Compact pulsed electron beam system for microwave generation

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Abstract. A compact 180 kV electron beam system is designed for high power microwave generation. The electron beam system is consists of a secondary energy storage device, which can deliver energy to the load at faster rate than usual primary energy storage system such as tesla transformers or marx generator. The short duration, high voltage pulse with fast rise time and good flattop is applied to vacuum diode for high power microwave generation. The compact electron beam system is made up of single turn primary tesla transformer which charges a helical pulse forming line and transfers its energy to vacuum diode through a high voltage pressurized spark gap switch. We have used helical pulse forming line which has higher inductance as compared to coaxial pulse forming line, which in turns increases, the pulse width and reduce the length of the pulse forming line. Water dielectric medium is used because of its high dielectric constant, high dielectric strength and efficient energy storage capability. The time dependent breakdown property and high relative permittivity of water makes it an ideal choice for this system. The high voltage flat-top pulse of 90 kV, 260 ns is measured across the matched load. In this article we have reported the design details, simulation and initial experimental results of 180 kV pulsed electron beam system for high power microwave generation.

1. Introduction
The pulsed power field is driven by weight, size and volume constraints nowadays. In both the military and commercial areas it is needed to provide more and more capability in smaller and lighter systems. The need for higher energy density, power density, reliability, and efficiency is driving progress in the field. Some applications also require technology that can be deployed in smaller spaces under stressful environments. The pulsed electron beam has utilization in various applications such as flash X-ray generation [1], Compact laser drivers[2], high power microwave generation [3] etc. The electron beam generator system consists of primary energy storage system, high voltage generator, pulse compression system, high voltage switch and vacuum field emission diode.

2. Compact Pulsed Power System
The compact pulsed power system is consists of primary energy storage capacitor, charged with high voltage dc power supply and discharges in to the primary of tesla transformer, which produces high voltage pulse with the rise time of microsecond duration and charges a helical pulse forming line. The block diagram of the system is shown in Figure.1. The inductance of helical pulse forming line is
higher than normal coaxial pulse forming line so it produces longer duration high voltage pulse. The helical pulse forming line transfers its energy through high voltage self breakdown

![Block Diagram of electron beam system](image)

Figure 1. Block Diagram of electron beam system

2.1 Primary Energy Storage Capacitor
The capacitor is charged with 25 kV high voltage DC power supply. Electrical energy is electrostatically stored in the capacitor bank which discharges into the primary of the tesla transformer. The specifications of capacitor bank are

- Energy stored – 400 J
- Capacitance - 1.29μF
- Maximum Charging Voltage – 25kV
- Peak Current – 125kA
- Inductance - <50nH

Four numbers of coaxial cable (RG 213) are used to keep the inductance low and connected to the primary of tesla transformer through a pressurized spark gap closing switch. The capacitor is charged with unregulated 25 kV DC power supply.

2.2 High Voltage Tesla Transformer
The high voltage tesla transformer is a primary and secondary circuit coupled with air core. The optimum design of tesla transformer depends upon the coefficient of coupling, turning ratio and dielectric medium [4,5]. The secondary capacitance of tesla transformer is determined by the capacitance of the helical pulse forming line. The primacy capacitance is the capacitance of the energy storage capacitor.

The specifications of tesla transformer are

- Primary Inductance, Lp = 145 nH
- Secondary Inductance, Ls = 150 μH
- Coupling coefficient, k = 0.56

2.3 Helical Pulse Forming Line and Spark-gap Switch
The transmission line characteristics of helical line can be used for generating rectangular high voltage pulse across the vacuum diode. The helical pulse forming line produces longer pulse compared with conventional coaxial transmission line [6-8] as it has higher inductance compared to coaxial pulse forming line.

