N78-10145

Contents

4. Preliminary Report on the CTS Transient Event Counter Performance Through the 1976 Spring Eclipse Season

N. John Stevens, Robert R. Lovell, and Vernon W. Klinect
Lewis Research

Abstract

The first known harness transient detector flown on a synchronous satellite has been operating on the joint Canadian-American Communications Technology Satellite (CTS) since 31 January 1976. This detector, called the transient event counter (TEC), senses and counts transients having a voltage rise of greater than 5 volts in three separate wire harnesses: the attitude control harness, the solar array instrumentation harness, and the solar array power harness.

This report describes the TEC, defines its operational characteristics, and presents the preliminary results obtained through the first 90 days of operation including the Spring 1976 eclipse season. The results show that the CTS has been charged to the point where discharges have occurred. The discharge induced transients have not caused any anomalous events in spacecraft operation. The data indicates that discharges can occur at any time during the day without preference to any local time quadrant. The number of discharges occurring in the 1 sec sample interval are greater than anticipated. The compilation and review of the data is continuing.

I. INTRODUCTION

The joint Canadian-American Communications Technology Satellite (CTS) is the first of a new generation of high power, high frequency communications satellites utilizing a 12 GHz, 200 W rf transmitting system.[1] This satellite was launched 17 January 1976, and placed in a synchronous equatorial orbit at 116° West Longitude.

Since the early 1970's satellites in synchronous orbits have been experiencing anomalous electronic switch events.[2] This anomalous behavior is believed to be caused by the coupling of environmentally induced discharge pulses into the low level logic circuits used on these satellites. The data from an experiment on the ATS-5 and -6 satellites has shown that clouds of kilovolt electrons can occur at synchronous altitudes.[3] It has been shown that these clouds can charge the satellite ground to potentials that range from a few hundred volts to several kilovolts negative.[4, 5] The range to which the spacecraft grounds can be charged in a given particle environment is determined by the areas of the satellite grounded metal surfaces that are in the sunlight. The photo-emitted electron current from these sunlit surfaces can partially balance the incoming electron flux and maintain the spacecraft potential within a few hundred volts relative to the space plasma potential. If the spacecraft ground can be charged in this manner, then it must be assumed that the insulators can also be charged. Furthermore, the insulator surfaces that are shaded can be charged to the kilovolt level even when the spacecraft grounds are maintained at the few hundred volt level. When the satellite insulator surfaces are charged to the kilovolt level, a discharge can be triggered and the resulting pulse of electromagnetic energy can cause anomalous behavior in sensitive electronic circuits.

The Communications Technology Satellite (CTS) was designed in the 1970-1971 time period when the spacecraft charging phenomenon was barely recognized by project personnel. As a result the satellite incorporated design techniques which were normally used at that time for lightweight satellites. Thermal blankets were used to close the top and bottom spacecraft body openings and solar cells, optical solar reflectors, and silvered Teflon were used on the satellite exterior (see Figure 1).

The unique feature of the satellite is the size and construction of the deployable solar arrays, each 1.2 × 7.6 m long which have the solar cells mounted on a 3-mil Kapton fiberglass composite substrate. The satellite is three axis stabilized and the solar arrays track the Sun. Therefore, this satellite has large areas of exposed insulator surfaces that are shaded when the satellite is in orbit. These surfaces can be charged by the electron clouds at synchronous altitudes.

ORIGINAL PAGE IS
OF POOR QUALITY

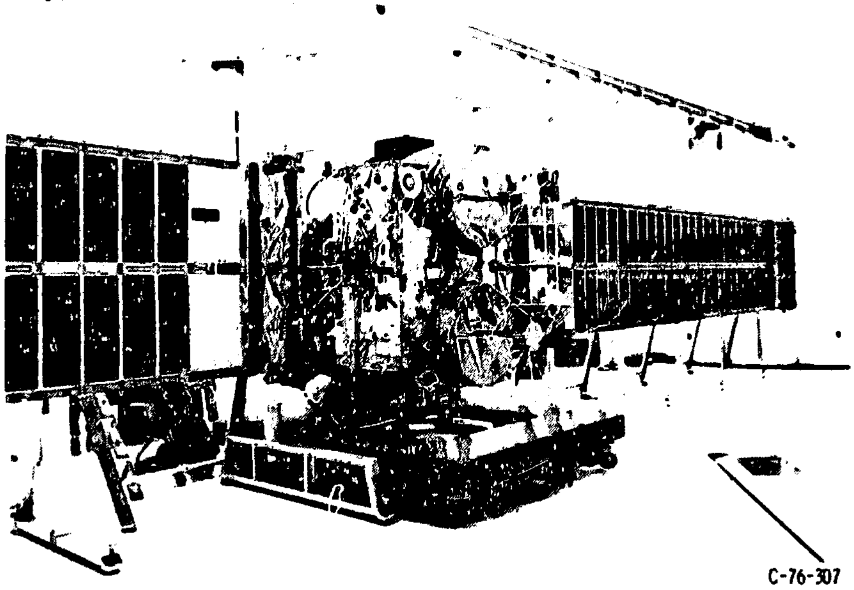

Figure 1. CTS Spacecraft (Prelaunch Checkout)

The concern for possible spacecraft charging effects on the CTS led to the establishment of an investigation to determine the response of the spacecraft surfaces to the substorm particle fluxes.[6] Late in the CTS program, a recommendation was made to incorporate a charging diagnostic device. This recommendation was accepted by the CTS Project provided that the weight and power consumption were minimized. A decision was made that a harness transient detector would be an acceptable minimum device. It was assumed that the data on the environment that could charge the surfaces could be obtained from other sources. Thus, the harness transient detector, called the Transient Event Counter (TEC) was built, qualified, and integrated into the flight spacecraft 6 months prior to launch. This is the first such detector known to be on a satellite in geosynchronous orbit.

This report will describe the TEC, define its operational characteristics, and present the preliminary results obtained through the 1976 Spring eclipse season. The data on charging environment is still being collected. However, the preliminary data of an indication of the state of the environment, the K index, from the ground station at Anchorage, Alaska, is given as a gross indicator. This K index measures the geomagnetic effects of solar particle flux at a specific station at 3 hr intervals.[7] Hence, it can be used as an indication of the state of the environment. The K index values are given on a scale of 0 to 9. The higher numbers indicate a disturbed or charging environment, while the lower numbers indicate a quiet environment.

2. TRANSIENT EVENT COUNTER (TEC) DESCRIPTION

The Transient Event Counter (TEC) is a small electronic device capable of sensing and counting transient pulses having an amplitude greater than 5 volts that are transmitted along the spacecraft internal wiring harnesses. The objectives of this device are:

(1) to obtain flight data on arc discharge events related to spacecraft charging which would aid in the design of future spacecraft,

(2) to count the number of discharges as a function of satellite time,

(3) to locate approximately the sources of the discharge, and

(4) to provide diagnostic information relating anomalous performance to charging events.

