IDENTIFICATION AND SOLUTION OF A CHARGING PROBLEM IN A HIGH-ALTITUDE DETECTOR

George J. Berzins, John E. Valencia, and Harry E. Felthauser

(Los Alamos National Laboratory, Los Alamos, NM)

and

Joseph E. Nanevicz and Jeffrey S. Thayer

(SRI International, Menlo Park, CA)

I. INTRODUCTION

The unwanted response of spacecraft borne instruments to electrons and other charged particles in orbit has long been at least a nuisance. In the benign case these particles generate background signals that require processing on orbit, increasing the instrument "dead time", and sometimes interfere with the measurement of small effects. In the severe extreme, electrons can charge dielectrics in or near the instrument. Such charging can be followed by a breakdown discharge that can either generate false data, or, in rare cases, cause malfunction of the instrument.

Instruments flown on one of the Los Alamos programmatic missions have experienced all of these effects. Initially, some of these were not understood, and were regarded as simply "false data". A few years ago we began a systematic study of our database that had been accumulating for several years and included data from similar instruments on several spacecraft. We focused especially on the unusual and unexplained signatures. Observations that resulted from the sifting of that database, followed by correlations with measurements of background electron activity, suggested that, in at least some instances, charging might be the culprit. In the case of one particular set of false data signatures, we were able to postulate a model from such observations, were able to test some aspects of that model in laboratory simulations, and perhaps most important, were able to devise and effect a cure that has eliminated the particular problem.

In recounting how we identified and solved the problem, we would like do so from the viewpoint of experimenters who were unfamiliar with the phenomenology of spacecraft charging and unaware of the considerable work that had been done already on the subject. Such a perspective is not only descriptive, but may be potentially useful to others in similar situations. A preliminary report was presented as a poster paper at the 1986 Hardened Electronics And Radiation Technology (HEART) conference.

II. DETECTOR, SPACECRAFT, AND DATA

Representations of the programmatic detector and of the satellite are diagrammed in Figs. 1 and 2, respectively. Two, nominally identical instruments, referred to as Detectors 1 and 2, are located diametrically opposite on the slowly spinning (1 sec < T< 1 min) spacecraft (Fig 2.) in high altitude orbit. Each detector has four similar input channels. Pertinent details of a typical channel are visible in Fig. 1.

The detector senses charged particles via a traditional, standard technique. The particles enter through a window and strike a scintillator whose light output is seen (through a lightpipe) by a photodiode. The charge pulse from the photodiode is amplified and can be digitized. The four input channels differ primarily in their window and scintillator material compositions and thicknesses. Count rates (number of pulses per unit time that exceed a preset threshold) are tallied and recorded for each channel. Simultaneous signals in multiple channels, such as would arise from cosmic-ray showers, for example, are defined as "events". The amplitudes of the signals that constitute an event are digitized and recorded.

Two categories of event amplitudes are shown in Fig. 3. The lower data are representative of events recorded several times per day by each detector, and have been attributed to cosmic-ray showers. The upper curve typifies a signature that had puzzled us for several years. This signature, recorded with similar frequency by all detectors of this type, is characterized by a very large signal amplitude in Channel 1 (thinnest input window), and much smaller signals in the other channels.

III. OBSERVATIONS

As we examined the database and attempted to understand some of the unusual signatures, our attention focused on events represented by the upper curve in Fig. 3. We noted specifically that

1. Events of this type had been recorded by all detectors of this type, on all spacecraft, and with about the same occurrence rate.

2. The large amplitude signal was essentially always in channel 1 (i.e. channel with the thinnest input window). The large amplitude was present in another channel less than about 0.01% of the time. In these latter cases channel 1 recorded a small amplitude.

3. A modified version of this detector did not record any events of this type. The modification involved removal of the scintillator and light pipe (see Fig. 1) from the front end. Specifically, a silicon photodiode replaced the scintillator in a geometry similar to that in Fig 1, and the light pipe was replaced by a (shorter) support stand.

