MMIC ACTIVE FILTER WITH TUNED TRANSVERSAL ELEMENT

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

Abstract - A novel GaAs 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 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 simulated results and layout. The simulated results demonstrate its superior performance when compared with the traditional lumped and transversal technique.

I. INTRODUCTION

The increasing demand for high integration of light weight mobile communication equipment shouldered with GaAs MMIC technology imposes an urgent need for the implementation of smaller compact systems. Independently of the reasons for integration of the mobile communication equipment in several fields of applications (Wireless LAN, Wireless Multimedia etc.), one of the main problems that will be usually faced would be the filter design because of the traditional drawback of low Q inductors. Thus, the realisation of active filters in GaAs MMIC technology in the microwave frequency range is highly desirable, taking full advantage of the small size lumped element in order to achieve a basic filter response and the consequent neutralisation effect of the losses achieved by the active devices.

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 realisation 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 includes a tuned amplifier for realising 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.

II. NOVEL CIRCUIT STRUCTURE

High frequency monolithic microwave transversal filters usually have as 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 (i = 1) are constant.

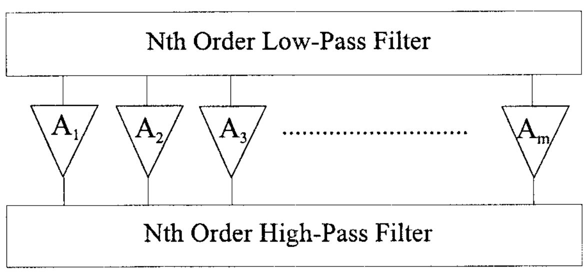

Fig. 1 Conventional microwave lumped and transversal filter structure.

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0-7803-3583-X/97 $10.00 ©1997 IEEE

The new filter structure proposed in this paper is shown in Fig. 2. It utilises a variable transversal element to obtain the filtering response by a combination of the transversal technique and tuned amplifier in the main signal path. On the other hand, 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 the tuned amplifier with only one pair of complex conjugate poles (and also one pair of complex conjugate zeros). This additional degree of freedom in the design allows the simplification of the structure of the Nth order lumped and transversal filters and also overcomes the limitation of the even-order number of pair of complex conjugate poles of conventional lumped and transversal filters.

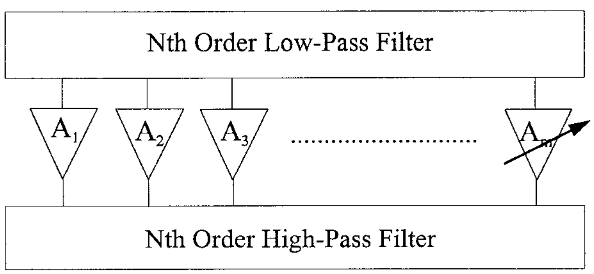


Fig. 2 Novel microwave lumped and tuned transversal filter structure.

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 circuit with a 50Ω termination in both sides in order to meet the requirements of the transversal elements.

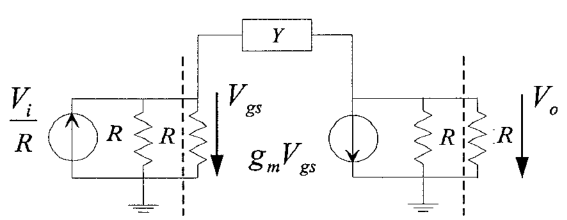


Fig. 3 Ideal equivalent circuit of tuned amplifier.