Due to the limited time available to design, build, qualify, and integrate the TEC, a decision was made to count the transients only at three specific locations on the satellite. It was desirable to record the amplitude of the transients, but it was felt that the additional development time might jeopardize the incorporation of the TEC on the satellite.

The elements of the TEC are shown in the block diagram of Figure 2. The three detectors sense the transient pulses in the harnesses. These pulses are counted for a 1 sec interval and stored in a register. The stored counts are transmitted to ground through the satellite telemetry system. The general specifications for the TEC are given in Table 1.

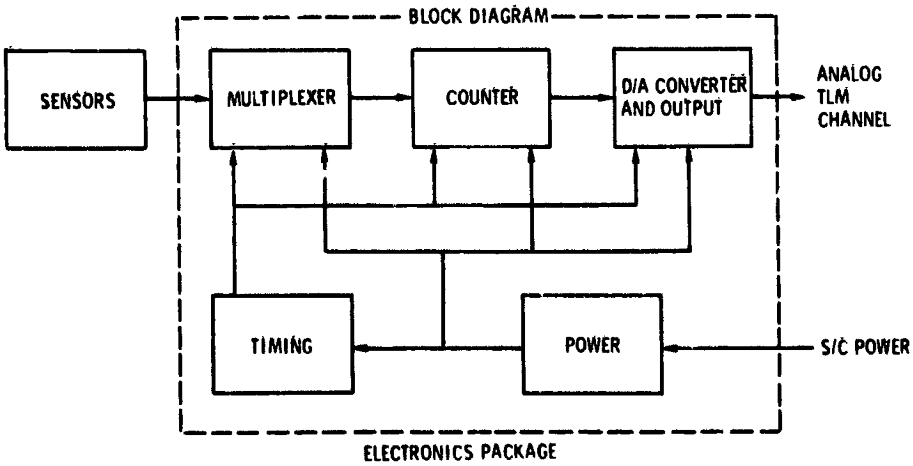

Figure 2. Transient Event Counter

Table 1. TEC Specifications

Power	330 mW
Size	7.62 × 10.16 × 5.5 cm (3 × 4 × 2.16 in.)
Weight	326.6 grams (11.5 oz)
Input Voltage	+15 VDC ± 15 percent
Output Voltage	0-5V DC
Output Impedance	<3 ohms
Telemetry	one analog channel
Commands	none
Outgassing	venting holes provided
Measurements	3 channels, subcommutated with calibrated and ID signal
Counting Capacity	64 transients/sec

2.1 Sensors

The sensors are coaxial cables with 60 cm of the shield removed at one end. These unshielded portions of the cables are laced to the spacecraft wire harnesses at three separate locations within the spacecraft. Each sensor acts as an antenna coupling to the transient pulse within the harness. The location of the sensors are as follows (see Figure 3):

(1) Channel 1: Attached to the attitude control instrumentation wire harness between the nonspinning Earth sensor assembly and the attitude control electronics assembly. It is assumed that this sensor would pick up discharges from the forward platform thermal blankets, the antenna system, the silver Teflon on the variable conductance heat pipe radiator, and the Earth sensor assemblies. The shielded length of this cable is about 1.5 m.

(2) Channel 2: Attached to the south solar array instrument harness within the spacecraft body at the slip rings. The instrument lines on the solar array are unshielded and are routed down the center of the wing. This sensor will detect arc discharges occurring in the center area of the solar array wing. The shielded length of this cable is about 0.5 m.

(3) Channel 3: Attached to the south solar array power harness within the spacecraft body at the slip rings. The power lines on the solar array are also unshielded and run along both the outside edges of the wing. This sensor, then, will detect discharges occurring at the edges of the wing and at the solar cells. The shielded length of this cable is also about 0.5 m.

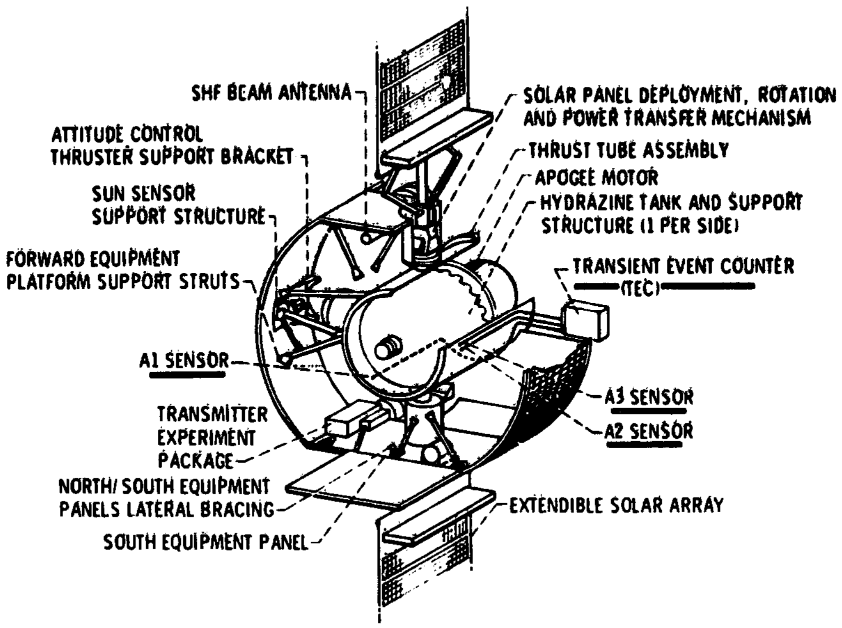

Figure 3. TEC and Sensor Locations

These locations were chosen so that the sensors would monitor those parts of the spacecraft where discharge activity was anticipated.

The unshielded sensors were attached to the outside of these wire harnesses instead of within the harness because the wire harnesses were completed and installed in the flight spacecraft before the decision to fly the TEC was made. Mounting the sensor in this manner decreased the sensitivity and increased the possibility of pickup from sources outside the harness. However, testing of the TEC on the satellite using a portable spark source indicated that the desired threshold of 5 volt sensitivity could be achieved.

2.2 Electronics Package

The electronics package houses the counting and storage circuits in a box, 7.6 × 10 × 5.5 cm, that weights 327 grams (see Figure 4). This package is mounted on the exterior CTS aft platform under the thermal blanket (see Figure 3).

