MMIC active filters for microwave applications

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Abstract

MMIC technology is a key part of the "wireless revolution" and MMIC transceivers have many new civil applications such as wireless data communications, micro- and pico-cellular mobile communications, and automotive radar and tolling systems. Active filters have an important part to play in increasing the level of integration of MMIC transceivers for these applications. This paper describes and compares three key techniques for the realisation of MMIC active filters for microwave applications. The design and measured performance of the three MMIC active filters is described.

Introduction

The filters and duplexers required in real systems are so large and expensive that the full benefits of MMIC technology are not readily realised when complete integration is required. There are many applications, however, where a low cost and/or low mass integrated circuit based module is an essential part of the enabling technology. For example, advanced satellite payloads using phased arrays may have hundreds of transceiver modules, and it is desirable to integrate the filters into the MMIC modules. Conventional passive filters are not a practical solution, however, because of the size limitations of MMICs and the low Q-factor of MMIC lumped elements. It is only at frequencies well over 20 GHz that microstrip or CPW coupled-line filters might be acceptably small. As a result, there is a great deal of world-wide activity in the area of MMIC active filters. The advantages of active filters are small size and mass, high selectivity, easy integration with amplifiers, mixers, oscillators, etc., and their potential for electronic tuning. However, the drawbacks associated with active techniques are poor noise figure, limited power handling, their DC power requirement, sensitivity to fabrication tolerances and their environmental sensitivity. In order to investigate these points quantitatively and identify an optimum active filter technology, these MMIC active filters have been designed and tested.

Filters Using Actively-Coupled Passive Resonators

The well known cascaded cells approach to active filter design involves breaking the required filter transfer function down into its constituent factors, realising each factor with the appropriate passive filter section, and then obtaining the complete filter transfer function by cascading these sections together via amplifiers, which prevent the resonators interacting. Hussmann-Fort has presented a second-order bandpass filter using this technique [1] and Bonetti (Comsat Labs) has applied the technique to the design of a 4 to 6 GHz bandpass MMIC active filter [2]. A two resonator actively coupled filter has been designed using parallel LC resonators buffered by MESFET amplifiers as shown in Fig. 2. The centre frequency of the filter was chosen to be 1.6 GHz, for potential application in satellite mobile systems, with a prefiltered 75 MHz 3dB bandwidth. The prototype circuit was fabricated on a 1.3 x 2.7 mm GaAs chip (GMMT F20 Foundry, Casseal). A photograph of the filter is shown in Fig. 2. The measured transmission response is shown in Fig. 3. A few dB of gain at 1.6 GHz centre frequency and 40 dB of rejection at 800 MHz from the centre frequency are achieved. However, the measured response clearly shows that this filter does not have sufficient selectivity for demanding communications applications. The active coupling in this filter is not able to compensate sufficiently for the low Q-factor of the passive resonators. An alternative approach is to use negative resistance elements to boost the resonator Q-factor, and two methods of achieving this are described in the following sections of the paper.

Active Inductor Based Filter

The use of transitions to realise inductors for LC resonator type filters was presented in three particularly notable MMIC Transistors papers [3-5]. More recently, the active inductor demonstrated by ATR in Japan [6] has received considerable interest in active inductors for MMIC applications. They use a cascode FET pair with a cascode feedback loop to create an inductor with a reasonable inductance and small size. Hefele [7] reported a tunable active inductor in which the inductor feedback was replaced with a cold FET, used as a voltage-controlled resistor. At KTH we have employed a modified cascode active inductor topology which has been found to achieve negative resistance. This has been achieved by employing an active load and a FET as the feedback element. The complete tunable active inductor circuit topology is shown in Fig. 4. The cascode FET arrangement, common to most active inductor designs, is implemented with T2 and T3. Since a high series resistance results from this bias toplogy, an extra FET is introduced, T1, to provide a variable amount of negative resistance. A 'cold-FET', T4, is employed as a variable feedback resistor to control the value of inductance [7]. Finally, since a spiral inductor load requires a significant amount of chip space, an active load, T5, is used. The measured value for our active inductor chip is tuneable.
from 4 to 11 Hz. The measured Q factor for the inductor can be arbitrarily high. Indeed, it is possible to produce a fixed value negative resistance and this allows the structure to compensate for other losses in the filter.

Fig. 5 shows the measured impedance of the active inductor tuned for an inductance of 1 nH. The Q factor is over 15000. In practice, series resistance values of approximately 4 Ω were used to overcome the overall losses in the MMIC filter.

