, Nov. 2008, pp. 72-75.

[6] C. Caloz, "Dual composite right/left-handed (D-CRLH) transmission line metamaterial," IEEE Microwave and Wireless Components Letters, vol. 16, no. 11, Nov. 2006, pp. 585-587.

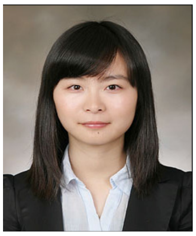
[7] R. N. Simons, *Coplanar waveguide circuits, components, and systems*, John Wiley & Sons, Inc., 2001, pp. 87-109.

[8] C. P. Wen, "Coplanar waveguide: a surface strip transmission line suitable for nonreciprocal gyromagnetic device applications," IEEE Transactions on Microwave Theory and Techniques, vol. 17, no. 12, Dec. 1969, pp. 1087-1090.

[9] G. Ghione and C. U. Naldi, "Coplanar waveguides for MMIC applications: effect of upper shielding, conductor backing, finite-extent ground planes, and line-to-line coupling," IEEE Transactions on Microwave Theory and Techniques, vol. 35, no. 3, Jan. 2003, pp. 260-267.

[10] Y. C. Shih and T. Itoh, "Analysis of conductor-backed coplanar waveguide," Electron Letters, vol. 18, no. 12, Jun. 1982, pp. 538-540.

Doo-Yeong Yang
He received the B.S. degree in telecommunication engineering from Jeju National University, Korea in 1984, and M.S., Ph.D. degrees in electrical and telecommunication engineering from Hanyang University, Korea in 1989, 1992 respectively. Since 1992, he has been a professor in telecommunication engineering of Jeju National University in Korea. His current research interests include RF devices, microwave circuits and wireless and satellite communication systems.



Lei Yang
She received the B.S., M.S in telecommunication engineering from Jeju National University, Korea in 2011, 2013, respectively. And then, she worked for one year at R&D Research Institute of Innertron in Korea. Since 2015, she has been with Key Laboratory of Network and Intelligent Information Processing, Hefei University, China. Her main research interests include RF devices and wireless communication system.