The allocation of only one telemetry channel to the TEC necessitated the inclusion of a multiplexer and timer to control this experiment. The multiplexer switches in the first sensor channel for about 1 sec. During this interval the counter will count the transients in the harness with an amplitude greater than 5 volts and store the total count in the register. A maximum of 63 transients can

ORIGINAL PAGE IS
OF POOR QUALITY

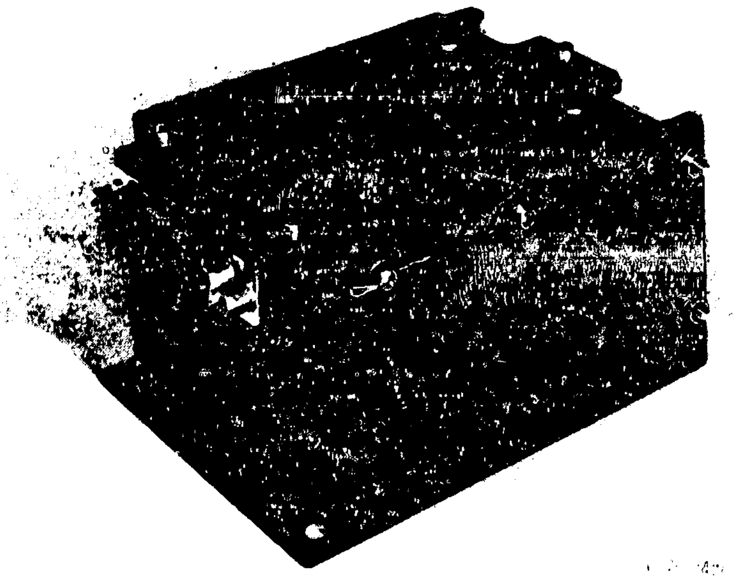

Figure 4. TEC Electronics Package

be counted in the sampling period. An overflow indicator (the sixty-fourth transient count) is used when greater than 63 transients are counted. There is a built in 5 μsec delay after a discharge pulse is counted. This delay is to prevent the counting of line ringing as separate discharge pulses. The delay was selected as a result of the ground tests on materials' characteristics conducted at the LeRC.

At the end of the 1 sec interval the total count is stored in the register, the timer resets the counter to zero, and the multiplexer switches to the next channel. Discharge transients on this line are then counted for a second after which this total count is stored in the register. The cycle is then repeated for the third sensor. The multiplexer has a fourth position at which time a calibrate signal is fed into the register. After the calibrate signal, the cycle repeats. The telemetry format is shown in Figure 5.

The telemetry system samples the storage register at about once per second. Hence, the transient pulses on each sensor are counted for about 1 sec every 4 sec. Since the telemetry rate and the TEC counter are not synchronized, the channel being sampled is determined from the calibrate signals: every other cycle has a maximum count calibrate signal with a zero count calibrate in between. The TEC timer was allowed to be free running to minimize the ties to the CTS telemetry system.

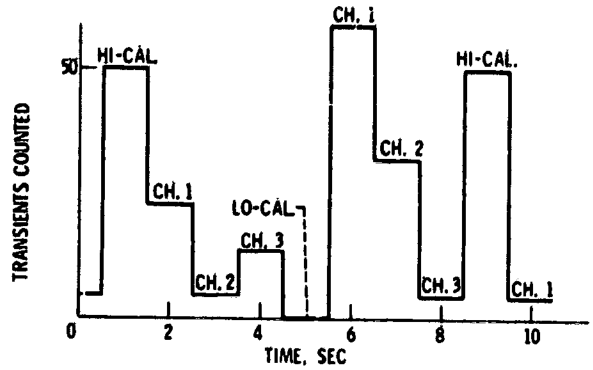

Figure 5. Typical Telemetry Output

3. DISCUSSION OF TEC FLIGHT DATA

The CTS was launched on 17 January 1976, and placed in a synchronous, equatorial orbit at 116° West Longitude. The TEC has been operating continuously since the main solar array deployment on 31 January 1976.

A complete summary of the TEC flight data for the period from 31 January 1976, through the Spring eclipse period until 30 April 1976, is given in Table 2 as a function of satellite local time. The data given in this table are the total number of transients counted in the 1 sec sampling of that channel. The satellite local time is defined such that local noon occurs when the satellite is on the Sun-Earth line. This time scale is of more interest for spacecraft charging investigations since it allows for a better visualization of surface shadowing and correlation of substorm data. The satellite local time can be converted to Universal Time (UT) by adding 7 hr and 44 min.

The number of transients counted on each channel by TEC for this 90 day period is summarized in Figure 6. This same data is shown in more detail on the 15 day graphs of Figures 7 to 12. Preliminary values of the K index from the Anchorage, Alaska station have been plotted on the 15 day transient data plots as a gross indicator of the state of the environment. The K index value is given on a scale of 0 to 9; the higher the number, the more severe the substorm. It must be realized that the data from the Anchorage station may not be indicative of the state of the environment at the CTS location since the environment can be highly localized; a short, intense substorm at the CTS position may not be indicated in the station data averaged over the 3 hr period.

Table 2. TEC Flight Data

Date	S/C time	No. of Transients			Eclipse	
		CH 1	CH 2	CH 3	Start	Stop
1/31/76	23:16			3		
	23:18		3			
	23:20		2			
2/1/76	18:53	8				
2/2/76	11:08			4		
	11:24			3		
	15:19		6			
2/18/76	05:19			1		
	09:15			3		
	09:30		3			
	09:32			33		
	09:32			6		
	09:33		12			
	09:34		2			
	09:40			3		
	09:42	12				
	09:45		33			
	09:47	33				
	18:05		49			
2/19/76	11:24		33			
	14:11		12			
2/20/76	03:04	1				
	03:06		1			
	15:25		12			
	16:19			1		
	18:13		24			
	21:15	1				
2/21/76	01:17		33			
	02:32			3		
	06:34			3		
	09:05			6		
	23:20		1			
2/22/76	01:24		1			
	11:01	1				
2/23/76	02:03		1			
	02:49	1				
	04:52			3		
2/24/76	08:01		6			
	09:38		49			
	13:31		46			
2/25/76	14:33			33		

Table 2. TEC Flight Data (Cont.)

Date	S/C time	No. of Transients			Eclipse	
		CH 1	CH 2	CH 3	Start	Stop
2/26/76	07:51	24				
	13:38	6				
	19:59	6				
2/27/76	08:41		1			
	10:17			12		
	18:14	1				
	18:14		12			
2/28/76	10:49	62				
	18:35		24			
	18:53	33				
2/29/76	00:26			1		
	20:36	12				
3/1/76	01:57	12			00:02:53	00:22:14
	08:28		3			
3/2/76	04:48		26		23:58:32	00:26:07
	05:04			6		
	05:26		41			
	05:32		3			
	05:34		6			
	05:38		19			
	05:53	6				
	06:07	1				
	06:13		3			
	17:33	14				
	21:06		1			
3/3/76	12:28		3		23:55:19	00:26:07
	12:28		3			
	12:29		33			
3/4/76	16:16		24		23:51:25	00:28:53
	16:31			6		
	16:40		1			
	18:19		24			
3/5/76	02.42		1		23:49:11	00:33:54
3/6/76	04:56	2			23:47:14	00:35:23
	10:45		1			
	16:10		31			
3/7/76	22:14		1		23:45:26	00:36:36
3/8/76	23:01			1	23:43:49	00:37:37

Table 2. TEC Flight Data (Cont.)

