

COMPARISON OF GAINP/GAAS HBT RFDS WITH RESISTIVE LOADS AND SHUNT-SHUNT FEEDBACK ACTIVE LOADS

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ABSTRACT: An integrated GaInP/GaAs heterojunction bipolar transistor (HBT) regenerative frequency divider (RFD) with active loads is demonstrated from 4 to 26 GHz. In this work, the RFDs with resistive loads and active loads are fabricated in the same chip for comparison. From the measured results, the active loading type obviously has wider operating frequency and lower input sensitivity. The f_{max}/f_{min} ratio of 6.5 is higher than that of general RFDs. The core power consumption is 36.7 mW at the supply voltage of 5 V. The chip size is $1.0 \times 1.0 \text{ mm}^2$. © 2007 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 50: 433–435, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23096

Key words: regenerative frequency divider (RFD); GaInP/GaAs HBT; shunt–shunt feedback active load; resistive load; double-balanced mixer

1. INTRODUCTION

As the demand for the wireless or satellite systems increases rapidly, higher data-rate and wider-bandwidth are required for more accurate usage of finite channels. In such systems, frequency synthesizer and phase-locked loops (PLL's) play a crucial role in the channel selection and frequency translation. The conventional PLL's utilizes frequency dividers for the multiplication in the feedback loop. Its power consumption and speed almost depend on what kind of frequency divider is used in the loop. The conventional flip-flop-based digital frequency dividers, such as static [1], HLO-FF [2], or super-dynamic structure [3, 4], have the maximum frequencies ($f_{max} = 1/2\tau_D$) that are limited by the gate-delay of emitter couple logic pair. Because of many cascade D-latch stages, the higher power consumption is another drawback.

For high-speed and low-power applications, analog frequency dividers are good candidates, such as a regenerative frequency divider (RFD) [5, 6] and an injection-locked frequency divider. The RFD used in the core circuit of this article has substantial benefit to the operation bandwidth. As shown in Figure 1, the basic diagram consists of a mixer, a low-pass filter, and an amplifier. The maximum frequency is limited by the loop's unit-gain cut-off frequency, $f_{cut-off}$, rather than the total gate-delay of the D flip-flop type divider. Furthermore, the minimum operating frequency oc-

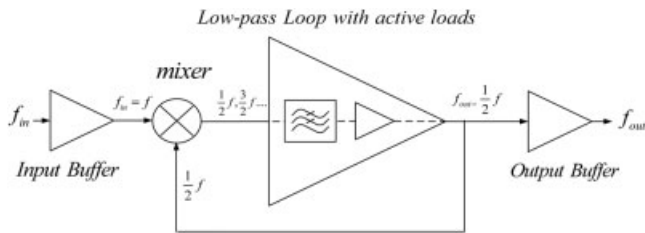


Figure 1 Block diagram of the dynamic frequency divider with the active loads

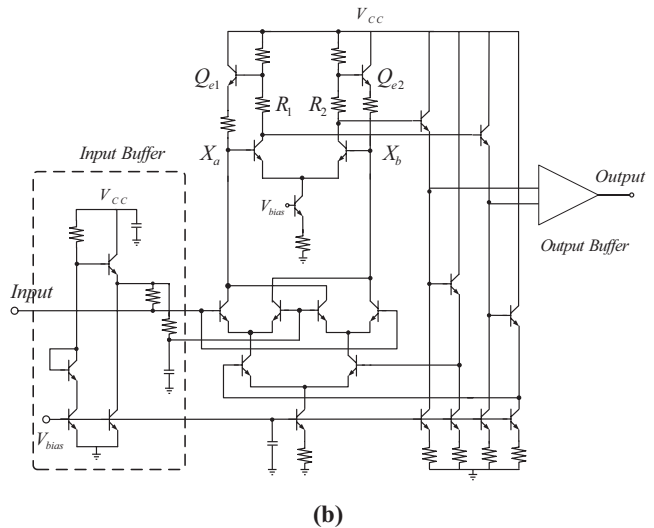
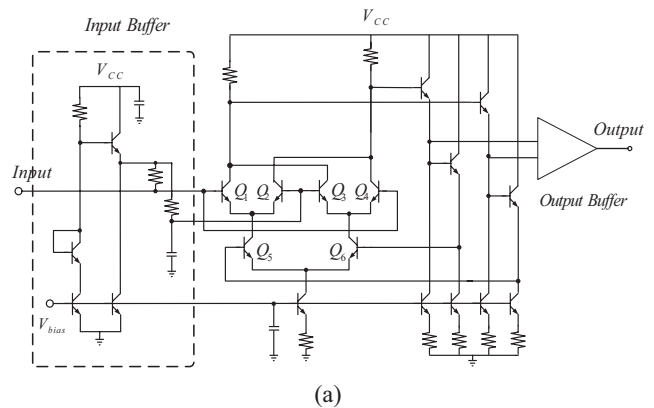


