NOVEL ACTIVE DIFFERENTIAL PHASE SPLITTERS IN RFIC FOR WIRELESS APPLICATIONS

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ABSTRACT

Two novel active differential phase splitters have been designed and fabricated in a GaAs MESFET process. The new circuits employ a concept of feedback to adjust gain and phase unbalance separately and accurately. The active phase splitters feature simplicity, low power supply and wide-band performance. The circuits can provide ± 1 dB and 180 ± 1° differential signals within 4 GHz bandwidth, well covering the frequency range currently used for dual mode commercial wireless communications. In narrow-band application more accurate balanced differential signals can be achieved by external tuning.

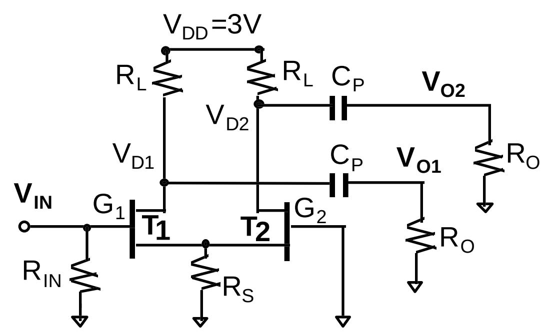
INTRODUCTION

Differential phase splitters (or baluns) are basic cells required in microwave components such as balanced mixers and multipliers. An ideal differential phase splitter generates a pair of differential signals which have balanced amplitude and phase (0 dB and 180°) from a single input.

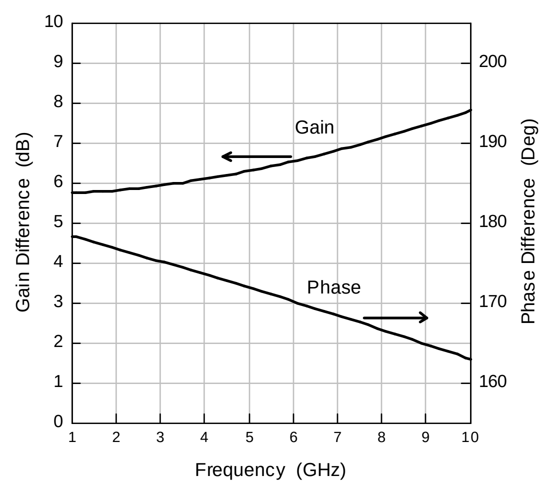
In RFIC there are passive and active baluns. LC networks can be used for narrow-band passive baluns, microstriplines can be used for wide-band passive baluns [1]. However, at lower microwave frequencies the passive L, C and microstriplines are too expensive due to their large physical size. There are three categories of MESFET active balun circuits normally employed at lower microwave frequencies for wireless applications: 1. Single FET circuits [2][3]; 2. Common-gate common-source circuits [4][5], and 3. Differential amplifier circuits [6][7].

A conventional MESFET differential pair is not a good candidate since the tail current source can only provide limited impedance due to the short channel effects and the strong parasitic effects at very high frequencies. Further more, low V_{DD} requirement for portable wireless applications (V_{DD} < 3V or even < 2V) makes it impossible to have the tail current source at the bottom of the differential pair in RFIC, since it needs a substantial potential drop across itself (1 ~ 1.5 V). In [6] the current source was replaced by an inductor to increase the high frequency impedance. However, at low microwave frequencies an inductor with a very big value is needed, which is very expensive and may have a very low resonant frequency. In many cases, a biasing resistor R_S is used instead as shown in Fig. 1 (a). However, the output balance is poor due to its limited impedance, see Fig. 1 (b). To overcome this problem, a compensation method was invented [7], where complicated compensation circuits make the balun design more difficult and consume additional power.

This paper proposes two novel active differential phase splitters using a concept of feedback to adjust gain and phase unbalance separately and accurately. In the feedback



(a)



(b)

Fig. 1. (a) The simple differential pair with a biasing resistor R_S; (b) Simulated gain and phase differences versus frequency for circuit (a).

circuit a tunable resistor can be realised by using a MESFET to tune the unbalance caused by the process variations. The circuits were realised successfully by using a 0.5-μm MESFET technology with $V_P = -0.9$ V. The simulation and measured results will be reported.