Date	S/C time	No. of Transients			Eclipse	
		CH 1	CH 2	CH 3	Start	Stop
3/9/76	04:34	1			23:42:19	00:38:30
	05:10			1		
	17:09		11			
3/10/76	02:17		1		23:40:57	00:39:14
	16:00	1				
3/11/76	03:31		1		23:40:31	00:39:03
	23:15		33			
3/12/76	00:52		1		23:39:21	00:39:35
	03:56	3				
	04:01		33			
3/15/76	09:28			12	23:36:33	00:40:42
	22:46		12			
	22:51	33				
3/16/76	10:19	4			23:35:47	00:40:53
3/17/76	02:36	5			23:35:06	00:40:59
	07:29	2				
3/20/76	15:17		2		23:33:28	00:40:45
	15:31		5			
	15:32	2				
	15:58			2		
	17:40	1				
3/23/76	08:27		4		23:32:28	00:39:47
	11:02		4			
	12:35			1		
	17:23			2		
	21:06			24		
3/24/76	00:40			1	23:32:16	00:39:19
	02:24		36			
	04:27		6			
	17:14	10				
3/25/76	17:15	3			23:32:09	00:38:45
3/26/76	21:34	1			23:32:07	00:38:07
	21:59	3				
	22:07			25		
	23:18		1			
3/27/76	10:45		24		23:32:11	00:37:27
	21:57		12			

Table 2. TEC Flight Data (Cont.)

Date	S/C time	No. of Transients			Eclipse	
		CH 1	CH 2	CH 3	Start	Stop
3/28/76	02:04		16		23:32:18	00:36:39
	02:08			41		
	09:47	33				
	09:48		3			
	09:57	10				
	10:35		1			
	12:29		1			
	12:49		6			
	14:29			1		
	15:45		2			
	15:51			12		
	15:54			6		
	17:25		24			
	19:29	25				
3/29/76	19:36	1			23:32:31	00:35:47
3/30/76	02:28	6			23:32:48	00:34:50
	06:00	1				
	07:07	8				
	09:59			1		
	12:27		1			
3/31/76	06:21		33		23:33:11	00:33:47
	06:21	1				
4/1/76	21:19			1	23:33:39	00:32:39
4/6/76	08:13			1	23:38:12	00:23:26
	12:46			33		
4/7/76	06:01			49	23:39:37	00:23:26
	12:24		1			
	14:31	6				
4/8/76	18:40	49			23:41:18	00:21:15
	19:16	51				
	20:52		49			
	23:42		1			
4/9/76	00:11	6			23:43:19	00:18:44
	00:11		49			
	00:12		33			
	00:13			24		
	00:13			12		
	00:14	6				
	00:15		1			
	00:15			3		
	00:17			1		
	00:17	33				
	00:18	12				

Table 2. TEC Flight Data (Cont.)

Date	S/C time	No. of Transients			Eclipse	
		CH 1	CH 2	CH 3	Start	Stop
4/9/76	00:20		6			
	09:34	49				
	09:37			3		
	09:38	1				
	09:41	1				
	12:15			33		
	16:09			42		
	22:39			1		
4/10/76	07:53	49			23:45:48	00:15:46
	15:19		6			
	20:52		31			
4/11/76	15:28	1			23:49:02	00:12:01
	19:14		24			
4/12/76	09:58		1		23:54:20	00:06:13
4/13/76	00:02		1			
	02:01			1		
	02:10		1			
	02:12			1		
	02:15			1		
	02:28			1		
	02:37		1			
	02:41		1			
	02:42	1				
	02:47	1				
	02:52			1		
	03:12		1			
	03:21		1			
	10:44	33				
	11:37			6		
4/15/76	06:10		1			
	06:20		6			
	06:26			1		
4/1[illegible]/76	18:13		33			
4/18/76	01:02			6		
	17:12	1				
4/19/76	03:12		1			
4/20/76	14:37			1		

Table 2. TEC Flight Data (Cont.)

Date	S/C time	No. of Transients			Eclipse	
		CH 1	CH 2	CH 3	Start	Stop
4/21/76	07:30		33			
	17:01			33		
	17:01	49				
	17:13			24		
	17:14		1			
	17:15		6			
	17:16		24			
	17:27	6				
	17:28	33				
	18:25		49			
	19:33		12			
	22:04	33				
	22:27	24				
	22:50		1			
	22:54		24			
	23:04			49		
	23:55		12			
4/22/76	00:31	24				
	01:01		3			
	05:02	3				
	05:39		1			
	06:08			33		
	06:26		12			
	06:35		1			
	07:12			6		
	07:37		12			
	09:08		12			
	09:15	6				
	09:59	12				
	10:07			6		
	11:10	24				
	12:59		33			
	13:08		6			
	13:10		1			
	13:27			3		
	21:03	6				
4/23/76	03:32	3				
	07:29	1				
	15:06	1				
4/24/76	04:29		24			
	04:29					
	11:49	24				
4/25/76	12.44	2				
4/26/76	12:13		12			
	12:13		49			

Table 2. TEC Flight Data (Cont.)

Date	S/C time	No. of Transients			Eclipse	
		CH 1	CH 2	CH 3	Start	Stop
4/27/76	02:53	1				
4/28/76	08:57	33				
	23:39	3				
4/29/76	07:57	49				
	08:00		1			
	08:07	1				
	19:30	10				
	20:34		12			
4/30/76	00:37	33				
	01:32	25				
	04:06			1		
	04:17	3				
	06:58			33		
	08:17		3			
	09:57		12			

The TEC data shows that transients exist in the wire harnesses. All satellite data have been reviewed to verify that no commands were being executed and that there were no power fluctuations at the times of the TEC counted transients. Therefore, it is assumed that these transients are caused by discharges resulting from the environmental charging of the satellite surfaces.

The number of transients being sensed by the TEC in the 1 sec sampling time is, at times, higher than one would anticipate based on the ground test data. The TEC does have a built-in 5-μsec delay after it counts a transient pulse and this should prevent the counting of line ringing as transients. These high TEC counts may be due to sequential discharging of the large insulator surfaces on the satellite. The ground data does indicate that this sequential discharging may be possible. The evaluation of the high number of TEC transients is continuing.

The correspondence between the transients and the state of the environment as shown in Figures 7 to 12 is rather poor. At times that the environment appeared to be very active (for example, February 7, 8, and 27, March 25 and 26, and April 1), no transients were counted. At other times when the environment is reasonably quiet, there are transients. Transients are also counted when the environment is active. This apparent inconsistency could be due to the uncertainty of the actual substorm conditions at the satellite position in space. Environmental monitors on

