Contents

11. Space Environmental Effects on the SKYNET 2B Spacecraft

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Abstract

This paper refers to environmentally induced electrical anomalies which are known to occur on geosynchronous spacecraft, and in particular to those which have occurred on the SKYNET 2B communications spacecraft. Details are given of the investigation made into anomalous telemetry data received from SKYNET 2B during its first 23 months of operation. The frequency and timing of these anomalous events appear to differ from those described in earlier reports of such phenomena. Attempts are made to correlate the anomalous telemetry data with data describing the spacecraft environment. Some details are given of the spacecraft configuration and comments made on its susceptibility to anomalies of this type.

1. INTRODUCTION

The SKYNET System forms part of the United Kingdom (UK) Defense Communications Network. The most recent spacecraft, SKYNET 2B[1] was launched from the American Eastern Test Range on 23 November 1974 into geosynchronous orbit and was stationed at longitude approximately 49° East. The spacecraft is controlled and monitored continuously by the Royal Air Force from its Telemetry and Command Station (TCS) located at Oakhanger, England. Throughout the period of orbital operations, although satisfactory communications have been maintained, a considerable number of anomalous telemetry events have been recorded and investigated. This report refers to those events that have been attributed to electromagnetic interference (EMI) caused by electrical discharges within the spacecraft, which have been deduced as having been environmentally induced.[2,3,4] Anomalies of this type are caused by EMI generated by electrical discharges within the spacecraft. Electrical discharges can result from the differential charging of spacecraft surface materials to high voltages after exposure to the local plasma environment at geosynchronous altitude. Spacecraft charging is frequently associated with magnetic substorm activity when energetic plasma is dispersed after the interaction of the solar wind with the magnetosphere.[5,6,7]

2. INVESTIGATIONS OF ANOMALOUS TELEMETRY DATA

The SKYNET 2B telemetry data, transmitted continuously from the spacecraft are received by TCS, recorded on tape and also automatically checked by a computer in real time to ensure that individual telemetered parameters remain within prescribed limits. All deviations from nominal values, omissions or mistimed data are scrutinised and in each case standard anomaly investigation procedures are observed, involving the detailed assessment of every new type of anomaly by a special committee of advisers. Anomalies are classed either as discrete or repetitive, those in the latter category recurring at various times throughout the year. Certain of the discrete anomalies observed to date indicated individual malfunctions within the spacecraft, and in each of these cases a detailed failure mode analysis was carried out, and where necessary, redundant spacecraft systems were switched in by command. In all such cases, contingency action was successfully employed and satisfactory communications operations were maintained.

It is not proposed in this paper to refer further to operational aspects of SKYNET 2B, but rather to consider in more detail the investigations which led to the conclusion that most of the repetitive anomalous telemetry events were caused by the effects of the space environment on the spacecraft.

3. ANOMALIES ATTRIBUTED TO ELECTROMAGNETIC INTERFERENCE

During the first 3 months of orbital operations, a small number of discrete anomalies had been observed on the SKYNET 2B spacecraft. During March/April

1975, repetitive anomalies occurred with increasing frequency and far outnumbered the discrete anomalies. A special investigation of these anomalies was made which concluded that most, but not all, of the repetitive type of anomalous events occurred within the spacecraft. These anomalies were generally of short duration and gave no immediate indication of permanent component failure. The most likely explanation was the introduction of EMI, from unknown sources within the spacecraft, into the logic timing circuits of the Telemetry and Command Subsystem. It was apparent by this time that the characteristics of these particular anomalies were very similar to the environmentally-induced anomalies experienced by other geosynchronous spacecraft.[8, 9, 10, 11, 12]

