Designing a high gain dual-band DA with CRLH-TL

Mohammad Mahdi Pezhman, Esmat Rashedi
Dept. Electrical and Computer Engineering
Kerman Graduate University of Technology, KGUT
Kerman, Iran
pezhmannehdi@ymail.com, c.rashedi@kgut.ac.ir

Ahmad Hakimi
Dept. Electrical Engineering
Shahid Bahonar University of Kerman
Kerman, Iran
hakimi@mail.uk.ac.ir

Abstract— A dual-band distributed amplifier with composite right/left handed transmission line (CRLH-TL) is proposed. The CRLH-TL is a new meta-transmission line that provides several unique features. Dual-band operation is the most important feature of these lines. In this paper, by using the CRLH-TL in the structure of distributed amplifier, both the forward gain and reverse gain are available. Also, to increase the gain of the amplifier, a novel circuit architecture for the dual-band distributed amplifiers is proposed. The results show that the propose amplifier has high gain, reasonable input and output matching and wide bandwidth in the forward and reverse bands.

Keywords-component; composite right/left handed (CRLH), dual-band DA, forward gain, reverse gain.

I. INTRODUCTION

Broadband amplifier is one of the main components in modern communication systems. There are special techniques in order to achieve wide bandwidths. Distributed amplifier (DA) is one of the most popular broad-band amplifier configurations. DAs are well known in providing a broad band gain and are suitable to be integrated with transmission lines (Tls) [1-3]. In the conventional distributed amplifiers (CDAs), the right-handed (RH) transmission lines or left-handed (LH) transmission lines are frequently used. In the last few years, a novel DA with unique application is proposed [4, 5]. In this type of DAs, the CRLH-TLs are used. CRLH-TLs are a new artificial transmission line that have drawn much attention in the microwave Community due to their distinctive characteristics. This kind of transmission line included both Right-Handed (RH) and Left-Handed (LH) transmission lines properties. As a result, by using these transmission lines in distributed amplifiers, two amplified frequency bands are produced. This type of amplifiers are named dual-band distributed amplifiers. But the power gain of the conventional dual band DA is relatively low. For solving this problem, a new structure of the dual-band DA is proposed. In this topology, the one-stage DA with cascaded gain cell cascades the conventional dual-band DA. The theoretical analysis of the dual-band DA with CRLH-TL is given in section II. In section III, the proposed dual-band DA is designed and the simulation results and conclusion are presented in Sections IV and V, respectively.

II. ANALYSIS OF DUAL-BAND DA

DAs consist of cascading active devices coupled by input and output transmission lines. The general structure of the DA is shown in Fig.1. The input signal propagates in the actives devices (FETs) by the gate transmission line and the amplified signal of each stage is added to the output by drain transmission line. The forward and reverse gains of the DA can be defined as Eqs. (1) and (2), respectively, assuming that the input and output resistances of the transistors are neglected [6, 7].

\[ G_{fwd} = \frac{P_{fwd}}{P_{in}} = \frac{g_m^2 z_{0g} z_{sd}}{4} \left( \frac{\sin \frac{n}{2} (\beta_s - \beta_d)}{\sin \frac{1}{2} (\beta_s - \beta_d)} \right)^2 \]  

Fig.1. conventional distributed amplifier

This paper is authentic if it can be found in www.isseem.ir
\[ G_{nv} = \frac{P_{nv}}{P_n} = \frac{g_m z_0 z_{ad}}{4} \left( \frac{\sin \frac{n}{2} (\beta_x + \beta_y)}{\sin \frac{1}{2} (\beta_x + \beta_y)} \right)^2 \] (2)

Where \( z_0 \) and \( z_{ad} \) are the gate and drain line characteristic impedance, \( g_m \) is the FET transconductance, \( \beta_x \) and \( \beta_y \) are the propagation constants of the gate and drain line, and \( n \) indicates the number of unit cells. In the conventional DAs, RH transmission lines are usually used. Fig.2 shows the equivalent circuit of the RH-TL.

The propagation constant for the RH-TL is given by Eq.3.

\[ \beta = \omega \sqrt{L_{RH} C_{RH}} \] (3)

As the sign of propagation constant of the RH-TL is only positive, so the total output wave at the drain transmission line is added in phase, only when the propagation constants of the gate and drain transmission lines are equal (\( \beta = \beta_x \)). As a result, according to (1), (2), only the forward gain is available in the conventional DA. But, by replacing the CRLH-TL with conventional transmission line (RH-TL), a new performance of the DA can be achieved. The equivalent circuit of the CRLH-TL is given in Fig.3.

The CRLH-TL consists of series inductor \( L_{RH} \) and capacitor \( C_{RH} \) cascaded with shunt capacitor \( C_{LIH} \) and inductor \( L_{LIH} \). The propagation constant of the CRLH-TL can be expressed as Eq. (4) [8].

\[ \beta = s(\omega) \left( \frac{\omega L_{RH}}{\omega L_{LIH}} \right)^{1/2} \] (4)

Where \( s(\omega) \) is:

\[ s(\omega) = \begin{cases} -1 & \text{if } \omega \leq \min(\omega_{se}, \omega_{sh}) \\ +1 & \text{if } \omega \geq \max(\omega_{se}, \omega_{sh}) \end{cases} \] (5)

According to Eqs. (4) and (5), the propagation constant of the CRLH-TL could be both positive and negative. Hence, the situations of \( \beta = \beta_x \) and \( \beta = \beta_y \) can be achieved at various frequencies. As a result, according to Eqs. (1) and (2), the forward and reverse gain are both available in two separate frequency bands.

