A New Design Concept For Realising Highly Tunable Microwave Filters Using Recursive Principles

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1 Abstract

In this paper, new active monolithic microwave integrated bandpass filters employing recursive principles are developped. A 7 GHz fixed center frequency filter with 2% bandwidth, and a tunable filter with 2.5 GHz tuning range around 8 GHz, are succesfully implemented employing 0.2 μm GaAs P-HEMT monolithic technology, and exhibit excellent measured performances.

2 Introduction

Conventional active filter design techniques, widely used at low frequencies for integrated circuits, are not directly applicable to microwave filters because of the lack of suitable op-amps at such high frequencies. A number of alternative techniques have been reported in the litterature for microwave active filters [1] [2] [3] [4] [5] [6]. Among these, recursive and transversal filter techniques have been taken from the digital filtering domain and applied to microwaves by a number of researchers [7] [8] [9].

In this paper, we describe a novel technique for the design of miniature microwave recursive filters. This approach yields cheap solutions together with high performances. Two design topologies, starting from the same principle, are discussed and are adressed to different applications, since they fulfil different requirements.

3 Design concepts

Theory of recursive filters has been essientially developped at low frequencies. The recursive transfer function of a first-order structure, with one feedback branch, can be written in the following form

$$H(f) = \frac{Y(f)}{X(f)} = \frac{a_0}{1 + b_1.e^{-j2\pi f\tau}} \tag{1}$$

Moreover, the filter response $H(f)$ can be tuned by the introduction of a phase shift in the feedback loop of the filter. The expression below gives the transfer function shifted over a frequency band Δf

$$H(f-\Delta f) = \frac{Y(f-\Delta f)}{X(f-\Delta f)} = \frac{a_0}{1 + b_1.e^{-j2\pi f\tau}.e^{j\Phi}} \tag{2}$$

with

$$\Phi = 2\pi\Delta f\tau$$

Following these principles, the new approach, developped in this work, is the design of a voltage complex function according to equation (1) for the non-tunable filter and to equation (2) for the derived tunable reponse. Figure 1 shows the circuit topology. By a simple application of kirchoff rules, summation of voltages V_i and V_r at the input of the active device gives

$$V_e = (\frac{Z_{s\beta}}{Z_g})V_i + V_r \tag{3}$$

if $Z_{e\mu}$,Z_g and Z_L are respectively much higher than $Z_{s\beta}$ and $Z_{s\mu}$

Under these assumptions, the overall voltage gain may be written as

$$G_v = \frac{V_L}{V_i} = (\frac{Z_{s\beta}}{Z_g})(\frac{\mu}{1 - \mu.e^{-j2\pi f\tau}}) \tag{4}$$

It can be clearly seen that the circuit above realises a first-order recursive filter and its voltage gain can be identified to the recursive transfer function (1).

4 Non-tunable filter

For physical implementation, the active forward device of figure 1 is replaced by a P-HEMT in a common-drain configuration (CD1). The passive delay-element is built with lumped high-pass T-cell and low-pass cell [10] providing the required time-delay τ imposed by the recursive process. Then the final objective is to match the filter to 50 Ω at both ports. Because, the whole device uses voltage-matched elements as mentioned above, this obviously leads to a strongly mismatched circuit even within the passband. To overcome this problem, two active networks in common-gate (CG) and common-drain (CD2) configurations are respectively used [11] [12], instead of passive elements, for broadband matching to external 50 Ω systems. Moreover, these active devices assume two important roles. They achieve simultaneously, a voltage matching of the filter feedback loop and a power matching of the global filter, thus leading to more compact circuit realisation.

The circuit diagram is shown in figure 2. The MMIC chip (figure 3) is implemented on a 100 μm-thick GaAs substrate and dimensions of the chip are 1x1.5 mm^2.

The circuit includes three transistors of 0.2 μm gate length, with a total DC power consumption of 30 mW. Moreover, the low value inductances L_h and L_b are substituted with high impedance microstrip lines, thus reducing significantly the final chip size.

The measured and computed S-parameters of the filter are represented in figure 4, and show excellent agreement. The filter exhibits a 140 MHz 3 dB-bandwidth and operates at 7 GHz with 5.5 dB gain. The out-of-band rejection is better than 20 dB, 2 GHz from either passband edge, and higher than 40 dB at 2.5 GHz and 9.2 GHz. The computed noise figure, not yet measured, indicates an acceptable 5.5 dB noise figure at 7 GHz.

5 Tunable filter

The tunable filter is derived from the non-tunable structure by inserting a phase shifter into the feedback branch. The capacitance C_h is then substituted with a varactor diode, as shown in figure 5, to provide a phase shift within the loop, and thereby tune the filter center frequency.

The flatness of the filter response depends on how the series diode resistor varies with biasing voltage within the tuning band. Simulations show that as the response is tuned up in frequency, the diode resistor, for some diode capacitance values, is no longer the same, leading to high decrease in gain and in Q-factor of the filter. The only available control is the bias point of the common-drain transistor placed in the forward branch of the loop. Adjusting correctly this command leads to a constant gain level over the frequency tuning range.

