A GAAS MMIC ACTIVE FILTER WITH LOW NOISE AND HIGH GAIN

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ABSTRACT

An active image rejection filter applying actively coupled passive resonators is presented. The filter has very low noise and high insertion gain, which may eliminate the use of an LNA in front-end applications. The filter is applicable as a single block LNA and image rejection filter in cordless and mobile telephone systems working around 2 GHz, e.g. DECT and DCS-1800 systems. The GaAs MMIC chip area is 3.3 mm^2. The filter has 12 dB insertion gain, 45 dB image rejection, 6.2 dB SSB noise figure and consumes 13 mW power from a 3 V supply.

INTRODUCTION

The European mobile and cordless market is developing rapidly. This together with rapid development of new technologies and circuit topologies have made many companies (e.g. National Semiconductor, Philips, and Siemens) start development of RF Application Specific Integrated Circuits (RF-ASICs). Consequently, many chipsets combining different functions of transmit/receive modules for mobile and cordless standards have been made available in the last few years. However, filtering functions are still placed off-chip in almost all available chipsets and reported research work in this area. The present work concentrates on development of an active image rejection filter applying GaAs MMIC technology for use in a DECT front-end.

According to the filter's application in cordless and/or mobile telephone handsets the circuit should be suitable for mass production. Hence, the circuit should not require any postfabrication tuning or off-chip components. It is also important that the number of bias lines is low such that simple biasing circuitry is applicable. As a demand on high degree of integration, high insertion gain and low noise is of importance in order to somehow integrate the low noise amplifier, usually preceding the image rejection filter, into the same circuit. The low microwave frequency restricts the design further to only apply more lossy lumped elements rather than large distributed elements.

Excellent works are reported on narrow-band active filter configurations in the last few years [1, 2, 3, 4, 5]. However, these solutions are not restricted to the above mentioned requirements due to the specific application and mass production, and in best case either suffer from demands on postfabrication tuning or insertion loss. The noise figure is not addressed in the mentioned works but may be quite high according to Krantz's [6] investigations. The present paper presents an active image rejection filter suitable for mass production with simple circuitry and low power consumption. Furthermore, the proposed filter has high insertion gain and low noise figure, which eliminates the need for an LNA before the filter in a DECT front-end.

CIRCUIT CONFIGURATION

Applying actively coupled resonators in a

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cascade configuration, shown in Fig. 1a, the circuit sensitivity to process tolerances is reduced due to the noninteractive resonators. At the same time the task of designing a high-order filter is reduced to simple low-order sections. The transistors are not actually a part of the resonators but are integrated into the resonators in calculations, since they do not act as true unilateral gain sections. By this method the influence of the port impedances is reduced by including the influence of the transistors' input and output impedances in the resonators' transfer characteristic. This is illustrated in Fig. 1b, where the transistor is modeled with only its gate-source capacitance and resistance at the input and transconductance and channel resistance at the output.

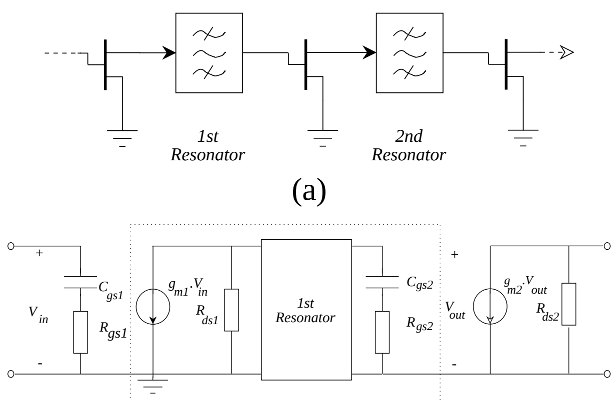

Figure 1: (a) Basic configuration of the actively coupled resonators and (b) including the coupling transistors effect into each section.

Different filter section types can then be applied to achieve the desired characteristic. However, investigations among parallel and series bandpass, bandreject, and elliptic filter configurations show that the parallel bandpass configuration is best regarding out of band rejection and spurious responses [7]. It also has the advantage that grounded inductors in the resonators can serve as choke inductors as well as DC-grounding of the gates in a self biasing circuit.

