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Filter with Selectable Passband Based on a Miniaturized Resonator

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Abstract—A passband filter where the central frequency can be one of seven selectable frequencies is presented. Its operation region ranges from 325 to 455 MHz, and each bandwidth is about 20 MHz. The filter is based on a highly miniaturized ring resonator with a size reduction from about 77% to 83% compared to a conventional closed ring. The reconfiguration of its resonant frequency is implemented by shifting a short location, thus changing its effective inductance. This is opposed to the conventional capacitance change of other reconfigurable filters. Simulated and experimental results are in good agreement. Reflections are below -10 dB at central bandpass frequencies for all selectable bands.

1. INTRODUCTION

In recent years, the number of telecommunication system users has been constantly increasing. Due to economic and customer service reasons, an efficient use of the assigned bands is one of the top priorities. One way of maximizing an assigned band is to improve filter performance. A high-performance filter must be tunable and highly selective. In addition, for modern mobile communications systems, cost reduction and circuit miniaturization are required. Several reconfigurable filters can be found in the literature. A theoretical investigation of reconfigurable asymmetric filters based on a network prototype with capacitive tunning is shown in [1]. Here, a transmission zero can be shifted from the lower to the upper stopband. Another method is focused on tuning the central frequency and bandwidth without adjusting the internal coupling, but the tuning is limited to small values [2]. Switchable bandpass filters based on MEMS have also been reported in [3–5]. In [6] a reconfigurable bandpass filter using *LC varactor* resonators is presented with a 16% tunning range. In [7] a CMOS filter using an activation transistor is capable of shifting from lowpass to bandpass configuration. Moreover, in [8], a filter with concentrated capacitors (a combination of mechanical, fixed and a varactor) is demonstrated offering a wide tunning range from 450 to 850 MHz ($\approx$ 61.5%). In addition, reconfigurable filters using PIN diodes [9, 10] or switches [11] have also been described in the literature. Finally, a coplanar waveguide filter with miniaturized fluidic devices has been reported in [12].

In this paper, we present a novel reconfiguration technique implemented by shifting a short location on a miniaturized square ring resonator. This changes the effective resonator inductance as opposed to conventional capacitive reconfiguration. This design has seven selectable-passbands, each having 20 MHz. The overall tuning range is about 29%. It is shown that the frequency tuning range follows a quasilinear relation with the short location, in contrast with varactor reconfiguration techniques that are nonlinear in nature. In addition, in this resonator we control the inductance value, and external biasing is not required. We report simulated and measured results.

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2. RECONFIGURABLE RESONATOR

In this design we use an open-square-ring forced-mode resonator, where the resonant frequency can be changed by modifying the short location. The design starts with a conventional loop resonator on a Rogers RO3010 substrate with $\varepsilon_r = 11.2$, $\tan\delta = 0.0022$ and thickness of 1.28 mm. Its dimensions are 15.6 mm × 15.6 mm with lines of 0.8 mm width ($Z_0 = 56.7$ ohms). This open ring has a resonant frequency $\omega_0/2\pi = 1.948$ GHz and its associated inductance and capacitance are $C = \pi/Z_0\omega_0$ and $L = 1/C(\omega_0)^2$ [13]. Fig. 1 shows a closed-square-ring, an open-square-ring, an open-square-ring with capacitive loading, and an open-square-ring with capacitive loading and a short, along with their equivalent circuits. The mean ring-perimeter is p, and d indicates the short location.

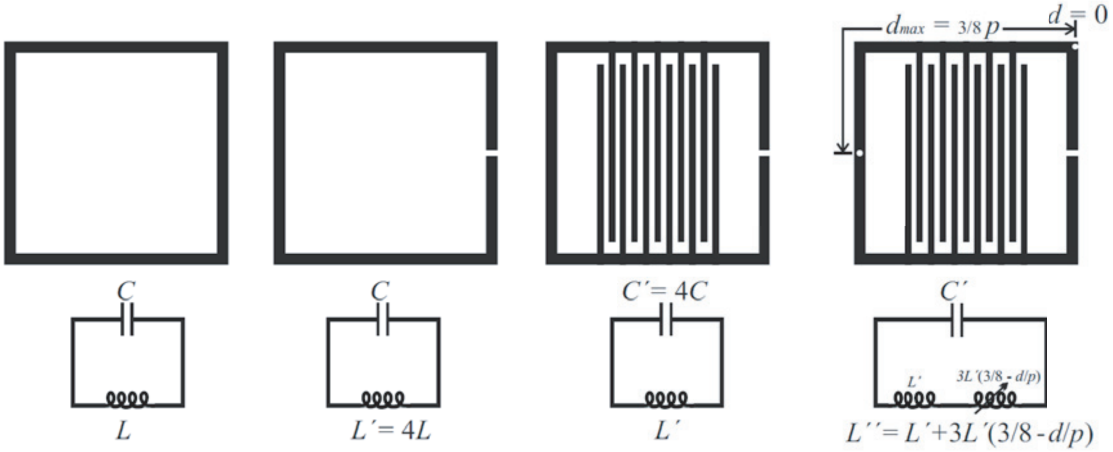


Figure 1. Equivalent circuits for four different square-rings.

