RF Phase Shifter Using Coupled Microstrip Square Rings Tunable Bandpass Filter

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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 ADSTM; 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 b andwidth o f 3 00MHz?360MHz. W e c ompute a f ractional bandwidth between 13

Index terms— Bandpass filter, Square ring, Phase shifter, Microstrip line, Varactor diode, Coupled line, RF engineering.

1 INTRODUCTION

or 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.

2 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

3 Bandpass width BW = 200 MHz

Insertion loss IL ? 0.3 dB Stopband attenuation L As = 20.0 dB at normalized frequency ? s = 2.0.

4 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 **??**, gives three examined filter response, the equation 1 determine the filter n order of chosen Butterworth approximation [4] :( ) s L . ? n As log 2 1 10 log 1 0 ? = (1)

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.

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

5 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. 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:, 0 0 i c s g ? FBW ? ? L = i c s g ? ? ? FBW C 0 0 1 = (2) , g ? ? ? FBW L i c p 0 0 = 0 0 ? g FBW ? ? C i c p = , 0 0 0 g Z ? = (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 **??** 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).3 1 2 Input Ouput 0 Y 0 Y J01 J12 J23 J30 J13 B1 g1 B2 g2 B3 g3

Fig. **??** : Lowpass filter admittance inverter

The frequency transformation lowpassbandpass is given by the equation (**??**), B i is invariant susceptance.i i i i C j L j jB g j? ? ? j? FBW ? ? 1 1 0 0 ? = + ? ? ? ? ? ? ? ? ? + (4) i i i L ? C ? B 0 0 1 ? = (**5**) i i i L ? C g ? FBW 2 0 0 1 2 1 + = ? ? ? ? ? ? ? ? ? (6) ? ? ? ? ? ? + = 2 1 0 i i i B FBW g ? C (7) 1 0 2 1 ? ? ? ? ? ? ? ? = i i i B FBW g ? L (8) 2 1 1 0 i i i i i i B FBW g B C L ? + ? = = (9) ? ? ? ? ? ? + = = 2 0 0 0 i i i i i B FBW g ? ? C ? b (10)

The external quality factor and the coupling coefficients can be found by the equation (**??** b J M ext j i ij ij = =**(11)**

With normalized cutoff frequency ? 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. 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 TM) 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. The geometrical parameters of square resonator can be determined by using the equation (10); the characteristic impedance of the resonator is given by:M 13 M 32 M 12 Q ext Q ext L2/2 C 2 C 3 C 1 Input Output L2/2 L3/2 L3/2 L1/2 L1/2i i c C L Z = (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.

6 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] 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? and L=0.55nH [6,8].

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

This section contains simulated results obtained for the proposed filter and phase shifter. This structure has been designed using electromagnetic simulator Momentum of ADS TM . 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 ? 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 III. The coupling parameters as: M 12 =M 23 =0.058, M 13 =0.083 and the quality factor Q in = Q out = 12.05.

7 RESULTS AND DISCUSSION

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?, 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. 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. 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 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 ??1 illustrates the linear variation of phase versus capacitances at 2.4GHz.

Figure 1: F

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Fig. **??**1 : 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.

.2 IV.

.3 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.

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