

A Technique for Tunable Filters with Low Insertion Loss and Narrow Bandwidth

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Abstract: A technique for tunable filters with low insertion loss and narrow bandwidth is proposed in the form of comb-line structure. Both resonant capacitor with pin-diodes and resonant inductance in the tunable filter were analyzed and the main source of insertion loss was obtained. A series of filters with same pin-diodes, center frequency, absolute bandwidth and low return loss was simulated. The results showed that, by changing the values of the resonant capacitor and inductance, insertion loss of the filter can be greatly restricted. This technique will allow the design of tunable LC filters with low insertion loss and narrow bandwidth.

1 Introduction

Tunable filter is one of the suitable solutions for intelligent RF applications satisfying multi-band or multimode standards [1]. Compared to a bank of fixed filters, a tunable filter promises greater functionality, better channel selectivity, reduced size, and lower weight since the same hardware can be employed at multiple bands [2]-[5]. However, for tuning over an octave frequency by using pin-diodes switches or varactors, the insertion loss of the tunable filter is larger than normal fixed filters. Up till now, some method has been used to restrict the insertion loss of the tunable filter [6]-[10]. But few research has reported the influence of values of the resonant capacitor with pin-diodes and resonant inductance on the insertions loss of the tunable filter.

In this paper, both resonant capacitor with pin-diodes turned on and resonant inductance in the tunable filter were analyzed and a technique for restricting the insertion loss of tunable filters by changing the values of the resonant capacitor and inductance is reported.

2 Theoretical Analysis Of The Resonant Circuit With PIN-DIODES

The insertion loss and bandwidth of band-pass filter is shown in (1).

$$L(f) = -10 \log \left[\frac{1 + (2Q_l \frac{f - f_0}{f_0})^2}{\left[1 - \frac{Q_l}{Q_u}\right]^2} \right] \quad (1)$$

$L(f)$ is insertion loss, Q_l is loaded quality factor, Q_u is unloaded quality factor, f is frequency and f_0 is center frequency.

The fractional bandwidth of band-pass filter is shown in (2).

$$BW = \frac{\Delta f}{f_0} = \frac{1}{Q_l} \quad (2)$$

According to (1) and (2), it could be concluded that, if the fractional bandwidth of the filter is fixed, the insertion loss mainly depends on Q_u of the filter and higher value of Q_u means lower insertion loss in the filter.

The original definition of quality factor is:

$$Q_u = 2\pi \frac{\text{The energy storage in the circuit}}{\text{The energy consumption in the circuit}} \quad (3)$$

In this paper, for the convenience of comparison and discussion, only the tunable filter with pin-diodes all turned on and can be equal to be a resistance was taken into considerations.

The structure of the resonant capacitors with pin-diodes is shown in Figure 1.

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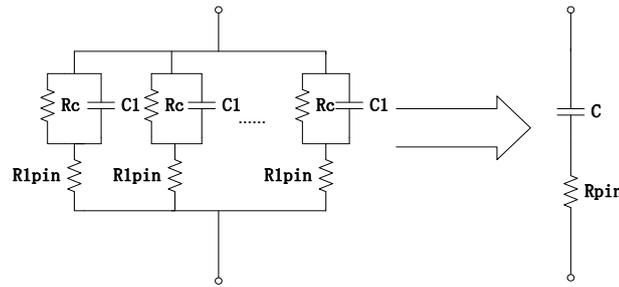


Figure 1 The structure and equivalent circuit of the resonant capacitors with pin-diodes

$C1$ is the resonant capacitor, Rc is the dissipative resistance and $R1_{pin}$ is the resistance of pin-diodes turned on. For the dissipative resistance Rc of the resonant capacitor $C1$ is much smaller than the resistance of pin-diodes, the structure can be transformed. The result is shown in (4) and (5).

$$C \approx nC1 \tag{4}$$

$$R_{pin} \approx \frac{R1_{pin}}{n} \tag{5}$$

The structure of the resonant circuit is shown in Figure 2.

