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Distributed amplifier of L-type network with 2-μm GaAs HBT process

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Abstract: The characteristic impedances of L-type and T-type networks are first investigated for a distributed amplifier design. The analysis shows that the L-type network has better frequency characteristics than the T-type one. A distribution amplifier based on the L-type network is implemented with the 2-μm GaAs HBT (heterojunction-bipolar transistor) process of WIN semiconductors. The measurement result presents excellent bandwidth performance and gives a gain of 5. 5 dB with a gain flatness of ±1 dB over a frequency range from 3 to 18 GHz. The return losses S_{11} and S_{22} are below –10 dB in the designed frequency range. The output 1-dB compression point at 5 GHz is 13. 3 dBm. The chip area is 0. 95 mm^2 and the power dissipation is 95 mW under a 3. 5 V supply.

Key words: distribution amplifier; L-type network; GaAs HBT process; ultra-high broadband

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With the rapid development of wireless and optical communications, the continuous increase of transmission data rates gives the requirements fon higher bandwidths for amplifiers. Distributed amplifiers (DAs) provide an effective solution to extend the bandwidths and, therefore, they are widely used in the design of ultra-broadband amplifiers.

The concept of the DA was first proposed in 1937 by Percival[1]. In 1950, it was implemented by Horton et al.[2]. With the development of semiconductor processes, the bandwidths of DAs is pushed to a higher bandwidth limit. Ref. [3] reported a design of a DA with a bandwidth as high as 750 GHz.

There are two kinds of lumped equivalent circuit models for transmission lines, namely L- and T-type networks. If the transmission line section is sufficiently small, these two models are accordingly equivalent. The working mechanism of a DA uses the parasitic capacitance of the transistors and the on-chip inductors to constitute an artificial transmission line for extending the bandwidth. The input impedance characteristics of both the artificial L- and T-type networks for DA design are first investigated in this paper. The analysis shows that the L-type network has better frequency characteristics than the T-type one.

Based on an L-type network, a distribution amplifier is fabricated with the 2-μm GaAs HBT process of the WIN semiconductors. With the power dissipation of 95 mW under a 3. 5 V supply, the measurement result proves that it has good small signal performance and shows the potential prospects of application.

1 Principle of Distribution Amplifier with GaAs HBT Process

The principle of DAs using discrete transistors is that the input and output capacitances of the transistors are combined with the lumped inductors to form artificial transmission lines according to

$$Z_0=\sqrt{\frac{2L}{C}} \tag{1}$$

So the gain-bandwidth product of an amplifier may be increased.

In order to maximize the gain of the amplifier, the phase delays of the input and the output transmission lines are typically matched. Therefore, the currents generated by the individual gain cells can be constructively added at the output point of the amplifier. Assuming that the transmission lines are lossless, the low-frequency gain of conventional DAs can be estimated by

$$A_{\mathrm{v}}=\frac{1}{2}ng_{\mathrm{m}}Z_0 \tag{2}$$

where n is the number of the distributed stages; g_{m} represents the transconductance of each stage; and Z_0 is equal to 50 Ω typically.

Fig. 1 shows the simplified schematic of a classical DA with four common-emitter stages[4]. The inductor values of the base line are given by its characteristic impedance $Z_{0\mathrm{b}}$ and the base-emitter-capacitance:

$$L_{\mathrm{b}}=\frac{Z_{0\mathrm{b}}^2C_{\mathrm{be}}}{2} \tag{3}$$

The cut-off frequency of the base line can be expressed as

$$f_{\mathrm{c}}=\frac{1}{2\pi\sqrt{L_{\mathrm{b}}C_{\mathrm{be}}}} \tag{4}$$

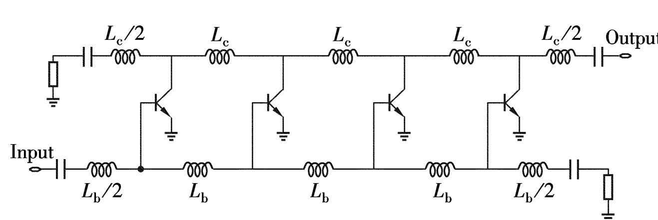

Fig. 1 Distributed amplifier with four common emitter stages

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The characteristic impedances and the cut-off frequency of the collector line are calculated analogically.

