BRIEF PAPER

A Design of Dual Band Amplifiers Using CRLH Transmission Line Structure

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SUMMARY A design of dual band amplifier using composite right/left handed (CRLH) transmission line structure is described. First, two single-band matching networks are designed for two frequencies, and they are synthesized into one dual band matching network. It is shown that CRLH transmission lines with arbitrary dual frequencies and dual electrical lengths can be designed. The CRLH transmission line section for the dual band matching network is implemented by lumped inductors and capacitors as the left handed (LH) section, and normal transmission line elements as the right handed (RH) section. As an example, a dual band amplifier for 1800 MHz and 2300 MHz is designed and measured. The simulated and measured performances well verify the proposed design by showing good matching and gain responses at the desired frequencies.

key words: *composite right/left handed, CRLH, amplifiers*

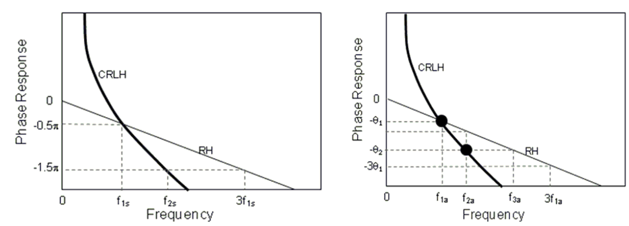

Fig. 1 Phase responses of RHTL and CRLH TL when (a) typical phases of "$-\pi/2$" and "$-3\pi/2$, and (b) arbitrary phases, θ_1 and θ_2, are shown.

1. Introduction

Recently, studies for multiband applications of left handed transmission lines (LHTL) or negative refractive index (NRI) transmission lines have been performed widely [1]–[6]. Those metamaterial sections are implemented on planar circuits with normal right handed transmission lines (RHTL), because RHTL sections play the role of physical base in order for LHTL components to be attached or connected in circuits. So LHTL structures are realized with the form of composite right/left handed (CRLH) transmission lines (TL) structures [4], [5].

One of popular applications of CRLH TL is to design multiband microwave circuits because of the proper multiple phase response of CRLH TL. For example, Lin et al. have proposed a synthesis method of CRLH TL structure for two typically standardized phase values, $-\pi/2$ and $-3\pi/2$, at arbitrary frequencies, f_1 and f_2, respectively, and design a dual band branch line coupler [5].

In many cases, the application of CRLH TL to multiband circuits has been focused on passive devices such as Wilkinson divider and branch line coupler so far [3], [5], [6]. In those passive circuits, typical electrical lengths of transmission lines such as "$-\pi/2$" and "$-3\pi/2$" are so important, and it has been relatively easy to design a CRLH TL of which phases are those typical values at two arbitrary frequencies.

In this work, a dual band amplifier is designed by adopting the CRLH TL in matching network. For this purpose, the CRLH TL with arbitrary phases of θ_1 and θ_2 at two frequencies, which are not the typical values of "$-\pi/2$" and "$-3\pi/2$", is designed in advance because the lengths of transmission line sections in matching networks are usually arbitrary values. The CRLH TL has the required electrical lengths for the dual band matching. The proposed dual band amplifier using CRLH structure will be verified through a design example.

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2. Phase Characteristics of CRLH Transmission Lines

Figure 1(a) shows the phase responses of CRLH and RH transmission lines [5]. The phase or electrical length of RHTLs is straightforward and dependent of frequency directly. So, for example, if the phase of a RHTL is $-\pi/2$ at frequency f_{1s}, then that is $-3\pi/2$ at $3f_{1s}$, definitely. However, in CRLH TL, this proportional relation is not valid any longer, because the frequency, f_{2s}, where the electrical length is $-3\pi/2$, is different from $3f_{1s}$.