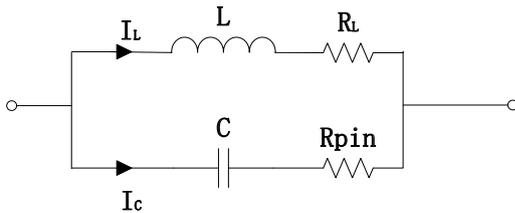


Figure 2 The structure of the resonant circuit

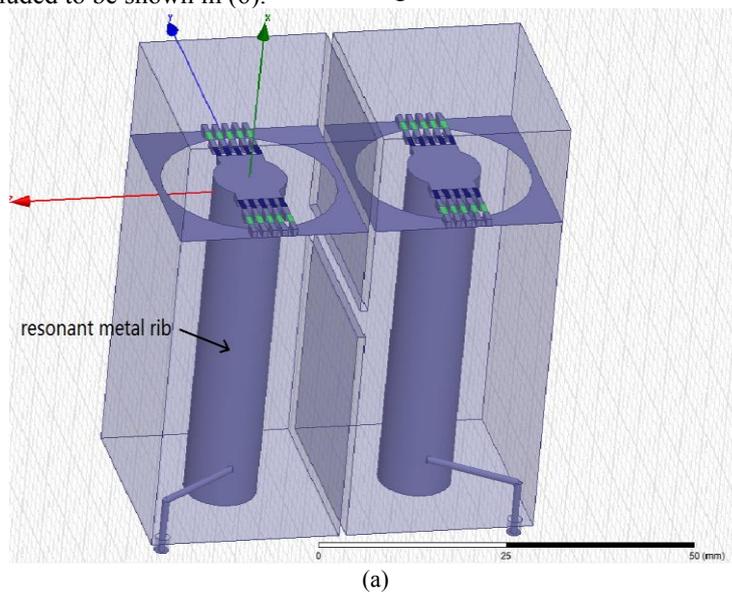
For the value of R_{pin} and RL is much smaller than impedance of the resonant capacitor and inductor, IC is almost equal to IL and the value of unloaded quality factor could be concluded to be shown in (6).

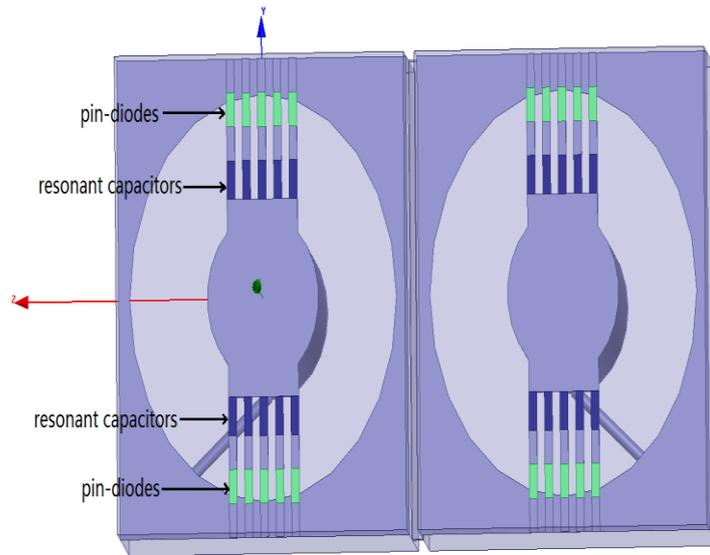
$$Q_u = \frac{\frac{1}{2} I_C^2 \frac{1}{\omega_0 C} + \frac{1}{2} I_L^2 \omega_0 L}{I_C^2 R_{pin} + I_L^2 R_L} \approx \frac{\omega_0 L}{R_{pin} + R_L} = \frac{1}{\omega_0 C (R_{pin} + R_L)} \tag{6}$$

The value of R_{pin} is fixed and much bigger than RL . So the main source of the insertion loss in the filter is the resistance of pin-diodes R_{pin} . It could be concluded that, although big resonant inductor may cause big dissipative resistance RL , small value of resonant capacitor means higher Qu and lower insertion loss of the tunable filter at the same center frequency.

3 Simulation Examples

According to Section 2, a series of tunable comb-line filters with different resonant capacitor and 1% bandwidth were simulated. The models of the tunable filters with the same pin-diode switches but different resonant inductors and capacitors are made and shown in Figure 3.