4. Events tended to occur at a greater rate during periods of elevated, high-energy electron flux. An example that spans 6 consecutive days in December, 1983 is shown in Fig. 4. The curve represents the count rate in an instrument designed to specifically measure high energy (> 1.0 MeV) electrons. Rates lower than 10 and greater than about 100 are regarded as indicative of low- and high-level background electron activity, respectively. Occurrence of the strange events is indicated by the triangles on the time lines for detectors 1 and 2 (on the same spacecraft) below the count rate plots.

5. During the more intense periods, such as 12/7 through 12/9 in Fig. 4, there was a suggestion of "pairing" in events recorded by the two detectors. Namely, an event in either detector was soon followed by an event in the <u>other</u> detector. We pursued this observation by examining the entire database. We tabulated (a) whether, following any event in either detector, the next event occurred in the same detector or in the other detector, and (b) the time of the next event. The results for one spacecraft, displayed in Fig. 5., showed that the next event was likely to occur soon (next few hours) and was likely to be in the other instrument. In cases where the events were far apart (many hours, as during periods of low background electron activity), the next event was about as likely in either detector.

IV. THE HYPOTHESIS

The above observations indicated that electrons played a role, ruled out cosmic-ray showers (i.e. pairing), implied that the scintillator and/or lightpipe were somehow involved (i.e. modified vs. original instrument). To reconcile all of the observations we postulated that

(a) the scintillator or light pipe becomes charged by the background electrons, and

(b) the resulting discharge breakdown is accompanied by an intense light flash and by copious rf that couples into the electronics.

Besides accounting for the existence of the event (coupling of rf into all channels to satisfy coincidence criteria), and for the signature (very large amplitude in channel 1 only as a result of the light flash), this hypothesis provided a way to at least qualitatively reconcile all of the observations.

1. All detectors on all spacecraft were similar and on a long-term average basis sampled a similar environment. Thus they should all respond similarly.

2. Since channel 1 had the thinnest window, it was the most likely one to charge to breakdown potential. The window thickness in terms of electron penetration energy is shown for the four channels against a typical electron spectrum measured during a disturbed period in Fig. 6. That figure shows, for example, that electrons need to have at least 70 keV energy to penetrate the window in channel 1, and nearly 300 keV to penetrate that in channel 2. The data suggest that channel 1 is therefore subjected to at least 10 times as much charge. The very rare instances when the observed event had the large amplitude in channel 2 would therefore occur only when the background flux levels are extremely high, which is reasonably consistent with observations.

3. The modified detectors did not contain a scintillator or light pipe, hence the absence of these events. In those detectors almost all of the input area exposed to electrons is conductive.

4. There is an apparent lack of consistency (as opposed to inconsistency) between the data in Figs. 4 and 6, since the former shows a correlation with high-energy (> 1 MeV) electrons, and the latter suggests that lower energies (> 70 keV) should be responsible. However, a more recent, rather cursory examination has not shown the occurrence correlation to be any better with softer electrons. A speculative interpretation might be that the higher energies may somehow be more directly associated with the discharge mechanism. This could be an interesting area for subsequent study.

5. The "pairing" arises as a natural consequence of charging. Both detectors accumulate charge at about the same rate (i.e. because spacecraft spins, both sample a similar time-averaged environment). Thus a discharge in either is more likely to be followed by a discharge in the other, because the latter is "primed", while the first one must now accumulate more charge.

V. SIMULATOR TESTS

We felt that a limited set of tests in a simulator facility might be useful, realizing that the conditions on-orbit could be only poorly approximated. As a further complication, there were no more complete detectors available. The last instrument that had been fabricated had been delivered to the spacecraft contractor some time earlier and was undergoing flight qualification tests.

The available parts included several front end assemblies (without electronics), which were, of course, the critical components. We therefore experimented with these in the simulator facility at SRI International. A diagram of the experiment is shown in Fig. 7. External bias was supplied to the photodiode, and signals from the diode were recorded directly on an oscilloscope. Signals from a nearby electric-field sensor were also recorded. Because of the low electron energy (selectable 20 to 40 keV), the detector window material was removed and the electrons impinged on the scintillator directly.

