A Novel Design of Waveguide-Coax Millimeter-wave Equalizer

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Abstract—**Based on theories of transmission line and resonance, a novel waveguide-coax equalizer for millimeter wave is presented through studying the features of various equalizers. The structure utilizes stepped waveguide as the main transmission line, coaxial cavity loaded with absorbing material as the resonant unit. The influences, which the coaxial cavity length, the radius and the inserted depth of the probe, the characteristic of absorbing material have, on the attenuation amplitude and resonant frequency are analysed. With the HFSS simulation software, the attenuation amplitude and the operating frequency are adjusted by changing the factors mentioned above, the stepped waveguide height and the location of the absorbing material. According to the gyro-traveling wave tube output power curve, the required equalization value is obtained. The designed equalizer preferably achieves the goal in 33-37GHz.**

INTRODUCTION

Gyro-TWT (Gyro-traveling wave tube) is a high-output-power device in millimeter wave. It generally reaches the saturated output power in the required frequency band under the same excitation condition. However, the output power usually varies with the working state in the utilization, which affects the performance. In order to get a stable output power, an equalization network is necessary. According to the best excitation curve of the gyro-TWT, the aim line should be in accordance with the output power line when the equalizer is at input port of the tube. If the equalizer is at output port, the aim line should be mutually complementary with the output power line.

There are three types of equalizer, microstrip line, waveguide and coaxial structure. Microstrip line is characterized with the small size, light weight and easy fabrication, but the power capacity is low and it is unsuitable in the high frequency. The theory of microstrip line equalizer design is quite abundant [1][2].Waveguide equalizer is usually used in high frequency with electromagnetic wave absorber in its cavity resonators. However, it is so hard to decide the position and amount of the wave absorber that the reflection coefficient and the max attenuation are difficult to control. Coaxial equalizer is used widely in high frequency and high power due to the big power capacity and easy tune [2-5]. It contains several sub-structures and obtains corresponding attenuation through adjusting the probe length, which undoubtedly changes the boundary condition of the main transmission line and increases the reflection coefficient.

The paper suggests a novel design of waveguide-coax equalizer, which combines the advantages of waveguide and coaxial structure to improve the transmission characteristic. The equalizer adopts the stepped waveguide as the main transmission line to get matched. The coaxial resonator is connected with the broadside of the waveguide. The inner conductor is used as a probe to couple the energy. The other end of the probe is loaded with tapering wave absorber to change the attenuation. With the help of HFSS(high frequency structure simulator), the equalizer presents an equalization value of 9.1dB in 33-37GHz, the minimum attenuation at 34.3GHz is -11.5dB, the maximum attenuation at 37GHz is -2.4dB and the reflection coefficient is under -7.3dB, which satisfies the design goal preferably.

FORMULATION AND SIMULATION

A. Theory

A single branch of equalizer structure is shown as Fig. 1. The rectangle waveguide is the main transmission line. In order to transmit the microwave in 33GHz-37GHz and avoid the competition of high order mode, the waveguide adopts the standard BJ320 waveguide. The coupling probe inserts the waveguide in center of the broadside so that the TE_{10} mode can be excited efficiently. The wave absorber is a dented cone which can increase the relative absorbing area and decrease the reflection.

Since the structure of waveguide-coax equalizer is complex, it is hard to find an analytic solution to decidethedistribution of electromagnetic field and the change of energy. Thus, we use the transmission line theory and resonance theory to study the structure.The coupling probe is equivalent to capacitance and the absorber is equivalent to resistance,so the coaxial resonator can be equivalent to a resonant circuit.

Fig. 2 shows the equivalent series resonant circuit. Based on the resonance theory [6-8], we build the transcendental equation [9] about the resonant frequency, capacity value and the cavity length:

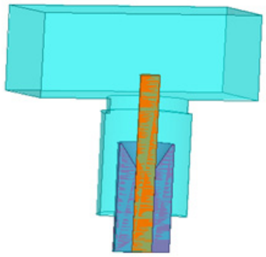

Figure 1.A single branch of the equalizer structure.