CIRCUIT DESCRIPTION

Circuit 1. The first circuit is shown in Fig. 2. Compared with Fig. 1, a series LCR feedback circuit is proposed and connected from node D1 through G2 to ac ground. The feedback circuit consists of 2 resistors R_{G2} and R_F, an inductor L_F and a capacitor C_F. The resistor R_{G2} plays two roles: to keep dc bias of T2 the same as T1, and to sense the signal fed back from D1. C_F provides a dc block. The reactance of the feedback circuit between D1 and G2 is $X_F = \omega L_F - 1/(\omega C_F)$. This means that X_F can be positive (inductive), zero (resistive) or negative (capacitive) by just adjusting L_F and C_F values at the application frequency ω. Thus, the phase difference between the output port signals V_{O1} and V_{O2} can be effectively tuned. The amount of the signal fed back from node D1 to G2 can be adjusted by changing the ratio of R_F to R_{G2}. Thus adjusting the ratio of R_F to R_{G2} will effectively tune the amplitude unbalance between output port signals V_{O1} and V_{O2}. It is clear that the output termination impedance R_O will affect the choice of values of the components in the feedback circuit.

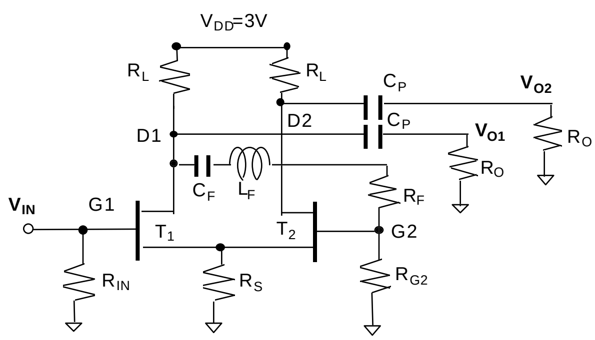


Fig. 2. Circuit 1, the differential phase splitter with a series LCR feedback balancing circuit.

Circuit 2. Fig. 3 shows the second circuit which is based on the first one but externally tunable. In this new circuit, one more MESFET T3 is connected in series with the feedback resister R_F. The externally changeable dc voltage V_B will adjust the channel resistance of T3. Thus T3 and R_F are considered as a combined variable feedback resistor R_{TF}. T3 and R_F are relocated to node D1. This relocation keeps V_B operating in a positive range ($0 < V_B < V_{DD}$) for the depletion MESFET which has the negative pinch-off voltage. In the circuit design, the initial bias point of V_B, the size of T3 and the values of R_F and R_{G2} are chosen in such a way that external tuning of V_B will vary the gain and phase balance within a specific small range centered at the balanced point. In this way the unbalance (or off-set of gain) of the differential signals caused by the process variations can be effectively cancelled in high performance RF applications.

SIMULATION AND MEASUREMENT

Both circuits were designed and optimized at 1.67 GHz

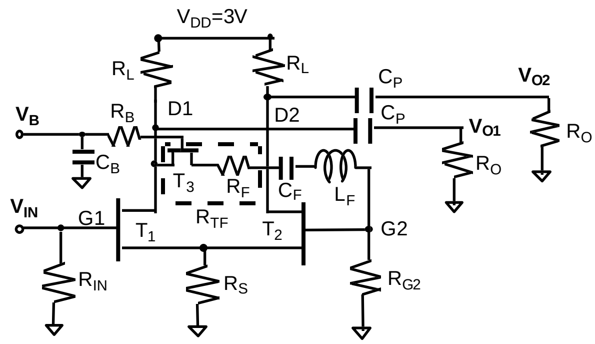


Fig. 3. Circuit 2, the tunable active differential phase splitter.

for the PHS application and the results were verified through on-wafer S-Parameter measurement.

Fig. 4 is the simulation and measurement results of Circuit 1. The gain difference of ±1 dB and phase difference of 180 ± 1° have been easily achieved within 0.5 ~ 3.5 GHz frequency range, which covers all frequencies currently used for commercial wireless communication systems. If the circuit was optimized for a wider band application, the

