A Calibration Source for Low Energy Electron Detectors

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Sounding rockets and satellites typically carry a variety of instruments that almost always includes a low energy ($\leq$20 keV) electron detector. While the principle of operation of these electron detectors is often simple, the actual electrical and/or mechanical configuration usually requires that several approximations be made while designing for optimal instrument response. The situation is often further complicated by spatial nonuniformities in electron multiplier devices such as microchannel plates. Because of the difficulties in analytical and numerical modeling of these approximations, the response of the instrument is best determined by calibration with an appropriate electron beam. A facility for testing and calibrating low energy electron detectors has been designed and built based on basic physical principles. The electron source is very nearly uniform in energy and parallel across a 12.7 cm diameter. Both the energy and the intensity of the beam can be varied smoothly, up to approximately 20 keV. The facility has been used in conjunction with a positioning table to test several rocket and satellite instruments and has proven to be an essential tool in the development of quality instruments.

1. INTRODUCTION

Satellites and sounding rocket payloads used to make plasma measurements in the Earth's magnetosphere and the solar wind typically contain a variety of particle detectors, at least one of which is used to measure low energy electrons. These low energy detectors are usually electrostatic analyzers, which have inherent sources of error due to stray electric fields, non-uniform response of the electron multiplier (e.g. microchannel plate), etc. While it is not possible to accurately predict these errors, they can be quantified by determining the response of the detector to a known source. Such a source should have an angular and energy width that is much narrower than the response of the instrument and a beam that is spatially uniform and large enough to flood the entire aperture of the instrument. Of course, the beam energy and intensity must also be tunable to accomodate the range of instrument. The source can then be used to quantify various components of the instrument geometric factor which, in principle, can be used to obtain a nominal value for the total geometric factor. In practice, however, the geometric factor will change over time due to degradation of the electron multiplier and so its determination has limited usefulness.

A variety of other techniques for generating such electron beams have been developed in the past. *Pierce* [1940] devised a novel method for obtaining a parallel electron beam that uses electrostatic lenses, although for low beam current this method seems to have no

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Measurement Techniques in Space Plasmas: Particles
Geophysical Monograph 102

significant advantage over a long beam line method. *Arnoldy et al.* [1973] combined a thermionic source with a scanning positioning table to measure instrument response and *Paschmann et al.* [1970] generated a calibration beam by acclerating electrons emitted from a beta source. While all of these methods have advantages and disadvantages, the type of source discussed in this paper is unique in the sense that it provides an improved combination of the important beam parameters.

2. DESCRIPTION

The principles of operation of this calibration source are based on a similar design by *Marshall et al.* [1986]. Ultraviolet photons, generated by a mercury arc lamp, are incident on a thin (350 Å) chromium film (see Figure 1). The chromium used in our case is 99.99% pure and is applied to one side of a quartz window which is lit from the opposite side so that the light passes through the window and strikes the film from the back side. The film is backlit in order to more easily obtain uniform lighting of the film. The film thickness is such that the light penetrates the film, releasing electrons that are accelerated to the desired energy. For a low pressure mercury arc lamp, the photon spectrum is sharply peaked at 2537 Å, corresponding to a photon energy of 4.9 eV. This energy is slightly greater than the work function of chromium (4.5 eV as stated in *Anderson* [1981]), so the photoelectrons have a nominal kinetic energy of ~0.4 eV. The chromium film is negatively biased and is placed in close proximity (5 cm) to a grounded screen. The resulting electric field accelerates the photoelectrons to an energy corresponding to the bias on the film which is controlled by a high voltage power supply. The upper limit to the electron energy is determined by the power supply capacity, assuming that high voltage arcing does not occur.