For implementation reasons, the maximum distance d that the short can be moved away from the location $d = 0$ is limited to $d_{\max} = 3/8\,p$, such that $(1 + d/p) = (1 + 3/8\,p/p) = (1 + 3/8) = (11/8)$. The resonant frequency f_0 can then be expressed by Eq. (1), where f_{0g} is the resonant frequency without a short ($L'' = L'$).

$$f_0 = \frac{8}{11}\,(1 + d/p)\,f_{0g}. \tag{1}$$

Figure 2 shows the relation between the resonant frequency and the distance of the short for a resonator with capacitive loading when f_{g0} is 454 MHz, and p is 60.8 mm. These resonators were simulated using a Full-Wave simulator [14].

3. FILTER DESIGN

A second-order Butterworth filter response is chosen for the design with a central frequency of 410 MHz and fractional bandwidth (FBW) of 5%. The g-parameters [15] are: $g_0 = g_3 = 1$ and $g_1 = g_2 = 1.4142$.

The required design parameters are calculated with the methodology presented in [16]. Using Eq. (2) we calculate the mutual coupling coefficients $k = 0.036$. From Eq. (3), we obtain the physical resonator separation of 0.2 mm. Subsequently, the mutual couplings (k) and external coupling were calculated using Eqs. (2) and (4) for all the 7 reconfigurable bands with the same resonator separation (0.2 mm).

$$k = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2}, \tag{2}$$

$$FBW = k_{12}\sqrt{g_1 g_2}, \tag{3}$$

$$Q_{e1} = g_0 g_1/FBW, \quad Q_{e2} = g_2 g_3/FBW. \tag{4}$$

Table 1 shows the effective size reduction compared with a close loop for the seven short locations, shown in Fig. 2, and the contact point location for the external coupling Q_e. Table 2 shows the central

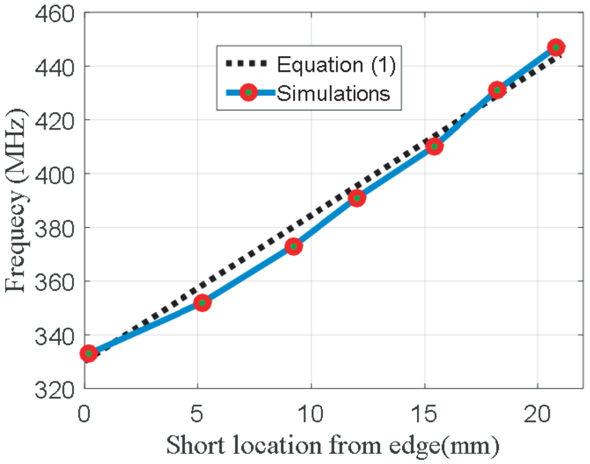


Figure 2. Resonant frequency as a function of the short location.

frequencies f_c, the upper and lower cutoff frequencies (f_2 and f_1), the mutual coupling factor k, the fractional bandwidth FBW, and the external coupling Q_e for the seven passbands (B1–B7). In Fig. 2 each dot displays the value of each distance d and its resultant resonant frequencies for B1–B7. Fig. 3 shows the layout of the designed second-order filter using microstrip technology, as well as a photograph of the fabricated structure. The white circles along with B1–B7 indicate the location of each needed short for each selectable passband. The very-short open stubs along with Q1–Q7 show the needed contact point to have the required external coupling for each selectable band. The resonators are symmetric, as well as the feeding lines and short locations. To have the filter configured for B1, a short at the distance $d = 0.2$ mm is made by connecting a cooper wire (via) to ground, and the rings are fed by connecting the feeding lines at Q1 of Fig. 3(a) using liquid metal (Galistan). For B2, the short is at $d = 5.2$ mm, and the rings are fed at Q2 (coupling location = 12.0 mm), and so on.

