A Low-Power HBT MMIC Filter Based on Tunable Active Inductors

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***Abstract*— An integrated active microwave filter employing high-Q active inductance simulating circuits is presented in this paper. Heterojunction bipolar transistor (HBT) technology is best-suited for this specific application facilitating the design and giving optimum performance with low power consumption. The prototype triple-resonator filter operates at 2.32 GHz with a 300-MHz −3-dB bandwidth. The power consumption is only 25 mW drawn from a 3-V supply.**

I. Introduction

SIZE reduction is one of the key objectives in modern mobile telecommunication systems. The passive filter modules in radio frequency (RF) front ends are cumbersome and expensive in the manufacturing process. The use of integrated active filters to reduce size and cost, while providing acceptable performance, is potentially attractive.

At microwave frequencies, traditional active filters are not applicable due to the lack of high-gain elements. One of the most promising alternatives has been the use of active resonators for replacing lossy passive elements in LC-filters. An active resonator can consist of a tunable active inductor and a passive high-quality capacitor [1]–[5], or a passive spiral inductor with active loss compensation and a tunable capacitor, i.e., a varactor [6]–[8]. The former has the advantage of employing no passive spiral inductors, which reduces the size and allows the use of inductorless technologies. Active inductors are, however, susceptible to higher noise [9], and they are inherently sensitive to process variations. For adequate performance and low power consumption the g_m/g_{ds} ratio of the transistors needs to be high [4]. This makes technologies with high device heterojunction bipolar transistor monolithic microwave integrated circuit (HBT MMIC) g_m/g_{ds} ratios best suited for the application. In this letter, we present an active inductor filter which takes advantage of low-power and high-gain capabilities of GaAs HBT's.

II. Designed Circuit

The underlying topology of the active inductor is based on the findings by Hara *et al.* [1] and the Q-enhanced version by the authors [4]. Inductance is formed in a gyrator (Fig. 1) which is realized with a common-emitter and a common-base transistor connections (Fig. 2). The equivalent series inductances and resistances of nonideal gyrator-based active inductors are typically

$$L_s \propto \frac{C}{g_{m1}g_{m2}},\quad R_s \propto \frac{1}{g_{mx}}. \tag{1}$$

The unidealities of the transistors result in high losses in a standard gyrator configuration. The extra Q-enhancing resistor in the base of the noninverting transistor gives additional phase shift and ensures high-Q operation at the desired frequency band.

The schematic of the realized circuit is shown in Fig. 3. The current of the transistor chain is controlled via a current mirror Q_3, Q_5. This adjustment controls the gyrator transconductances in Q_2 and Q_3, and thus the inductance value enabling center frequency tuning of the resonator. A p-i-n diode-connected HBT Q_4 forms a voltage-controlled resistor which shunts part of the signal to ground and adjusts the Q-value of the resonator. Q_1 isolates the signal from the supply, and Q_6 is for biasing. Only a little additional phase compensation as a form of R_{Qen} is needed thanks to the very high g_m/g_{ds} ratio of the HBT's.

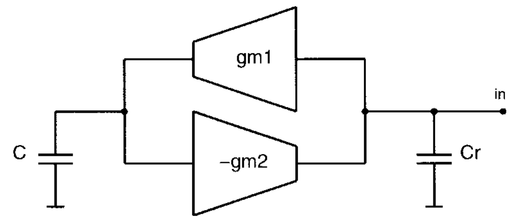

Fig. 1. Basic principle of active resonators based on gyrators.

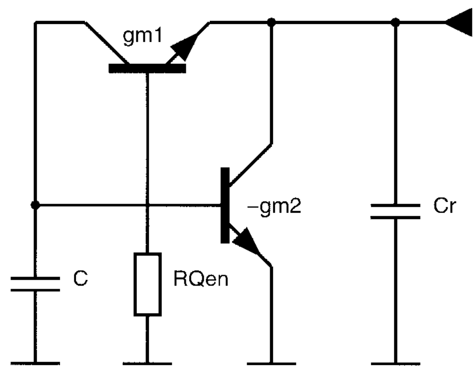

Fig. 2. HBT realization of a gyrator with a Q-enhancing resistor in the base of the noninverting transistor.

