UWB Gilbert downconverter utilising a wideband LR-CR quadrature generator

J.-S. Syu, C. Meng and Y.-H. Teng

An ultra-wideband (UWB) I/Q downconverter with an LR-CR quadrature generator is demonstrated using 0.35 μm SiGe HBT technology. The I/Q outputs of this generator are always in quadrature phase at any frequency while the BJT-type active mixer inherently tolerates much LO power difference for a flat gain response. Consequently, the amplitude imbalance and phase error of the I/Q outputs are less than 1 dB and 2° in the RF frequency range 3–11 GHz.

Introduction: A quadrature signal generation with accurate amplitude and phase is always an important issue for a communication system because the quadrature accuracy determines the bit-error-rate (BER) performance. Traditionally, there are four main methods for generating quadrature signals: (a) a frequency divider, (b) a quadrature voltage-controlled oscillator (QVCO), (c) a microwave coupler, such as a quarter-wavelength coupler or a branch-line coupler, and (d) a polyphase filter.

An even-modulus divider, e.g. a divide-by-two divider, can generate accurate quadrature signals but it requires an input signal with twice the RF frequency and an extra DC power consumption. Besides, the quadrature accuracy of a QVCO is difficult to cover the whole UWB band. A passive coupler has an advantage over the lumped circuits especially at high frequencies; however, it occupies a bulky area at low frequencies [1], e.g. below 10 GHz. Besides, the RC-CR polyphase filter [2] has balanced I/Q amplitude and phase only at the centre frequency of $1/(2\pi RC)$. The wider bandwidth is achieved by adding more RC-CR sections. However, a significant loss and noise figure arise owing to the additional resistors in each section.

In this Letter, an LR-CR quadrature signal generator generates quadrature outputs for a full-band UWB application. The resistance (R) is the input impedance of the following circuits and thus there is no additional noise or power loss for this topology. Furthermore, the LR-CR topology can also be extended to a dual-band prototype but with a narrower bandwidth [3].

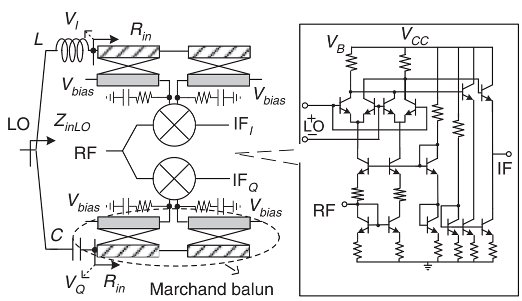

Fig. 1 *Block diagram of UWB I/Q downconverter and schematic of micromixer employed in this downconverter*

Circuit design: The block diagram of the UWB I/Q downconverter is shown in Fig. 1. The ratio of V_Q (CR-path) and V_I (LR-path) can be described as

$$\frac{V_Q}{V_I} = \frac{R + j\omega L}{R + 1/j\omega C} = \frac{1 + j\omega/\omega_o}{1 - j\omega_o/\omega} = j\frac{\omega}{\omega_o} \qquad (1)$$

where $L = R/\omega_0$ and $C = 1/(\omega_0 R)$. Equation (1) indicates that the outputs are always 90° out of phase under the balanced condition $L/C = R^2$ as long as the load impedance ($R = 50\ \Omega$) and the centre frequency [$f_0 = 1/2\pi\sqrt{LC}$] are specified. However, the amplitude imbalance is proportional to the operating frequency with 6 dB/octave. For a UWB application, the centre frequency (f_0) is designed at 5.5 GHz with $L = 1.447$ nH and $C = 0.58$ pF. As a result, the I/Q signals have the maximum amplitude imbalance of 6 dB within the 4 : 1 bandwidth, i.e. from $f_0/2$ (2.75 GHz) to $2f_o$ (11 GHz).

Such amplitude imbalance seems impossible for wideband applications at first sight; however, a BJT-type active mixer only needs a small LO voltage swing for a full current commutation and there is an LO input power range of over 10 dB for a flat gain response [1]. Consequently, a suitable LO power can be selected so that the IF I/Q output amplitude imbalance can be minimised with an excellent quadrature accuracy.

A broadband Marchand balun [4] consisting of two coupled-line couplers is employed to generate differential signals at the LO port of each I/Q mixer. The DC bias (V_{bias}) of the mixer core is fed from the AC-ground node of the Marchand balun, as shown in Fig. 1. A 50 Ω resistor in series with a DC-blocking capacitor is utilised at each output node to achieve a wideband 50 Ω input impedance of each balun. It is worth mentioning that an active balun can also be applied with a compact die size [3] but the linearity of an active balun should be designed carefully since the limited voltage swing degrades the operating bandwidth. The micromixer topology [5] is chosen in this work because it achieves wideband matching and provides balanced RF currents by the input trasnconductance balun stage, as shown in Fig. 1.

