# VIII.   RELATIVISTIC BEAMS[*]

### Academic and Research Staff

Prof. G. Bekefi
Prof. R. J. Briggs
Prof. E. V. George

### Graduate Students

J. Golden
J. A. Rome

## A.   BEAM-PLASMA INVESTIGATIONS USING MARX GENERATOR TECHNOLOGY

Since the preliminary announcements of our research objectives[1] we have adapted the Coaxial Generator (Cogen), so named because of its coaxial symmetry. This machine is on long-term loan from EG and G.  Preparations for the initial experiments are nearly complete, and production of a 100-kV, 35-kVA, electron beam lasting 30 ns is imminent.  In this report we look at Marx generator technology and give a brief description of the first experiment to be attempted on the machine.

The Cogen system consists of three parts:  a Marx generator, a concentric cylinder capacitor and a field-emission diode.  The Marx generator stores energy at the rate of 50 W and when triggered delivers up to 500 J at up to 400 kV to the concentric cylinder capacitor (hereafter referred to as the water capacitor because water is the dielectric) at $10^8$ W.  When the voltage on the water capacitor rises sufficiently high, a precalibrated solid dielectric switch breaks and connects the diode to the water capacitor.  The water capacitor then acts as a transmission line applying a potential of up to 200 kV for 30 ns to the diode.  Electrons field-emitted from the cathode are accelerated and penetrate the anode (which consists of a very thin film) to emerge as a $10^{10}$ W beam in a drifting, field-free state.

The circuitry of the Marx generator, which dates from the 1920's, is shown in Fig. VIII-1.  The generator consists of a chain circuit of capacitors and resistors. The capacitors are diffusively charged in parallel through the resistors by application of a potential at one end.  The first-stage capacitor (nearest the charging supply) charges most quickly.  By using Laplace transform and Heaviside expansion techniques elucidated by Elsner,[2] we solved the initial value problem of finding the voltage on each stage for a charging potential of the form

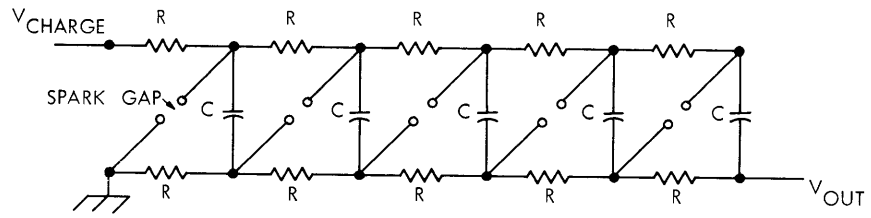$$V_{ch} = V_o(1 - exp[-.24\ t]),\tag{1}$$

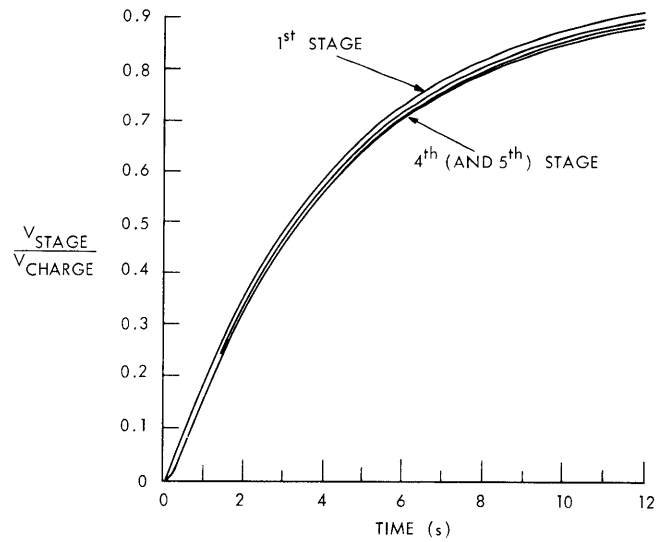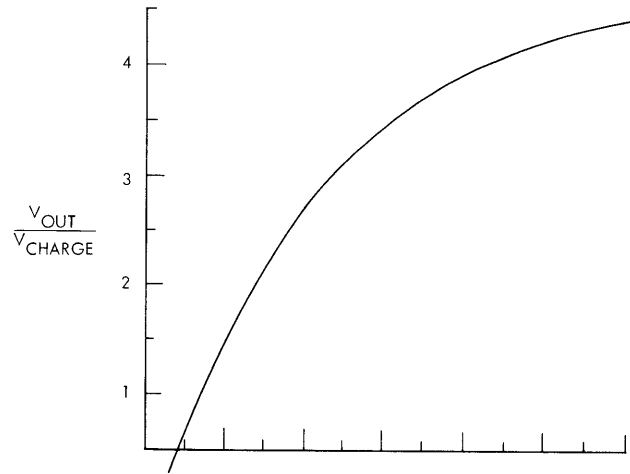Fig. VIII-1.  Marx voltage multiplication circuit.



