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HIGH VOLTAGE SPACE PLASMA INTERACTIONS

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All large space structures in Earth orbit are immersed in a very tenuous ionized "gas". This ionized "gas" (called plasma) exists everywhere in space. Although so tenuous as to be completely insignificant for most purposes to date, this plasma provides a source of electric current carriers which can become very significant for large structures and/or high voltages. Adequate consideration of such effects should be included during design of the SPS.

There have been two primary problems identified to result from plasma interactions; one of concern to operations in geosynchronous orbit (GEO), the other in low orbits (LEO). The two problems are not the same. Spacecraft charging has become widely recognized as a problem, particularly for communications satellites operating in GEO. The very thin (0.1-10/cc) thermal plasmas at GEO are insufficient to bleed off voltage buildups (>10 kv) due to higher energy charged particle radiation collected on outer surfaces. Resulting differential charging/discharging causes electrical transients, spurious command signals and possible direct overload damage. An extensive NASA/Air Force program has been underway for several years to address this problem (1,2). At lower altitudes, the denser plasmas of the plasmasphere/ionosphere provide sufficient thermal current to limit such charging to a few volts or less. Unfortunately, these thermal plasma currents which solve the (GEO) spacecraft charging problem can become large enough to cause just the opposite problem in LEO.

Ionospheric plasma densities exceeding one million/cc exist around spacecraft in LEO. Operation of large solar arrays at high voltage, for SPS developmental testing or LEO assembly/self-propulsion, could drive substantial leakage currents through this surrounding plasma (Fig. 1). The resulting power loss to these parasitic currents has been observed to exceed solar cell output capability for small (10 cm) test objects in the laboratory. Recent estimates of this effect for large arrays, based on limitation of the leakage currents by formation of space charge limited sheaths around the high voltage surfaces, indicate that such losses should remain within acceptable limits for very large (>100m) arrays (Fig. 2). Large (10m) scale lab tests in simulated LEO plasmas at JSC tend to support these estimates (Fig. 3), but much more detailed work remains to be done (3).

Several other plasma effects have been observed which may become more important as design considerations for SPS than the basic parasitic plasma currents. Focusing of the currents collected within a specific electrostatic "lens" configuration produced by the sheath fields surrounding a high voltage panel has been observed to produce local concentrations of current which could potentially overload or damage a small area of cells within a larger string, even though the average current density "leaking" from the plasma to the entire array is less than the design limits. Fig. 4 is a tracing of relative current density contours observed on the face of a simulated solar array operating at -2,000V in an argon plasma of density about 10^5/cc. The panel area included in the figure is about 1 meter by 2 meters, at one end of the 1X10m panel. The total current flow measured to the entire panel indicated an average current density of 1.0 ma/m^2 (0.1 μamp/cm^2). Most of this current was concentrated within the roughly triangular region within the contours shown; with contour level #1 containing local current densities roughly 0.1 μamp/cm^2, increasing linearly to more than 0.8 μamp/cm^2 within contour #8. Currents outside contour level 1 dropped sharply, to probably less than 0.01 μamp/cm^2throughout region 0.

Early work at Boeing (4) showed that thin films of insulation probably would not be effective in reducing plasma current leakage, due to intense flow of currents through even a small number of pinholes in the insulation (Fig. 5). Examination of the sheath model of plasma interaction in Fig. 6 shows that, above a threshold voltage where sheath dimensions equal or exceed the spacing between exposed conductors (bare interconnects or pinholes), very little reduction of total current collected should be expected from insulation of even most of the panel surface. This is probably related to the "snap-over" phenomena reported by NASA-LeRC (5). Tests were done at JSC using a 1X10m stainless steel panel, first operated at voltages to -3,000V with no insulation, then operated in identical (10^5/cc) plasma densities with >90% of the total surface area insulated by application of mylar tape. Results are shown in Fig 7. Not only was the insulation not effective in reducing current leakage leakage at voltages over 100V, but it also caused increased currents and transient "arcing" to the plasma that prevented measurement of currents for voltages in excess of 200V.

Such transient increases in current above the equilibrium space charge limiting values have frequently been observed. These "arcs" have been observed as bright flash points near solar cell interconnects at LeRC and from most dielectric surfaces within the high voltage plasma sheath volume surrounding the 10 meter panels tested at JSC. Current densities greatly in excess of even bipolar space charge limited values are observed. The arcing from large panels has been reduced by making exposed surfaces conductive, while adding large areas of insulation was observed to reduce the on-set voltage for arcing from -3,000V to -250V for the otherwise unaltered panel used in Fig. 7 test. The "arcing" mechanism is not understood at this time. It is clearly of importance to determine reliable criteria to avoid this phenomena on operational space systems. The needed solution may well come from existing plasma and materials investigations directed toward the GEO spacecraft charging problem. Although LEO plasma densities eliminate charging for most passive spacecraft surfaces, in the case of high voltage sheaths exclusion of the repelled species and accelleration of the attracted current carriers results in a local environment within the sheath similar to GEO during an intense storm. These sheaths may occur around known high voltage surfaces such as solar arrays, or even passive surfaces of large structures which acquire magnetically induced voltages due to orbital velocity.