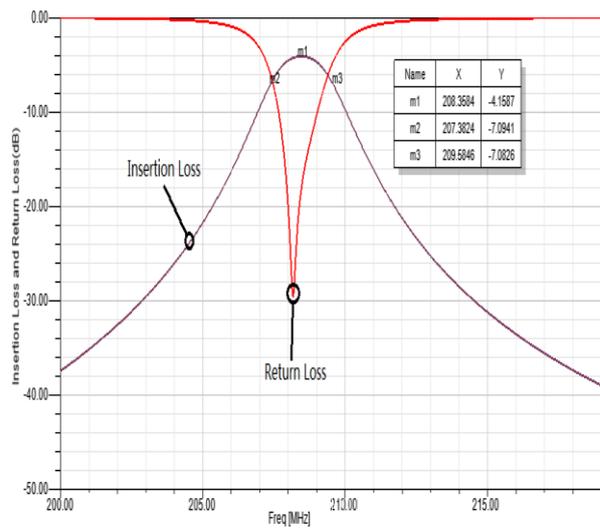


(b)

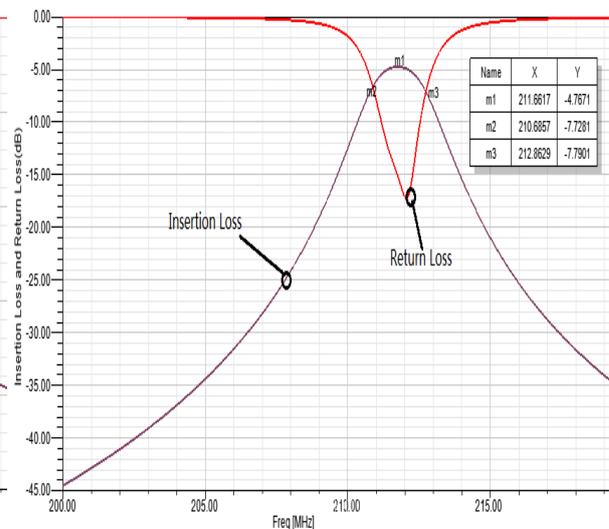
Figure 3 The models of the tunable filters with the same pin-diode switches

The pin-diodes are all turned on and can be equal to be a resistance as 0.5Ω as shown in Fig.3. The value of the capacitors varies from 2 pf to 4 pf and the radius of the resonant metal rib varies from 1 mm to 5 mm which keeps the center frequency of the filters at about 210 MHz. The material of the metal rib is set as aluminum.

By changing the coupling window and the height of the tap-line, the tunable filters with pin-diodes get the same values of bandwidth, return loss and center frequency. However, the values of the insertion loss are different. The simulation results are shown in Figure 4 and table 1.



(a)



(b)

