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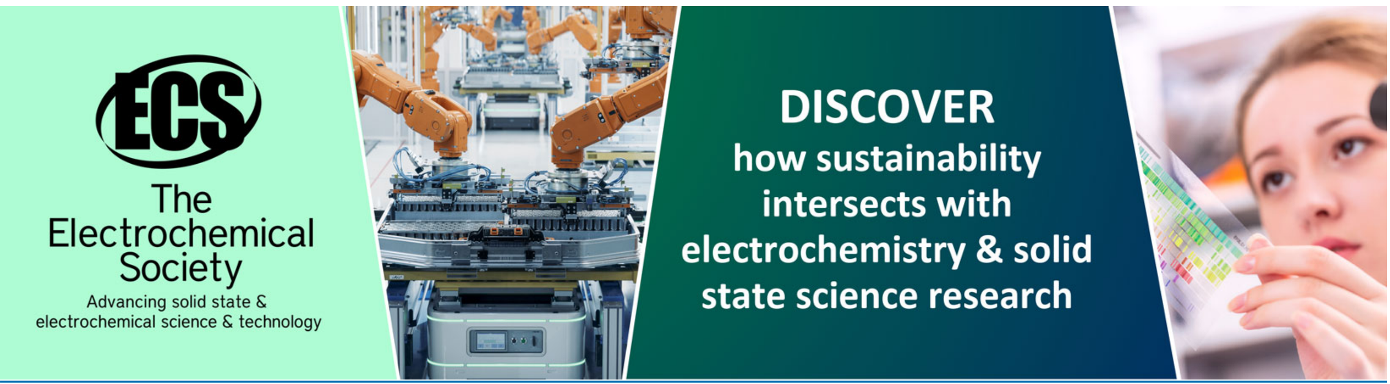

Microwave emission from an AXIAL-Virtual Cathode Oscillator driven by a compact pulsed power source

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Abstract. For the generation of microwaves, Electron beam devices operating in vacuum are most widely used. For pulsed and high power microwave generation, Virtual cathode oscillators (VIRCATORs) are said to be simple in operation and construction. They are generally driven by a pulsed power source which gives high input powers to the Vircator connected as load. Vircator, depending upon its efficiency, converts the electrical input power to the microwave power. We are presenting the results of an axial Vircator operating in $2X10^{-4}$ mbar vacuum and is driven by a compact pulsed power source. The energy source and pulse compression is realized in very user friendly approach to run the system. The radiating system presently runs at relatively low powers but has the scope of reaching to high power by a logical improvement. A study of effect of collapsing diode impedance, of the vacuum field emission diode of the Vircator, on the microwave emission is presented in the paper. We are also presenting the microwave emission measurement conducted in the given system. Effect of vacuum is also studied to the extent of present experimental limits.

1. Introduction

Axial Virtual cathode oscillators are the devices which are recently being studied by various groups-worldwide [1-2] as a source of high power microwave radiations operating with relatively much ease as compared with other conventional and well established high-power-microwave generating devices. This device requires huge amount of electrical power, in the form of power of generated Electron beam inside it, which is converted to microwave power in the geometry of Vircator. To the best knowledge of the authors it is first system of its kind using coaxial cable based system driven by the compact pulsed power source to drive the complete assembly. Because of its compact nature, the system has potential of operating at repetitive mode also. The results of a bulkier pulsed power system driving a solid dielectric PFL and Vircator connected to it have been reported previously [3].

The principle of operation of Vircator is as given under. A high voltage source is connected with the Electron beam diode which is part of Vircator geometry inherently. In the case of axial Vircator, which is in fact the case of present study, the electron beam diode is formed of cylindrical cathode and mesh/thin foil anode. The high power Electron beams are emitted from the surface of cathode mainly by two emission mechanisms viz. Field Emission and Explosive Electron Emission depending upon the material and surface properties of the cathode. Once high power electron beam is generated it is accelerated towards anode by the same electric field which is responsible for its generation. As the electrons of the emitted beam reach the anode, some of them pass through anode depending upon the transparency for the anode. These passed electrons are forced to propagate inside a drift tube of Vircator which interacts electromagnetically with the beam passing through it. The space charge effects causes the bending of cylindrical beam towards axis of drift tube and this results in the formation of electron cloud of certain charge density inside the drift tube. This charge cloud is formed only when the electron beam current is higher than space charge limiting current of this drift tube.

