GaAs RF-Modules for Wireless Applications

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Abstract

In this paper three MMIC designs—a front-end, a VCO, and a high-pass filter—are presented. The circuits include some non-conventional solutions, such as integrated resonators and active filtering, in order to demonstrate the capability to integrate larger RF-systems for 2 GHz wireless telecommunication applications. The measurements of the three circuits showed a good performance, and the agreement with the simulations was excellent due to the process-tolerant design approach.

Introduction

The 2 GHz frequency band attracts many wireless applications, such as cellular phones, mobile satellite communication systems, and wireless data networks. At this frequency band GaAs technology begins to have obvious advantages compared to silicon. The substrate isolation is better implying smaller cross-couplings and lower dielectric losses. In high-power applications GaAs offers more linear operation and better efficiency than silicon. Potentially, the GaAs MESFET circuits have lower noise figures than silicon BJT circuits and are more suitable for low supply voltage operation.

To achieve advantages in expenses and in size, larger RF-systems must be integrated. In Fig. 1 a principal block diagram of a wireless transceiver is shown. Depending on the particular wireless communication system, the individual transceiver blocks can be combined differently on chips. Although with GaAs technology complete transceivers can be integrated on a pair of chips, large scale GaAs RF-integration has been demonstrated little. To increase the degree of integration some non-conventional solutions, such as integrated resonators for oscillators and active RF-filters, must be investigated.

The objective of this paper is to present RF-modules showing the possibility to increase the degree of integration in the wireless transceivers using GaAs technology. The circuits reported here are: a double-balanced mixer, a VCO with integrated resonator and varactor, and an active inductor based high-pass filter. Active filters are not yet good enough to be directly applied. They can, however, be used for easing up the specifications for external RF-filters. The designed modules are identified in Fig 1.

Design Criteria

As the key design criteria external components were avoided; in other words, the degree of integration was maximized for demonstration purposes. This might not, however, be the optimally cost-effective solution for actual applications. Moreover, the packaging affects the degree of integration: the level of power gain is limited in the low-cost plastic packages preferred for mass-production RF-circuits.

The designed circuits were targeted to be tolerant against process parameter variations. This is especially important because the nonlinear MESFET models are typically relatively inaccurate. As a result, broadband circuit blocks have been utilized as much as possible. The problems associated with MESFET models in active mixer design ([1]) were avoided using the passive MESFET ring mixer topology.

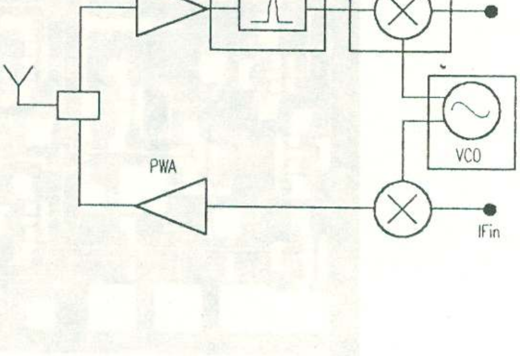

Fig. 1. Wireless transceiver RF-part block diagram. Test circuits presented in this paper are targeted to the identified blocks.

The MMICs were designed for GEC-Marconi F20 process, which can be characterized to be a conventional, stable commercial process with D-type MESFETs. An E/D process would lower the power consumption ([2]) but for a prototype development the F20 process is quite adequate. Although the mixer was optimized for 5 V voltage supply, all the circuits are capable for 3 V operation

Mixer MMIC

The mixer chip includes a one-stage preamplifier, a double balanced mixer, and active baluns. The schematic of the circuit is shown in Fig. 2. For the preamplifier circuit topology a large MESFET (600 μm) with resistive feedback was selected. This topology provides high gain and easy input matching with a series inductor. The baluns and the IF-amplifier are based on the differential amplifier configuration. The resistive MESFET ring was selected for the mixer topology because of its broadband, process variation tolerant performance and good linearity [3]. Relatively large (200 μm) MESFETs maintain a low conversion loss. The size of the driving source follower is designed to produce the optimal impedance level for the ring mixer. A photograph of the 1.8 x 1.8 mm^2 chip is shown in Fig. 3.

