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Strictly as per the compliance and regulations of:

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Abstract - This paper presents a study, optimization and simulation of tunable bandpass filter centered at 2.4GHz and used as phase shifter based on coupled microstrip square ring loaded by varactor diodes. We have performed an electromagnetic simulation on Momentum software of ADS™; we have used the power of the Momentum software for the optimization and simulation of our circuit. A good results were obtained; the filter results in an insertion loss of 0.35 dB–0.26 dB over tuning range and 3–dB bandwidth of 300MHz–360MHz. We compute a fractional bandwidth between 13% and 14.5% for our circuit and for different value of capacitance. We compute also a good dynamic range of phase shifting about 90° at operating frequency 2.4GHz for different value of capacitance.

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I. Introduction

For almost three decades, tunable filters have been a popular choice to adapt multiple RF bands of operation using a single filter [1]. As consequence, tunable filter can replace the necessity of switching between several filters to have more than one filter response by introducing tuning elements embedded into a filter topology. Depending on type of tuning element, tunable filters can be classified in two categories with discrete and continuous tuning [2]. In this case we interest on continuous tuning device more precisely on varactor diodes, the use of this type of diode as capacitors has been the most popular choice to modify the effective electrical length of the resonator and tune the center frequency of the passband.

The coupling is carefully controlled by coupled microstrip square ring resonators and the tuning is performed by changing the bias on the varactor diodes. As the first step we begin by synthesizing bandpass filter from a prototype low pass filter, this process can be done by implementing frequency transformation and circuit conversions [1].

Bandpass filters can also be used as delay line [4], by using the correct amount of delay; the signal can be shifted for the intended amount of phase shift. In several applications of electronic it is often necessary to change the phase of signals, for this reason RF and microwave phase shifters have many applications in various equipments.

In this paper, we present a combining study design used for two functions as a phase shifter and as tunable band pass filter in the same time. The filter configuration studied, is based on three square ring resonators. Tunable bandpass filters are designed using half wavelength open loop resonators. A bandpass filter with *14.5%* bandwidth centered at *2.4GHz* was designed. In the following, a phase shifter is constructed with filter designed. A good dynamic range of phase shifting of 90° at operating frequency is obtained.

II. Circuit Design

In order to characterize our filter there are different types of approximation (Chebyshev, Butterworth, Elliptic and quasi-Elliptic) [3]. For this purpose we have studied the three cases of filter approximation by using our filter characteristic given as following:

Center frequency $F_c = 2.4$ GHz

Bandpass width BW = 200 MHz

Insertion loss IL ≤ 0.3 dB

Stopband attenuation L_{As} = 20.0 dB at normalized frequency $\Omega_s = 2.0$.

a) Filter Synthesis

We start our filter synthesis by choosing the lowpass prototype; we discuss the design of passband filter described by the specifications above. The figure 1, gives three examined filter response, the equation 1 determine the filter n order of chosen Butterworth approximation [4] :

$$n = \frac{\log\left(10^{0.1L_{As}} - 1\right)}{2\log \Omega_s} \tag{1}$$

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By using equation 1 and the filter specifications, we can calculate the filter order as n = 3. The figure 1 gives the transmission characteristics of different approximations Butterworth, Chebyshev and Elliptic.

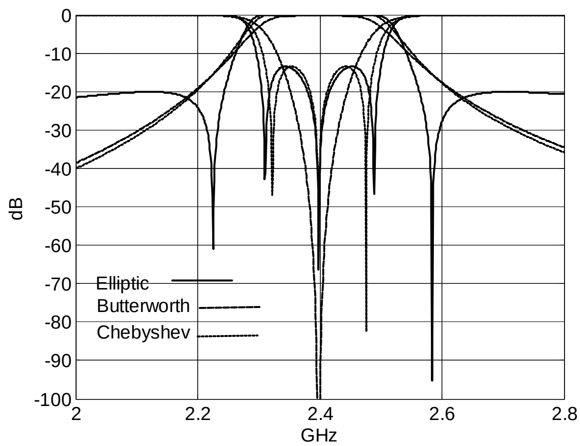

Fig.1 : Transmission characteristics of different approximations

We chose Butterworth approximation for satisfaction of our fixed filter characteristics. The figure 2 presents Butterworth lowpass prototype [4] filter and the bandpass calculated filter.

