Application of filter in TWT energy transmission coupler

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Abstract: *The coupler is an important part of the input and output structure of Traveling Wave Tube (TWT). Its performance directly affects the working bandwidth and efficiency of the tube. It is significant to design a coupler with wide bandwidth and compact structure for the miniaturization of TWT. In this paper, the design idea of filter is applied to the design of TWT energy transmission coupler. A stepped impedance transformer composed of seven transmission lines of different sizes is designed. Compared with the traditional quarter-wavelength impedance transformer, it achieves better performance with shorter length. The voltage standing wave ratio (VSWR) of the impedance transformer is lower than 1.1 in the frequency band of 11.9-13.2GHz, and it presents similar characteristic of bandpass filter.*

Keywords: TWT; filter; impedance transformer.

Introduction

For the helix TWT with coaxial coupler, the characteristic impedance of helix and coaxial line is different, some measures must be taken to realize the impedance matching between the energy transmission window and the slow wave structure. But for a traditional multi-section quarter-wavelength impedance transformer, the length is too long when the bandwidth is wide, which is not conducive to the miniaturization of TWT, so it is necessary to find a more compact stepped impedance transformer.

Design of filter transformer

A distributed parameter filter consisting of shunt open circuit stubs and transmission line elements is shown in Figure 1.

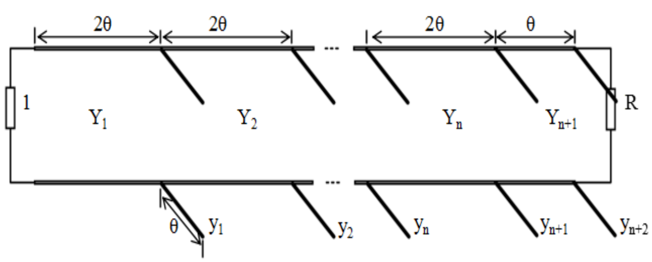

Figure 1. A prototype of a low-pass filter consisting of stubs and transmission line elements.

Where R is the output input impedance ratio, θ is the electrical length of the corresponding stubs when the angular frequency is ω, and the calculation formula is $\theta = 2\pi l / \lambda$, Y_i and y_i are the characteristic admittance of the i-th transmission line element and the stub, respectively. This low-pass filter with second-order transmission zeros can be regarded as a band-pass filter when the attenuation requirements outside the passband are not strict, because it has a finite maximum attenuation near zero frequency.

The shunt open circuit stubs can be replaced by the shunt lumped capacitors. According to the transmission line theory, a low impedance transmission line with high impedance transmission lines connected at both ends and electrical length less than $\pi / 4$ can be used to simulate the lumped capacitor, the conversion relationship can be determined by the following formula.

$$\omega C_i = y_i \tan\theta \tag{1}$$

Where C_i is the shunt lumped capacitor in place of the i-th stub. Theoretically, ω should be the exact equivalent frequency selected.

If the initial impedance of the filter is replaced by the real impedance seen in a certain section of the coaxial line directly connected with the helix, and the terminal impedance R is replaced by the normalized characteristic impedance of the energy transmission window, the filter is converted into an impedance transformer with filtering function.

In this paper, we aim to design a impedance transformer for TWT energy transmission coupler with a working frequency band of 12.25 ~ 12.75GHz. Because there are ceramic slice in the energy transmission window, and radius of inner and outer conductor of the window are inconsistent with the size of filter part, access of helix and waveguide outside the tube will affect filter performance, so enough margin should be left in the design.

Based on the above considerations, it is required to design a stepped impedance transformer with a matching passband of 12~13GHz, characteristic impedance of the transmission line connected to two terminals of filter are 42 Ω and 84 Ω, and VSWR of the whole impedance transformer in the passband is less than 1.1. Theory of modern microwave filter design has been very mature, and there are a lot of empirical data available. Given the design requirements of a filter, required number of segments can be determined by looking up the table, normalized characteristic admittance of the stubs and transmission lines can be further known, then initial size of each transmission line can be calculated. The final hybrid equivalent circuit of filter is shown in Figure 2, corresponding model realized by coaxial line as shown in Figure 3 is established in the electromagnetic simulation software CST.

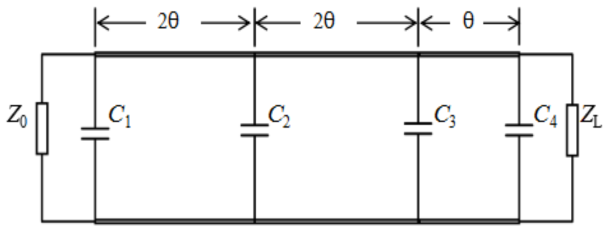

Figure 2. Equivalent circuit of filter transformer.

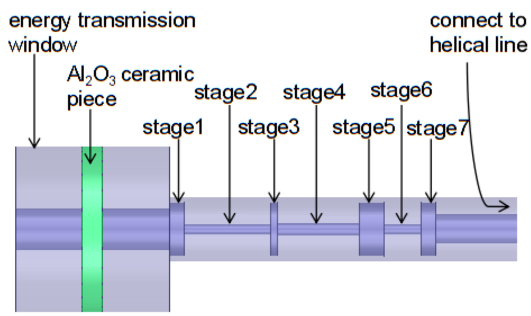

Figure 3. Schematic of filter transformer.

The filter transformer is composed of seven coaxial lines of different sizes. The green disk in Figure 3 is the window piece made of aluminum oxide. Considering the influence of step edge capacitance, the radius and length of each transmission line section are optimized appropriately, the final size is shown in Table 1.

Simulation results of impedance transformer

VSWR curve of the filter transformer calculated by CST is shown in Figure 4. In the frequency band of 11.9 ~ 13.2GHz, the VSWR is lower than 1.1, this result meets the design requirements, and total length of the filter transformer is just 10.4 mm, the impedance transformer presents similar characteristics of band-pass filter. As a comparison, Figure 4 also shows the optimized result of quarter-wavelength stepped impedance transformer (3 sections), although the quarter-wavelength impedance transformer is longer than the filter transformer, its performance is not better than the latter.

Table 1. Parameters of impedance transformer

Stage number	Radius of inner conductor (mm)	Length (mm)
stage1	0.97	0.60
stage2	0.19	3.35
stage3	0.97	0.30
stage4	0.24	3.16
stage5	0.97	1.00
stage6	0.19	1.42
stage7	0.97	0.57
Radius of outer conductor of the filter：1.15 mm		

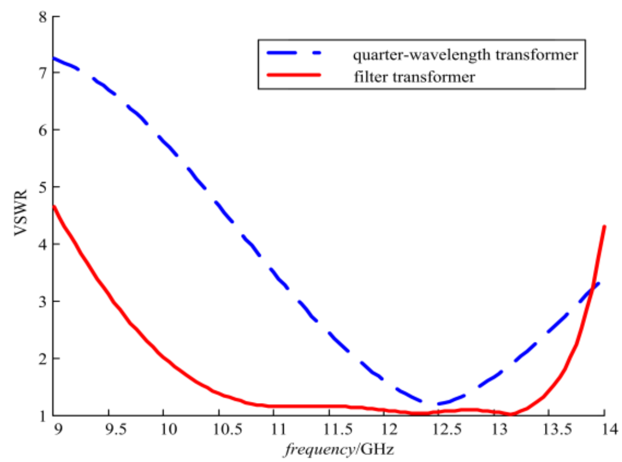

Figure 4. Comparison of VSWR between filter transformer and quarter-wavelength transformer.

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