BROADBAND MONOLITHIC ANALOG PHASE SHIFTER AND GAIN CIRCUIT FOR FREQUENCY TUNABLE MICROWAVE ACTIVE FILTERS

A. CENAC - L. NENERT - L. BILLONNET - B. JARRY - P. GUILLON

I.R.C.O.M. - Faculté des Sciences - UMR CNRS 6615
123 Avenue Albert Thomas - 87060 LIMOGES Cédex - France

ABSTRACT

In this article, a lossless variable gain and analog transmission type phase shifter. The final function of this original monolithic circuit is to be introduced in a ring resonator planar filter to tune the frequency response and to compensate for the intrinsic losses of the resonators.

INTRODUCTION

Phase shifters at low frequencies have been introduced in phase arrays for communication and radar systems at microwaves and more recently in recursive and transversal filters [1]. Layout simulated and measured results of a broadband monolithic phase shifter amplifier are presented. Then, an original tunable microstrip ring resonator active filter including two of these monolithic circuits is analytically studied. Simulations show that selective microwave filter is frequency tunable over an octave bandwidth from 2,5 GHz to 5,5 GHz.

I- TRANSMISSION PHASE SHIFTER USING SINGLE GATE MESFET AND VARACTOR DIODES

As shown in figure 1, the chosen structure consists of a MESFET with a series resonant impedance Z_2 between drain and gate of the transistor and a series resonant impedance Z_1 at the input of the circuit. Each resonant impedance circuit includes a single varactor diode used as a voltage controlled element for the phase shift tuning.

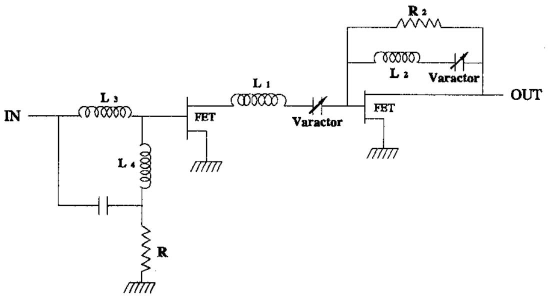

Fig 1 : Amplifier/Phase shifter structure

The feedback loop between drain and gate of the transistor is used to control the gain of the circuit. An analytical study of the S_{21}, S_{11} and S_{22} parameters shows that the optimal configuration is obtained when Z_1 and Z_2 are both implemented with a varactor diode in series with an inductor.

An amplifier is cascaded with the phase shifter to compensate for its losses. This amplifier includes one MESFET, two inductors and one resistor. The element values are derived from the MESFET characteristics thanks to equation described in [2]. Figure 2 shows the layout of the amplifier/phase shifter

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chip finally designed, following the MMIC design process rules. Dimensions of the MMIC chip are 1.0 mm x 3.0 mm. Figures 3, 4, 5, 6 show a perfect agreement between simulated and measured results for the phase shift and for the S_{21} parameter. The maximum phase shift finally performed and presented in figure 5 is 75° in the [2.5 GHz, 5.5 GHz] frequency bandwidth.

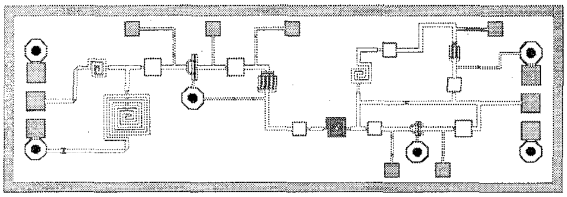

Fig 2 : Phase shifter layout

A good input and output matching is observed for this very simple structure including a small number of components and a small number of bias voltages.