Results of the simulation supported our hypothesis. Scintillator breakdown could be observed visually, and was accompanied by a large signal from the photodiode and by a substantial signal from the E-field sensor. Amplitudes recorded with the photodiode were typically 2 to 3 times smaller than those recorded in orbit. In view of the different conditions (electron spectrum, flux level, vacuum, etc.) we felt this agreement to be remarkably good.

The unavailability of a full detector, or even of relevant components, precluded any useful interpretations of the measured rf signal, other than to confirm its existence.

VI. PROOF-OF-THE PUDDING

During the course of the simulator tests we pursued a notion based on work that had been done earlier at SRI. We coated the outside surface of the scintillator with a thin (less than 100 nm) layer of aluminum, which in turn was grounded. Our assumption was that the proximity of a grounded conductor would permit the embedded charge to leak off more readily (i.e. leakage path less than 1 mm, vs. several cm in the original, uncoated version). Tests with the aluminized units confirmed this to be a fruitful approach. No discharges were observed.

We were sufficiently encouraged by the support that the simulator tests gave to our hypothesis that we obtained permission to exchange the front end assembly of channel 1 of the last, remaining instrument that was awaiting launch. Success was obvious in the first few weeks after launch. In the first six weeks of operation the detector with the aluminized scintillator did not register any of the large-amplitude, scintillator-discharge caused events, while other, similar instruments in orbit averaged 13 events per instrument. After more than a year of operation these events were still absent. Real events, such as cosmic-ray showers, on the other hand, have been recorded at the anticipated rate and with amplitudes consistent with a slight, calibrated, sensitivity change due to the aluminizing.

VII. CONCLUDING REMARKS

It was extremely gratifying to effect a cure that could be flight tested. We only wish that we had been able to do so earlier in the program. A review of the experience and knowledge gained from this entire exercise seems to single out a few, important points.

1. Correlation with the background electron environment was critical toward the suggestion that charging was the problem. However, in this case it was not necessary to possess detailed knowledge such as electron spectral data or high-resolution time information. Namely, an electron monitor was crucial, but a crude monitor would suffice.

2. The charging details and the mechanism that produced the unusual signals were identified from instrument- and project specific observations, i.e. comparison of performance histories of the "standard" and "modified" detectors, and the "pairing" that resulted from geometric symmetry.

3. A knowledge of the answer may be justification for a further and more detailed study of correlation details with the electron environment. Such a study might uncover subtle features that could lead to isolation of mechanisms in other, still unresolved, charging situations.

4. As of this writing, the evaporated aluminum coating on the scintillator appears to be functioning satisfactorily and has weathered numerous storms. Appearance of the suppressed event signatures, or other change in detector performance, will be an indication of environment-induced changes and one measure of the lifetime of such a cure.

