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SECONDARY EMISSION EFFECTS ON SPACECRAFT CHARGING: ENERGY DISTRIBUTION CONSIDERATIONS

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SUMMARY

Calculations of the floating potential V of a spacecraft in geosynchronous orbits often lead to multiple voltage root solutions to the current balance equation $(J_i(V) - J_e(V) + J_s(V) + J_{scat}(V) = 0)$ for the ion, electron, secondary emission and backscattered currents. The multi-valued solutions result from the double-valued nature of the incident electron energy when expressed as a function of secondary electron yield.

We have examined the conditions under which multiple valued solutions occur by computing the floating potential of an isolated eclipsed surface on a geosynchronous orbit spacecraft. Two different surface materials were considered, aluminum with an oxide coating and BeCu (activated). Several different approximations for the electron spectra during a geomagnetic substorm were used.

The result of the study indicates that if the incident electron flux has a Maxwellian energy distribution, the ratio of the secondary emitted current to the incident electron current is independent of the spacecraft potential. In this case a single valued solution to the current equation occurs. However, if the electron spectra can be described by the sum of two Maxwellian energy distributions then either multiple potentials or a single small positive or a single large negative potential can occur. Under certain conditions the nature of the solution can change from positive to negative to multiple by making relatively small changes in the incident electron spectrum shape. In this case of variable spectral shape large temporal changes in potential of a spacecraft surface in eclipse could occur during a geomagnetic substorm.

INTRODUCTION

In the early 1970's, plasma clouds containing kilovolt electrons were observed in the magnetosphere at synchronous latitudes (ref. 1) resulting in the chargeup of spacecraft to thousands of volts potential. Since then numerous calculations of the floating and differential potential of a spacecraft in geosynchronous orbit (refs. 2, 3, 4, 5) and in the Jupiter environment (refs. 6 and 7) have been performed. More recently it has been shown that the spacecraft current balance equation can have multiple solutions yielding two stable and one unstable solution for the floating potential of the charged up spacecraft (ref. 4). Multiple roots are a consequence of secondary emission from the surface. They can occur when the maximum value of the secondary electron fractional yield δ_{max} is greater than one.

In this paper we have examined some of the conditions under which multiple solutions to the current balance equation can occur. We have assumed that the spacecraft surface in question is in eclipse and is spherically symmetrical and that the spectrum of the ambient electron flux could be described by one or two Maxwellian energy distributions.

COMPUTATIONS

To determine the current-voltage characteristics one must balance the current to the spacecraft. If J_{net} is the net current to the spacecraft, then in the steady state

$$J_{net} = J_e(V) - J_i(V) - J_s(V) - J_{scat}(V) = 0 \tag{1}$$

where the J's are the voltage dependent current densities for electrons, ions, secondary electrons and back scattered electrons, respectively. The current density for electrons that can be described by a single Maxwellian energy distribution is given by $J_e(V) = J_{oe} \exp [eV/kT]$ for electrons incident on a negatively charged surface.

In the case of ions, we have used the same assumptions as Prokopenko and Laframboise (ref. 4), i.e., that the ion flux is Maxwellian with an ion temperature of one kilovolt and that the ratio of ambient ion to electron current densities $J_{oi}/J_{oe} = 0.025$. With these assumptions the ion current density in the attractive case (i.e., positive ions incident on a negatively charged surface) becomes

$$J_i = .025 \, J_{oe} \, (1-V) \tag{2}$$

where V is in kilovolts.

In order to compute the secondary electron current it was assumed that the fractional yield, $\delta(E)$, as described by Sternglass (ref. 8) could be approximated by the difference of two exponentials, i.e.,

$$\delta(E) = c(e^{-E/a} - e^{-E/b}) \tag{3}$$

To compute the constants a, b and c, equation (3) was compared to the Sternglass relation for the fractional yield

$$\delta(E) = 7.4 \, \delta_{max}(E/E_{max}) \, e^{-2(E/E_{max})^{1/2}} \tag{4}$$

The values of δ_{max} and E_{max} for the materials used in the study were taken from the table in reference 4. A comparison of the $\delta(E)$ obtained from the two relations for an aluminum surface is shown in figure 1. In the case of aluminum the Sternglass expression can be fit to the difference of two exponentials fortuitously well.