2 Frequency Characteristics of L- and T-type Networks

The design of DAs is based on the transmission line theory. The small-signal equivalent circuit model of the transistor of an HBT can be described with the shunt of a resistance and a capacitance [5-6]. With the on-chip inductors, the artificial transmission lines with T- and L-type networks are shown in Fig. 2 and Fig. 3, respectively. The T- and L-type networks can be considered as an approximation of a continuous transmission line. If the values of the inductance, the capacitance, and the resistance tend to be infinitesimal, it is completely consistent for the two models. However, the artificial transmission lines are composed of lumped elements, and we consider that two models will express different frequency characteristics in the design.

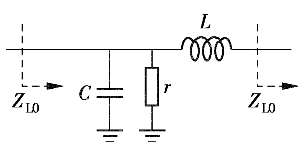

Fig. 2 L-type network

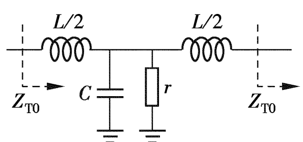

Fig. 3 T-type network

For the L-type network, the characteristic impedance is

$$Z_{L0} = \frac{j\omega L}{2} \pm \sqrt{-\left(\frac{\omega L}{2}\right)^2 + \frac{j\omega L}{j\omega C + 1/r}} \tag{5}$$

For the T-type network, the characteristic impedance is

$$Z_{T0} = \sqrt{-\frac{\omega^2 L^2}{4} + \frac{j\omega L}{j\omega C + 1/r}} \tag{6}$$

We investigate the single stage of an L- and a T-type network terminated by a resistive absorbing load as shown in Fig. 4 and Fig. 5, respectively. The input impedance of the L-type network is

$$Z_{L_{in}} = \frac{1}{j\omega C + 1/r + 1/(j\omega L + R)} = \frac{j\omega Lr + Rr}{-\omega^2 LrC + j\omega RrC + r + j\omega L + R} \tag{7}$$

And the input impedance for the T-type network is

$$Z_{T_{in}} = j\omega L + \frac{1}{j\omega C + 1/r + 1/(j\omega L + R)} = j\omega L + \frac{j\omega Lr + Rr}{-\omega^2 LrC + j\omega RrC + r + j\omega L + R} \tag{8}$$

When $\omega \ll 1/\sqrt{L_c}$, Eqs. (7) and (8) can be simplified as

$$Z_{L_{in}} \approx \frac{j\omega Lr + Rr}{j\omega RrC + r + j\omega L + R} \tag{9}$$

$$Z_{T_{in}} \approx \frac{-\omega^2 L^2 + j\omega L(2r + R) + Rr}{j\omega RrC + r + j\omega L + R} \tag{10}$$

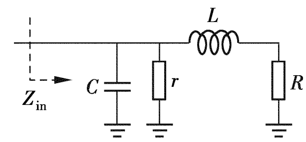

Fig. 4 L-type network with resistive end

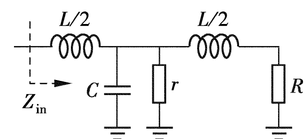

Fig. 5 T-type network with resistive end

From Eqs. (9) and (10), we obtain the impedance diagram of the L- and T-type networks with a resistive terminal, respectively, as shown in Fig. 6. We can see that the input impedance of the L-type network has lower frequency sensitivity than that of the T-type. We deduce that the L-type network can have a better bandwidth performance in the design for distribution amplifiers[7].

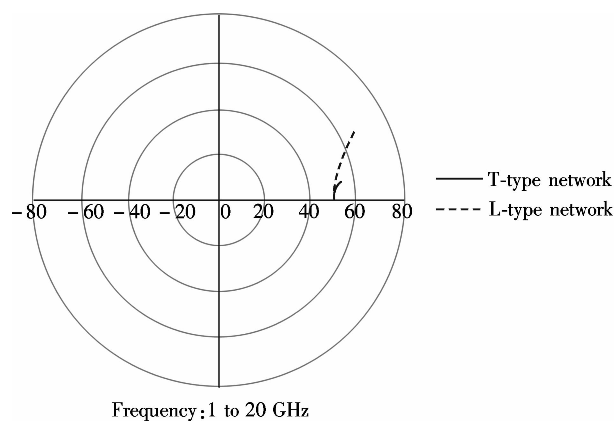

Fig. 6 Impedance diagram of L- and T-type networks with resistive terminal

3 Circuit Design

As shown in Fig. 7, a distribution amplifier based on an L-type network is fabricated with the 2-μm GaAs HBT process of WIN semiconductors. Here, the common-emitter gain cell is used to obtain high power gain because it simultaneously has the voltage gain and the current gain. In addition, with the more cascaded gain cells, the attenuations of the gate and drain lines are increased. So, four stages are

