Wide-ratio broadband SiGe HBT regenerative frequency divider enhanced by differential TIA load

H.-J. Wei, C. Meng and Y.-W. Chang

A regenerative frequency divider with a differential transimpedance amplifier (TIA) active load using 0.35 μm SiGe HBT technology is demonstrated. The differential TIA is beneficial for higher frequency and lower sensitivity operation, and the inductive peaking enhances the bandwidth of the output buffer. From the experimental results, the operating frequency ranges from 5 to 27 GHz ($f_{max}/f_{min} = 5.2$) for a supply voltage of 5 V and core power consumption of 49.5 mW. The chip size is 0.86 × 0.822 mm.

Introduction: Recently, interest in personal wireless communication systems has been growing rapidly. The faster and accurate frequency synthesiser or phase-locked loop (PLL) systems are required at the transceiver for more efficient usage of finite channels. A frequency divider plays an important role because it dominates the maximum operating frequency and power consumption of the frequency synthesiser or PLL system. A regenerative frequency divider (RFD) [1–4] is a type of analogue frequency divider and has lower power consumption than that of a digital D flip–flop frequency divider. A basic RFD consists of a mixer, a lowpass filter and an amplifier. In the analysis of [2], the emitter of the LO pumping transistor is viewed as a virtual ground when injecting a feedback signal to the LO port. The operating range is strongly related to the lowpass filter and independent of the input signal. However, if the feedback signal is fed to the RF port, the loop gain varies as the input signal of the LO port. In this Letter, the related design issues and performance of this proposed RFD are discussed and described.

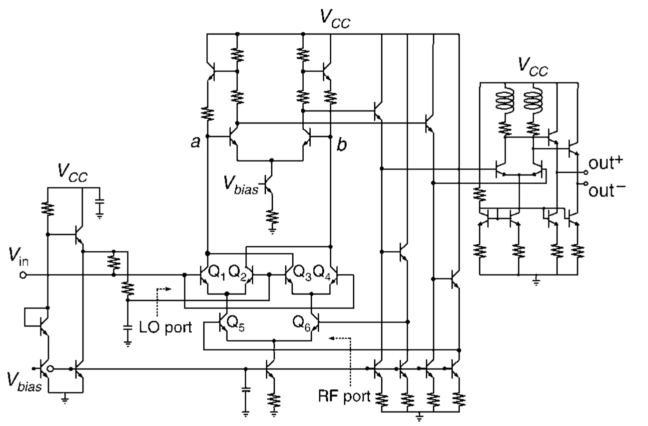

Fig. 1 *Schematic of wide-ratio broadband SiGe HBT regenerative frequency divider*

Circuit design: The core circuit of the RFD shown in Fig. 1 is an active Gilbert cell mixer, which combines all the functional blocks of the RFD. This active mixer providing conversion gain seems to have a built-in amplifier in the feedback loop. The input and feedback signal are separately applied to the upper switching quad, Q_1–Q_4, and the lower differential pair, Q_5–Q_6, respectively. As in the experiment described in [5], the conversion gain of the Gilbert cell mixer is a function of the LO power and frequency. When the input frequency increases, more input power for pumping the switch-quad, Q_1–Q_4, is required to maintain the loop gain higher than one. In addition, the wanted signal through the down-conversion has higher gain than 3/2 harmonic component through the up-conversion after the feedback signal (RF port) mixes with the input signal (LO port) again. Therefore, the minimum operating frequency extends toward a lower limit until the 3/2 harmonic component goes beyond the 0 dB conversion gain and significantly affects the waveform of the wanted signal. The maximum operating frequency could be extended to higher frequency as long as the feedback signal can be steady in the feedback loop. The detailed decay slope of the open-loop gain and the LO pumping condition decides the exact ratio of f_{max}/f_{min}. The design of a wide-ratio SiGe HBT broadband RFD is described in this Letter.

The differential TIA active load with emitter followers replacing resistive loads increases the loop bandwidth without degrading the conversion gain [4]. This shunt–shunt feedback topology reduces the resistance of the points *a* and *b*, so as to lower the open-loop time constant. At the same time, the differential TIA converting small output current of the switching-quad to larger voltage swing is helpful to the input sensitivity. A high-speed double emitter follower (E^2CL) in the feedback path adjusts the DC level of the output buffer and feedback input port. In the output buffer, the inductors are added in series with resistive loads. As the operating frequency increases, this inductor peaking topology compensates for the impedance degradation caused by the parasitic capacitor to enhance bandwidth.

