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INTRODUCTION

Satellites in geosynchronous orbit have been exhibiting anomalous behavior, particularly during the local dusk to dawn portion of their orbit (Ref. 1). It is now believed that these anomalies are due to the noise generated by the discharges from the differential electrostatic charging of the various spacecraft surfaces to kilovolt potentials by the environment. The electromagnetic energy released from such discharges can trigger sensitive electronic logic systems, resulting in the anomalous spacecraft behavior. In addition, the discharges can damage thermal control surfaces, resulting in higher than anticipated temperatures in the

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Data from the ATS-5 and -6 satellites have shown that clouds of kilovolt electrons can occur at geosynchronous altitude in the local midnight to dawn quadrant (Ref. 2). The occurrence of such particle clouds has been correlated with geomagnetic substorm activity (Refs. 3 and 4); furthermore, they persist for periods of several hours. These kilovolt electrons impinging on the spacecraft can cause the spacecraft surfaces to charge to kilovolt potentials. ATS-5 and -6 observations indicate charging of the spacecraft grounds to greater than 10KV negative in the eclipse phases of their mission and to a few hundred volts negative in sunlight in the presence of these kilovolt particles. If the spacecraft grounds can be charged in this manner, then it must be assumed that insulator surfaces can also be charged to kilovolt levels. The shaded insulator surfaces can be charged to these levels even when the spacecraft grounds are maintained at the few hundred volt level, resulting in differential charging of the various satellite surfaces.

The spacecraft charging phenomenon is currently under investigation at several ground facilities (Refs. 5-9). It has been shown in these investigations that insulating surfaces can be charged by beams of kilovolt electrons and that the subsequent discharges do produce conducted and radiated electromagnetic interference. In addition, it has been shown that the discharges can damage the insulator surfaces. The number of discharges which must be absorbed by electrical systems as well as the degree of damage to surfaces has been shown to be proportional to the average particle energy and to the incoming flux of particles. From an engineering standpoint it is important to know the anticipated discharge rate for multiyear missions so that this factor can be considered in the specifications for the electronic circuit design and for the thermal design. Therefore, it is desirable to develop a specification defining the time per year that a synchronous satellite could expect to spend in a substorm environment, the relative proportions of time spent in severe, moderate and mild substorms, and the particle energies and currents characteristic of these substorms. With such a specification in hand, it would be possible to conduct tests to determine the performance of surface materials for a proposed mission. In this report the available data on the substorm environment are used to generate a provisional specification for use in designing satellite systems.

DERIVATION OF THE SPECIFICATION

The information on the geomagnetic substorm environment at synchronous altitude is based on data from the ATS-5 and -6 Auroral Particles Experiments. Considerable data exists on particle flux as a function of energy both in quiet times and in substorms; however, data on substorm particle energy and current flux variations over the local dusk to dawn quadrants is scarce. This latter type of data is necessary in order to derive a specification for the time history of particle energy and flux per year of mission life.

The available data include: a survey of the substorm environment for a three month period of 1970 (Ref. 4); time histories of two substorms obtained as a result of this survey; and data on the level of charging of ATS-6 spacecraft grounds during the fall 1974 eclipse season (Ref. 10). These data are shown in Table 1 and figures 1, 2, and 3 respectively, and form the basis for the present specification for the substorm environment.

A study of the table and figures mentioned above indicates a number of factors which must be considered in developing the specification. First, particle energies are not constant over the substorm period; they fluctuate throughout. Second, there is a large variation in substorm intensity; the average particle energies are higher in some substorms than in others. This is shown by the variation in the level of charging of the spacecraft grounds in figure 3. Third, the electron current density is low when the average electron energy is high, and conversely (figures 1 and 2). Finally, the relationship between proton and electron average energies and current densities is reasonably linear. For the purposes of this specification, it is assumed that the average proton energy is twice the average electron energy, and that the proton current density is about 1/50 of the electron current density. These assumptions are based on figures 1 and 2.

The temporal specification deduced from these limited data and the considerations noted above is shown in figure 4. A more detailed discussion of the derivation of the specification is given in the following paragraphs.

Total Hours Per Year In Substorm

It is necessary to specify particle energy and current density as functions of time in a substorm environment per year of mission life. The first task is therefore to determine the average number of hours per year that a synchronous spacecraft will spend in a substorm environment.

