Design of a compact dual-band branch line coupler using composite right/left-handed transmission lines

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The design of a compact dual-band (DB) branch line coupler (BLC) using composite right/left-handed (CRLH) transmission lines (TLs) is described. By properly choosing the parameters of the CRLH TLs, the structure yields phase responses of $\pi/2$ and $-\pi/2$ at two arbitrary operating frequencies. Employing this structure, a DB microstrip BLC operating at 0.93 and 1.78 GHz is achieved. The size of the proposed DB BLC is significantly compact, at 34.4% of the previous DB BLC when they are both designed using CRLH TLs for the same DB frequencies. The simulated and measured performances of the proposed DB BLC are reliable compared with those of the previous DB BLC.

Introduction: The branch line coupler (BLC) is one of the most widely used microwave devices for practical wireless systems. As wireless system technologies have developed further, the need for dual-band (DB) circuits has continued to increase. A normal right-handed (RH) transmission line (TL) only has a linear phase response. Thus, conventional BLCs designed based on RH TL can only work at one frequency band, lacking the flexibility for the DB operation. However, composite right/left-handed (CRLH) TLs have non-linear phase responses and controllable zeroth-order resonance position, which provides convenience for arbitrary DB designs [1–3]. The DB BLC using CRLH TL was proposed in [4], in which the adopted phase responses are '$-\pi/2$ and $-3\pi/2$' at two frequency bands (f_1 and f_2); however, the circuit is bulky. In this work, the specifications of CRLH are modulated so that the structure yields phase responses of $\pi/2$ and $-\pi/2$ at the same bands, and a more compact DB BLC with even better performances at 0.93 GHz (f_1) and 1.78 GHz (f_2) is designed. The simulated and measured results agree well and are promising.

CRLH TLs and BLC: The units of RH and LH TLs are shown in Fig. 1 [4]. In general, RH TLs represent normal TLs, and CRLH TLs are realised by combining RH and LH TLs. The phase responses of RH and LH TLs, ϕ_R and ϕ_L, are expressed by (1) and (2), respectively.

$$\phi_R = -N\omega\sqrt{L_R C_R} \tag{1}$$

$$\phi_L \approx \frac{N}{\omega\sqrt{L_L C_L}} \tag{2}$$

where N denotes the number of cascaded units, and subscripts R and L refer to RH and LH, respectively. The phase of the CRLH TL (ϕ_C) is the superposition of the RH and LH parts as shown.

$$\phi_C = \phi_R + \phi_L \tag{3}$$

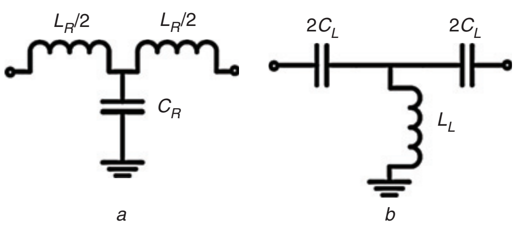

Fig. 1 *Unit cells of RH and LH TLs*
a RH transmission line
b LH transmission line

For conventional RH TLs, the two frequencies of DB should be f_1 and $3f_1$. However, by implementing the CRLH TL structure, the phase response of the CRLH TL can be controlled by adjusting the values of L_R, C_R, L_L, and C_L. Therefore, two arbitrary frequencies (f_1 and f_2) can be realised to meet the requirements of the application.

In this work, the adopted phase responses at f_1 and f_2 are:

$$\phi_C(f_1) = \frac{\pi}{2}, \quad \phi_C(f_2) = -\frac{\pi}{2} \tag{4}$$

The characteristic impedances of RH and LH TLs are defined as

$$Z_{0R} = \sqrt{\frac{L_R}{C_R}}, \quad Z_{0L} = \sqrt{\frac{L_L}{C_L}} \tag{5}$$

The values of L_R, C_R, L_L, and C_L can be calculated from (1)–(5), then CRLH TLs working at the required DB can be designed to replace the $\lambda/4$ TLs in the BLC. Therefore, the designed BLC can work at both f_1 and f_2.

Comparison of the proposed design and previous design in [4]: If the BLC works at the two frequencies of f_1 and f_2, the corresponding phase response pair at the DB should be ($-\pi/2$ and $-3\pi/2$) or $\pm\pi/2$. There is an obvious influence on how we chose the pair of phase responses.

If the pair of '$\pi/2$, $-\pi/2$' is chosen, then

$$\begin{cases} -2\pi f_1 N\sqrt{L_R C_R} + \dfrac{N}{2\pi f_1\sqrt{L_L C_L}} \approx \dfrac{\pi}{2} \\ -2\pi f_2 N\sqrt{L_R C_R} + \dfrac{N}{2\pi f_2\sqrt{L_L C_L}} \approx -\dfrac{\pi}{2} \end{cases} \tag{6}$$

Letting $P = 2\pi N\sqrt{L_R C_R}$, the solution of (6) can be found as

$$P = \frac{\pi}{2}\frac{1}{f_2 - f_1} \tag{7}$$

It is noted that the pair of phase responses in [4] are

$$\phi_C(f_1) = -\frac{\pi}{2}, \quad \phi_C(f_2) = -\frac{3\pi}{2} \tag{8}$$

Similarly, P' can be found in [4] as

$$P' = \frac{\pi}{2}\frac{3f_2 - f_1}{f_2^2 - f_1^2} \tag{9}$$

The RH TL part of the BLC is realised with a normal microstrip line. P or P' can be used to obtain the proper length of the RH TL part, which determines the overall circuit size of the BLC. As a result, at the same DB frequencies, the length of the RH TL part can change according to P.

$$\frac{P}{P'} = \frac{(\pi/2)(1/(f_2 - f_1))}{(\pi/2)((3f_2 - f_1)/(f_2{}^2 - f_1^2))} = \frac{f_2 + f_1}{3f_2 - f_1} = \frac{\alpha + 1}{3\alpha - 1} < 1 \tag{10}$$

P can be compared with P' with $f_2 = \alpha f_1$ and $\alpha > 1$ using (10). It is obvious that P is always smaller than P'. Consequently, the length of TL can be reduced, along with the circuit size. Moreover, another conclusion can be drawn from (10), stating that the reduction of circuit size is more obvious if f_2 is further from f_1.