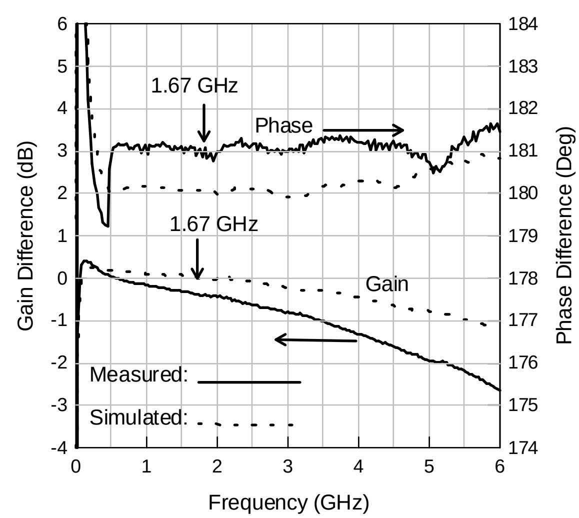


Fig. 4. Simulated and measured gain and phase differences versus frequency for Circuit 1.

same results could be obtained within 4 GHz bandwidth. Since the circuit is based on the symmetrical differential pair and has a broadband performance, this feature makes it have the best performance against IC process variations. Table 1 is the simulation of gain and phase difference against variation or mismatch of parameters in the circuit. From Table 1, it is seen that the circuit has an excellent process tolerance. Fig. 5 is the measured performance of Circuit 1 against variation of V_{DD}.

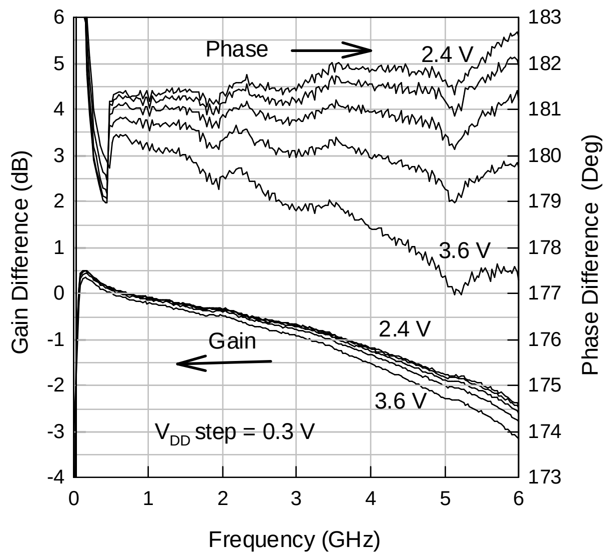


Fig. 5. Measured gain and phase differences versus frequency with variation of V_{DD} for Circuit 1.

For Circuit 2, Fig. 6 shows measured gain and phase differences versus frequency when tuning V_B externally. At 1.67 GHz (optimized operating frequency), by tuning external dc voltage V_B, the gain difference can vary from −3 to +2 dB while the change of phase difference is within 3°. With Circuit 2, the RF mismatch or off-set (not dc off-set) of the differential amplifier next to Circuit 2 can be cancelled by this external tuning. Therefore, Circuit 2 provides a critical unbalance cancellation technique that can be used in high performance RFICs.

Both circuits consume 3.8 mA dc current. Their chip photos are shown in Fig. 7. Obviously, the feedback circuits do not consume any extra dc current. They are easy to understand and design.

CONCLUSIONS

Two novel active differential phase splitters with LCR series feedback circuits have been designed, measured and discussed. The feedback circuits can adjust gain and phase unbalance separately and accurately, without consuming extra dc current. The new circuits have excellent performance against process variations due to their inherent symmetrical topology. The circuits can achieve ± 1 dB and 180 ±1° differential signals within 4 GHz bandwidth, well covering the frequencies for dual mode wireless communication. With the tunable feedback circuit more accurately balanced differential signals can be achieved by external tuning. This circuit topology can be extended to other technologies like CMOS, BiCMOS or Bipolar for RF applications. Compared with other active baluns, the new circuits feature simplicity, low power supply, wide-band performance, and consume small die