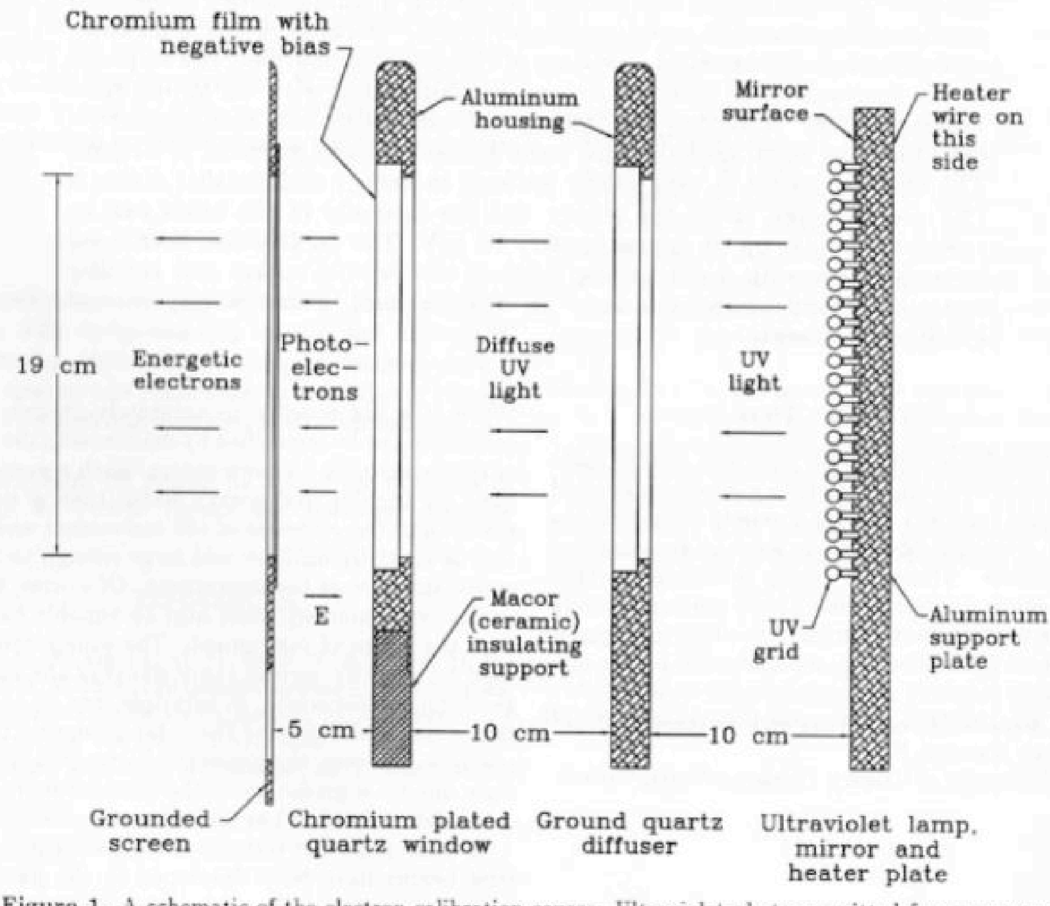

Figure 1. A schematic of the electron calibration source. Ultraviolet photons emitted from a mercury arc lamp are passed through a ground quartz diffuser and strike a thin chromium film. The film is biased and placed near a grounded screen so that photoelectrons emitted from the chromium film are accelerated to the desired energy.

Different aspects of the beam quality are affected by different components in the system. While the electron energy and angular spread are determined by the geometry of the window and accelerating screen, the beam uniformity, stability and intensity are nominally dependent on the ultraviolet source. The following two subsections present a discussion of these issues.

2.1. *Ultraviolet Source*

The quality of the ultraviolet photon source, as the first stage in the generation of the electron beam, is extremely important since any instabilities or nonuniformities in the arc will be directly transferred to the electron beam. This is a difficult problem because any arc lamp is inherently unstable. As the temperature and pressure of the vapor inside the lamp change, the conductivity of the vapor will also change and this variation will, in turn, affect the temperature and pressure, etc., resulting in a negative volt-ampere characteristic. The usual solution is to drive an arc lamp using an ac power supply, which causes the lamp to flash 120 times per second, making the lamp appear to be stable. This flicker rate, however, is often close to the sample rate of the instrument being calibrated, resulting in aliasing of the beam with the sample rate. A solution to this problem that also allows control of the lamp intensity is to use a ballast resistor in series with the lamp. The resulting circuit then has a positive volt-ampere characteristic and can be driven from a dc power supply [*Koller*, 1952]. By using a dc power supply in a current limited mode, the light intensity (and resulting electron beam intensity) can be controlled with arbitrary precision.

This technique is implemented in our system. The lamp is a commercially available EPROM eraser that is effectively a 20 cm square grid, formed by shaping a 7 mm tube into evenly spaced rows, 1 cm apart. The large size was chosen in order to illuminate the 17.8 cm diameter chromium window uniformly over its total area, while avoiding the use of lenses and the problems of focusing, vignetting, etc. By trial and error, we found that a ballast resistor of 80 kΩ is enough to stabilize the lamp. A higher resistance produces an arc that is more stable but results in a reduced lamp output. With the 80 kΩ resistor in series with a high voltage dc power supply, the lamp is stable in the sense that it will not extinguish itself, although some flickering in the arc will still be present at normal temperatures, apparently because temperature and pressure equilibrium is not reached. The flickering can be eliminated by heating the lamp to a temperature of 75 C, which is a warmer temperature than the arc would attain by itself. This solution is accomplished by mounting the lamp to a large aluminum plate and heating this plate with a molybdenum filament epoxied into a machined groove. A thermistor is epoxied to the plate to monitor its temperature and to control the current through the filament to keep the temperature constant. In practice, once the lamp and heater have been turned on for 30 minutes, all flickering in the lamp appears to stop and no flickering in the electron beam has ever been observed after warm-up.

