Design of A Wideband Active Differential Balun by HMIC

Chaoyi Li[1, a] and Xiaofei Guo[2, b]

[1]School of Electronics Engineering, Chongqing University of Posts and Telecommunications, Chongqing 400065, China;

[2]School of Electronics Engineering, Chongqing University of Posts and Telecommunications, Chongqing 400065, China;

[a]lichaoyi121@foxmail.com, [b] 1019172550@qq.com

Abstract

In this paper, a wideband active differential balun based on discrete Pseudomorphic High Electron Mobility Transistor (PHEMT) device and Hybrid Microwave Integrated Circuit (HMIC) process is designed in L-band. The designed balun circuit takes advantage of FET's inherent phase reversal characteristics. The three stage cascade mode is adopted to reduce the phase and amplitude imbalance. The simulated results show the output signals have an amplitude difference is less than 0.08 dB, and the phase difference is less than 1.2 degrees. The measured values are basically consistent with the simulation.

Keywords

Active balun, phase balance, amplitude balance, wideband

1. Introduction

The differential structure is widely used in the radio frequency front-end of modern wireless communication system. This is because the differential structure can dramatically improve the system anti-interference ability. For example, the differential signals can enhance the fundamental rejection in the balanced frequency doubler [1], the port-to-port isolation in the mixer [2], and the bandwidth in the balanced amplifier [3].

A single channel signal is converted into a differential signal, which is usually realized by differential balun[4]. An ideal differential balun generates a pair of differential output signals of balanced amplitudes and phases (0 dB gain difference and 180°phase difference) from a single input[5]. The baluns can be classified as passive balun and active balun. For active balun, it can not only guarantee high quality balance, but also be easy to integrate on chip. Another important feature is that it can provide some power gain and better input and output isolation while converting signals, and it is also easier to achieve wideband[4]. Therefore, active balun is more suitable for for microwave integrated circuits. Different configurations have been found in literatures for implementation of active balun circuits, such as single FET circuits [6], common-gate common-source circuits [7], [8], and differential amplifier circuits [3]. In the first two configurations, circuit design utilizes the feature that the output signals at the drain and the source are out of phase. The single FET active circuit is only useful for low frequency band. The common-gate common-source (CGCS) circuit is only suitable for narrowband applications. The parasitic effects limit these two circuits to the high-frequency and broadband applications. At high frequencies, it is very popular to apply the configuration of a differential amplifier. However, the current source gives finite output impedance (Zs) due to parasitic effect at the high frequencies. A portion of signal power flows through this path resulting in gain and phase imbalance.

In this paper, a three cascaded balun circuit working in L-band is designed, which can be potentially applied to microwave integrated circuits. The three cascaded structure allows the amplitude and phase offsets, which contributed by the dominant FET parasitics to be largely cancelled which substantially increases balance. The balun utilizes RC matching to widen the band. The third stage amplifier on the one hand to compensate for circuit power, the other fine-tune the output balance. The active balun circuit has a good phase and amplitude balance, which can facilitate the miniaturization, and lead a certain output gain. The test results and simulation results have consistency.

2. Balun Design

Balun circuits are the critical block required in Radio Frequency and microwave circuits whereas signal in a balanced format is necessary. Figure 1 shows the schematic of the basic circuit. This is the common low-frequency phase splitter which provides two signals of equal amplitude and 180-degree phase balance to the drain and source load resistors[3].

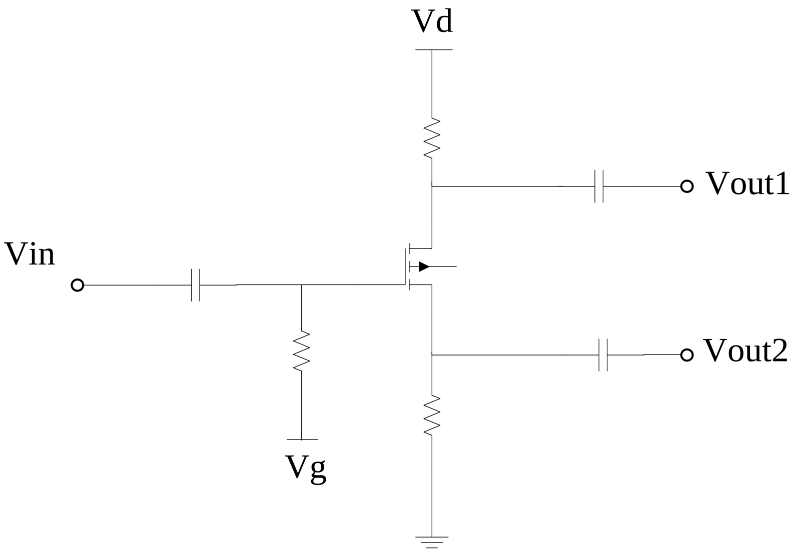


Fig.1 Circuit schematic of the basic balun.