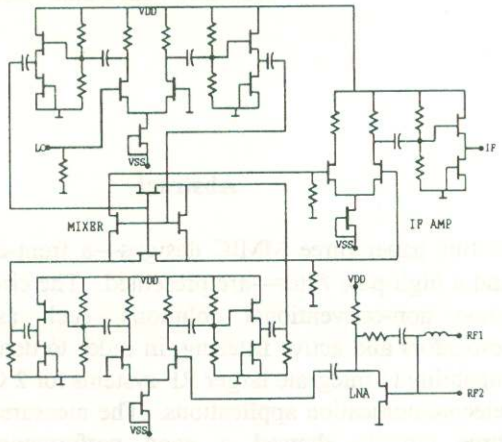

Fig. 2. Double-balanced 2 GHz mixer

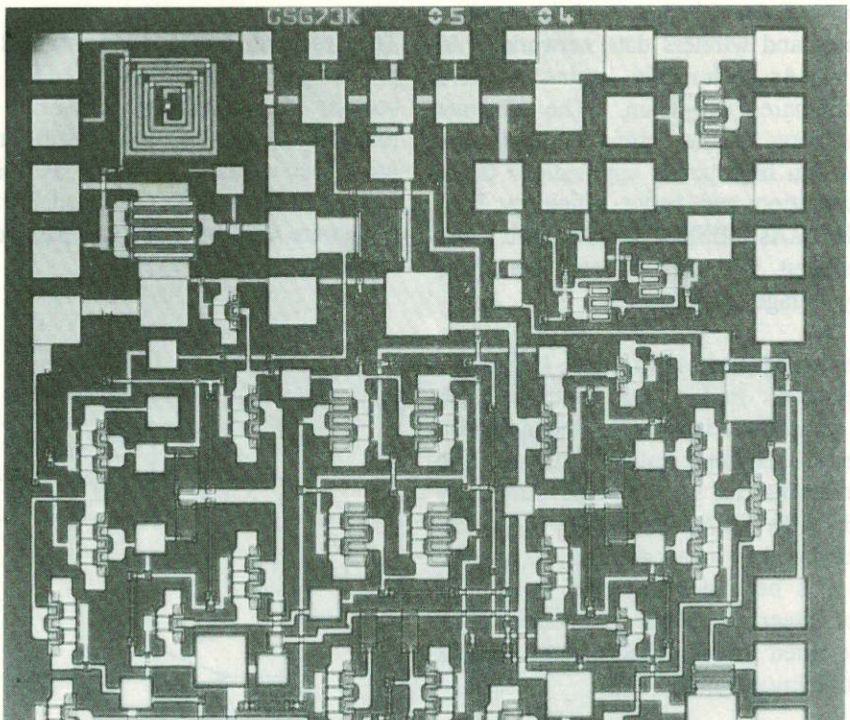

Fig. 3. Double-balanced 2 GHz mixer chip

At 2.2 GHz the mixer measurements showed a 10 dB conversion gain with the lossy on-chip matching inductor. At 1.6 GHz the conversion gain was 12 dB respectively. With an off-chip high-Q matching inductor an approximately 3 dB improvement for the gain can be expected. The level of intermodulation distortion was -30 dBc at P_{in} = -25 dBm. The LO leakage to the output was -40 dB and the RF leakage -30 dB respectively. The measured SSB noise figure was 11 dB and the RF, IF ,and LO port return losses were less than -15 dB.

VCO MMIC

As a completely integrated VCO a slightly modified Clapp topology was selected as shown in Fig. 4. The Clapp topology is well suited for an MMIC implementation because the inductor needed for the LC-tank can be used for DC-biasing. A MESFET-based varactor is used for frequency tuning. The required 7 nH spiral inductor has the Q-factor of 6 at 2.4 GHz. A two-stage common-drain buffer was designed to provide isolation and output matching. The layout of the 1.2 x 1.0 mm^2 circuit is shown in the photograph in Fig. 8. The VCO measurements showed that the frequency tuning range is 2.35 - 2.50 GHz. The measured and simulated frequency tunings are shown in Fig. 5. The disagreement is caused by the inaccurate varactor model utilized. Since there are no amplifying stages the output power is only -2 dBm. The level of phase noise was measured to be -65 dBc at 10 kHz from the carrier frequency and -85 dBc at 100 kHz from the carrier frequency respectively.

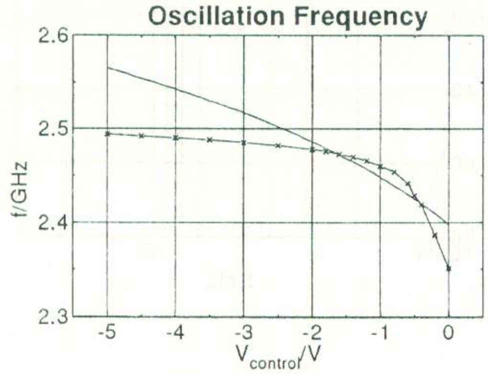

Fig. 5. Measured and simulated oscillation frequencies of the VCO

Active High-Pass Filter

An integrated fifth-order Chebyshev high-pass filter was designed using broadband active inductance simulation circuits. The active inductors are based on a new broadband topology developed by the authors [4]. The circuit diagram is shown in Fig. 6. In Fig. 7 the measured frequency response of the fabricated high-pass filter is shown. The filter performance is still not suitable for channel filtering. The topology can, however, be integrated in a larger system and be used for easing up the specifications for an external filter. The layout of the 0.8 x 0.8 mm^2 circuit is shown in the photograph in Fig 8. In near future, the high-Q narrow band inductors currently in development offer improved performance for RF-filters [5].