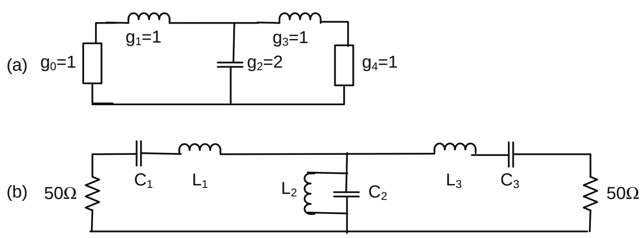

Fig.2. (a) : Three poles lowpass prototype, (b): Lumped components bandpass filter

The parameters of the Butterworth lowpass prototype [4] i.e. are $g_0=1$, $g_1=1$, $g_2=2$, $g_3=1$ and $g_4=1$ are determined by using the known formulas in [4], this lowpass prototype is given by the figure 2-a and transformed to lumped element bandpass filter given by figure 2-b when the series and shunt lumped elements were calculated as follows:

$$L_s = \frac{\Omega_c}{\omega_0 FBW}\gamma_0 g_i,\quad C_s = \frac{FBW}{\omega_0 \Omega_c}\frac{1}{\gamma_0 g_i} \tag{2}$$

$$L_p = \frac{FBW}{\omega_0 \Omega_c}\frac{\gamma_0}{g_i},\ C_p = \frac{\Omega_c}{\omega_0 FBW}\frac{g_i}{\gamma_0},\ \gamma_0 = \frac{Z_0}{g_0} \tag{3}$$

L_1=40nH, C_1=0.1pF, L_2=0.13nH, C_2=32pF, L_3=40nH and C_3=0.1pF.

The figure 3 gives lowpass prototype obtained by impedance inverters. This figure consists of J-inverters and shunt resonators only. The derived formulas [4] permitted to calculate the (B_i, g_i) lumped components that are given by the equations (1-5).

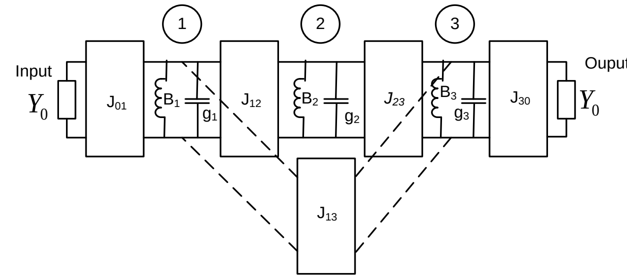

Fig.3 : Lowpass filter admittance inverter

The frequency transformation lowpass-bandpass is given by the equation (4), B_i is invariant susceptance.

$$\frac{1}{FBW}\left(\frac{j\omega}{\omega_0}+\frac{\omega_0}{j\omega}\right)g_i + jB_i = j\omega L_i - \frac{1}{j\omega C_i} \tag{4}$$

$$B_i = \omega_0 C_i - \frac{1}{\omega_0 L_i} \tag{5}$$

$$\frac{1}{FBW}\left(\frac{2}{\omega_0}\right)g_i = C_i + \frac{1}{\omega_0^2 L_i} \tag{6}$$

$$C_i = \frac{1}{\omega_0}\left(\frac{g_i}{FBW}+\frac{B_i}{2}\right) \tag{7}$$

$$L_i = \frac{1}{\omega_0}\left(\frac{g_i}{FBW}-\frac{B_i}{2}\right)^{-1} \tag{8}$$

$$\omega_{0i} = \frac{1}{\sqrt{L_i C_i}} = \sqrt{1-\frac{B_i}{g_i/FBW + B_i/2}} \tag{9}$$

$$b_i = \omega_{0i} C_i = \frac{\omega_{0i}}{\omega_0}\left(\frac{g_i}{FBW}+\frac{B_i}{2}\right) \tag{10}$$