According to a simplified evaluation of the occurrence of substorms (Ref. 4), substorm activity occupies about 30% of the time during any given year. For purposes of this specification, it is assumed that a satellite can find itself in a changing environment during the local dusk to dawn portion of its orbit. Based on these assumptions, a satellite can be in a substorm environment for a total of 1314 hours per year. This number is denoted by H_S (hours per year in substorm).

Particle Energy

Two further factors are required to obtain a specification for particle energy as a function of time. First, it is necessary to determine a "time variation factor" indicating the fraction of time in any one substorm that the particles can be at or above various energy levels. This factor depends on the particle energy of interest and is herein denoted by $f_t(E)$. The second required factor is a "substorm intensity factor" indicating the proportions of severe, moderate and mild substorms expected to occur in a year. This factor is also related to the energy level of interest (via the ATS-6 ground potential data) and is herein denoted by $f_s(E)$.

In order to determine $f_t(E)$, it is necessary to characterize the variation of particle energies during a substorm. For this purpose, the January 2, 1970 substorm (figure 1) is taken as the model of a severe substorm in terms of energy fluctuations. Data from this substorm are used to define the fractions of the total substorm time (10 hours) during which the average energy of the charged particle population attained or exceeded specified values. The model for the moderate substorm is assumed to be the same as the severe but with the average energy scale cut in half. The mild substorm model is assumed to be the same as the moderate substorm model but with the energy scale again halved.

The "substorm intensity factor" $f_s(E)$ is obtained from the measurements of the ATS-6 spacecraft ground potential during the 1974 eclipse period (figure 3). It is assumed that when the ATS-6 spacecraft ground had been biased to a voltage level of between -6KV and -12KV, the satellite had encountered a severe substorm. When the ATS-6 ground had been biased to values between -3KV and -6KV, it is assumed that the satellite encountered a moderate substorm. An encounter with a mild substorm is assumed to have occurred when the ATS-6 ground had been biased to values between 0 and -3KV. The intensity factor is determined by the ratio of the number of days that the spacecraft ground voltage reached these voltage ranges to the total number of days that the satellite experienced a substorm during this eclipse period. Therefore, the intensity factor takes on 3 values: 0.33 for severe substorms (10 days out of 30), 0.27 for moderate substorms (8 days out of 30) and 0.4 for a mild substorm (12 days out of 30). It is assumed that this ratio remains constant throughout the year.

The specification for the average electron energy as a function of time (figure 4) is then obtained by determining H(E), i.e. hours per year in a substorm environment of average electron energy $\geq$ E, from the

$$H(E) = H_s\left\{\left[f_t(E)f_s(E)\right]_{severe} + \left[f_t(E)f_s(E)\right]_{mod} + \left[f_t(E)f_s(E)\right]_{mild}\right\}$$

Values of these terms for selected average energies are given in Table 2.

The specification for ion energy versus time in the substorm environment is simply that the average ion energy is approximately twice the average electron energy as was discussed above. It is recognized that catagorizing the substorms in the manner outlined above is arbitrary. As more information on the substorm environment becomes available, the assumptions which have been used can be improved.

Particle Current Density

The specification for the electron current density in figure 4 is again based on data from the January 2, 1970 substorm as the model substorm. These data indicate that the current density is 0.5 na/cm^2 at the high average electron energies, and that as the average electron energy decreases, the current density increases monotonically to 2 na/cm^2 in approximate inverse proportion to the average energy. The current density specification is devised based on this information plus the previously derived energy specification. Again, the ion specification is simply stated based on the earlier observation that the ion current density is about 1/50 of the electron current density.

Field Aligned Fluxes

It should be noted that throughout the development of this specification, isotropy of the environment has been assumed. Recent data indicate that field aligned fluxes are in fact present (Ref. 11), and that particle fluxes aligned with the magnetic field lines are considerably larger at certain energy levels than the fluxes at large pitch angles. No attempt has been made to incorporate such anisotropies into the present specification.

DISCUSSION

The specification presented in figure 4 shows that for a large fraction of time, the satellite will encounter only mild substorms. Computations of surface behavior of the normal spacecraft materials in this environment show that the resulting surface potential in such substorms is not high enough to cause discharges. This may explain the apparent randomness of the observed spacecraft anomalies, which do not always occur when substorms are detected at a ground station.