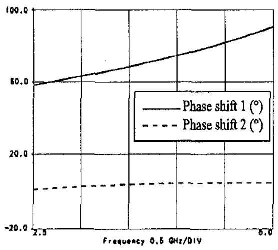

Fig 3 : Simulated phase shift for 3 bias values of the diodes V_{min} V_{med} , V_{max}

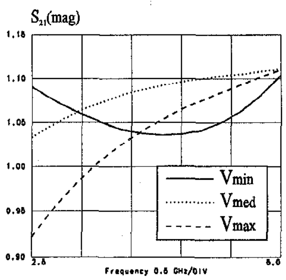

Fig 4 : Simulated S_{21} for 3 bias values of the diodes V_{min} , V_{med} V_{max}

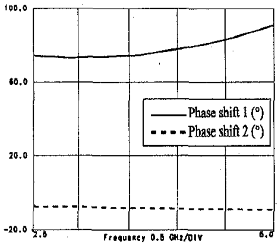

Fig 5 : Measured phase shifts for 3 bias values of the diodes V_{min} V_{med} , V_{max}

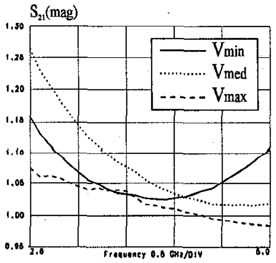

Fig 6 : Measured S_{21} for 3 bias values of the diodes V_{min} ,V_{med} V_{max}

As said before, the objective is to use this amplifier/phase shifter monolithic circuit in frequency tunable microwave active filters. An example of these filters is presented now.

II - RING RESONATOR FILTERS

II-1) Planar ring resonators basic theory

Microstrip ring resonator length is defined to obtain the resonance condition at f_0 as follows:

$$L = k\lambda \text{ and } \lambda = \frac{v}{f_0} = \frac{c}{\sqrt{\varepsilon_{eff}}\, f_0}$$

where ε_{eff} is the effective permittivity of the microstrip line

The different topologies of the active ring resonators considered now consist of two pairs of parallel coupled lines with either one amplifier or two amplifiers within the passive ring resonator branches. The amplifiers/Phase shifters can be placed at the top or at the bottom of the resonator in the forward or in the reverse direction with the filter output taken at the top or bottom access of the output coupler. Moreover, the fourth port of each coupler can be loaded either with a short circuit or an open circuit.

Our objective is to calculate the coupling values and the amplifier gain to ensure the compensation of the intrinsic losses, the input and output matching and the stability of the bandpass filter that is, to obtain $|S_{21}|=1$, $|S_{11}|=0$ and $|S_{12}|\leq 1$ at the center frequency f_0 of the frequency bandwidth. The transfer function of all the ring resonator filters considered here can be expressed as :

$$H(f)=\frac{AG(f)}{1-BG(f)} \qquad (1)$$

with $G = G_0\, e^{-j2\pi f\tau}$

G_0 : real amplifier gain value

$\tau=\frac{1}{f_0}$: delay time of the resonator

Then, the response of these filters are similar to bandpass recursive filters responses. So they can also simply provide frequency tunable responses thanks to arbitrary analog phase shifter structures [1].

II-2) Planar ring resonator theoretical results

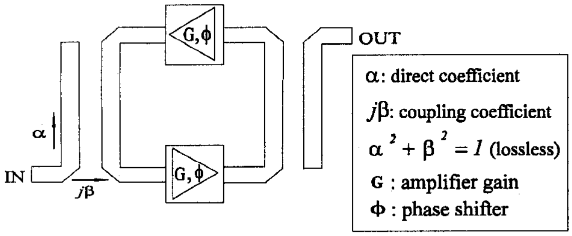

Fig 7 : Two-amplifier structure

Figure 7 shows the chosen topology which uses two variable gain and phase amplifiers, placed symmetrically from the median axis within the resonator. To compensate for the losses at the center frequency, the amplifier gain value can be analytically derived as :

$$G=-\frac{1}{2}\,\frac{\beta^2-\sqrt{\beta^4+4}}{\alpha}\geq 1 \qquad (2)$$

This leads to : $S_{11}=S_{22}=\frac{2+\beta^2-\sqrt{\beta^4+4}}{\alpha}$

$|S_{12}|=|S_{21}|=1$

These expressions show that β parameter values must be small (wide gaps of the couplers) to obtain $|S_{11}|=0$ and $|G|$ near 1. According to this, simulation results are presented in figures 8 and 9 and in table 1. Simulated results are in perfect agreement with the previous theory and verify at the center frequencble y f_0 the conditions $|S_{21}|=1$ and $|S_{ii}|=0$ as expected. It can be analytically demonstrated that the lowest the coupling β is, the best the selectivity of the filter.