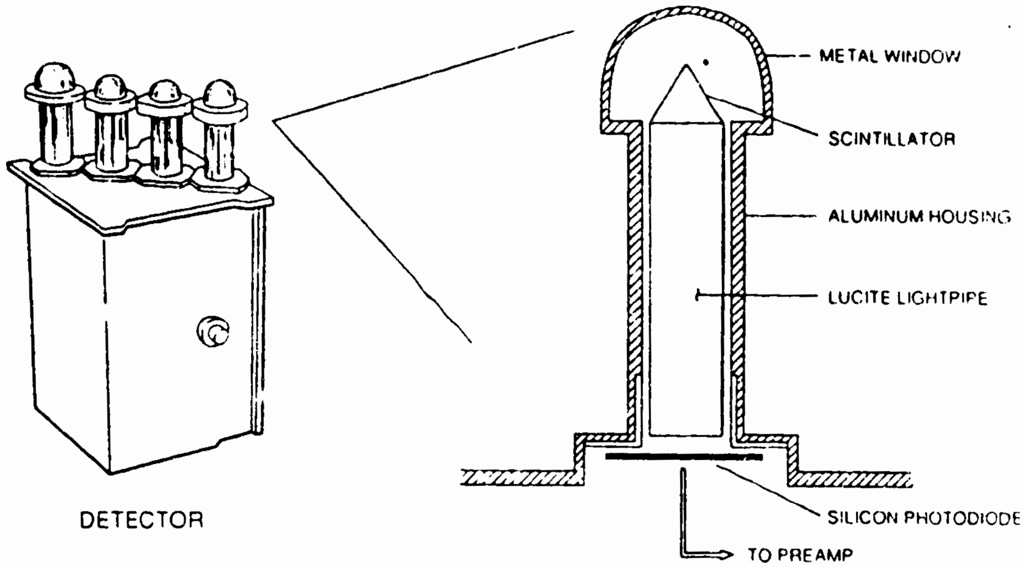

Fig. 1. Diagram of programmatic detector with four input channels. Charged particles enter through metal window and strike scintillator, whose light is seen by photodiode.

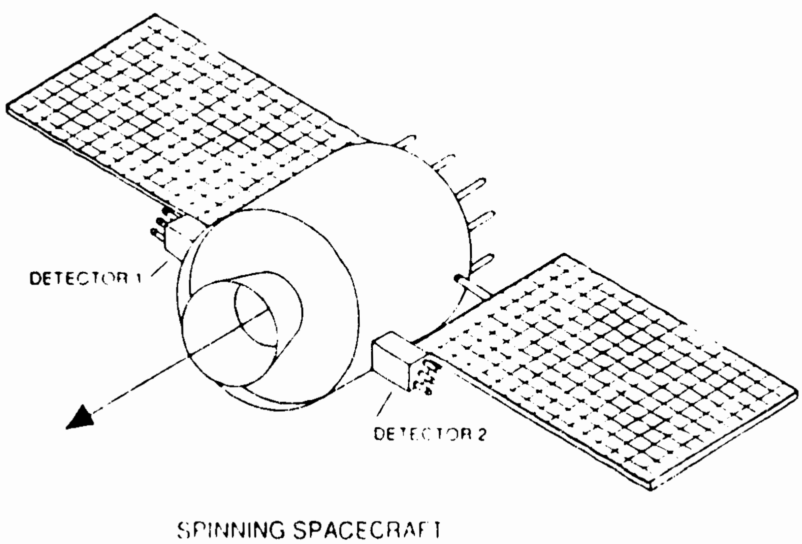

Fig. 2. Artist's sketch of spacecraft. Note relative orientation of detectors.

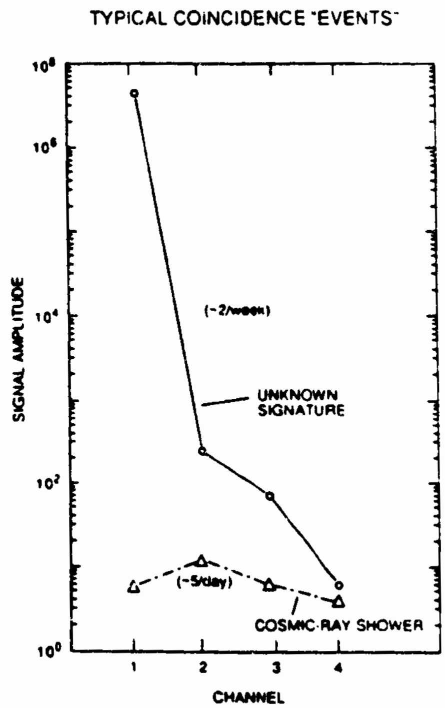

Fig. 3. Representative "event" data.

