MMIC Tunable Transversal Bandpass Active Filter at 9–12 GHz

Roberto Gómez–García[1], César Briso–Rodríguez[2], Mustapha Mahfoudi[3] and José I. Alonso[1]

[1]Departamento de Señales, Sistemas y Radiocomunicaciones, ETSI Telecomunicación, Universidad Politécnica de Madrid, C/ Ciudad Universitaria s/n, 28040 Madrid, Spain. Tel: 91–3367358, E-Mail:roberto@gmr.ssr.upm.es.
[2]Departamento de Ingeniería Audiovisual y Comunicaciones, EUIT Telecomunicación, Universidad Politécnica de Madrid, Cra. Valencia km. 7, 28031 Madrid, Spain.
[3]Hittite Microwave Corporation, 12 Elizabeth Drive, Chelmsford, 01824, USA

***Abstract*— In this paper a novel microwave tunable filtering structure based on a transversal configuration is proposed. A specific MMIC prototype is designed, fabricated and measured at 9–12 GHz range. The main constraints of the monolithic technology in tunable transversal filter design and construction are also discussed.**

I. Introduction

In the last few years, transversal filters have been considered as a good option for active filter design in many radiofrequency applications. Effectively, the typical problems involved in traditional active filter design techniques, such as high noise or potential unstability, can be totally overcome with transversal configurations.

The design techniques of transversal filters at microwave range appear from theoretic concepts involved in transversal digital structures [1]. The initial transversal configurations are only constituted by delay sections and transversal amplitude blocks. Thus, the global power transmission response is achieved through the interference between the different signal components in which the input signal is divided among the transversal configuration [2]. An obvious disadvantage of this basic circuit lies in the great number of transversal elements required to synthesize high–order responses, that results in filters with excessive physical dimensions.

In more advanced transversal structures, the traditional delay lines are replaced by LC sections [3]. By means of LC blocks, an amplitude frequency–dependant modification in addition to a phase variation is produced over the signal compounds. This allows to reduce the number of transversal elements needed to achieve a specificated power transmission response. Nevertheless, the resulting physical dimensions of the filter are yet excessive in narrow–band applications.

Lately, the growing use of MMIC technology, as well as the employment of more sophisticated transversal configurations, have allowed to circumvent the main disadvantage of this type of circuits: its excessive physical dimensions when high–order responses are synthesized [4]. However, more recently requirements of high–flexibility systems in new military and commercial applications add tunability as a key concept in new active filter design techniques [5]. To date, no tunable transversal filter has been proposed.

In this paper, the viability of tunable filtering structures based on transversal configurations is discussed. The theoretic results are validated with the construction and the measurement of a specific prototype at 9–12 GHz range in MMIC technology.

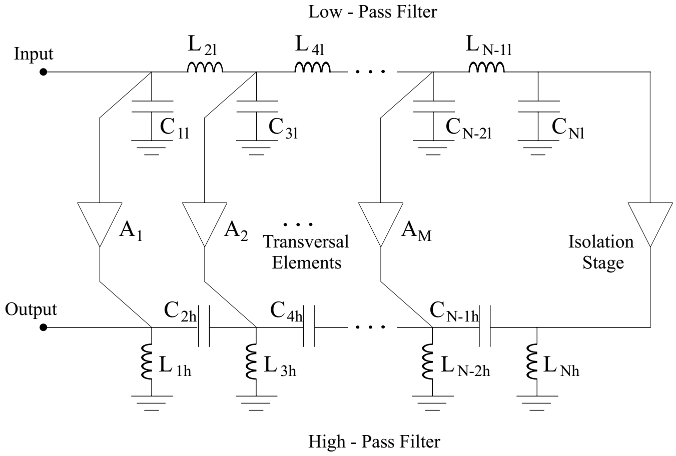

Fig. 1. Transversal filter circuital topology.

II. Tunable Transversal Bandpass active filter

A. Transversal bandpass filter

The circuital topology of the proposed transversal configuration is shown in Figure 1.