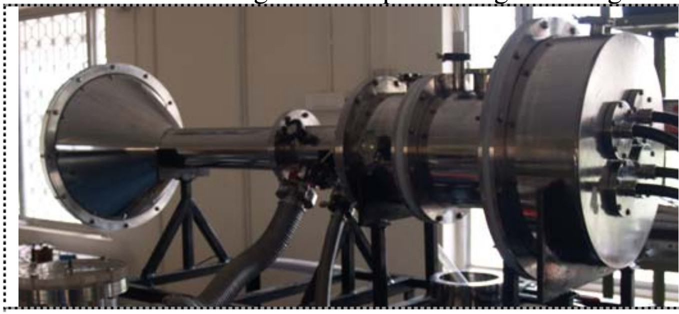

Figure 1 : Axial Virtual Cathode Oscillator System

This charge cloud is also called virtual cathode. After formation of virtual cathode some part of the successive electrons emitted from cathode are reflected back by the virtual cathode. Because of this they get trapped between cathode and virtual cathode and keep on oscillating in the space between cathode and virtual cathode till they are lost either by diffusion or by hitting the foil/mesh. These oscillating electrons radiate the radiations depending upon their oscillating frequency which again depends upon the A-K gap and electron velocity considerably.

Figure 2. Stainless Steel Cathode

Figure 3. Punctured RG218 Cable

Other than the radiations caused by oscillating electrons between cathode and virtual cathode, there is another mechanism which contributes to the total microwave radiations from the virtual cathode oscillator. The virtual cathode which is an electron cloud also keeps on oscillating in space and in time.

The oscillation of the virtual cathode oscillator in space and time also causes the emission of electromagnetic radiation to take place. The frequency of the radiation from virtual cathode oscillations is dependent on the electron plasma frequency of the charge cloud. Moreover there is always a loss of the electrons from the virtual cathode and electron beam in the form of drift and diffusion loss of electrons. This loss of electrons from the virtual cathode is compensated by the incoming electron beam which is emitted from the cathode.

There is formation of plasma on the cathode surface and also on the anode surface caused by the impact of energetic electrons of the beam on it. This plasma also expands in all free directions and occupies the space in between the region of anode cathode. Once the plasma is filled in this region the electric field between anode cathode gap regions diminishes to a value where no further field emission of electrons takes place. The event is called diode closure. This requirement makes the pulse compression and pulse shaping necessary before applying it to the Vircator.

As discussed above the Vircator requires high electrical powers for its operation and only for very short durations. This is done by pulse-compression and pulse-shaping. An attempt has been made to do pulse-compression and pulse-shaping by compact pulse compression system mentioned in the details given under. The experimental results are also presented after the system details.

2. Experimental Setup

The Vircator system is shown in figure 1. The Virtual cathode oscillator is a vacuum chamber with a measured vacuum inside the chamber of $2X10^{-4}$ mbar. The vacuum is created with a diffusion pump of 500liter/ second pumping speed backed by a rotary pump. The Vircator chamber is shown in figure 1 and is made by stainless steel. The cathode is also made of S.S. electrode of 60mm diameter and is shown in figure 2. The anode is made of S.S. mesh of 80% optical transparency. In the present study at different PFL voltages, the anode cathode spacing is fixed at 4mm. The drift tube diameter is 140mm and estimated space charge limited current in this geometry is less than 1kA.

The Vircator is operated using a solid dielectric pulsed forming line (PFL) made of four pieces of 50-ohm, RG-218 coaxial cables connected in parallel to make a net estimated impedance of 12.5 ohms. The length of each cable is 12 meters and hence the estimated pulsed-width which is twice of its transit-time, is expected to be nearly 140nS.

The Pulsed forming line is being charged by the compact pulsed transformer [4] which has its primary capacitor bank made in the shape of its primary. The capacitors used in the bank have shown very high power delivery driving a plasma focus device [5]. The connection between pulse transformer and pulse forming line is done using specialized connectors at the ground part in order to reduce the electric filed strength caused by sharp braid wires to such levels where the breakdown at feed point (as is shown in figure 3) does not take place which, otherwise, happens only at 20kV otherwise. The improved connections between the transformer and Pulsed forming line result in charging of PFL to still higher voltages reaching few hundreds of kV. The compact transformer with the combination of Pulsed forming line is having 1:20 Voltage gain when compared with primary charging voltage and PFL peak voltage at its second peak. The capacitor bank –cum- transformer, when first charged to 10kV and then discharged, delivers 200kV peak voltage in the second peak in 2.0 microseconds at the Pulsed forming line which is connected to the Virtual cathode oscillator system using a self triggered spark gap switch. A conical horn antenna is also designed for the system with input waveguide matching with the dimensions of drift tube.