The MMIC tunable filter is fabricated using the same foundry process as for the non-tunable filter. The circuit layout is shown in figure 6 and dimensions of the chip are 2x1.5 mm^2.

The measured transmission and return losses for the filter are respectively plotted in figures 7 and 8. A frequency shift from 7.03 GHz to 9.5 GHz is achieved with a constant gain of 3.5 dB, across the tuning band. Moreover, the filter exhibits a good 50 Ω matching over the 2.5 GHz frequency tuning band. The expected noise figure is 5 dB at center frequencies. To the authors knowledge this tuning range greater than 30% of relative tuning bandwidth is the widest published to date for an active MMIC filter at these frequencies.

6 Conclusion

A new approach for realising microwave active recursive filters has been described. This technique well fits MMIC applications, and two monolithic bandpass filters have been demonstrated. The fixed frequency filter have a center frequency of 7 GHz with a 140 MHz 3 dB-bandwidth. The varactor-tuned filter exhibits a 2.5 GHz tuning band around 8 GHz. Both filters achieve good return loss performances. Excellent measured results demonstrate the accuracy of the design concept. To our knowledge, this is the first tunable microwave recursive filter, with 2.5 GHz tuning range, realised at these freqencies.

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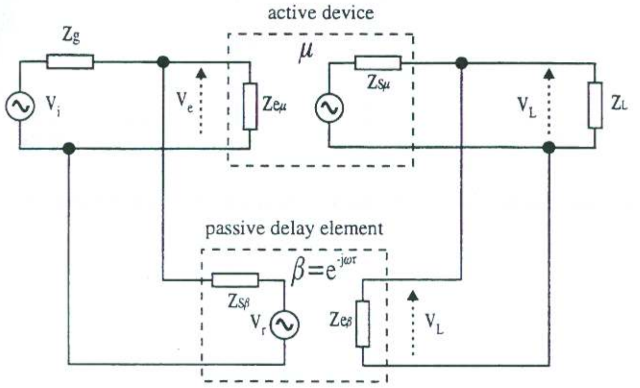

Figure 1: General scheme of a recursive filter using voltage-matched function blocks

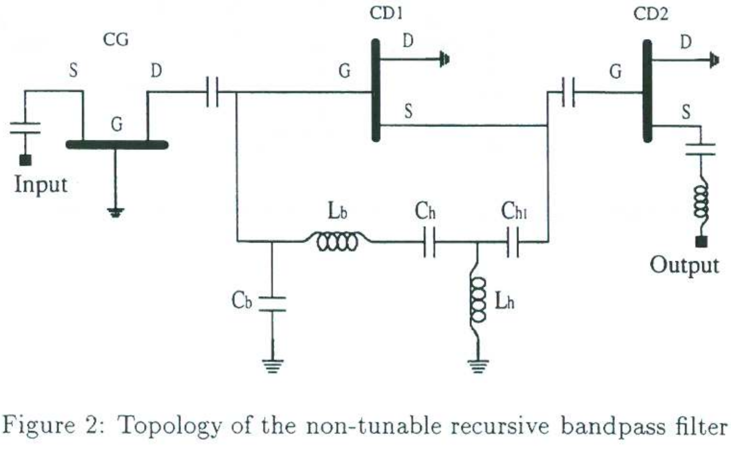

Figure 2: Topology of the non-tunable recursive bandpass filter

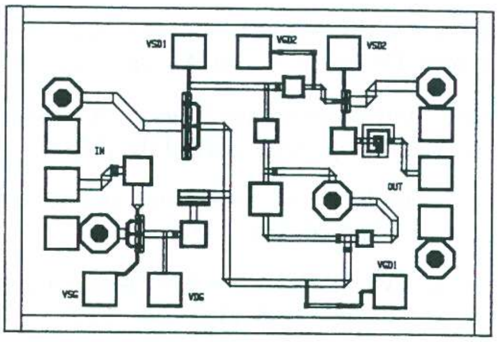

Figure 3: Layout of the MMIC non-tunable recursive filter

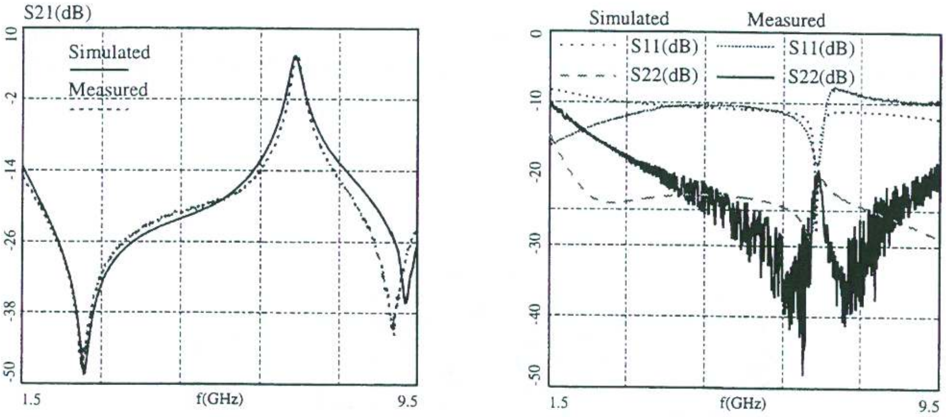

Figure 4: Comparison between simulated and measured S-parameters of the non-tunable filter