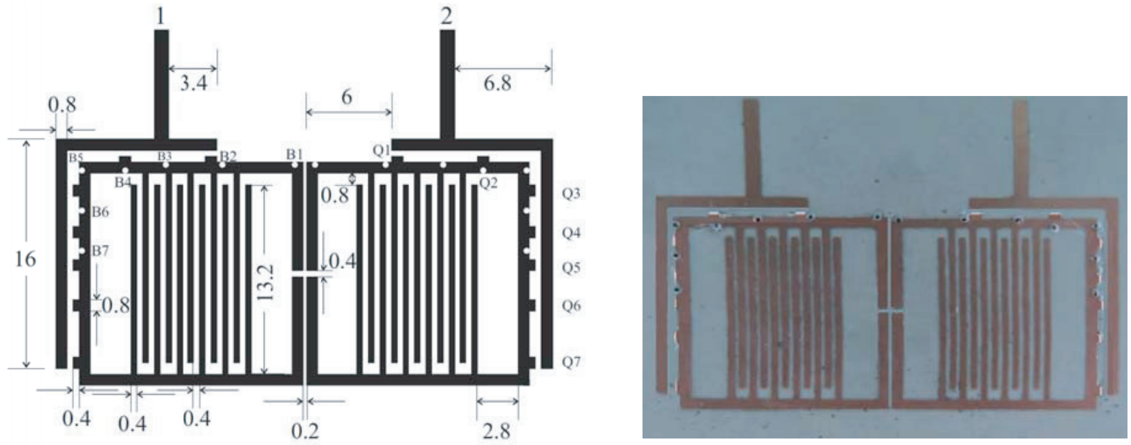
Table 1. Size reduction as a function of the short location.

	B1	B2	B3	B4	B5	B6	B7
Short location d (mm)	0.2	5.2	9.2	12	15.4	18.2	20.8
Q_e coupling location (mm)	6.0	12.0	17.2	20.1	22.4	25.2	29.2
Size reduction (%)	82.92	81.95	80.87	79.95	78.97	77.9	77.0

Table 2. Simulated and calculated parameters for filter designs.

Band	f_c^a	f_2^a	f_1^a	k	Q_e	BW^a
B1	447	454.4	441.2	0.0295	33.9	19.5
B2	431	436.6	422.8	0.0322	31.0	20
B3	410	416.6	402.4	0.0347	28.8	21
B4	391	397.6	383.6	0.0358	27.9	21
B5	373	377.8	364.4	0.0361	27.7	21
B6	352	357.2	344.0	0.0376	26.6	20
B7	333	336.8	325.6	0.0338	29.6	17

^{a}In MHz.

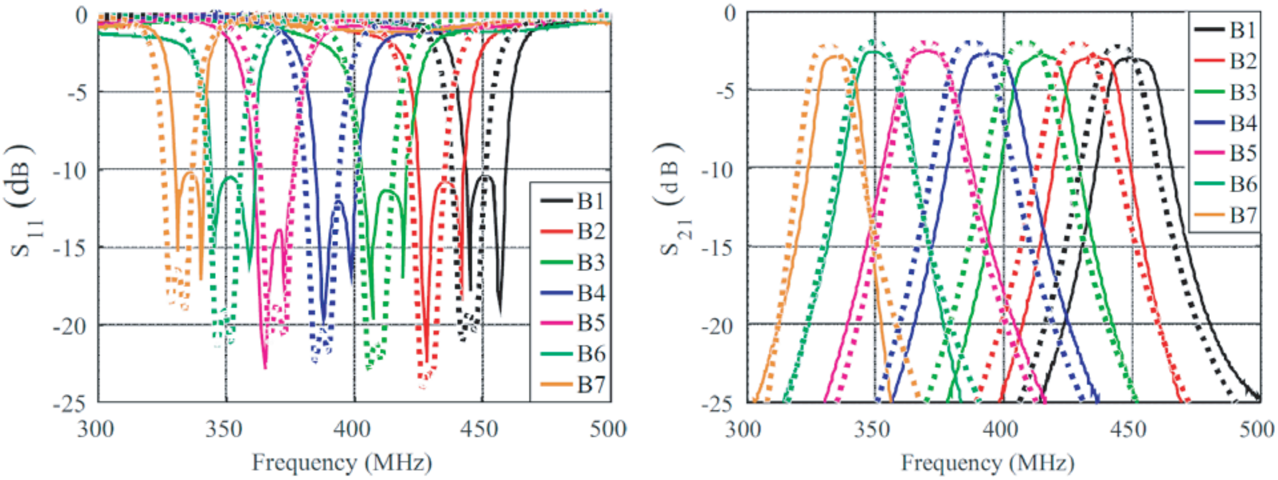


(a) (b)

Figure 3. (a) Layout of the designed filters with all the dimensions in mm where the location of each short B and external coupling Q are indicated to obtain the seven bands described in Table 2. (b) Photograph of the fabricated filter where the dimensions are 34.6 mm × 17.2 mm plus feeding lines of 1 mm × 7.6 mm.