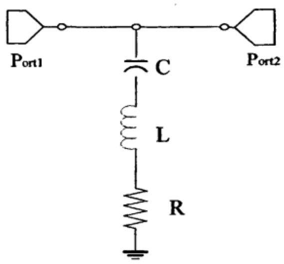

Figure 2.The equivalent series resonant circuit

$$S_{21}(\omega)=\frac{2(1-\omega^2LC+j\omega RC)}{2(1-\omega^2LC+j\omega RC)+j\omega RC} \quad (1)$$

It can be seen that the resonant frequency can be changed by the capacitance and the inductance. Besides, the resistance can regulate the attenuation.

The relation between attenuation and Q factor is:

$$Q_L=\omega_0\frac{W}{P_l} \quad (2)$$

$$BW=\frac{1}{Q} \quad (3)$$

With the attenuation increases, the Q factor decreases. So it sacrifices the Q factor to improve the flatness.

Since the single resonance branch has the low equalization value and narrow frequency band, it can't satisfy the demand. If we put a series of resonance branches together, we may get an appropriate equalization curve through choosing the right resonance frequency and Q value. Besides, considering the mismatch introduced by the branches, stepped waveguide is adopted. According to the transmission line theory, the input impedance of the point in the transmission line is:

$$Z_{in}=Z_c\frac{Z_L+jZ_c\tan\beta l}{Z_c+jZ_L\tan\beta l} \quad (4)$$

When the length of transmission line is $\lambda_g/4$ (λ_g is guide wavelength), the equation is simplified as:

$$Z_{in}=\frac{Z_c^2}{Z_L} \quad (5)$$

In this way, the two parts of the transmission line get matched. But, the single segment can only be effective in a specific frequency. In order to expand the operating frequency band, cascading $\lambda_g/4$ impedance transformers is utilized.

B. Simulation

The main indexes of equalizer include resonant frequency and attenuation. The radius and length of the probe, the coaxial cavity length andthe resistance value are the primary factors of the equalizer performance. In the following part, the effect of these factors is analyzed using HFSS software.Fig 3 shows the varying curve about attenuation versus the radius of probe. It is obvious that the larger the probe radius is, the higher the resonance frequency is and the attenuation changes little. Fig 4 suggests that the deeper the inserted probe is, the larger the attenuation is and the lower theresonancefrequency is. This phenomenon can be explained that the coupling capacitance coefficientbetween the probe and the waveguide grows when the probe inserts deeper, so that the resonance frequency gets down.