Incident Maxwellian Electron Flux

If the incident electron flux is Maxwellian then the current continuity equation has at most one root, $J_{net}(V) = 0$. This can be seen by computing the secondary emission current density from

$$J_s = J_{oe} \int_{eV}^{\infty} \delta(E+eV)\, e^{\frac{eV}{kT}} \left(1 + \frac{eV}{E}\right) dE \tag{5}$$

Using equation (3) for $\delta(E)$ one finds

$$J_s = cJ_{oe}\, e^{\frac{eV}{kT}} \left\{ \frac{1}{(1+\frac{kT}{a})^2} - \frac{1}{(1+\frac{kT}{b})^2} \right\} \equiv \left(J_{oe}\, e^{\frac{eV}{kT}} \right) \cdot S$$

so that the secondary emission factor S defined by

$$J_s / J_e \equiv S = c \left\{ \frac{1}{(1+\frac{kT}{a})^2} - \frac{1}{(1+\frac{kT}{b})^2} \right\} \tag{6}$$

is independent of V. Therefore the current continuity equation can be written as

$$J_i(V) - J_e(V)\,(1-S) = 0 \qquad \text{or}$$

$$.025\, J_{oe}\,(1-V) - J_{oe}\, e^{eV/kT}\,(1-S) = 0$$

for a negatively charged surface. Since S is a constant, equation (5) has only one root.

Incident Electron Flux Described by Two Maxwellians

The synchronous orbit electron flux during a substorm is not always well described by a single Maxwellian. We have therefore also examined the multi-root nature of the current continuity equation in the case where the incident electron flux is more appropriately described by two Maxwellian energy distributions. In this case the current continuity equation can be written as

$$J_{net} = J_i(V) - J_{e_1}(V)\ (1-S_1) - J_{e_2}(V)\ (1-S_2) = 0 \tag{8}$$

This equation has more than one root only if $(1-S_1)$ and $(1-S_2)$ have opposite polarities. The conditions on J_{net}, S_1 and S_2 for a single positive, single negative or multiple roots are shown in table 1.

SYNCHRONOUS ORBIT STORM SPECTRA

As an application of the above we have computed the current-voltage characteristics for two different surface materials exposed to the storm electron spectra for synchronous orbit described by Knott (ref. 2). This spectrum is based on ATS-5 data (ref. 1). We have approximated the Knott spectrum by three approximations, each of which consisted of two Maxwellians. Each approximation to the electron spectrum had a differential flux given by

$$\frac{d\phi}{dE} = 10^8\ E\ e^{-\frac{E}{4}} + 10^9\ E\ e^{-\frac{E}{kT_2}} \tag{9}$$

The three different approximations were generated by selecting different values of kT_2, i.e., kT_2 = 0.4, 0.5 and 1.0 keV. These approximations and the Knott spectra are shown in figure 2. Also shown in the figure are the in-orbit data points obtained by DeForest.

Roots for a BeCu (Activated) Surface

Using the spectrum described, the floating potential of an activated BeCu surface in eclipse was computed. This material was selected because of the large number of secondary electrons released by it per incident electron. For BeCu (activated) δ_{max} = 5.00 and E_{max} = 0.4 keV yields

$$\delta(E) = 6.3\left(e^{-\frac{E}{1.9}} - e^{-\frac{E}{0.1}}\right)$$

for our approximation to the Sternglass equation.

The net flux (J_{net}/e) vs potential of the surface is shown in figure 3 for each of the three spectra used. Note that even though the three spectra differ only slightly from each other, the nature of the three solutions are dramatically different. The solution for the spectra with $kT_2 = 1$ keV has only one positive root. In the case of $kT_2 = 0.4$ keV there is only one negative root, whereas if $kT_2 = 0.5$ keV three roots are found. In this case the middle root is unstable (ref. 4).

In figure 4 we show the nature of the floating potential solutions for an eclipsed BeCu (activated) surface in an ambient electron flux given by

$$\frac{d\phi}{dE} = 10^8 E e^{-\frac{E}{4}} + A_2 E e^{-\frac{E}{kT_2}}$$

We notice from the figure that the spectra selected for this study had values of A_2 and kT_2 near the boundaries in the figure separating the different kinds of solutions. As a result small changes in kT_2 or A_2 can produce significantly different solutions to the current continuity equation.

Voltage Solutions for an Aluminum Surface with Oxide Coating

A similar calculation was performed for an oxide coated aluminum surface in eclipse. In this case $\delta_{max} = 2.6$ and E_{max} 0.3 keV resulting in $a = 1.33$, $b = 0.115$ and $c = 3.6$.

