HIGH POWER MICROWAVE GENERATION FROM COAXIAL VIRTUAL CATHODE OSCILLATOR

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Abstract

A coaxial virtual cathode oscillator (VIRCATOR) has been designed to generate Relativistic Electron Beams and High Power Microwaves. Coaxial virtual cathode oscillators are known for better efficiency compared to the axial virtual cathode oscillators. This Coaxial VIRCATOR has been designed for the KALI-5000 (*1MeV, 60kA, 100 ns*) pulse power system. Provision for a large anode cathode gap has been kept to avoid the prepulse effect during the electron beam generation from the KALI-5000 system. Experimental studies are carried out to generate and characterize Relativistic Electron Beams and High Power Microwaves. Relativistic Electron Beams are generated by the Coaxial Explosively emitted graphite cathodes. Electron beam voltage has been measured by a copper sulphate voltage divider and beam current by a B-dot probe. High Power Microwaves are detected by the glow of neon lamps placed closed to the output window.

INTRODUCTION

Virtual Cathode Oscillators [1, 2] consist of an electron-beam diode and a waveguide. The electron beam is accelerated in the axial or coaxial direction and is injected into the waveguide. Electron beam is accelerated in the diode gap where pulsed high voltage is applied between the anode and the cathode. The beam passes through the anode, which is usually a thin foil or a mesh, and is injected into the area on the other side of the anode.

In the Vircator device the beam front forms a virtual cathode at a distance equal to the Anode Cathode (AK) gap if the injected current is greater than the space charge limiting current, I_l given by (for axial vircator)

$$I_l = \frac{4\pi\varepsilon_o m_o c^3(\gamma^{2/3}-1)^{3/2}}{e[1+2\ln(R/r_b)]} \qquad (1)$$

Where r_b is the beam radius and R is the drift column radius, (γ is the relativistic factor, and e and m_o are electron charge and rest mass respectively.

The virtual cathode reflects the electrons that follow the beam front. Thus electrons oscillate between the cathode and virtual cathode and cause microwave emission. The reflexing frequency is given by [3, 4]

$$f_r = \frac{v}{4d} \qquad (2)$$

where v is the velocity of the electrons.

The virtual cathode also emits radiation around the beam plasma frequency. The frequency at which maximum power emitted is given by [3, 4]

$$f_{vc} = 10.0\left(\frac{J}{\beta\gamma}\right)^{1/2} \qquad (3)$$

where J is the current density expressed in kA/cm^2.

Schematic of Coaxial Vircator is shown in Figure 1, it has a coaxial pair of cathode and anode that injects the electron beam radially into the circular waveguide. The interaction is between the electron beam current and the radial electric field of the waveguide mode.

COAXIAL DIODE DESIGN

Space charge limited current in a coaxial diode is given by [5],

$$j = \frac{4\in_o}{9}\left(\frac{2e}{m_e}\right)^{1/2}\frac{V^{3/2}}{d^{1/2}r_c^{3/2}}\left[\frac{1}{\ln\left(\frac{r_c}{r_a}\right)}\right]^{3/2} \qquad (4)$$

Coaxial diode impedance is given by

$$Z_d = \frac{68307}{V^{1/2}}\frac{(dr_c)^{1/2}}{h}\left[\ln\left(\frac{r_c}{r_a}\right)\right]^{3/2}\ \Omega \qquad (5)$$

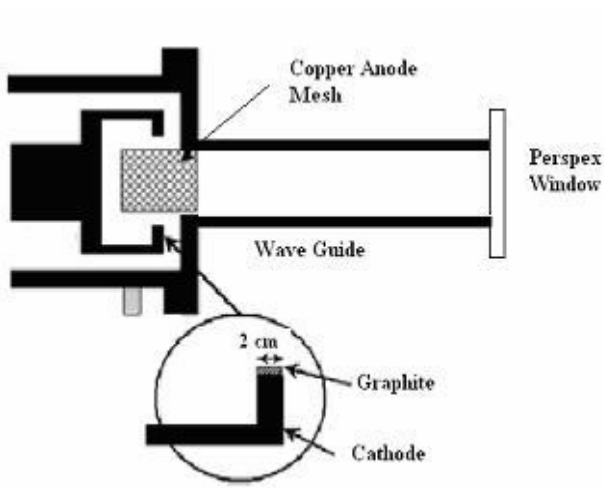

Figure 1: Schematic of Coaxial Vircator.