In this structure, the bandpass behavior is achieved through a cascade connection of low–pass and high–pass filters properly isolated with a MESFET stage. Both filters are coupled with MESFET elements referred as "transversal elements". It's main task is increasing the selectivity of the global power transmission response.

As shown in Figure 1, the inclusion of transversal elements provides numerous input–output signal paths in filtering structure. Thus, thanks to a controlled interference between signal components that travel among the filter, the transmission zeros can be generated in both bandpass to stop–band transitions of the initial bandpass transmission response. This is very appropriate to obtain a more selective global power transmission response, in which the filter flank steepness and the stop–band rejection are increased.

The selection of the number of transversal elements to be included in the circuit, as well as their amplitude and phase factors, are the key design issues of this type of filters.

B. Circuit tuning

As previously described, the bandpass behavior of the proposed transversal structure is defined by the cascade connection of low–pass and high–pass filters. These filters are designed to satisfy the out of band rejection specifications by themselves. Thus, the cut–off frequencies of the bandpass response, f_{c1} and f_{c2}, are assigned to cut–off frequencies of the low–pass and the high–pass filters, f_l and f_h, that can be expressed as follows (for even order N filter responses, the upper limits of the i, j–index must be interchanged):

$$f_l = \frac{1}{2\pi}\sqrt{\frac{g_i g_j}{L_{il}C_{jl}}} \qquad f_h = \frac{1}{2\pi\sqrt{g_i g_j L_{ih} C_{jh}}},$$
$$i \in \{1, 3, 5, ..., N\}$$
$$j \in \{2, 4, 6, ..., N-1\} \tag{1}$$

being $\{g_k\}_{k\in\{1,2,..,N\}}$ the normalized impedance parameters of the low–pass equivalent prototype.

Additionally, the relation $\sqrt{L_i/C_j} = Z_0$ must be satisfied if matching to a Z_0 reference impedance value is required.

From equation (1) is easily deduced that the tunability of the transversal filter can be achieved by means of the incorporation of variable capacitors in both low–pass and high–pass filters. Thus, tunable bandwidth, $f_{min} \div f_{sup}$, will be defined by the maximum and the minimum variable capacitor values, respectively.

Some additional considerations must be taken into account:

- The relation of matching to a Z_0 reference impedance is unsatisfied if the capacitors are modified from its initial values. This results on a increase of the global insertion losses.
- The physical realization of the variable capacitors with low losses in a wide tuning range is extremely complicated.

III. MMIC Prototype design and fabrication

A specific tunable transversal bandpass active filter prototype is designed and fabricated in MMIC technology.

The initial specifications are the following:

- Tunable bandwidth: $9 \div 12$ GHz.
- *Instantaneous*[1] bandwidth: 1 GHz.
- Maximum amplitude variation allowed in the instantaneous passband: < 1 dB.
- Out of band rejection: > 50 dB at $0.8 f_{c1}$, $1.2 f_{c2}$.

being f_{c1},f_{c2} the cut–off frequencies of the global power transmission bandpass response referred to 1 dB attenuation level.

A. Ideal design and simulation

Initially, the inductances and the variable capacitors are considered as ideal elements. Thus, 13–order Chebyshev responses with 0.2 dB ripple to be synthesized in the low–pass and the high–pass filters are adequate to satisfy the fixed initial specifications. The design central frequency is selected to be $f_0 = 11.5$ GHz. The transversal elements and the isolation stage are simulated with MESFETs.

In Figure 2 the simulated power transmission response of ideal filter without transversal elements is presented. The tuning performance is also included.