Figure 1(b) shows the phase responses of CRLH and RH transmission lines with similar concept, but arbitrary phases, θ_1 and θ_2, are illustrated. If there are two single band matching networks, and if the electrical lengths of transmission line sections in matching networks are θ_1 and θ_2 at f_{1a} and f_{2a}, respectively, then a CRLH structure should be adopted instead of RHTL for the dual band matching network. It should be note that there is no way to get θ_2 at f_{2a} using RHTL when the electrical length of a TL is θ_1 at f_{1a}. This is the key idea of this work to design a dual band amplifier using the phase characteristics of CRLH TL.

3. Design of Dual Band Amplifier

Figure 2 shows the basic concept of amplification responses

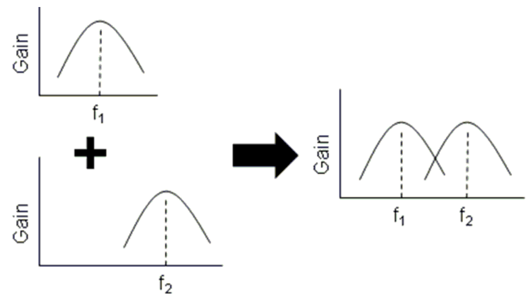

Fig. 2 Concept of the dual band amplifier response at two frequencies, f_1 and f_2.

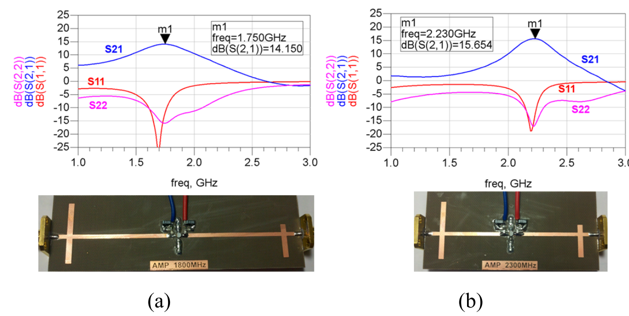

Fig. 4 Measured S-parameters and photos of two single band amplifiers at frequencies (a) f_1 and (b) f_2.

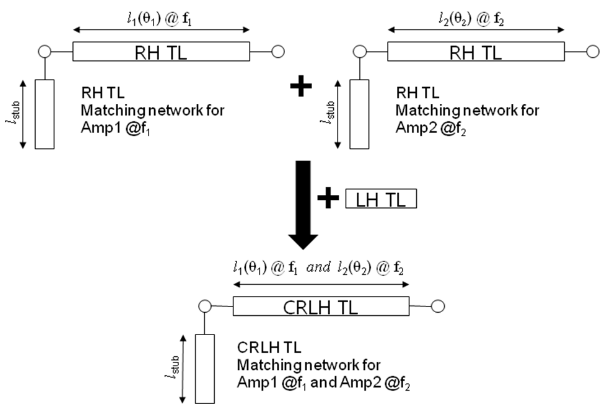

Fig. 3 Principle of the matching network for the dual band amplifier.

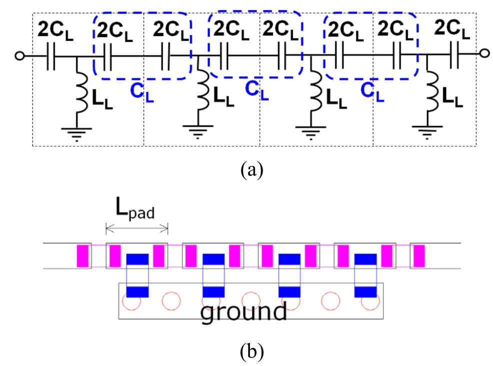

Fig. 5 Four units of the CRLH TL sections in the dual band matching network. (a) schematic and (b) layout

of two single bands and one dual band. When there are two single band amplifiers at frequencies f_1 and f_2, it is possible to design one dual band amplifier by design the dual band matching circuit using the phase characteristics of CRLH TL. Because the matching at both frequencies is preserved independently, the gain is obtained separately.

