PROFILES OF INNER- AND OUTER-BELT INTERNAL CHARGING CURRENTS AGAINST GEOMAGNETIC PARAMETER 'L': RESULTS FROM THE FIRST SURF EXPERIMENT

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ABSTRACT

The first flight data from SURF, a new instrument designed to measure charging effects on satellites, are presented in the form of profiles through 'L' of inner- and outer-belt internal charging currents detected at two different shielding depths. These profiles are consistent with our general knowledge of the trapped electron belts as well as with data taken from other satellites over the same time period. At lower shielding depths (0.6mm Al) substantial charging currents are observed within the inner belts: these currents are caused, without doubt, by inner belt electrons since SURF does not suffer in the same way as particle counting instruments from the effects of penetrating protons. This measurement is particularly significant, since inner belt intensity has sometimes been questioned following contamination of early models by exoatmospheric nuclear tests. Large temporal variations of outer-belt peak currents have been observed covering two orders of magnitude to date.

1. INTRODUCTION

SURF was conceived as an engineering instrument to provide satellite operators with real-time 'easy to use' measurements of the radiation and electrostatic charging environments encountered by their satellites. As such it can perform a hazard warning function as well as provide data to assist in anomaly diagnosis. The emphasis was firmly on low mass (~300g), low power (~0.3W), simple interfaces and easy integration. The design of the instrument, the operational modes available and some early ground test results were first reported in 1999 [1]. At that time a flight evaluation opportunity had not been identified. However, shortly afterwards the possibility arose to incorporate the instrument on the STRV1d satellite which was to be launched into geostationary transfer orbit (apogee 39,000 km, perigee 550 km, inclination 7°) and which would remain there to conduct various investigations. Late integration of SURF onto the satellite was feasible only because of its minimal interface requirements. The STRV1d orbit was ideal for the SURF flight-test since it traversed a wide range of radiation environments including the entire width of the inner belt and most of the outer belt. The satellite was launched on 16th November 2000. The digitised data from SURF was downloaded periodically and analysed; in addition, during visibility periods the data were displayed in real-time on the operator's consoles.

2. DESCRIPTION OF THE DETECTOR

SURF can be used to monitor either surface charging or internal charging. It was decided that, for the flight on STRV1d, the instrument would be configured to detect internal charging which is increasingly recognised as a significant hazard to high altitude spacecraft e.g. [2]. The surface charging mode was not used in this mission.

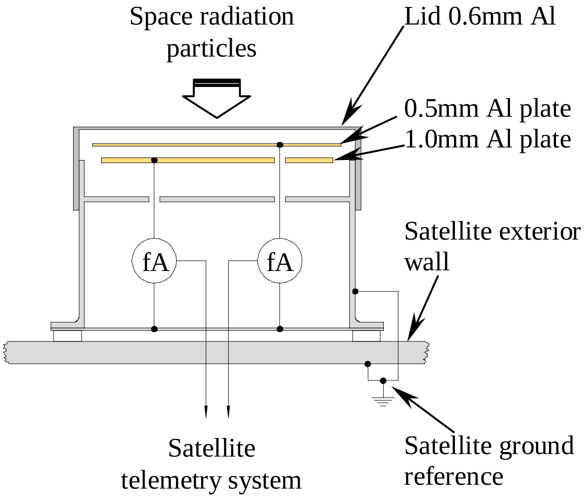

Figure 1 Schematic cross-section of SURF instrument

The basic principle of SURF when configured to detect internal charging is shown in Fig. 1 together with details of the shielding arrangements for the STRV1d flight experiment. Two current collector plates are housed inside a Faraday cage. These plates are situated one below the other, and the shielding is chosen to be representative of that present around much satellite equipment. The current deposited in these plates is primarily due to penetrating energetic electrons above 0.5 MeV and 0.8 MeV for the top and bottom plates respectively. Assuming an omni-directional 2π incident flux with exponential spectrum, modeling with the DICTAT tool [3,4] shows that the plates are in fact most sensitive to 1.0 MeV and 1.7 MeV electrons respectively.

According to basic electrostatic theory the charge deposited on these plates will move to the exterior of the Faraday cage *regardless of the absolute potential of the satellite*. Thus by measuring the current flowing out from the plates, the internal charging currents can be determined. Since the currents are generally in the sub-pico-amp region they require a number of practical measures to be taken to avoid noise and contamination. The Faraday cage is itself connected to the satellite ground reference.

Figure 2 SURF flight unit

A photograph of the flight instrument is shown in Fig. 2: it was mounted on the exterior surface of STRV1d as shown in Fig. 3. The spacecraft was spin-stabilised about the 'vertical' axis.