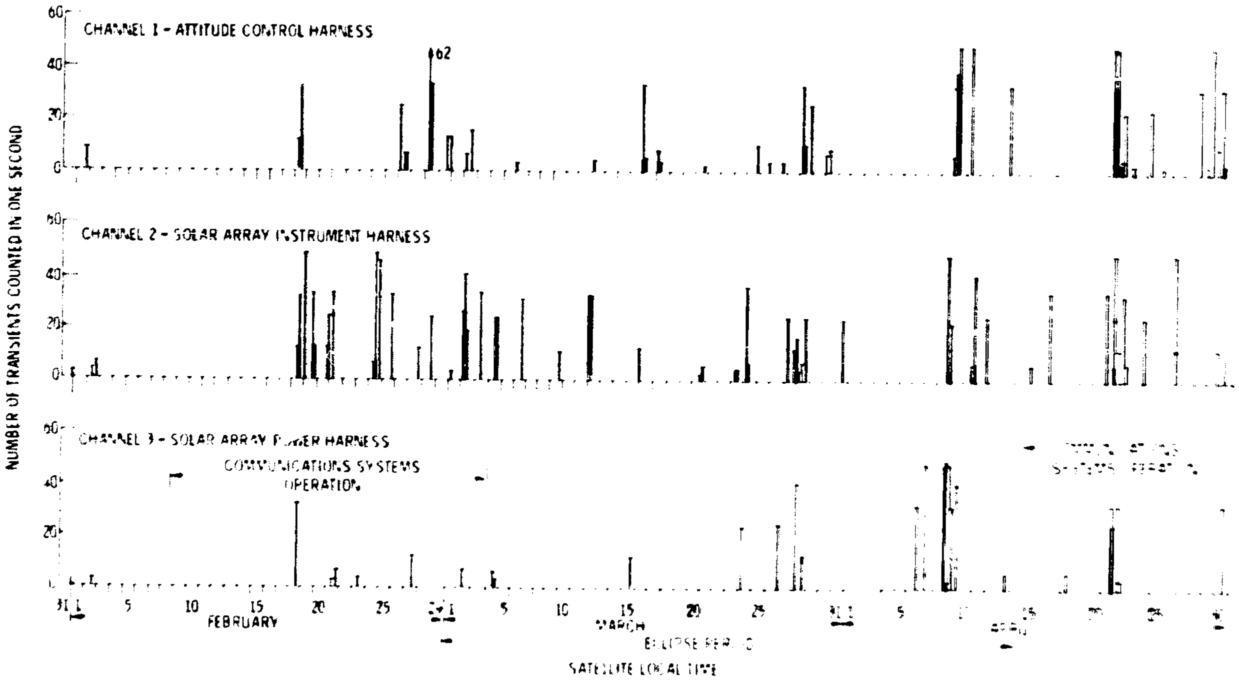

Figure 6. Preliminary Data — CTS Transient Event Counter January 31–April 15, 1976