Figure 3 explains the dual band matching network of the proposed design. When two single band amplifiers at frequency f_1 and f_2 are called as "Amp1" and "Amp2", respectively, one can design the matching network easily by adopting L-section topology with single or double stubs [7]. Although the length of stub ("l_{stub}") is fixed to be the same intentionally, the lengths of transmission line sections in matching networks should be different at f_1 and f_2. Those are l_1 and l_2 with the corresponding electrical lengths θ_1 and θ_2, respectively.

In most dual band amplifier applications, the ratios between f_1 and f_2, and θ_1 and θ_2 are not integer values, but arbitrary real numbers. Therefore, two RHTL can be synthesized into one CRLH TL based on the phase response in Fig. 1(b), and the dual band matching network is obtained.

In order to design the dual band matching circuit using CRLH TL structure with the consideration of arbitrary electrical lengths, θ_1 and θ_2, instead of typical lengths, "$-\pi/2$" and "$-3\pi/2$", Eqs. (10)–(18) in [5] should be modified properly. The resultant equations can be written as (1) and (2), which should be reflected into the implementation of the dual matching circuit.

$$P = \frac{\theta_2 f_2 - \theta_1 f_1}{f_2^2 - f_1^2} \tag{1}$$

$$Q = \frac{\theta_2/f_2 - \theta_1/f_1}{1/f_2^2 - 1/f_1^2} \tag{2}$$

As a design example of dual band amplifier, first, we have designed two single band amplifiers at 1.8 GHz and 2.3 GHz. In the case of input matching networks, the required l_1 and l_2 at f_1 and f_2 are 0.305λ and 0.244λ, respectively, and the open stubs have been fixed to have the same length intentionally. The same design procedure has been applied to the output matching circuit, so the description about the output matching networks is omitted here.

The measured S-parameters and photos of the fabricated single band amplifiers are illustrated in Fig. 4. Even though mild frequency shifts are observed commonly, the measured S-parameters are proper as examples to illustrate the concept in Fig. 2.

Now, the dual band amplifier can be designed by applying the theory in [5] and modified Eqs. (1) and (2) and using the above single band amplifiers. The resultant right handed section, ϕ_R, has been calculated as 0.606π at 1.8 GHz which corresponds to 34.8 mm in physical length for the given substrate with 2.6 of dielectric constant and 20 mils of thickness.

Figure 5(a) shows the schematic of CRLH TL section for the dual band matching network. Four units have been implemented into the dual band amplifier. From the results

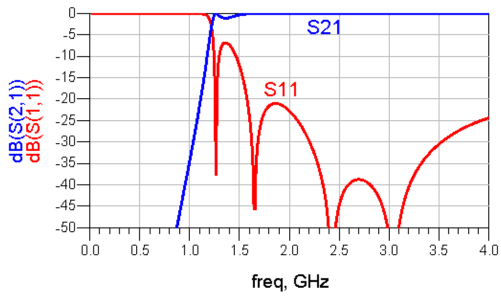

Fig. 6 High pass characteristics of the LHTL section.

of the design procedure and consideration for the available lumped chip capacitors and inductors, C_L and L_L with 1.2 pF and 3.9 nH have been selected.

Strictly speaking, Fig. 5(a) shows a schematic of pure LHTL. However, it is noted that lumped elements are attached to transmission line elements as shown in Fig. 5(b), which shows the practical layout of the RHTL section with lumped capacitors and inductors attached. So it is reasonable to recognize this structure as a CRLH TL section.

In practice, short transmission line elements or pads like stepping stones play roles of physical base to attach chip inductors and capacitors to planar substrate as well as the section of RHTL to compose CRLH TL. The adopted L_{pad} is 3.4 mm, and these four short transmission line pads have to be deducted from the initial length of ϕ_R, 34.8 mm. Then, the remaining length of RHTL section, 21.2 mm, is divided and connected to the CRLH section in series as will be shown later in Fig. 7.

It should be proved that the high pass circuit in Fig. 5(a) passes the signal at the desired frequencies, f_1 and f_2, safely without a critical loss or rejection. Figure 6 shows the S-parameters of the CRLH TL section of Fig. 5 with C_L and L_L with 1.2 pF and 3.9 nH, respectively. No critical problem is shown above 1.5 GHz.

