New Approach to Hybrid Multiplexer Using Composite Right-Left Handed Lines

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***Abstract*—In this letter, a new approach to hybrid multiplexer is proposed which is based on the frequency dispersive characteristic of the Composite Right Left Handed (CRLH) lines, which in conjunction with dual band filters permit one single module to handle two frequencies. This allows size reduction since only half as many modules are required for multiband systems. Simulated and measurement responses are presented showing good agreement.**

***Index Terms*—Composite right left handed (CRLH) lines, defected ground surface, filters, multiplexer.**

I. Introduction

THE hybrid coupler multiplexer is a well-known configuration [1]–[3] consisting of two 3 dB hybrid-couplers connecting two identical filters to form one module.

However, one of the main drawbacks of the conventional hybrid multiplexers is their large size since two broadband hybrid couplers and two identical filters are utilized per frequency channel. In this letter, a novel approach to Hybrid Multiplexer using CRLH lines is described, where two CRLH lines are connected to two identical dual band filters. These in turn are connected to two broadband hybrid couplers to form one module. By doing this, each module handles two frequencies instead of a single frequency as in conventional systems. This new technique is based on the frequency dispersive characteristic of the CRLH lines [4]. The circuit schematic is shown in Fig. 1(a). Module 1 consists of a dual band filter operated at f_1 and f_2 and two CRLH lines (CRLH 1 and CRLH 2). The input signal is applied to port 1, which is divided into two equal halves with 90° phase shift between terminals 1 and 2 (see Fig. 1(a)). The two dual band filters will select f_1 and f_2. Here, the CRLH lines (CRLH 1and CRLH 2) are designed with the condition such that they provide 0° phase shift at f_1 and 180° phase shift at f_2. Hence, due to the nature of the quadrature hybrid coupler, f_2 will be coupled to port 3 and f_1 will be coupled to port 4. In this work, a four band multiplexer is presented consisting of two modules fabricated on RT/ Duroid 5880 substrate with thickness $h = 0.5$ mm and Tan$\delta = 0.0009$. Module 1 operates at $f_1 = 1.6$ GHz and $f_2 = 2.2$ GHz. Module 2 operates at $f_3 = 1.9$ GHz and $f_4 = 2.5$ GHz. Simulation and experimental responses are given with good agreement.

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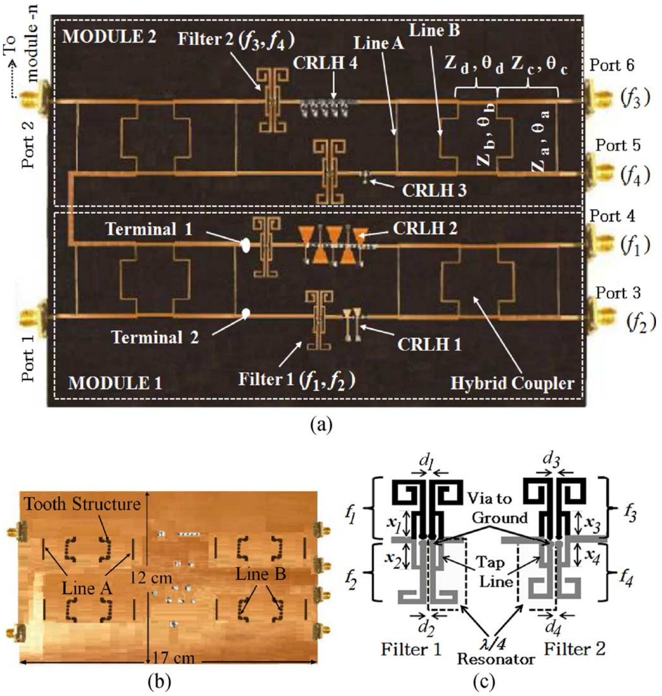

Fig. 1. (a) Top view photo of proposed four-channel Mux. system, (b) Ground plane of system, and (c) Layout of dual band filters ($x_1 = 7$ mm, $x_2 = 5.8$ mm, $x_3 = 6.2$ mm, $x_4 = 5.4$ mm, $d_1 = 0.6$ mm, $d_2 = 0.4$ mm, $d_3 = 0.6$ mm and $d_4 = 0.4$ mm).

