Balun Bandpass Low-Noise Amplifier in GaAs

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***Abstract*—In this work, the design of an on-chip balun bandpass low-noise amplifier (LNA) is proposed so as to achieve the functional integration of balun, bandpass filter, and LNA in a compact circuit structure. Specifically, the input matching network of the LNA is designed as a bandpass filter while its output matching network is realized with a balun. The resulted multi-functional circuit effectively reduces the circuit size and cost of RF front-end circuitry. The proposed balun bandpass LNA is implemented using a commercial GaAs pHEMT process. The measured in-band small signal gain is within 11.2±0.35 dB from 5.4 to 6 GHz, and the in-band input and output return losses are all better than 10.8 dB. The measured in-band noise figure is better than 6.2 dB with a minimum noise figure of 4.9 dB at 6 GHz. The measured in-band amplitude imbalance between the balanced output ports is with 1.2 dB while the in-band phase imbalance is within 6.4 degree. Notably, the proposed balun bandpass LNA achieves 30-dBc stopband rejection from DC to 4.3 GHz and from 8.3 to 20 GHz.**

Keywords—bandpass filter; balun; low-noise amplifier; GaAs

I. INTRODUCTION

To further improve the level of integration for RF front-end designs, various multi-functional RF circuit designs have been reported in recent years. In addition to the reduction in circuit size and power loss, due to the reduction of mismatch loss as well, the performance of RF front-end can also be improved with these multi-functional RF circuits. In an RF receiver front-end, a bandpass filter in front of the low-noise amplifier (LNA) is usually required for band selection and interference suppression. If the LNA can be designed with a frequency selective small-signal gain response, the bandpass filter may no longer be required. Several bandpass LNA designs have been reported in [1]-[3]. In addition, the functional integration of balun, bandpass filter, and LNA has been demonstrated in [4] and [5], but the resulted circuit size is large due to the employment of coupled-line sections as the building block.

In this work, an on-chip balun bandpass LNA is proposed, which can achieve a much smaller circuit size than the conventional designs in [4] and [5]. It is accomplished by designing the input matching network as a bandpass filter and the output matching network as a bandpass balun. As a result, the band selection filter usually connected with the LNA in an RF front-end may no longer be required. In addition, a single-ended antenna can be used with a differential receiver through this proposed balun bandpass LNA.

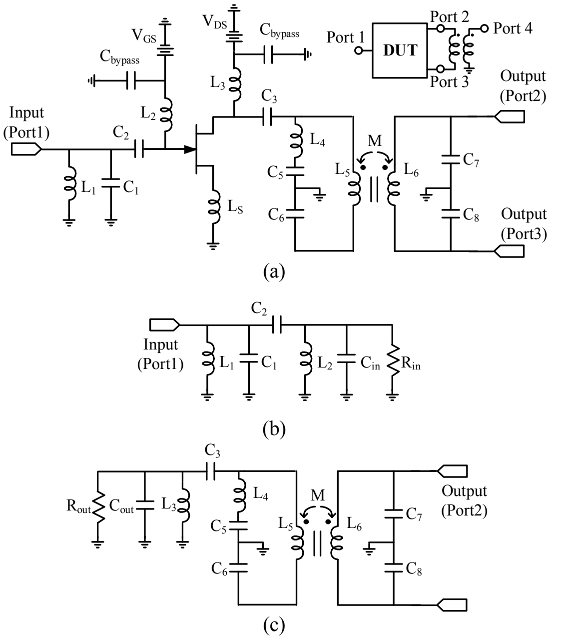

Fig. 1. (a) Circuit model of proposed balun bandpass LNA. (b) Equivalent-circuit model of the input matching network. (c) Equivalent-circuit model of the output matching network.

II. CIRCUIT DESIGN AND IMPLEMENTATION

Shown in Fig. 1(a) is the circuit model of proposed balun bandpass LNA. Its input matching network is designed as a 2nd-order bandpass filter as shown in Fig. 1(b). Here, the input impedance of the transistor is modeled as a parallel RC circuit. With the introduction of inductor L_2, a parallel LC resonator (i.e., L_2 and C_{in}) is formed, which is capacitively coupled to another parallel LC resonator (i.e, L_1 and C_1) through C_2. The input matching network is thus equivalent to a conventional 2nd-order bandpass filter prototype, which can be designed with the desired 2nd-order bandpass response through conventional filter synthesis techniques. On the other hand, the output matching network of this LNA is designed as a 3rd-order balun bandpass filter as shown in Fig. 1(c). Here, the output impedance of the transistor is also modeled as a parallel RC network, and the transformer-coupled balun bandpass filter in [6] is adopted as the bandpass matching network. As a result, the proposed LNA in Fig. 1(a) exhibits a single-ended input and a differential output with a bandpass frequency response. The effective integration of balun, bandpass filter, and LNA is thus achieved.