Although it is now known that most geosynchronous spacecraft have experienced anomalous behaviour that could be due to spacecraft charging phenomena, few have been fitted with the necessary instrumentation for monitoring the extent of electromagnetic noise generated by electrical discharges during orbital operations.[13] and SKYNET 2B has no special instrumentation for this purpose. For this reason it was decided to continue to maintain careful records of all SKYNET 2B anomalous telemetry events, and from those diagnosed as being caused by EMI, to isolate those anomalies that could only have been caused by phenomena occurring within the spacecraft. Anomalous telemetry data could of course arise from a variety of sources including the effects of electromagnetic interference at any point in the overall communication system, that is, the spacecraft, the radio frequency transmission link, the receivers, and the data reduction equipment at the ground station. It was necessary to discard anomalies from the analysis unless additional evidence showed that they originated in the spacecraft and hence might have originally been induced by the geosynchronous environment. In order to maintain a high confidence level when attributing an anomaly to electrical discharges within the spacecraft, numerous checks were carried out to eliminate the ground-based receiving and data processing equipment as a possible source. Fortunately the SKYNET 2B system utilizes two separate transmission links operating in different frequency bands, with separate ground stations, and with parts of the standard telemetry format duplicated in each link. This means that anomalies occurring simultaneously on both transmissions can be considered as originating within the spacecraft to a high level of confidence.

Figure 1 shows the distribution since launch of repetitive anomalous telemetry events attributed to EMI generated within the spacecraft (a total of approximately 300). These anomalies represent approximately 20 percent of the total number that were considered to be the result of electromagnetic interference somewhere in the overall system. It is probable that a large proportion of the remaining 80 percent could also have originated within the spacecraft; however, this cannot be rigorously proved. The anomalies shown in Figure 1 are unevenly distributed

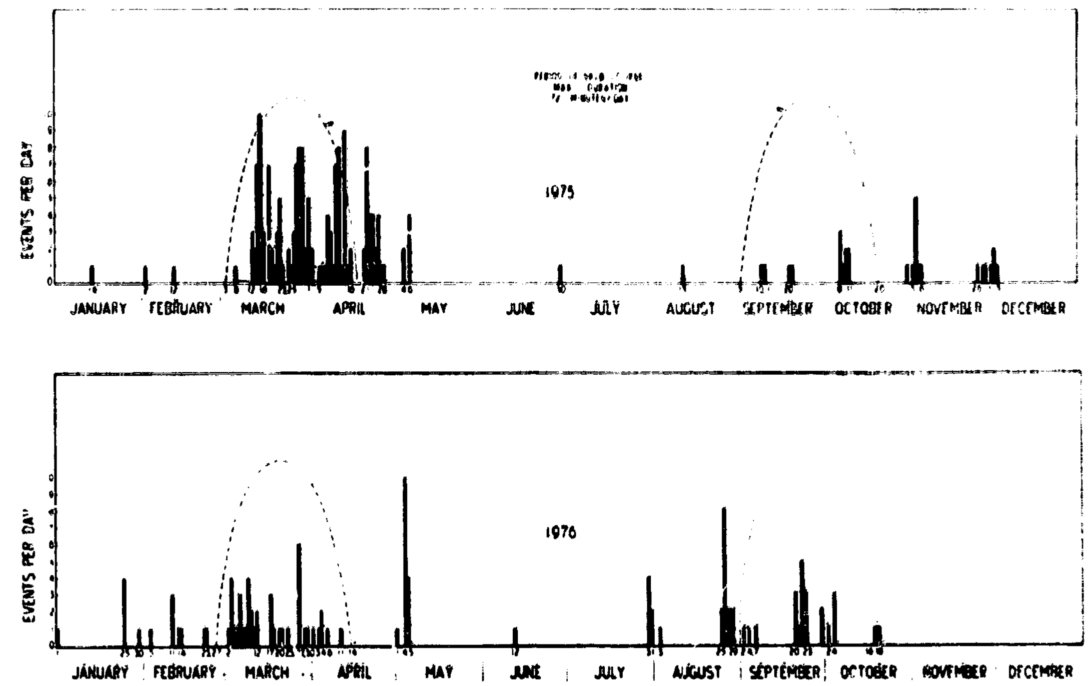

Figure 1. SKYNET 2B Anomalies in Flight Telemetry Data Attributed to Electromagnetic Interference Within the Spacecraft

with time of year, fewer occurring in Summer and Winter months than Spring or Autumn. The largest number of anomalies occurred in 1975 after the commencement of the Spring eclipse season, when the spacecraft is eclipsed by the Earth once per daily orbit. Anomalies during 1976 have followed a similar pattern to 1975 but are fewer in number.