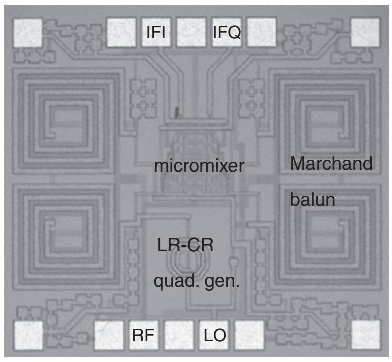

Fig. 2 *Chip micrograph of UWB I/Q downconverter*

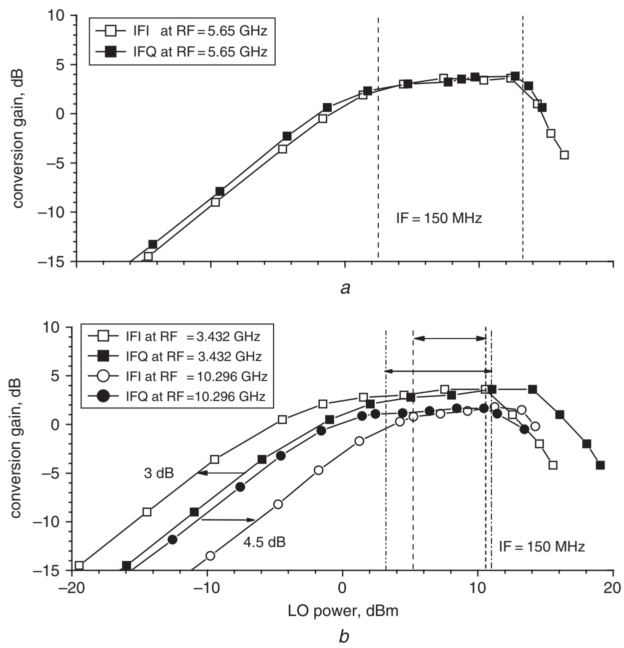

Fig. 3 *Conversion gain of UWB I/Q downconverter against LO power when LO frequency is 5.5 GHz and LO frequency is 3.282 and 10.146 GHz*

a $f = 5.5$ GHz
b $f = 3.2882$ and 10.146 GHz

Measurement results: The chip micrograph of the UWB I/Q downconverter is shown in Fig. 2 and the die size is 1.05 × 0.95 mm. The supply voltage is 3.3 V with a current consumption of 4.7 mA for each mixer. Fig. 3*a* shows the conversion gain of the I/Q downconverter against the LO power when $f = 5.5$ GHz $= f_0$, and Fig. 3*b* shows the results when $f = 3.282$ GHz $< f_0$ and $f = 10.146$ GHz $> f_0$. The I/Q mixers need the same LO power for a full current commutation when the LO frequency is at the centre frequency. On the other hand, the *I*-mixer needs less (more) LO input power to reach the flat gain region than the *Q*-mixer when the LO frequency is lower (higher) than the centre frequency owing to the amplitude imbalance of the LR-CR topology as described in (1). However, the I/Q mixers still have a wide common region of the LO power for balanced quadrature outputs. As shown in

Fig. 4, the RF 3 dB bandwidth of one random selected sample ranges from 2 to 11 GHz when LO power = 8 dBm. In addition, the IP_{1dB} and IIP_3 are better than −9 and 6 dBm, respectively. Fig. 4 also indicates an amplitude imbalance and a quadrature phase error with respect to the input RF frequency when IF = 150 MHz. Five randomly selected samples from the same wafer were tested and all of them had similar RF performance and I/Q amplitude/phase imbalance <1 dB and 2°, respectively. The measured results are limited by the measurement accuracy of ±0.1 dB amplitude and ±0.5° phase error. The input return loss for RF and LO ports are better than 10 dB when frequency ranging from DC to 20 GHz and from 1.6 to 13 GHz, respectively. The IF 1 dB bandwidth is 500 MHz with a noise figure of 17 dB as the IF frequency ranges from 200 kHz to 100 MHz thanks to the low flicker noise corner of the SiGe HBT devices.

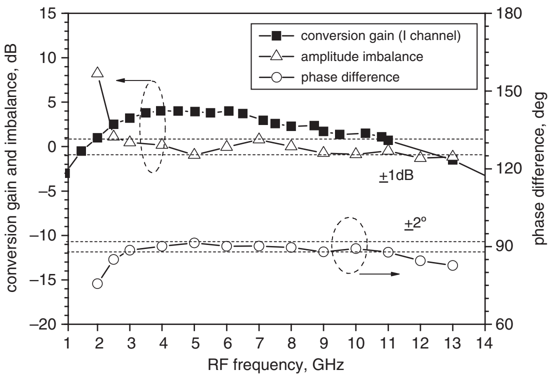

Fig. 4 *Conversion gain, amplitude imbalance and phase difference for I/Q channels against RF frequency*

Conclusions: A differential quadrature signal generator with a constant quadrature phase has been applied to a UWB I/Q downconverter. By combining the LR-CR constant-quadrature-phase signal generator, the wideband Marchand balun and the hard-switching nature of the Gilbert mixers, the proposed downconverter has excellent I/Q balanced outputs covering the whole UWB band.

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