Ka-satellite Communication: A Filter with High Restraint in Band-stop

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Abstract. Based on theoretical calculation and CST simulation, a Ka band-pass filter with high restraint in Band-stop is designed for the purpose of satellite communication. Resonators are formed by introducing appropriate capacitive posts at suitable intervals along the waveguide. High restraint in band-stop can be realized by moving the first post and last post into the input and output coupling waveguide, which can reach the requirements of satellite communication.

1. Introduction
In 1917, American and German scientists respectively invented LC filter, and the following year it led to the emergence of the first multiplexed system in the United States. Passive filter became more sophisticated in the 1950s. Since the 1960s, with the development of computer technology, integration process and material industry, the development of filter has reached a new stage. And it is working towards low power consumption, high precision, small volume, multi-function, stability, reliability and cheap price. Among them, small volume, multi-function, high precision, stability and reliability become the main focused direction after the 1970s. This led to the rapid development of RC active filter, digital filter, switching capacity filter and charge transfer filter. By the late 1970s, the monolithic integration of these filters has been developed and applied. In the 1980s, they devoted themselves to the research of various new types of filters, striving to improve the performance and gradually expanding the application range. From the 1990s to now, they are mainly committed to the research and development of various filters for various products. With military demand and the rapid development of wireless communication technology, China launched the first Ka communication satellite in October 2015, and the corresponding satellite antenna of ground stations needs to be developed and designed. Meanwhile, with the rapid development of modern communication technology, microwave filters are playing an increasingly important role in microwave and millimeter wave system. It is widely used in satellite communication, radar navigation, missile guidance, electronic countermeasures, test instrumentation and other systems, among which the filter is an indispensable part of the receiver and transmitter, and it is the core device to realize frequency duplex. Waveguide filter has been given wide attention because it has low insertion loss, can withstand the high power, has small size, and light weight. The best way to achieve such low loss in millimeter wave frequency is to use waveguide filter. In particular, its parasitic passband is very far away, can achieve 1.5 times frequency, and high harmonic suppression is also very good. There are many papers on ridge waveguide filters. However, there are few to calculate the equivalent capacitance in detail and prove it feasible theoretically. In this paper, a design method is proposed on the basis of theory to design high performance and simple structure. It can be mass produced and really used in practice.
2. Theoretical principle of filter

Regarding ridge waveguide [1], we know that when the transmission frequency is less than the waveguide's cut-off frequency, the wave is cut-off along the longitudinal direction (z direction) of waveguide. In a rectangular waveguide, a standing wave is formed by a wave in transverse propagation (in the x and y directions). The basic model is shown in figure 1, and the design of a single ridged waveguide equivalent model is shown in figure 2.

![Figure 1. schematic diagram of single segment ridge waveguide filter.](image1)

\[ L_o \quad L_c \]
\[ C = 2C_f + C_p \]

**Figure 2. Equivalent circuit form of TE module**

According to reference [2], the calculation of equivalent total capacitance of single positive ridge waveguide is as follows:

\[
C_p = \frac{\varepsilon a_2}{b_2} \quad (1)
\]

\[
C_f = \frac{\varepsilon}{\pi} \left[ \alpha^2 - 1 \right] \ln \left( \frac{1 + \alpha}{1 - \alpha} \right) - 2 \ln \left( \frac{4\alpha}{1 - \alpha^2} \right) \quad (2)
\]

Among them:

\[
\alpha = \frac{b_2}{b_1} \quad (3)
\]

The equivalent capacitance is:

\[
C = C_p + 2C_f \quad (4)
\]

The equivalent total inductance per unit length:

\[
L = L_0 / 2 = \frac{1}{2} \mu (a_1 - a_2) b_1 \quad (5)
\]

Where, \( \mu \) is the magnetic conductivity filled by waveguide media and the resonant frequency is:
\[ f_c = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{\pi\sqrt{\mu\varepsilon} \left( \frac{a_2}{b_2} + \frac{2C_f}{\varepsilon}(a_1 - a_2)b_1 \right) } \]