II. Prototype Description

A. Dual Band Filter

For the operation of the proposed multiplexer, two dual band filters are required. The first filter operates at $f_1 = 1.6$ GHz and $f_2 = 2.2$ GHz and the second one at $f_3 = 1.9$ GHz and $f_4 = 2.5$ GHz. Each filter has a 2-pole Chebyshev response with parallel-coupled $\lambda/4$ resonators (Fig. 1(c)). Their fractional bandwidth is FBW $= 4.5\%$ and ripple 0.01 dB. For a normalized lowpass cutoff frequency ($\Omega_c = 1$), the prototype element values are $g_0 = g_3 = 1$, $g_1 = g_2 = 0.4078$. The external Q (Q_{ext}) and resonator coupling ($\mathrm{M}_{1,2}$) parameters can now be calculated from (1) and (2) [5]. In order to relate the required Q_{ext} to the filter layout, a single resonator is simulated in [6]. For the simulation, one port is weakly coupled and the other one is tap-coupled. For the f_1 filter, by changing the tap distance x_1 (Fig. 1(c)), the value of Q_{ext} is modified and can be calculated with (3) [5]. For the resonator coupling ($M_{1,2}$),

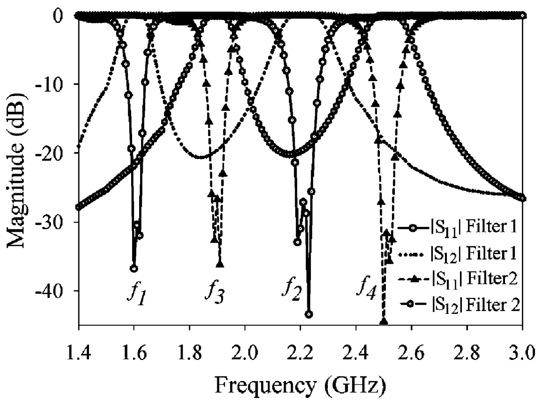

Fig. 2. Simulation results of dual band filters.

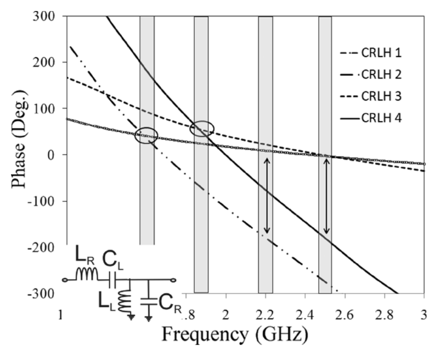

Fig. 3. Unwrapped phase of CRLH lines.

two resonators are simulated with both ports weakly coupled. Then, for the f_1 filter, d_1 is adjusted until the required value is achieved by (4). The same applies for f_2, f_3, and f_4 filters. The design procedure is detailed in [5]. The final values for both filters are outlined in Fig. 1(c). Fig. 3 shows a simulation [6] of the insertion and return losses of the filters, where the required center frequencies can be clearly observed

$$Q_{ext} = \frac{g_0 g_1}{FBW} \tag{1}$$

$$M_{1,2} = \frac{FBW}{\sqrt{g_1 g_2}} \tag{2}$$

$$Q_{ext} = \frac{f_0}{BW_{3\text{ dB}}} \tag{3}$$

$$M_{1,2} = \frac{[f_m^2 - f_n^2]}{[f_m^2 + f_n^2]} \tag{4}$$

where f_0 is the center frequency, $BW_{3\text{ dB}}$ is the 3 dB bandwidth, and f_m and f_n are the resonant frequencies of two resonators (see Fig. 2).

B. CRLH Lines

For our multiplexer, the basic condition for designing CRLH lines is such that both lines of Module 1 (CRLH 1 and CRLH 2) should offer 0° phase shift between them at $f_1 = 1.6$ GHz and 180° at $f_2 = 2.2$ GHz as shown in Fig. 3. In order to calculate the component values, the procedure shown in [4] was followed. One designing restriction is that the phase slope (ϕ versus f) for CRLH 1 should be relatively small so that the phase slope

TABLE I
COMPONENT VALUES OF CRLH LINES AND THEIR SIMULATION LOSSES

	n	C_R (pF)	L_R (nH)	C_L (pF)	L_L (nH)	*IL (dB)*	*RL (dB)*
CRLH 1	2	0.9	2.4	2.15	5.4	0.3	20
CRLH 2	5	2.3	5.8	1.48	3.7	0.5	14
CRLH 3	1	0.48	1.2	2	5.3	1	10
CRLH 4	5	2	4.2	1.7	5	2	14

for CRLH 2 does not become impractically high. An equivalent circuit of a unit cell is shown in Fig. 3.