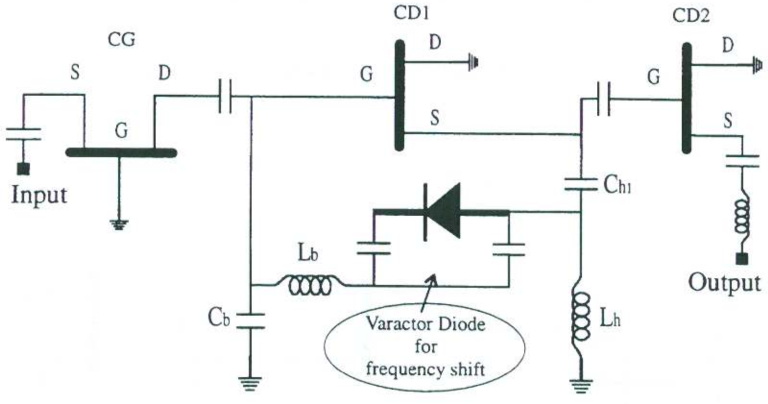

Figure 5: Topology of the varactor-tuned recursive filter

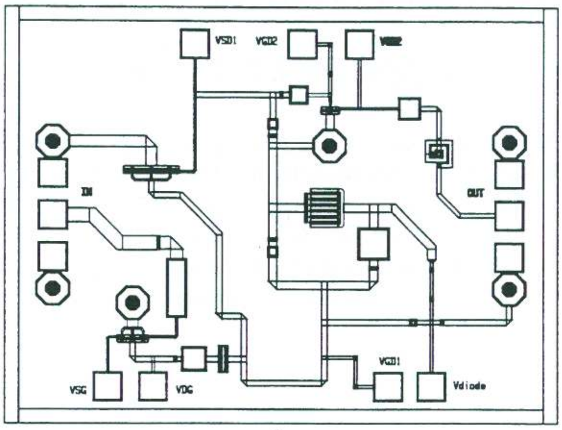

Figure 6: Layout of the MMIC tunable recursive filter

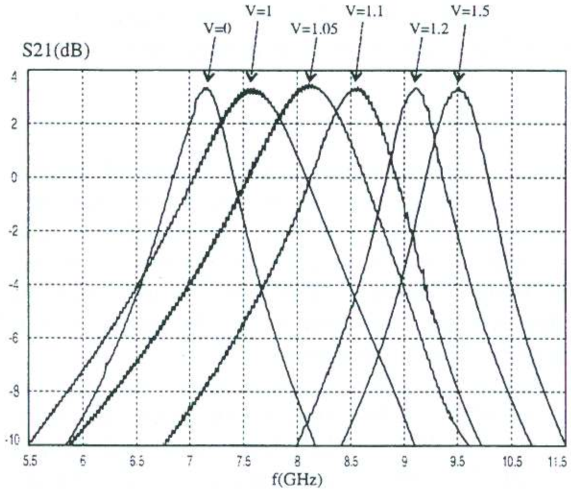

Figure 7: Tuned S21 for different varactor diode bias values:V=0v to V=1.5v with a constant gain over the tuning range

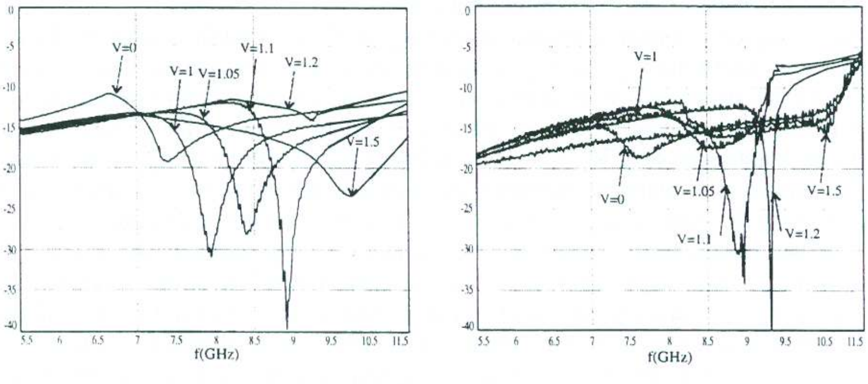

Figure 8: Measured S11 and S22 of the varactor frequency-tuned filter