Broadband SiGe HBT Gilbert downconverter with 1.8 to 36 GHz integrated dual Marchand balun

J.-S. Syu, C. Meng and S.-W. Yu

A broadband Gilbert downconverter with an integrated dual Marchand balun (balanced to unbalanced transformer) is demonstrated by using 0.35 μm SiGe heterojunction bipolar transistor (HBT) technology. A dual Marchand balun consisting of a lower band balun and an upper band balun is employed in the LO stage of the downconverter to maintain balanced LO signals from 1.8 to 36 GHz. The broadband downconverter has peak conversion gain of 3 dB at RF = 3 GHz and 3 dB bandwidth of 1.8 to 20 GHz at 3.3 V DC supply.

Introduction: Recently, passive components have been implemented on low-cost silicon substrate for monolithic microwave integrated circuits (MMICs) [1–3]. However, a quadrature coupler on a high-resistivity silicon substrate [1] is incompatible with the standard CMOS technology. The Marchand balun is implemented by using interconnect metals with a shielding ground plane on a standard silicon substrate [2], but the size of the Marchand balun is large because the intermetal dielectric, silicon dioxide, has a small dielectric constant. In this work, each planar Marchand balun is implemented directly on the low-resistivity silicon substrate (∼10 Ωcm) without any shielding ground plane and the balanced outputs are maintained because of equal path loss [3].

The demonstrated dual Marchand balun [4] is formed by lower and upper band baluns with subsequent diplexers and successfully generates balanced signals over 20:1 bandwidth while a conventional Marchand balun implemented on chip has approximately 4:1 bandwidth [5]. A broadband micromixer with a single-ended input stage is employed to test and verify the dual Marchand balun in the LO port.

Circuit design: The schematic of the SiGe HBT broadband downconversion micromixer with a dual Marchand balun is shown in Fig. 1. The micromixer topology [6] consists of an RF active balun ($Q_1 - Q_4$) and an LO Gilbert switching core ($Q_5 - Q_8$). The RF active balun is composed of a common-base-configured input stage and a common-emitter-configured input stage while the current mirror ($Q_3 - Q_4$) provides balanced DC currents of the two input stages. Therefore, the output signals through the two signal paths have equal magnitude with opposite signs. The emitter width and length of $Q_1 - Q_8$ are 0.3 and 5.1 μm, respectively. The DC current consumption of the mixer core is 1.6 mA and thus the current density of $Q_1 - Q_4$ is 0.52 mA/μm^2 with f_t (cutoff frequency) of 40 GHz. The 3 dB bandwidth of the micromixer is about half of the cutoff frequency owing to the mirror pole of the current mirror path [7] as shown in Fig. 1.

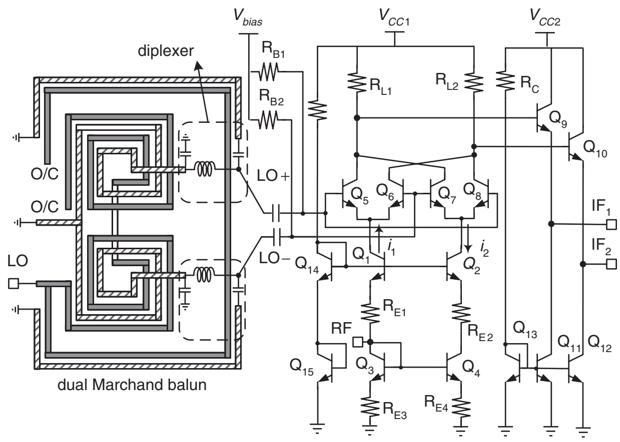

Fig. 1 *Schematic of SiGe HBT broadband downconversion micromixer with integrated dual Marchand balun*

In the LO port, a dual Marchand balun consists of a lower band balun and an upper band balun. Each planar Marchand balun is composed of two quarter-wavelength couplers as shown in Fig. 1. To reduce the size of the lower band Marchand balun, the transformer type quadrature couplers are chosen and each has 8 μm line width, 2 μm line spacing and 310 μm outer diameter. On the other hand, parallel coupled-line couplers are employed in the upper band Marchand balun and the length, width, and spacing of each coupler are 1 mm, 8 μm and 2 μm, respectively. Two diplexers followed by the differential outputs of the two baluns are also shown in Fig. 1. The diplexer can be decomposed to a Π-shaped lowpass filter (LPF) and an L-shaped highpass filter (HPF), respectively. By superposition, the total output of the dual Marchand balun is formed of the signal through the lower band balun with an LPF and the signal through the upper band balun with a HPF. Fig. 2 shows the amplitude response, phase difference of the dual Marchand balun and the amplitude response of each individual Marchand balun. The designed bandwidths of the two baluns are 3–12 and 10–38 GHz, respectively. Therefore, the amplitude variation is less than 2 dB while the phase mismatch is within 5° among 1.8–36 GHz. The DC bias voltage for the LO port is fed from the large resistors ($R_{B1} - R_{B2}$). The output common-collector-configured (CC) buffers ($Q_9 - Q_{12}$) facilitate the 50 Ω RF measurements. The photograph of the SiGe HBT broadband downconverter with an integrated dual Marchand balun is shown in Fig. 3. The die size is 1.3 × 1.2 mm^2.