4. CORRELATION OF ANOMALIES WITH ENVIRONMENTAL EFFECTS

Environmentally-induced anomalies, as the name implies, result from the interaction between a spacecraft and its environment. Important factors contributing to this interaction are: first, the daily impact of the solar wind on the magnetosphere and the resulting composition and variations in energy state of the geosynchronous environment in the vicinity of the spacecraft; second, the operational conditions of the spacecraft, for example, its velocity, position, solar illuminance, the spacecraft-sun angle, attitude, eclipse or shadowing effects etc; and third, the spacecraft type and configuration.

In the case of SKYNET 2B attempts were made to correlate the repetitive anomalies of Figure 1 with environmental data such as: time of day, sun-spot or magnetic activity, operational conditions, degree of solar illumination, eclipse periods, etc.[14,15] Figure 2 indicates the distribution throughout the day of anomalies attributed to environmentally-induced effects within the spacecraft. The relatively even daily local-time distribution of anomalies is significant, because it differs from distributions reported from other geosynchronous satellite projects, which indicated that anomalies tended to occur with greater frequency in the local midnight to dawn sector. Such distributions are consistent with the theory that spacecraft, after passage through the antisolar tail of the magnetosphere, become charged to very high potentials as they encounter high energy electrons which are injected into this sector of geosynchronous orbits during local magnetic substorm activity. Furthermore, it was assumed that anomalies due to this cause would be unlikely to occur in significant numbers outside this time sector.[2,16] There is now, however, little doubt that a significant number of environmentally-induced

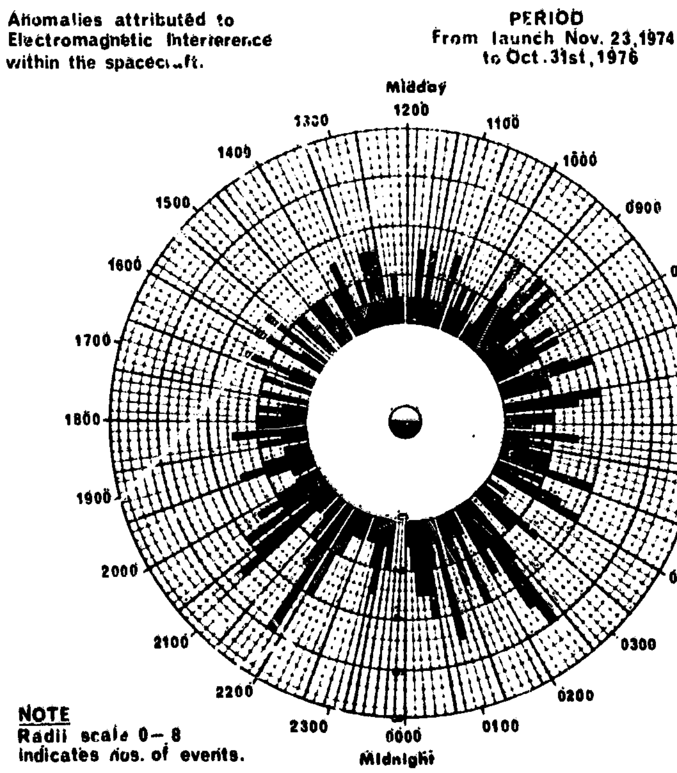

Figure 2. SKYNET 2B Anomalies in Telemetered Data Local Time Dependence

anomalies do in fact occur outside the local morning sector. The precise mechanisms to explain the occurrence of such anomalies are not yet understood. One possibility suggested in the case of the US DSCS II Communications satellite anomaly investigations, is the subsequent interaction of a spacecraft, charged during the midnight to dawn sector, with detached regions of cold (low energy) plasma causing partial discharge and differential voltage breakdown.[17]