A kind of voltage solution of the current continuity equation obtained are depicted in figure 5. We notice that in this case, all three spectra used to fit the Knott storm spectrum result in single negative solutions to $J_{net}(V) = 0$.

CONCLUSIONS

The possibility of the occurrence of multiple solutions for the floating potential of a body in eclipse has been studied particularly for the case where the electron flux is described by two Maxwellian energy distributions. In this case mutliple solutions can be obtained. In some instances, particularly if the material in question has a large fractional secondary emission yield (such as activated BeCu), the nature of the solutions can be sensitive to small changes in the spectrum. For example, for activated BeCu, a change in the flux of the incident electrons of about a factor of three at the spectral peak can change the solution for the floating potential from a large negative potential of over 3.5 kilovolts to a small positive potential of less than a kilovolt. This mechanism can result in large rapid changes in the floating potential of a body in eclipse during a substorm without requiring that the body move into sunlight.

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TABLE I. VOLTAGE SOLUTIONS TO $J_{NET}(V) = 0$ USING A TWO MAXWELLIAN SPECTRA

ONE POSITIVE	ONE NEGATIVE	ONE POSITIVE & TWO NEGATIVE
$S_1 < 1$, $S_2 < 1$ and $J_{net} > 0$ at $V = 0$	$J_{net} < 0$ at $V = 0$	$(1-S_2) < 0$, $(1-S_1) > 0$ and $J_{net} > 0$ at $V = 0$ and $J_{net} < 0$ for some $V < 0$
or $S_1 > 1$, $S_2 > 1$		
or $(1-S_2) < 0$, $(1-S_1) > 0$ and $J_{net} > 0$ for all $V < 0$		

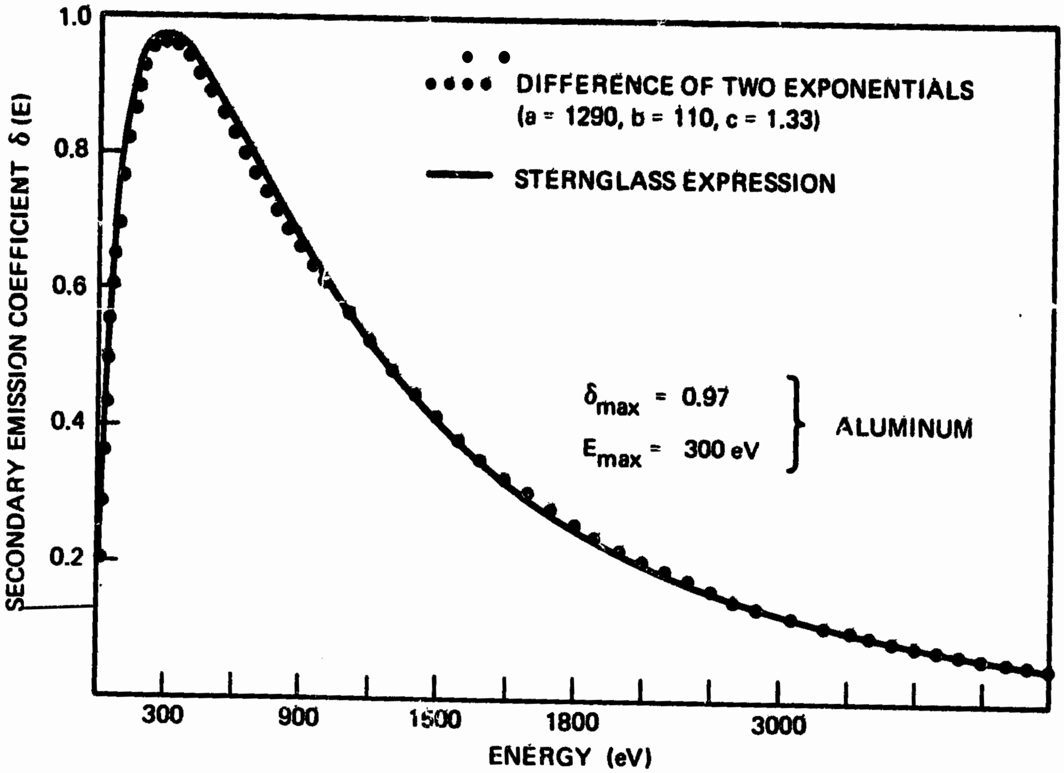

FIGURE 1. APPROXIMATION TO SECONDARY EMISSION COEFFICIENT, δ(E), FOR ALUMINUM USING THE DIFFERENCE OF TWO EXPONENTIALS.

