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TITLE: ON-ORBIT SCIENCE IN A SMALL PACKAGE: MANAGING THE ALEXIS SATELLITE AND EXPERIMENTS

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On-Orbit Science in a Small Package:
Managing the ALEXIS Satellite and Experiments

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ABSTRACT

The Array of Low Energy X-ray Imaging Sensors (ALEXIS) satellite is Los Alamos' first attempt at building and flying a small, low cost, rapid development, technology demonstration and scientific space mission. The ALEXIS satellite contains the two experiments: the ALEXIS telescope array, (which consists of six EUV/ultrasoft x-ray telescopes utilizing multilayer mirrors, each with a 33 degree field-of-view), and a VHF ionospheric experiment called BLACKBEARD. The spacecraft is controlled exclusively from a ground station located at Los Alamos.

The 113-kg ALEXIS satellite was launched by a Pegasus booster into a 750 x 850 km, 70 degree inclination orbit on April 25, 1993. Due to damage sustained at the time of launch, ground controllers did not make contact with the satellite until late June. By late July, full satellite operations had been restored through the implementation of new procedures for attitude control. Science operations with the two onboard experiments began at that time.

This paper will discuss our experience gained in launching and managing this small scientific and technology demonstration satellite.

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Key Words: Small Satellites, Miniaturized Instruments

1. INTRODUCTION

ALEXIS is one of the first modern, sophisticated, miniature satellites, and as such offers a lesson in miniature satellite design and development. It was developed by a small skunks-work project at Los Alamos National Laboratory in collaboration with a startup aerospace company, AeroAstro Inc., and was launch-ready 3 years after its preliminary design review. In a 113-kg package, ALEXIS includes a six-telescope ultrasoft X-ray array (the ALEXIS experiment), a broad-band VHF receiver and digitizer (BLACKBEARD), a digital processing unit (DPU), and a service bus (spacecraft). A major objective of the project was to develop the capability at Los Alamos to design, construct, integrate, launch, and fly capable but cost-effective small satellites. Experiments, spacecraft, and integration cost approximately $17 million. Besides demonstrating new technical capabilities, the experiments are performing state-of-the-art measurements relevant to astrophysics and ionospheric physics.

ALEXIS experienced a serious mechanical anomaly during launch and is therefore not working as originally designed. A quick synopsis of the anomaly is that a solar paddle broke loose from its attachments during launch. It remains attached to the satellite by a cable bundle, and all systems with the exception of the magnetometer, which is mounted on the paddle, are fully functioning. Because the automatic attitude control system required a working magnetometer, it could not function correctly to point the satellite at the Sun, thus delaying by two months the initial acquisition. The anomaly currently affects attitude control and all activities requiring attitude reconstruction. Because of the anomaly, there is a need for constant ground control of the spin axis orientation, and all attitude reconstruction efforts require a detailed computer models to account for the shifted principal axes of the satellite due to a broken paddle, and the fact that it no longer rotates as a rigid body. A detailed review of the launch, rescue mission and initial flight results was presented last year[8]. The purpose of this paper is to review experience gained in the areas of flight operations and the individual system flight performance based upon a year's flight experience.

2. OPERATIONS

The ALEXIS satellite is controlled from the ALEXIS Satellite Operations Center (SOC) located at Los Alamos National Laboratory. ALEXIS flight operations is a 24 hours per day, 365 days per year proposition. Details of the operations scenario are discussed below:

2.1 Operations team

ALEXIS may be the satellite run by the smallest team of operators to-date with less than 10 full time team members. Although only one of them has worked in satellite operations previously, the team members have a diverse range of specialties/interests which contribute to the success of the ALEXIS satellite. Below are listed the various types of flight positions and the number of people in that position along with the background and duties of the individuals.

--satellite flight operations leader: number people--1
background: computer science programmer and Aurora and Antares System Laser Operator
duties: lead member of ground station operations team responsible for overseeing/trending the satellite health and status, coordinating activities between the experiments, arbitrating memory/power usage during times of high demand and training and standardization of operations.

--ground station operators: number people--3
backgrounds: two computer science programmers and Aurora and Antares System Laser Operators and nuclear physicist
duties: configure ground station for pass, confer with experiment duty scientists on command files to be sent, operate ground station during a pass, post-pass processing of satellite data, and preliminary archive of the data

--telescope flight operations leader: number people--1
background: telescope physicist
duties: lead member of telescope duty scientist team responsible for overseeing/trending the telescope health and status, determining operational HV setting and turn-on/turn-off times for telescope operation, coordinating with the Satellite Flight Operations Lead on long term experiment activities, managing personnel, training and standardization of operations.

--telescope duty scientists: number people--4
backgrounds: graduate research assistants with backgrounds ranging from aerospace to liberal arts.
duties: review shift handover notes, generate telescope commands for upload during satellite contact, generate contact script for ground station operator with detailed list of activities for both the ALEXIS telescopes and the BLACKBEARD experiment, provide second set of eyes during contact supporting the ground station operators, post-contact quicklook processing of data to verify correct operations and detector state-of-health, generate the session satellite status report that is e-mailed to all ALEXIS team members (not just the operations team), and generate shift handover notes.