3. Formatting the Text Dimension parameter design

Table 1. Filter Index Requirements

| Parameter                        | Requirement                              |
|----------------------------------|------------------------------------------|
| Passband center frequency        | 19.95 GHz                                |
| Passband range                   | 18.7 GHz ~ 21.2 GHz                      |
| Passband attenuation             | $IL \leq 0.5\text{dB}$                   |
| Passband fluctuation             | $L_{Ar} \leq 0.02\text{dB}$              |
| Passband suppression             | $\geq 50\text{dB}$ (The frequency range of suppression out of band is 27 GHz ~ 31 GHz) |

3.1. Calculation of waveguide dimension parameters

The input and output ports adopt the national standard BJ220 waveguide according to the frequency within the passband 18.7~21.2GHz, which can be obtained through tabulation. The size of the wide edge of the cut-off waveguide will affect the characteristics of the stop band. The further the stop band is, the greater the filter loss will be. Considering that $f_c = 25\text{GHz}$ is about to enter the stop band, the cut-off wavelength is designed in this paper to determine the evanescent mode waveguide frequency.

\[ \lambda_c = \frac{c}{f_c} \]

From formula \( \lambda_c = \frac{c}{f_c} \), the corresponding wavelength is 12mm, so from formula \( a_1 = \frac{\lambda_c}{2} \), that is, the wide edge of the cut-off waveguide is 6mm. Narrow side \( b_1 \) should not exceed wide side \( a_1 \) and standard waveguide narrow side \( b \), but should also take into account the height of the ridge. Therefore, the cut-off waveguide narrow side, 3.5mm, is chosen for comprehensive consideration. Therefore, the comprehensive design is shown in table 2. Two steps of order gradual transition and cut-off waveguide are adopted to connect the rectangular standard waveguide and cut-off waveguide.

Table 2. Waveguide dimension selection parameters

| Parameter                        | Value         |
|----------------------------------|---------------|
| Standard waveguide wide side a   | 10.65 mm      |
| Standard waveguide narrow side b | 4.32 mm       |
| Cut-off waveguide wide side $a_1$| 6 mm          |
| Cut-off waveguide narrow side $b_1$| 3.5 mm       |

3.2. Calculation of ridge dimension parameters

Table 3 shows the relationship between ridge blocks and waveguide in reference. From table 3 we can get the width and height of the ridge at the resonant point frequency. Since the cut-off waveguide width \( a_1 = 6\text{mm} \) is determined, the cut-off frequency in table 3 is \( \frac{\lambda_c}{2} = 2.762 \times 6 \), which is 16.572mm, i.e., the resonant frequency is 18.1GHz, which satisfies the resonant frequency in the passband. Therefore we select \( b_1/b_2 = 0.5; \ a_1/a_2 = 0.5 \) in table 3. The inductance can be referred to reference [3], regarding...
the order of the filter, the equivalent low-pass transformation and the equivalent capacitance. From the table, we can determine the ridge height and ridge width, according to reference [5]. Because ridge height variation is very sensitive to filter, it is taken as variable optimization. Therefore, the seventh order filter is uniformly equal in ridge height. The length L between the ridge and the ridge will affect the width of the passband and the ripple of the transmission coefficient. Therefore, the basic model is drawn. The length of the ridge and the distance between the ridge and the ridge are taken as the optimization variables, and the optimization can be carried out using CST.