4. IMPLEMENTATION AND RESULTS

The filter was implemented on Rogers RO3010 with conventional photolithography and fed using SMA connectors. Measurements were made with the VNA N9914A-211. The simulated and measured S-parameters for the seven bands are shown in Fig. 4. There is a good concordance between simulated and measured results, and there are some mild discrepancies in amplitude and frequency values attributable to the manufacturing and measuring processes.



(a) (b)

Figure 4. Simulated (dotted lines) and measured (solid lines) S-parameters for the designed filters. (a) S_{11} and (b) S_{21}.

The main parameters of the seven bands are presented in Table 3. All S_{11} values are below -10 dB at the central frequencies for all passbands. The BW is larger than 20 MHz for all bands except for B7, and the central frequency displacement is below 8 MHz. Fig. 5 shows the wide band S_{21} response. Table 4 shows the comparison between this work and some other filters.

Table 3. Simulated and measured main filter parameters values.

	Simulated				Measured			
Band	S_{11}^{a}	S_{21}^{a}	BW^{b}	f_c^{b}	S_{11}^{a}	S_{21}^{a}	BW^{b}	f_c^{b}
B1	−19.1	−2.26	19.5	445	−10.6	−3.14	21.3	449.8
B2	−22.9	−2.09	20	429	−10.8	−3.02	22.2	434.9
B3	−21.1	−2.02	21	409	−11.2	−2.96	22.1	413.8
B4	−20.3	−2.02	21	388	−11.8	−2.78	22.7	393.9
B5	−18.6	−2.01	21	370	−14.2	−2.53	22.9	370.5
B6	−19.0	−1.99	20	349	−10.5	−2.74	20.1	351.5
B7	−16.4	−2.15	17	331	−10.2	−2.87	15.7	338.3

^{a}In dB at f_c; ^{b}In MHz.

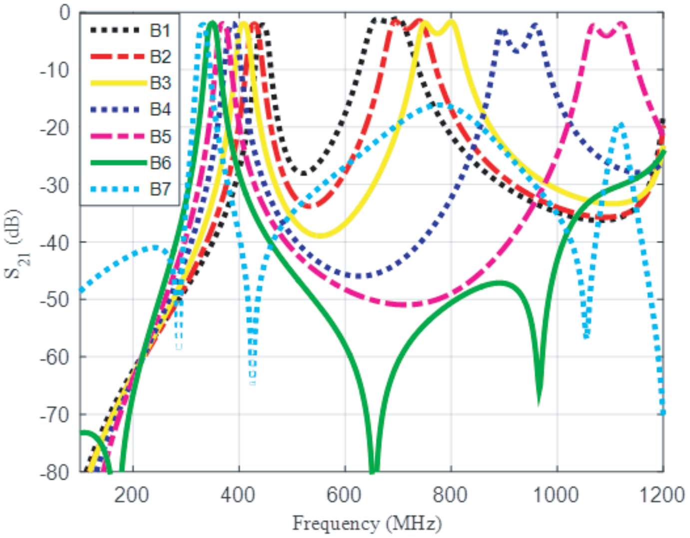


Figure 5. Entire filter response in the frequency spectrum to see out-of-band rejection and transmission zeros.

Table 4. Comparison with some filters.

	This work	[4]	[5]	[6]	[8]	[10]	[12]	[17]
No. bands	7	2	2	6	5	5	4	2
Tuning (%)	29	8	8	16.2	69	40	47	NA
f_c (GHz)	0.41	62.5	12.5	2.7	0.645	2.5	4.45	2.45
Size in λ_g	0.156 × 0.078	4.6 × 3.0	0.71 × 0.10	0.2 × 0.18	0.19 × 0.159 × 0.08	0.63 × 0.47	2.7 × 0.35	0.14 × 0.11

5. CONCLUSION

We present a reconfigurable seven-band bandpass filter based on a highly miniaturized resonator using novel shorting pin tuners on microstrip technology. The miniaturization oscillates between 77% and 83% compared to conventional square ring resonators. The available tuning range is 29%. It is shown that the frequency tuning range follows a quasilinear relation with the short location. There is a good agreement between measurements and simulations.

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