Design of the Wide-tuning-range Notch Filter with Wide Constant Absolute Bandwidth

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Abstract— A compact notch filter with a wide tunable frequency range is developed. This tunable filter is composed of two varactor-tuned resonators, shunted at input/output ports separately, and one quarter-wavelength transmission line connecting two varactor-tuned resonators. By enlarging impedance of the quarter-wavelength transmission line, the proposed tunable filter can obtain a wide and constant absolute bandwidth. The measured results show that there is a wide tuning range, 124.3%.

1. INTRODUCTION

For the dynamic frequency-agile front end receivers, the cognitive radios have the potential to improve spectrum efficiency with the tunable notch filter. Moreover, frequency-tunable filters are often used for the multiband communication systems, wide-band radar systems, and measuring instruments to track the operating frequency.

In [1–4], the T-shaped notch filters with multiple stages have been studied. With these notch filters, it is indicated that the more the LC resonator pairs there are, the wider the stopband bandwidth there is. However, when tuning the central frequency, a constant absolute bandwidth cannot be sustained.

On the contrary, a wide and constant absolute bandwidth can be obtained with the π-shaped circuit shown in Figure 1. This tunable filter is composed of two varactor-tuned resonators, shunted at input/output ports separately, and one quarter-wavelength transmission line connecting two varactor-tuned resonators. These two varactor-tuned resonators are arranged symmetrically, and realized by a varactor and an inductor with series connection. Particularly, the varactor is introduced to control the central frequency within the stopband. Significantly, the absolute bandwidth of the stopband can be easily increased by enlarging impedance Z_2 of the transmission line section in this study. Moreover, if the bandstop filter is with a higher order, the roll-off stopband gets sharper.

2. DESIGN OF NOTCH FILTER

The proposed structure shown in Figure 1(a) is generally used for the design of the three-ordered notch filter. The design equations of the notch filter can be then derived as

$$L_1 = L_3 = Z_0/(\omega_0 g_1 \Delta) \tag{1}$$

$$C_1 = C_3 = (g_1 \Delta)/(\omega_0 Z_0) \tag{2}$$

$$Z_2 = g_2 \Delta Z_0 \tag{3}$$

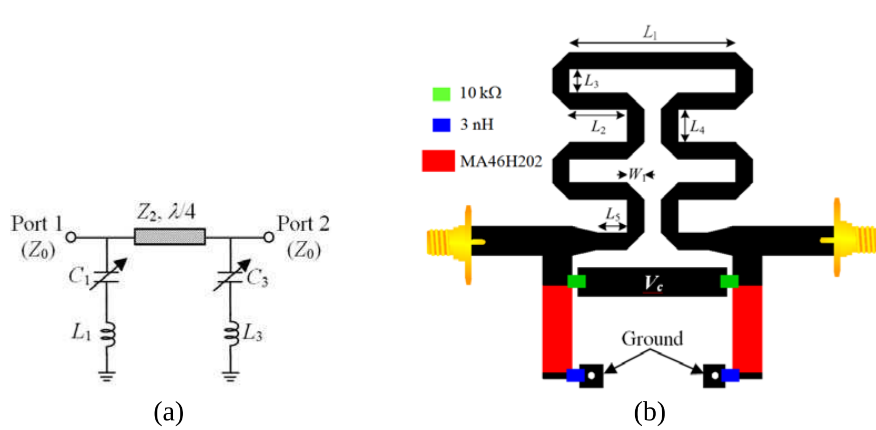


Figure 1: Proposed tunable notch filter. (a) Schematic diagram. (a) Layout.

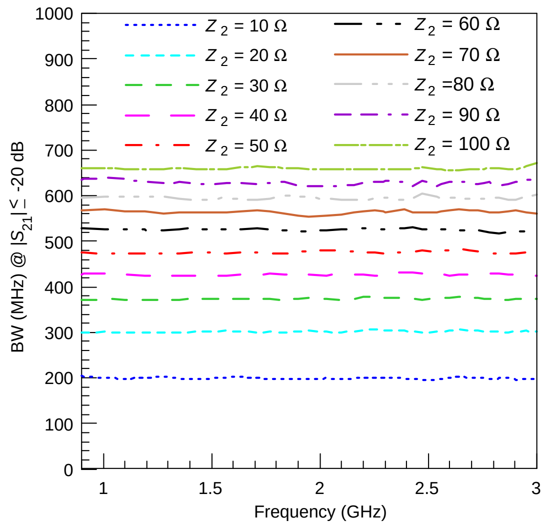


Figure 2: Influences of impedance Z_2 on the proposed tunable notch filter.