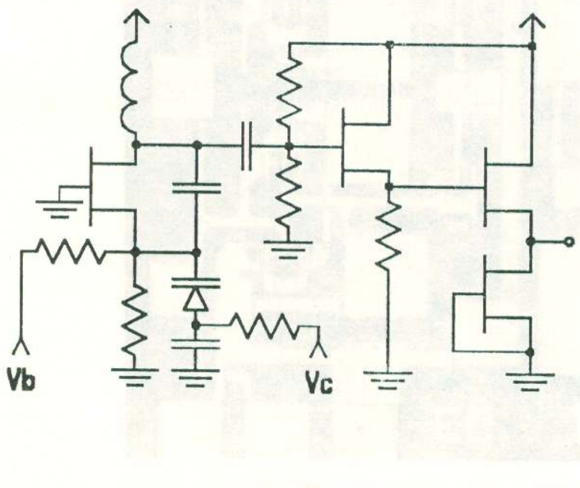

Fig. 4. 2.4 GHz VCO

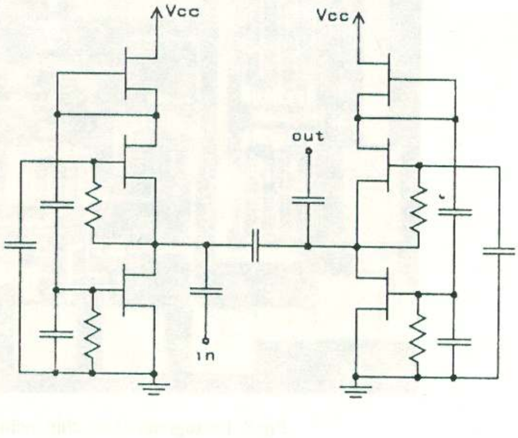

Fig. 7. Active high-pass RF-filter

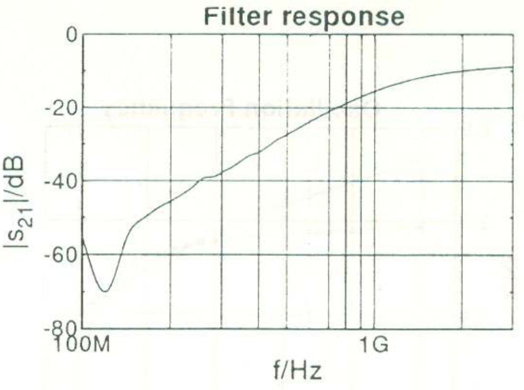

Fig. 7. Active high-pass RF-filter frequency response

Conclusions

GaAs technology shows promise for increasing the degree of integration in RF-modules. Three test circuits including some new topological solutions were designed in order to demonstrate the integration possibilities for wireless telecommunication applications at the 2 GHz frequency band. The measurements of the three circuits showed a good performance and an excellent agreement with the simulations.

References

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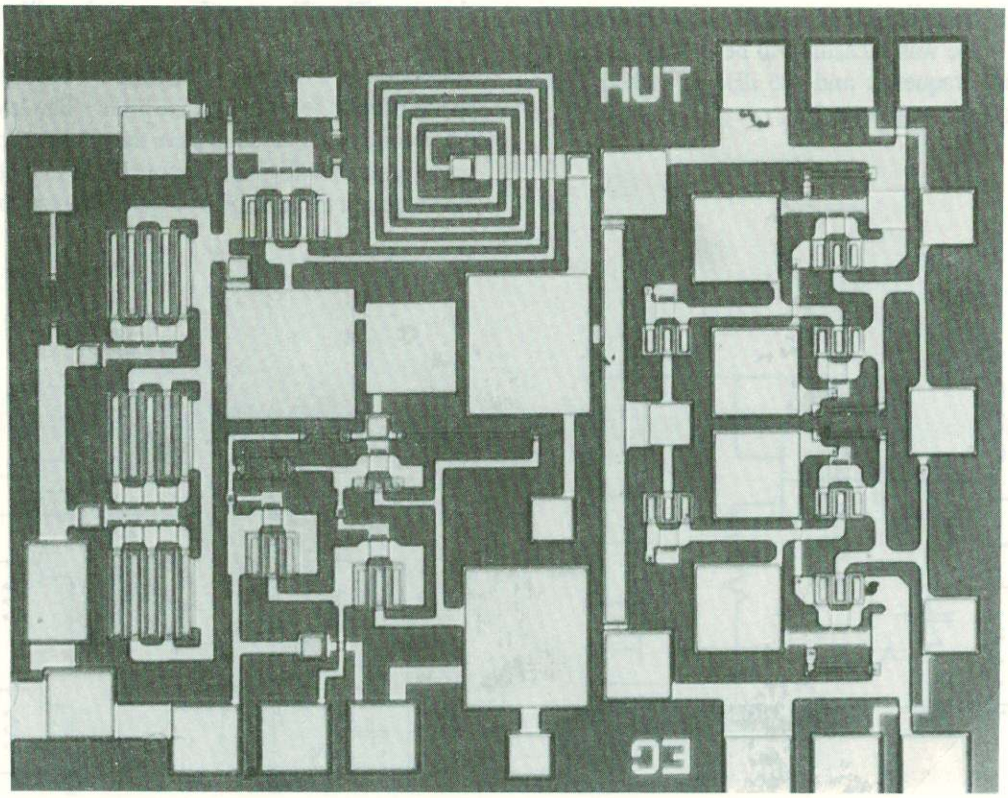

Fig 8. Photograph of the chip including the VCO (left) and the active high-pass filter (right)