DESIGN OF COAXIAL RESONANT CAVITY FOR TRIODE RF GUN

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Abstract

The 2856-MHz direct bunching of a conventional triode electron gun (Triode RF Gun) is currently investigated. In this scheme, an efficient feeding of RF power to the cathode-grid assembly(Y-824, provided by CPI Eimac) is critical for the proper operation of the gun. Because the capacitance of the Y-824 is quite large (~24 pF), much portion of incident RF power will be reflected back. In order to overcome this problem, a resonant cavity was considered instead of conventional impedance-matching network. In this article, we present the design concepts and procedure of the resonant cavity; First, we neglect the beam loading to analytically calculate the length of the cavity for resonance. This is refined by a computer simulation using the FISH code. Second, the effect of the resistive beam loading is included. For this, we treat the diode region as a lossy material with complex dielectric constant

1 INTRODUCTION

The triode RF gun is a conventional triode gun with its pulser replaced by an RF power source. Figure 1 shows the schematic representation of the conventional triode gun and Figure 2 the layout of the triode RF gun.

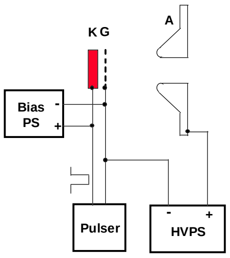

Figure 1: Schematic representation of conventional triode gun (K:cathode, G:grid, A:anode)

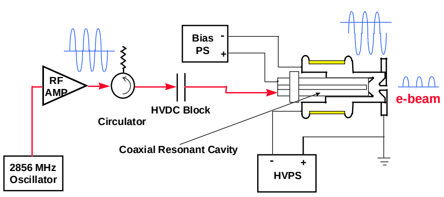

Figure 2: Layout of triode RF gun

If the RF power is properly transferred to the diode, a very short and high-rate electron bunches could be obtained directly from the gun. If this is realized, one could construct the injector module of an RF linac with very simple arrangement and at low cost. Furthermore, industrial RF linac which usually needs high-duty operation could be also economically constructed.

Efficient feeding of the RF power to the cathode-grid assembly (Y-824) is critical for proper operation of the triode RF gun. This is important because the capacitance of the Y-824 is quite large (~24 pF). In order to overcome this problem, a resonant cavity is considered. The cavity is consisted of the diode region of the Y-824 which acts as a large capacitive load combined with a resistance, a coaxial line whose dimensions are made to meet those of Y-824 sockets, and a movable shorting plane to make the cavity resonant for the different load condition.

In Y-824, the area of cathode and grid and the distance between them are 2 cm^2 and 0.17 mm respectively. In this article, we conveniently assume that the diode can be represented by a parallel combination of a capacitance, C and an unknown conductance G (see the Figure 3).

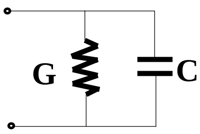

Figure 3: Equivalent-circuit representation of Y-824 diode

We also assume that C is given by the vacuum capacitance value of the diode as follows,

$$C = \varepsilon_o \frac{A}{d} \qquad (1)$$

where, A = Electrode area,
d = Interelectrode distance,
ε_o = 8.854 pF/m, vacuum permittivity

The capacitive susceptance, B_C of the Y-824 is about 0.42 mhos (Capacitive reactance, X_C = 2.4 ohms). Note that the actual value in the presence of the electron beam will be different from this, but not much if we operate the diode with the current level well below the space-charge limited value. The G is determined by the resistive beam-loading effect and represent the power dissipation due to the electron beam.

2 DESIGN OF COAXIAL CAVITY(WITHOUT RESISTIVE BEAM LOADING)

The diode region of the Y-824 was represented by a capacitance in parallel with a beam-loading conductance. In this section, we conveniently neglect the beam-loading effect, then the diode is a simple capacitive load (Y = jωC) terminating a coaxial transmission line. Since all of incident RF power will be reflected back, we can make a coaxial resonant cavity by providing a shorting plane at a proper position.

The input impedance of a lossless one-port circuit is a pure reactance and given by[1],

$$jX = \frac{4j\omega(W_m - W_e)}{II^*} \qquad (2)$$

Resonance occurs when the stored magnetic energy, W_m is equal to the stored electric energy, W_e and then the input reactance is zero. In other word, if one make the input reactance of a lossless one-port circuit, the circuit is at resonance. This general property of the one-port circuit is directly used to find out the resonant condition of the coaxial cavity for the Y-824.

The actual geometry of the supporting structures and the sockets of the Y-824 is not simple and there are several different sections with different dimensions and materials. However we assume that there is only air(ε_r=1) region. Then the line impedance is determined only by the dimensions of the line. In the figure 4, we show dimensions of cathode, grid, supporting structure, and sockets of the Y-824 together with a coaxial line terminated by a shorting plane to form the resonant cavity.

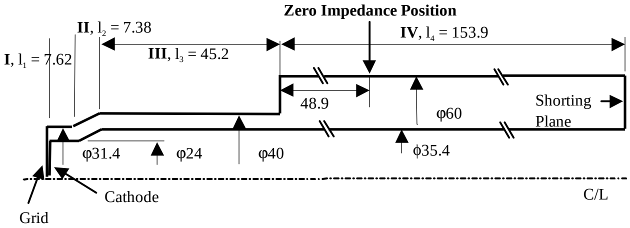

Figure 4: Structure of Y-824 cathode-grid assembly

There are four sections numbered as I, II, III, and IV. The *effective* electrical length of the section I is roughly 16.7 mm = 0.159λ. Section IV is coaxial cavity body. Section III include the junction of sockets and cavity and its length are set to make the total length of sections I, II, and III be 60.2 mm.