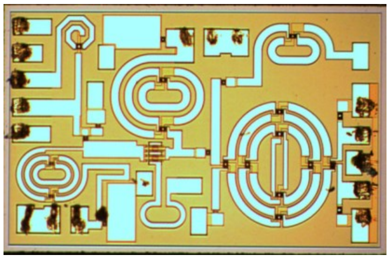

Fig. 2. Chip photograph of proposed balun bandpass LNA in GaAs. (Chip size: 1.5 mm × 1.0 mm.)

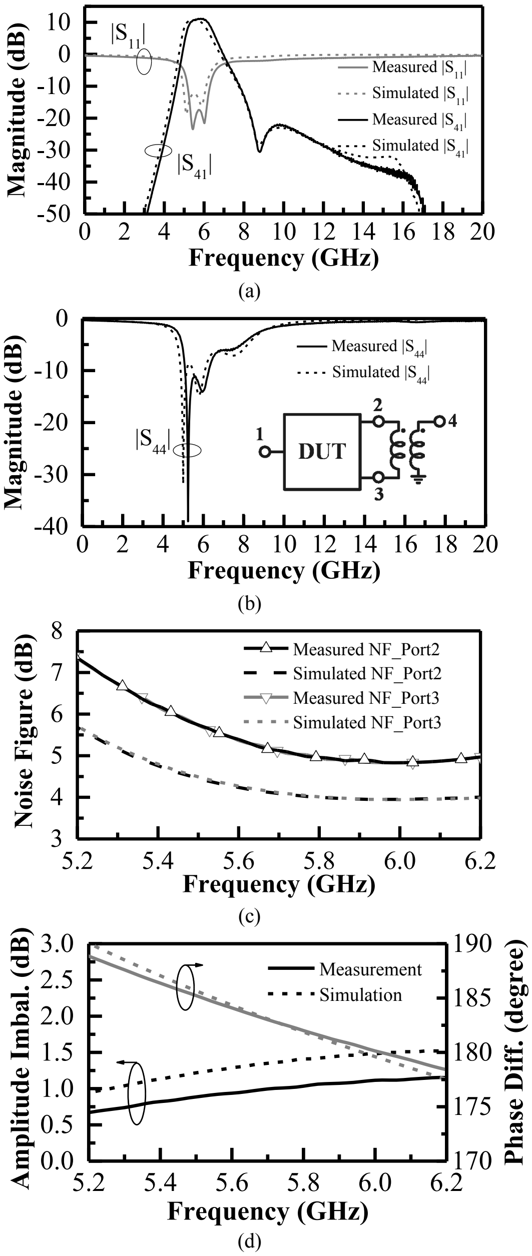

Fig. 3. Measured and simulated frequency responses of proposed balun bandpass LNA in GaAs. (a) Small-signal gain and input return loss. (b) Output return loss. (c) Noise figure. (d) Amplitude imbalance and phase difference.

The proposed balun bandpass LNA is realized using the WIN 0.15-μm pHEMT process on 4-mil GaAs, and the chip photograph is shown in Fig. 2. Here, spiral inductors and MIM capacitors are used to realize the L's and C's in Fig. 1(a). The center frequency f_0 is chosen as 5.5 GHz, and the pHEMT transistor with four fingers and a gate width of 50 μm is chosen. Both the input and output matching networks are designed with a 0.01-dB equal-ripple bandpass response, and the required element values can be determined accordingly with the aid of conventional filter synthesis techniques.

Shown in Fig. 3 are the measured and simulated results. The measurement is done through on-wafer probing with two GSGSG probes. So two additional dummy pads are introduced at Port 1. The measured small-signal gain response in Fig. 3(a) features the desired bandpass response. The measured in-band small signal gain is within 11.2±0.35 dB from 5.4 to 6.0 GHz, and the measured input and output return losses are all better than 10.8 dB in the same frequency range. Notably, the proposed balun bandpass LNA achieves 30-dBc stopband rejection from DC to 4.3 GHz and from 8.3 to 20 GHz. The measured in-band noise figure is better than 6.2 dB according to Fig. 3(c), with a minimum noise figure of 4.9 dB at 6 GHz. As shown in Fig. 3(d), the measured in-band amplitude imbalance is with 1.2 dB while the in-band phase imbalance is within 6.4 degree. The power consumption is 11 mW and the input P_{1dB} is -7 dBm. The chip size is 1.5 mm × 1.0 mm.

III. CONCLUSION

In this work, a narrowband bandpass LNA in GaAs with single-ended input port and differential output port is proposed. The proposed design can effectively integrate the functions of balun, bandpass filter, and LNA in a compact chip area. As a result, the additional band-selection filter in front of the LNA in an RF front-end may no longer be required. The circuit size, cost, and power losses of RF front-end can thus be reduced.

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