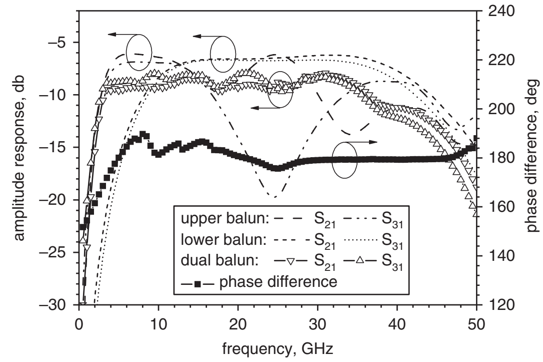

Fig. 2 *Simulated amplitude response, phase difference of dual Marchand balun and amplitude responses of lower and upper band baluns*

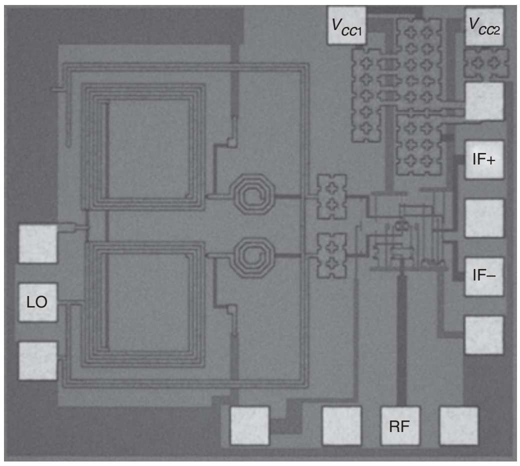

Fig. 3 *Photograph of SiGe HBT broadband downconverter with integrated dual Marchand balun, die size 1.3 × 1.2 mm^2*

Measurement results: The measured conversion gain against RF frequency of the downconverter with a dual Marchand balun is shown in Fig. 4 when compared to the simulated result of the downconverter with an ideal LO balun. The measured peak conversion gain is 3 dB at 3 GHz and the 3 dB bandwidth is 1.8 to 20 GHz at 1 dBm LO input power. In Fig. 4, the conversion gain degrades violently below 1.8 GHz and above 36 GHz because of the dual Marchand balun in the LO port while the high frequency 3 dB pole frequency of the downconverter is 20 GHz owing to the current mirror pole in the RF input stage. The IF 3 dB bandwidth reaches 1.2 GHz. The IP_{1dB} varies from −13 to −7 dBm and IIP_3 from −4 to 4 dBm for RF frequency ranging from 3 to 24 GHz. The double sideband noise figure varies from 15 to 23 dB for RF frequency ranging from 3 to 20 GHz with IF = 500 MHz. The LO-to-RF, LO-to-IF, and RF-to-IF isolations are better than 22, 26, and 20 dB, respectively. The RF input return loss is better than 15 dB over 40 GHz.

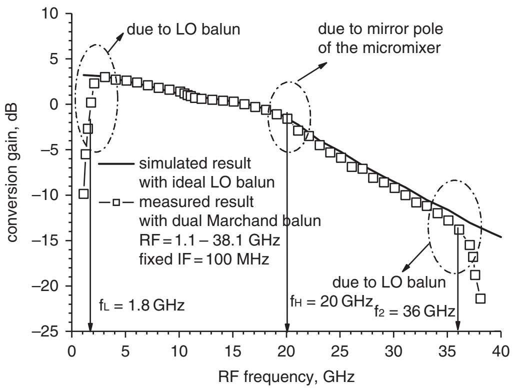

Fig. 4 *Conversion gain against RF frequency of SiGe HBT broadband downconverter with integrated dual Marchand balun*

Conclusion: A broadband Gilbert downconverter is demonstrated by using 0.35 μm SiGe HBT technology. A dual Marchand balun is employed in the LO stage to generate balanced signals over 20:1 bandwidth while the micromixer topology acts as an active balun to maintain the double balanced topology of the Gilbert mixer. The 3 dB bandwidth of the Gilbert downconverter is 1.8 to 20 GHz while the bandwidth of the dual Marchand balun is up to 36 GHz.

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References

1 Frye, R.C., Kapur, S., and Melville, R.C.: ‘A 2-GHz quadrature hybrid implemented in CMOS technology’, *IEEE J. Solid-State Circuits*, 2003, **38**, (3), pp. 550–555
2 Chang, H.-Y., Wu, P.-S., Huang, T.-W., Wang, H., Chang, C.-L., and Chern, J.G.J.: ‘Design and analysis of CMOS broadband compact high linearity modulators for gigabit microwave/millimeter-wave applications’, *IEEE Trans. Microw. Theory Tech.*, 2006, **54**, (1), pp. 20–30
3 Tseng, S.-C., Meng, C.C., Chang, C.-H., Wu, C.-K., and Huang, G.W.: ‘Monolithic broadband Gilbert micromixer with an integrated Marchand balun using standard silicon IC process’, *IEEE Trans. Microw. Theory Tech.*, 2006, **54**, (12), pp. 4362–4371
4 Meharry, D.E.: ‘Decade bandwidth planar MMIC balun’, *IEEE MTT-S Int. Microw. Symp. Dig.*, 2006, pp. 1153–1156
5 Wu, P.-S., Wang, C.-H., Huang, T.-W., and Wang, H.: ‘Compact and broad-band millimeter-wave monolithic transformer balanced mixers’, *IEEE Trans. Microw. Theory Tech.*, 2005, **53**, (10), pp. 3106–3114
6 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
7 Sedra, A.S., and Smith, K.C.: ‘Microelectronic circuits’ (Oxford, New York, 2004, 4th edn.), pp. 744–747