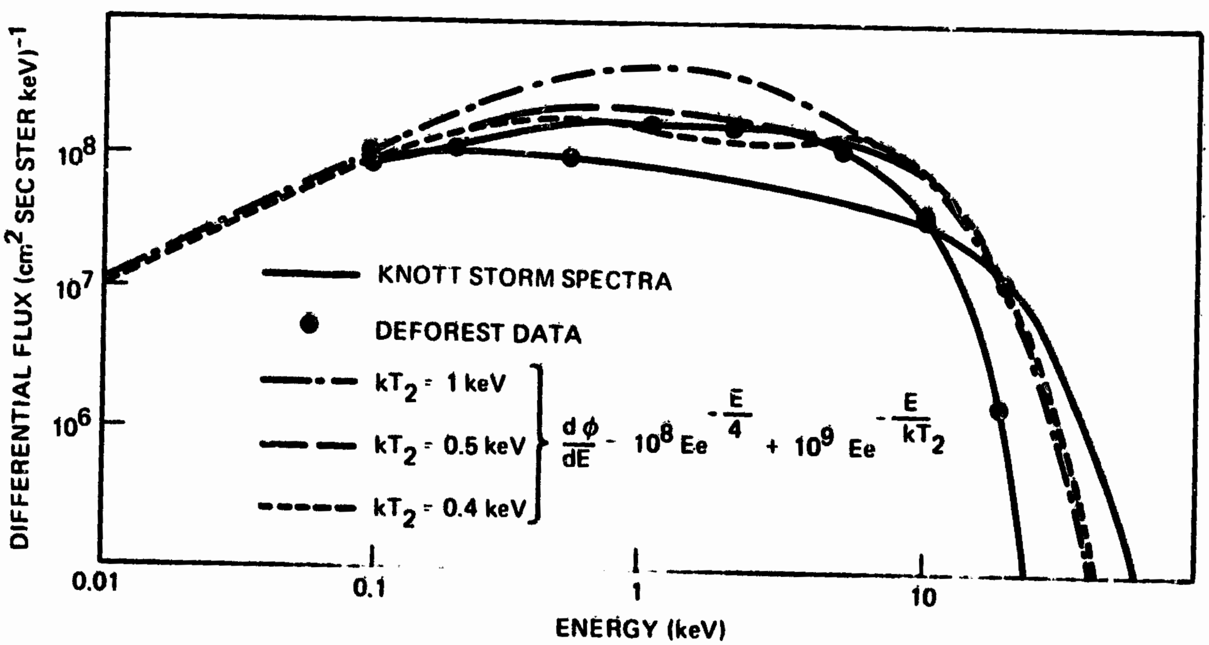

FIGURE 2. STORM SPECTRA USED IN STUDY

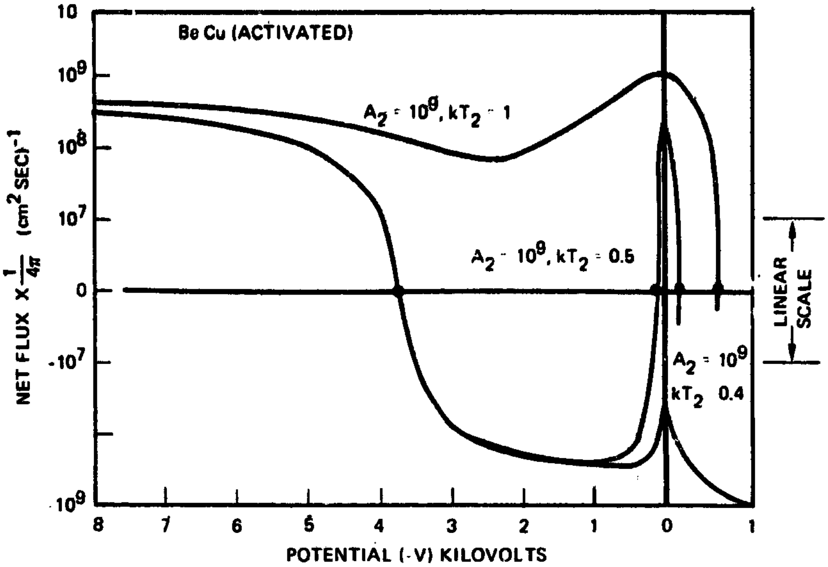

FIGURE 3. NET FLUX TO SPACECRAFT VS FLOATING POTENTIAL FOR THREE DIFFERENT STORM SPECTRA DESCRIBED BY

$$\left(\frac{d\phi}{dE} = 10^8 \; E \; e^{-E/4} + A_2 \; E \; e^{-E/kT_2} \right)$$