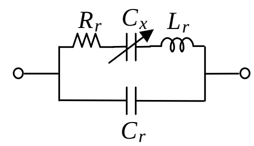


Figure 3: Physical model of the varactor MA46H202.

where the g_i's (for $i = 1$ or 2) are the element values of the prototypical lowpass filter, and Δ is the fractional bandwidth.

Larger capacitances C_1 and C_3 would result in lower operating central frequency for the design of the proposed notch filter. However, there are upper limits of capacitances for the physical application. Therefore, the central frequency of the exemplary notch filter has to be set at 0.9 GHz; moreover, its ripple of Chebyshev response and fractional bandwidth are selected as 3 dB and 82%, respectively. According to (1)–(3), the component values L_1 (or L_3), C_1 (or C_3), and impedance Z_2 can be derived as 3.22 nH, 9.71 pF, and 29.18 Ω, respectively.

The absolute bandwidth of the proposed notch filter is 364 MHz with insertion loss greater than 20 dB. Consequently, by increasing impedance of the quarter-wavelength transmission line, absolute bandwidths of the proposed notch filter can be expanded. As shown in Figure 2, with the impedance Z_2 of the proposed notch filter increasing from 29.18 Ω to 50 Ω, the absolute bandwidth will be 479 MHz with insertion loss greater than 20 dB.

In order to simplify the analysis of the tunable notch filters in Figure 1(a), firstly, the varactors C_1 and C_3 are treated as ideal. Then, the varactor can be physically modeled as Figure 3, where there are parameters R_r, C_r, L_r, and C_x. For this study, MA46H202, the varactor made by M/A-COM, is employed. Parameters R_r, C_r, and L_r are 0.3 Ω, 0.15 pF, and 0.45 nH, respectively; the available range for capacitance C_x is from 0.65 to 14 pF. Consequently, the capacitors C_1 and C_3 are substituted with the physical model.

With the varactor in Figure 3 employed for the tunable notch filter, an approximate equation of C_x, resulted from the curve fitting, can be adopted for the tunable filter simplification.

$$C_x\,(\mathrm{pF}) \approx \frac{10^3}{(2\pi f_0)^2 L_1\,(\mathrm{nH})} - C_r\,(\mathrm{pF}) - \exp\left(-0.14 f_0^3 + 0.506 f_0^2 - 2.48 f_0 + 1.76\right) \tag{4}$$

where f_0 is the operating central frequency of the notch filter, with "GHz" as the unit.

As for the two-stage transmission lines, Figure 2(a) shows the simulated results of $|S_{11}|$ with various corrected coefficient K_1. It is indicated that the smaller the corrected coefficient is, the larger the available fractional bandwidth (FBW), and the $|S_{11}|$ are. Moreover, there is a wider operating bandwidth with $K_1 < 1$ than that with the binomial response, $K_1 = 1$. Figure 2(b) also shows the similar tendency that the larger the impedance ratio R is, the smaller the FBW is.

3. FABRICATION AND MEASUREMENT OF TUNABLE NOTCH FILTER

With 14 pF for the upper limit of the capacitance C_x, a wider tuning range will be obtained for the fabricated notch filter, from 0.7 to 3 GHz. According to (4), Table 1 presents the relationship between the capacitance C_x and the corresponding central frequency f_0; consequently, Figure 4 illustrates the simulated responses of this tunable notch filter.

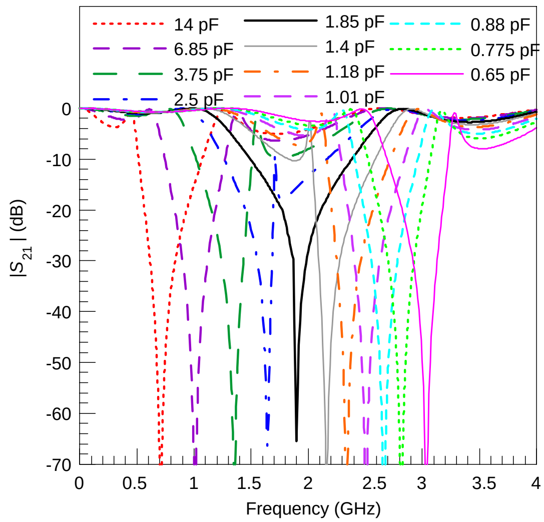
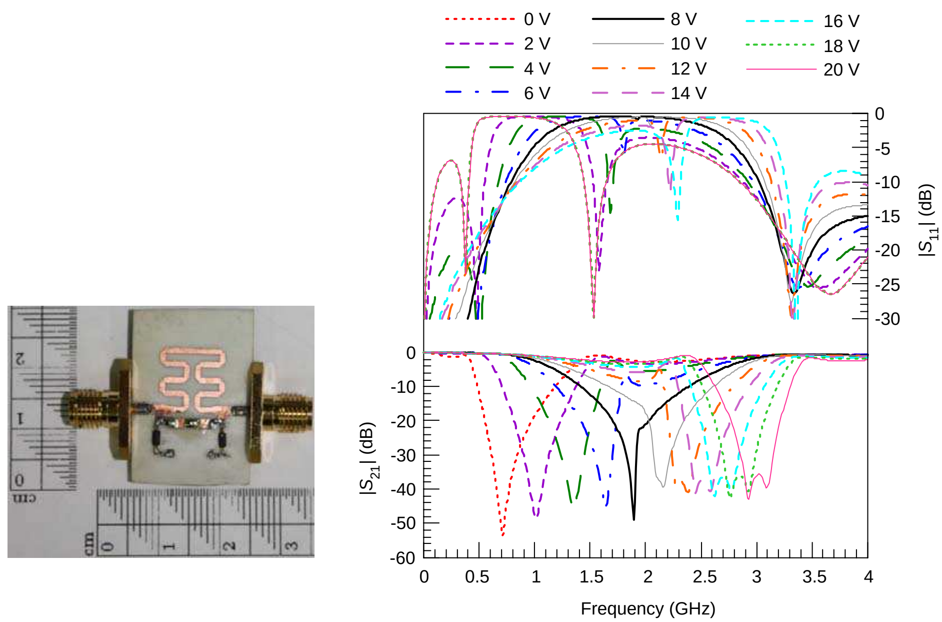


