

Design and Construction of a Small Electron Accelerator

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1. Abstract

The Houghton College electrostatic electron accelerator uses a small Van de Graaff generator and an accelerator column made from alternating high-density polyethylene and aluminum rings to create a uniform electric field. The accelerator column is evacuated to about 10^{-6} torr by a rotary forepump and a diffusion pump. To produce the electrons, an electron gun made from a 3RP1 CRT is located inside the high voltage terminal. The electrodes of the electron gun require user-controlled voltages for the anode, focus and intensity grids. Since the gun is located in the HV terminal, a microcontroller/amplifier circuit was designed to produce the required voltages and communicate with the user via a non-conducting, fiber optic RS232 link. The remote control system has been tested on the electron gun attached to the vacuum system.

2. History and Motivation

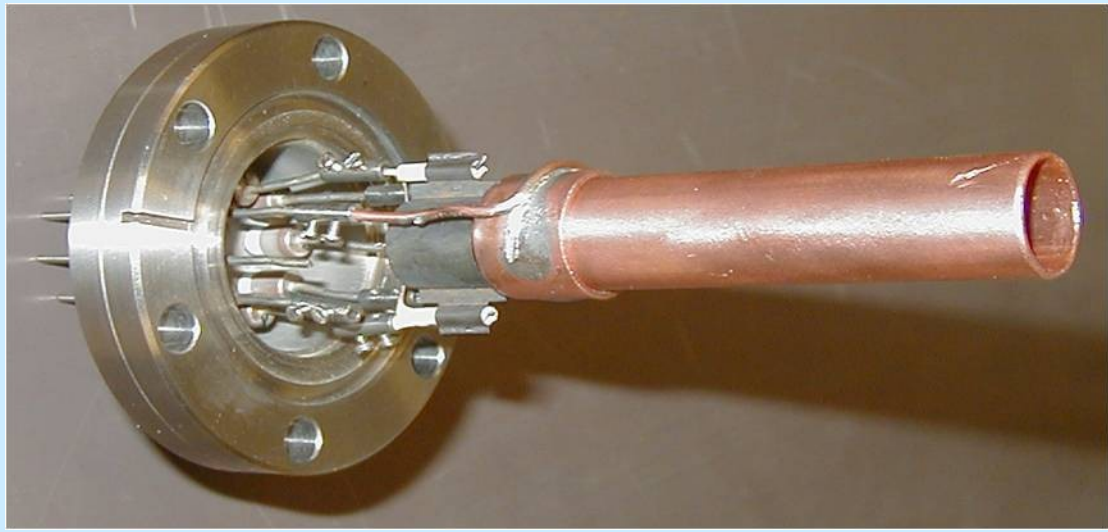
In the early 1930's Robert Van de Graaff designed and constructed an electrostatic generator in order to uniformly accelerate charged particles. At this time, physicists were attempting to accelerate particles for use in scattering experiments in order to study the structure and interactions of nuclei. As the voltage which the electrostatic generator reaches is related to the energy of the particle beam, attaining extremely high voltages allowed physicists to study nuclei using scattering experiments with high incident particle energies.

3. Houghton Electrostatic Accelerator

The original design of the accelerator included a glass accelerator tube and a homemade electron gun. Stray electrons from the electron gun became imbedded in the glass accelerator column causing charge to build up and deflect the electron beam. A new design with alternating high-density polyethylene and aluminum rings was glued together, with the conductive rings being of smaller inner radius. This made it impossible for stray electrons to build up. This design did not hold vacuum. The next design used alternating Teflon and stainless steel washers sealed with o-rings and compressed by 6 nylon rods. This too leaked when the nylon rods stretched. The nylon rods were replaced with acrylic rods, which have a higher tensile strength and did not stretch. Instead, they shattered because they were too brittle. These problems have been solved by using pre-stretched nylon rods to compress the o-rings.