In order to account for the very large numbers of anomalous events recorded on SKYNET 2B, it seems more likely that different types of discharge which have a lower threshold or do not require very high breakdown potentials may be responsible. Alternative mechanisms that have been reported are so called 'Malter' discharges or Bilayer 'scintillation' types of discharge.[18, 19]

A very significant factor concerning the SKYNET 2B data is that, by recording and analysing relatively minor occurrences throughout each day, a relatively large statistical sample of anomalies has been obtained. A check was made of the length of time during which the ground receiving station or the computer monitoring were out of commission. It was concluded that on average this was less than 10 percent of the total time and, therefore, did not significantly affect the time distribution of recorded anomalies.

There was no obvious correlation between the anomalies and daily values of sunspot number (Zurich relative sunspot number RZ). However, this would be unlikely in view of the variable time delay of between 20 and 100 hr before any significant effects are experienced at geosynchronous altitude following surface activity on the sun.

Figure 3 shows the geomagnetic activity index Ap plotted to the same timescale as the anomalies. There is evidence of correlation between some of the higher peaks of magnetic activity and the frequency of anomalous events. Correlation was also sought between the anomalies and the 3-hourly magnetic K indices from selected high-latitude observatories North of the spacecraft, with similar results.

It is apparent from the overall distribution of anomalies through the year, that factors other than geomagnetic activity must also be significant. There was, for example, a very noticeable increase in anomalous events during the 1975 Spring spacecraft eclipse season, which seemed to suggest that each daily eclipse increased the likelihood of differential spacecraft charging and hence of subsequent discharge events. Although other eclipse seasons also show an increase in the number of anomalies there is, nevertheless, a small but significant number outside the eclipse seasons. One possible explanation is that changes in sun angle with respect to the spacecraft and the detailed spacecraft configuration are also relevant factors.

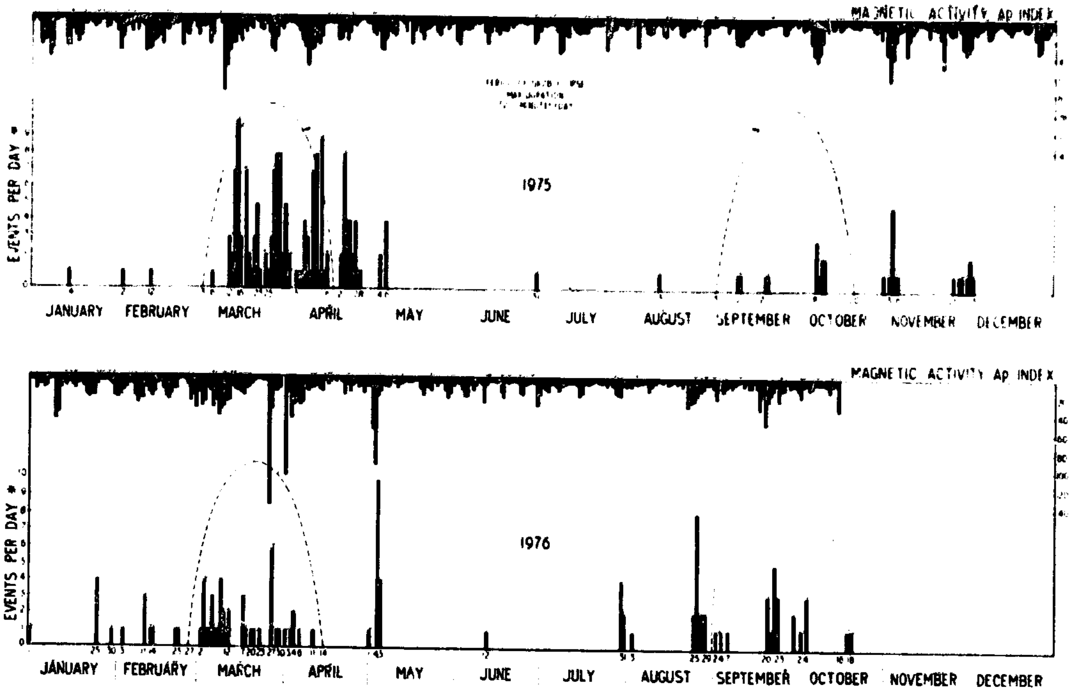

Figure 3. SKYNET 2B Anomalies in Flight Telemetry Data (Attributed to Electromagnetic Interference Within the Spacecraft)

