MMIC Active Filter with Tuned Transversal Element

Kam Weng Tam, Pedro Vitor, and Rui P. Martins

***Abstract*— A novel GaAs monolithic microwave integrated circuit (MMIC) active filter structure based on the lumped and transversal technique is proposed for operation in the X-band. This new structure includes a tuned amplifier as transversal element of the filter in order to improve the band-edge rejection. A design example of a bandpass filter centered @7.5 GHz with 2-dB passband ripple and 30-dB rejection @1 GHz apart from passband edges is presented in terms of computer simulations and layout. The simulated results demonstrate its superior performance when compared with the traditional lumped and transversal technique.**

***Index Terms*—MMIC, microwave active filter, transversal filter.**

I. Introduction

The increasing demand for high integration of light weight mobile communication equipment shouldered with monolithic microwave integrated circuits (MMIC's) technology imposes an urgent need for the implementation of smaller compact systems. Independent of the reasons for integration of the mobile communication equipment in several fields of applications (satellite telephony, remote sensing, wireless LAN, wireless multimedia etc.), one of the main problems would be the filter design because of the drawback of low Q inductors. Thus the realization of active filters in GaAs MMIC technology in the microwave frequency range is highly desirable, taking full advantage of the small size lumped element that is essential to achieve a basic filter response. Then, low Q inductors' losses could be neutralized by the proper arrangement of active devices topology.

Recent development of GaAs MMIC technology in the design of active filters [1]–[4] allows the classification, according to technological similarities, in the following four main categories for realization of the active filters.

1) Negative Resistance;
2) Operational Amplifier;
3) Pre-distorted;
4) Transversal/Recursive.

This paper presents the computer simulation results and layout design of a novel X-band bandpass filter, with a basic filter structure based on the lumped and transversal technique [4] and it also includes a tuned amplifier for realizing the transversal element. This tuned amplifier in the transversal element allows not only the implementation of the transversal gain of the traditional transversal filter, but also the filtering of the lower and upper frequencies, reducing the number of lumped elements in the structure.

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K. W. Tam and R. P. Martins are with the Faculty of Science and Technology, University of Macau, Caixa Postal 3001, Macau, on leave from IST-Portugal, 1096 Lisbon, Portugal.

P. Vitor is with the Departmento de Engenharia Electrotécnica e de Computadores, IST, 1096 Lisbon, Portugal.

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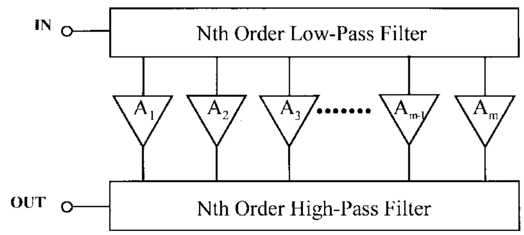

Fig. 1. Conventional microwave lumped and transversal filter structure.

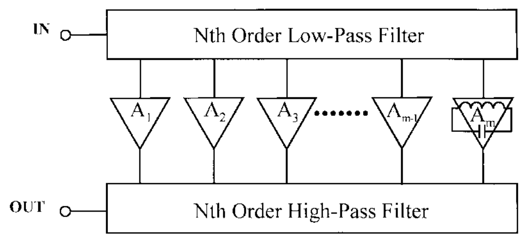

Fig. 2. Novel microwave lumped and tuned transversal filter structure.

II. Novel Circuit Structure

High-frequency monolithic microwave transversal filters usually have a major limitation the need of bulky resonant elements and high gain operational amplifiers. A typical bandpass filter structure with lumped elements is presented in Fig. 1, where for an Nth order Chebychev low-pass/high-pass filter, the transversal elements A_i where $(i = 1, \cdots, m)$ are constant.

The new filter structure proposed in this paper is shown in Fig. 2. It utilizes a transversal element with a resonant circuit to obtain the filtering response by a combination of the transversal technique and tuned amplifier in the main signal path. In the conventional transversal filter structure of Fig. 1, the number of complex-conjugate pole pairs is always even, while this number becomes odd in the new filter structure of Fig. 2 due to the contribution of one pair of complex-conjugate poles of the tuned amplifier. On the other hand, this filter topology also realizes transmission zeros and this new feature indeed highlights the difference between the proposed filter and the traditional all-poles lumped and transversal filter and also allows an additional degree of freedom.