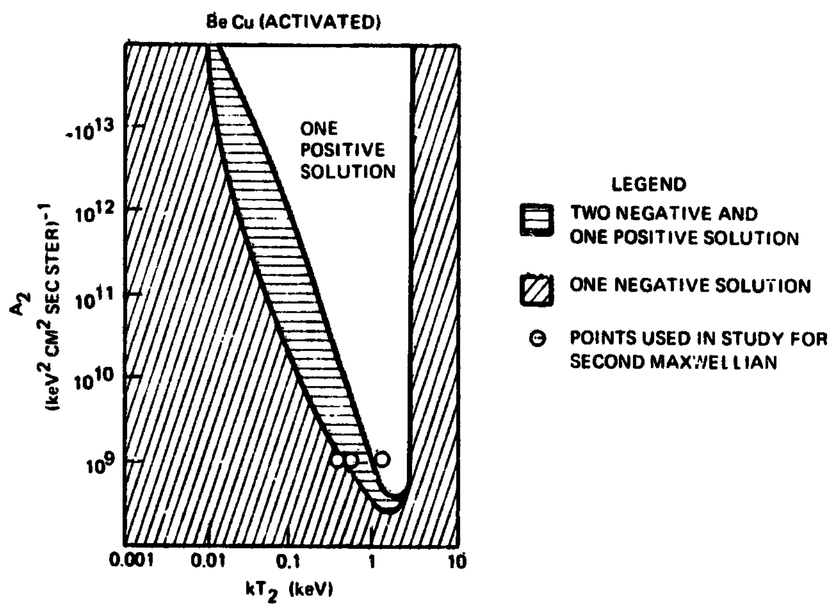

FIGURE 4. NATURE OF FLOATING POTENTIAL SOLUTIONS FOR BeCu (ACTIVATED) USING A TWO MAXWELLIAN SPECTRAL FIT

$$\left(\frac{d\phi}{dE} = 10^8 \; E \; e^{-E/4} + A_2 \; E \; e^{-E/kT_2} \right)$$

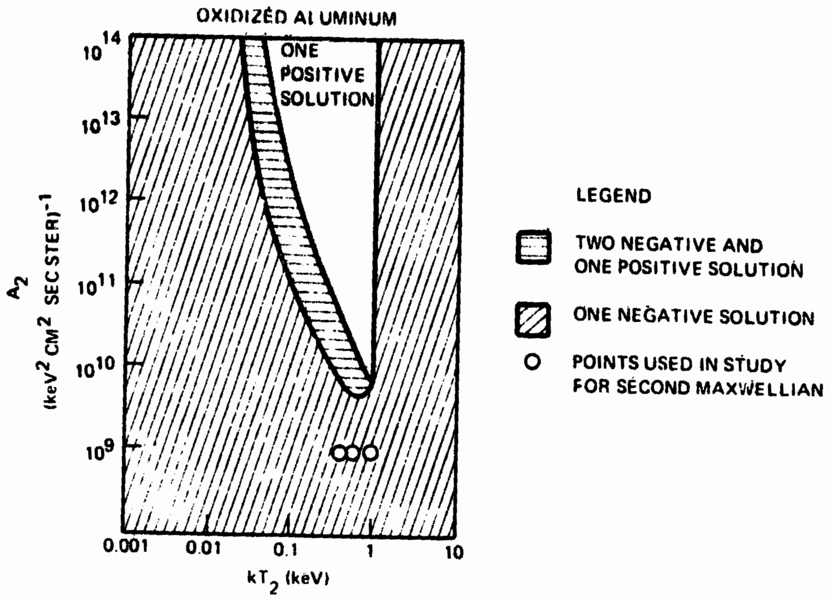

FIGURE 5. NATURE OF FLOATING POTENTIAL SOLUTIONS FOR OXIDE COATED ALUMINUM USING A TWO MAXWELLIAN SPECTRAL FIT

$$\left(\frac{d\phi}{dE} = 10^{8}\ E\ e^{-E/4} + A_2\ E\ e^{E/kT_2}\right)$$