Fig. VIII-2.  Voltages on the Marx capacitors, and the sum as a function of time.

where $t$ is in seconds. We evaluated and plotted an analytic form for the potential on each capacitor using the IPC's SC4020 (see Fig. VIII-2). From this form, which (not surprisingly) is much like Elsner's solution for a step-function charging potential, the characteristic time for diffusive charging was found to be

$$T = \frac{rc}{4 \sin^2 [\pi/4n]} \approx \frac{4n^2 rc}{\pi^2} \sim \frac{1}{2} \text{ s,} \qquad (2)$$

where $n = 5$ is the number of stages. For the sum of the stage voltages to reach 90% of the asymptotic maximum, $nV_o$, one must wait about $20\ T = 10$ s. The entire Marx generator is immersed in mineral oil in order to withstand the necessary potentials during charging.

In discharging, stray capacitances and inductance are important. For fast-rise times we must keep the linear dimensions (and thus the inductance) small while the ratio of the stage capacitor to ground capacitance and to the spark-gap capacitance must be kept large so that the spark gaps can be operated with a reasonable safety factor and so that only the first-stage gap need be triggered. In part this is accomplished by arranging the stage capacitors in two stacks, one for the odd-numbered stages, one for the even. The interstage capacitances of this "zig-zag" arrangement thus ensure definite firing of subsequent gaps after the first gap is fired.[3]

As the Marx erects, the voltage on the water capacitor rises. Figure VIII-3 shows an approximate equivalent circuit.[4] Using elementary Laplace transform techniques, this voltage is found to be

$$V = V_M \frac{C_M}{C_M + C_W} \left\{ 1 - \exp\left(-\frac{R_M t}{2L_T}\right)\left(\frac{R_M t}{2L_T \omega} \sin \omega t + \cos \omega t\right) \right\}, \qquad (3)$$

where

$$\omega \equiv \left[ \frac{C_M C_W}{L_T (C_M + C_W)} - \frac{R_M^2}{4L_T^2} \right]^{1/2} \qquad (4)$$

It follows that if $(R_M/2L_T) \ll \pi/\omega$ and $C_W \ll C_M$ the attainable voltage is $2V_M$, but little energy is transferred. If $C_W = C_M$, maximum energy transfer occurs and $V = V_M$. We estimate the Cogen energy transfer to be above 70%.

In order to ensure fast rise for the diode potential, the switch between the water capacitor and the diode must have low inductance. We used a solid dielectric switch developed by J. C. Martin, et al. at the Aldermaston Weapons Research Establishment in England. The switch, which is a sheet of plastic stabbed by a pin to produce a void

of known depth, is placed between the inner conductor of the water capacitor and the lower surface of the diode cathode. (The diode sits atop the water capacitor firing the beam vertically.) Inductances less than 5 nH have been calculated.
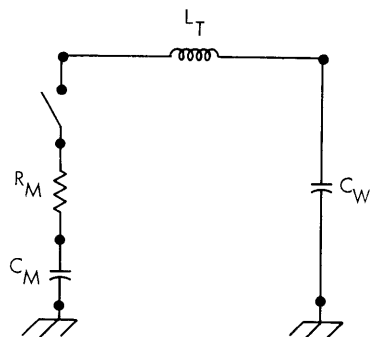


Fig. VIII-3.

Marx/water capacitor equivalent circuit. $L_T$ is the sum of the Marx inductance and the water capacitor inductance. $R_M$ is the internal resistance of the Marx generator.

Discharge to the diode requires that the diode impedance equal that of the water capacitor-transmission line for maximum voltage and minimal reflections. The Cogen diode has a planar geometry; the cathode is 1 cm in diameter and the spacing to the anode is on the order of 1 mm. The estimated impedance is about $2.5\,\Omega$. Because the diode must be highly evacuated, and because the beam ruptures the anode with each shot, the expected duty cycle is dependent on the length of time required to pump down the diode and to replace the anode and stabbed switch. We expect to be able to make one shot each half hour.

The drift tube which is a lucite chamber 1/4 m in diameter and 1/4 m high sits directly above the diode. Typically, the tube is gas filled to about 1/2 Torr. A prodigious x-ray and electromagnetic pulse is expected. The large radiation fluxes require an attenuation factor of $10^5$ which is more than adequately provided by a lead shield 30 mm thick which encompasses both the drift tube and diode. (The lead is on loan from the Laboratory of Nuclear Science, M.I.T.)

The investigation of the beam plasma will begin with electric and magnetic probe measurements of the diode voltage and beam current. At the same time, we will gain familiarity with the beam-plasma spectroscopy by using a Jarrell-Ash 1.5 Wadsworth mounting spectrograph. Our research program includes a spectroscopic survey of a He afterglow; a search for forbidden lines and optical satellites[5] to measure density, temperature, and the turbulent electric fields; and an attempt to gain spatial resolution across the beam. Later experiments involving time resolution and studies of $CO_2$ spectra are also being planned. From these experiments, we hope to learn more about plasma conductivity, beam-plasma energy transfer, and ionization history.

J. Golden

## References

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    of Electronics, M.I.T.: No. 98, July 15, 1970, pp. 53-55; No. 100, January 15,
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