The effect of the transversal elements in the global power transmission response is depicted in Figure 3, where only the third transversal element is considered for several bias conditions (A_3 in Figure 1). As shown, two transmission zeros

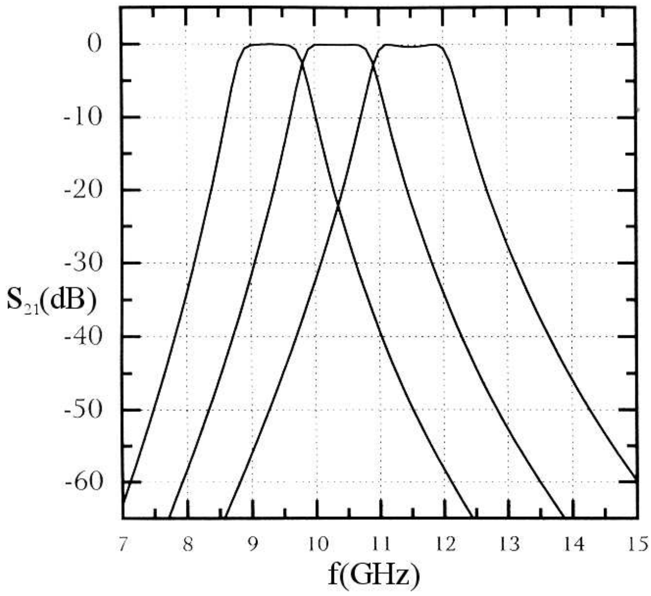

Fig. 2. Simulated ideal power transmission bandpass response (no transversal element).

are generated in both bandpass to stopband transitions of the initial bandpass response defined by the cascade connection of the low–pass and the high–pass filters. Thus, the filter flank steepness and, consequently, the out of band rejection in the passband proximities is improved. The increase of the global response selectivity produced by other transversal elements is practically invaluable.

B. MMIC design and simulation

Finally, the behavior of the inductances and the capacitors in MMIC technology is considered in the design. The inductances of the low–pass filter are simulated as spiral inductors, while short transmission line inductors are used in the high–pass filter due to its resulting low values. Variable capacitors are simulated with MESFET in ColdFET configuration (gate to source capacitance, C_{gs}, is used when $V_{ds} = 0$). The tuning voltage is the same for all the capacitors of the low–pass and the high–pass filter respectively. In the simulation, the S–parameter values provided by the foundry have been used.

The transmission response of the simulated MMIC tunable transversal filter is depicted in Figure 5 (the control voltage of the transversal element must be readjusted). As shown, the main undesired effect are the high losses in the global response due to the MMIC inductors and variable capacitors (≈ 25 dB). The passband of the simulated MMIC transmission response is also slightly distorted.

C. MMIC Fabrication

The layout and the photograph of the fabricated MMIC tuning transversal active filter are shown in Figure 6 and 7, respectively.

The measured response is also depicted in Figure 8.

As shown, the agreement between the measured and simulated MMIC filter response in the passband is good: the accused losses in the global response due to MMIC inductors and variable capacitor is preserved in measured prototype. Furthermore, mismatching problems remarked by the increase of losses with the reduction of tunable central frequency

[1] *Instantaneous* is referred to a specific tuning frequency in the tunable bandwidth

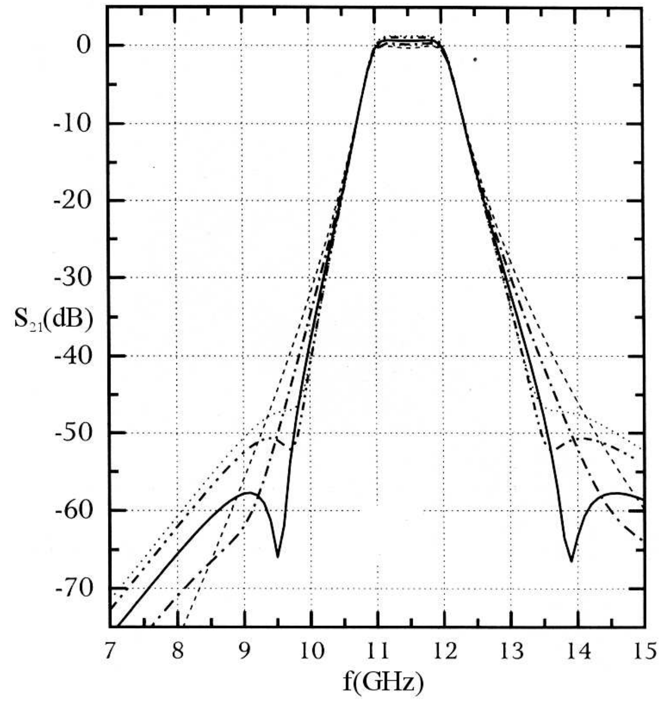

Fig. 3. Simulated ideal power transmission bandpass response (the third transversal element is considered).