As far as diagnostics are concerned, the standard diagnostics are used for the measurement of the PFL discharge current, PFL charging voltage, and microwave (power envelop and frequency). For the measurement of Pulse forming line charging voltage we have used 10000X resistive voltage divider. For the measurement of currents we have used a 17nS rise time current transformer with standard sensitivity of 50V/kA. The current transformer output is connected to the oscilloscope using standard 20dB attenuator in order to reduce the voltage to the oscilloscope input requirements for the given current pulse. The current transformer is placed inside the spark gap chamber. The microwave signal is recorded on a 10GHz, 40GSa/sec oscilloscope using a double-ridged horn antenna having bandwidth of 800MHz to 18GHz. The receiving antenna is kept at 1.2 meters from cathode location facing the drift tube which has no radiating antenna. The receiving antenna is connected to the oscilloscope using high Bandwidth cable LMR-400 having a cut-off at 16GHz. This signal coming directly from the receiving antenna to the oscilloscope is analyzed for its FFT to give frequency spectrum of radiated microwave signal. To see the power envelop of radiated microwave, the output of antenna is bifurcated and passed through microwave detector diode Agilent-423B and its output is smoothened to average out the acquisitions over 1ns (40samples) comparable to the rise time of diode.

3. Experimental Results

Initially when the spark gap connecting the PFL with Vircator was filled in air, the peak voltages possible were not exceeding 160kV on PFL and consistent breakdowns took place at the output side. The PFL charging voltages under these circumstances are shown in figure 4 collectively. Irrespective of the primary charging voltages which were varied from 8kV to 12kV in steps of 2kV the output voltage could not exceed 160kV.

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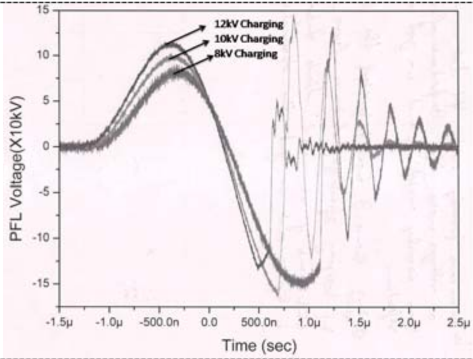

Figure 4 : Voltage time history **of** PFL (when spark gap is in air)

To enhance the Voltages on PFL, the spark gap was filled with transformer oil and the gap was reduced to hold a maximum of 200kV which is also shown in figure 5

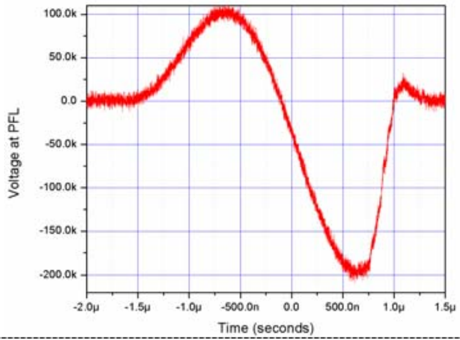

Figure 5. Voltage time history of PFL when spark gap is in oil

Once a peak voltage of 200kV was achieved on the pulsed forming line the Vircator which was connected to its output was operated in vacuum. It was noted that when the Vacuum was not there inside the Vircator, the high frequency components (of higher that 2.5 GHz) in the FFT of antenna signal were not present.

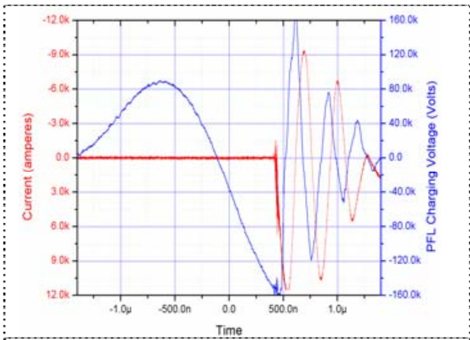

Figure 6. : PFL Charging Voltage and PFL Discharge Current

The microwave experiments with Vircator were conducted at two different PFL-charging-voltages of 160kV and 180kV decided by the spark gap settings. Figure 6 shows the voltage measured at PFL charging end and discharge current of PFL measured using Current Transformer (CT). The peak discharge current reaching in the system is 12kA. The peak PFL charging voltage is 160kV and the small Anode cathode gap leads to fast reduction of diode impedance. The net impedance of the complete discharge-circuit comes out to be nearly 13ohms.