It may be needed to check the characteristic impedance of CRLH TL section, because the series lines in matching networks in Fig. 4 are 50 Ω microstrip lines. If we calculate the characteristic impedance of CRLH TL section using the simple equation, $(L_L/C_L)^{1/2}$, then 57 Ω is obtained. However it is noted that the rectangular soldering pad with the size of 3.4 mm × 1.4 mm has been inserted, and this gives 0.22 pF of additional capacitance per unit section. So calculating $\{L_L/(C_L+0.22\,\text{pF})\}^{1/2}$, 52.4 Ω is produced. Even though it is not 50 Ω exactly, it is believed to be reasonable value.

4. Fabrication and Measurement

Figure 7 shows the fabricated dual band amplifier. The planar substrate with the dielectric constant of 2.6 and thickness of 20 mils has been adopted, and FHX35LG microwave transistor has been used for the amplification device. The CRLH TL sections have been implemented in matching circuits.

It is noted that DC blocks such as capacitors or coupled lines, which are essential to all amplifiers conventionally,

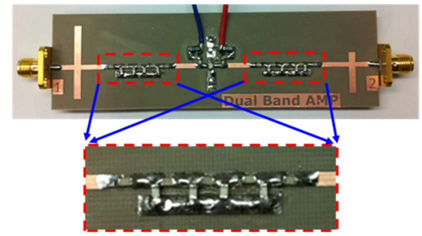

Fig. 7 Fabricated dual band amplifier.

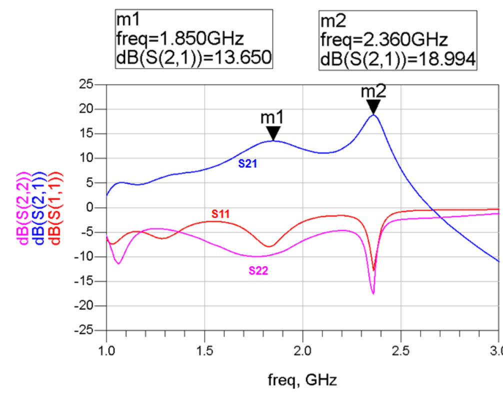

Fig. 8 Measured S-parameters of the fabricated dual band amplifier.

are not required any more in the proposed dual band amplifier, because series capacitors are included in the CRLH TL section inherently. So, additional DC blocks have not been inserted intentionally in two single band amplifiers in Fig. 4.

Figure 8 represents the measured performance of the dual band amplifier. Even though matched frequency points and gain peaks shifted slightly from Fig. 4, the characteristics as a dual band amplifiers are observed evidently. One can recognize that dual band gain performances have been obtained not by chance but matching from the measured S_{11} and S_{22}.

It is believed that the minor discrepancies in frequency and gain have been caused by the tolerance (percentage error) of chip inductors and capacitors, and unwanted parasitic components which exist in chip elements. However, the tolerance is inevitable and the extraction of parasitic elements might be another research issue, so this step has been omitted in this work.

In addition, lumped chip components are available with discrete values, which are pre-determined by the vendors. In this work, the required C_L and L_L were 1.13 pF and 3.67 nH at first, but they were not available, so replaced by 1.2 pF and 3.9 nH, respectively. In spite of limitations due to the discrete lumped elements' value and tolerances, the measured gain and matching performances at dual frequencies are promising. It is believed that the proposed design method would be a good choice for dual band high frequency amplifiers and systems.

5. Conclusion

In this work, a dual band amplifier has been proposed with the design method, and verified successfully by the fabrication and measurement. A CRLH transmission line structure has been implemented in the matching networks of the dual band amplifier. As a design example, a dual band amplifier has been designed and measured for the frequencies at 1.8 GHz and 2.3 GHz. Even though the operating frequencies shifted slightly due to the tolerances of lumped chip inductors and capacitors, the measured dual band gain and matching performances were so good for the proposed amplifier to be considered as a dual band amplifier. The authors are going to study the proposed amplifier further to apply to high power amplifiers in the future.

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