4. Electron Gun

Many different electron gun designs have been used. Originally a homemade electron gun with no focus grid or deflection plates was used [see Figure 1a]. Although it functioned, it was inadequate because the beam spot was out of focus. To solve this problem, an RCA 3RP1 was dismantled and its filament, cathode, focus and accelerating grids were used [see Figure 1b]. The electron gun worked, but the beam was off-centered. To solve this problem the filament, cathode, accelerating grid, focus grid and deflection plates were all taken from an RCA 3RP1 and now serve as our electron gun [see Figure 1c]. This allows the electron beam to be focused and centered.



a



b



c

Figure 1. Three different electron guns. The homemade electron gun is shown in (a). The electron gun shown in (b) is composed of a filament, cathode can, accelerating and focusing grids. The electron gun shown in (c) adds horizontal and vertical deflection plates to allow more control over the position of the beam spot.

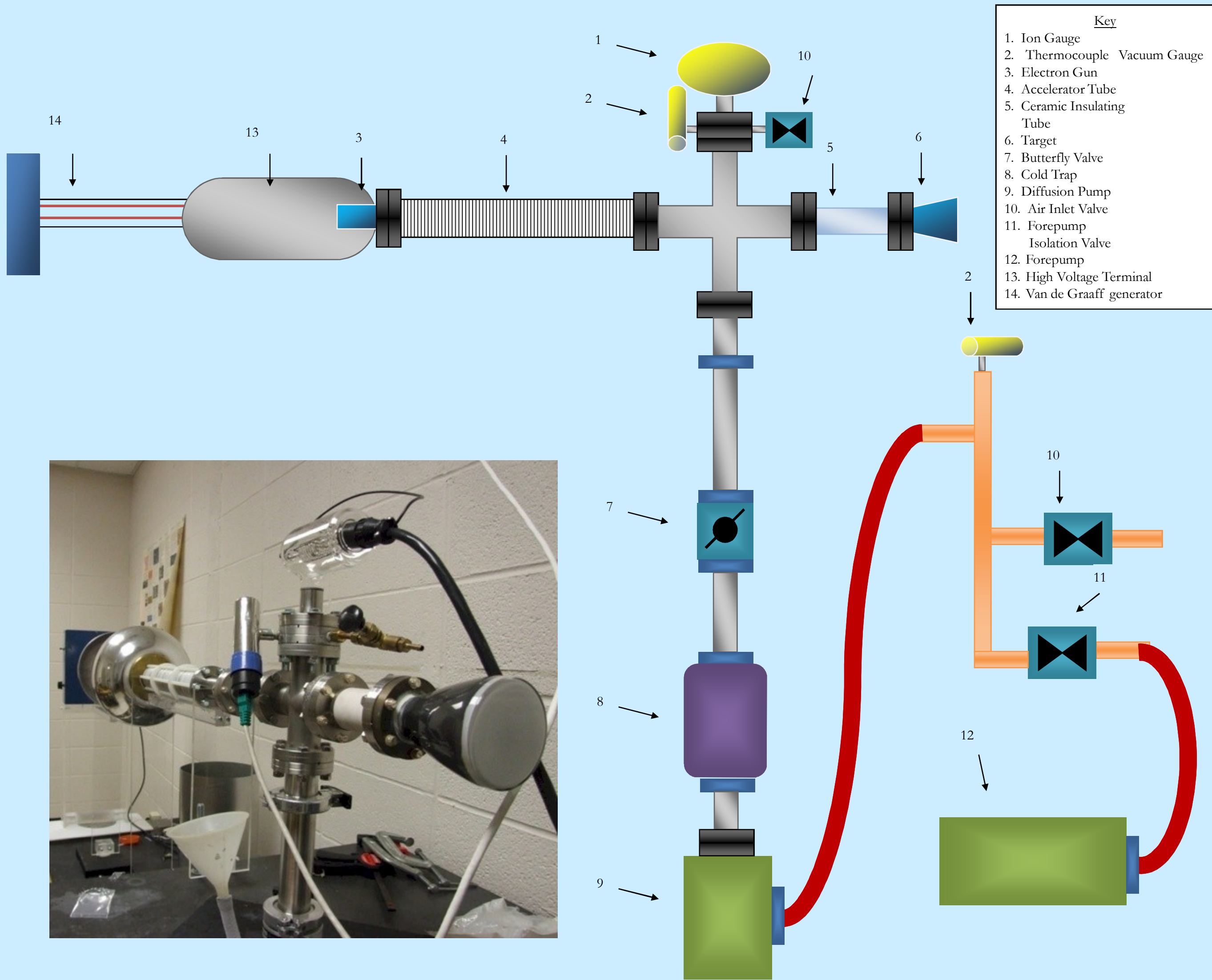


Figure 2. The electron accelerator and vacuum system. The Van de Graaff generator is horizontal, with the electron gun and electrical control circuit inside the high voltage terminal. Electrons are accelerated through the accelerator column. At the end of the accelerator column, the electrons reach their peak energy and continue to drift until hitting a phosphorescent screen. The forepump reduces pressure to about 10^{-3} torr, at which point liquid nitrogen is added to the cold trap and the diffusion pump is turned on. Pressures of order 10^{-7} torr can be reached.

5. Control Circuit for the Electron Gun

Because the electron gun is located inside the high voltage terminal, a method for controlling the electron gun which avoids sending electrical signals into the high voltage terminal is implemented. A BASIC Stamp 2 microcontroller and a four-transistor amplifying circuit located inside the high voltage terminal receives signals from the user via fiber optic (Figure 4). A serial signal from the BASIC Stamp 2 is sent to two MAX525 DACs. The DACs can output a voltage between 0 V and 2.5 V, which is too small to control the electron gun, so the DAC outputs continue to the four-transistor amplifying circuit. The amplifying circuit amplifies the voltage to a maximum of 15 V while also providing larger current capability. EMCO DC to HV DC chips amplify the voltage up to 2000 V, enough to control the electron gun. The EMCO DC to HV DC chips can supply up to 5 mA, while the most required is about $16 \mu\text{A}$.

