A Miniaturized Tunable Bandpass Filter Using Asymmetric Coupled Lines and Varactors

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Abstract—Nowadays, it becomes more and more important to miniaturize bandpass filters(BPFs) in RF front-ends because of size requirement of communication systems. As to achieve multifunction of RF front-end, BPFs with tunable passband, on the other hand, is another popular direction of BPF design. In this paper, a new three-order chebyshev BPF using asymmetry coupled lines and varactors, whose passband is widely tunable while the size is extremely reduced at the same time, is presented. Measurement results show that the center frequency of the proposed BPF has an amazing large tuning range from about 521MHz to 1123MHz for different bias voltage of varactors.

***Index Terms*—bandpass filter, miniaturization, tunable**

I. INTRODUCTION

With the development of wireless communication systems, the size of the RF front-end is required smaller and smaller. Since the band pass filter (BPF) is quite an important part of the RF front-end, realizing BPF by new methods that ensure the filter not only reach excellent performance but also meet the requirement of size miniaturization, has become important for the development of microwave filters. Various methods have been reported to achieve miniaturization of BPFs[1]-[4]. Among them, the process using microstrip coupled lines is one of the most popular because of its light weight, easy and low cost of processing. In [3] and [4], a structure of coupled lines with shunt capacitors is used to reduce the size of BPFs, which is very attractive owing to its simplicity.

Meanwhile, tunable filters are also required by the expansion of new communication systems. A number of different design approaches for tunable filters have been proposed[5]-[7]. A tunable filter using p-i-n diodes is given in [5]. Varactors and micro-electromechanical systems (MEMS) are used to make BPFs tunable in [6] and [7], respectively. However, none of the above methods concentrate on the size of the tunable BPFs.

In this paper, we propose a new method for the BPF design based on microstrip asymmetric coupled lines and shunt varactors, by which the center frequency of the BPF can be tuned by varactors, while the size is miniaturized at the same time. In section II, design details about how the size is miniaturized and how the center frequency of the BPF is tunable by the proposed method is given. A third-order miniaturized tunable Chebyshev BPF using the proposed method for verifications is represented in Section III. EM simulation and measurement results of the designed BPF using different capacitors and SMV1148 varactors are shown in Section IV. Finally, a conclusion is drawn in Section V.

II. PROPOSED NEW METHOD

The principle of the proposed new method is given by two steps. The structure of asymmetric coupled lines and shunt capacitors to realize miniaturization of BPFs is demonstrated in part A. Thereafter, we pay attention to the relation between the center frequency of the BPF and the capacitance. The complete block diagram of miniaturized tunable BPFs is given in part B.

A. Miniaturization of BPFs Using Coupled Lines and Shunt Capacitors

The structure of asymmetric coupled lines with shunt capacitors is employed for the design of miniaturized tunable BPF. The schematic of an asymmetric coupled-line, whose electrical length is θ, is shown in Figure1.(a). The equivalent circuit for it, in which an transmission line is loaded with two shunt different stubs, is given in Figure1.(b)[8]. In Figure1.(c), the two shunt stubs can be separated into two parts respectively, so that the center part(shadowed), which is a π shaped structure, can be equal to a J-inverter. Finally, the asymmetric coupled lines are expressed by a J-inverter loaded with two new shunt stubs, as Figure1.(d) shows. The characteristic impedances for two stubs are Y_{s1} and Y_{s2}, respectively. The value of J-inverter, Y_{S1} and Y_{S2} are calculated as following [4]:

$$J = \frac{(Y_{0\pi}^a - Y_{0C}^a)}{2\sin\theta} \tag{1}$$

$$Y_{S1} = \frac{(Y_{0\pi}^a + Y_{0C}^a)}{2} \tag{2}$$

$$Y_{S2} = Y_{0C}^b + \frac{(Y_{0\pi}^a - Y_{0C}^a)}{2} \tag{3}$$

where Y_{0C}^a, $Y_{0\pi}^a$, Y_{0C}^b and $Y_{0\pi}^b$ are the C- and π- mode admittance of strip a and b.

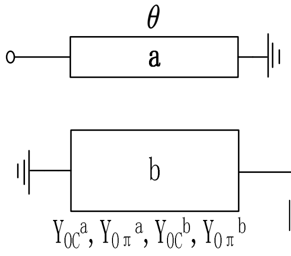

Figure1(a).

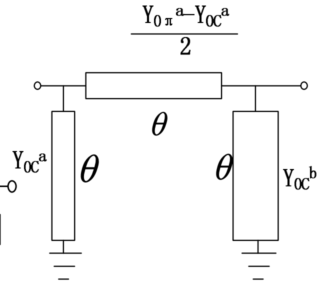

Figure1(b).