For CRLH 1, two unit cells are utilized. ϕ is chosen as $\phi_{\text{CRLH\_1}} = 40°$ at f_1 and $\phi_{\text{CRLH\_1}} = 8°$ at f_2. Therefore, for CRLH 2, $\phi_{\text{CRLH\_2}} = 40°$ at f_1 and $\phi_{\text{CRLH\_2}} = -172°$ at f_2. From [4], the component values are calculated and exhibited in Table I. For CRLH 1, a chip capacitor was employed for C_{L1} and the rest were implemented as distributed elements. For CRLH 2 five unit cells were employed. Here, L_{R2} and C_{L2} are implemented as chip components and the rest as distributed elements. For Module 2, $\phi_{\text{CRLH\_3}} = 50°$ at 1.9 GHz and $\phi_{\text{CRLH\_3}} = 0°$ at 2.5 GHz. Therefore, $\phi_{\text{CRLH\_4}} = 50°$ at 1.9 GHz and $\phi_{\text{CRLH\_4}} = -180°$ at 2.5 GHz. Table I shows the component values and Fig. 1(a) shows the layout of the lines.All the lines were simulated in [6] including material losses. The maximum insertion losses for the required bandwidth (1.5–2.6 GHz) are shown in Table I. The high insertion losses presented by CRLH 3 and 4 are due to the lossy characteristic of the SMD components. The return losses are better than 10 dB, being the worst-case line 3.

C. Defected Ground Hybrid Coupler

For this system, hybrid couplers covering the whole multiplexer bandwidth (1.6–2.5 GHz) are needed. Therefore, in order to implement a wide band coupler, the defected ground technique shown in [7] was implemented. As it is well known, for wide bandwidths multiple-branch line couplers can be utilized. However, the impedances of the middle lines [Z_a and Z_b of Fig. 1(a)] become impractically high for fabrication purposes. For a conventional 4-branch coupler, the required impedances are $Z_a = 217\ \Omega$, $Z_b = 131\ \Omega$, $Z_c = Z_d = 50\ \Omega$. Nevertheless, in order to decrease the high impedance values (Z_a and Z_b), an optimization was performed in [6] to reduce their values while still covering the required bandwidth. The optimized impedance and electrical length of each section are $Z_a = 142\ \Omega$, $Z_b = 154\ \Omega$, $Z_c = 50\ \Omega$, $Z_d = 57\ \Omega$, $\theta_a = 70°$, $\theta_b = 103°$, $\theta_c = 73°$ and $\theta_d = 48.4°$ [Fig. 1(a)]. Notice that θ_c and θ_d are shorter than 90°. In order to implement $Z_a = 142\ \Omega$ of line A, a slot on the ground plane was utilized as described in [7] [Fig. 1(b)]. The slot on the ground plane reduces the capacitance per unit length of the transmission line and hence, can increase the characteristic impedance of the line. For line B, a tooth like defected ground structure is added to achieve $Z_b = 154\ \Omega$. The final coupler is shown in Fig. 1. By using [6], its response was simulated giving an insertion loss of the coupled port of $3 + / - 0.6$ dB for the required bandwidth. In addition, the matching and isolation are better than 20 dB. It is also observed that the phase difference between output ports is $90° + / - 2°$ for the same bandwidth.