The external quality factor and the coupling coefficients can be found by the equation (9):

$$M_{ij} = \frac{J_{ij}}{\sqrt{b_i b_j}} \text{ and } Q_{ext} = \frac{b_1}{g_0} \tag{11}$$

With normalized cutoff frequency Ω_c=1, the following figure 4 gives the general coupling graph of our filter, while the parameters M_{ij} are the inter-resonator coupling parameters.

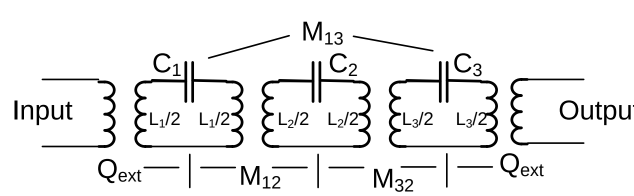

Fig.4 : General bandpass filter coupling structure

b) Filter optimization and method engineering

In the following part, we describe the optimization methodology engineering of our circuit; its principle is given by the figure 5. In this engineering process, we use the filter specifications to determine lumped elements of bandpass filter, and then we introduce the coupling coefficient and the J-inverters. We have used the LinCalc program of Advanced Design System (ADS™) software to design the circuit and to calculate the geometrical parameters, and by using Momentum we can compare the lumped components and coupled resonator model in order to get more efficient bandpass filter. The proposed engineering method reduces the computational cost with respect to the theory filter synthesis. Moreover the output EM simulation results could be feed back in order to adjust the parameters such resonator dimensions, input feed positions and coupling distances for a better filter performances.

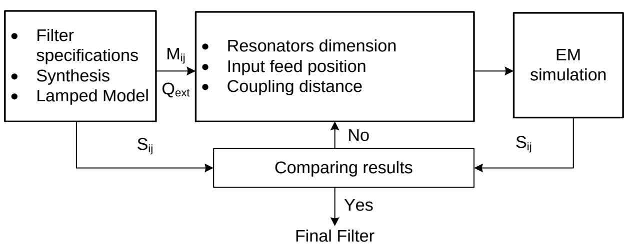

Fig.5 : Bandpass filter optimization

Microwave ring resonators are proposed components for designing our filter. Fig 6 illustrates the filter using three cascaded half wavelength square ring resonators. By using lineCalc program we can calculate the coupling distances (S*)* for three square rings in order to perform the electromagnetic simulation.

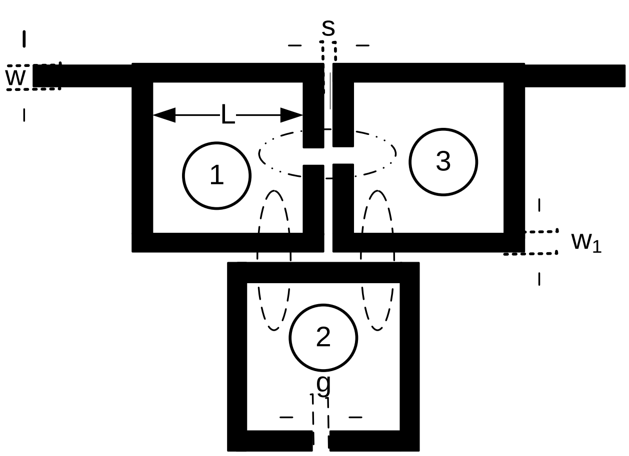

Fig.6 : Three square rings filter and phase shifter

The geometrical parameters of square resonator can be determined by using the equation (10); the characteristic impedance of the resonator is given by:

$$Z_c = \sqrt{L_i / C_i} \qquad (10)$$

The excitation inputs have been placed to get a maximum power transferring and have been matched to reference impedance. To insure a maximum power transferring, we use a tapering input section. We change the width of input transmission line to have the same width of main transmission line that constitutes the resonator.