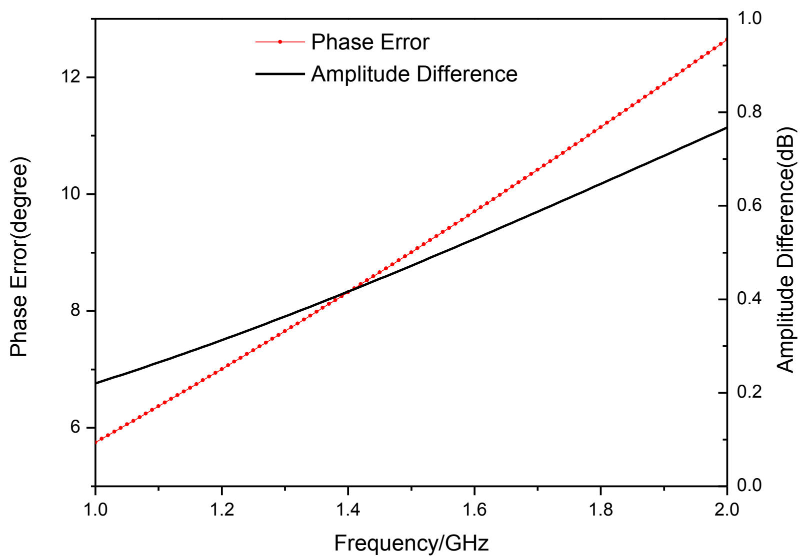


Fig.2 Phase error and amplitude difference of the basic balun.

The upper frequency range of a single balun is limited by the imbalances caused by the parasitic capacitances of the FET [8]. As shown in Fig. 2, its output phase/amplitude imbalance increases while the frequency increases. However, the cross-cascaded circuits can eliminate the imbalance caused by parasitic parameters. Figure 3 shows the schematic of the three cascaded balun circuit. It is assumed that the amplitude imbalance factors of the first, second and third-order balun are a, b and c, respectively. Then the following derivation will show that a three-stage cascaded balun will eliminate imbalances.

$$V_{1d} = V + a; V_{1s} = V; \tag{1}$$

Equation 1 is the output of source and drain of the first-stage balun.

$$\begin{aligned} V_{2d} &= V_{1d} + b; V_{2s} = V_{1d}; \\ V_{3d} &= V_{1s} + b; V_{3s} = V_{1s}; \end{aligned} \tag{2}$$

Equation 2 is the output amplitude of source and drain of the second-stage balun.

$$V_{21} = V_{3d} + V_{2s} + c = V + V + a + b + c; \tag{3}$$

$$V_{31} = V_{2d} + V_{3s} + c = V + V + a + b + c; \tag{4}$$

Therefore, from (3) and (4), it can be seen that the output amplitude differences cancel each other after the second-order crosstalk is cascaded. Among them, the role of the third stage FET circuit is power compensation. Similarly, the phase imbalance generated by the FET parasitics can also cancel each other by cross-cascade.

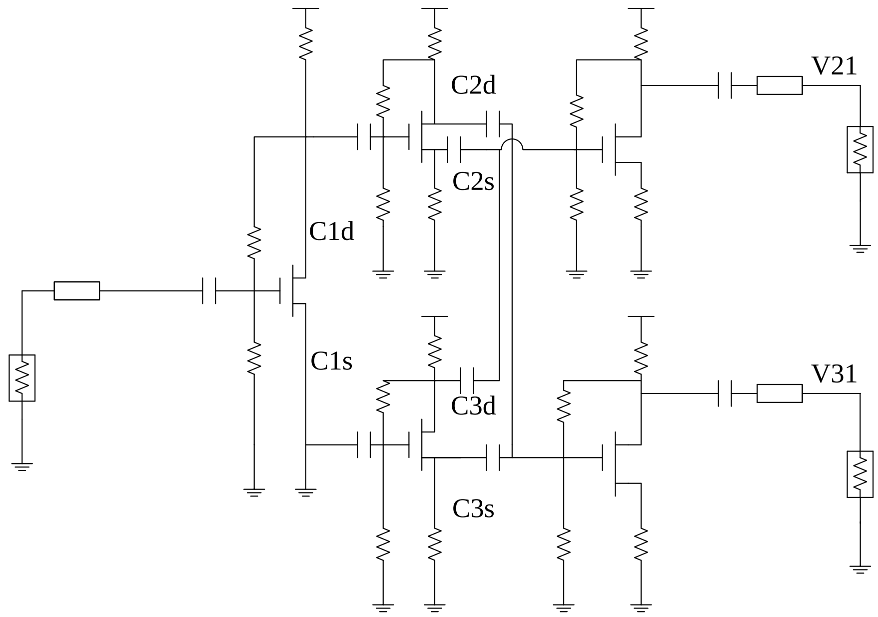


Fig.3 Circuit configuration of the three cascaded active balun.

