Design of a C-band Coaxial Cavity Band Pass Filter

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Abstract— In this paper, a coaxial cavity band pass filter was presented with the volume of 28 mm × 15 mm × 13 mm working at 4.88 GHz and the 3 dB bandwidth of 654.52 MHz. The classical comb lines structure in the coaxial cavity filter was un-applicable for small size. The dressing-line structure was introduced in the coaxial cavity. By adding the capacitance circular plate on the cavity resonant column, the resonant frequency was increased with the volume of the cavity reduced greatly, and requirement of small-size was satisfied. The designed filter was fabricated and measurement was conducted. From measurement, the insertion loss at the center frequency is less than 0.7 dB. The band rejection is greater than 49 dB at 1–2 GHz, and greater than 39 dB at 8 GHz–18 GHz. These showed that the designed filter met the requirements.

1. INTRODUCTION

With the rapid development of science and technology, waveguide filters, coaxial filter, strip-line filter and micro-strip filter and so on are widely used in recent years. However, when filters are asked to withstand high power capacity, low insertion loss, high rejection, narrow bandwidth, cavity filters are the best choice.

However, the biggest disadvantage of the cavity filter is that its size is much larger than the other filters available in microwave application. In order to adapt to the development needs of electronic system miniaturization and portability, to develop new kind and miniaturization of waveguide filters is a widespread concern subject in the industry. Coaxial cavity filter has a wide operating frequency range, high-Q value, good electromagnetic shielding, low loss, large power capacity and other characteristics, taking these factors and design requirements into consideration, this paper uses a coaxial cavity filter. Since the value of $\lambda/4$ at center frequency is approximately $L = \lambda/4 = c/(4\sqrt{\varepsilon_r}) \approx 15.344\,\text{mm}$, that is, the height of the required resonant rod is about 15.344 mm, this value can not meet the design requirements. Therefore, this designed filter uses loaded coaxial resonator cavity. Through using a form of stepped impedance to change the resonant rod structure, the designed filter further reduced the volume of the filter.

This paper is organized as follows: Section 2 presents the proposed resonator structure and describes the design principles of this structure. Section 3 presents the design of the filter. Section 4 presents and analyzes the obtained results of the proposed filter.

2. RESONATOR STRCTURE

Coaxial resonator cavity [1] are generally divided into three types: $\lambda/2$ type, $\lambda/4$ type, capacitor-loading type. From the literature [1], by calculation and simulation, this paper derived the traditional capacitance-loaded coaxial resonator cavity does not meet the design requirements, therefore, based on the theory of predecessors, via adding stepped impedance to chang the structure of the resonator rod, the single cavity model was successfully established. The structure diagram and equivalent circuit is shown in the following Figures 1(a) and 1(b) is equivalent to l_c segment, capacitance C_d is equivalent to discontinuity capacitance at the interface section l_c and section l_b, characteristic impedance Z_b of transmission line is equivalent to l_b segment, capacitance C_0 is equivalent to a discontinuity capacitance at the gap segment.

Resonance condition of the resonance circuit [2] is:

$$Y_L + Y_R + j\omega C_d = 0 \tag{1}$$

Here

$$Y_L = \frac{1}{Z_L} = \frac{-j}{\omega Z_c \tan\beta l_c} \tag{2}$$

$$Y_R = \frac{1}{Z_R} = \frac{-j}{Z_b} \cdot \frac{Z_b + \tan\beta l_b/\omega C_0}{Z_b \tan\beta l_b - 1/\omega C_0} \tag{3}$$

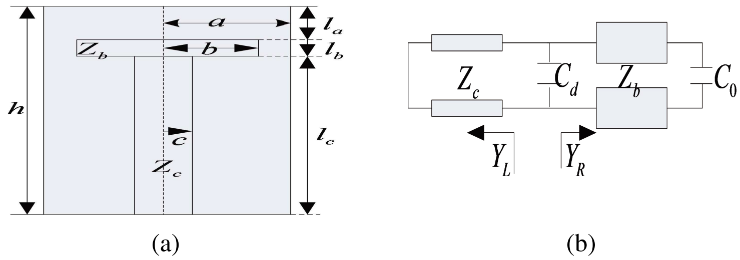

Figure 1: (a) The structure of resonator. (b) The equivalent circuit.

From [4], the impedance calculation formula of the rectangular cavity's resonance bar is

$$Z = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{1.0787R}{r} \tag{4}$$

In (4), r, R respectively represent the radius of the inner and outer conductors.