Results and conclusions: A high-frequency RFD is fabricated using 0.35 μm SiGe HBT technology. Fig. 2 shows the die photo; the die size is 0.86 × 0.82 mm. The core of the RFD consumes a supply current of 9.9 mA at a supply voltage of 5 V. Input sensitivity against frequency is shown in Fig. 3. Above an input frequency of 18 GHz (region III), the upward trend of input power means that the conversion gain gradually decreases. More input power (LO power of this mixer) is needed to drive the switching-quad until conversion gain against input (LO) power is saturated, or even reduced. In region II, the loop gain is under the maximum, flat and smooth condition. The sensitivity levels off from 7 to 18 GHz, and the switching quad using SiGe HBT transistors only needs a small twist voltage of 4 V_T (approximately −10 dBm) to commutate the current. As the input signal enters the lower frequency region of I, the $(3/2)f_{in}$ term grows quickly but the $(1/2)f_{in}$ signal still might prevail by increasing input power. Fig. 4 shows the output spectra at the maximum input frequency. The broadband SiGe HBT regenerative frequency divider is successfully demonstrated from 5 to 27 GHz.

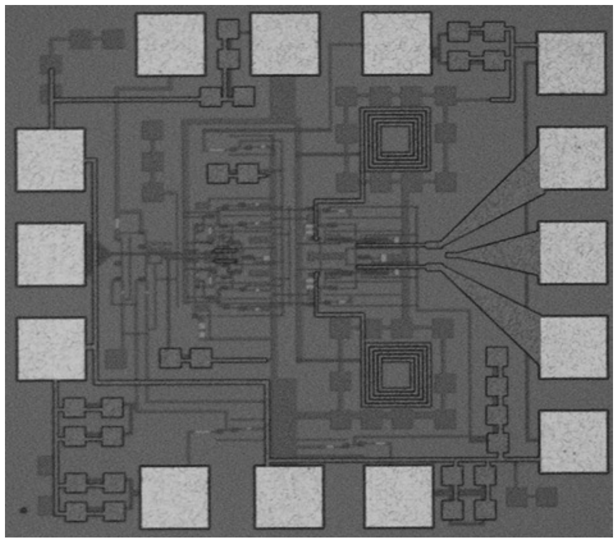

Fig. 2 *Die photo of fabricated SiGe HBT regenerative frequency divider*

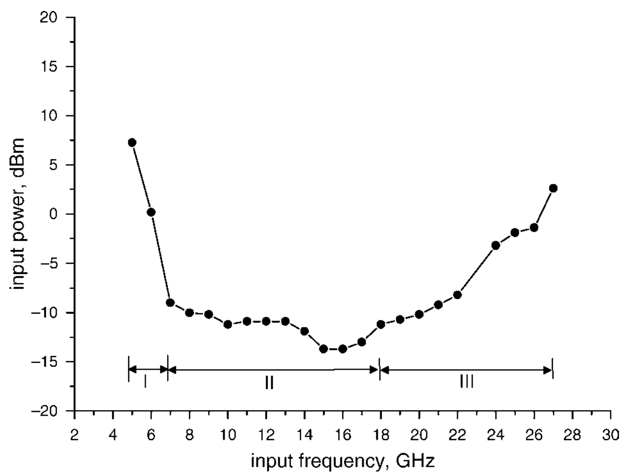

Fig. 3 *Measured input sensitivity of SiGe HBT RFD ($f_{max}/f_{min} = 5.2$)*

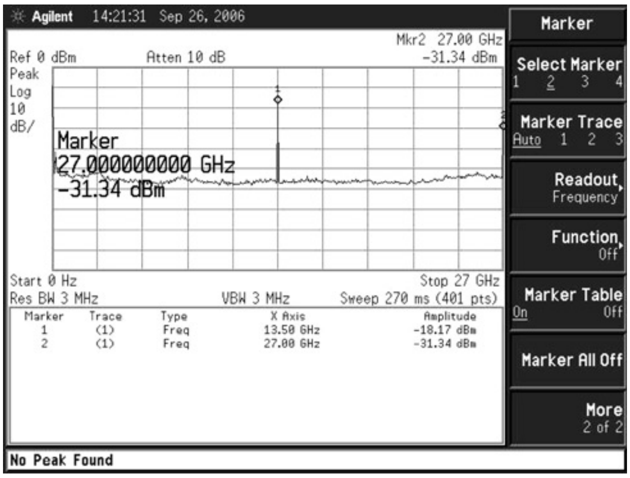

Fig. 4 *Spectrum under 27 GHz input signal*

Acknowledgments: This work is supported by National Science Council of Taiwan, Republic of China, under contract numbers NSC 96-2752-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, MoE ATU Program under contract number 95W803, and by the National Chip Implementation Center (CIC).

12 May 2007
Electronics Letters online no: 20071384
doi: 10.1049/el:20071384

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