The proposed MESFET tuned amplifier to be used in the new filter is based on the circuit structure of Fig. 3. This structure should be equivalent to a 50-Ω terminated circuit in both sides in order to meet the transversal element's requirement where

$$R = 50\ \Omega$$
$$Y = sC + \frac{1}{sL}$$
$$g_m = \text{transconductance}$$

The voltage transfer function of the above circuit is given by

$$\frac{V_o}{V_i} = \frac{1}{4 + Rg_m}\left[\frac{s^2LC - sLg_m + 1}{s^2LC + s\dfrac{4L}{R(4 + Rg_m)} + 1}\right] \tag{1}$$

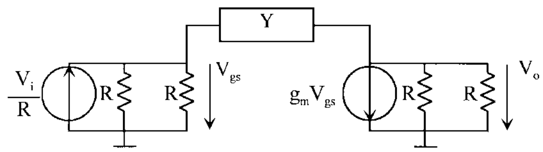

Fig. 3. Ideal equivalent circuit of tuned amplifier.

and the equivalent S-parameter of the above-tuned amplifier is given by

$$S_{21} = \frac{2}{4 + Rg_m}\left[\frac{s^2LC - sLg_m + 1}{s^2LC + s\dfrac{4L}{R(4+Rg_m)} + 1}\right] \tag{2}$$

which can be also written as

$$S_{21} = \frac{2}{4 + Rg_m}\left[\frac{\dfrac{s^2}{\omega_Z^2} - \dfrac{s}{\omega_Z Q_Z} + 1}{\dfrac{s^2}{\omega_P^2} + \dfrac{s}{\omega_P Q_P} + 1}\right] \tag{3}$$

where

$$\omega_Z = \omega_P = \frac{1}{\sqrt{LC}} \tag{4}$$

$$Q_Z = \frac{1}{g_m}\sqrt{\frac{C}{L}} \tag{5}$$

$$Q_P = \frac{R(4+Rg_m)}{4}\sqrt{\frac{C}{L}}. \tag{6}$$

In this tuned amplifier, the frequency response will be of bandpass type for $Q_P/Q_Z > 1$, and notch type for $Q_P/Q_Z < 1$. The addition of the transmission zeros as depicted above allows the implementation of better bandpass approximation like elliptic one, while comparing to the Chebychev approximation or transversal one alone. Also, this introduced resonant circuit acts as part of the feedback network for other transversal elements. Therefore, the introduction of this transversal zero/pole function adds the proper zeros to the complete filter, giving a sharpen response for the filter. This feature of the novel structure is of paramount importance in the design of transversal filters because it will introduce a new type of filtering response which is impossible to obtain with the conventional transversal filters.

III. Computer Simulated Results

In order to demonstrate the advantage of the introduction of the tuned amplifier as a transversal element for the filter, three filters have been designed and simulated having the basic bandpass function of a seventh-order Chebychev low-pass/high-pass filter with 2 dB of ripple in the passband. The first filter with the basic circuit architecture of Fig. 4(a) is a traditional Chebychev bandpass filter combining the low-pass and high-pass sections. The second filter in Fig. 4(b) is a conventional lumped and transversal filter with constant gains while the third filter in Fig. 4(c) is the novel structure proposed designated as tuned transversal filter.

The comparison between the frequency response of the three filters is shown in Fig. 5, obtained by simulation with HP-EEsof Libra 6.0, where the parasitics of passive elements and active devices were considered. From Fig. 5, the band edge rejection skirts are clearly sharpened when the tuned transversal element is added. In addition, post fabrication investigation of frequency tuning is prepared in terms of GEC-Marconi 4×150 cold MESFET for capacitors. By using tuning voltages (−3 V–0 V), it is possible to foresee a reasonable filter centre frequency variation from 8.5 to 10.5 GHz (2 GHz of interval) having a relative bandwidth of 800 MHz.