The obtainable Q-value in one resonator section determines the number of resonators needed in the cascade configuration. For MMIC implementation at this low microwave frequency, around 2 GHz, spiral inductors should be used to reduce the chip size. However, the area of the spiral inductor is still large compared to that of other lumped elements. This results in increased costs and unavoidable parasitic effects with low Q values. Different active inductor configurations as an alternative to the spiral inductor has been investigated [7]. Two active inductor circuits has been designed and their measured results are compared with passive spiral inductors from GMMT's F20 GaAs process [8] with the same inductance value. This has shown that the active inductors have almost the same Q value with significant power consumption and contribution to noise. Hence, passive spiral inductors are applied in the resonators.

The filter is matched to 50 Ω at both ports applying tapped-capacitor matching, which resembles a bandpass response and can be used to improve the attenuation. In order to minimize the number of bias lines the self biasing method is applied with a single 3 V power supply. The series feedback capacitor in the biasing circuitry is further applied to adjust the transistors input impedance for better gain and noise performance. The final circuit configuration is shown in Fig. 2.

The circuit is fabricated on 3.3 mm^2 GaAs substrate applying GMMT's F20 process which is a 0.5 micron ion-implanted GaAs process. In order to reduce the circuit sensitivity to process tolerances interdigital capacitors are applied rather than overlay capacitors, where the capacitance value allow this, since the interdigital capacitors' variation due to process tolerances is negligible compared to about 15% for overlay capacitors. This results in more chip area but the benefit of reducing the sensitivity to process

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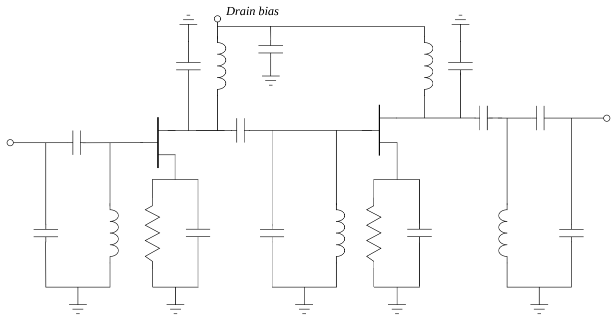

Figure 2: Schematic diagram of the proposed active filter.

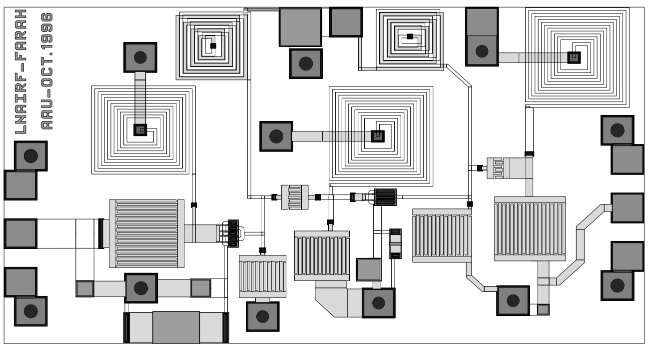

Figure 3: Layout of the proposed active filter.

tolerances is of much more importance for the yield. The circuit layout is shown in Fig. 3.

RESULTS

Measurements on 20 samples from the same wafer show less than 0.6% variation in the current consumption and less than 0.2% in the small signal S-parameters as well as noise performance. The measured transfer characteristic is shown in Fig. 4 by means of $|S_{21}|$ within the band of interest.

The dashed curve on Fig. 4 indicates the simulated transfer characteristic of the center design while the dotted curves are worst case simulation results due to the variations in the components according to process tolerances. The filter introduces 11-13 dB insertion gain within the DECT band, 1880-1900 MHz, and has an

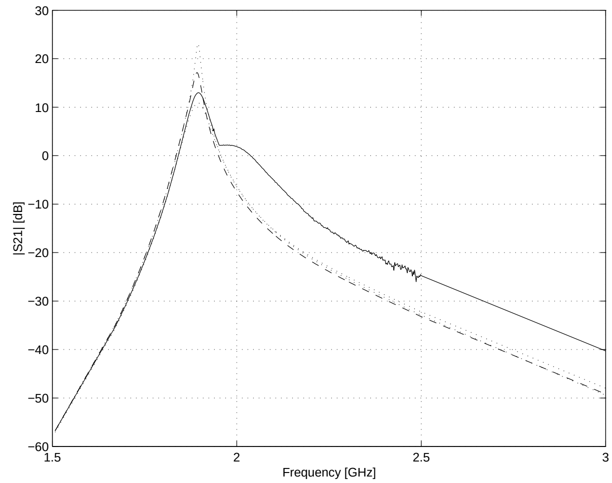

Figure 4: The measured (solid) and simulated (dashed and dotted) transfer characteristic of the filter.