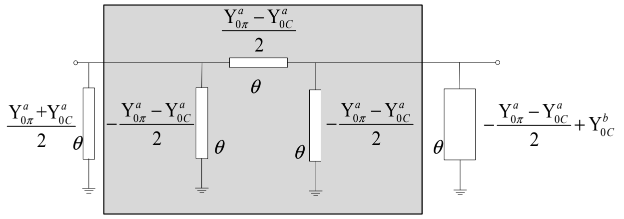

Figure1(c).

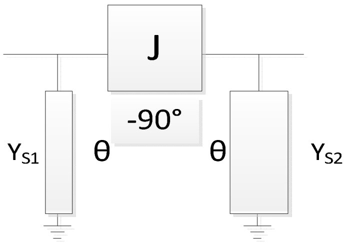

Figure1(d).

Figure1. (a) The schematic of asymmetric coupled lines (b), (c) and (d) are the three equivalent circuit of asymmetric coupled lines[4]

When N-1 asymmetric coupled lines are cascaded together with shunt capacitors before and after each, the block diagram is then expressed in Figure2.(a), while the equivalent circuit can be described as a Nth-order BPF containing N shunt resonators(B_1,B_2...B_N) and N-1 J-inverters, as shown in Figure2.(b). Each shunt resonator is made up of owe or two shunt stubs and one capacitor. If the capacitance of each shunt resonator is the same, then we have [4]:

$$B_1(\omega)=\omega C-Y_{s1,1}\cot\theta \tag{4}$$

$$B_i(\omega)=\omega C-(Y_{S2,i-1}+Y_{S1,i})\cot\theta \tag{5}$$

$$B_N(\omega)=\omega C-Y_{s2,N-1}\cot\theta \tag{6}$$

where i=2,3,...,N-1, C is the capacitance, θ is the electrical length, and B_i represents the susceptance of each shunt resonator. As is known to all, the shunt resonators have to resonate at center frequency ω_0, so that we can get

$$B_1(\omega_0)=\omega_0 C-Y_{S1,1}\cot\theta_0=0 \tag{7}$$

then the capacitance is got from

$$C=\frac{Y_{S1,1}}{\omega_0}\cot\theta_0 \tag{8}$$

θ_0 represents the electrical length of center frequency. What should be emphasized is θ_0 is determined by designers rather than 90° in a conventional structure without capacitors, so that theoretically the size of the BPF can be miniaturized to arbitrary degree as long as value of C is reasonable..

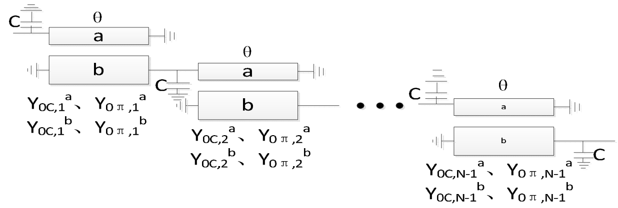

Figure2(a). The block diagram of miniaturized BPF

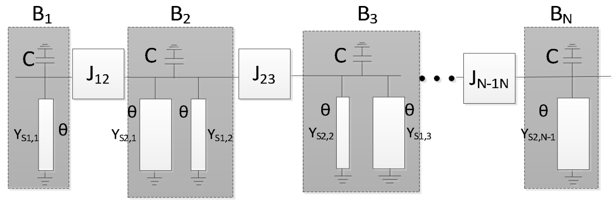

Figure2(b). The equivalent of the miniaturized BPF

The admittance slope of each section is then

$$b_i=\frac{\omega_0}{2}\frac{dB_i}{d\omega}\Big|_{\omega=\omega_0}=\frac{\omega_0}{2}\frac{dB_1}{d\omega}\Big|_{\omega=\omega_0}=\frac{1}{2}Y_{S1,1}(\cot\theta_0+\theta_0\csc^2\theta_0) \tag{9}$$

where i=1,2,...,N. Thus, the capacitance can be rewritten by b_i

$$C=\frac{2b_i}{\cot\theta_0+\theta_0\csc^2\theta_0}\frac{\cot\theta_0}{\omega_0} \tag{10}$$

From (10) it is not difficult to find out that b_i of each section is the same because of the invariable capacitance. On the other hand, the admittance slope of the first section can be determined as follows[8]:

$$b1=\frac{g_0 g_1}{\Delta Z_0} \tag{11}$$

$$J_{ii+1}=\Delta\sqrt{\frac{b_i b_{i+1}}{g_i g_{i+1}}}=\frac{\Delta b_1}{\sqrt{g_i g_{i+1}}} \tag{12}$$

where Δ is the fractional bandwidth, Z_0 and g_i are the characteristic impedance and the i-th section's Chybeshev low-pass prototype value respectively. It is clear that once ω_0, Δ, and the prototype values of Chebyshev low-pass filter are determined, the capacitance and the J-inverter of each section are decided by (10)-(12). Thus, the C- and π-mode admittance of strip a and b of each section can be calculated by (1) -(3).