Figure 2 Schematic of the regenerative frequency dividers with (a) resistive loads and (b) active loads

urs when the $3/2$ harmonic component of input signal is no longer suppressed by the low-pass filter. The ratio of f_{max}/f_{min} depends on the decay slop of the open-loop gain above f_{3dB} and the LO pumping condition. As describe in the Ref. 7, the conversion is a function of the LO pumping power and frequency.

For increasing operating frequency, active loads are added in the RFD. From the measured data [6], RFD with active loads operates almost up to the f_T of transistor. The switching pairs of the double-balanced mixer implemented in HBT technology are the superior current switches because a small input voltage is sufficient to steer the total current to one side of the switching pair. In our work, the RFD with resistive loads and active loads are simultaneously implemented in $2 \mu\text{m}$ GaInP/GaAs HBT technology. From the measured results, the RFD with active loads has the wider operating frequency and better input sensitivity.

2. CIRCUIT DESIGN

The core circuit of RFD with resistive loads is a Gilbert double-balanced mixer, as shown in Figure 2(a). The input and feedback signal are separately applied to the upper switching pairs, Q1–Q4, and the lower differential pair, Q5–Q6. Because an active mixer provides conversion gain, it seems to build an amplifier in the loop. The frequency response of the mixer's open-loop gain is an inherent low-pass behavior [6, 8]. The basic blocks of RFD are already merged into the active double-balanced mixer. The characteristic

of the built-in low-pass filter above f_{3dB} is not sharply steep. The maximum operating frequency could be higher than $2 \times f_{3dB}$, even equals $2 \times f_{cut-off}$.

Differential shunt–shunt feedback amplifier replaces resistive loads to improve the open loop bandwidth of RFD without degrading the conversion gain, as shown in Figure 2(b). Because of the shunt–shunt feedback, the lower resistance of the points (X_a and X_b) results in higher frequency poles. The reduction of the open-loop time constant makes the RFD suitable for higher frequency operation. This type also has better input sensitivity thanks to active loads, which can convert the small output current of the LO switching-quad to the larger voltage swing. Furthermore, R_1 and R_2 added to the feedback path of the shunt–shunt feedback amplifier can avoid the unstable condition, such as selfoscillation. In the feedback path, a high speed double emitter follower (E^2CL) adjusts the DC level of the output buffer and feedback input port. The input buffer with AC-coupling topology is employed to generate a nearly out-of-phase signal with a slight magnitude mismatch.

3. EXPERIMENTAL RESULTS

For the comparison between the two RFDs, they are all fabricated in the same chip using $2 \mu\text{m}$ GaInP/GaAs HBT technology. The die photo is displayed in Figure 3 and its size is $1.0 \times 1.0 \text{ mm}^2$. The devices used in the circuit have a peak f_{MAX} of 50 GHz and peak f_T of 40 GHz. The chip was on-wafer measured by using 50- Ω GSG RF probes, GSGSG RF probes and DC probes.

The core of RFD with resistive loads consumes a supply current of 5.89 mA at the supply voltage of 5 V. Input sensitivity versus frequency is presented in Figure 4. The operating frequency ranges from 5 to 24 GHz, and the minimum input power is about -17.6 dBm . Between 8 and 13 GHz, the minimum input power levels off. Above input frequency of 14 GHz, the upward trend of input power means that the operating point of open-loop of RFD goes beyond the 3-dB cut-off frequency (f_{3dB}). More input power (LO power of this mixer) is needed to drive the active mixer until conversion gain versus input (LO) power is saturated. Its f_{max}/f_{min} ratio is about 4.8.