3. Simulation And Analysis

The main parameters of active balun: phase difference, amplitude difference, the result of co-simulation circuit layout shown in Fig.4 to Fig.6. The phases balance are shown in Fig.4, where their relative phase maintains 180°(±1.2°) in L-band. The amplitude of the two output ports of the balun circuit is shown in Figure 5, where the output has a 6 dB gain across the L-band. The proposed balun adopts RC matching for ultra-wideband, so the gain is only about 6 dB. System principal figures of merit are represented by differential phase shift and differential amplitude imbalance: as can be deduced from Figure 6 phase and amplitude errors are respectively bounded within +/-1.2° and +/-0.08 dB limits all over the entire operating band.

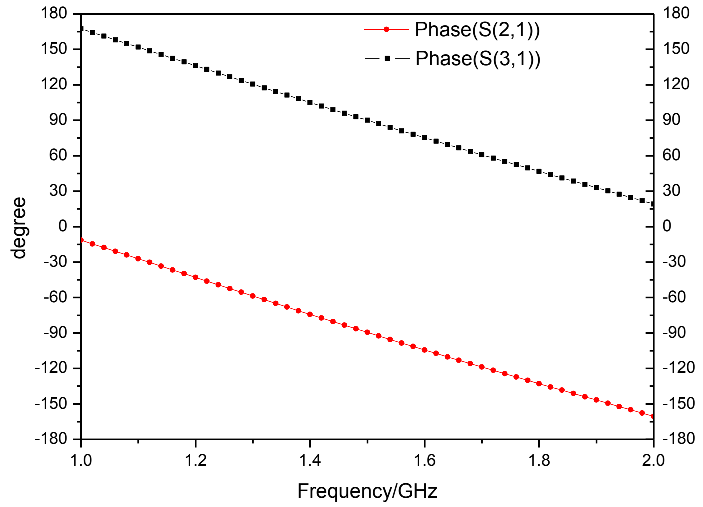


Fig.4 Simulated phase differences of the proposed active balun.

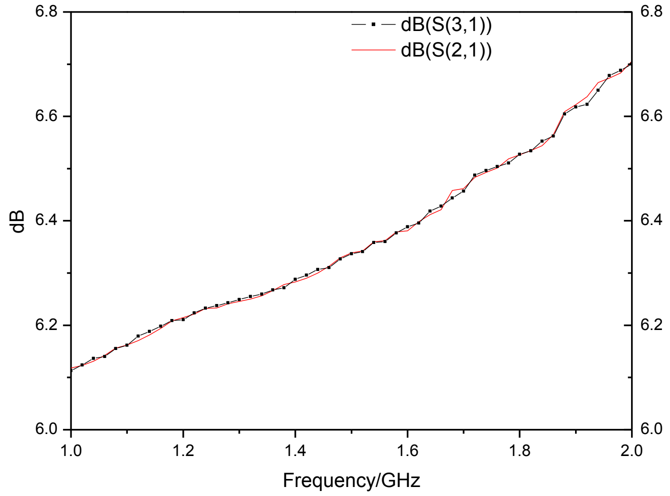


Fig.5 Simulated amplitude differences of the proposed active balun.

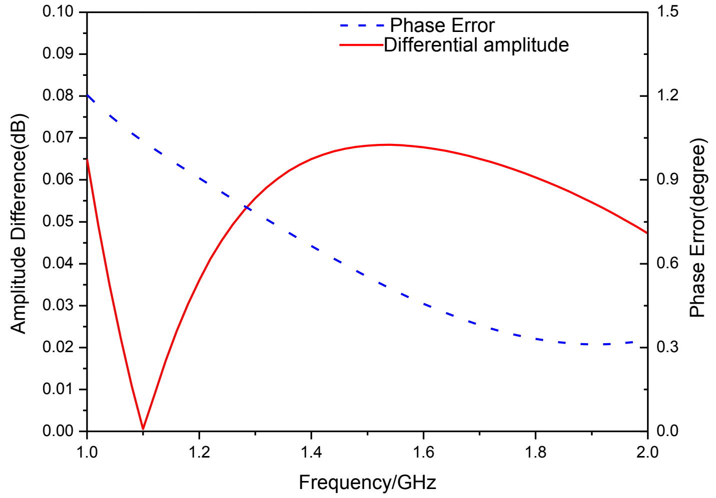
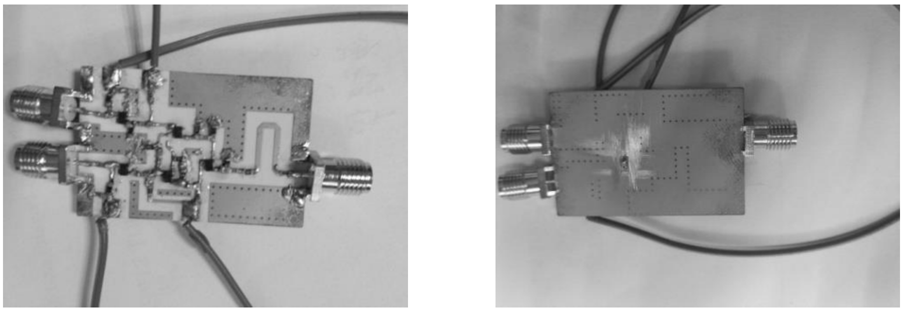


