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Composite Righg/Left-Hand 전송선로를 이용한 새로운 이중대역의 CPW 윌킨슨 전력 분배기

A New CPW Dual Band Wilkinson Power Divider Using Composite Right/Left-Handed Transmission Line

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요 약

본 논문에서는 새로운 기법의 광대역 저손실 CRLH(composit right/left handed) 전송선로와 윌킨슨 전력 분배기에 대해 제안한다. 전송선로는 평형 미엔더 인덕터와 직렬 캐패시터로 구성된 coplanar 도파관 (CPW)으로 구성되며, 전력 분배기는 CRLH 전송선로를 일반 전송선로 부분에 대체하여 설계를 한다. 실험 결과 동작 주파수 대역 8.4 GHz 에서 30.0 GHz내에서 반사손실은 12 dB 이하로써 비교적 만족한 결과를 얻었다. 전력 분배기의 주파수는 12.05에서 13.15 GHz 그리고 16.50에서 19.30 GHz 로써 대역폭은 20 dB 기준으로 8.9 % 및 17.9 % 이며 이는 측정결과와 시뮬레이션 결과와 비교를 하였을 때 상당히 일치하는 것을 알 수 있다.

핵심어 : 메타물질, CPW, CRLH, 전력분배기, 이중대역

ABSTRACT

In this paper, a new kind of wideband, low-loss composite right/left-handed (CRLH) transmission line (TL) and a Wilkinson power divider are presented. The TL is composed of a parallel meander inductor and a series cutting capacitor based on coplanar waveguide (CPW) structure. The power divider is designed by substituting the CRLH-TL into the conventional transmission line. The experiment results show that the TL has a good agreement with the desired results, exhibiting the return losses under 12 *dB* from 8.4 *GHz* to 34.4 *GHz*. The operating frequencies of the power divider are 12.05 GHz to 13.15 GHz and 16.50 GHz to 19.30 GHz, respectively. The 20 dB bandwidths are 8.9 % and 17.9 %, respectively. Typical experimental measurements are conducted and compared with the simulated results.

Key words : metamaterial, CPW, CRLH, power diveider, dual-band

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Ⅰ. INTRODUCTION

In recent years, the left-handed (LH) metamaterials, first theoretically proposed by Veselago [1-3], have gained a significant interest. A number of RF/microwave practical component, antenna and system applications based on the powerful concept of CRLH metamaterials introduced in [2], have already been demonstrated to exhibit unprecedented performances and functionalities [2]. Due to the greater degrees of freedom, the dispersion characteristics of the CRLH lines can be engineered, and they can be applied to the design of novel microwave components with superior performance, as compared to conventional implementations, or based on new functionalities.

In particular, CRLH lines can be applied to the design of dual-band microwave components. Such components exhibit a certain functionality at two arbitrary different frequencies, which cannot be easily implemented through traditional distributed approaches since conventional transmission lines have a certain phase only at the fundamental frequency and its odd harmonics [4]. The dual band Wilkinson power dividers [5, 6] implemented using conventional transmission lines have employed shunt connections of open and short stubs, resulting in limiting factors for device size reduction and band selection. On the other hand, the dual band implementation of power dividers using CRLH-TLs show a size reduction, a broad frequency ratio, and a design simplicity characteristics [4, 7].

In this paper, a new kind of CPW transmission line using a CRLH metamaterial is presented. A CPW dual-band Wilkinson power divider taking use of this transmission line is also discussed. The design steps of the TL and power divider are exhibited in section 2 and section 4, respectively. The method of adjusting the circuit performance is discussed.