However, the physical dimensions of asymmetric lines still need to be solved. Many techniques have been proposed such as Green's function integral equation method[9], full-wave method[10], the approximate method[11] and so on. In this paper, the approximate method in [11] is developed by using numerical computation relation between coupling coefficients and the coupled lines' width of each strip/gap between strips [12].

B. Further Design to make the Miniaturized BPF Tunable

Notice that the electrical length can be described

$$\theta = \beta l = \frac{\omega}{v_p} l \tag{13}$$

where l is the physical length of the coupled-line and v_p is a constant. So (10) can finally be rewritten as

$$C = \frac{2b_1}{\cot(\frac{\omega_0 l}{v_p}) + (\frac{\omega_0 l}{v_p})\csc^2(\frac{\omega_0 l}{v_p})} \frac{\cot(\frac{\omega_0 l}{v_p})}{\omega_0} \tag{14}$$

As is shown in (14), the relation between C and ω_0 notice us that the center frequency can be tuned by changing the value of shunt capacitors. Figure3 gives the relation between ω_0 and C, from which we can observe distinctly that ω_0 increases rapidly as the capacitance becomes smaller. Therefore, a miniaturized tunable BPF, whose block diagram is shown in Figure 4, center frequency tunable by capacitors in series with varactors, instead of capacitors only, is demonstrated. C_{CAP} and C_{VRA} are the capacitance of the capacitor and the varactor, respectively.

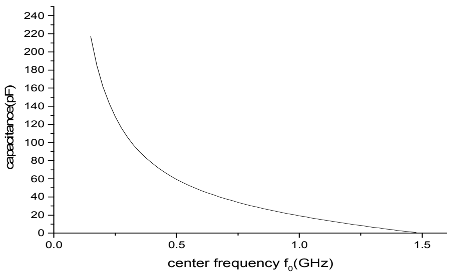

Figure3. Relation between center frequency and capacitance (l=9.35mm)

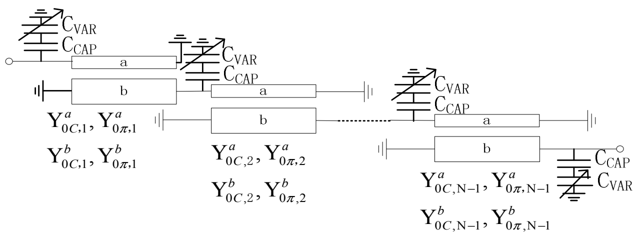

Figure4. The block diagram of the tunable miniaturized BPF

III. DESIGN OF A THIRD-ORDER MINIATURIZED TUNABLE BPF

A third-order Chebyshev miniaturized tunable BPF with a 0.1-dB passband ripple level and 10% bandwidth is designed by the proposed method for verifications. The third-order filter has two sections of asymmetric coupled lines, at which frequency θ_0 is miniaturized to 30° at ω_0=500MHz to define physical dimensions. According to (1)-(12), we can get parameters such as the capacitance C, and $Y^a_{0C,i}$, $Y^a_{0\pi,i}$, $Y^b_{0C,i}$, $Y^b_{0\pi,i}$(i=1,2), the C- and π- mode admittance of strip a and b easily. The BPF is fabricated on a ROGERS RT6010 substrate with a relative dielectric constant of 10.2 and a thickness of 0.635mm. The physical dimensions are listed in Table 1, where W_a is the width of strip a, W_b is the width of strip b, S is the Gap spacing between strip a and b. Besides, the photograph of the BPF is given in Figure5. The whole size of the BPF is only 20.8mm*5.7mm.

TABLE I
PHYSICAL DIMENSIONS OF THE FILTER

	W_a	W_b	S	Length
Section1	1.7 mm	0.6 mm	0.5 mm	9.35 mm
Section2	0.6 mm	1.7 mm	0.5 mm	9.35 mm

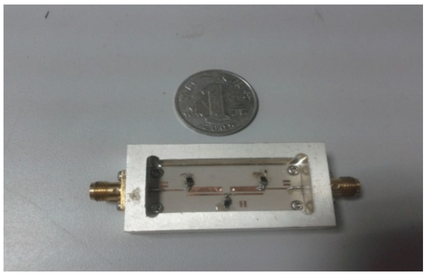

Figure5. The photograph of the tunable miniaturized BPF

IV. EM SIMULATION AND MESUREMENT RESULTS

Different values of capacitors and varactors in series with capacitors are both tested for the designed third-order BPF to make comparisons. Figure6 gives simulation and measurement results when different Murata GQM type capacitors are shunted. The capacitance is 27pF, 15pF, 10pF and 5pF, respectively, while the center frequency is 550MHz, 717MHz, 837MHz and 1168MHz, respectively.