Table 1

Diode Voltage (kV)	Cathode Radius (cm)	Anode Radius (cm)	A K Gap (cm)	Cathode Width (cm)	Diode Impedance (ohm)
300	5.5	4.5	1.0	2	13
	5.9	4.5	1.4	2	25
	6.3	4.5	1.8	2	41
	6.9	4.5	2.4	2	71
400	5.5	4.5	1.0	2	11
	5.9	4.5	1.4	2	22
	6.3	4.5	1.8	2	35
	6.9	4.5	2.4	2	61

Table 2

Diode Voltage (kV)	Cathode Radius (cm)	Anode Radius (cm)	A K Gap (cm)	*fr* (GHz)	*fvc* (GHz)
300	5.5	4.5	1.0	5.8	4.8
	5.9	4.5	1.4	4.0	4.7
	6.3	4.5	1.8	3.0	4.5
	6.9	4.5	2.4	2.4	4.3
400	5.5	4.5	1.0	6.2	4.4
	5.9	4.5	1.4	4.4	4.3
	6.3	4.5	1.8	3.5	4.1
	6.9	4.5	2.4	2.6	3.9

Coaxial diode impedance for various anode cathode radiuses is given in the Table I.

Coaxial Vircator is constructed around KALI-5000 pulse power system. KALI-5000 [6] is capable of generating an Intense Relativistic Electron Beams of *1MeV, 60 kA, 100 ns* when connected to impedance matched electron beam diode. This indigenously developed pulse accelerator consists of a *1.5MV, 25 kJ* Marx generator, *1MV, 5kJ* Blumlein type transmission line and *60 kA* electron beam diode with voltage and current diagnostics.

Since Blumlein impedance is 18 ohm the diode impedance matches at 1.4 cm gap for 400 kV voltage. But the Prepulse voltage as shown in Figure 3 reduces the diode impedance significantly and perfect matching occurs at 1.8 cm diode gap. In this gap no reversal in the Marx out put (Figure 4) voltage confirms the impedance matching.

Coaxial Vircator microwave reflex and virtual cathode oscillation frequency are calculated from equations (2) and (3) respectively and listed in the Table II. Coaxial Vircator emits the maximum microwave power when the reflex and virtual cathode oscillation frequency are same.

For 400 kV diode voltage both the frequency are same for 1.4 cm diode gap and the calculated frequency is around 4.4 GHz. Figure 2 shows Beam Voltage and Current waveform from the Coaxial Vircator for 1.8 cm diode gap. Beam Voltage is measured by a resistive ($CuSO_4$) Voltage Divider and Current wave from is measured by a B-Dot probe and rogowski coil.

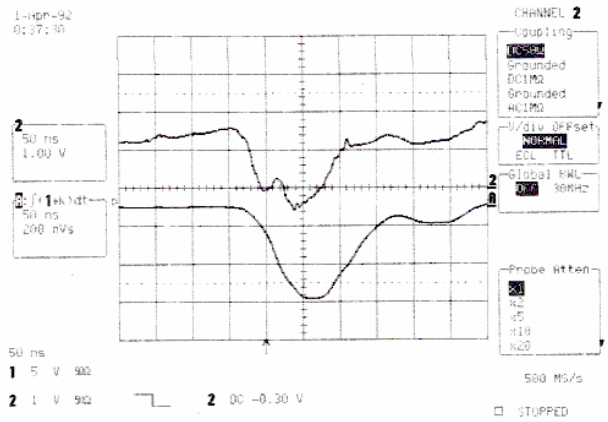

Figure 2: Coaxial Diode Voltage (top 200 kV/ Div) and Current (Bottom 10 kA/ Div) (Time 50 ns/Div).

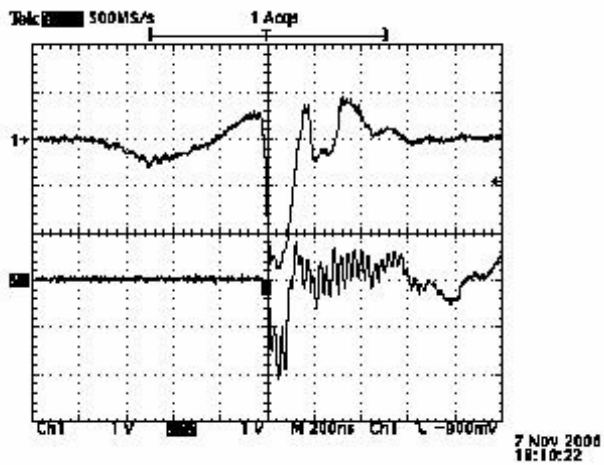

Figure 3: Coaxial Diode Prepulse voltage (Top 100 kV/Div) and diode current (Bottom 10 kA/Div) (Time 200 ns/Div).