Fig.6 Phase error and amplitude imbalance

The circuit is fabricated by the HMIC process and tested by Agilent's vector network analyzer. The simulated and measured S11 are shown in Figure 8. The measured results are consistent with the simulation results to meet the set targets. The results are lower than -10dB in the L-band.



(a) (b)

Fig.7 Photograph of fabricated HMIC balun.

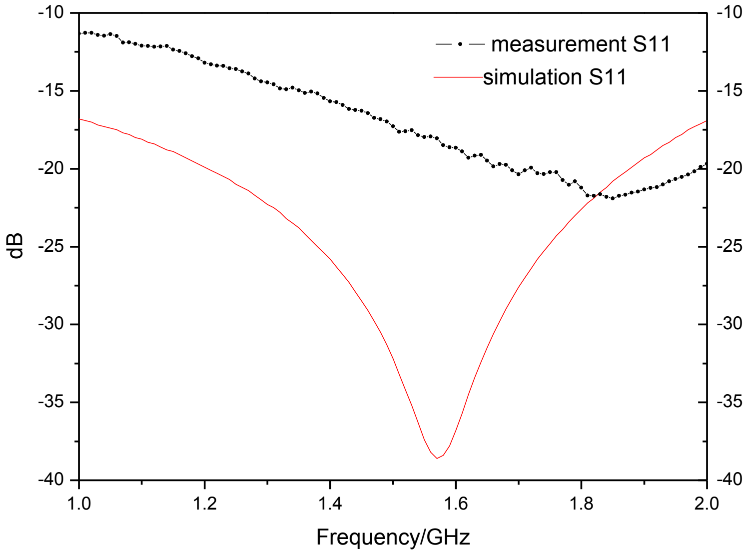


Fig.8 Simulated and Measured S11 of the proposed balun

4. Conclusion

This paper describes a broadband active balun adopt three cross-cascade source/drain type FETs. This proves that the cascaded balun can be greatly improved in both phase and amplitude balance over traditional single-FET circuits. The results of simulation show that the phase imbalance is less than 1.2 degrees and the amplitude imbalance is less than 0.08 dB across the L-band. The active balun circuit is fabricated by the HMIC process. The measurements show that the S11 is below -10 dB across the L-band. The active balun in the type of cascade source/drain can be used for L-band wireless communication system and microwave integrated circuit.

References

[1] Huynh C, Nguyen C. Ultra-Wideband Active Balun Topology and Its Implementation on SiGe BiCMOS Across DC-50 GHz [J]. IEEE Microwave & Wireless Components Letters, 2016, 26(9):720-722.

[2] Choi C, Ju H S, Lee O, et al. A +12-dBm OIP3 60-GHz RF Downconversion Mixer With an Output-Matching, Noise- and Distortion-Canceling Active Balun for 5G Applications[J]. IEEE Microwave & Wireless Components Letters, 2017, 27(3):284-286.

[3] Manstretta D. A Broadband Low-Power Low-Noise Active Balun With Second-Order Distortion Cancellation [J]. IEEE Journal of Solid-State Circuits, 2012, 47(2):407-420.

[4] Koizumi H, Nagata S, Tateoka K, et al. A GaAs single balanced mixer MMIC with built-in active balun for personal communication systems [M]. IEEE, 1995.

[5] Richard Chi-Hsi Li,RF Circuit Design[M]. BeiJing: Pulishing House Of Electronics Industry, 2011:108-136.

[6] Hsu T, Kuo C. Low power 8-GHz ultra-wideband active balun [J]. 2006.
[7] Hur B, Eisenstadt W R. CMOS Broadband Programmable Gain Active Balun With 0.5-dB Gain Steps [J]. IEEE Transactions on Microwave Theory & Techniques, 2015, 63(8):2650-2660.
[8] Jung K, Eisenstadt W R, Fox R M, et al. Broadband Active Balun Using Combined Cascode–Cascade Configuration[J]. IEEE Transactions on Microwave Theory & Techniques, 2008, 56(8):1790-1796.