Figure 3 Preparation of the STRV1d satellite for launch

3. FLIGHT RESULTS

An example of the flight data returned by SURF is provided in Fig. 4 which shows the profile of the normalised current deposited in the upper plate (yellow/lighter line) and lower plate (blue/darker line) around one half-revolution of the geostationary transfer orbit. The data in Fig. 4 is taken from 21 Nov 2000 during the 'return leg' of the orbit (i.e. from apogee to perigee). Perigee was reached at 1115UT. The data is plotted against the McIlwain parameter, L. It should be noted that where the current appears as 'zero' it is simply below the instrument sensitivity in this particular experiment. A compromise was necessary on sensitivity (given that only 8-bit analogue-to-digital conversion was available) since the 'full scale deflection' had to allow sufficient headroom to avoid saturation while passing through the peak of the outer belt under enhanced conditions. For other applications (e.g. GEO) the sensitivity would be increased.

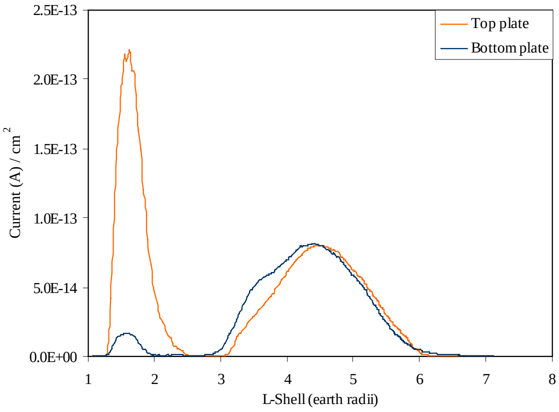

Figure 4 Inner and outer radiation belt profiles as detected by SURF on 21 November 2000.

It is evident that the upper plate sees a strong current when passing through the inner electron belt, peaking at about L = 1.6. However, even the relatively thin additional shielding afforded to the lower plate is enough to reduce this current by a factor of about 10; also the location of the peak is shifted to a slightly lower L value. The response of the instrument in the inner electron belts is significant since their intensity has sometimes been open to question [5] as a consequence of the Starfish exoatmospheric nuclear explosion which contaminated early measurements. Also, when particle-counting detectors are used, proton contamination of count-rates can occur. SURF does not employ particle counting and responds only to negative charge deposited on the collector plates; hence the detected signal is unambiguously due to electrons (proton deposition will tend to reduce the measured current slightly but this is a small effect in general).

The currents detected when passing through the outer belt are also apparent from Fig. 4, peaking at about L=4.5. In this region the currents measured on the upper and lower plates are seen to be similar in profile. The upper plate detected less current at the peak of the outer belt than at the peak of the inner belt (on that day) whereas the situation was the reverse for the lower plate. Clearly the additional shielding which was so effective at reducing current to the lower plate in the inner belt proves to be far less effective in the outer belt. This is a clear indication of the much harder spectrum in the outer belt.

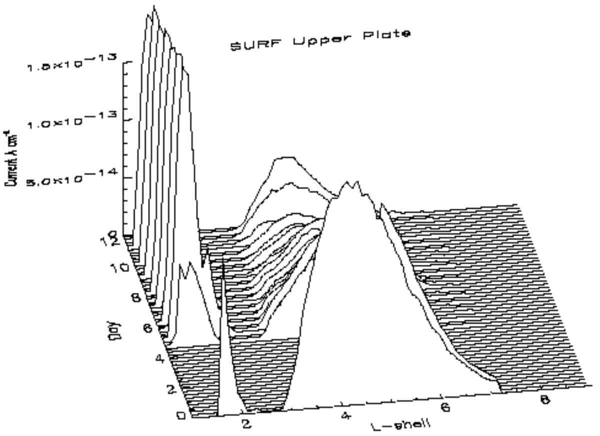

Figure 5 Time series of radiation belt profiles using the upper plate.

Figures 5 and 6 show the evolution of normalised current in the top and bottom plates respectively over the first 12 days of the mission. The inner belt intensities vary between alternate orbits, due to variation in the magnetic latitude of perigee but otherwise appear unchanging. In contrast, the outer belt current profiles vary considerably over time.

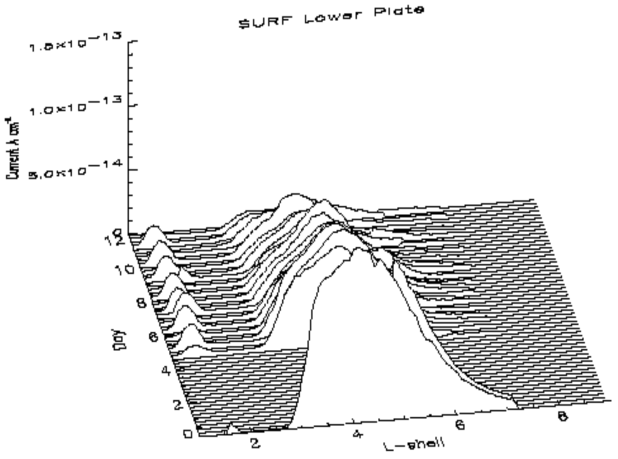

Figure 6 Time series of radiation belt profiles using the lower plate.

SURF data became available as soon as STRV1d was deployed from the Ariane 5 third stage which, from Fig. 5, clearly occurred inside the inner electron belt. Data collection was then interrupted for a few days introducing a gap in the profiles: nevertheless, it is apparent from Figs 5 and 6 that the satellite was launched into an enhanced period for outer belt energetic electrons but that thereafter the belt declined in intensity. Looking at the upper plate data (Fig. 5) there are some signs of an outer belt resurgence towards the end of the period shown. However, this recovery was clearly restricted to less energetic electrons since the lower plate shows no equivalent trend.