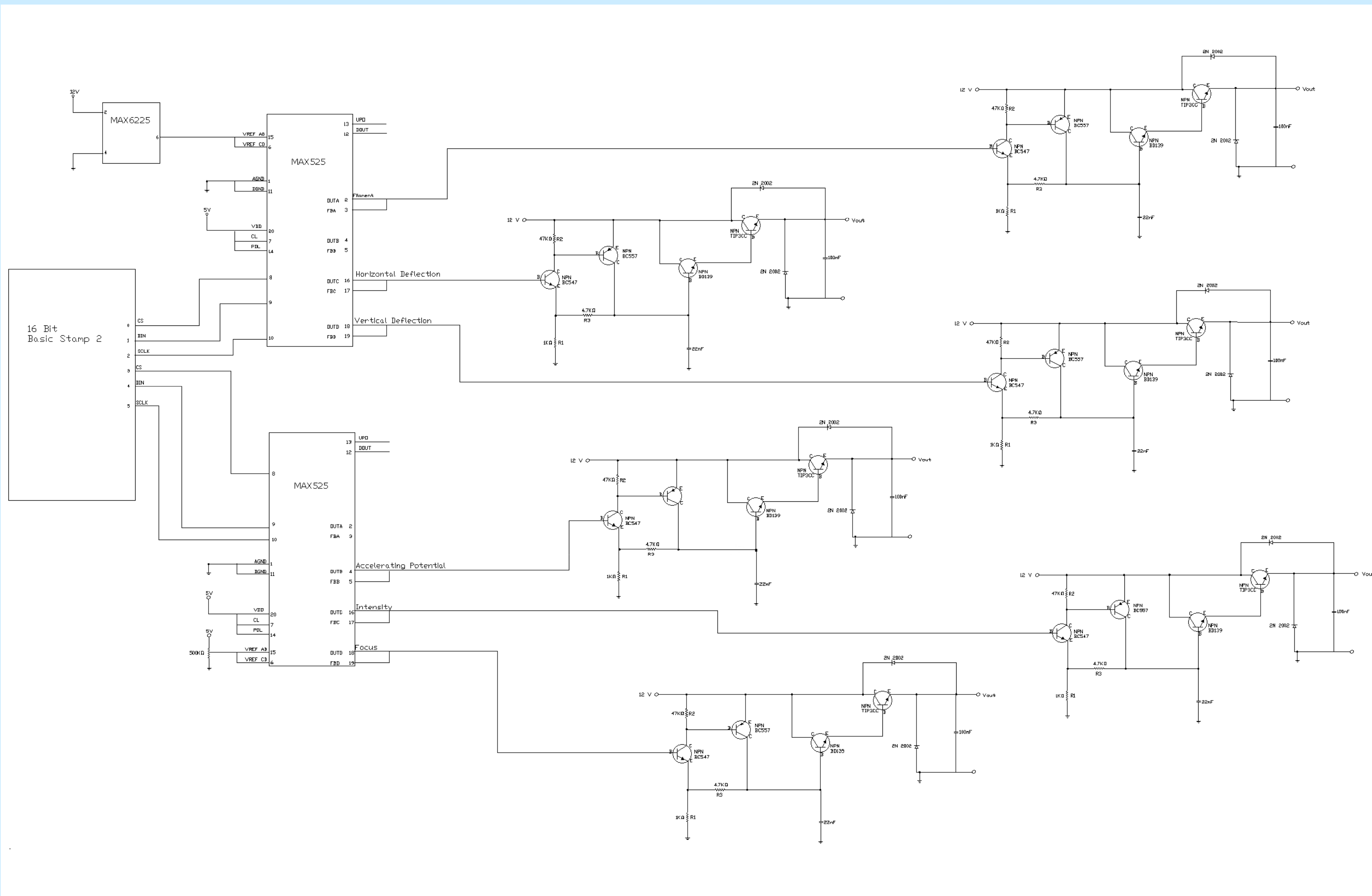


Figure 3. A schematic of the control circuit for the electron gun. The basic stamp sends a serial signal to the MAX525 DAC chips, which then output corresponding voltages between 0 and 2.5 V. These signals are amplified by the four-transistor amplifier circuits, whose outputs are sent to EMCO DC to HV DC converters. The outputs from the EMCO converters are sent to the electrodes in the electron gun. One of the transistor circuits outputs 6 V directly to the electron gun filament.

6. Results

The control circuit for the electron gun, shown in Figure 6, has been assembled and tested on a 3RP1 cathode ray tube. It properly controlled both the horizontal and vertical deflection plates, as well as the focus and accelerating grids of the electron gun, as shown in Figure 7. A separate power supply was used to control the filament. The electron gun has been directly attached to the vacuum system in place of the accelerator tube [see Figure 2]. This setup has produced a beam while the control circuit is controlling the cathode, focus, accelerating grids and deflection plates of the electron gun. It has been found that the circuit can supply enough current to heat the filament.