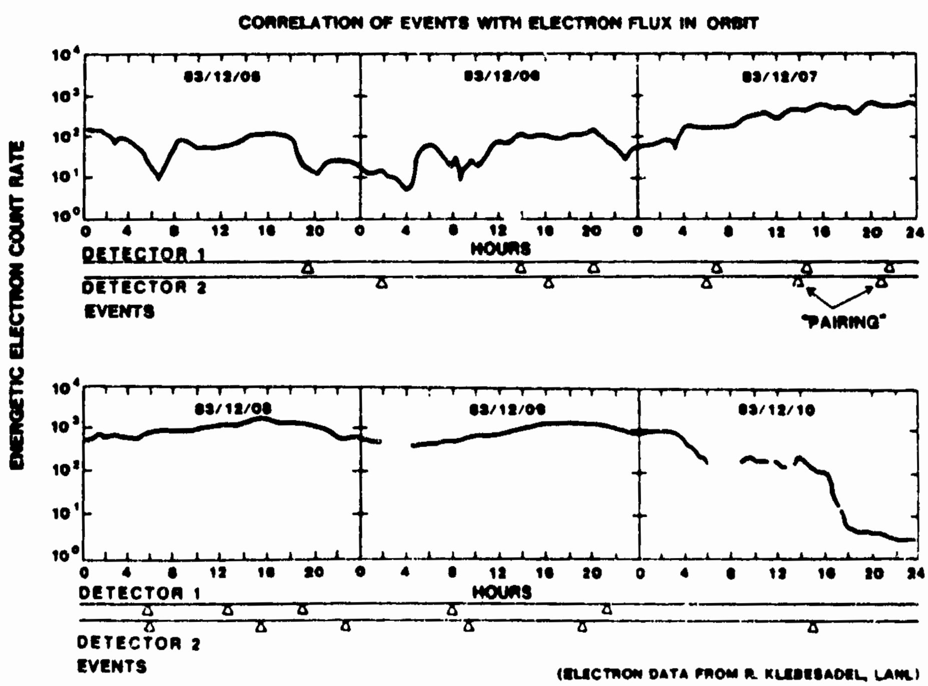

Fig. 4. Time history of charging-related events (triangles) plotted below count rate from high-energy background electron detector on same spacecraft. The six-day period shown here is representative of periods of fairly intense electron activity, and is typical of conditions encountered 8-12 times per year. Note the "pairing" visible on 12/7-12/9.

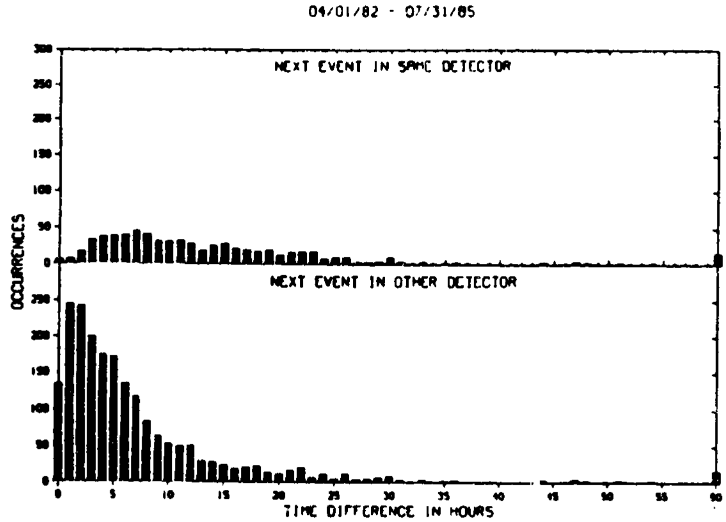

Fig. 5. Tabulation of the time-distribution of "next events" after any event if next event was observed in the same detector and if next event was observed in the other detector.