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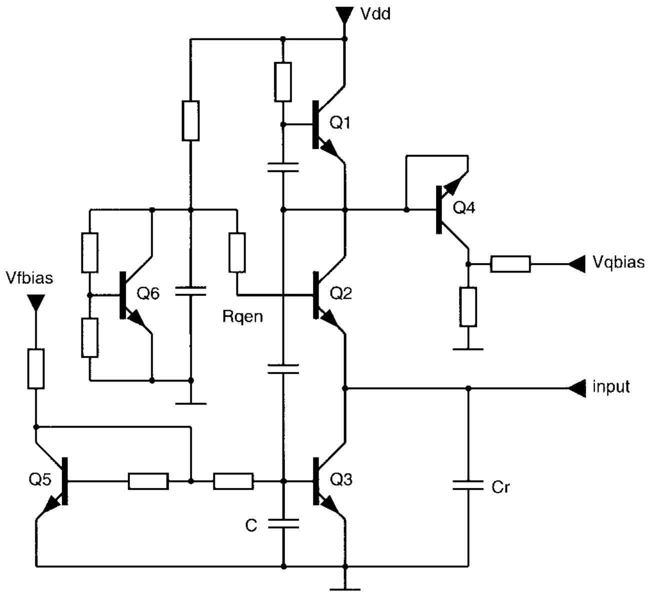

Fig. 3. Schematic diagram of the realized active resonator.

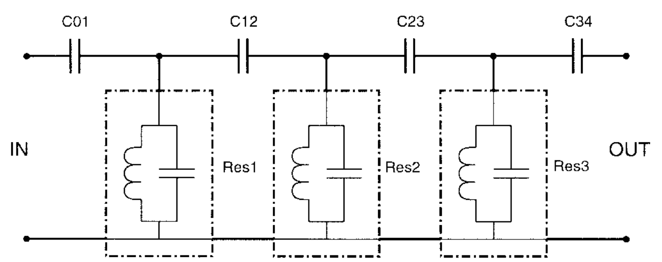

Fig. 4. Top-level schematic of a sixth-order filter with grounded resonators.

The prototype sixth-order Chebyshev bandpass filter was constructed by chaining three active resonators with capacitative coupling, as seen in Fig. 4. This topology with grounded resonators is the most straightforward when active resonators are to be used. The drawbacks of this approach are very small coupling capacitances that are difficult to integrate accurately, and high inner nodal voltage swings restricting dynamic range. These problems can be alleviated if the overall impedance level is raised, but since the circuit was designed for on-chip measurements the impedance level remained 50 Ω.

To facilitate the measurements all the resonators have common bias voltages. This prevents precise adjustments of individual resonators and full control over the response. In a practical circuit, however, real-time tuning of several independent biases will not be possible, and, therefore, common biasing was explored.

$GaAs/Al_{0.3}Ga_{0.7}As$ HBT technology was used in the design with SPICE compatible transistor models. The f_T and $f_{\max}$ of the devices are 22 and 55 GHz, respectively. The chip size is 1.2 × 1.2 mm^2. The microphotograph of the chip is shown in Fig. 5.

III. Measured Results

The measured response is shown in Fig. 6. The tuning range is 2.17–2.39 GHz but, due to the common biasing, the passband is clearly distorted at both extremes. The frequency

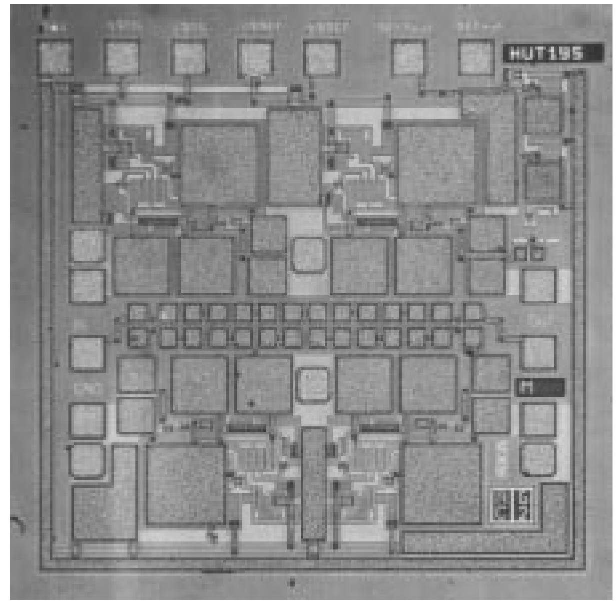

Fig. 5. Microphotograph of the chip. The physical size is 1.2 × 1.2 mm^2. The chip contains a triple-resonator filter and a slave resonator oscillator with an output buffer amplifier.