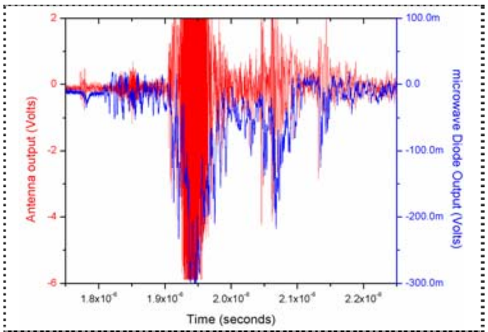

Figure 7. : Receiving Antenna (kept at 1.2Meters from Cathode) signal and envelop seen by the microwave detector diode (Vircator operating with PFL at 160kV)

Figure 7 represents the microwave signals received from the antenna and fed to the oscilloscope at 50ohm input impedance. The microwave pulse record of not more than 50nanosecond also suggest that fast closure of diode is taking place because the applied high voltage pulse is nearly 140ns in duration. The reflections of voltage and current also suggest the same sequence of events to be happening in the Vircator.

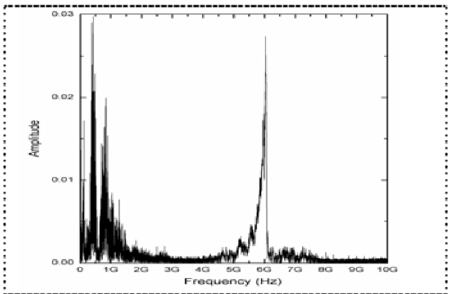

Figure 8. FFT of receiving antenna signal (Vircator operating at 160kV PFL Voltage)

Figure 8 is more informative in terms of the frequency content of radiated signal from the Vircator. It is clearly visible from the spectrum that high frequency of higher than 5GHz is present in the signal. The Vircator has successfully demonstrated the high frequency radiations from the compact pulsed power system.

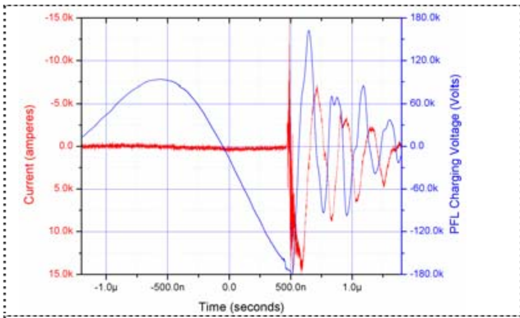

Figure 9. : PFL Charging Voltage and PFL Discharge Current

The other set of results achieved at 180kV of Vircator operation are also highly interesting. Figure 9 is the record of PFL charging voltage and discharge current reaching 180kV and 14kA peak current again demonstrating the same 13 ohm impedance of the discharge circuit. The microwave signal is shown in figure 10.

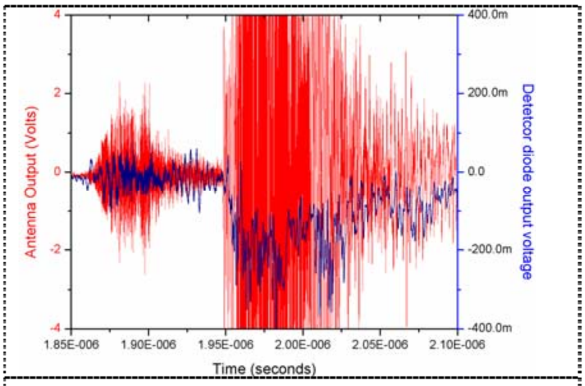

Figure 10. : Receiving Antenna (kept at 1.2Meters from Cathode) signal and envelop seen by the microwave detector diode (Vircator operating at 180kV PFL Voltage)

The microwave envelop is higher as compared with the signal at 160kV indicating a higher emisision of microwave at higher voltage.

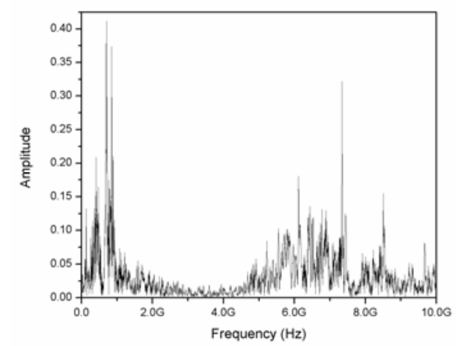

Figure 11. : FFT of Receiving antenna signal (Vircator operating at 180kV PFL Voltage)

Figure 11 represents the FFT of radiated fields indicating that a frequency spectrum of greater than 5GHz is present as a result of Vircator operation.

4. Conclusion

A successful operation of Vircator is demonstrated in the article using a compact pulse power source. The energy involve in each experiment was 125Joules making the system efficient in terms of power compression and shaping and also for a futuristic view of achieving repetitive operation.

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