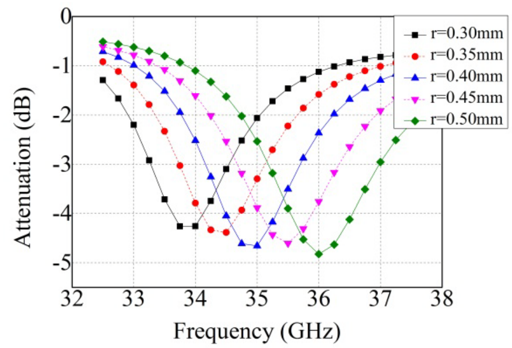

Figure 3.Attenuationvary with the probe radius

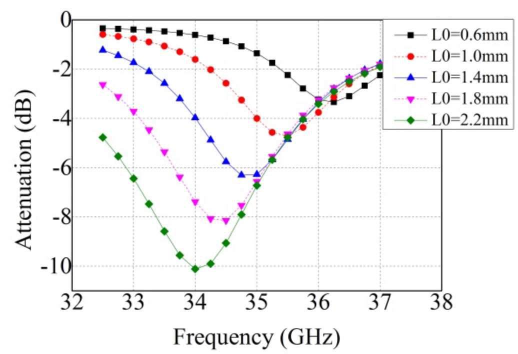

Figure 4.Attenuationvary with input length of the probe

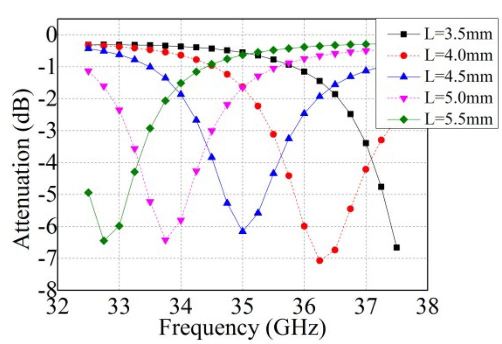

Figure 5.Attenuationvary with the coaxial length

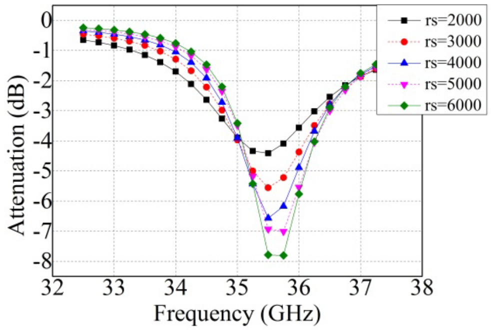

Figure 6.Attenuationvary with the resistance value

Fig 5 indicates that in a resonant period, the resonant frequency becomes lower witha longer cavity lengthand the attenuation has small changes. From Fig 6, we can see that the attenuation increases when the resistance increases.

In conclusion, the adjustment of attenuation can be changed by the inserted probe length and resistance.The resonance frequency can be changed by the probe radius, the inserted probe length, and the coaxial cavitylength.

Generally, there are 2-6 resonance branches in a cascade structure. Considering the big equalization value and small volume, we adopt the four resonance branches to construct the equalizer, as shown in Fig 7. To match neighboring branches and reduce reflection, each stepped waveguide length is $3\lambda_g / 4$. The simulation results are shown as Fig 8 and Fig 9. From Fig 8, we can see that the simulation line is quite approximate to the aim line. The equalization value isabout 9.1 dB in 33-37GHz. And the low inserted attenuationis about -11.5dB at 34.3GHz, the high inserted attenuation is about -2.4dB at 37GHz.

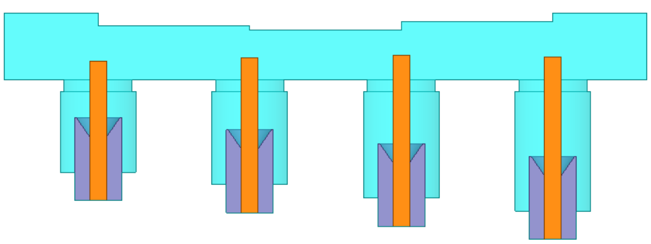

Figure 7.The equalizer structure by a series of resonance branches

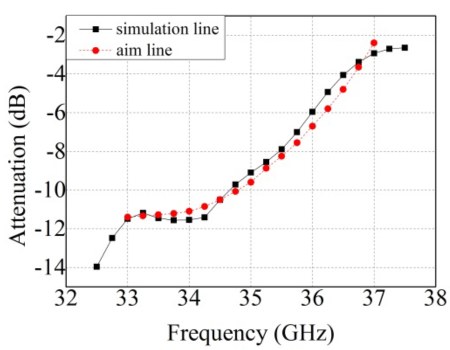

Figure 8.The comparison between simulation line and aim line

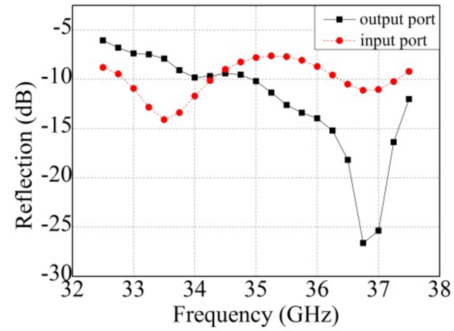

Figure 9.The reflection of input port and output port

CONCLUSION

In this paper, we research a novel design of waveguide-coax millimeter wave equalizer. The structure has the advantage of large power capacity, high operating frequency band, convenient tune and good transmission performance. Through simulation, an equalizer operating at 33-37GHz is presented and meets the design requirement well. This design will promote the study of the millimeter wave equalizer in the future.

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