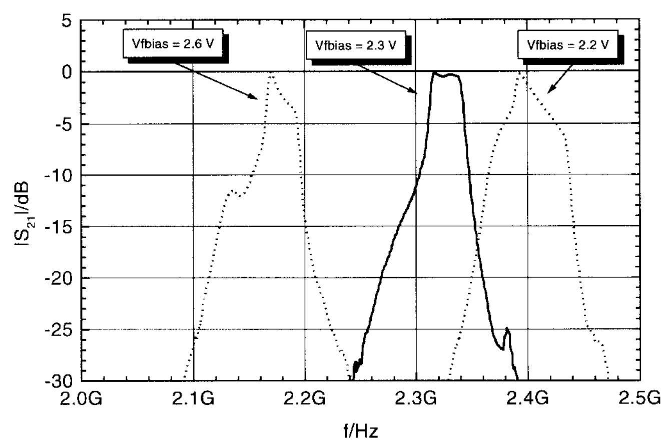

Fig. 6. Measured S_{21} of the filter. The tuning range extends from 2.17 up to 2.39 GHz with V_{fbias} settings of 2.2–2.6 V. The optimum is at 2.32 GHz ($V_{fbias} = 2.3$ V).

tuning voltage is swept from 2.2 to 2.6 V, and the Q-tuning voltage is set within 1.25–1.95 V to give zero loss at the passband. The optimum is at 2.32 GHz with 300-MHz −3-dB bandwidth.

The operating current of the whole filter varies from 7 to 10 mA depending on the frequency adjustment. At the optimum, it is 8.3 mA resulting in only 25-mW power consumption with a 3-V supply voltage. This is only a fraction of that of GaAs MESFET active inductor filters.

Nonlinearities cause limited dynamic range and distortion and passband shape degradation. These remained satisfactory up to −20-dBm input level. The maximum power level can be increased by raising the operating current, naturally at the price of higher power consumption. A noise figure estimate of 35 dB was obtained with the Y-factor method. High noise levels are unavoidable in gyrator-based active resonators.

IV. Conclusions

An active bandpass filter based on inductance simulating circuits has been presented. The use of HBT technology enables comparably very low operating currents while not compromising the functionality. The inherent properties of gyrator-based circuits, however, set limits to the performance in spite of the optimum technology for the application. In a noise-tolerant environment active inductor filters with proper automated tuning circuitry can potentially be utilized as totally integrated and tunable filter building blocks.

References

[1] S. Hara *et al.*, "Lossless broad-band monolithic microwave active inductors," *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 1979–1984, Dec. 1989.

[2] G. Zhang *et al.*, "New broad-band tunable monolithic microwave active inductor," *Electron. Lett.*, vol. 28, pp. 78–81, Jan. 1992.

[3] D. Haigh, "GaAs MESFET active resonant circuit for microwave filter applications," *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 1419–1422, July 1994.

[4] R. Kaunisto *et al.*, "Active inductors for GaAs and bipolar technologies," *Analog Integr. Circ. Signal Processing*, vol. 7, pp. 35–48, Jan. 1995.

[5] W. Aparin and P. Katzin, "Active GaAs MMIC band-pass filters with automatic frequency tuning and insertion loss control," *IEEE J. Solid-State Circuits*, vol. 30, pp. 1068–1073, Oct. 1995.

[6] C. Chang and T. Itoh, "Microwave active filters based on coupled negative resistance method," *IEEE Trans. Microwave Theory Tech.*, vol. 38, pp. 1879–1884, Dec. 1990.

[7] B. Hopf *et al.*, "Coplanar MMIC active bandpass filters using negative resistance circuits," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 2598–2602, Dec. 1994.

[8] U. Karacaoglu and I. Robertson, "MMIC active bandpass filters using varactor-tuned negative resistance elements," *IEEE Trans. Microwave Theory Tech.*, vol. 43, pp. 2926–2932, Dec. 1995.

[9] A. Abidi, "Noise in active resonators and the available dynamic range," *IEEE Trans. Circuits Syst. I*, vol. 39, pp. 296–299, Apr. 1992.