The uniformity of the electron beam depends on several variables, but it depends fundamentally on the uniformity of the ultraviolet source. In order to produce a broad, uniform source of photons from the EPROM eraser, the horizontal rows that constitute the grid need to be diffused. Two steps are taken to accomplish this. First, the aluminum plate that contains the heater filament and supports the lamp is machined to act as a mirror to reflect as much light as possible toward the chromium film. The goal of this step is to reduce the contrast between the rows and the spacing in between the rows. In addition, a quartz window, ground on both sides to act as a diffuser, is placed in between the lamp and the window that supports the chromium film. The combination of this mirror and diffuser results in a photon flux that shows no visible signs of nonuniformity due to the shape of the lamp.

Finally, we note that a significant amount of ultraviolet light leaks through the chromium film and is incident on any instrument being calibrated. While we haven't yet been able to quantify this flux, we point out that instruments that do not have the usual baffles and coatings to inhibit sunlight contamination will normally detect the ultraviolet photons. Although this may often be undesirable, it is possible to use the photon beam to act as a crude measure of the effectiveness of the baffles.

2.2. *Electron Production and Acceleration*

The production of a useful beam in this system requires that a significant number of electrons be released from the film to become accelerated by the applied electric field. *Marshall et al.* [1986] used a gold film of 385 Å thickness in their electron source. Gold works well as a photocathode since it is very stable, but it does not adhere to quartz very well and must be recoated periodically. Over time, the quality of the coating deteriorates and the electron beam becomes increasingly nonuniform. Most metallic coatings would suffice as a long as the photon energy exceeds the work function. We use chromium because it adheres well to quartz and can even be washed with a solvent if necessary. Crude measurements show that 350 Å is nearly an optimal thickness for chromium, although further testing should be done to determine the optimal thickness more accurately.

The 17.8 cm coated quartz window is mounted in a large frame (30 cm in diameter) in order to reduce non-parallel accelerating fields. The frame is made of aluminum but is coated with graphite since aluminum oxidizes very quickly and aluminum oxide is a poor conductor. The frame and film are electrically isolated from the rest of the chamber and are biased to provide the desired electron energy. The accelerating field is provided by placing a grounded screen nearby (5 cm). The screen is made from 0.1 mm diameter stainless wire that is coated with graphite to reduce stray reflections. The screen wires are spaced 3.2 mm apart, providing 94% transmission.

3. PERFORMANCE

In this section, the characteristics of the electron beam are discussed. Data was obtained using a simple instrument consisting of a channeltron electron multiplier mounted behind two pinhole apertures. The apertures are made to be removable so that different sizes could be used and in routine operations apertures with areas of 1 mm^2 and 10 mm^2 are used. The angular acceptances of these apertures are 1.26° and 3.9° half-angle, respectively. The instrument was mounted on a five axis positioning table that is controlled by stepping motors interfaced to a personal computer. Translational motions can be stepped by as little as 0.025 mm and rotational motions can be stepped by 0.1°.

3.1. Beam Energy Spread and Angular Spread

The electron beam has an inherent energy and angular spread due to the physical processes which produce it. Following *Marshall et al.* [1986], we consider the simple case where we ignore thermal fluctuations and assume that the initial kinetic energy of each photoelectron is simply the difference between the photon energy and the work function. Although a more thorough anaylsis would include the effect of thermal fluctuations, this has not been carried out in our work. In our simplified situation, we take photoelectrons to be ejected from the photocathode in some arbitrary direction with initial kinetic energy E_i. After the electron has been accelerated to the beam energy E_b, an angular deviation $\Delta\theta \simeq \arctan(E_i/E_b)^{1/2}$ exists, where θ is measured from the normal to the cathode. Because the deviation is inversely proportional to the beam energy, it decreases as the beam energy is increased so these two quantities are not independent.