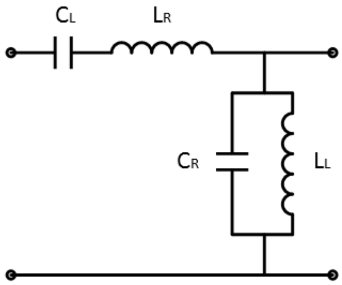
Ⅱ. Equivalent Circuit Model of the Proposed CRLH-TL

A left-handed transmission line model is based on the conventional transmission line theory, and is obtained by interchanging the capacitors and inductors of the transmission line model [8, 9]. As shown in Fig. 1, a perfect left-handed transmission line is a structure with low loss and broad-band performance. The combination of series capacitance and shunt inductance supports a fundamental backward-wave. At high frequencies, it has dual resonant structure with resonance frequencies, ω_L and ω_R [10], which are given by

$$\omega_L = \frac{1}{2\sqrt{C_L \times L_R}} \tag{1}$$

$$\omega_R = \frac{1}{2\sqrt{C_R \times L_L}} \tag{2}$$

If $\omega_L \neq \omega_R$, which is called unbalanced type, the frequency lower than ω_L is the LH region and the frequency higher than ω_R is the RH region. The frequency range between ω_L and ω_R is the stopband. When $\omega_L=\omega_R$, the balance condition is achieved, and there is no stopband and the LH and RH regions are connected. In the LH region, the phase velocity and group velocity have different sign, which is different from the conventional RH region.



〈그림 1〉 CRLH 전송선로의 등가회로
〈Fig. 1〉 Equivalent circuit of CRLH-TL

The effective permittivity, permeability, and propagation constant β are negative in the LH region.

Artificial transmission lines exhibiting left- and right-handed wave propagation [that is, composite right/left handed (CRLH) lines) can be implemented by loading a host line either with series capacitances and shunt inductances (LC-loaded approach) or with complementary split ring resonators (CSRRs) combined with series gaps (resonant type approach). In LC-loaded lines, the key element to achieve left-handedness consists of a host line loaded with series capacitances and shunt inductances. These lines can be implemented by using lumped loading elements, or, alternatively, by means of semi-lumped planar components such as series gaps, interdigital capacitors, grounded stubs or vias.

In this paper, the CRLH CPW TL is implemented by the embedded inductances and cutting capacitances.

Ⅲ. Experimental Results of the Proposed CRLH-TL

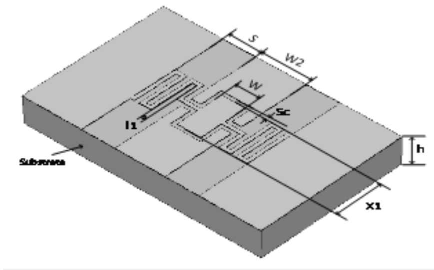
1. CRLH-TL structure element

The structure of a CRLH unit cell is shown in Fig. 2*a* and a photograph of the proposed CPW TL is shown in Fig. 2*b*.

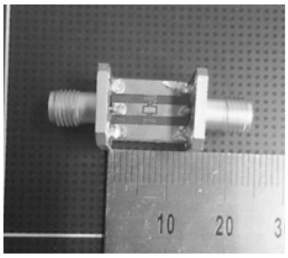
For increasing the inductance value of LH-TL, a meander line inductive structure is adopted. With a fine design of the space between meander lines (*l1*), and space between signal line and gaps (*s*), and for other parameters (*w* and *sc*), a balanced condition ($\omega_L = \omega_R$) can be obtained and thus there is no stopband between the LH and RH regions.

In Fig. 2a, the values for *h, x1, sc, w2, w, l1*, and *s* are 1.52 mm, 2.0 mm, 0.16 mm, 2.1 mm, 1.0 mm, 0.2 mm, and 1.4 mm, respectively. The size of this proposed CPW TL is 10.5 × 10 mm^2.

The structure is fabricated on a 1.57-mm-thick Taconic TLY-5 substrate which has a relative permittivity of 2.2, a conductor thickness of 0.035 mm, and a dielectric tangent loss value of 0.002.