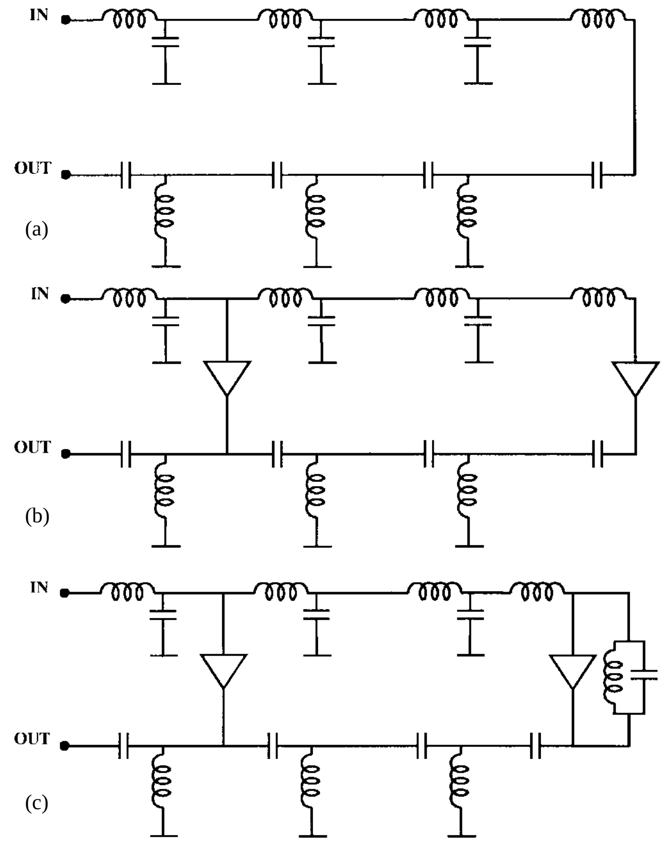

Fig. 4. (a) Seventh-order 2-dB ripple traditional Chebychev bandpass filter. (b) Lumped and transversal filter. (c) Lumped and tuned transversal filter.

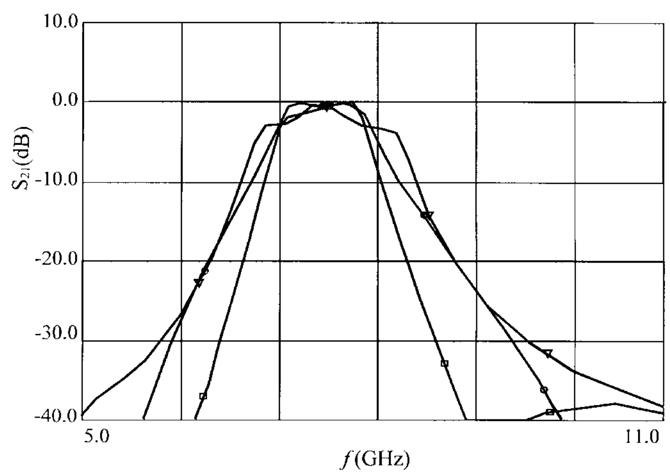

Fig. 5. Simulated bandpass characteristics of the seventh-order traditional Chebychev filter ▽, lumped and transversal filter ◯, and lumped and tuned transversal filter □.

IV. Circuit Architecture and Layout

The circuit architecture of the tuned transversal filter designed with the previous presented characteristics is shown in Fig. 6, where the bias voltages points are depicted as $V_{G1}, V_{D1}, V_{G2},$ and V_{D2} for the transversal MESFET. It is mainly composed by one fixed gain MESFET amplifier and one tuned MESFET amplifier. For the implementation of the tuning circuit, all the capacitors are replaced by 4-Finger cold MESFET. V_{Tune1} and V_{Tune2} as depicted in Fig. 6 are represented for the tuning voltages points for these MESFET and the units for inductors and capacitors are presented in terms of foundry