From [2], the gap capacitance is calculated as

$$C_0 = \varepsilon_0 \frac{\pi b^2}{l_a} + 4\varepsilon_0 b \ln \frac{a-b}{l_a} \tag{5}$$

From [3], the discontinuity capacitor at the interface section l_c and section l_b is calculated as

$$C_d = 2\pi a C'_d \tag{6}$$

$$C'_d = \frac{\varepsilon_0}{100\pi} \left(\frac{\alpha^2+1}{\alpha} \ln\left(\frac{1+\alpha}{1-\alpha}\right) - 2\ln\left(\frac{4\alpha}{1-\alpha^2}\right)\right) + 1.11\,(1-\alpha)\,(\tau-1) \times 10^{-15} \ \ (\mathrm{F/cm}) \tag{7}$$

In (7), $\alpha = \frac{a-b}{a-c}$, $\tau = \frac{a}{c}$.

Taking these principles and the volume requirements of this design into consideration, the design uses Chebyshev response. From [3], this paper calculated the cavity number is three.

The resonator cavity uses rectangular cavity, its length and width are 3 mm, the height is 8 mm.

According to the coaxial cavity theory, when the value of resonator impedance is 76 Ω, the Q value of the resonator is the highest. In the engineering, generally we take 70–80 Ω. Taking into account the processing problems, this design takes 70 Ω. Based on formula (4), the radius c is calculated as following:

$$c = \frac{1.0787b}{e^{70\sqrt{\varepsilon_r}/60}} \approx 1\,\mathrm{mm} \tag{8}$$

To integrate cavity filter design requirements and simulation, we pre-set the initial of the parameters as following: $6\,\mathrm{mm} \le l_c \le 7\,\mathrm{mm}$, $0.3 \le l_b \le 0.8$, $2\,\mathrm{mm} < b < 2.8\,\mathrm{mm}$, by solving the transcendental Equation (1), the value of the parameters above were determined: $l_c = 7\,\mathrm{mm}$, $l_b = 0.5\,\mathrm{mm}$, $b = 2.56\,\mathrm{mm}$, then substituted into the HFSS simulation and optimization, we get the optimal resolve.

3. DESIGN

3.1. Proposed Structure Model Establishment

Selected eigenmode solver in HFSS 15, through adjusting the height of the resonator rod in order to make the cavity resonate at the center frequency 4887.9 MHz, ultimately we obtained the optimizing value: $l_c = 6.91\,\mathrm{mm}$, $l_b = 0.5\,\mathrm{mm}$, $b = 2.53\,\mathrm{mm}$, as is shown Fig. 2.

3.2. Coupling Coefficient Extraction

The coupling coefficient between two cavities is

$$k_{12} = k_{23} = \frac{BW}{\sqrt{g_1 g_2}} = \frac{BW}{\sqrt{g_2 g_3}} = 0.1 \tag{9}$$

Due to the volume of the filter is much smaller while the coupling coefficient is much bigger, therefore, we use this coupling structure which is in the form of coupling window plus a connecting rod, as is shown in Fig. 3. The change curve of the coupling coefficient versus the height of resonator rod plus line is shown in Fig. 4.

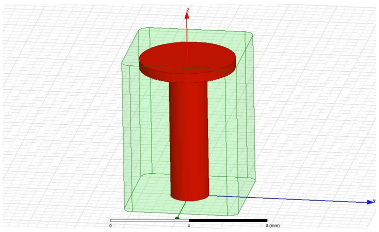

Figure 2: Proposed structure model.

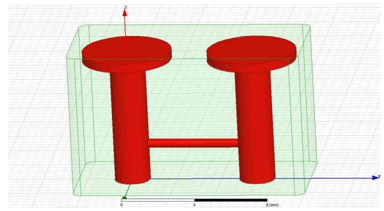

Figure 3: Coupling coefficient extraction between two cavities.

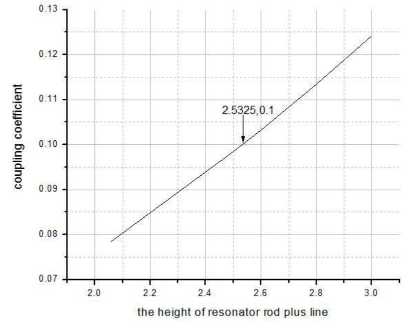

Figure 4: The coupling coefficient versus the between two cavities height of resonance rod plus line.

4. RESULTS

The results S_{21} are shown in Fig. 5. and Fig. 6. As can be seen from the figure, the filter center frequency is 4887.9 MHz, 3 dB bandwidth is 688.8 MHz, band insertion loss is $L_0 = -0.5165$ dB, the band rejection is less than −50.2 dB at 1–2 GHz, and less than −44 dB at 8 GHz–18 GHz, the results show that it meet the design requirements, simultaneously verify the validity of the theory.

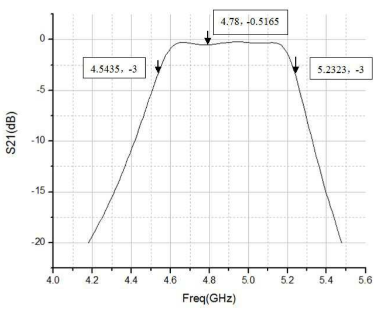

Figure 5: 4.18 GHz–5.48 GHz S_{21} image.