(a)



(b)

〈그림 2〉 CRLH 전송선로 unit-cell의 구조 및 사진
(a) 물리적인 구조,
(b) 제안된 CRLH 전송선로의 사진
〈Fig. 2〉 Unit cell structure and photograph of the CRLH-TL, (a) physical structure (b) a photograph of the proposed CPW TL

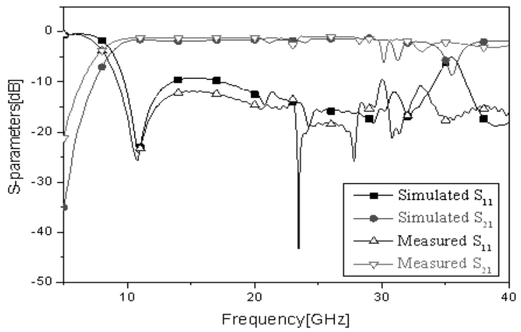
2. Simulation and experiment results of the proposed CRLH-TL

The simulated and measured results of the proposed CPW CRLH-TL are shown in Fig. 3. The results show that the measured insertion loss, S_{21} and return loss, S_{11} are 1.0 *dB* and 12 *dB* through the frequency range of 8.4-30.0 GHz with bandwidth of about 100%, respectively, which is in good agreement with the simulation results.

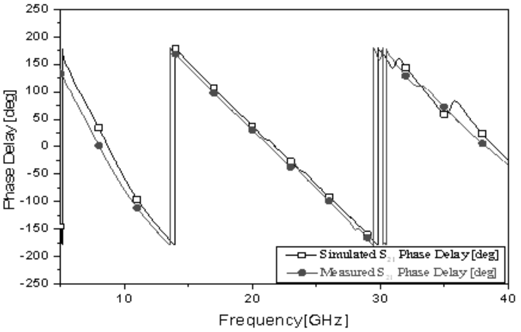
Fig. 4 shows the simulated and measured results of phase response of CRLH CPW structure. From the Fig. 4, the cut-off frequency is 8.4 GHz and the phase response is 0° at 8.4 GHz. Then, stop band is up to 8.4 GHz and RH area is above 22.0 GHz. Also, the LH area is between 8.4 GHz and 22.0 GHz and the 0° point is 22.0 GHz.

The RH area in metamaterial is 22.0 GHz to 30.0 GHz, where the 30.0 GHz is -180° point. On the other hands, the LH region has negative β corresponding to the effective permittivity and permeability at CRLH unit cell for the proposed structure. Then, the above -180° point of 30.0 GHz, there is non-metamaterial area.

Compared with other kinds of LH-TL, this transmission line has wide-band, and low-loss characteristics. S_{21} is less than 1.5 *dB* and has good performance in all transmission bands.



〈그림 3〉 제안된 CRLH 전송선로의 시뮬레이션 및 측정결과
〈Fig. 3〉 Simulated and measured results of the proposed CPW TL



〈그림 4〉 위상응답의 시뮬레이션 및 측정결과
〈Fig. 4〉 Simulated and measured results of phase response

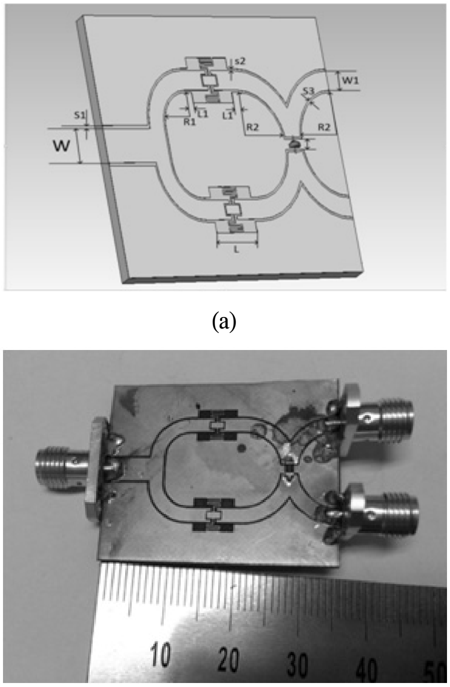
IV. Realization of Equal Wilkinson Power Divider