5. SUSCEPTIBILITY OF SKYNET 2B TO ENVIRONMENTALLY INDUCED ANOMALIES

The susceptibility of a geosynchronous spacecraft to environmentally induced anomalies is very dependent upon its precise geometric configuration and detailed mechanical and electrical properties.[20,21,22] The accumulation of charge and spacecraft floating potential will depend upon the type of surface materials exposed to the energetic plasma environment, and the different secondary electron emission and photoemissive properties of individual conductors and dielectrics. An important factor is the extent to which such surfaces are illuminated by the Sun or shadowed. Furthermore, apertures and projections in the spacecraft configuration can become significant when related to the spacecraft Sun angle and its attitude. Other important factors include the voltage breakdown characteristics of individual surfaces and the susceptibility of the various spacecraft subsystems to EMI.

Figure 4 shows the basic SKYNET 2B configuration. The spacecraft uses spin stabilization with a nominal 90 rpm spin rate. The sides of the spacecraft, apart from the thrusters and sensors, are almost completely covered with solar

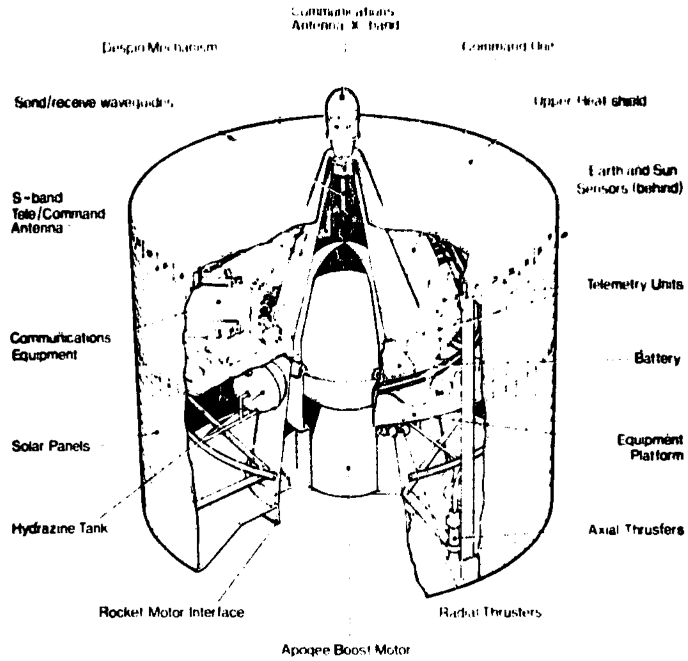

Figure 4. SKYNET 2B Satellite

cells mounted on fiberglass substrates. The solar cells having fused silica cover slips should be relatively immune from large discharges. The forward and aft end shields, however, seem more likely to be susceptible to spacecraft charging effects.

Figure 5 shows the variations in sun angle relative to the spacecraft equator with time of year for SKYNET 2B. During the Winter months the forward shield is in shadow and the aft shield illuminated, these conditions being reversed during the Summer months. The spacecraft is eclipsed for a maximum period of approximately 70 min each day during March and September when the Sun angle is normal to the sides of the spacecraft. There are a number of small apertures in the sides of the spacecraft and the possibility of solar illumination reaching isolated conductive of dielectric surfaces inside the spacecraft cannot be discounted.