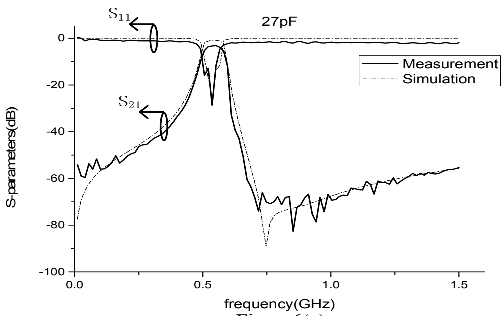

Figure6(a)

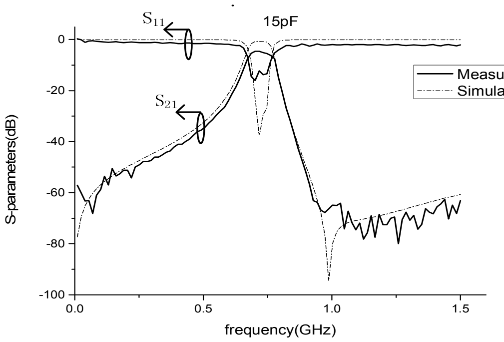

Figure6(b).

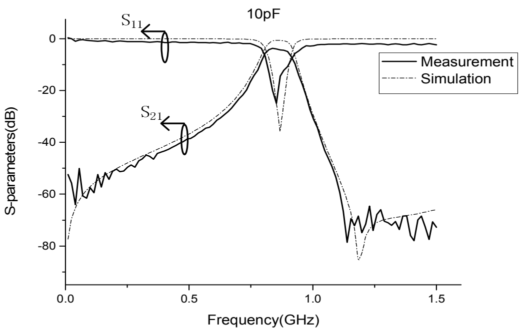

Figure6(c)

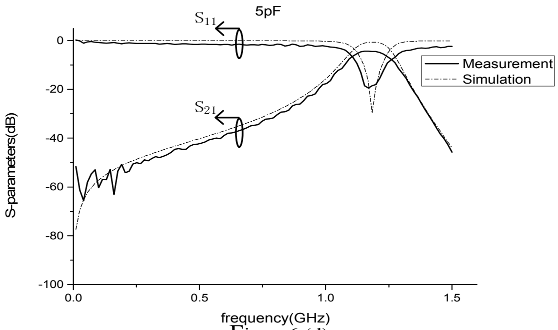

Figure6 (d).

Figure6. Simulation and measurement results of the BPF shunting (a)27pF, (b)15pF, (c) 10pF, (d)5pF capacitors

Then we use capacitors in series with SMV 1148 varactors to replace capacitors so as to make center frequency tunable. The measurement results of S-parameters with different bias voltage on varactors are given in Figure7. The center frequency changes from 521MHz to 1123MHz and the miniaturization ratio varies from 65% to 25%.

V. CONCLUSION

A new method for miniaturized tunable BPF is proposed by using asymmetric coupled lines with shunt capacitors cascaded by varactors in this paper. Design detail of the method is represented. A third-order bandpass filter, whose center frequency can be tuned from 521MHz to 1123MHz is designed, simulated and fabricated. Experiment results show good agreement with simulation ones, although there is slightly difference in passband flatness and fractional bandwidth.

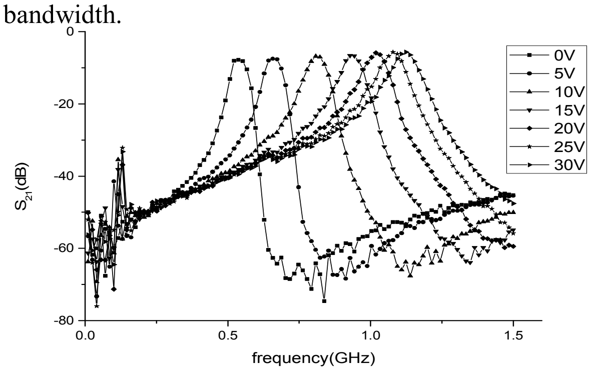

Figure7(a). Measured S_{21} parameters of the BPF with different bias voltage

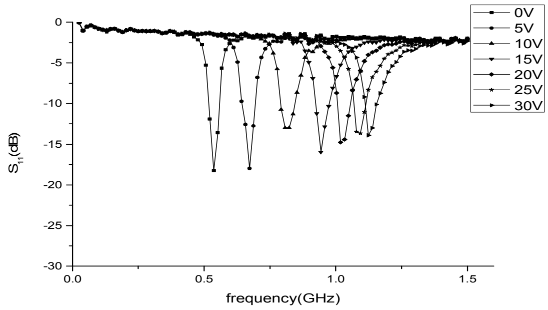

Figure7(b). Measured S_{11} parameters of the BPF with different bias voltage

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