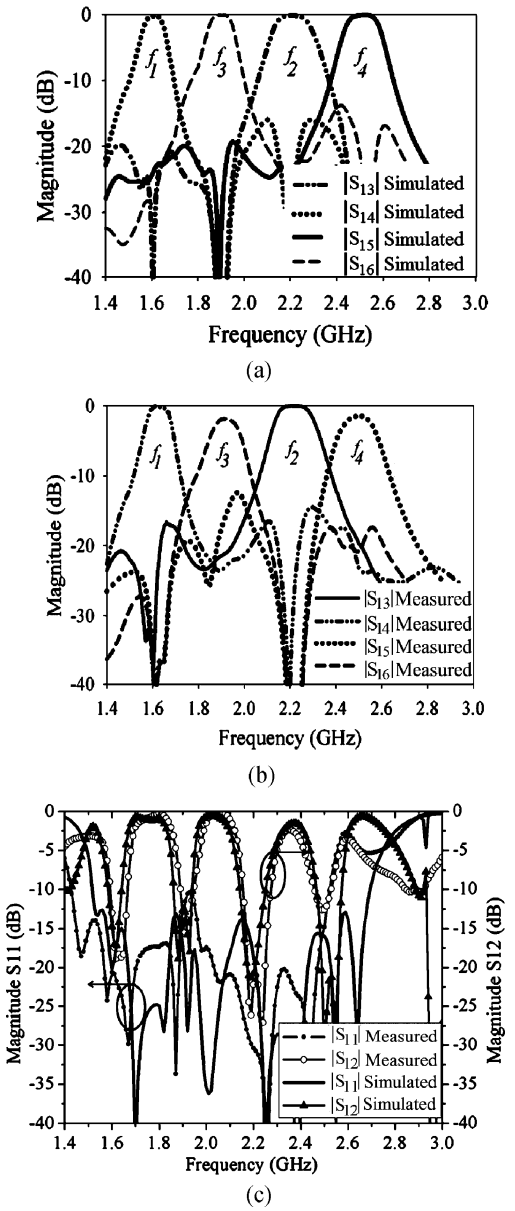

Fig. 4. Simulation and measured results of the proposed four-channel system, (a) Simulated insertion losses, (b) Measured insertion losses, (c) Simulated and measured $|S_{11}|$ and $|S_{12}|$.

III. Simulated and Experimental Results

The complete system is shown in Fig. 1. The simulation of the complete system was carried out in [6] assuming lossless materials. Measurements were performed using a Network Analyzer (Agilent E8361A).

Fig. 4(a) presents the simulation response of the insertion loss parameters ($|S_{13}|$, $|S_{14}|$, $|S_{15}|$, and $|S_{16}|$). It is seen that the out of band rejection is higher than15 dB throughout the band, with the worst case $|S_{16}|$ being at 2.4 GHz. This rejection is mainly due to the reflection of the CRLH lines. Fig. 4(b) presents the measurement responses of the insertion loss parameters ($|S_{13}|$, $|S_{14}|$, $|S_{15}|$, and $|S_{16}|$). The passband insertion losses of Module 1 are 0.4 dB at f_1 and 0.5 dB at f_2. For Module 2 the insertion loss at f_3 is 1.9 dB and 1.5 dB at f_4.

Losses for Module 2 are about 1 dB higher than for Module 1 due to the lossy contribution of CRLH 4, which was implemented purely with chip components. CRLH 2 of Module 2 was implemented with a combination of distributed and chip components, hence its losses are about 1 dB lower compared to CRLH 4. For the experimental out of band rejection, the worst case is for $|S_{15}|$ at 1.95 GHz with 14 dB. This relatively low value is mainly caused by the high return loss contributions of CRLH 3 and 4 (Table I). Moreover, since both lines are manufactured with SMD components, mismatches not considered in the simulations occur such as soldering and manufacturing errors in the via-holes.

Fig. 4(c) shows the $|S_{11}|$ and $|S_{12}|$ simulation and measured responses. Reflection ($|S_{11}|$) is better than 15 dB throughout the band for the simulation, whereas for the measurement it is better than 12 dB. Isolation ($|S_{21}|$) is experimentally better than 14 dB at the center of the bands, whereas in the simulation it is better than 18 dB. It can be observed that isolation is much better for frequencies f_1 and f_2 compared to f_3 and f_4. This is mainly caused by the matching conditions of CRLH 3 and 4 (Table I).

The experimental isolation characteristics between Module1 and 2 ($|S_{35}|$, $|S_{36}|$, $|S_{45}|$ and $|S_{46}|$) are better than 18 dB from 1.5–3 GHz. For $|S_{56}|$, the experimental value is 16 dB at 1.6 GHz, 11 dB at 1.9 GHz, 14 dB at 2.2 GHz and 12 dB at 2.5 GHz. In the case of $|S_{34}|$ the value is 25 dB at 1.6 GHz, 30 dB at 1.9 GHz, 18 dB at 2.2 GHz and 18 dB at 2.5 GHz. By comparing $|S_{56}|$ and $|S_{34}|$. It is observed that the module with purely SMD CRLHs shows poorer isolation, which can also be attributed to poor matching conditions of CRLH 3 and 4.

IV. Conclusion

In this letter, a novel approach to Hybrid Multiplexer, using CRLH lines was proposed. This technique is based on the frequency dispersive characteristic of the CRLH lines, which in conjunction with dual band filters enable one single module to handle two frequencies. The proposed multiplexer consists of four channels using two modules at 1.6, 1.9, 2.2, and 2.5 GHz. Simulated and experimental responses have been presented showing good agreement.

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