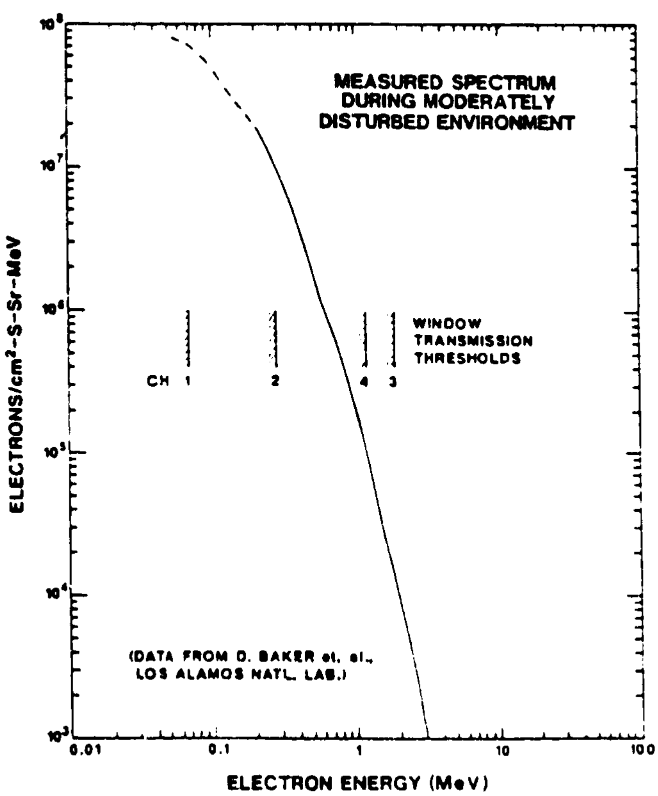

Fig. 6. Representation of window thickness in the four input channels in terms of electron minimum penetration energy, plotted against a typical electron spectrum measured during moderately disturbed conditions.

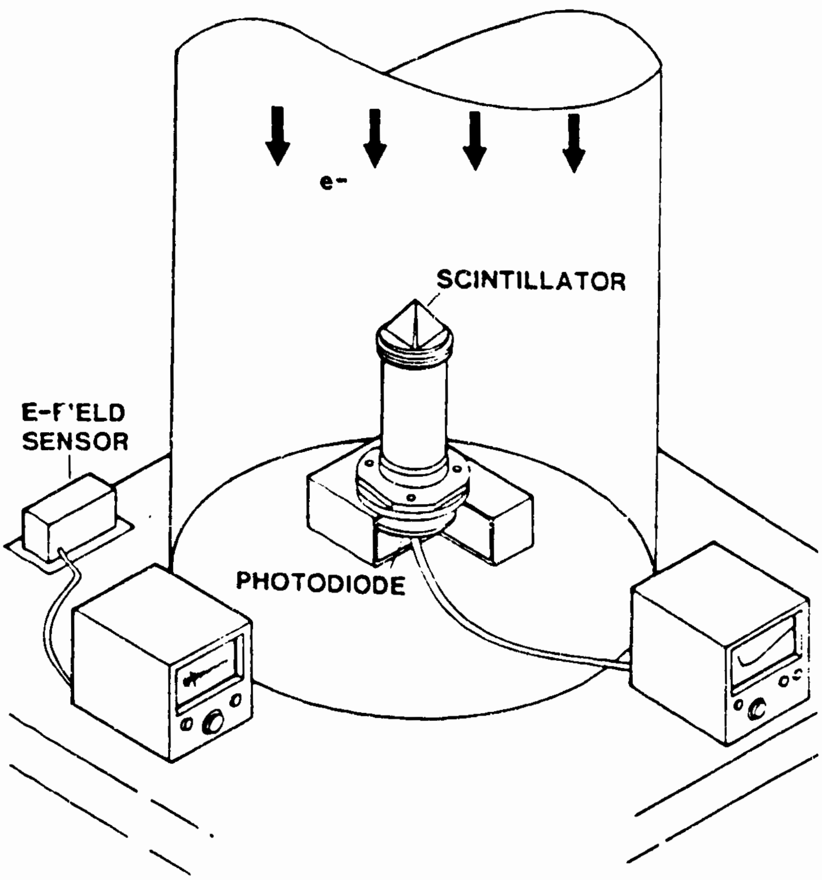

Fig. 7. Diagram of the simulation experiment showing a front end assembly in an evacuated bell-jar, equipped with an electron gun at the top. Light output from the photodiode and the signal from an rf sensor (external to the chamber) were recorded on oscilloscopes.