10 GHz dual-conversion low-IF downconverter with microwave and analogue quadrature generators

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

A 10 GHz dual-conversion low-IF downconverter using 0.18-μm CMOS technology is demonstrated. The high-frequency quadrature RF and LO_1 signals are generated by broadside-coupled quadrature couplers while a two-section polyphase filter is utilised for the low-frequency LO_2 quadrature signal generation. As a result, the demonstrated downconverter achieves a conversion gain of 7 dB, IP_{1dB} of −16 dBm, IIP_3 of −5 dBm and noise figure of 26 dB at a 1.8 V supply. The image-rejection ratio of the first/second image signal is 33/42 dB for IF frequency ranging from 10 to 60 MHz, respectively.

Introduction: Both direct-conversion (zero-IF) architectures [1] and low-IF architectures [2] are widely employed in wireless local area network (WLAN) systems. The passive mixer has a low flicker noise corner but the conversion loss forfeits the ability of suppressing noise contributions of the following stages. Thus, a preceding low-noise amplifier with much higher gain is necessary. On the other hand, the conversion gain of an active Gilbert mixer performs good suppression of subsequent noise contributions but the flicker noise issue becomes much serious, especially for high-frequency applications [3, 4]. Although the inductor was placed at the source nodes of the Gilbert core to resonate the parasitic capacitances, the performance was still limited [4]. Therefore, the low-IF architecture is preferred for a 10 GHz receiver because the several tens of megahertz IF band is away from the flicker noise corner. In addition, the DC offset problem can be alleviated by placing a large DC-blocking capacitor at the output.

A polyphase filter generates quadrature signals with accurate phase and balanced amplitudes within a narrow bandwidth [5]; however, the parasitic capacitance and the process variation result in the shifting of the centre frequency and the degradation of the phase accuracy, especially at high frequencies. Therefore, a microwave passive quadrature coupler [6] is introduced in this work to generate high-frequency quadrature signals.

Circuit design: Fig. 1 shows the block diagram of a 10 GHz dual-conversion low-IF downconverter. The first downconversion system consists of two stacked-LO sub-harmonic mixers with quadrature RF and LO inputs while four Gilbert mixers and a following complex polyphase filter are employed for the second downconversion.

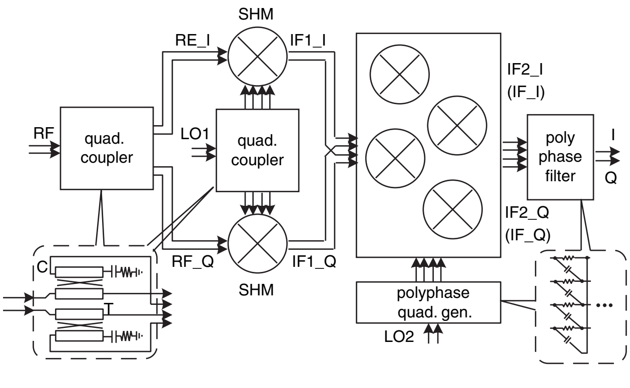

Fig. 1 *Block diagram of 10 GHz dual-conversion low-IF downconverter with microwave and analogue quadrature generators*

The frequency relations for the dual downconversions are given by

$$f_{RF} = 2f_{LO1} + f_{IF1} = 2f_{LO1} + f_{LO2} + f_{IF} \tag{1}$$

$$f_{IM1} = 2f_{LO1} - f_{IF1} = 2f_{LO1} - f_{LO2} - f_{IF} = f_{RF} - 2f_{IF1} \tag{2}$$

$$f_{IM2} = 2f_{LO1} + f_{LO2} - f_{IF} = f_{RF} - 2f_{IF} \tag{3}$$

Because a sub-harmonic mixer is employed, the effective LO_1 frequency is thus twice the LO_1 frequency. In this work, $f_{LO1} = 4.175$ GHz and $f_{LO2} = 1.615$ GHz while f_{IF} ranges from 10 to 60 MHz to avoid the effects of flicker noise. As a result, f_{RF}, f_{IM1} and f_{IM2} are about 10, 6.7 and 9.93 GHz, respectively.

The conventional quadrature coupler (QC) is implemented by a quarter-wavelength coupled line [6]. As a result, the 3 dB QC is realised with a coupling factor of $1/\sqrt{2}$ and a description of the *S*-parameters is shown in Fig. 2. To widen the bandwidth, the coupling factor can be chosen larger if the amplitude imbalance between the coupled and through ports is still tolerable. Note that the phase difference between these two ports of a quarter-wavelength QC under the loseless condition is always 90° [6].