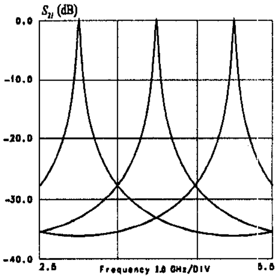

Fig 8 : S_{21} parameter of ideal two-amplifier structure

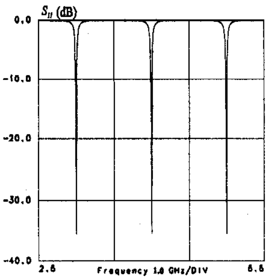

Fig 9 : S_{11} parameter of ideal two-amplifier structure

C (dB)	-20	-15	-10
G	1	1.0003	1.0024
Q	312.5	99.50	31.50

Table 1 : Quality factor for different coupling values for ideal two-amplifier structure

II-3) Simulated results of active planar ring resonator using monolithic amplifier/phase shifter circuits

In this part, the ideal amplifiers of the planar ring resonator are replaced by monolithic amplifier/phase shifter circuits previously presented, and the delay time elements by microstrip lines. In the first step, simulations are realized with quarter wavelength coupled lines.

Thanks to the MMIC phase shifter performances, figures 10 and 11 give simulated results of the tunable filter topology.

Figure 10 shows that the amplifiers compensate for the intrinsic ring resonator filter losses over a wide frequency bandwidth. Moreover, the use of our phase shifter performs a 32 % relative tuning frequency bandwidth around 3,5 GHz. Figure 10 shows that the loaded quality factor at f_0 is near 800 for a coupling factor value equal to -22 dB which is technologically very easy to implement with a wide coupling gap. We observe that the S_{11} parameter is less than 1 (0 dB) for all the diodes biasing values.

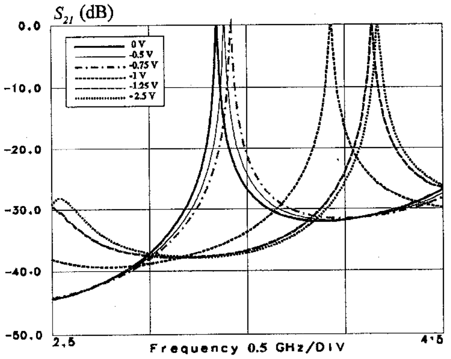

Fig 10 : S_{21} parameter of two-amplifier topology using MMIC chips

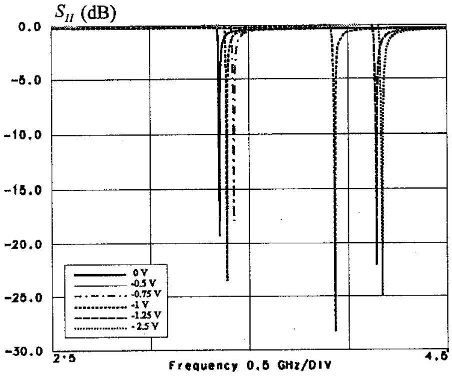

Fig 11 : S_{11} parameter of two-amplifier topology using MMIC chips

CONCLUSION

In this paper, a lossless analog phase shifter structure using monolithic technology has been developed. A flat phase shift of 75° has been obtained with a quasi constant corresponding gain over more than an octave bandwidth, centered at 3.5 GHz and thanks to a specific CAD optimization methodology. With this simple efficient and flexible approach, the S_{21} parameter magnitude is not only flat over the bandwidth, but more importantly, invariant relatively to the frequency tuning command of the global structure. Excellent agreement is shown between computer simulated and measured S parameters. Moreover, a ring resonator active filter using both hybrid and monolithic technologies including two MMIC amplifier/phase shifters is also presented. With this approach it is shown that both losses compensation and wideband frequency tuning can be achieved. The validity of our approach is verified according to the theory with computer simulations for the tunable filter structures. These active filters are at now in process and it will be possible to present experimental results at the conference

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