1. Wilkinson power divider model

The Wilkinson power divider is a three-port network that is lossless when the output ports are matched; where only $\sqrt{2}\,Z_0$ reflected power is dissipated. Input power can be divided into two or more in-phase signals with the same amplitude. For a two-way Wilkinson divider using λ/4 impedance transformers with a characteristic impedance of and a lumped isolation resistor of $2Z_0$ with all three ports matched, high isolation between the output ports is obtained [11].

The dual band Wilkinson power divider requires the usage of transmission lines which act as inverters at the two working frequencies, meaning that they must introduce a pair of phases of (π/2, -π/2) so that particular CRLH transmission lines can be implemented. After the designing of the transmission line, we can design the Wilkinson power divider with that. The scheme is the classical one, where the quarter wavelength transmission lines with different characteristic impedances are replaced by CRLH transmission lines previously designed. Through several times of adjusting on the impedances by the width, the gap size and the length of the CPW-TL, the structure of Wilkinson power divider using CRLH metamaterials is obtained as shown in Fig. 5a, and a photograph of the proposed power divider is shown in Fig. 5b. As shown in Fig. 5a, W, W1, S1, S2, S3, R1, R2, L and L1 are 3.60 mm, 2.10 mm, 0.15 mm, 0.20 mm, 0.11 mm, 3.67 mm, 5.80 mm, 1.00 mm, and 1.20 mm, respectively.

Also, the index of the CRLH TL part is the same as Fig. 2a. The size of this proposed power divider is 35.0 × 25.0 mm^2.



(a)

(b)

〈그림 5〉 CRLH 전송선로 unit-cell을 적용한 위킨슨 전력 분배기 (a) 물리적인 구조, (b) 제안된 전력 분배기의 사진

〈Fig. 5〉 An equal Wilkinson power divider using CRLH-TL unit cell, (a) physical structure (b) a photograph of the proposed power divider

2. Simulation and experiment results of the proposed power divider

The simulated and measured results of the proposed power divider using CRLH-TL is shown in Fig. 6. As shown in the figure, there are two bands at Ku-band radar ranges. At the first band, the bandwidth is 8.7% at 12.6 GHz, the insertion loss is less than 3.8 *dB,* the value of S_{21} is as the same as S_{31}, which can be clearly observed that the proposed dual-band divider provides equal in-phase power split between output ports in the two passband. The input return loss is greater than 8.0 *dB*, and the isolation loss is greater than 8.5 *dB*. At the second band, the bandwidth is 10.1 % at 17.9 GHz, the insertion loss is less than 4.2 *dB,* while the value of S_{21} is different from S_{31} slightly. The input return loss is greater than 11.0 *dB*, and the isolation loss is greater than 14.5 *dB*. Last but not least, the power is perfectly divided into half at the two output ports at both frequencies.

The isolation of the designed divider is -10 dB, which is not good enough for the application in practice. That's because the parts of CRLH-TL induce extra effects and affect the input impedances of port 2 and 3 greatly. The matching condition of these ports is relatively hard to meet perfectly on a PCB board because of the size limitation during the fabrication in our lab. Tuning the value of resistor across port 2 and 3 would be a good way to optimize the working condition. A design based on a better fabrication precision could also make the divider perform better.

Also, it can be observed the fact that the performances are slightly better for the upper frequency rather than for the lower one. In fact, the approximate value of the components and the dual band behavior make it hard to obtain a similar results for both bandwidths.