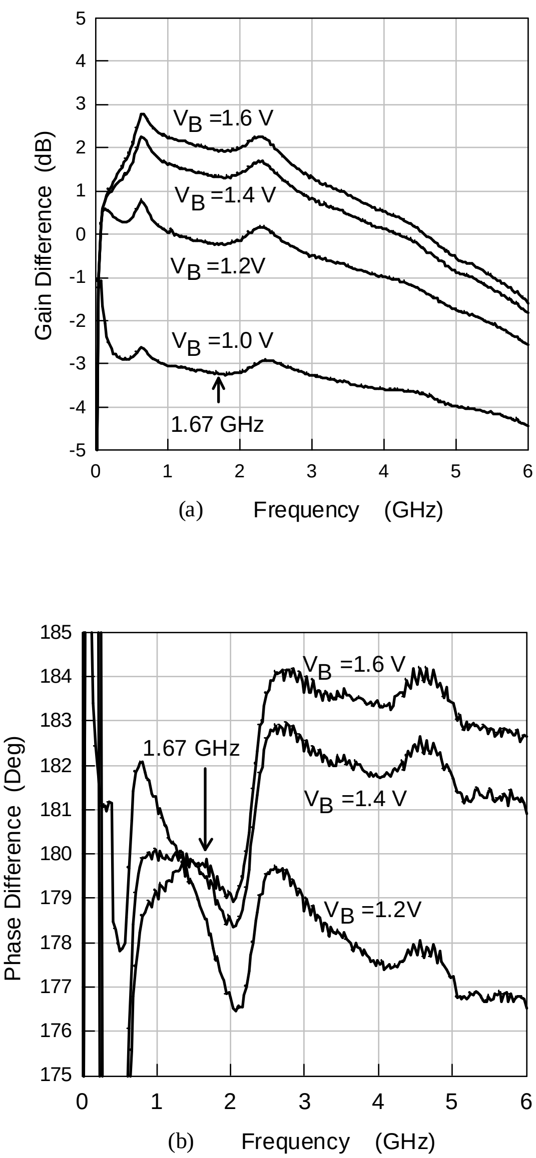


Fig. 6. Measured gain difference (a) and phase difference (b) versus frequency with external tuning of V_B.

area at lower microwave frequencies.

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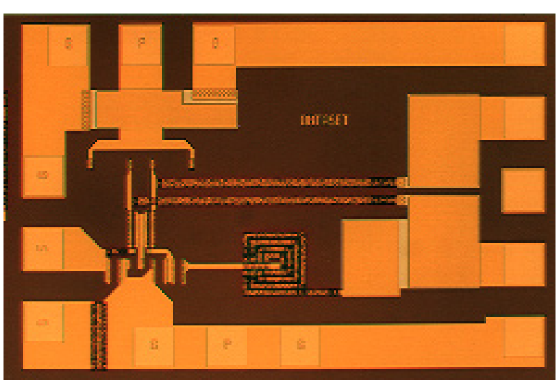
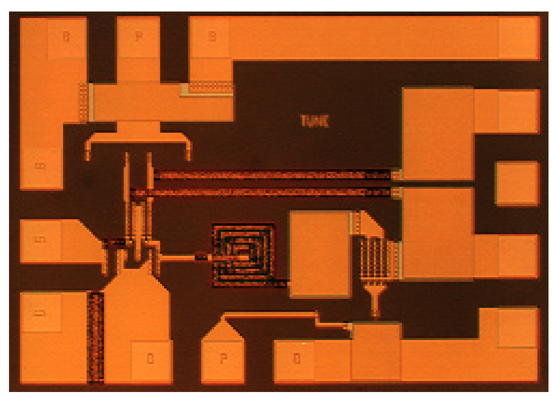
TABLE 1.
Simulated Gain and Phase Difference Against Process Variations

Circuit 1		**Optimized@1.67GHz**		**Optimized@5.8GHz**	
Variation Items	Mismatch Values	ΔGain (dB)	ΔPhase (Deg)	ΔGain (dB)	ΔPhase (Deg)
ΔV_P	± 20mV	– 0.15 ~ 0.11	179.5 ~ 179.6	– 0.16 ~ 0.16	180.0 ~ 180.1
ΔC_F	± 20%	– 0.026 ~ – 0.027	179.7 ~ 179.4	– 0.0045~ – 0.0037	180.2 ~ 179.9
ΔC_P	± 10%	– 0.027~ – 0.026	179.7 ~ 179.4	0.0011~ – 0.032	178.9 ~ 180.2
ΔR_L	± 10%	0.17 ~ – 0.26	179.2 ~ 179.9	0.21 ~ – 0.16	179.2 ~ 180.9
$\Delta (R_F / R_{G2})$	± 10%	0.17 ~ – 0.26	179.2 ~ 179.9	0.34 ~ – 0.39	179.5 ~ 180.6



(a)



(b)

Fig. 7. Chip microphotos of Circuit 1 (a) and Circuit 2 (b).