image rejection higher than 45 dB at the image frequency, 1.68 GHz. $|S_{11}|$ and $|S_{22}|$ are measured less than –15 dB within the DECT band. The measured results match reasonably with the expected ones below 3 GHz. The applied electrical model for the spiral inductors is only valid up to 80% of the spirals' self resonance, i.e. around 2.9 GHz. The noise performance is illustrated in Fig. 5, which shows a single sideband noise figure of 6.2 dB within the DECT band.

DISCUSSION

An active image rejection filter is presented for use in a DECT front end applying actively coupled passive resonators. With more than 11 dB gain and maximum SSB noise figure of 6.2 dB the circuit also fulfills the demands on the low noise amplifier in DECT application. Hence, there is no need for an extra LNA in front of the image rejection filter in a DECT receiver front-end. The power dissipation is only 13 mW applying a single 3 V voltage supply. This solution as the first one within its type requires no off-chip components or postfabrication tuning

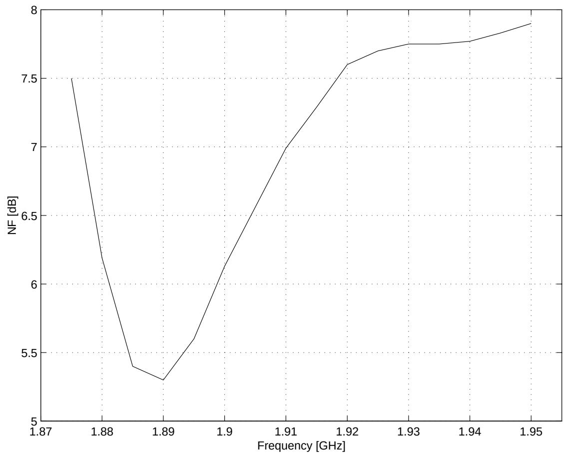

Figure 5: Measured single sideband noise figure of the filter.

and it has good margins for changes in performance due to process tolerances. Hence, the designed circuit is suitable for direct usage in the receiver front-end of commercial cordless and mobile telephone handsets, which today use separate LNA and image rejection filters.

REFERENCES

[1] P. Alinikula, R. Kaunisto, and K. Stadius, "Monolithic Active Resonators for Wireless Applications", in *IEEE MTT–S International Microwave Symposium Digest*, San Diego, USA, May 23–27 1994, pp. 1151–1154.

[2] C. Rauscher, "Microwave Active Filters Based on Transversal and Recursive Principles", *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-33, no. 12, pp. 1350–1360, December 1985.

[3] C. Rauscher, "Distributed Microwave Active Filters with GaAs FETs", in *IEEE MTT–S International Microwave Symposium Digest*, St. Louis, Mo., April 1985, pp. 273–276.

[4] U. Karacaoglu and I. D. Robertson, "MMIC Active Bandpass Filters Using Varactor-Tuned Negative Resistance Elements", *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-43, no. 12, pp. 2926–2932, December 1995.

[5] R. V. Snyder and D. L. Bozarth, "Analysis and Design of a Microwave Transistor Active Filter", *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-18, no. 1, pp. 2–9, January 1970.

[6] E. C. Krantz and G. R. Branner, " Active Microwave Filters with Noise Performance Considerations", *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-42, no. 7, pp. 1368–1379, July 1994.

[7] Farahnaz Sabouri-S., *A MMIC DECT Front-End - with special emphasis on Active Filter*, PhD thesis, Aalborg University, Aalborg, Denmark, May 1997, R97–1005, ISSN 0908–1224.

[8] GEC-Marconi Materials Technology, *GaAs IC Foundry Design Manual, Process F20/F14, Issue 1/3*, The GEC-Marconi Company plc, 1995.

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