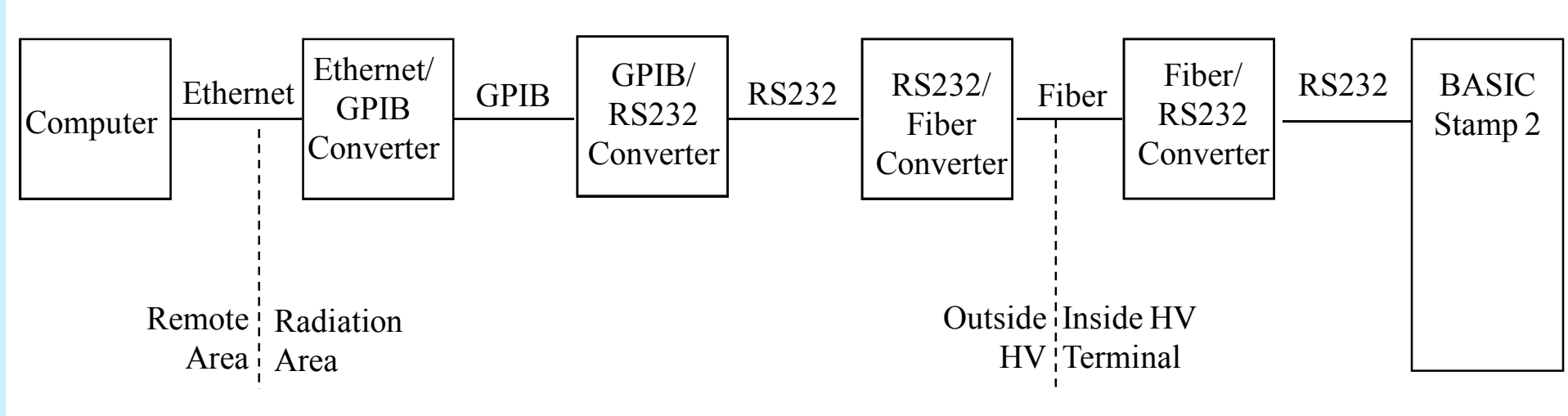


Figure 4. Communicating with the microcontroller. Communication protocol conversions are necessary to control the Basic Stamp 2 microcontroller while inside the high voltage terminal. Note that the conversion to fiber optic disables the ability to reprogram the microcontroller remotely.

Experiments have been performed to measure the linearity of the high voltage converters. Also, the stability of the high voltage output gun has been monitored over time. This is especially important for the deflection plates of the electron gun, as fluctuations could cause the beam to wander. It is also important for maintaining monoenergetic beams. It appears that once the circuit reaches thermal equilibrium the output voltage fluctuates by only about 0.1%.