The specification can be used in conjunction with a ground test program to determine the behavior of an insulator surface proposed for a satellite. By simulating the substorm parameters, the test surface can be subjected to the specification profile to determine the surface charging characteristics for a given mission life. The discharge threshold will also be determined along with the material degradation and transients associated with the discharges. This information can then be used in designing the satellite systems to accommodate the surface behavior. Hence, the specification is used as an engineering tool to aid in system designs.

CONCLUDING REMARKS

The specification presented herein is based on a very limited amount of data, and many assumptions. No margins or variances have been included in this specification simply because the data are insufficient to allow reasonable calculations of such parameters. For these reasons, the present specification has been denoted as a provisional specification; it is expected that refinements will be made as more data become available.

Despite the preliminary nature of this specification, it is felt that it provides a useful engineering tool which can be used to provide a guideline for ground test procedures to estimate the effects of substorm activity on a spacecraft during a specified mission life.

REFERENCES

1. McPherson, D. A.; Cauffman, D. P.; and Schober, W.: Spacecraft Charging at High Altitudes - The Scatha Satellite Program. AIAA Paper 75-92, Jan. 1975.
2. DeForest, S. E.; and McIlwain, C. E.: Plasma Clouds in the Magnetosphere. J. Geophys. Res., vol. 76, no. 16, June 1971, pp. 3587-3611.
3. DeForest, S. E.: Spacecraft Charging at Synchronous Orbit. J. Geophys. Res., vol. 77, no. 4, Feb. 1972, pp. 651-659.
4. Rosen, A.: Spacecraft Charging: Environment Induced Anomalies. AIAA Paper 75-91, Jan. 1975.
5. Stevens, N. John; Lovell, Robert R.; and Gore, Victor: Spacecraft Charging Investigation for the CTS Project. Presented at the Conf. on Spacecraft Charging by Magnetospheric Plasmas, Amer. Geophys. Union, Annual Spring Meeting, Washington, D.C., June 16-19, 1975 (also NASA TM X-71795).
6. Sellen, J. M., Jr.: Spacecraft Materials Response to Geosynchronous Substorm Conditions. Presented at the Conf. on Spacecraft Charging by Magnetospheric Plasmas, Amer. Geophys. Union, Annual Spring Meeting, Washington, D.C., June 16-19, 1975.
7. Adams, R. C.; and Nanevicz, J. E.: Spacecraft Charging Studies of Voltage Breakdown Processes on Spacecraft Thermal Control Mirrors. Presented at the Conf. on Spacecraft Charging by Magnetospheric Plasmas, Amer. Geophys. Union, Annual Spring Meeting, Washington, D.C., June 16-19, 1975.

8. Balmain, K. G.; Orszag, M.; and Kremer, P.: Surface Discharges on Spacecraft Dielectrics in a Scanning Electron Microscope. Presented at the Conf. on Spacecraft Charging by Magnetospheric Plasmas, Amer. Geophys. Union, Annual Spring Meeting, Washington, D.C., June 16-19, 1975.

9. Fogdall, Lawrence B.; et al.: Combined Environmental Effects on Polymers. Proc. of 8th Conf. on Solar Simulation, NASA SP-379, 1975, pp. 259-260.

10. Bartlett, R. O.; DeForest, S. E.; and Goldstein, R.: Spacecraft Charging Control Demonstration at Geosynchronous Altitude. AIAA Paper 75-359, Mar. 1975.

11. McIlwain, C. E.: Auroral Electron Beams Near the Magnetic Equator. Presented at the Nobel Symp., Kiruna, Sweden, April 1975.