The active inductor has been used to design a bandpass filter using the topology of Fig. 6, which is most suitable since it has no series inductors. A photograph of the active inductor filter chip is shown in Fig. 7. The measured transmission response is shown in Fig. 8. The measured response shows excellent high selectivity, with 0 dB insertion loss in the 100 MHz passband centred at 2 GHz. The out-of-band response is exceptionally good. While the passband transmission bands all the way up to 30 GHz, as shown in Fig. 9.

Novel Active Resonator Filter

The drawback of the active inductor filter is that the large number of FETs leads to high DC power consumption and demands the application of many biasing voltages. Previously, the use of a simple single-FET negative resistance circuit was demonstrated for the compensation of losses in a microstrip ring-resonator filter [8]. In this paper, this negative resistance FET circuit has been extended to the realisation of active lossless resonators for use in fully monolithic filters with high selectivity. The negative resistance circuit consists of a FET with a series feedback capacitor in its source. The input impedance looking into the gate has a large negative resistance component in common with a small capacitance. A parallel shunt resonator is formed by connecting an inductor from the FET gate to ground. It can be shown that the resonator is not only lossless itself, but can also compensate for other losses in the complete MMIC filter.

A three resonator filter was chosen to demonstrate the new technique. In order to allow frequency tuning of the individual resonators, additional varactors were added to the final filter topology shown in Fig. 10. These varactors are realised using MECS/FETs with the source and drain used as common terminals. While these varactors are not high Q varactors, the active resonator can easily compensate for their loss by introducing more negative resistance. A photograph of the fabricated chip is shown in Fig. 11. The measured response in Fig. 12 shows it operating at 2.3 GHz centre frequency with 120 MHz 3 dB bandwidth, with 0 dB insertion loss and less than ± 0.1 dB ripple in the passband. The out-of-band rejection is as high as 80 dB at low frequencies and is over 50 dB up to 6 GHz. Furthermore, even up to 20 GHz there are no significant spurious transmission bands.

Conclusions

The advantages and disadvantages of active filters for MMIC transceivers have been discussed and three designs have been described. The best performances have been achieved with the techniques which employ negative resistance to compensate for the low Q-factor of MMIC lumped elements. The active inductor and active resonator filters have both achieved excellent selectivity with superb spurious-free range. Comparing the two, the active inductor filter gives the best spurious-free range, since it has absolutes/ no spiral inductors, but it also has much higher DC power consumption and requires many DC bias voltages. In comparison, the novel active resonator filter has a simpler topology which leads to a simpler biasing arrangement and lower DC power consumption. However, since spiral inductors form a key part of the resonator, the spurious-free range is noticeably worse than for the active inductor filter, due to the high frequency resonances of the spiral inductors. Both these filters are tuneable to a similar extent: In principle a MMIC active filter could be designed that could be electronically tuned from the 900 MHz mobile radio band (e.g. GSM), to the 1.9 GHz band (e.g. DECT), or to the 2.4 GHz ISM band (e.g. wireless LANs). Hence, it can be seen that MMIC active filters have tremendous performance capability and can be directly integrated with other circuits. However, process variations and changing environmental conditions make some form of electronic tuning essential, and varactor tuning is expected to play a vital role in narrowband active MMIC filters. Varactors provide well controlled tuning characteristics and draw no current. Hence a multi-pole filter could be tuned up by employing varactor bias potentiometers, which become analogous to the tuning screws in waveguide cavity filters. Such an approach cannot easily be avoided if brick-wall responses are required. Other tuning methods could involve control of DC bias, laser-trimming of resistors, switched spiral inductors, and incorporating conveniently removable air-bridges in the circuit.

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References

Fig. 1 Filter using actively-coupled passive resonators.

Fig. 2 Photograph of MMIC filter with actively-coupled LC resonators.

Fig. 3 Response of the 1.6 GHz filter.

Fig. 4 Topology of the tunable active inductor.
Fig. 5 Measured impedance of the active inductor

Fig. 6 Topology of the active inductor filter

Fig. 7 Photograph of the active inductor filter

Fig. 8 Measured response of the active inductor filter
Fig. 9 Out-of-band response of the active inductor filter

Fig. 10 Filter topology using novel active resonators

Fig. 11 Photograph of the filter using novel active resonators

Fig. 12 Response of the active resonator filter