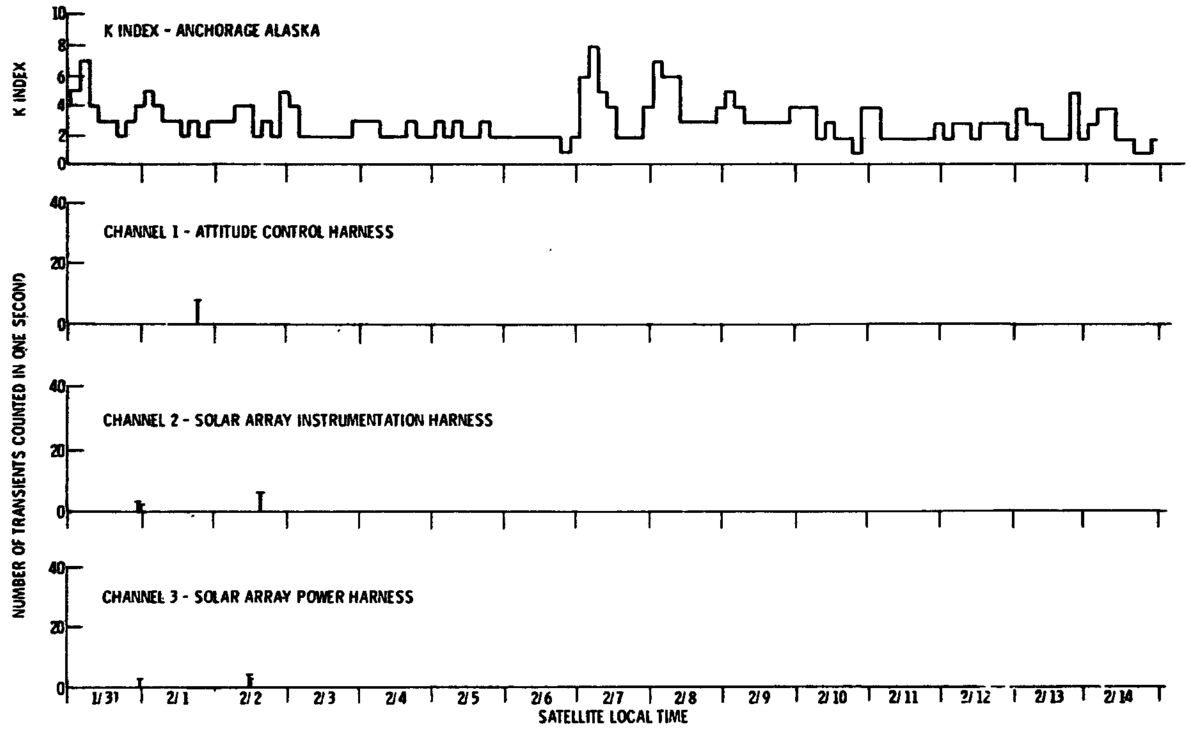

Figure 7. TEC Preliminary Data January 31–February 14

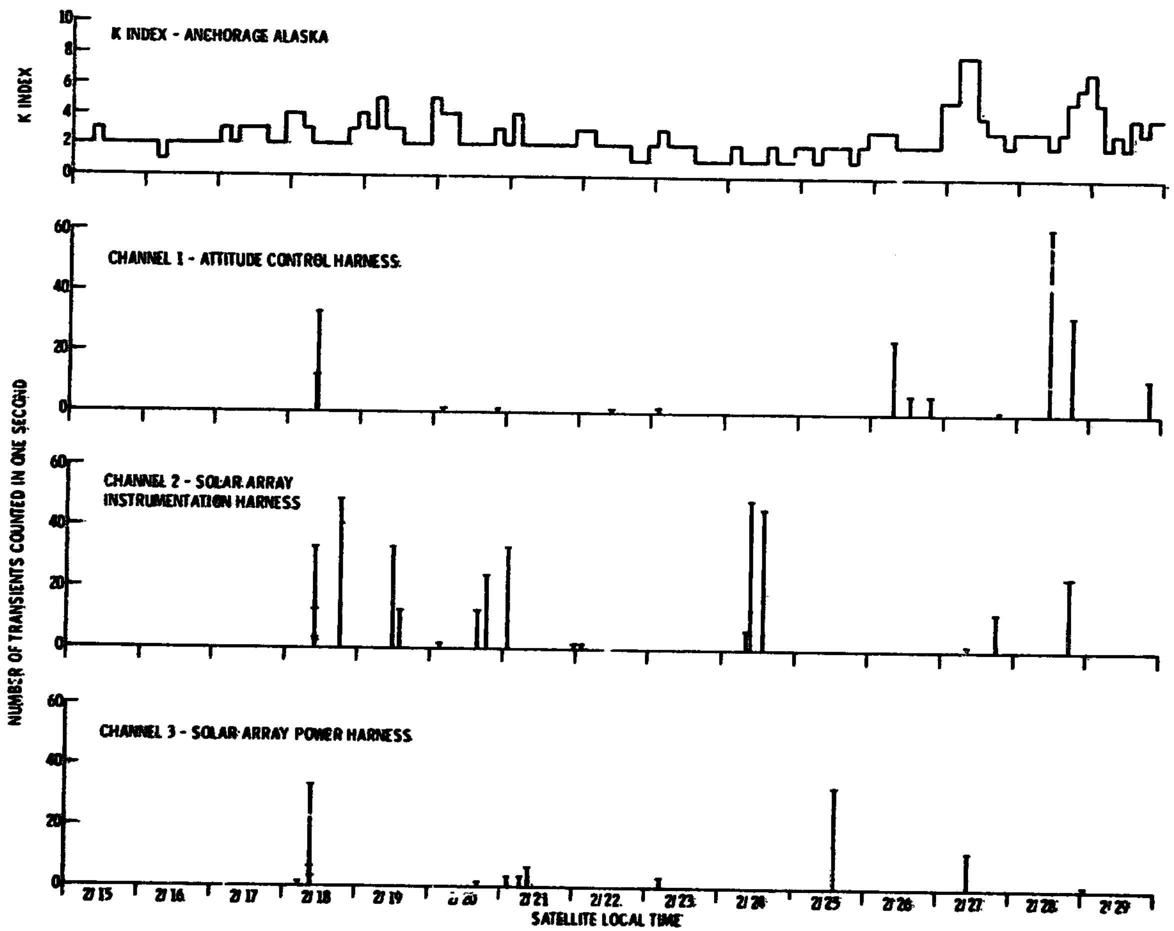

Figure 8. TEC Preliminary Data February 15–February 29

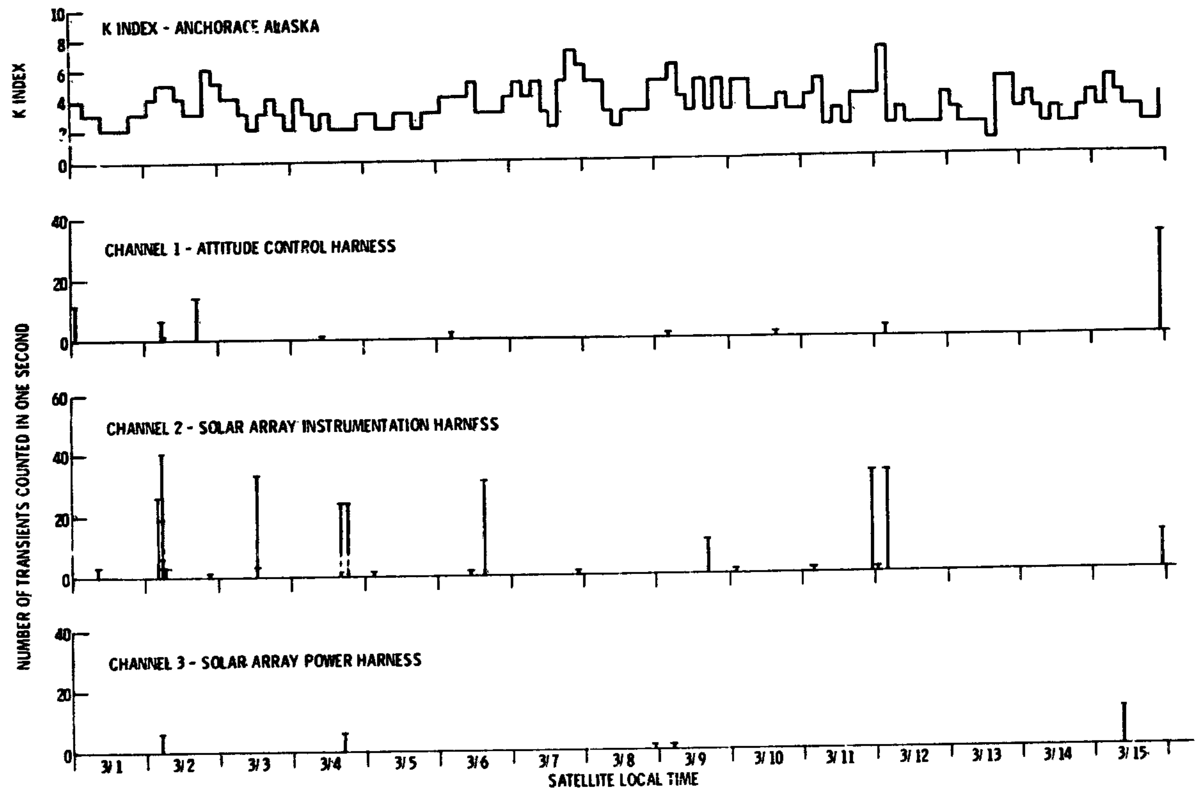

Figure 9. TEC Preliminary Data March 1—March 15

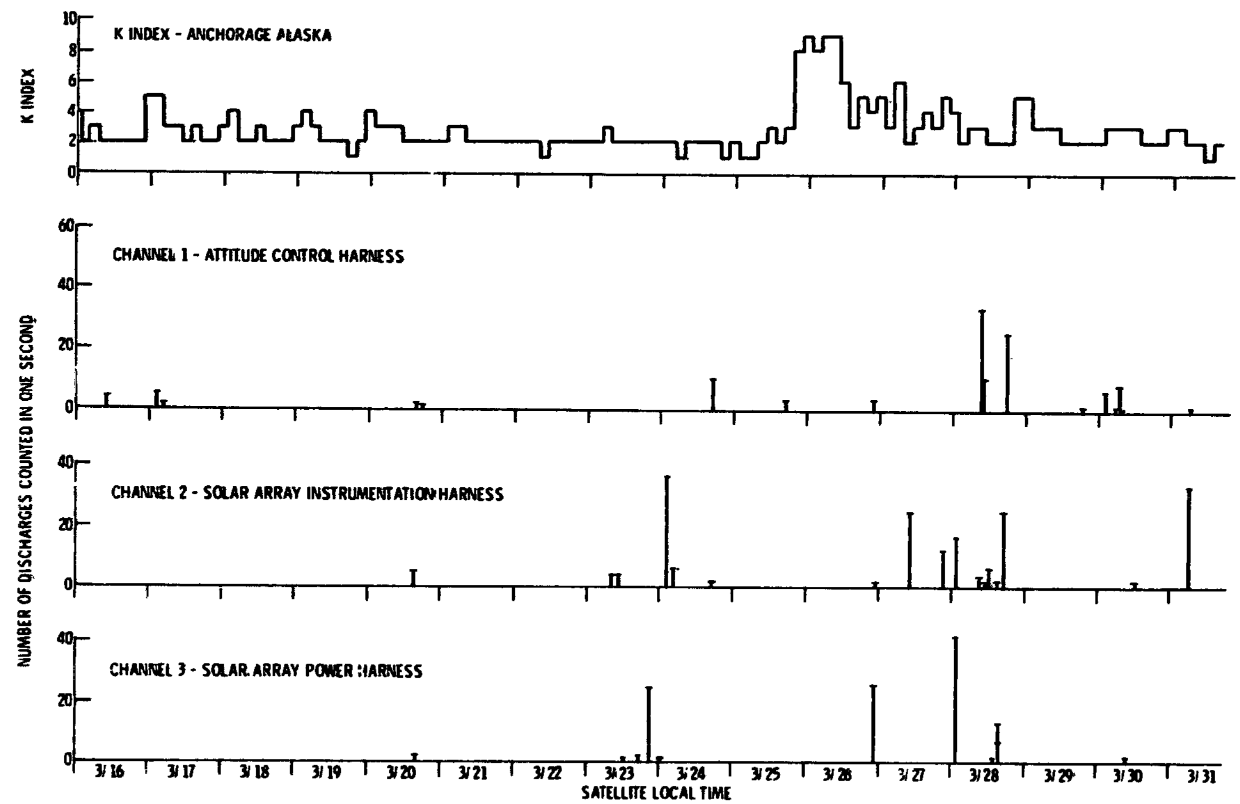

Figure 10. TEC Preliminary Data March 16–March 31

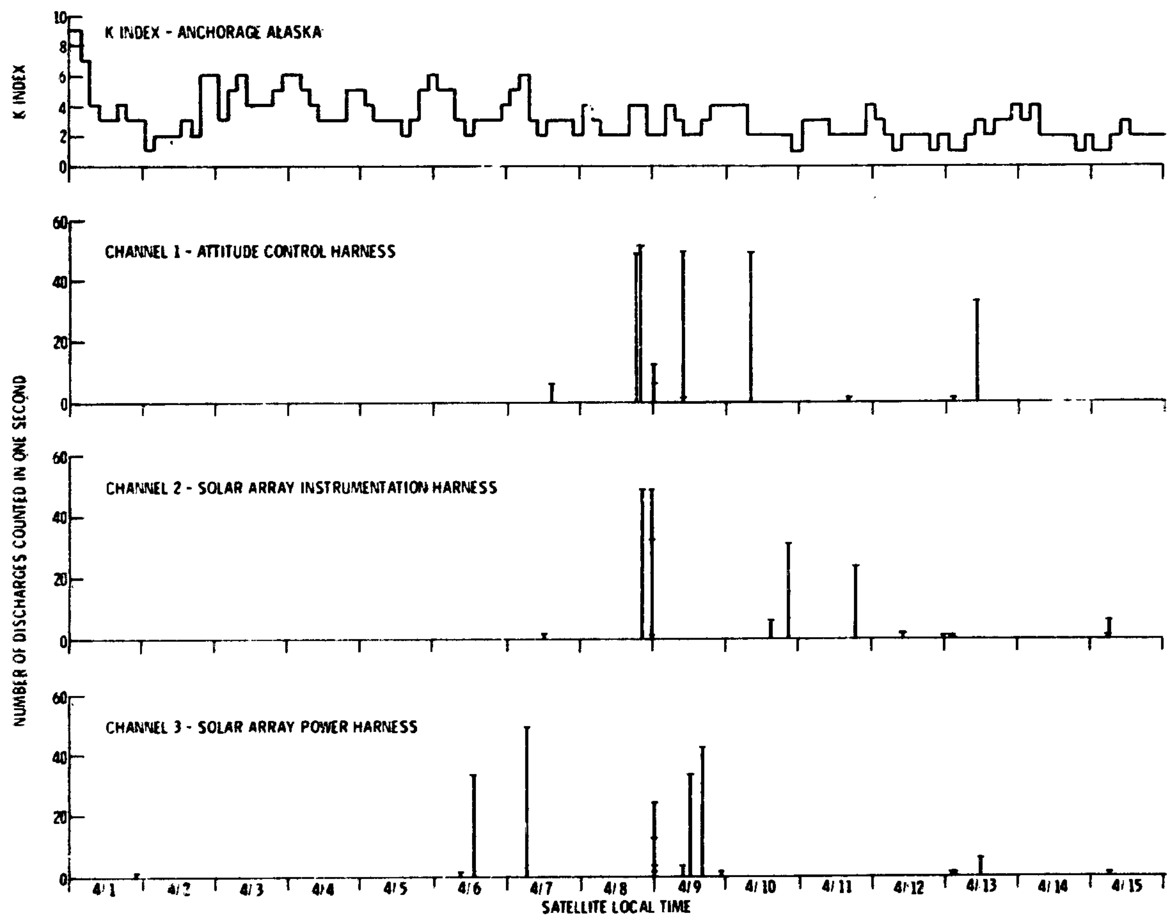

Figure 11. TEC Preliminary Data April 1–April 15

ORIGINAL PAGE IS
OF POOR QUALITY

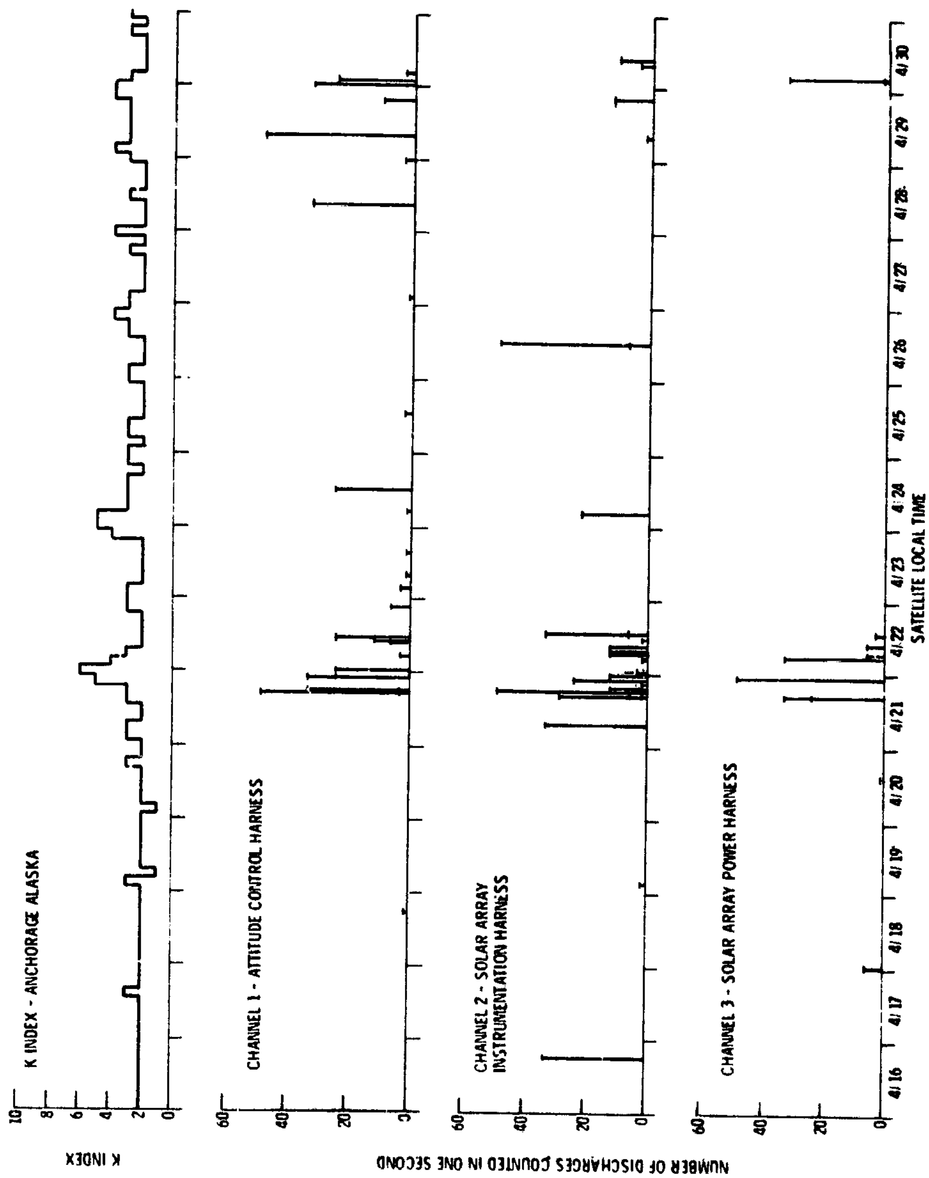

Figure 12. TEC Preliminary Data April 15–April 30

the satellite are necessary to determine if the transient occurred as an immediate result of a substorm or as a delayed discharge due to a differential voltage condition.

The distribution of discharge events is plotted in Figure 13. This is a polar view of the Earth with a 24 hr local time scale superimposed. The TEC transients for each channel are plotted at the spacecraft local time of occurrence without concern for the number of transients. The radial distance on these plots is proportional to the K index. From this figure it is apparent that the pattern of the occurrence of transients is random. This behavior is believed to be due to the fact that the CTS has large insulator surfaces that can be alternately sunlit and shaded so that differential charging is possible. Once charged, the insulators can maintain this charge for long periods of time. These surfaces can discharge, then, at any time in its orbit by responding to an, as yet unknown, trigger mechanism. The evaluation of this behavior is also continuing.

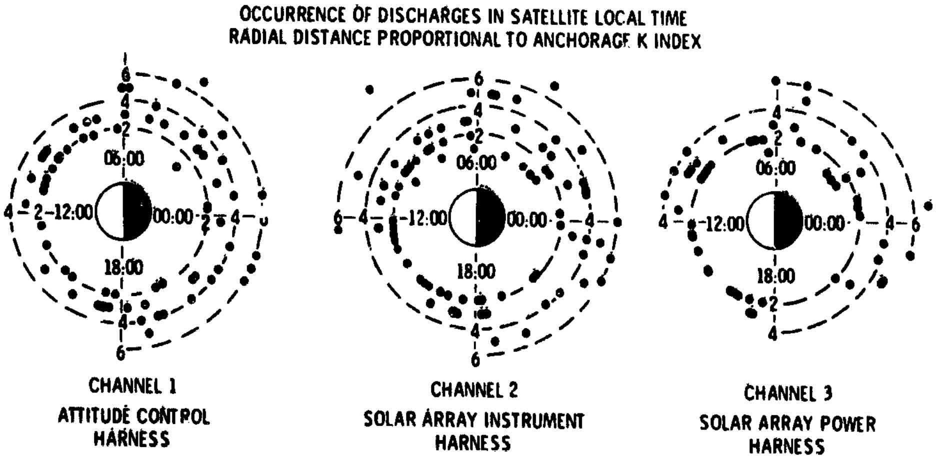

Figure 13. TEC Transient Data January 31–April 30, 1976