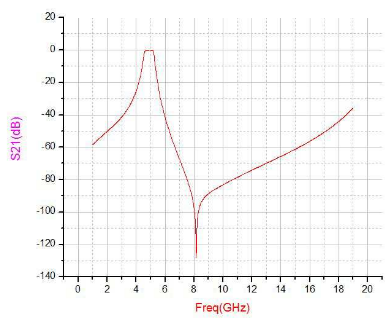

Figure 6: 1 GHz–19 GHz S_{21} image.

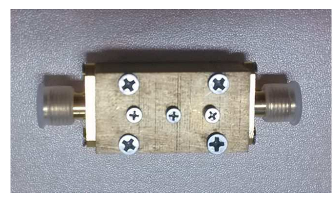

Figure 7: The physical cavity filter picture.

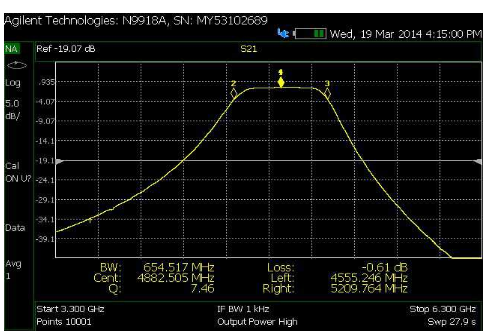

Figure 8: At 3.3 GHz–6.3 GHz S_{21} image.

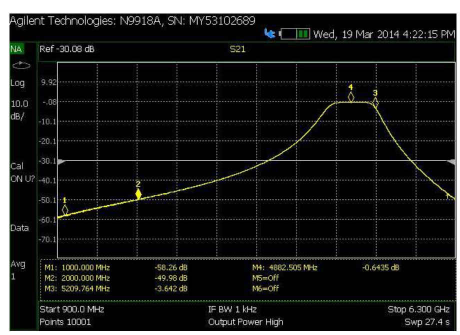

Figure 9: 900 MHz–6.3 GHz S_{21} image.

Via processing and debugging, the physical is shown in Fig. 7. Using vector analyzer to measure the physical filter, the measured results S_{21} curve are shown in the following Fig. 8, Fig. 9, Fig. 10 and Fig. 11.

As is shown in figures above, the center frequency of the physical filter is 4882.505 MHz, the frequency deviation is $\Delta f = 5.4$ MHz, the bandwidth is 654.517 MHz, the insertion loss at the center frequency is less than 0.7 dB, the band rejection is greater than 49 dB at 1–2 GHz, and greater than

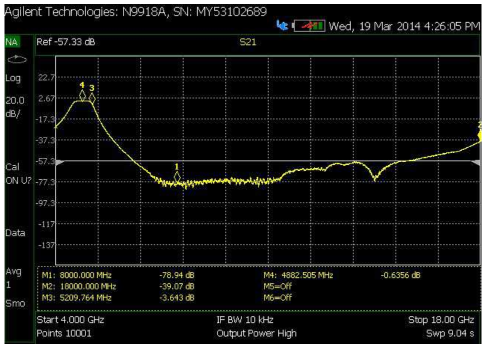

Figure 10: 4 GHz–18 GHz S_{21} image.

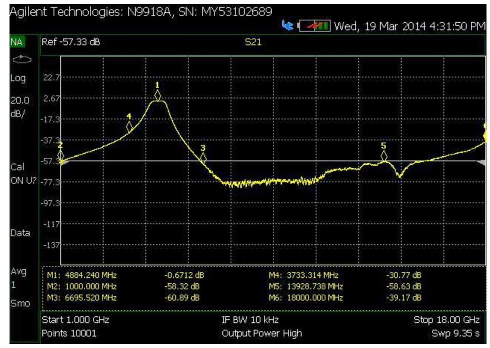

Figure 11: 1 GHz–18 GHz S_{21} image.

39 dB at 8 GHz–18 GHz, the frequency deviation in the range of allowable error, these results meet the design requirements.

5. CONCLUSION

The design of a highly miniaturized cavity band pass filter is presented. By adding the capacitance circular plate on the cavity resonant column, significant size reduction of resonators was obtained. Using these miniature resonators in a compact designed cavity filter, good performance as well as considerable size reduction were achieved. Compared with the $\lambda/4$ coaxial cavity filter, the volume of this designed filter reduced 51.37%. Experimental results and simulation results are biased due to the following reasons: (1). In the filter assembly, the assembly of the resonator rod can not achieve the ideal simulation conditions, there will be a certain degree of bending and the height will be also some deviation; (2). The surface finish of the capacitance circular plate as well as the cavity outer wall on the cavity resonant column can not achieve the ideal simulation case in the manufacturing process, resulting in some projections or depressions. Overall, the experimental results agree with the simulation results.

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