c) Loaded square ring resonator

In this part, with the aim of moving the operating frequency of our circuit as to vary the phase, we load the ring resonators with varactors diodes [5]. The choice of the location of the diodes is made according to the constraints of geometry. The originality of our work is that we load the varactor diode inside of the open loop ring resonator; because in the literature we charge the open loop rings in the slots. The following figure illustrates the location of the varactor diodes and gives the diode model and the via-hole model used to connect the diode to ground.

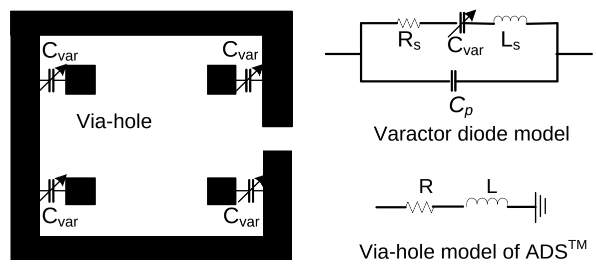

Fig.7 : Loaded varactor diode square ring with varactor diode model and via-hole model

To load the square ring resonator by the varactor diode, we use a via-hole that allows to be connected to the ground through the substrate layer. In this study we have used a model given by the ADS software constituted by serial inductance L and resistor R, this via-hole is defined by $R=0.2\Omega$ and $L=0.55nH$ [6,8].

The model of diode varactor has variable capacitance Cvar and a series resistance $Rs=0.4\Omega$, parasitic series inductance $Ls=0.45nH$, and parasitic parallel capacitance $Cp=0.015pF$ [7].

III. Results and Discussion

This section contains simulated results obtained for the proposed filter and phase shifter. This structure has been designed using electromagnetic simulator Momentum of ADS™. The bandpass filter is designed at fundamental resonant frequency $F_C=2.4GHz$, and with bandwidth of *360MHz*. It is built on a microwave Rogers Duroid 4003 substrate having relative permittivity ε_r of *3.36* and height of *0.813mm*.

For this filter, structure of passive filter is realized using microstrip ring resonator. Fig. 8 illustrates the transmission frequency response of bandpass filter simulated with Momentum of ADS. By observing the frequency response, the simulated return loss of the filter in the bandwidth was better than 15dB. The bandpass filter has *3-dB* bandwidth of *360MHz*.

The coupling parameters as: $M_{12}=M_{23}=0.058$, $M_{13}=0.083$ and the quality factor $Q_{in}=Q_{out}=12.05$.

From *2.25GHz* to *2.9GHz* the obtained insertion loss is better than *0.18dB*.

By choosing $C_i=5pF$ and using the equation (10) we can calculate $L_i=34nH$, and $Z_c=82.46\Omega$, from these parameters and by using LineCalc we can obtain $W_1=0.73mm$, $W=1.23mm$, $L=9.88mm$, $g=0.2mm$ and coupling distance between two resonators 1 and 2 of S=0.4mm.

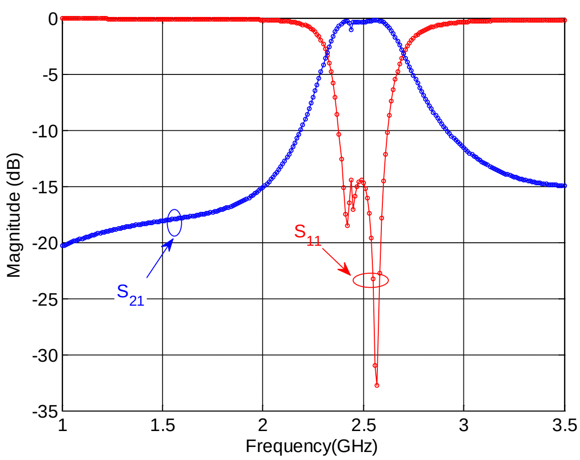

Fig.8 : Simulated frequency responses, transmission and reflection, obtained by three square ring filter