Table 3. Relationships between ridge dimension and resonant frequency

| \( \frac{a_2}{a_1} \) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( \frac{\lambda_c}{a_1} \) | 4.643 | 3.701 | 3.206 | 2.866 | 2.609 | 2.407 | 2.248 | 2.128 | 2.044 |
| 0.2       | 5.181 | 3.985 | 3.392 | 3.000 | 2.709 | 2.482 | 2.303 | 2.163 | 2.062 |
| 0.3       | 5.509 | 4.154 | 3.500 | 3.077 | 2.767 | 2.527 | 2.397 | 2.187 | 2.075 |
| 0.4       | 5.661 | 4.221 | 3.537 | 3.100 | 2.785 | 2.541 | 2.349 | 2.198 | 2.082 |
| 0.5       | 5.855 | 4.391 | 3.595 | 3.072 | 2.762 | 2.526 | 2.340 | 2.194 | 2.082 |
| 0.6       | 5.941 | 4.666 | 3.404 | 3.094 | 2.991 | 2.709 | 2.480 | 2.310 | 2.077 |
| 0.7       | 5.127 | 3.836 | 3.230 | 2.856 | 2.596 | 2.405 | 2.259 | 2.148 | 2.063 |
| 0.8       | 4.619 | 3.485 | 2.970 | 2.660 | 2.449 | 2.299 | 2.189 | 2.107 | 2.046 |
| 0.9       | 3.796 | 2.961 | 2.587 | 2.387 | 2.254 | 2.164 | 2.101 | 2.057 | 2.024 |

As shown in figure 3, the evanescent mode filter model is designed by simulation software CST. Black is the ideal PEC conductor, blue is the air cavity, and the background boundary condition is the ideal electric boundary. The advantage of this setting is that it can be simulated to optimize the sweep speed of parameters quickly, unlike the traditional background condition of air. If the actual model is constructed according to the actual situation, it will greatly increase the number of grids, which will slow down the calculation speed. The central frequency of the filter is 19.95GHz and the bandwidth is 2.5GHz. The reflectance in the passband is less than -20db, and the off-band suppression is up to 50dB, that is, the standing wave is less than 1.2. FIG. 4 and FIG. 5 show the CAD drawing of the processed object in unit mm. It uses precise numerical lathe milling, and the metal material is made of aluminium, the feature of which is light weight. Because there is no knife of this length extending into the inner part, the physical processing is realized by cutting and reassembling.

Figure 3. Simulation model
4. Test Results

4.1. CST simulation results
As can be seen from figure 6 and figure 7, the image is simulated by CST microwave studio. In the range of passband, the return loss is >20dB, and the insertion loss is up to 0.03dB. The required stopband suppression is >50dB, and there are some fluctuations between 30~36GHz, which is because the software itself will generate continuous oscillation during simulation of time-domain resonant devices, so as to achieve convergence. However, the overall simulation is correct and basically meets our requirements for the design index parameters.
4.2. Physical objects and measured results

As shown in figure 8, the interior of the object designed according to the above method can be fixed with screws. The actual test results by Agilent vector net instrument are shown in FIG. 9 and FIG. 10. Because it is not an ideal dielectric medium, the insertion loss will be large, and the standing wave ratio will be slightly larger than the theoretical simulation. However, the isolation, that is, the off-band suppression performance will be better. It is normal to note that the inner step is lower than the outer step when the upper and lower modules are processed in engineering. But the equipment can cause serious leaky wave. At this point, the S21 insertion loss will become very bad, which should be noted. The inner step should be slightly increased by about 0.2mm when processed with digital lathe milling.

Figure 7. Filter CST simulation S21

Figure 8. Physical processing diagram of filter
5. Conclusion

This paper designs and optimizes a simple evanescent mode filter by theoretical calculation and CST microwave studio software, and applies it in practical engineering. It plays a guiding role in the combination of theory and practice. Compared with the traditional e-side inductance diaphragm filter, the size is much smaller and the off-band suppression is enough to ensure the isolation of the duplexer. The reflectance in the passband is also guaranteed to be below -20db, that is, the standing wave is less than 1.2. The suppression of the stopband is also significantly improved, reaching over 50dB. At the same time, the waterproof rubber rings are reserved for the convenience of hermetic experiments. In conclusion, though this paper, we can effectively apply a kind of Ka frequency filter with high restraint in band-stop, which can be processed and produced in large quantity.

6. References

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