GaInP/GaAs HBT wideband transformer Gilbert downconverter with low voltage supply

S.-C. Tseng, C.C. Meng and C.-K. Wu

A low-voltage wideband downconverter along with an integrated transformer RF balun using the 2 μm GaInP/GaAs HBT technology is demonstrated. This transformer is a symmetric type and plays a role as a single-to-differential balun. Without the parasitic between the transformer and the substrate, the transformer can work at higher frequencies. This transformer downconverter operates from 1.5 to 14 GHz with around 20 dB conversion gain and 1.8 GHz IF 3 dB bandwidth. The frequency range of the mixing operation is wide and covers the digital video broadcasting via satellite (DVB-S) bands. This mixer is therefore useful for DVB-S applications.

Introduction: Wideband and high frequency communication systems are developed for high data rate applications. The balanced structure is often applied and needs a balun to generate differential signals. The operation bandwidth is limited by the frequency response of circuits and the useful bandwidth of baluns. The frequency response of circuits is enhanced along with the advancement in technology, while the balun is integrated into RF ICs to eliminate the mismatch of the external baluns and cables and then to extend the useful bandwidth. Baluns, such as Marchand baluns, phase inverter rat-race couplers [1], transformers [2] and so on, function as a single-to-differential converter with a broadband property and are popularly used. Especially, the transformer has smaller size and higher bandwidth ratio.

Though a micromixer, the variation of a Gilbert mixer, has a single-ended RF input and performs wideband operation, the supply voltage should be higher owing to the transistor stack [3]. The transformer takes the place of the RF single-to-differential transconductance amplifier of the micromixer. The transformer mixer can operate with low supply voltage because there is no DC voltage drop on the transformer. Besides, the transformer is a linear device compared with the active RF input stage of the micromixer. Thus, the transformer mixer takes advantage over the micromixer in terms of power consumption and linearity. The transformer integrated into the circuits had been demonstrated at 5 GHz using the silicon-based process [4]. In this Letter, the transformer mixer is realised using the 2 μm GaInP/GaAs HBT technology. Low loss and a high self-resonant frequency for the transformer result from the GaAs semi-insulating substrate. Therefore, the transformer can be applied for higher frequency applications. The transformer mixer is useful for wideband and higher frequency applications, especially the digital video broadcasting via satellite (DVB-S) applications the RF frequencies of which are from 10.7 to 12.75 GHz [5].

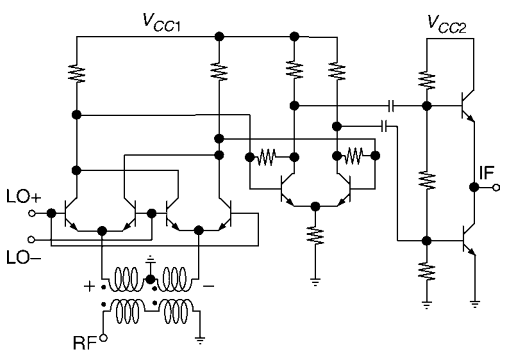

Fig. 1 *Schematic diagram of Gilbert downconversion mixer with transformer RF balun*

Circuit design: Not only does a transformer function as a single-to-differential converter, but also its bandwidth ratio, the ratio of the maximum operation frequency to the minimum operation frequency, is large. Thus, the transformer is suitable for wideband applications. Fig. 1 is the schematic diagram of the overall wideband downconverter. The symmetric transformer is employed at the RF stage to generate a truly differential and broadband RF signal. Thanks to the symmetry property, the centre tap is easily added in the middle. The centre tap of the transformer can provide a DC ground without degradation of the balanced structure. Besides, the mixer can operate with low voltage supply because there is no DC voltage drop on the transformer.

The symmetric transformer is made of two metal layers with thickness of 1.6 and 1 μm and occupies the estate of 150 × 150 μm^2. The width and space are 3 and 4.5 μm, respectively. The turn ratio is 4:3. The transformer has the flowing properties: $L_p = 3$ nH, $L_s = 2$ nH, $Q_{pmax} = 5$, $Q_{smax} = 4.5$ at $f_{Qmax} = 6.5$ GHz for the primary winding and the secondary winding. The coupling coefficient, k, between two windings is approximately 0.6. The transmission coefficient, S_{21}, from the primary winding to the secondary is about −5 dB. The performance of the transformer on GaAs substrate is much better than that of the transformer on Si substrate thanks to the semi-insulating GaAs substrate.

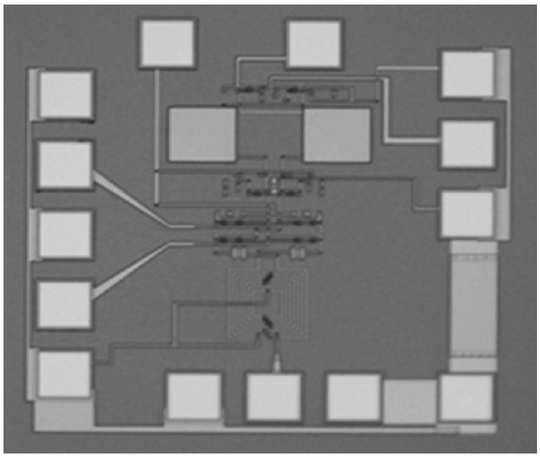

Fig. 2 *Die photo of transformer mixer*

The Gilbert cell switch quad takes responsibility for the frequency translation of the downconverter. The switch quad performs the current commutation. The output of the mixer core is connected to a differential shunt-shunt feedback transimpedance amplifier. This amplifier enhances the speed of the output stage of the mixer core. Thus, this mixer has a broad IF bandwidth. The output buffer is a differential-to-single stage formed by common-emitter-configured and common-collector-configured transistors with the unit gain.