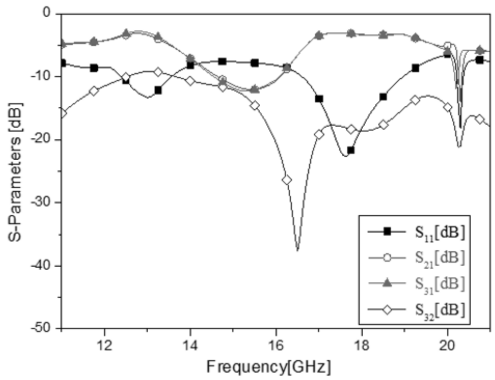
Fig. 6*a* and Fig. 6*b* also indicate that the experimental results agree well with the simulated results. The detailed data is summarized in Table 1.

Comparing with the Bagley polygon power divider using CRLH transmission lines [12] and other dual-band Wilkinson power divider [13, 14], the structure proposed in this paper exhibits comparable bandwidths. The designed power divider using CRLH TL performs wide bandwidth, especially at high frequency ranges, as shown in Table 2.

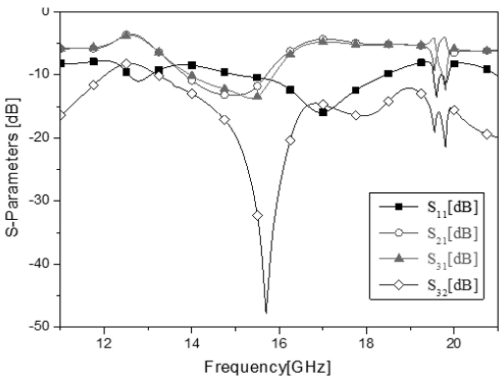
〈표 1〉 시뮬레이션 및 측정 데이터

〈Table 1〉 Simulated and measured data

Parameters	sim. f_1	sim. f_2	mea. f_1	mea. f_2
Frequency [GHz]	13.1	18.1	12.6	17.9
20 dB bandwidth [%]	8.90	11.6	8.70	10.1
insertion loss [dB]	3.50	3.30	3.80	4.20
Return loss [dB]	12.0	14.0	8.00	11.0
Isolation loss [dB]	9.9	18.0	8.50	14.5



(a)



(b)

〈그림 6〉 제안된 전력 분배기의 시뮬레이션 및 측정결과 (a) 시뮬레이션 결과, (b) 측정결과
〈Fig. 6〉 Simulated and measured results of the proposed power divider, (a) simulated result (b) measured result

〈표 2〉 20 dB 대역폭(S_{11})의 이중대역 전력 분배기의 비교
〈Table 2〉 Comparison of 20 dB bandwidth (S_{11}) of the dual-band power divider

ref [#]	20 dB bandwidth @ f_1	20 dB bandwidth @ f_2
This work	8.9 % @ 12.6 GHz	10.1% @ 17.9 GHz
[12]	19.6 % @ 2.55 GHz	4.60% @ 5.40 GHz
[13]	6.67 % @ 7.5 GHz	4.20% @ 17.9 GHz

Ⅴ. Conclusion

A compact ultra-wide band coplanar waveguide transmission line with low loss using composite right/left-handed metamaterial has been successfully designed, and an equal Wilkinson power divider using this CPW CRLH-TL has been discussed. The CRLH-TL shows a good performance that the insertion loss and return loss are 1.0 *dB* and 12.0 *dB* through the frequency range of 8.4-30.0 GHz with bandwidth of about 100 %, respectively. The power divider's dual-band operation can cover the entire Ku-band operating bands, and it has dual bands. The 20 *dB* bandwidths of the lower and upper operating bands are 8.7% at 12.6 GHz and 10.1% at 17.9 GHz, respectively. It performs wide bandwidth, especially at high frequency ranges.

The proposed coplanar waveguide transmission line with low loss using composite right/left-handed metamaterial can be used in UWB application. Also, it can be applied to ITS (Intelligent Transport System) and satellite communication systems.

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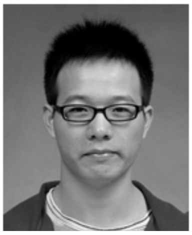
저자소개



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