With development of wireless communications system (TX/RX), the bandpass filter is one of most important key components in TX/RX systems, and should also be reconfigurable to meet the system requirements. The filter described previously can be modified to get an electronically tunable filter using varactor diodes.

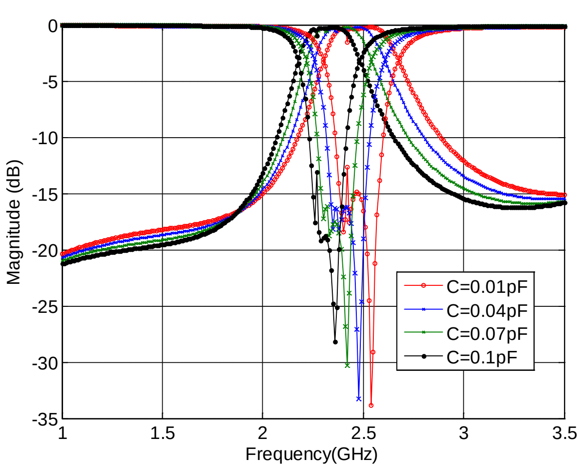

Fig.9 : Retun and insertion losses for three ring resonators filter at the operating frequency (2.4GHz)

The tunable filter is investigated, which implements with varactor diodes placed inside of square ring resonator as shown in Fig.7. The S_{11} and S_{21} simulation results of this filter are shown in Fig.8. The capacitances of varactor diodes C which are varied from 0.01 pF to 0.1 pF, have a fundamental role to tune filter center frequency. To reach a fractional bandwidth range from 13% to 14.5%, a variation of C is required. Fig.9 shows bandwidth tuning was controlled by capacitance C, which modifies the resonator capacitive coupling from the main transmission line. The filter center frequency from 2.48 GHz to 2.32 GHz, is changing by modifying capacitance bias from 0.01 to 0.1 pF. The Fig 9 shows the insertion and return loss variations of three square rings phase shifter given by the Fig. 6 versus frequency for different values of capacitance. We notice in the Fig. 9, the variation of insertion loss versus frequency for different values of capacitance. The maximums |S11| and |S21| losses, for C = 0.01pF are about |S11(2.48GHz)|=15.0dB, |S21(2.48GHz)|=0.35dB; for C = 0.1pF are about |S11(2.32GHz)|=19.0dB, |S21(2,32GHz)|=0.26dB. If we decrease the value of capacitance we get lower quantity of losses.

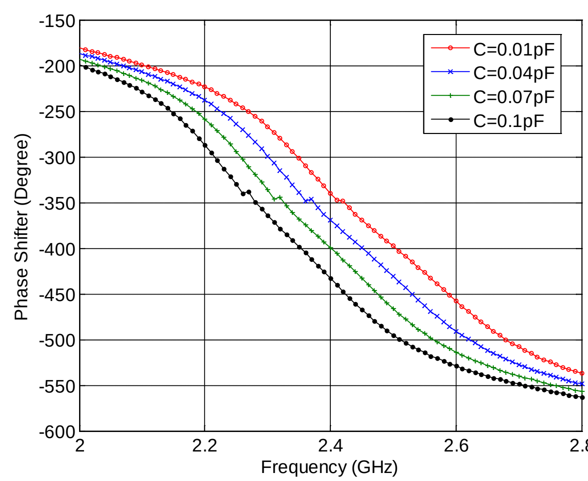

Fig.10 : Phase shifting in degrees versus frequency

Figure 10 shows the phase shift variation versus frequency, the capacitance varies between 0.01pF and 0.07pF. A linear phase shift variation is performed by the phase shifter for different value of capacitance. For C=0.01pF the maximum value of differential phase shift is about 10° while for C=0.07pF the phase shift varies from 0° to -80° at the frequency 2.4GHz. Figure 11 illustrates the linear variation of phase versus capacitances at 2.4GHz.