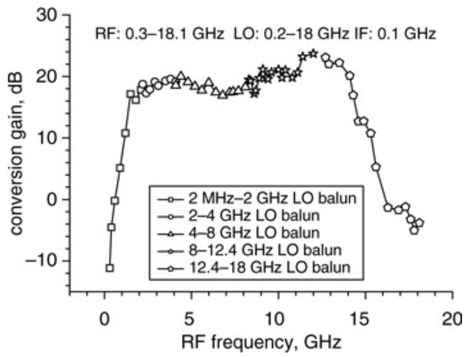

Fig. 3 *Conversion gain of transformer mixer with respect to RF frequencies*

Measurement results: A transformer Gilbert downconverter was fabricated using 2 μm GaInP/GaAs HBT process, as shown in Fig. 2. The entire chip size including probing pads is 1 × 1 mm^2. This mixer core consumes 8.6 mA at 2.4 V while the output buffer takes 6.8 mA at 3.3 V. The HBT transistor of the mixer core is 2 × 4 μm^2 with peak cutoff frequency, Ft, of 40 GHz and F_{max} of 50 GHz. As shown in Fig. 3, the conversion gain is measured with the fixed IF frequency of 100 MHz and the differential LO signals are provided by five external baluns. The mixer works from 1.5 to 14 GHz with the conversion gain of approximately 20 dB. The operation bandwidth ratio is still high as 9.3:1. Thanks to the frequency response improvement of the mixer output by the shunt-shunt feedback transimpedance amplifier, this mixer has a broad IF 3 dB bandwidth of 1.5 GHz, as shown in Fig. 4. In addition, the noise figure of the mixer is about 23 dB. The input 1 dB gain compression point, IP_{1dB}, and the input third-order intercept point, IIP_3, are about −17 and −3 dBm, respectively. The linearity of the transformer downconverter is also improved.

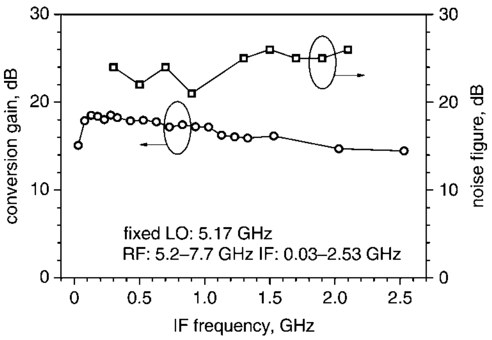

Fig. 4 *Conversion gain and noise figure of transformer mixer with respect to IF frequencies*

Conclusion: In this Letter a low-voltage wideband downconverter along with an integrated transformer RF balun is implemented using 2 μm GaInP/GaAs HBT technology. The transformer formed by two interconnect metal layers is a symmetric type; it possesses good electrical properties at high frequencies because of the semi-insulating GaAs substrate, and it plays a role as a single-to-differential balun at the RF stage. This transformer downconverter acts from 1.5 to 14 GHz and has conversion gain of around 20 dB, IF 3 dB bandwidth of 1.8 GHz, IP_{1dB} of −17 dBm, and IIP_3 of −3 dBm. The linearity of the transformer downconverter is also improved thanks to the linear property of the transformer. The operation frequency of the mixer covers the digital video broadcasting via satellite (DVB-S) bands and therefore this mixer is useful for DVB-S applications.

Acknowledgments: This work is supported by the National Science Council of Taiwan, Republic of China, under contract numbers NSC 95-2752-E-009-001-PAE, NSC 95-2221-E-009-043-MY3, by the Ministry of Economic Affairs of Taiwan under contract number 95-EC-17-A-05-S1-020, by the MoE ATU Program under contract number 95W803, and by the National Chip Implementation Center (CIC).

7 October 2007
Electronics Letters online no: 20082876
doi: 10.1049/el:20082876

S.-C. Tseng, C.C. Meng and C.-K. Wu (*Department of Communication Engineering, National Chiao Tung University, Hsinchu 300, Taiwan, Republic of China*)

E-mail: ccmeng@mail.nctu.edu.tw

References

1 Wang, T., and Wu, K.: 'Size-reduction and band-broadening design technique of uniplanar hybrid ring coupler using phase inverter for M(H)MIC's', *IEEE Trans. Microw. Theory Tech.*, 1999, **47**, (2), pp. 198–206

2 Long, J.R.: 'Monolithic transformers for silicon RF IC design', *IEEE J. Solid-State Circuits*, 2000, **35**, (9), pp. 1368–1382

3 Gilbert, B.: 'The MICROMIXER: a highly linear variant of the Gilbert mixer using a bisymmetric class-AB input stage', *IEEE J. Solid-State Circuits*, 1997, **32**, (9), pp. 1412–1423

4 Long, J.R.: 'A low-voltage 5.1–5.8-GHz image-reject downconverter RF IC', *IEEE J. Solid-State Circuits*, 2000, **35**, (9), pp. 1320–1328

5 Copani, T., Smerzi, S.A., Girlando, G., and Palmisano, G.: 'A 12-GHz silicon bipolar dual-conversion receiver for digital satellite applications', *IEEE J. Solid-State Circuits*, 2005, **40**, (6), pp. 1278–1287