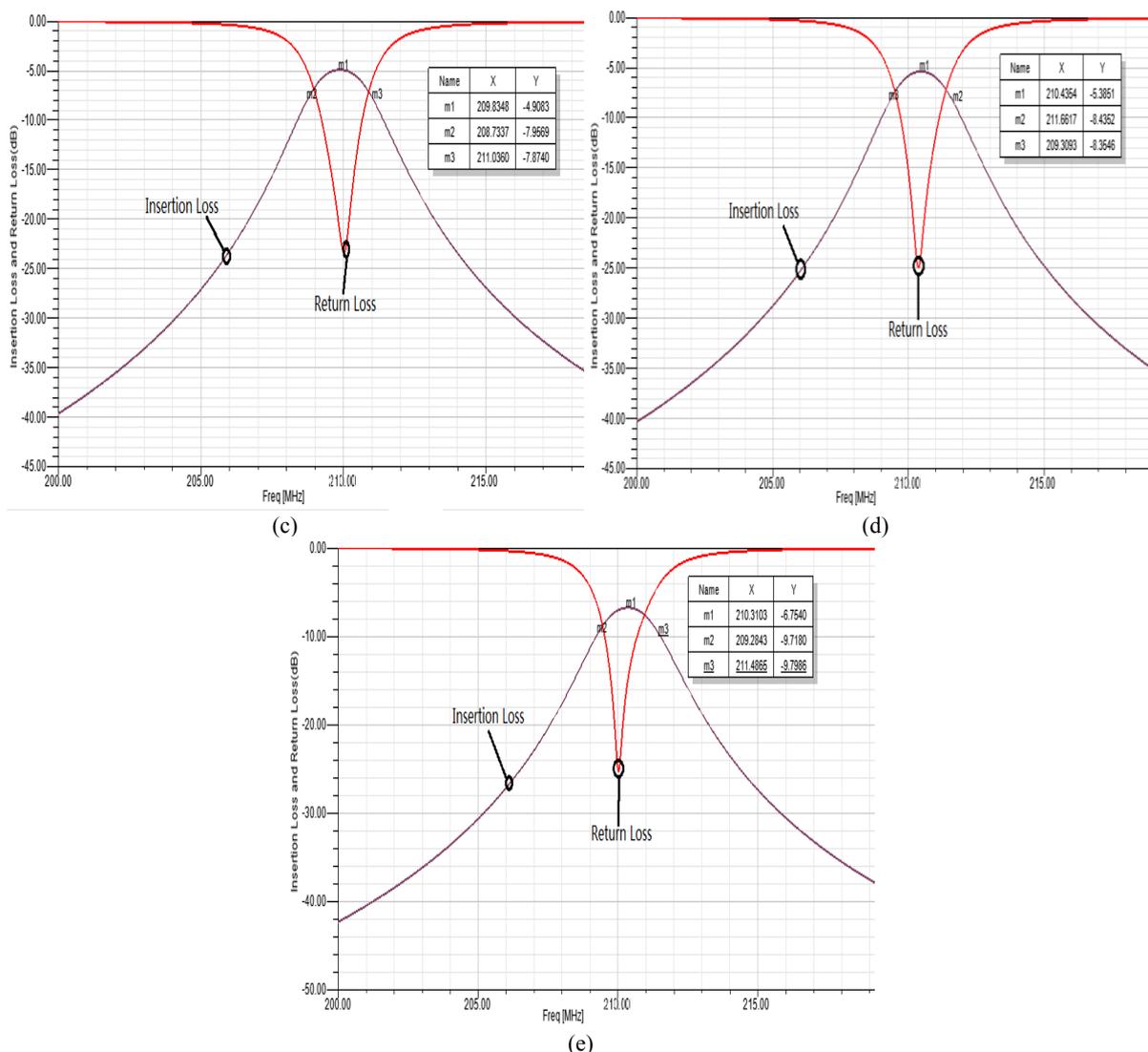


Figure 4 The simulation results of the tunable filters with pin-diodes switches

Table 1 Comparison Between Numerical and Experimental Results

Number	Single resonant capacitor	Radius of the metal rib	Center Frequency	Absolute Bandwidth	Return Loss	Insertion Loss
1	2 pf	1 mm	208.4MHz	2.2MHz	-20dB	-4.2dB
2	2.5 pf	2 mm	211.7MHz	2.2MHz	-15dB	-4.8dB
3	3 pf	3 mm	209.8MHz	2.3MHz	-25dB	-4.9dB
4	3.5 pf	4 mm	210.4MHz	2.3MHz	-15dB	-5.4dB
5	4 pf	5 mm	210.3MHz	2.2MHz	-25dB	-6.8dB

It could be concluded that, as the value of the capacitors varies from 2 pf to 4 pf and the radius of the resonant metal rib varies from 1 mm to 5 mm, the insertion loss of the filters with the same pin-diodes, center frequency, absolute bandwidth and low return loss increases from -4.2 dB to -6.8 dB. Smaller resonant capacitor means higher Q_u and lower insertion loss of the tunable filter with pin-diodes switches all turned on, which support the conclusion in section 2.

4 Conclusion

A technique for Tunable filters with low insertion loss and narrow bandwidth across the tuning range is proposed in the form of comb-line structure. The effect of values of resistant in pin-diodes, resonant capacitor and inductor on insertion loss in tunable filter has been analyzed and a series of tunable filter with the same pin-diodes, center frequency, absolute bandwidth, low return loss but different resonant capacitors and inductors

were simulated. It could be concluded that, as the value of the capacitors varies from 2 pf to 4 pf, the insertion loss of the filters with the same pin-diodes increases from -4.2 dB to -6.8 dB. Both the theory analysis and simulation result show that the small value of resonant capacitor means higher Q_u and lower insertion loss in the filter with pin-diodes turned on.

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