Where

$R = 50\Omega$

$Y = sC + \frac{1}{sL}$

g_m = transconductance

The voltage transfer function of the above circuit is given by

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

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

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

which can be also written as:

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

where

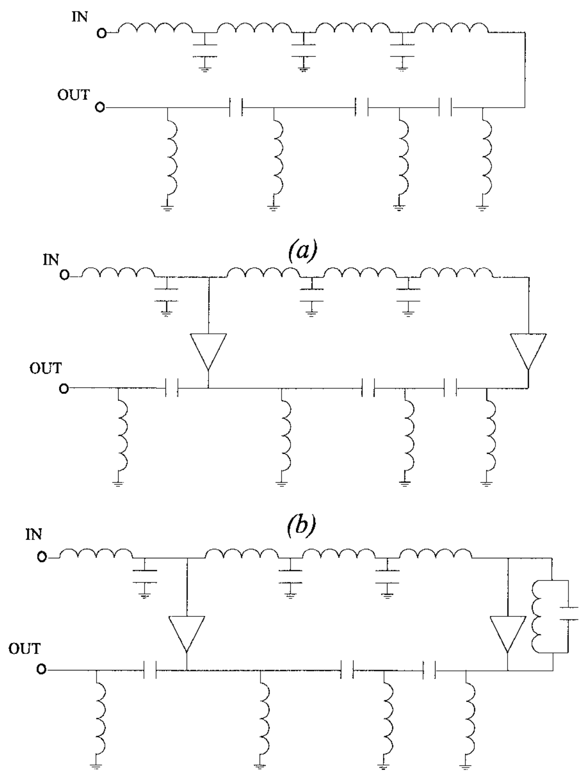
$$\omega_Z = \omega_P = \frac{1}{\sqrt{LC}} \quad (4)$$

$$Q_Z = \frac{1}{g_m}\sqrt{\frac{C}{L}} \quad (5)$$

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

In this tuned amplifier, the frequency response will be of bandpass type for $Q_P/Q_Z > 1$, and notch type for $Q_P/Q_Z < 1$. When this frequency response is combined with a Chebychev characteristic (Nth order Low-Pass/High-Pass) it will allow the implementation of elliptic filters. This feature of the novel structure is of paramount important in the design of transversal filters because it will introduce a new type of filtering characteristics which is impossible to obtain with the conventional transversal filters.

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 7th 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 section. 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.



(c)

Fig. 4 (a)7th order 2dB ripple traditional Chebychev bandpass filter, (b)Lumped and transversal filter, (c)Lumped and tuned transversal filter.

The comparison between the three filters is shown in Fig. 5, where we present their frequency response as simulated by HP-EEsof Libra 6.0. There, we can clearly see that the band edge rejection skirts are sharpened when the tuned transversal element is added.

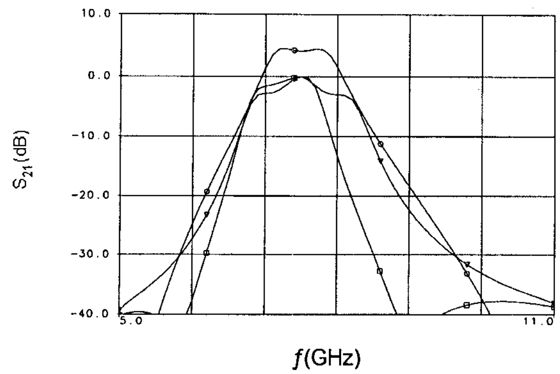


Fig. 5 Simulated bandpass characteristics of the 7th order traditional Chebychev filter ∇, lumped and transversal filter O, and lumped and tuned transversal filter □.

III. CIRCUIT ARCHITECTURE AND LAYOUT

The circuit architecture of the tuned transversal filter designed with the previous presented characteristics is shown in Fig. 6. It is mainly composed by 1 fixed gain MESFET amplifier and 1 tuned MESFET amplifier. For the implementation of the tuning circuit, all the capacitors are replaced by 4-Finger cold MESFETs. In Fig. 7, the chip layout of the GaAs MMIC active filter is presented, designed with the previous circuit architecture.