An interesting point is implied regarding the high voltage (Klystron, etc) vs. low voltage (solidstate microwave transmitter) options for SPS. Although avoidance of the "arcing" problem may appear to be a point in favor of selecting the low voltage option, just the opposite could be true. Physical damage to the "arcing" surface is very rare. The major design problems posed would seem to be increased average power loss and induced electrical transients. The low voltage devices may be much more susceptable to these transients than high voltage tubes, etc. Since arcing may occur due to other causes (induced voltages) than actual high operating voltage of the solar arrays, a high voltage system could well be less vulnerable to arcing problems.

Development of adequate computational tools (similar to the NASCAP program now available for GEO spacecraft charging effects) for use in design calculations is needed in order to proceed with reasonable confidence in the design of higher voltage power systems for operation in LEO. Criteria are also needed to define ground and flight test requirements to validate the proposed design calculation programs, as well as to check for the existance of any plasma instability or interaction modes that might be overlooked or scaled improperly in the general models.

References

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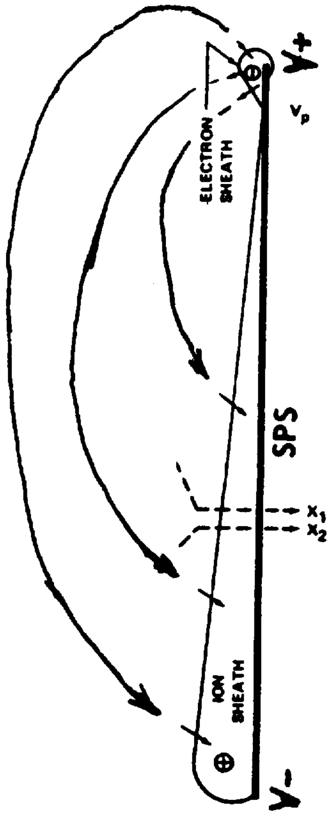

Fig. 1 - SPS Plasma Leakage Current Paths, edge view.

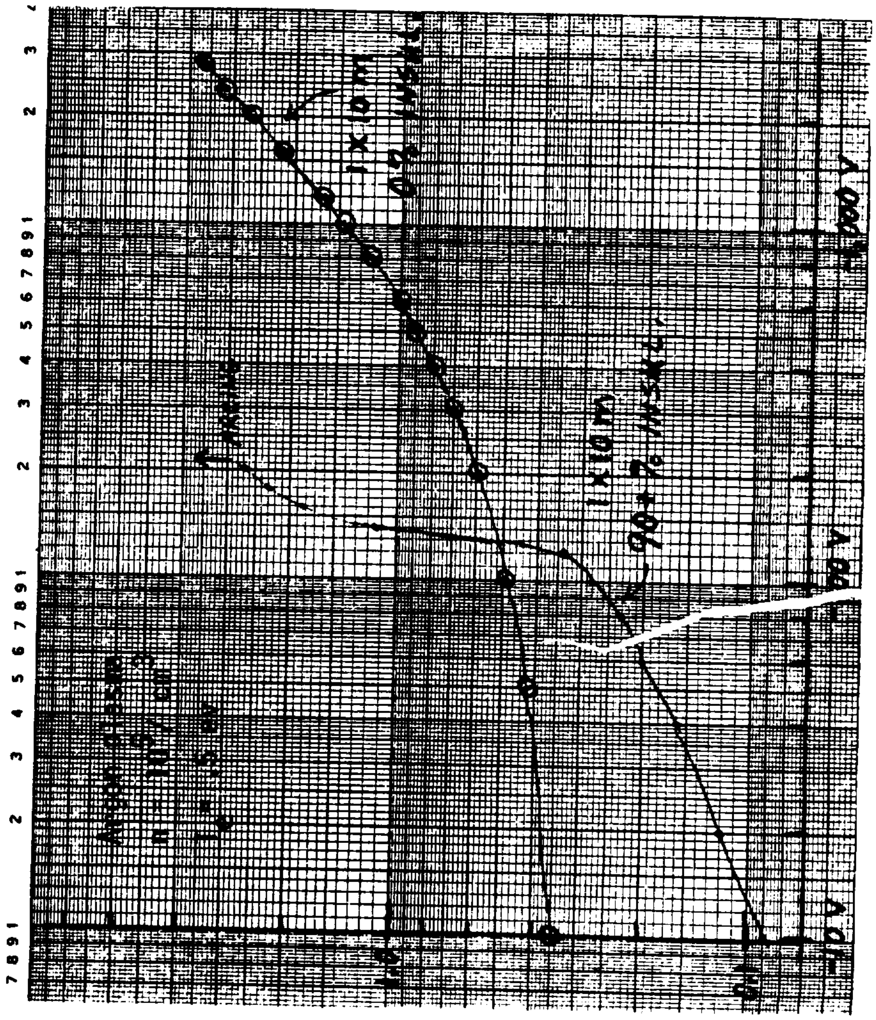

Fig. 7 - Insulated & Noninsulated Panels Leakage current (ma) vs. Bias Voltage Applied.