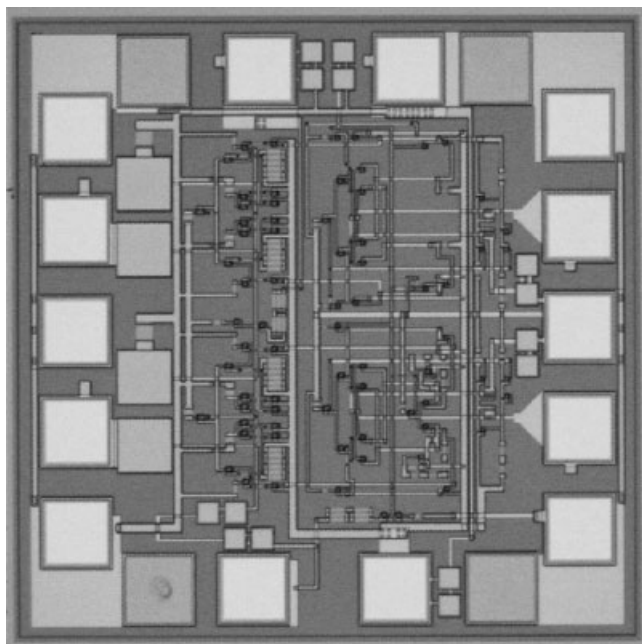


Figure 3 Die photo of the regenerative frequency dividers with the active loads and resistive loads. ($1.0 \times 1.0 \text{ mm}^2$)

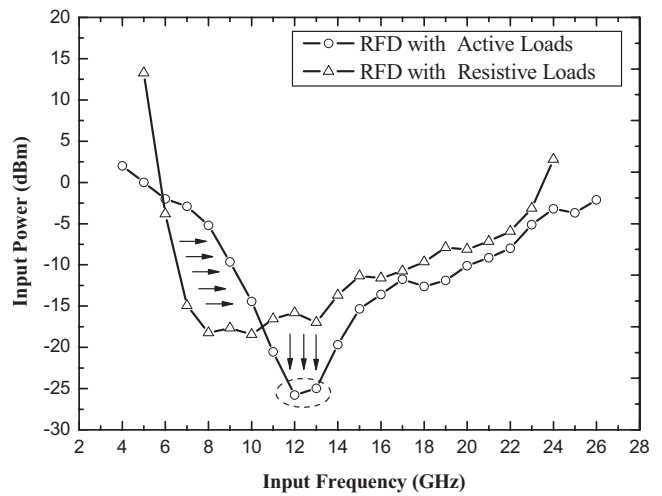
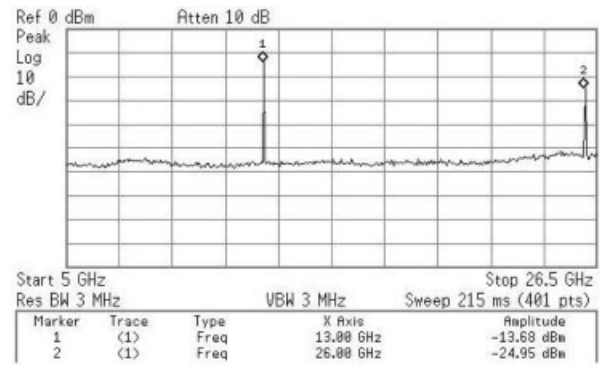
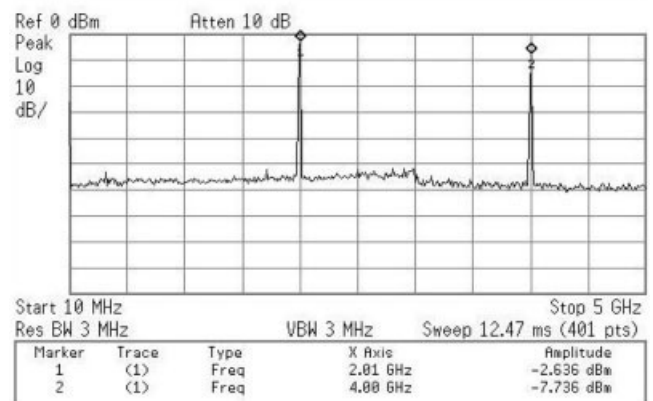


Figure 4 The input sensitivity of RFD with resistive loads and active loads

As to the RFD with active loads, the whole sensitivity curve tends towards the higher operating frequency and lower input sensitivity. The maximum operating frequency is slightly extended to 26 GHz due to the higher f_{3dB} , and the lowest deep of input power is -24.9 dBm . The core current of 7.34 mA is at the supply