III. DESIGNING OF THE PROPOSED DUAL-BAND DA

Fig.4. Shows the schematic of the proposed dual-band DA. The gate transmission line is realized with a MS-TL (RH-TL) and the drain transmission line is a CRLH-TL[9]. Port\#1 and port\#4 of the gate line are the input port and the isolated port, respectively. Port\#2 and port\#3 of the drain line are the output ports.
The objective is to design a dual-band DA at central frequencies 1.8GHz for reverse gain, and 3.1GHz for forward gain. The propagation constant of the gate transmission line (RH-TL) at critical frequencies is calculated as Eq. (6).

\[
\begin{align*}
    f_1 &= 1.8\text{GHz} \leftrightarrow \beta_1 = 1.035\text{rad} / \text{m} \\
    f_2 &= 3.1\text{GHz} \leftrightarrow \beta_2 = 1.73\text{rad} / \text{m}
\end{align*}
\]

According to Eqs. (4) and (5), The CRLH-TL lumped elements are designed as table I. In this design, the gate transmission line (RH-TL) can be released by \( C_e \) and \( L_e \).

<table>
<thead>
<tr>
<th>Lumped element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_e )</td>
<td>1.75 pF</td>
</tr>
<tr>
<td>( L_e )</td>
<td>4375 nH</td>
</tr>
<tr>
<td>( C_{mR} )</td>
<td>3.8 pF</td>
</tr>
<tr>
<td>( L_{mR} )</td>
<td>9.5 nH</td>
</tr>
<tr>
<td>( C_{mL} )</td>
<td>0.52 pF</td>
</tr>
<tr>
<td>( L_{mL} )</td>
<td>1.3 nH</td>
</tr>
</tbody>
</table>

In this paper, to increase the forward and reverse gains without sacrificing the bandwidth, one-stage DA with cascaded gain cell presented in[10-12], is used in the conventional dual-band DA structure. In this case, the maximum power gains for reverse and forward bands are given by Eqs. (7), (8):

\[
\begin{align*}
    G_{mod} &= \frac{1}{16} n^2 g_m^6 Z_0^6 \\
    G_{rev} &= \frac{1}{16} n^2 g_m^6 Z_0^6
\end{align*}
\]

Assuming that the gate and drain characteristic impedance are equal (\( Z_{0g} = Z_{0d} = Z_0 \)). Hence, by the one-stage DA cascaded conventional dual-band DA, the forward and reverse power gains can be increased without sacrificing the bandwidths. Since in this topology, the stage of the input is one, so the input can be matched to the 50Ω environment easily.

IV. SIMULATION RESULTS

In this paper, a high gain dual-band DA with CRLH-TL is designed. The number of stage for this amplifier is two (\( n=2 \)). The proposed dual-band DA is simulated in a BSIM3 0.13μm CMOS technology with Advanced Design System (ADS) simulator. The widths of the transistors are selected as 85 μm and termination resistances of the gate and drain transmission line are set 50 Ω. The central frequencies are designed to be 1.8 GHz for reverse gain (port 3) and 3.1 GHz for forward gain (port 2). The forward and reverse gain of proposed amplifier are shown in Fig.5. The results indicate that this dual-band DA exhibits a 22dB reverse gain with a bandwidth of 800 MHz and a 23 dB forward gain with a bandwidth of 1.2GHz. The proposed circuit achieves the highest forward and reverse gain-bandwidth product in compared to conventional dual-band DA[4, 5] while maintaining a compact chip size.

![Fig.5. the forward and reverse gains of the proposed dual-band DA.](image)

![Fig.6. Input and Outputs matching performances of the proposed dual-band DA](image)
Input and outputs matching performances of the proposed dual-band DA are shown in Fig. 6. As can be seen in Fig. 6, input and outputs match performances of the proposed dual-band DA are satisfactory through the forward and reverse bandwidths. Fig. 7 shows the simulated forward and reverse noise figure (NF) as a function of the frequency. The NFs are between 7–8 dB in the forward and reverse frequency bands. The performance summary of the multi-band amplifiers are listed in Table II.

![Simulated NF of the proposed dual-band DA](image)

**Table II. PERFORMANCE SUMMARY AND COMPARISON**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Tech.</th>
<th>Num. of outputs</th>
<th>Gain(dB)</th>
<th>BW(GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[13]</td>
<td>180nm CMOS</td>
<td>1</td>
<td>8</td>
<td>3.1, 8.72</td>
</tr>
<tr>
<td>[8]</td>
<td>130nm CMOS</td>
<td>1</td>
<td>10</td>
<td>2.5, 2.9, 3.4, 3.6, 5.2, 5.9</td>
</tr>
<tr>
<td>[9]</td>
<td>HEMT</td>
<td>2</td>
<td>8, 11</td>
<td>2.3, 2.8, 3.5, 4.2</td>
</tr>
<tr>
<td>This work</td>
<td>130nm CMOS</td>
<td>2</td>
<td>22, 23</td>
<td>1.8, 3.1</td>
</tr>
</tbody>
</table>

V. CONCLUSION

In this paper, a dual-band distributed amplifier with CRLH-TL has been presented. To increase the forward and reverse gains of this amplifier, one-stage DA is used in the structure of conventional dual-band DA. The proposed design exhibits a 22 dB reverse gain with a bandwidth of 800 MHz and a 23 dB forward gain with a bandwidth of 1.2 GHz.

**REFERENCES**