The data plotted in Figure 13 also shows that channels No. 1 and 2 are more active than channel No. 3. This behavior was expected since the solar array power bus line is filtered which should limit transients.

These transient pulses detected by the TEC have yet to cause an anomaly in the satellite operation. The CTS was built to conduct high voltage, high power, and high frequency communication experiments. Therefore, considerable care was taken to make the components insensitive to any transients that may result from breakdowns within the high voltage components. This care seems to have made the satellite immune to the anomalous electronic switching behavior of other synchronous satellites.

4. CONCLUDING REMARKS

The Transient Event Counter (TEC) has been monitoring transient pulses in three separate wire harnesses within the CTS spacecraft since 31 January 1976. This detector counts all transients within the harness that have a voltage rise greater than 5 volts. The three harnesses that are monitored are:

(1) Attitude Control Harness

(2) Solar Array Instrumentation Harness

(3) Solar Array Power Harness

The results to date show that the CTS surfaces seem to be charged to the point where discharges occur and these discharge pulses are being transmitted in the spacecraft harnesses. These pulses have not yet caused any anomalous behavior in the spacecraft.

The discharges can occur at any time during the satellite day with no special preference for any local time quadrant. This effect may be due to shadowing of the insulators which can cause differential charging which can result in discharges.

The number of transients being counted is larger than anticipated. This large number may be due to the sequential discharging of large insulator surfaces on the satellite producing a pulse train in the harnesses.