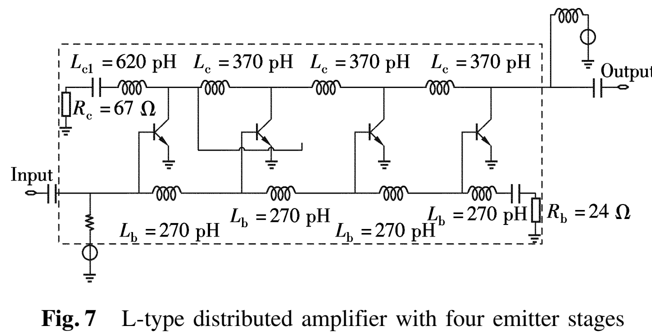

Fig. 7 L-type distributed amplifier with four emitter stages

chosen as a tradeoff between the high gain and the attenuations over the whole frequency range.

Considering the compromise among the gain, the bandwidth and the power consumption, the HBT transistor type of RQ1A201B2 in library is adopted. The cut-off frequency f_t of the transistor is 35 GHz. The width and length of each emitter mesa are 2 and 20 μm, respectively. The base and emitter fingers are with an inter-digital arrangement and the base metal wraps around the emitter fingers.

The inductors in the design are tuned to meet the optimum performance and their values are 620, 370 and 290 pH, respectively. Since the inductor with a value of 370 pH is not provided in the technology library, we design it using ADS. Fig. 8 gives its layout. The inductance value and Q versus the frequency are shown in Fig. 9 and Fig. 10, respectively.

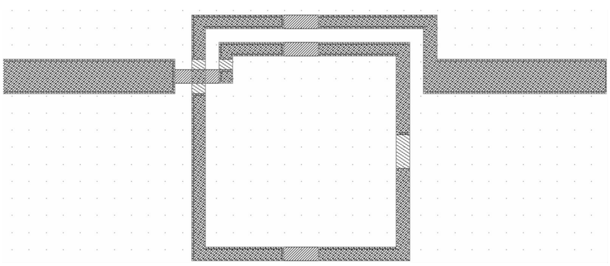

Fig. 8 Layout of 370 pH inductor

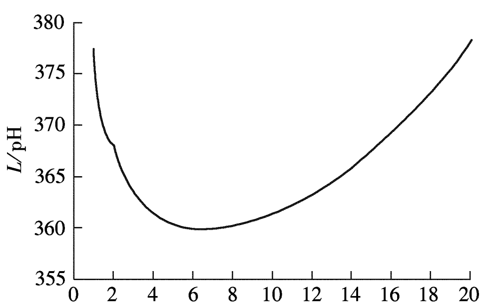

Fig. 9 Inductance value

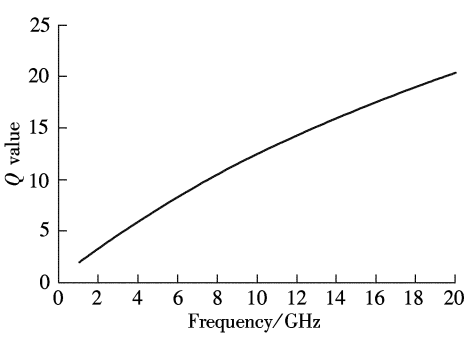

Fig. 10 Q value of the 370 pH inductance

4 Measurement Results

Fig. 11 gives the microphotograph of the distribution amplifier with an L-type network in our work. The chip area is 0.95 mm^2 and the power dissipation of the amplifier is 95 mW under a 3.5 V supply.

The distributed power amplifier chip is tested via on-wafer probing. The measurements of the circuit are carried out using an Agilent E8363B vector network analyzer and an E4440A spectrum analyzer. Fig. 12 gives the measured small-signal gain of 5.5 dB with a gain ripple of ±1 dB in the band of 3 to 18 GHz. The measured input and output return losses are shown in Fig. 13 and Fig. 14, respectively. The reverse isolation is illustrated in Fig. 15. Both the input and output return losses are below −10 dB over the entire frequency range. The measured reverse isolation remains under −12 dB. Fig. 16 shows the output power at a frequency of 5 GHz and the output 1-dB compression point is 13.3 dBm.