-- BLACKBEARD duty scientist: number people--1-2
backgrounds: RF scientist, RF technician
duties: generate BLACKBEARD commands for upload during satellite contact, quicklook processing of data to verify correct operations and to look for impulsive events.

--attitude control duty specialists: number people--2
backgrounds: aerospace and nuclear physicist
duties: trend spacecraft spin axis position, generate commands as needed to maintain the spin axis relative to the Sun and cosmic sources, and verify post-maneuver that maneuver executed correctly.

--data archivist: number people--1
background: computer science programmer
duties: generate data archives on CD's. In general, the CD's hold 600 mB of data each which is roughly 4-5 days worth of ALEXIS spacecraft and experiment data. Archive the data in a timely manner such that the archive location does not get too full.

Table 1 details the current number of personnel required to operate the ALEXIS satellite, and the task assignment.

Table 1

	satellite flight lead	ground station operator	telescope flight lead	telescope duty scientist	BLACK BEARD duty scientist	attitude control specialist	data archivist
person#1	✓	✓					✓
person#2		✓					
person#3		✓				✓	
person#4			✓				
person#5				✓		✓	
person#6				✓			
person#7				✓			
person#8				✓			
person#9					✓		

Note, each team member often has other additional duties. The experiment duty scientists are also responsible for individual data analysis projects. The BLACKBEARD duty scientists are also involved in creating the ground calibration pulse for certain experiments. In addition to these key members who are active in day-to-day activities, additional support is sometimes required from individual "experts" in specialty areas such as battery conditioning, RF uplink/downlink or attitude control during times of off-nominal operations.

2.2 General satellite operations center operations

Because of the ALEXIS' 70 degree inclination orbit, the SOC operators support 4 satellite contacts per day arranged in 2 sessions separated by about half a day. Each contact lasts about 10 minutes. Although some members of the team are proficient in both satellite and experiment operations, solo pass support has deemed too demanding and risky. Therefore, a minimum of two team members support each pass, one from the ground operations team and one from the telescope duty scientist team. As a backup data archive medium, a video camera with audio routinely records the most important RF displays and the operations teams comments for possible anomaly review after the pass. During times of off-nominal situations, additional personnel are also on hand. In general, telescope duty scientists are on shift duty five days on and five days off while the ground station operators are on two weeks and off one week. There is equal sharing of the good shifts (i.e. daylight hours) and bad shifts between all team members.

When ALEXIS was first launched, only a few terse operational procedures had been written. During the time of the ALEXIS rescue mission, a few fluid procedures were written in response to the emergency-of-the-day. Now as the project is reaching maturity, the operating procedures have become more formalized as day-to-day operations become more routine.

When anomalies are encountered, the team on shift is responsible for alerting the appropriate group of people to help with the anomaly resolution. Anomalies are usually discovered in a timely manner either during a real time contact or while looking through the quicklook data after a pass. In many instances, depending upon the severity of the problem, corrective procedures are developed, approved and ready before the next pass contact. More complex problems, of course, require careful thought and deliberation before action can be taken.

The daily task list for the ALEXIS Telescope Duty Scientists was initially quite extensive as most tasks had to be done manually. Not all tasks were completed before the second pass began. After several months of operations, however, many of the tasks were automated and streamlined, allowing the activities from the first pass to be completed before the second pass. As the project becomes more mature and routine, additional automations are being envisioned both on the ALEXIS telescope front (i.e.. automated command generation application) as well as on the over all ground station operations front and there is hope that the original, pre-launch operations plan of only supporting passes during normal working hours with automated contacts after hours and on weekends will be realized.

Although there is a significant amount of overlap of shift personnel in the SOC due to team members enthusiasm for the project and the occasional plate of munchies, to assure information transfer between team members, especially the team on during the night passes, there is a concerted effort to generate extensive e-mail pass summaries. Explicit written instructions are left for the next shift or e-mail discussions on a particular topic are distributed to the team. Weekly meetings of 0.5 hr duration are used for discussion of long term plans and additional meetings on specific topic of interest are scheduled for more in-depth discussions.

2.3 Operations observations

Reflecting upon the flight operations experiences of the past year and comparing the ALEXIS experience with the operations of other satellite operations, the following points can be made:

-- the small operations team leads to better information transfer rates than a large team. Often half of the flight team are in SOC when anomalies occur and are resolved, therefore, there is no 3rd or 4th hand reporting of anomalies

--because of the small, skunk-works type team, there is minimal paperwork and protocol requirements for everyday operations

--a small team busy with day-by-day activities is sometimes too busy to fully track/resolve/document anomalies

--as operations become more routine (i.e. time is not spent chasing anomalies), more time for ancillary activities, such as routine and special data analysis projects, becomes available

3. GROUND STATION

The ALEXIS system employs a "store-and-forward" architecture, passing data and commands between the spacecraft and a single ground station at Los Alamos. Commands are uplinked at 9600 bits s^{-1} and data are downlinked at 750 kilobits s^{-1} via a steerable 1.8-meter dish mounted on the roof of the Los Alamos Physics Building. The ground station was originally designed to receive data and transmit commands automatically without human intervention, but due to frequent, unpredictable ground station crashes, this hope has not been realized. The ground station hardware has been previously summarized by Priedhorsky[6,7,8]. The hardware can be categorized as 1) RF hardware and 2) control computers.