The SAMPEX spacecraft also observed the gradual decline in outer belt intensity from an enhanced state over this period. This spacecraft, in a polar low Earth orbit (~550x675km, inclination 82°), intercepts the low altitude ‘horns’ of the outer belt. Its 1.5 to 6MeV electron channel is broadly comparable with the electron population detected by SURF’s lower plate. Daily averaged SAMPEX radiation belt profiles are shown in Fig. 7, for the same 12-day period.

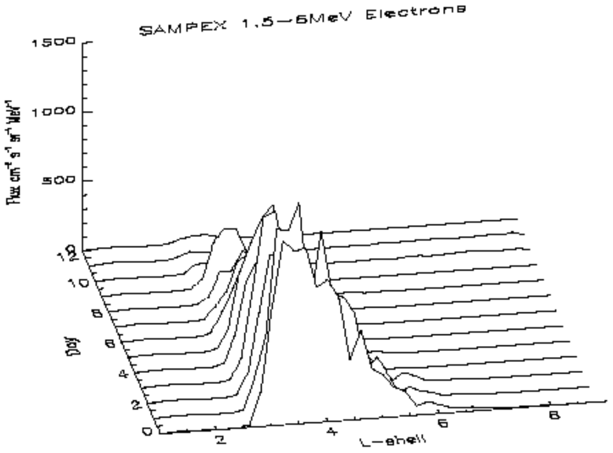

Figure 7 Time series of radiation belt profiles using SAMPEX 1.5-6MeV electron data covering the same period as the SURF data.

It is unfortunate that the STRV1d satellite went into an anomalous state two weeks after the launch and has not yet recovered; therefore good quality data is currently restricted to the period shown. Fragmentary data are still available, certainly enough to know the instrument continues to operate correctly. By chance, one such fragment coincided with a period of outer belt activity on 21 March 2001. The peak outer belt currents were found to be an order of magnitude higher than the previous peak values detected on the first day of the mission. This enhancement was also seen by GOES-8 electron spectrometers in GEO Future data collection will be concentrated mainly on these enhanced periods due to resource constraints.

4. CONCLUSIONS

The SURF instrument has produced profiles of charging currents through L which are consistent with our general knowledge of the trapped electron belts and also with data from other satellites operating at the same time (albeit in different orbits). Within the inner belt a significant and temporally stable current profile is observed: this is of interest since inner-belt intensity has sometimes been questioned as a consequence of exoatmospheric nuclear testing. The effect of shielding is found to be radically different in the two belts, confirming the very different spectral composition of their electron populations. Large temporal variations of outer-belt peak currents have been observed covering two orders of magnitude to date.

It is concluded that the SURF instrument provides a relatively simple but effective monitor of the energetic electron and internal charging environments. Apart from its intended use as a real-time radiation and charging monitor for operational spacecraft it can be employed as a scientific instrument in its own right. In the latter case it would be straightforward to arrange for additional collector plates to extract more information on the spectral composition of the charging currents. Since the device responds only to electrons it could be a useful complement to conventional electron spectrometers whose count rates are sometimes contaminated by protons.

As an aside, it is interesting to note that the total dose delivered to operational satellites located in the outer belts (e.g. GEO and MEO) is dominated by the contribution from energetic electrons for most practical shielding depths. The majority of this dose is delivered during outer belt enhancements i.e. the same enhancements which cause the internal charging hazard. Therefore the internal charging currents measured by SURF should also provide an indication of relative dose rates over time. Future versions of SURF will probably include a simple total dose monitor (e.g. RADFET) which would then allow the correlation between internal charging currents and total dose accumulation to be investigated.

Despite a major satellite anomaly, which has ended routine operations, it is still hoped to obtain some further data from the instrument. Any such activity will likely focus on periods of outer belt enhancements. Wider flight opportunities for the detector will now be sought covering a variety of orbital regimes.

ACKNOWLEDGEMENTS

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REFERENCES

1. K A Ryden, H Jolly, A Frydland, and P Morris, 'A compact electrostatic charging monitor for spacecraft', Proceedings of RADECS 99, Fontevraud, France, pp120-125, (2000).

2. G L Wrenn, 'Conclusive evidence for internal dielectric charging anomalies on geosynchronous communications spacecraft', J Spacecraft & Rockets, 28, 3, pp 324-329, (1991).

3. J Sorensen, D J Rodgers, K A Ryden, P M Latham, G L Wrenn, L Levy, G Panabiere, 'ESA's Tools for Internal Charging', Proceedings of RADECS 99, Fontevraud, France, pp27-33, (2000).

4. www.spenvis.oma.be

5. B Abel, R M Thorne, A L Vampola, 'Solar cyclic behaviour of trapped energetic electrons in Earth's inner radiation belt', Journal of.Geophysical Research, Vol 99, NO. A10, pp19427-19431, (1994).