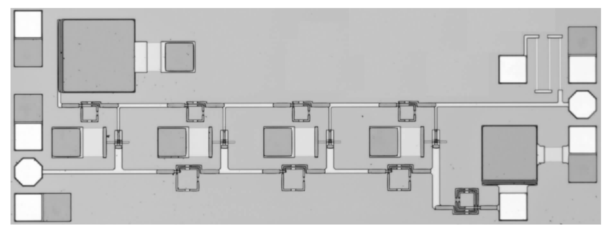

Fig. 11 Microphotograph of the distributed amplifier with L-type network

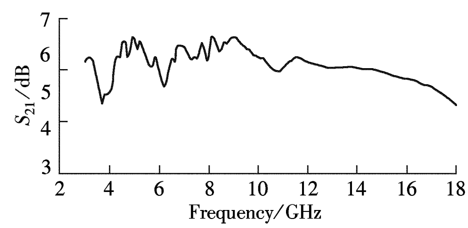

Fig. 12 Small signal gain S_{21}

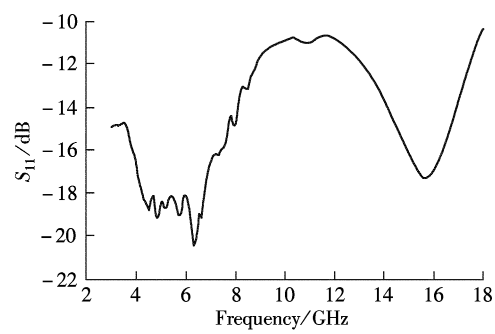

Fig. 13 Input return loss S_{11}

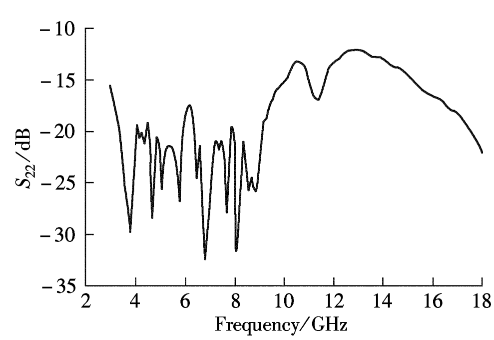

Fig. 14 Output return loss S_{22}

5 Conclusion

First, we investigate the characteristic impedances of L-type and T-type networks for the distributed amplifier design. The analysis shows that the L-type network has better frequency characteristics than the T-type one. Then, a

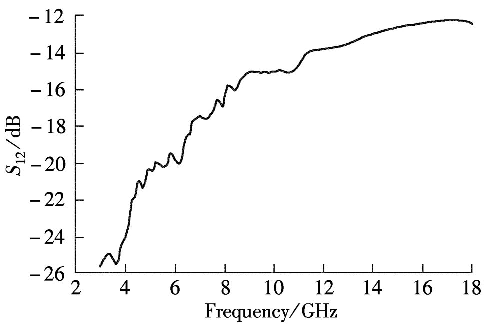

Fig. 15 Isolation S_{12}

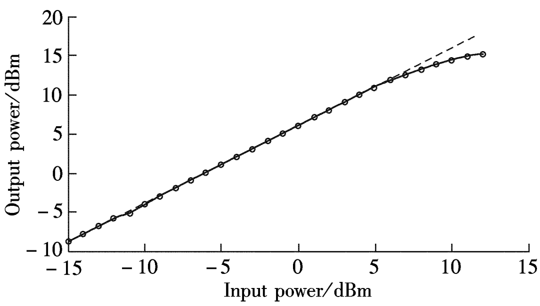

Fig. 16 Output power at 5 GHz

distribution amplifier based on the L-type network is implemented with the 2-μm GaAs HBT process from WIN semiconductors. The measured results give a gain of 5.5 dB with a gain flatness of ± 1 dB over a frequency range of 3 to 18 GHz. It represents excellent bandwidth performance. The return losses S_{11} and S_{22} are all below −10 dB in the designed frequency range. The output 1-dB compression point at 5 GHz is 13.3 dBm. The chip area is 0.95 mm^2 and the power dissipation of the amplifier is 95 mW under a 3.5 V supply.

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2-μm GaAs HBT 工艺的 L 型网络分布式放大器

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摘要:首先对分布式放大器中 L 型和 T 型网络的频率特性进行了研究. 分析表明,L 型网络比 T 型网络在设计中具有更好的频率特性. 基于稳懋半导体的 2-μm GaAs HBT 工艺实现了一种 L 型网络的分布式放大器. 测试结果表明,在 3~18 GHz 频率范围内其增益为 5.5 dB,增益平坦度为 ±1 dB,体现了很好的带宽性能. 此外,在设计的频率范围内反射损耗 S_{11},S_{22}均低于 −10 dB. 在 5 GHz 时的 1 dB 压缩点处输出功率为 13.3 dBm. 芯片面积为 0.95 mm^2,在 3.5 V 电源下功耗为 95 mW.

关键词:分布式放大器;L 型网络;GaAs HBT 工艺;超宽带

中图分类号:TN43