TABLE 1. SUMMARY OF ATS-5 MEASUREMENTS OF CHARGED PARTICLE ENVIRONMENT

PLOT OF 2 JAN 1970 SUBSTORM

ELECTRONS

CURRENTS UP TO 0.85 na/cm^2 FOR ≈ 30 MINUTES

AVERAGE CURRENT 0.5 na/cm^2 FOR >8 HOURS

PEAK TEMPERATURES OF 12-13 KILOVOLTS FOR ≈ 45 MIN

AVERAGE TEMPERATURE OF ~6 KILOVOLTS FOR ≈ 8 HOURS

PROTONS

CURRENTS UP TO 13 pa/cm^2

AVERAGE CURRENT 7 pa/cm^2

PEAK TEMPERATURES OF 16-20 KILOVOLTS FOR ≈ 30 MIN

AVERAGE TEMPERATURE OF ~12 KILOVOLTS

OTHER SUBSTORMS

ELECTRONS

CURRENTS OBSERVED UP TO 2 na/cm^2, TYPICAL 0.1 TO 0.2

POSSIBLE: 8 na /cm^2 MAXIMUM (NOISY DATA) FOR 5-10 MIN

TEMPERATURES UP TO 20-30 KEV

TYPICAL TEMPERATURE 2-6 KEV

TABLE 2. FACTORS USED IN DERIVING SPECIFICATION

Electron temp. (KeV)	Category of Storm						H(E) (hours)
	Severe		Moderate		Mild		
	$f_t(E)$	$f_s(E)$	$f_t(E)$	$f_s(E)$	$f_t(E)$	$f_s(E)$	
12	0.025	0.33	-----	----	---	---	11
10	.1	↓	-----	----	---	---	43
8	.2		-----	----	---	---	87
6	.5		0.025	0.27	---	---	226
4	.8		.2		---	---	418
2	1.0		.8		0.2	0.4	823

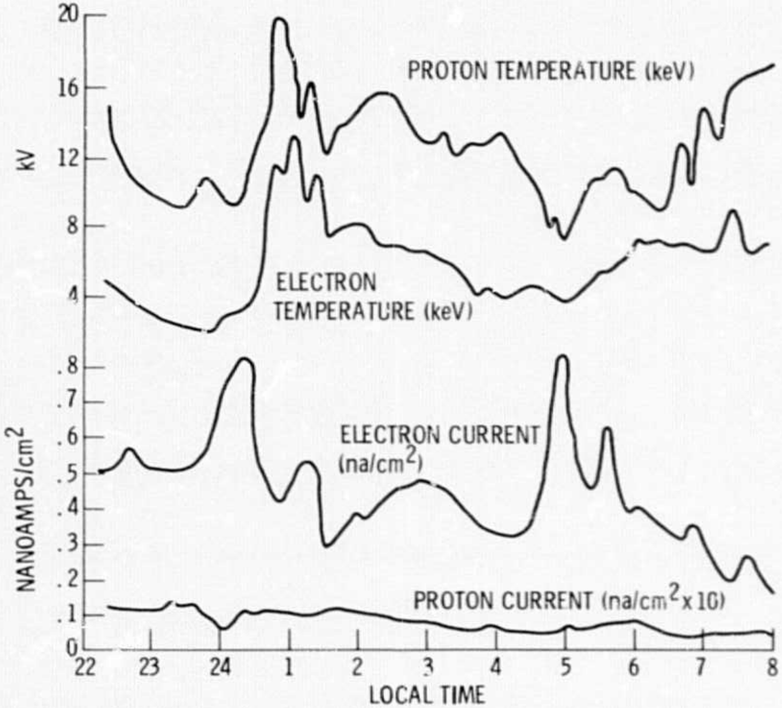

Figure 1. - Environmental conditions from January 2, 1970 substorm (ref. 4).

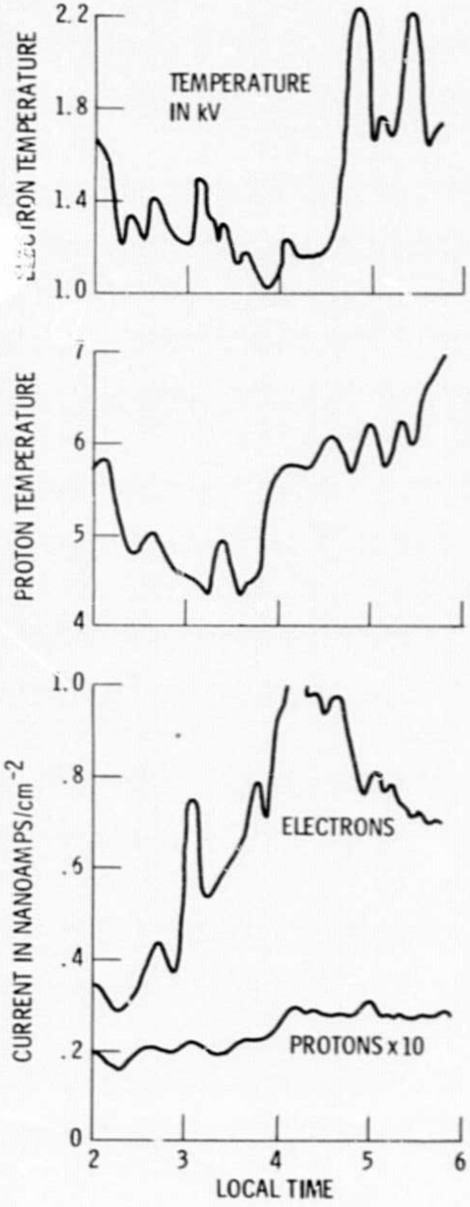

Figure 2. - Temperature and current profiles for March 27, 1970 substorm (ref. 4).