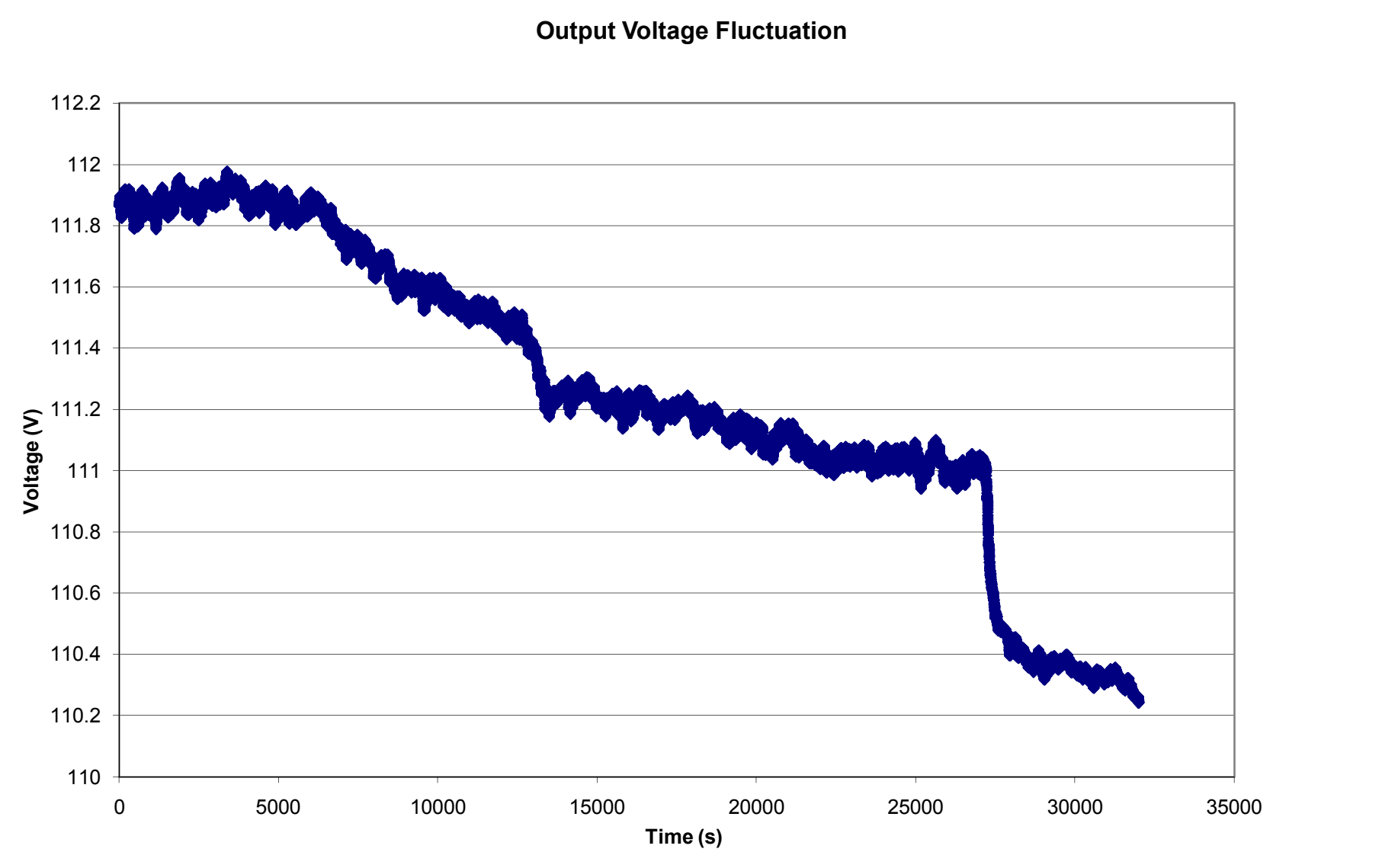


Figure 5. The output voltage of the EMCO chip over a period of 9 hours. The trend for the first 7.5 hours appears consistent with reaching thermal equilibrium.