Now let us find out the position of zero reactance. The reactance X_C is calculated to be -2.365 ohms. This is transformed to j18.464 ohms along the section I and II. At the end of the section III, the impedance is j6.869 ohms. To make this zero, we should go 0.466λ = 48.9 mm further toward generator. If we attach 1-λ coaxial line terminated by a shorting plane to this zero-impedance point, the length of the section IV is 105 + 48.9 = 153.9 mm. Total cavity length is 60.2 + 153.9 = 214.1 mm.

To confirm and refine the above result, we have run the FISH[2] code. Figure 5 shows the calculated electric field lines.

Fig. 5. Coaxial resonant cavity - FISH calculation

The total length of the cavity for resonance at 2856.00058 MHz was 213.47 mm. Detailed results including the shunt impedance (defined along the axis of the diode region) and the voltages at several points are summarized in the Table 1. The values are normalized to the diode voltage of 50 V.

Table 1. FISH calculation results

Resonant Frequency	2856.00058 MHz
Total Cavity Length	213.47 mm
Wall Dissipation Power	25.4 W
Shunt Impedance	98.6 Ω
Q	1621.4
Max. Peak Electric Field	0.294 MV/m

3 EFFECT OF RESISTIVE BEAM LOADING

Now let us take into account the resistive beam-loading effect. The G is given by the relation between the applied peak rf voltage, V_{rf} and the dissipated rf power, P_{rf}.

$$P_{rf} = \frac{1}{2}V_{rf}^2 \,\mathrm{Re}(Y) = \frac{G}{2}V_{rf}^2 \qquad (3)$$

From a simple rf modulation calculation of the diode[3], it was found that an RF power less than 100 W is required for an 1-A anode peak current with the pulse duration of

80 ps. For these values, V_{rf} was about 50 V peak. These mean that G = 2 × 100/50^2 = 0.08 mhos.

In order to incorporate the diode admittance into the SUPERFISH[3] calculation, let us write the Ampere's law,

$$\nabla \times \vec{H} = \vec{J}_f + \frac{\partial \vec{D}}{\partial t} = \sigma \vec{E} + j\omega\varepsilon \vec{E} \qquad (4)$$

In the FISH, there is no input parameter to specify the conductivity (or resistivity) of a material region. But we can specify the complex permittivity of the material using the CFISH[2] which can calculate the complex fields in the lossy material regions. In order to utilize the CFISH, we assume that the rf power dissipation is due to the imaginary part of the complex permittivity, not due to the conductivity. In other word, let

$$\begin{aligned} \sigma &= 0 \\ \varepsilon &= \varepsilon' + j\varepsilon'' \end{aligned} \qquad (5)$$

Then eq. (5) becomes,

$$\nabla \times \vec{H} = \omega\varepsilon'' \vec{E} + j\omega\varepsilon' \vec{E} \qquad (6)$$

Comparing (6) with (5), we may let σ = ωε″(or ε″ = σ/ω). The σ is related to the G by the following relation,

$$G = \sigma \frac{A_K}{d} \qquad (7)$$

where, G = Diode conductance,
A_K = Cathode area,
d = Interelectrode distance.

From this relation, ε″ = Gd/(ωA_K) = 0.08mho × 0.17mm/(2π × 2856MHz × 2cm^2) = 0.428ε_o. ε′ is set to 1ε_o. Thus the complex permittivity of the diode in the unit of ε_o is (1, 0.428).

Figure 6 shows the electric field lines obtained from the CFISH run with the complex permittivity input of (1, 0.428) for the diode region

Figure 6: Coaxial resonant cavity - CFISH calculation

The results from the CFISH run are shown in the table 2 together with those from the FISH run for comparison. All the values were normalized to the diode voltage of 50 V peak, as was done in the FISH calculation.

Table 2. CFISH and FISH results

		CFISH	FISH
Resonant Frequency		2856.01109 MHz	2856.00058 MHz
Total Cavity Length		213.427 mm	213.47 mm
Power Dissipation	Wall	26.4 W	25.4 W
	Beam (Dielectric)	95.8 W	NA
Shunt Impedance		20.57 Ω	98.6 Ω
Q		349.7	1621.4
Max. Peak Electric Field		0.294 MV/m	0.294 MV/m

4 CONCLUSIONS

A coaxial resonant cavity for driving the Y-824 cathode-grid assembly has been designed with and without considering the resistive beam-loading effect. The length of the cavity was determined by finding the position of zero impedance and adding 1-λ length coaxial line. Calculated results are confirmed and refined using the FISH and CFISH codes. Required rf power for a useful beam current was well within the practically achievable range.

As a further study, we may calculate the diode impedance using the PDP1[4] (1-D plasma PIC code) or making our own calculation code. But this is not thought to be critical for fabricating a real cavity. We may provide a movable shorting plane to provide flexibility against varying load condition.

5 ACKNOWLEDGEMENT

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6 REFERENCES

[1] Robert. E. Collin, *Foundations for Microwave Engineering*, 2nd ed. McGraw-Hill, (1992).

[2] James H. Billen and Lloyd M. Young, *POISSON/SUPERFISH*, LA-UR-96-18346-1834, LANL, (1996).

[3] S. J. Park, et al., "Proposal of Direct 2856-MHz Modulation of PLS Electron Gun(Triode RF Gun)", Presented at RF96 Workshop, Japan, (1996).

[4] XPDP1 - Plasma Device 1 Dimensional Bounded Electrostatic code, PTSG, EECS dept., Univ. of California, Berkeley, (1993).