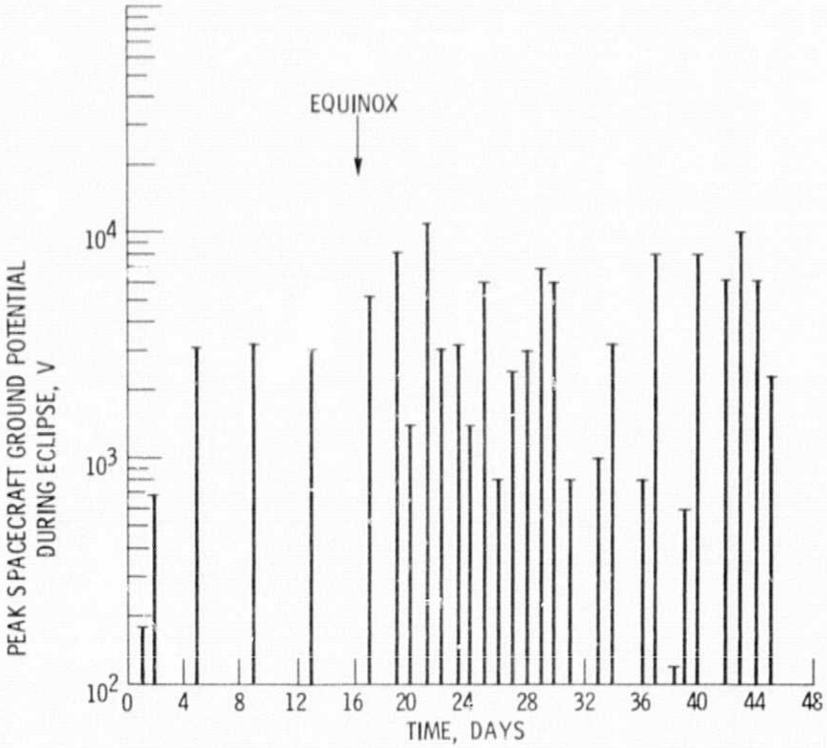

Figure 3. - ATS-6 spacecraft charging data. Fall eclipse period, 1974 (ref. 10).

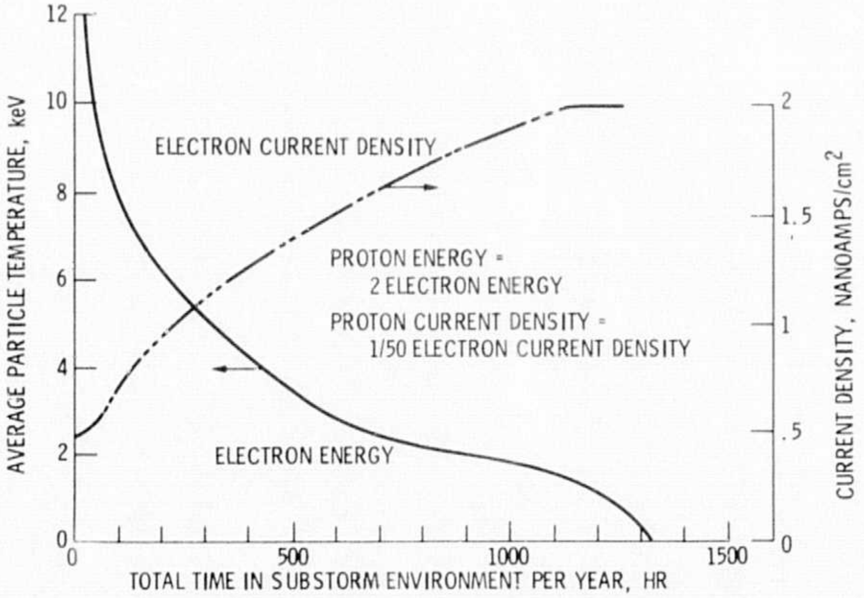

Figure 4. - Provisional specification for satellite time in a geomagnetic substorm environment.