Simulation and measurement: The proposed DB BLC working at f_1 = 0.93 GHz and f_2 = 1.78 GHz has been designed. The circuit has been fabricated on a substrate with the dielectric constant (ε_r) of 3.2 and thickness (h) of 31 mils. The LH part was realised using lump capacitors and inductors, and the RH part was realised using normal microstrip lines.

Fig. 2 shows the fabricated circuit of the proposed DB BLC and the layout designed by the method in [4] overlapped for the same f_1 and f_2 and substrate. The size of the circuit layout using the previous method is $90.5 \times 93.5\ mm^2$. It is noted that the size of the proposed DB BLC is $52 \times 56\ mm^2$, which is only 34.4% of that of the previous method. The lumped L_L and C_L are 3.7 nH and 2.9 pF for the 35 Ω line sections, respectively, and 5.2 nH and 2.1 pF for the 50 Ω line sections, respectively. The steps to determine lumped L_L and C_L are the same as those described in [4].

The electromagnetically (EM) simulated and measured S-parameters are presented in Figs. 3 and 4, respectively. The measured port matching performances (S_{11}) at f_1 and f_2 are −27.8 and −20.3 dB, respectively, and measured isolation characteristics (S_{41}) at f_1 and f_2 are −19.7 and −31.8 dB, respectively. The measured power divisions to output ports (S_{21} and S_{31}) are −4.28 and −4.37 at f_1, −3.64 and −4.3 dB at f_2, respectively. Even though the two centre frequencies are shifted slightly by 10 and 40 MHz, it is clearly observed that the simulated and measured S-parameters are in good agreement at both frequencies, and the proposed design principle is clearly verified.

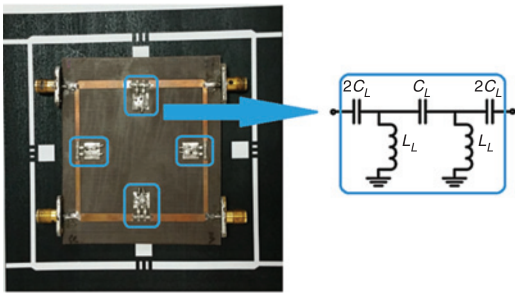

Fig. 2 *Comparison of circuit size of proposed DB BLC (fabrication) and CAD layout designed by Lin et al. [4]*

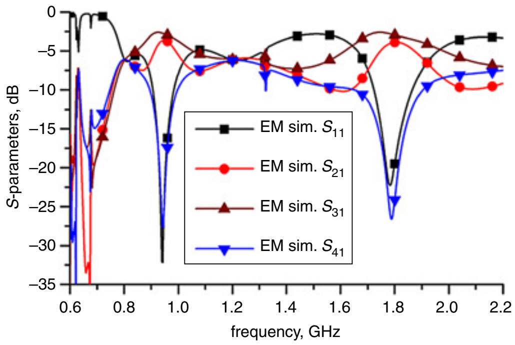

Fig. 3 *EM simulation S-parameters of proposed DB BLC*

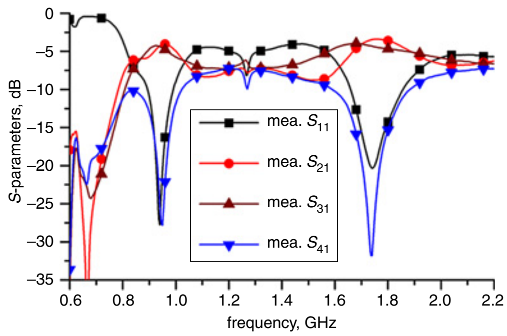

Fig. 4 *Measured performances of proposed DB BLC*

Ideal BLCs have the phase difference of +90° or −90° between output ports. Fig. 5 shows that the measured phase differences are +94.7° and −87.4°, respectively. Considering the non-ideality of the lumped elements and the parasitic components caused by soldering and via-holes, the obtained phase characteristics are acceptable at both bands.

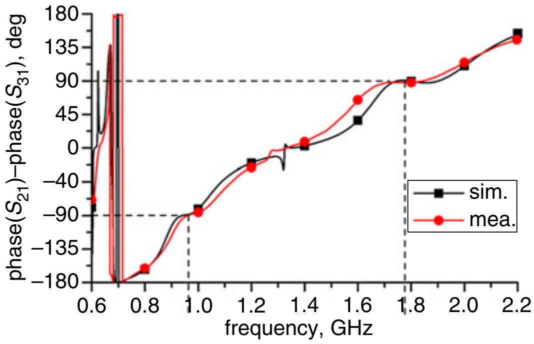

Fig. 5 *Simulation and measured phase differences between output ports*

Conclusion: A principle for compact DB CRLH TLs was proposed and successfully applied to design a BLC operating at 0.93 and 1.78 GHz. The size of the proposed circuit is only 34.4% of that designed using the previous method for the same dual frequencies, while the performances are acceptable at both bands with good agreement with simulation. The DB technique based on CRLH TLs was improved in this Letter.

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One or more of the Figures in this Letter are available in colour online.

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