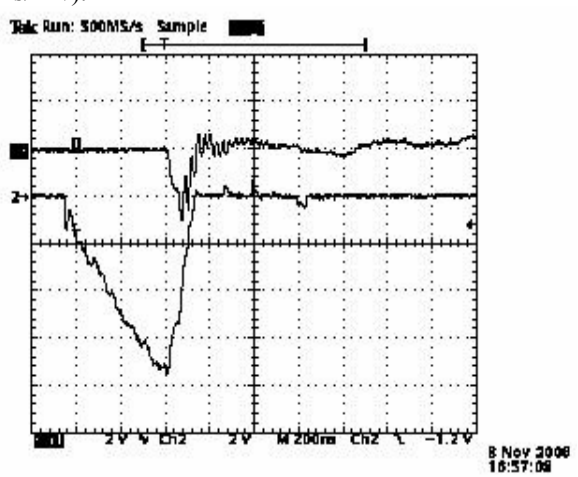

Figure 4: Marx out put voltage (Bottom 80 kV/Div) and diode current (Top 10 kA/Div) (Time 200 ns/Div).

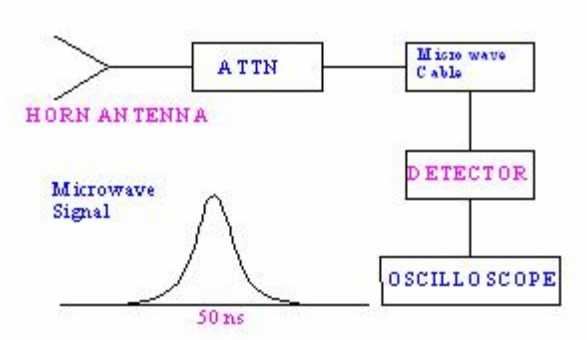

Figure 5: High Power Microwave Diagnostic Scheme.

EXPERIMENTAL RESULTS

Relativistic electron beam and HPM generation studies were carried out in the Coaxial Vircator for 1.8 cm and 1.2 cm AK gap. For 1.8 cm AK gap diode impedance matches exactly with the Blumlein impedance as can be seen from the Figure 4, there were no reversal in the Marx generator output pulse. But for 1.2 cm AK gap there is some reversal showing impedance mismatch. Prepulse voltages were recorded and for 300 kV diode voltage the Prepulse voltage was 50 kV. For 1.8 cm AK gap peak diode voltage obtained was 350 kV and the peak current was 25 kA. For 1.2 cm AK gap the peak diode voltage was 200 kV and the peak diode current was 40 kA.

The microwave pulse was measured by using the set up shown in Figure 5. The HPM radiation was received by a double-ridge horn antenna located a distance 4 meter away from the output window and after suitable attenuation given to a diode detector. The diode detector output is shown in the Figure 6. Also HPM discharge observed on Tube light and Neon Lamp placed a distance away from the output window.

For both the cases HPM generation was observed and microwave pulse recorded by the diode detector (Figure 6). For 1.2 cm diode gap HPM has got more peak power as the diode detector was getting saturated even when the antenna has been placed at around 4.5 meter distance from the vircator output window. At this place the measured HPM peak power was more than 20 dBm.

Also Neon Lamp Glow was observed at a distance of 10 cm from the output window and the power density required for HPM discharge is more than 1 kW/ cm^2. So the estimated peak power of the Coaxial Vircator was more than 1 MW. Further experiments are required to measure the HPM power more accurately. Also these experiments were carried out without a transmitting antenna from the vircator. With the transmitting antenna the measured HPM power is expected to be increased.

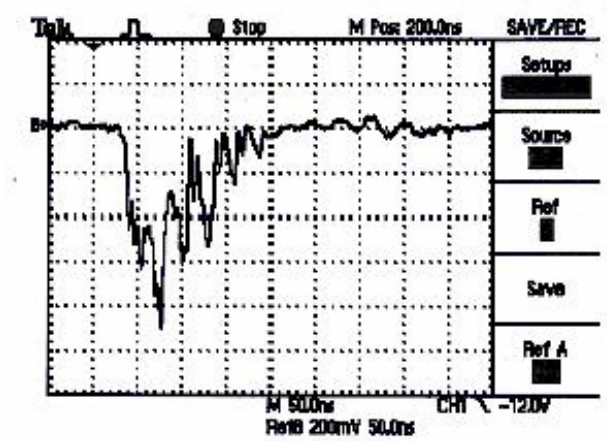

Figure 6: Microwave Signal recorded by Horn Antenna and Diode detector (200 mV/Div, 50 ns/ Div).

ACKNOWDGEMETS

We would like to express our sincere thanks to A. K. Ray, Director BTD group, for his constant encouragement and support. We are thankful to D. P. Chakravarthy, Head APPD and Dr. K.V. Nagesh for helpful discussions.

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