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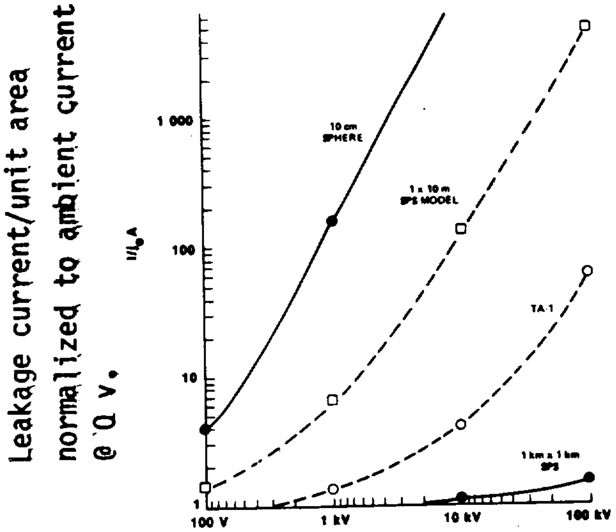


Fig. 2 - Est. size dependence

@ LEO plasma density relative panel size

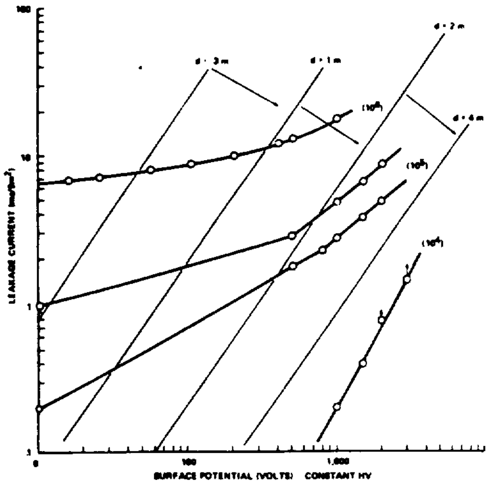


Fig. 3 - Measured leakage at various plasma densities (variation with sheath size relative to 1X10 m panel)

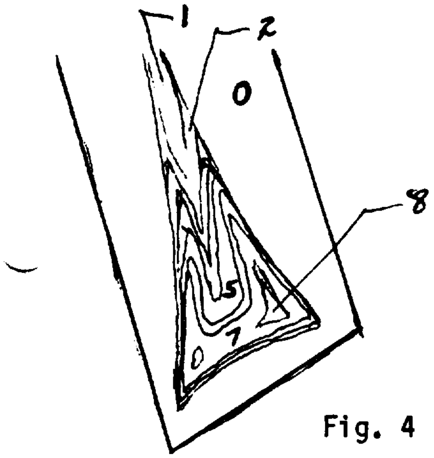
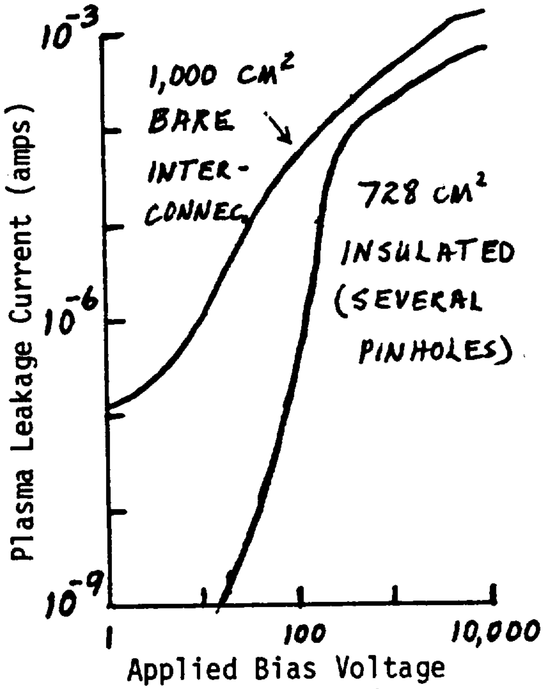


Fig. 4

Surface current density contours.



(From Boeing/Kennerud,1974)

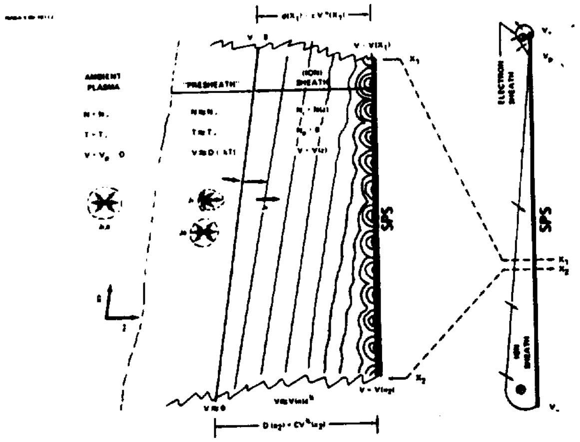


Fig. 6 - Space charge limited sheath-SPS surface dielectric except for small exposed conductors (dark spots).

Fig. 5 - Current leakage to completly insulated panel vs solar array with uninsulated interconnects. N=2x10^3