The specifications of helical pulse forming line are

- Capacitance of helical pulse forming line, C_h = 5.8 nF
- Impedance of helical PFL Z_0 = 21
- Pulse width = 240 ns

It should be ensured that no breakdown of dielectric occurs between the conductors. The radial electric field E_r between the conductors is given by E_r = V_0 / r . ln (b/a). The electric field stress is maximum on the surface of the inner conductor and it should not be more than the breakdown strength of the medium. The electrical field stress calculated on inner conductor is 61kV/cm, which is less than the breakdown strength of the medium. The helical pulse forming line transfers peak power to the vacuum diode through a high voltage self breakdown pressurized spark-gap switch.
2.4 Vacuum Field Emission Diode
The vacuum field emission diode is made of graphite cathode and SS mesh anode. The electron beam is generated by application negative high voltage across the cathode. Microscopic protrusions exist on all surfaces and when negative voltage of > 100 kV/cm is applied between the cathode and anode the electric field at the tip is enhanced many times and electrons are emitted from the surface of the cathode [9].

The current density for a planer diode is given by
\[ J_{CL} = \left( \frac{4e_0}{9} \right) \left( \frac{2e}{m} \right)^{1/2} \cdot V^{3/2} / d^2 \]

And impedance of system is given by
\[ Z = V / I = \left( \frac{9}{4\pi e_0 r^2} \right) \left( \frac{2e}{m_0} \right)^{1/2} \cdot V^{-1/2} \cdot d^2 \]

Helical Pulse Forming Line Voltage = 180 kV
Impedance of the vacuum diode = 20 ohm
Voltage across diode matched load, \( V = 90 \) kV
Electron beam current = 4.5 kA & Pulse width = 240 ns

3. PSPICE Modelling of Electron Beam Generator
The modelling of electron beam system is done with PSPICE software. The primary energy storage capacitor discharges into the primary of tesla transformer (Figure. 2). The tesla is modelled as an equivalent air core pulse transformer having primary and secondary inductances of 145 nH and 150 uH respectively with coupling coefficient of 0.56. Helical pulse forming line is modelled as ideal transmission line with characteristic impedance of 21 ohms and one-way transit time of 120 ns. It discharges into a 20 ohm load. For simulating practical condition inductance of 25 nH on load side is included and capacitor inductance of 25 nH and connecting cable inductance of 100 nH is taken on primary side. The simulation result when the primary is charged with 18 kV is shown for Helical pulse forming voltage, voltage across diode & electron beam current (Figure. 3).

4. Experiments
The primary energy storage capacitor was charged to 18 kV and discharged into the primary of tesla transformer using pressurized spark-gap switch (Figure. 4). The secondary of the tesla charges the helical pulse forming line to 180 kV. To measure the pulse duration across the load the
PFL was discharged into matched load of 20 ohms through a pressurized self breakdown spark-gap switch and the voltage is measured across the PFL & the load (Figure. 5). The vacuum field emission diode was connected after the self breakdown pressurized spark-gap switch. The switch closes at 180 kV and the voltage across the PFL and electron beam current is measured (Figure. 6). The neon bulb was kept at a distance of 15 cm and the glow was observed (Figure. 7). The microwave signal is
measured using an antenna at a distance of 50 cm. The microwave detector diode output (Figure. 8)

![Detector diode signal](image1)

![FFT of microwave signal](image2)

and the FFT of signal (Figure. 9) is done to determine the dominant frequency components.

5. Results & Conclusion

A compact electron beam is designed and fabricated. The pulse forming line was charged up to 180 kV and discharged into a matched load and voltage of 90 kV, 240ns has been measured. It is seen that helical pulse forming line produces longer duration high voltage pulse and makes the system compact as compared to coaxial pulse forming line, which requires longer system for producing same pulse width. The field emission diode was connected after the PFL and switch. The peak voltages of 90 kV have been applied across the diode & peak electron beam current of 4.5 kA has been measured. The microwave signal is measure at a distance of 50 mm and detector diode measure negative 425 mV signal and microwave pulse duration of 30 ns. The FFT of the microwave signal is done and the dominant frequency components of 2.5 GHz & 3.6 GHz are seen.

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