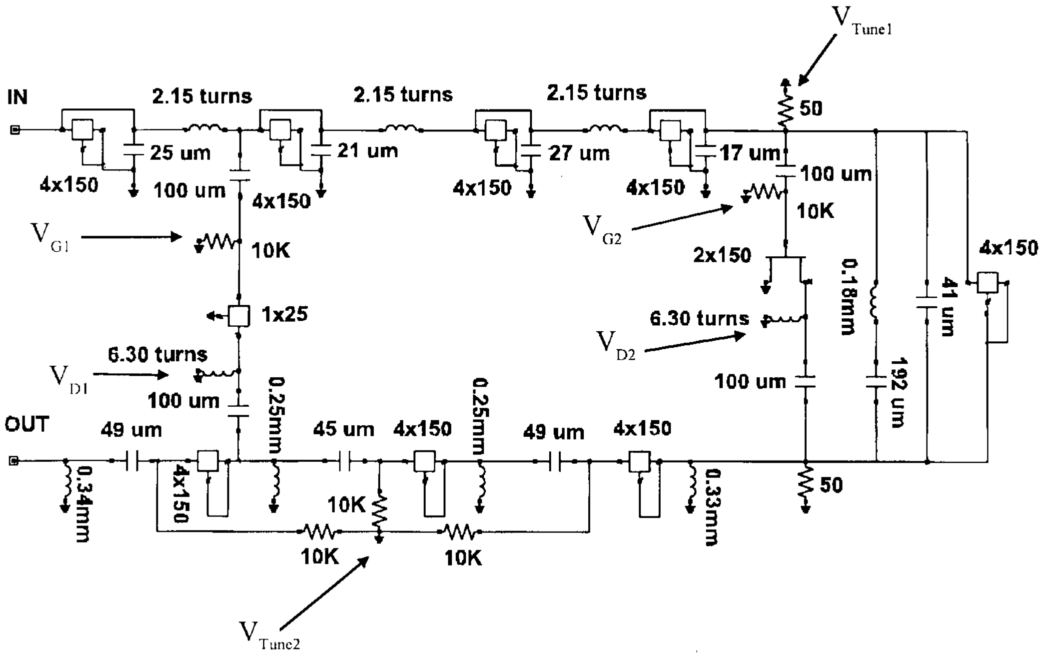

Fig. 6. Circuit architecture of the GaAs MMIC lumped and tuned transversal filter.

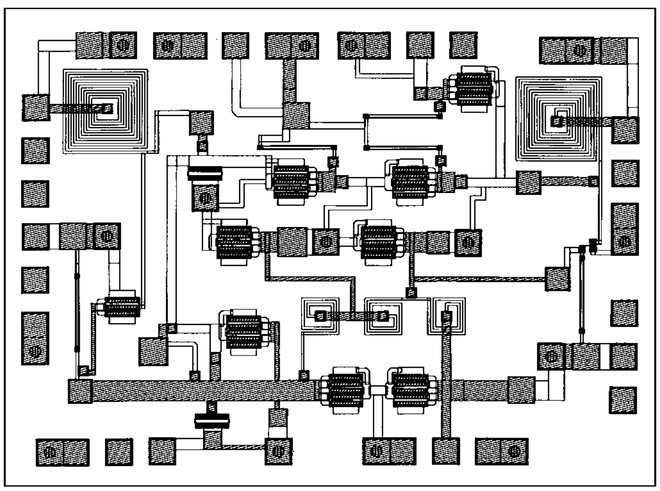

Fig. 7. Layout of GaAs MMIC lumped and tuned transversal filter.

component representations. In Fig. 7, the chip layout of the GaAs MMIC active filter is presented, designed with the previous circuit architecture.

The layout has been designed in order to be fully on-wafer testable having different bias voltages externally introduced in order that bias points may be controlled and tuned easily when the circuit is under measurement. The layout of the filter has been obtained with the MDIF data and design information from GEC-Marconi with its F20 process of 0.5 μm, which includes two metal levels and via holes. The total area of the GaAs MMIC active filter occupies 3×2 mm^2

V. Conclusions

This paper has proposed a novel GaAs MMIC active filter structure based on the lumped and transversal technique that allows the design of X-band MMIC active bandpass filters, using a tuned transversal element. A design example has been presented to demonstrate the feasibility of using GaAs MMIC technology to extend tuned amplifier techniques to higher frequencies. The simulation results show an overall good performance of the final filter which anticipates also good results for the future prototype MMIC to be fabricated later.

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