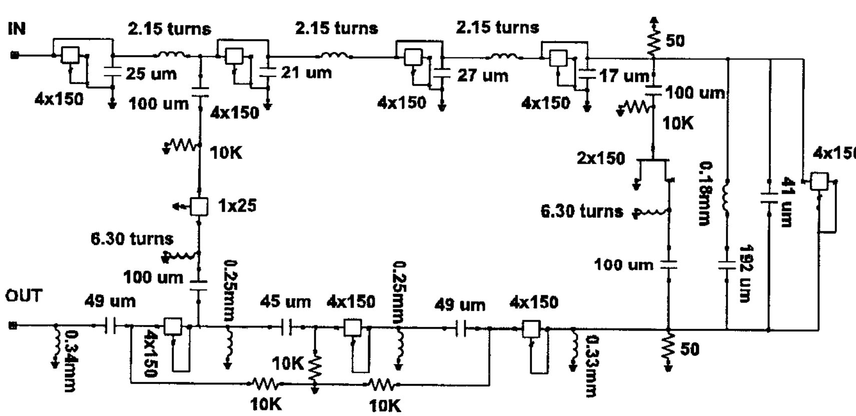


Fig. 6 Circuit architecture of the GaAs MMIC lumped and tuned transversal active filter.

The layout has been designed in order to be fully on-wafer testable having different bias voltages externally introduced so 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 0.5µm, which includes two metal levels and via holes. The total area of the GaAs MMIC active filter occupies 3x2 mm^2.

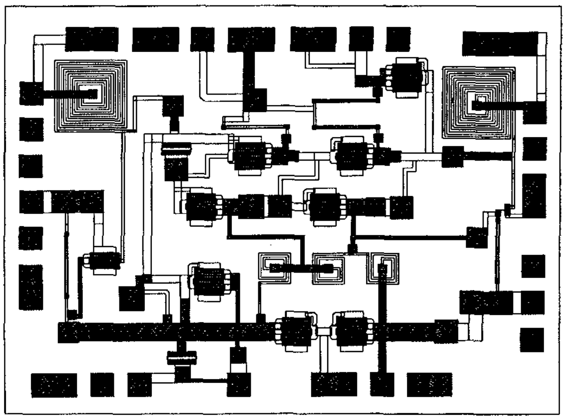


Fig. 7 Layout of GaAs MMIC lumped and tuned transversal active filter.

IV. COMPUTER SIMULATED RESULTS

The circuit has been designed using the HP-EEsof Libra 6.0. All the parasitics of the passive elements and active elements were introduced in the simulation. Fig. 8 illustrates the behaviour of the transmission coefficient S_{21} of the filter considering several tuning voltages of the cold MESFETs. The center frequency varies from 8.5 GHz to 10.5 GHz (2 GHz of interval) having a relative bandwidth of 800 MHz.

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.

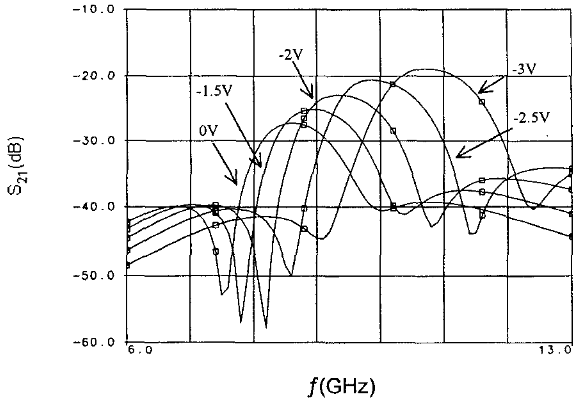


Fig. 8 Simulated S_{21} of the GaAs MMIC lumped and tuned transversal active filter for several tuning voltages.

ACKNOWLEDGMENTS

This work has been supported by University of Macau, INESC (Instituto de Engenharia de Sistemas e Computadores)-Portugal, Macau Foundation , UPM (Universidad Politecnica Madrid), INESC-Macau and IST (Instituto Superior Técnico)-Portugal. Special thanks are due to Dr. M. Mahfoudi and Prof. José I. Alonso for their help during the simulation and layout design.

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