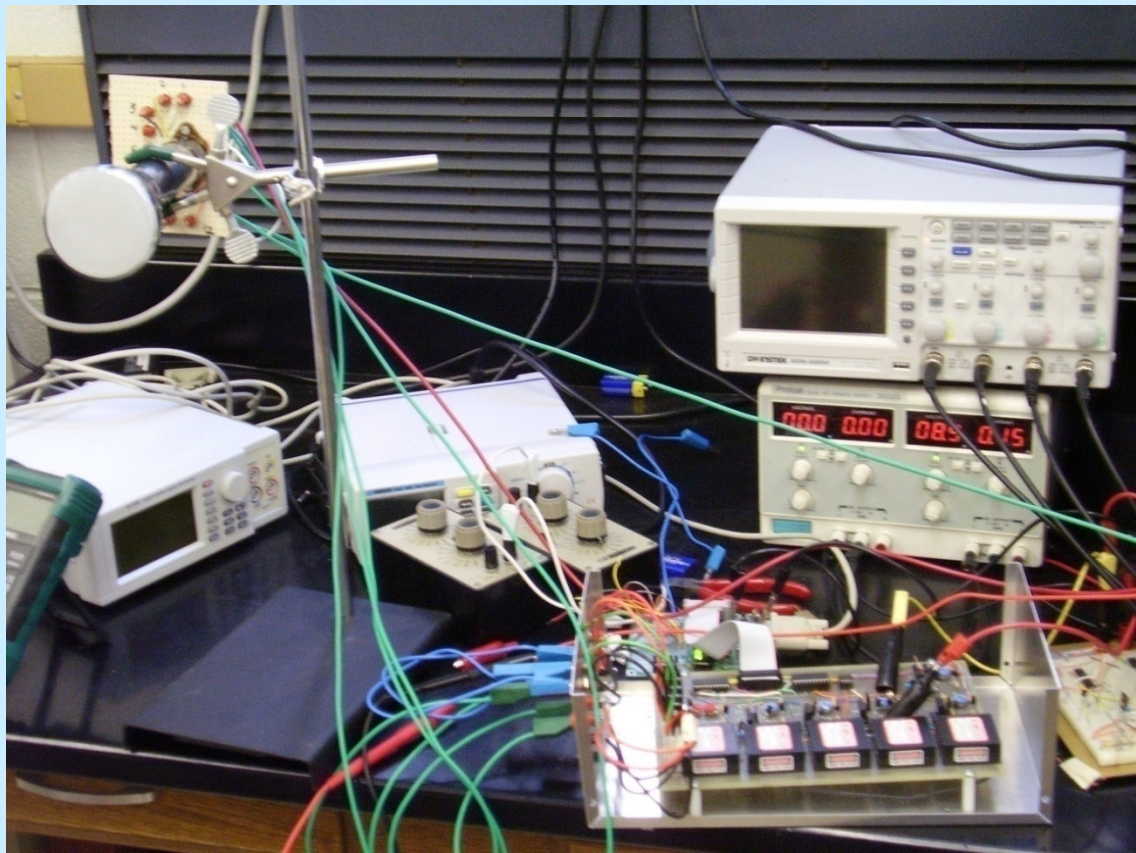


Figure 6. The microcontroller high voltage supply test circuit. A CRT is being controlled by the control circuit.

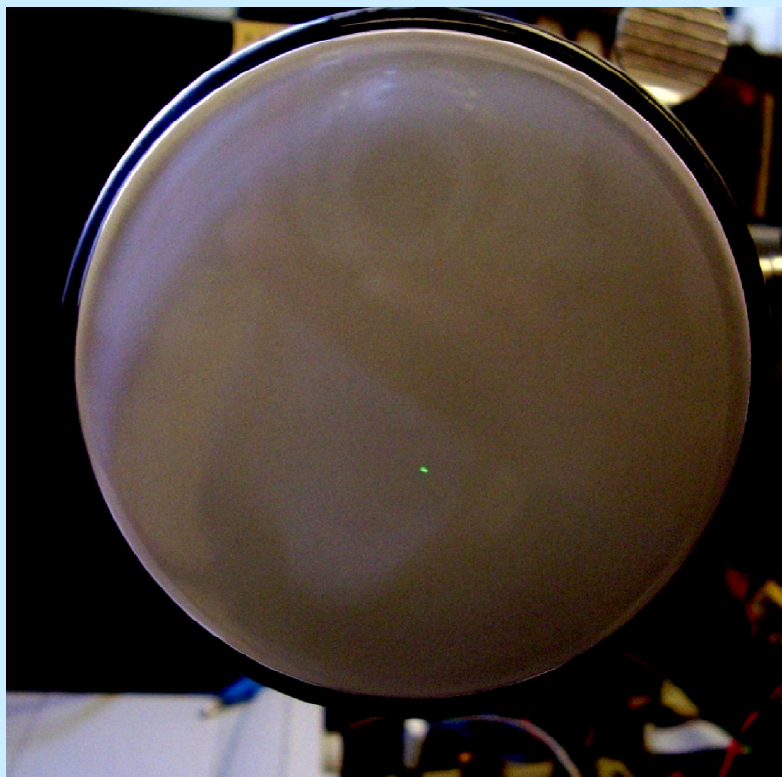


Figure 7. The beam spot on the CRT. The focus of the beam spot can be altered, the beam deflected horizontally and vertically and the accelerating voltage controlled.

7. Conclusions

The control circuit still needs to be tested while controlling the filament of the electron gun. Once this has been demonstrated the acceleration tube and Van de Graaff generator need to be added and tested. Based on previous measurements, we expect to achieve electron beams of about 0.1 to 0.5 μA at 150-200 keV which can be used to produce x-rays or be used directly for experiments.