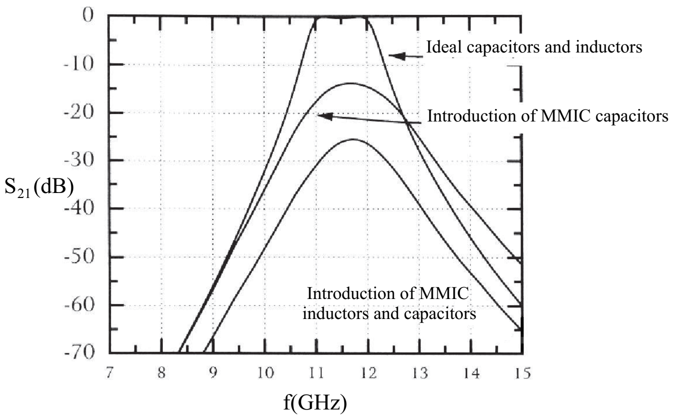

Fig. 4. Simulated MMIC power transmission bandpass response.

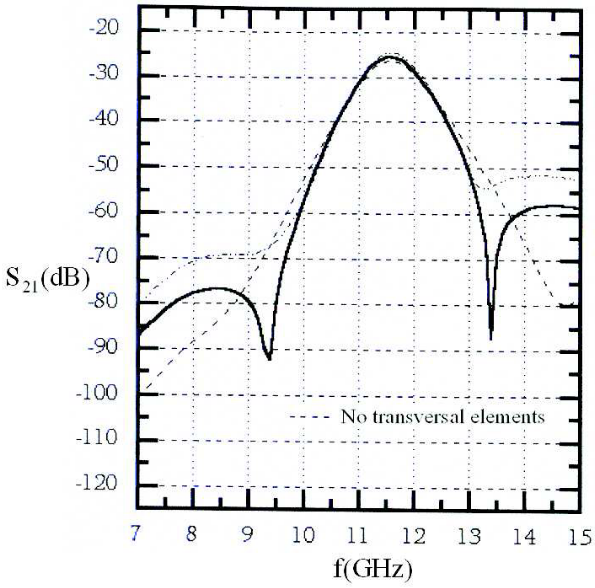

Fig. 5. Simulated MMIC transmission response.

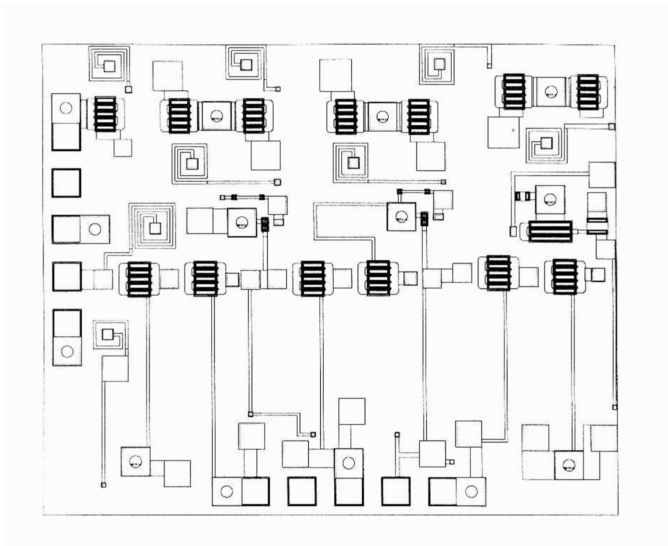

Fig. 6. MMIC transversal filter layout.

relative to 11.5 GHz are also demonstrated. The variation of the instantaneous bandwidth with the tuning voltage over the tunable bandwidth is small.

One undesired effect due to the employment of the MMIC technology not contemplated in the simulation is the reduction of the out of band rejection at frequencies sufficiently separated from the passband.