The response of a pinhole apertured detector such as the one described above is related to the angular spread of the beam as $W^2 = W_{ap}^2 + \Delta\theta^2$, where W is the measured angular spread and W_{ap} is the angular response of the detector [*Marshall et al.*, 1986]. The observed angular spread is defined as the full width at half maximum of the total angular acceptance. Typical calibration energies are such that $E_i/E_b \ll 1$, implying that this equation can be approximated by $W^2 = W_{ap}^2 + E_i/E_b$, an equation for a straight line with slope E_i, the initial kinetic energy of the photoelectrons. In the approximation that ignores thermal fluctuations, this energy corresponds to the energy spread of the beam since this initial kinetic energy can be directed at any angle relative to the accelerated beam and so can add arbitrarily to the beam energy. This method allows us to obtain a measure of the energy spread of the beam based on measuremnets of the angular spread. In particular, by measuring the angular spread of the beam W^2 at a number of different beam energies and plotting W^2 versus $1/E_b$ for all cases on a single plot, we can determine E_i from the slope of the line. Measurements were made using four beam energies, ranging from 1.5 keV to 8.0 keV and we found E_i to be 0.45 eV, consistent with the expected value of 0.4 eV. A typical value for the angular spread is $\Delta\theta = 1.6°$, measured at $E_b = 2$ keV.

3.2. Beam Current Uniformity and Density

The electron beam uniformity depends on a number of factors, including the uniformity of the photon beam, the uniformity of the chromium film and the configuration of the accelerating screen. Beam uniformity can also be adversely affected by stray ultraviolet light.

Several steps were taken to try to insure the uniformity of the incident photons. As mentioned above, the arc lamp was mounted on a reflector intended to decrease the contrast between the arc and the area immediately surrounding it. The light was then passed through a ground quartz diffuser, resulting in no visible nonuniformities in the photon beam. The problem of stray light, however, can be significant and can affect the beam in two ways. First, light incident on nearby metal surfaces such as chamber walls can emit photoelectrons that may possibly be accelerated in the direction of the detector by stray electric fields, although these electrons would not likely have enough energy to be confused with the beam. We have not been able to detect such stray beams in our system. Stray light can also be a problem if it is incident on the photocathode, since it can significantly modify the beam current in a small area. Although we have set up some simple baffles to try to reduce this problem, it does seem to affect the uniformity of the beam in our case, as discussed below and shown in Figure 2. The baffles we have used consist of graphite coated aluminum plates placed around the photon beam, although a more sophisticated baffling system would probably result in reduced stray light and a more uniform electron beam.

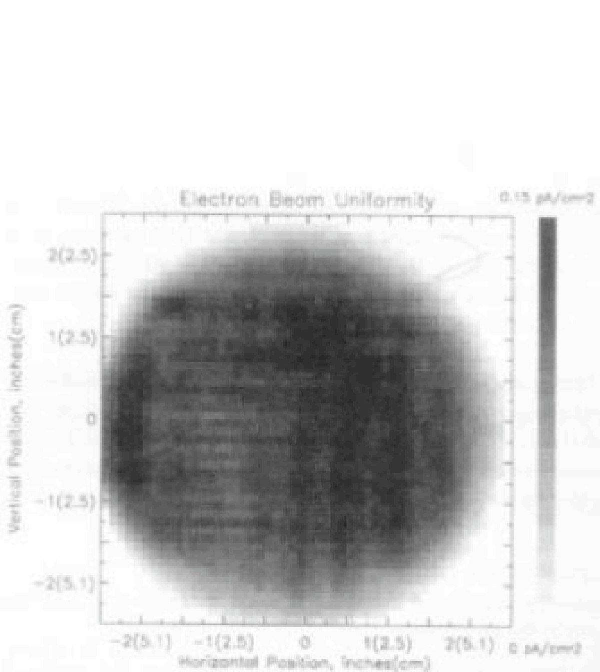

Figure 2. This plot shows the variation of the electron flux in different regions of the beam. Data for this plot was obtained by stepping the detector in increments of 0.25 cm horizontally and vertically. The entrance aperture of the instrument was 1 mm^2 and its angular acceptance was 2.5°.

Another possible source of nonuniformity of the electron beam may stem from problems with the chrome film. During the plating process, the quartz window was continuously rotated to minimize azimuthal variations in the film. Radial variations may be present but are estimated to be less than 5% by the maunfacturer. However, oxidation of the chromium will result in different emissivities in different regions and may account for some of the nonuniformities shown in Figure 2.