Figure 4: Simulated responses of the tunable notch filter with corresponding capacitance C_x.



(a) (b)

Figure 5: Measured results of the proposed notch filter with controllable stopbands. (a) Photograph. (b) $|S_{21}|$ and $|S_{11}|$ with bias voltage V_x.

Table 1: Relationship between C_x and f_0.

C_x (pF)	14	6.85	3.75	2.5	1.85	1.4
f_0 (GHz)	0.71	1.01	1.35	1.6	1.9	2.16
C_x (pF)	1.18	1.01	0.88	0.775	0.65	
f_0 (GHz)	2.34	2.51	2.67	2.82	3.04	

Table 2: Relationship between V_x and f_0.

V_x (volt)	0	2	4	6	8	10
f_0 (GHz)	0.71	1.01	1.35	1.6	1.9	2.16
V_x (volt)	12	14	16	18	20	
f_0 (GHz)	2.34	2.51	2.67	2.82	3.04	

Consequently, the tunable notch filter is fabricated on Rogers RO4003, the substrate whose dielectric constant, loss tangent, and layer thickness are 3.55, 0.0027, and 0.813 mm, respectively. Figures 1(b) and 5(a) show the layout and photograph, respectively, of the fabricated tunable notch

Table 3: Comparisons of recent studies on the notch filter.

Refs	Range (GHz)	Tuning Percent	Diodes	BW	Size ($\lambda_g \times \lambda_g$)
[5]	0.609–1.053	53.5%	ISV232∗2 JDV2S71E*2	No const.	0.115×0.147
[6]	2–2.25	11.8%	MEMS∗2	No const.	0.35×0.14
[7]	1.73–2.2	23.9%	1SV277∗4	Narrow & const.	0.395×0.197
This work	0.7–3	124%	MA46H202∗2	Wide & const.	0.125×0.125

filter. The overall size of the fabricated filter is 20 mm×20 mm. Moreover, its dimensions L_1, L_2, L_3, L_4, L_5, and W_1 are 8.5, 2.95, 1.2, 1.7, 1.5, and 0.86 mm, respectively. As for the measured results, Figure 5(b) illustrates the tuning performance of the developed tunable notch filter. Particularly, the voltage V_x is employed for the varactor to control the capacitance C_x. Thus, with the voltage V_x employed, the central frequency f_0 can be tuned correspondingly as indicated in Table 2. In addition, with a dc bias voltage from 0 to 20 V, the central frequency of this notch filter range from 0.71 to 3.04 GHz; that is, there is a wide tuning rage, 124.3%. Within the tuning range, the constant absolute bandwidth is near 450 MHz with measured insertion loss greater than 20 dB.

4. CONCLUSION

A compact π-shaped tunable notch filter is developed for the emerging wireless communication systems with multi-bands and multi-functions. A simple and effective method is proposed to broaden the stopband bandwidth in this paper by increasing the impedance of the quarter-wavelength transmission line. Compared with the conventional filters, the design procedure for the proposed filter is simpler. Table 3 compares recent studies on the notch filter. With the proposed structure, a wide tuning range and a broad constant absolute bandwidth are obtained. Moreover, the measured results show that within the tuning range, 0.71–3.04 GHz, the absolute bandwidth is obtained as 450 MHz with the measured insertion loss greater than 20 dB.

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