IV. CONCLUSIONS

In this communication a new tunable filtering structure based on an active transversal configuration has been proposed. A specific MMIC prototype has been designed and fabricated at 9–12 GHz range. The measured response has good performance in the passband proximities and the low instantaneous bandwidth degradation with the tuning voltage. The critical design issues are the excessive losses due to MMIC elements (variable capacitors and inductors) and the low out of band rejection at frequencies sufficiently separated from the instantaneous passband.

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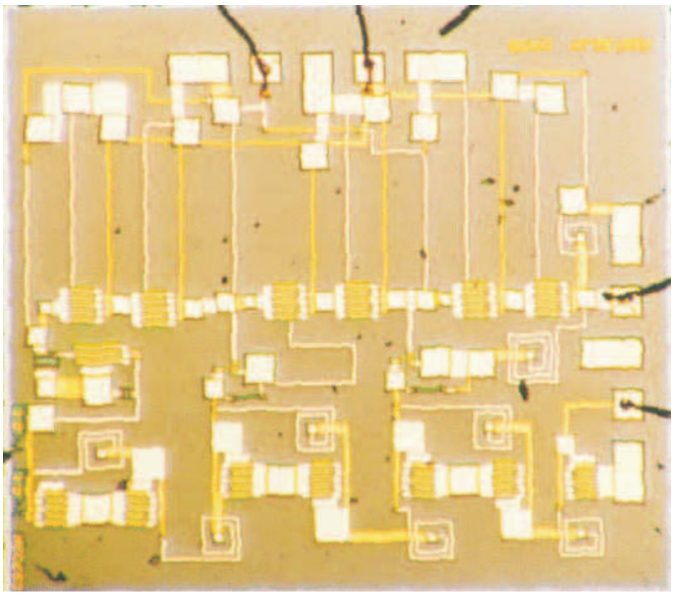

Fig. 7. MMIC transversal filter photograph.

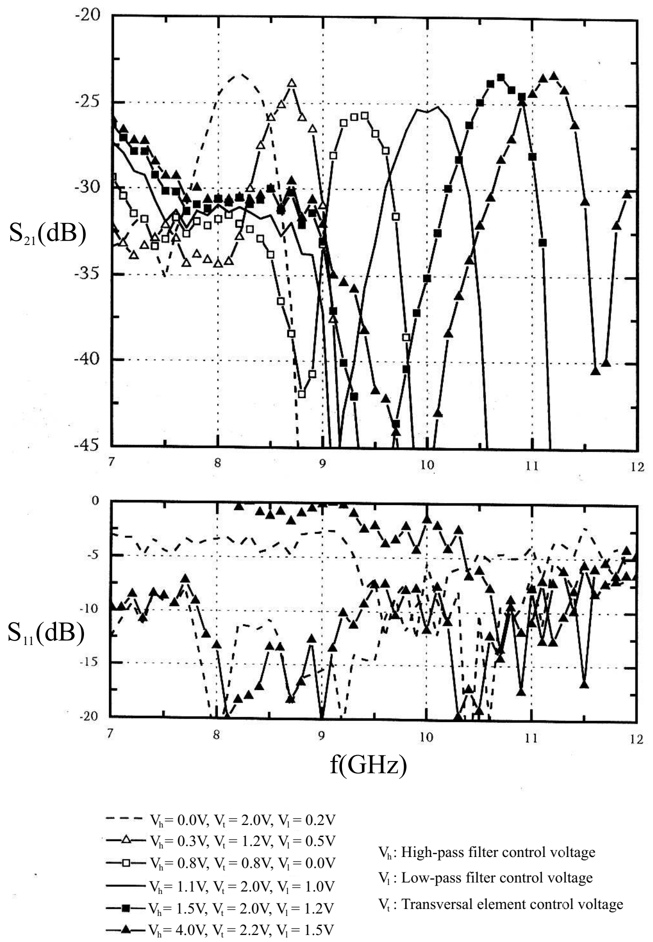

Fig. 8. Measured power transmission bandpass response.

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