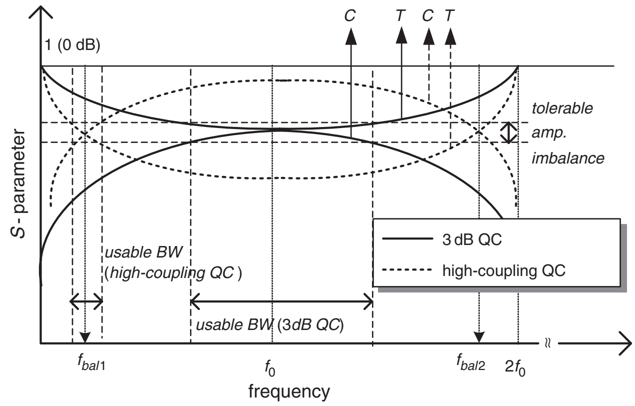

Fig. 2 *Description of S-parameters for 3 dB quadrature coupler and high-coupling quadrature coupler*

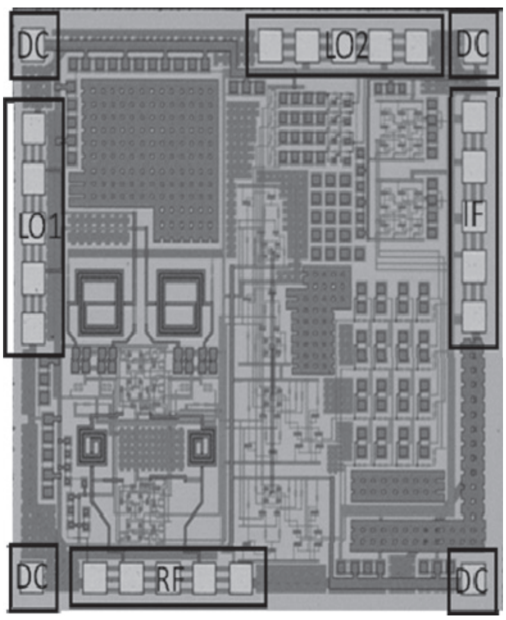

Fig. 3 *Die photo of 10 GHz dual-conversion low-IF downconverter with microwave and analogue the quadrature generators*

In this work, broadside-coupled 10 and 4 GHz QCs are implemented for RF and LO_1 quadrature signal generations, respectively. The high coupling factor (∼0.85) results in a significant amplitude difference at the centre frequency (f_0) and the perfect balanced amplitudes occur at two frequencies, f_{bal1} and f_{bal2}, as shown in Fig. 2. For our application of the fixed LO frequency without the criterion of a wide operating bandwidth, the high coupling factor makes the usable frequency band much below the centre frequency. In other words, for a given operating frequency, the coupler can be very compact since the centre frequency of the coupler is several times the operating frequency. The broadside-coupled QC is realised by two spiral inductors using metal 6 and metal 5. The line width, line spacing and outer diameter of each inductor for the 10 GHz QC are 10, 3 and 120 μm, respectively. The dielectric thickness between metal 6 and metal 5 is 0.8 μm, which is much less than the 3 μm line spacing of the inductor; thus, the broadside-coupling is dominant. On the other hand, the 4 GHz QC has 10 μm line width, 3 μm line spacing, 200 μm outer diameter and the same dielectric thickness of 0.8 μm. From simulation, the centre frequency of 10/4 GHz QC is 25/13 GHz.

Measurement results: The die photo of the 10 GHz dual-conversion low-IF downconverter is shown in Fig. 3 and the die size is 1.92 × 1.7 mm. On-wafer measurement is employed for the RF performance. The power consumption is 80 mW at a 1.8 V supply.

The conversion gain and the image-rejection performance are shown in Fig. 4 and LO_1 and LO_2 power are 10 and 8 dBm, respectively. The image-rejection ratio (IRR) of the first image signal (from 6.675 to 6.725 GHz) is 33 dB covering the IF frequency from 10 to 60 MHz, and the conversion gain of the RF signal is 7 dB. On the other hand, the IRR of the second image signal (from 9.905 to 9.955 GHz) is over 40 dB. The output I/Q waveforms have 0.2 dB amplitude mismatch and 0.15° phase error. IP_{1dB} is −16 dBm and IIP_3 is −5 dBm when $f_{RF1} = 10$ GHz and $f_{RF2} = 10.0005$ GHz. LO_1-to-RF and $2LO_1$-to-RF isolations are 40 and 55 dB, respectively. The single-sideband noise figure is 25 dB.

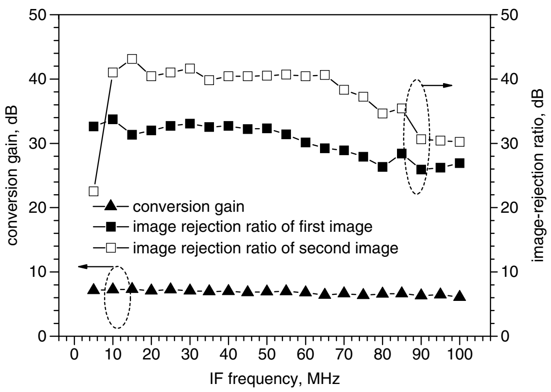

Fig. 4 *Conversion gain and image-rejection ratio against IF frequency of 10 GHz dual-conversion low-IF downconverter with microwave and analogue quadrature generators*

Conclusions: A 10 GHz dual-conversion low-IF downconverter employs microwave couplers for high-frequency quadrature signal generation. The broadside-coupled coupler with a high coupling factor leads to the size reduction for a narrow-band application. At low frequencies, the polyphase filter is still chosen for not only the quadrature signal generator but also the complex filter.

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