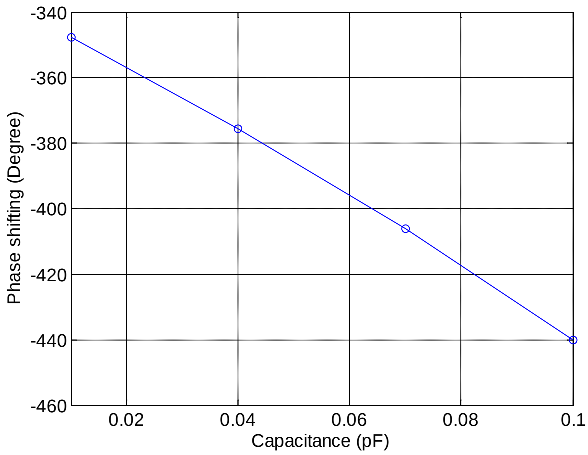

Fig.11 : Phase shifting in degrees at the operating frequency 2.4GHz versus variable capacitance.

By examining the figure above, we deduced that the phase dynamic at 2.4GHz is about 90° and linear behavior can be denoted.

IV. Conclusion

A new type of tunable filter and phase shifter has been proposed. The varactor diodes have been applied to the design of tunable band pass filter where center frequency and bandwidth can be controlled. A capacitance bias from 0.01 to 0.1pF was applied to shift the filter's center frequency from 2.48GHz to 2.32GHz and its 3-dB fractional bandwidth from 13% to 14.5%. We mention also a good dynamic range of phase shifting about 90° at operating frequency 2.4 GHz. In this study we have designed a circuit that could be used in the same time as tunable filter and phase shifter and good results was obtained.

References Références Referencias

1. Jia-Sheng Hong, Michael J. Lancaster "Couplings of Microstrip Square Open-Loop Renonators for Cross-Coupled Planar Microwave Filters" IEEE Trans. Microwave Theory Tech. Vol. 44. No. 12, pp. 2099-2109, December 1996.
2. Jia-Sheng Hong, Michael J. Lancaster "A differential 4-bit 6.5-10-GHz RF MEMS Tunable Filter" IEEE Trans. Microwave Theory Tech. Vol. 53. No. 3, pp. 1103–1110, March 2005.
3. Jia-Sheng Hong, Michael J. Lancaster "Theory and experiment of novel microstrip slow-wave openloop resonator filters," IEEE Trans. Microwave Theory Tech., vol. 45, pp. 2358–2365, Dec. 1997.
4. J.S. Hong and M.J. Lancaster, "Microstrip Filters for RF/Microwave Applications", New York, Willey, 2001
5. J.C. Bohorquez, "Contribution à la conception de filtres reconfigurables sur la base de technologies planaires et sim", unpublished-doctoral-dissertation Bretagne Occidentale, on Juin 2007.
6. M. Goldfarb and R. Pucel, "Modeling via hole grounds in microstrip," IEEE Microwave Guided Wave Letters, vol. 1, no. 6, pp. 135–137, June 1991
7. Ville S. Mottonen, Juha Mallat, Antti V. Raisanen "Characterisation of European Millimetre-Wave Planar Diodes", 34th European Microwave Conference, pp. 921-924, October 2004.
8. Darine KADDOUR, "Conception et réalisation de filtres RF passe-bas à structures périodiques et filtres Ultra Large Bande, semi localisés en technologie planaire", unpublished-doctoral-dissertation Joseph Fourier, Grenoble on July 2007.