A Tunable Filter with Different Kinds of Material for Good Electrical Performance

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Abstract. A tunable comb-line filter based on series of material with different conductivity is presented and optimized to achieve proper insertion loss and bandwidth. The coupled circuit technique is used and the varactor diode parallel resonance is employed to meet the requirement for external voltage control. Based on the analysis of the tunable filter, the influence of the material with different conductivity on insertion loss and bandwidth is analyzed and it is found that the material of the resonant rib in the filter is an important factor for the electrical characters and high conductivity can effectively restrict the insertion loss and realize the narrow bandwidth. The results also show that the narrow bandwidth could not be obtained when the conductivity of the material is too low.

1. Introduction

The filter plays an important role in RF and microwave systems with the great growth of wireless communication applications which has been continuously leading towards the requirement of microwave transceivers with multi-functional and multi-standard operability\cite{1-3}. At microwave frequencies, resonators such as dielectric pucks, transmission lines, or suspended rods are used to design the filter for wider bandwidth, lower insertion loss and other good electrical properties of the filters. The microwave tunable filters which can switch between frequencies electronically to meet the requirements for different applications have obtained much attention\cite{4-8}. The tunable filters have a number of advantages, however, the insertion loss and bandwidth of the tunable filter are worse than the normal filters for the loss of the active devices and the structures for compact size\cite{9-12}. Up till now, numerous research have presented the methods to improve the loss of the tunable filters within the working frequency, but few papers have reported the influence of the material of the rib in the filter on the electrical properties\cite{13-15}. In the paper, a kind of filter with varactor-diodes has been built and analyzed. The influence of the material of the rib in the filter on the insertion loss and bandwidth is analyzed and the method used to improve the electrical properties of the filter is presented.

2. Models of Filter and Equivalent Circuit of Varactor

The equivalent circuit parameter of the varactor is shown in figure 1.
Figure 1. The equivalent circuit parameter of varactor-diode switches.

The $C_j$ is junction capacitor, $C_p$ is Encapsulation capacitor, $L_s$ is lead inductance and $R_s$ is loss resistance.

As the core tuning element of tunable filter, varactor's important parameters include junction capacitance, quality factor and varactor ratio. The junction capacitance $C_j$ of the varactor varies with the change of the applied DC voltage and the resonance frequency of the tunable filter is realized by controlling the DC voltage. The ratio of the maximum capacitance to the minimum capacitance is the varactor ratio.

The quality factor of varactor will affect the loss of circuit and the physical meaning is the ratio of diode energy storage to energy consumption, which can be expressed by the following formula as:

$$ Q = \frac{1}{w C_j R_s} $$

Here, $w$ is the angular frequency. It can be seen from the above formula that the varactor could get higher Q value with smaller resistance value, smaller junction capacitance and lower working frequency. The encapsulation capacitance of the varactor also has a certain influence on its performance. The encapsulation capacitance would increase the equivalent capacitance of the varactor and reduce the tuning range. The loss resistance would increase the loss of the varactor. Therefore, small package of varactor should be chosen to reduce its impact on the performance of the filter and make the circuit structure more compact. Considering that the frequency of the filter in this paper is relatively low, only junction capacitance and resistance are considered in this paper.

3. Simulation and Discussion

Based on the theory of the comb-line filter, the equivalent circuit and simulation modeling of the second-order filter are completed and shown in figure 2.
Figure 2. The models of the tunable filters with varactor-diode switches.

Here: the height of the resonant rib is $H_1=30$ mm, the radius of the rib is 1 mm, the height of the tap is $H_2$, the width of the coupling window is $H_3$ and the conductivity of the rib is $D$, respectively.

When $H_2=4.6$mm and $H_3=2.3$mm, aluminium and bronze are used as the material of the rib and the return loss and insertion loss results are shown in figure 3.
Figure 3. The simulation results of the tunable filter ((a): D=3800000 S/m, (b): D=1000000 S/m).

It could be seen that the return loss is -25dB, insertion loss is -9dB, absolute bandwidth is 1.7MHz and the narrow bandwidth and low insertion loss can be obtained when the material of rib is aluminium and the conductivity is 38000000 S/m. When the material of rib is bronze and the conductivity is 10000000 S/m, the return loss is -19dB, insertion loss is -10.5dB, absolute bandwidth is 1.8MHz and the narrow bandwidth and low insertion loss also could be obtained.

It could be concluded that the Conductivity has little effect on filter performance when Conductivity is higher than 10000000 s/m.

Using graphite to replace the aluminium as the material of the rib and the width of the coupling window varies from 2.3mm to 0.1mm to get narrow bandwidth and the simulation results are shown in figure 4.

Figure 4. The simulation results of the tunable filter based on graphite.

It could been seen that the insertion loss is much greater than before and the absolute bandwidth become much wider than follow filter and the absolute bandwidth of the filter is kept constant at 8MHz and the narrow bandwidth could not be obtained. It could be concluded that, firstly, the
conductivity of the material of the rib has a great influence on the insertion loss and low conductivity would result in a sharp increase in insertion loss. On the other side, the conductivity of the material of the rib also affected by the bandwidth and the narrow bandwidth could not be obtained for the loss of the material.

Another material steel unstained which has a higher conductivity than graphite but lower conductivity than aluminium is chosen as material of the rib and simulation result of the filter is shown in figure 5.

It can be seen that the insertion loss is much better than the filter of rib made by graphite and the narrow bandwidth could be obtained by changing the structure of the filter including the width of the coupling window and position of the tap. The bandwidth of the filter can be restricted to 4MHz which support the fellow conclusion.

4. Conclusions
A series of 2nd-order tunable comb-line filter is designed and analyzed in this paper. The results show that the conductivity has little effect on filter performance when conductivity is higher than 10000000 S/m. However, the conductivity of the rib in the filter could extremely affect the insertion loss and narrow bandwidth of the tunable filter when conductivity is lower than 10000000 S/m. It could be concluded that a better conductivity of the rib would mean not only a better insertion loss but also the controllable bandwidth of the filter. Considering the skin effect at microwave frequency and the influence of metal oxidation and dirt on the conductivity of rib surface, the manufacturer needs to improve the conductivity of rib surface and cleanliness to ensure electrical performance of tunable filter. This study can be used to provide guidelines to design the performance of the tunable filters.

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