The correlation of the TEC data to the occurrence of substorms has been hindered by the lack of real time environmental data at the CTS position at synchronous altitudes. The preliminary ground station data for the K index from Anchorage, Alaska has been used as an indicator of activity. However, the correlation is poor. It is strongly recommended that any future satellite using a TEC-type detector also include a simple environment monitor as well. This would remove all uncertainity on the state of the environment when transients are counted.

The preliminary review of the TEC operation on the Communications Technology Satellite for the first 90 days has been completed. There are indications of discharge events but no anomalous behavior has been detected. The compilation and review of the data is continuing.

References

1. Franklin, C.A., and Davison, E.H. (1972) A high-power communications technology satellite for the 12 and 14 GHz bands. AIAA Paper 72-580.
2. McPherson, D.A., Cauffman, D.P., and Schober, W. (1975) Spacecraft charging at high altitudes, the SCATHA satellite program. AIAA Paper 75-92.
3. DeForest, S.E., and McIlwain, C.E. (1971) Plasma clouds in the magnetosphere, J. Geophys. Res. 76:(No. 16):3587-3611.
4. DeForest, Sherman E. (1972) Spacecraft charging at synchronous orbits, J. Geophys. Res. 77(No. 4):651-659.
5. Bartlett, R.O., DeForest, S.E., and Goldstein, R. (1975) Spacecraft charging control demonstration at geosynchronous altitude, AIAA Paper 75-359.
6. Stevens, N. John, Lovell, Robert R., and Gore, Victor (1975) Spacecraft charging investigation for the CTS Project, NASA TM X-71795.
7. Rosen, A. (1975) Spacecraft charging-environment induced anomalies, AIAA Paper 75-91.