SKYNET 2B successfully completed a prelaunch test program including standard EMC test procedures involving the injection of interfering pulses into selected power lines etc; however, no special tests were made that would simulate the effects of electrical discharges in the vicinity of the spacecraft. There was no obvious source of arcing within the spacecraft subsystems and no evidence of self-generated interference during prelaunch tests.

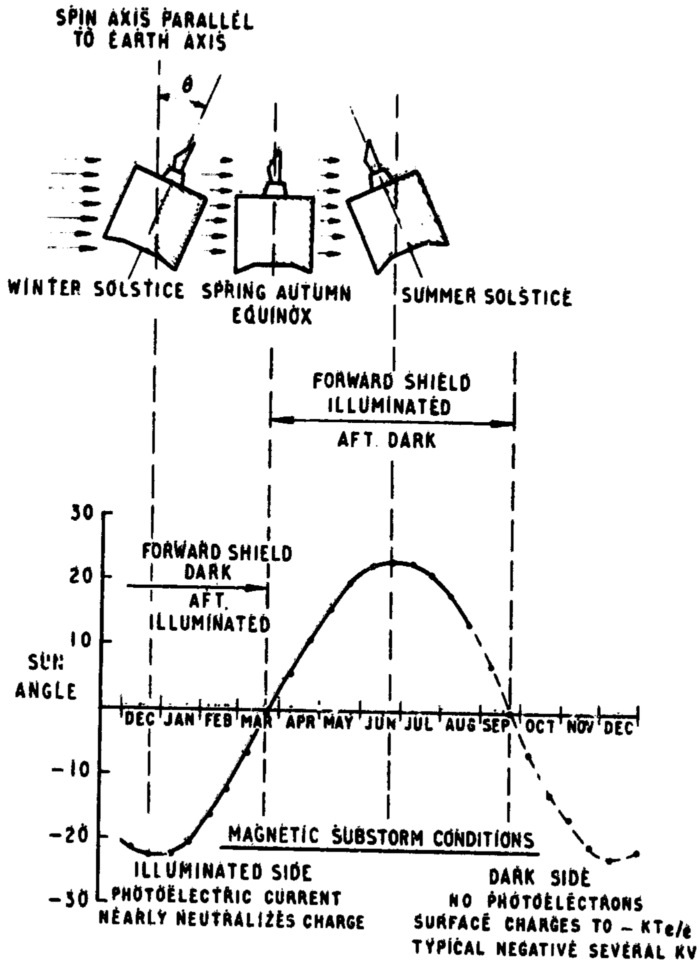

Figure 5. Seasonal Variation of Sun Angle With Respect to Satellite Equator

It seems likely that the SKYNET 2B Telemetry Subsystem would be more susceptible than other subsystems to external interference because of the relatively large number of switching devices that it contains.

6. CONCLUSIONS

The main conclusions reached from the investigations of SKYNET 2B anomalous telemetry data are as follows:

(1) The majority of the repetitive types of SKYNET 2B telemetry anomalies can be attributed to environmentally-induced spacecraft charging effects for the following reasons:

(a) The most likely source of these anomalies is the presence of short bursts of electromagnetic rf interference in the vicinity of the spacecraft. (Anomalies due to EMI from other sources having been eliminated by careful scrutiny of the data.)

(b) There was no other more conventional source of EMI within the spacecraft and there was no previous evidence of such interference during prelaunch ground test programmes.

(c) The occurrence of the anomalies is accentuated over the Eclipse seasons and, therefore, may be associated with photoemissive effects and changes in spacecraft Sun angle (see Figure 5).

(d) There is some degree of correlation of the anomalies with geomagnetic activity.

(2) Important features of the SKYNET 2B data compared with those of other spacecraft are:

(a) The very large numbers recorded due to continuous monitoring, and

(b) The relatively even daily distribution with local spacecraft time.

(3) The most important unanswered questions concern the precise nature of the environmental phenomena and their interaction with the spacecraft. The charge/discharge mechanisms which would produce a large number of anomalous events with a relatively even daily distribution such as observed on SKYNET 2B and additionally have the observed seasonal distribution, also require further study.

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