(a)



(b)

Figure 5 The output spectrum of RFD with active loads at (a) $f_{input(min)} = 4 \text{ GHz}$ and (b) $f_{input(max)} = 26 \text{ GHz}$

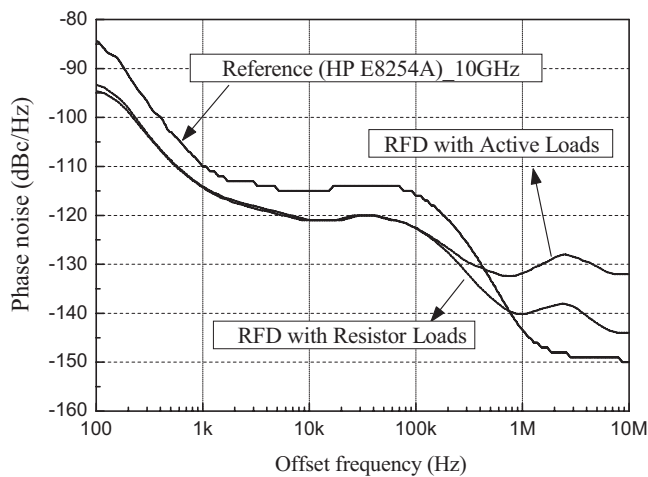


Figure 6 Measured phase noise of the regenerative frequency divider with resistive loads and active loads

voltage of 5 V. The final f_{\max}/f_{\min} ratio is 6.5, and the output spectrums at maximum and minimum input frequency are shown in Figures 5(a) and 5(b), respectively.

The phase noise of the two RFDs and reference signal are measured by an Agilent E5052A signal source analyzer, as shown in Figure 6. In the in-band range, the locked signal tracks the low-phase-noise reference signal and provides the obvious improvement of phase noise about 6 dB. In the out-band range, the RFD with active loads faces the phase noise degradation due to more resistors used in the shunt–shunt feedback amplifier.

4. DISCUSSIONS AND CONCLUSIONS

This article describes the design and performance of the RFD with active loads fabricated in the 2 μm GaInP/GaAs HBT technology. The active loads are used to increase circuit bandwidth and reduce the input sensitivity power. The operating frequency is from 4 to 26 GHz under the supply voltage of 5 V and the core power consumption of 36.7 mW. As the compared results, the active-loading type obviously has the higher operating frequency and the lower input sensitivity. The f_{\max}/f_{\min} ratio of 6.5 is higher than that of general RFDs.

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SEVEN GHz HIGH GAIN 0.18 μm CMOS GILBERT DOWNCONVERTER WITH WIDE-SWING CASCODE CURRENT MIRRORS

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ABSTRACT: A downconversion micromixer with low-voltage cascode current mirrors at both transistor and load stages has been implemented using the 0.18- μm CMOS technology in this article. This micromixer has a single-to-differential RF input transistor formed by the NMOS wide-swing cascode current mirror, while the PMOS wide-swing cascode current mirror is also employed to improve conversion gain. A super source follower is used at the output to reduce the output impedance and to transfer more power to the load. This fully integrated downconverter has the high conversion gain of 16 dB and high LO-to-IF isolation of 50 dB at 7 GHz. The current consumption of the mixer core is 1 mA at 1.8 V supply voltage. Thanks to the low-voltage operation property of the wide-swing cascode current mirror, six transistors can be stacked within 1.8 V supply voltage. © 2007 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 50: 435–437, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23095

Key words: cascode current mirror; downconverter; Gilbert mixer; micromixer; RFIC

1. INTRODUCTION

The Gilbert mixer is the commonly used active mixer performing the frequency translation in the all communication system. Naturally, the Gilbert mixer can operate wideband mixing. However, it does not achieve wideband matching easily because of the high input impedance of the common-source-configured transistors. The micromixer, which is a variant of the Gilbert mixer, is in possession of the wideband input matching and single-ended input [1]. Those features facilitate the realization of the wideband and single-ended mixer. Besides, the balanced structure of the mixer can provide excellent port-to-port isolations [2]. However, the common mode rejection provided by the biased current source in the Gilbert mixer deteriorates rapidly at high frequencies and so does the port-to-port isolations [3]. Comparatively, the rival, the