Measurements of the electron beam were made with the 1 mm^2 pinhole plates installed at the entrance to the channeltron. The instrument was mounted on the positioning table and the beam was scanned over a cross sectional area of 12.7 cm horizontally and vertically, in steps of 0.25 cm in both directions. The results of this scan are presented in Figure 2 and show that the beam diameter is approximately 12.7 cm. Figure 2 also shows some variation in beam current in different regions. The origin of the large scale variations is not well understood, but is probably due to stray light being reflected onto the chromium film, although some effect due to temporal changes in the lamp may be present. A more detailed measurement was repeated near the center of the beam to determine whether the wire spacing in the screen affects the beam uniformity. Figure 3 shows the results of this test. With the instrument placed at a distance of approximately 10 cm from the grounded screen, the wire spacing (0.32 cm) is clearly present in the electron beam, resulting in a beat pattern with the step size of the positioning table (0.064 cm for this test). This pattern can be a problem during calibration if an instrument aperture is of the same order, which is often the case. A proposed improvement is to decrease the wire spacing to a dimension that is much smaller than any instrument aperture. The optimal spacing needs to be balanced with the screen transmission, but this compromise should be straightforward.

The possibility of electrons scattering from the accelerating screen also needs to be considered, although we did not observe any events that my might be attributed to this effect. We expect that the effect is very small,

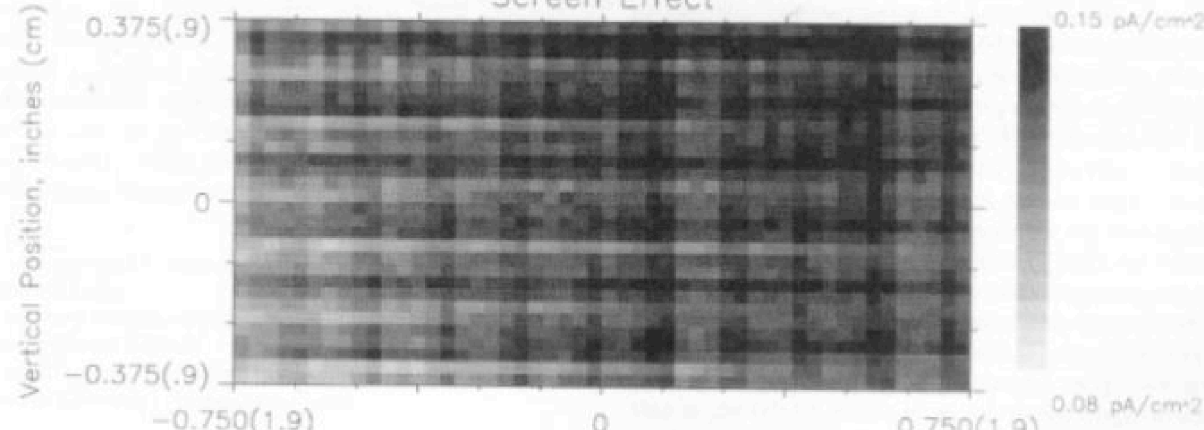

Figure 3. This figure shows the effect of the accelerating screen on the beam uniformity. The instrument, with the 1 mm^2 aperture, was located approximately 10 cm from the grounded screen and was moved in steps of 0.06 cm horizontally and vertically. The accelerating screen wire spacing is 0.32 cm and the screen pattern is clearly visible in the plot.

although a more thorough investigation needs to be carried out.

The data in Figure 2 shows the average beam current density to be approximately 0.1 pA/cm^2. We have been able to increase the current density by a factor of 2 above this value succesfully, but any further increases are done at the risk of damaging the ultraviolet lamp. On the other hand, the beam current can be decreased at least an order of magnitude. It would be very desirable for a system such as this to be variable over several orders of magnitude, however, so that it would be able to accomodate instruments with very different geometric factors, could test saturation effects, etc. While we have not tried to do so, it may be possible to build such a system by using multiple lamps that can be controlled independently.

4. SUMMARY

We described the design and construction of a low energy electron calibration source. This source consists of a broad beam (12.7 cm in diameter) with an energy spread of 0.45 eV and an angular spread of $\Delta\theta = 1.6°$ at E_b= 2 keV. The upper limit to the beam energy is restricted only by the capacity of the high voltage power supply used to bias the chromium film. The lower limit is near 10 eV, at which point the Earth's magnetic field bends the beam away from the instrument. Typical beam current densities are the order of 0.1 pA/cm^2 and can be controlled by varying the current through the uv lamp, although the dynamic range is only an order of magnitude.

Beam uniformity on a large scale (several centimeters) seems to be affected by stray uv light, although this problem can likely be alleviated with proper shielding. The uniformity on a scale the size of the screen wire spacing is also an issue. With the current spacing of 0.32 cm, the screen pattern is clearly visible in the beam at a distance of approxiamtely 10 cm. A proposed improvement is to decrease this spacing to a dimension much smaller than typical instrument apertures, although this will change decrease the beam current density somewhat.

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