3.1 RF Hardware

The ALEXIS ground station uses a 1.8-meter tracking dish for both uplink and downlink. It is controlled via a personal computer using the satellite ephemeris information and Universal time (which is read automatically from a WWVB receiver), to calculate azimuth and elevation angles for the dish. For the uplink, a 20 Watt transmitter is used. The uplink transmitter input and downlink receiver output both connect to a custom-built telemetry interface board which packetizes uplink data and de-packetizes downlink packets. For the most part, this complex system of more than two dozen components has worked extremely well with only two minor exceptions. Due to the availability of spare parts in hand and the local RF expertise from the BLACKBEARD team, not a single pass has been missed due to hardware failure.

--Diplexer

- On two occasions, problems with the diplexer occurred which resulted in a gradual decrease in receiver strength and finally in extremely marginal contacts. The first problem on 23 August, 1993 was attributed possibly to weather as the system was not enclosed in a radome and therefore, exposed to the harsh elements of New Mexico. To remedy the problem, the box was sealed shut with silicone sealant. On the second occurrence of the diplexer problem on 2 February, 1994, the box was opened and a migrant piece of metal fuzz was discovered inside the diplexer box. It is possible that both failures were attributed to the fuzz. Since that time as a precautionary measure, a salvaged military radome has been installed over the tracking dish to help protect it from the elements.

--Down Converter

-The down converter failed gradually over the course of 5 days after 3.5 years of continuous operations. This was quickly diagnosed and a spare swapped in its place before the next pass.

3.2 Control computer

The ALEXIS ground station control computer system has 2 types of control computers: a DOS based computer used to control the tracking dish and Apple based MAC IIfx computers used for command and data acquisition.

--Dell computer

Driving computer for the Telonics tracking dish is a DOS based Dell computer. Except for an occasional reboot, this computer has run without any problems

--Mac IIfx

The telêmetry interface board connects to a Macintosh IIfx computer which handles all the high level telemetry control as well as scheduling satellite passes and keeping track of the relationship between the satellite real time clock and Universal time. Due to configuration control, this computer is currently running Mac operating system v6.0.5. Problems encountered with this system are as follows:

-Repeated 20" monitor failures

The large screen monitors have failed recently three times within two months. We were able to ship them back to the company over night and a replacement arrived at the loading dock within 3 days. While the monitors were being repaired, a smaller screen display was arranged such that the most important information would be displayed on a backup 13" monitor.

-Second Mac IIfx required

After repeated problems with telemetry dropouts during contact, it was deemed necessary to separate the Doppler calculation function from the main Mac IIfx control computer onto a secondary IIfx since Mac architecture/speed does not seem to be able to keep up with both Doppler calculations and data-down/commands-up tasks. The separation of tasks has successfully corrected the drop out problem.

-Frequent ground station computer crashes

Ground station crashes usually occur during command upload for reasons unknown, which is either a problem at the ground station that causes it to hang or a handshaking problem resident at the satellite. The occurrence of crashes tends to be erratic and unpredictable. At times there may be only one ground station crash per week while at other times there may be one or two per day. When a crash occurs, it takes 3 minutes to re-boot and re-configure the command computer which often means if a crash occurs near the end of a contact that there is insufficient time to recover. This results in a loss of 3 minutes of down load data time that can usually be recovered on the next pass. As this seems to the most persistent failure mode of the entire satellite system, an effort has been made towards replacing the Mac IIfx, which has been known to be an unstable platform, with a SUN SPARC 20 computer. This effort, part of an advanced ground station technology initiative for the follow-on LANL FORTÉ and MTI small satellite programs, is nearing completion. Ground station crashes are the only remaining obstacle to automated operation. If the new ground station performs as expected, night and weekend passes will be tracked without human intervention.

4. SPACECRAFT BUS

The ALEXIS spacecraft bus is a complex, robust, and flexible assemblage comprised of communications, power, and control systems with nearly a gigabit of memory packaged into a miniature satellite weighing only 45 kg and occupying less than 25% of the total satellite volume[7]. Even under the duress caused by launch damage, this mighty little satellite was robust enough to survive until help from the ground could steer it towards the Sun. Details of the rescue mission have been discussed by Priedhorsky[8].

4.1 Attitude control system

Although, it was never possible to fully test or utilize the on-board ALEXIS attitude control system due to the damage to the magnetometer which occurred at launch[8], the ALEXIS attitude is routinely adjusted from the ground to keep the spin axis within 15^{o} of the Sun to maximize solar input to the solar cells. The maneuvering strategy selected to manually maneuver the ALEXIS satellite is to actuate specified torque coils at selected intervals during several orbits, causing the spacecraft to precess in such a way as to move to the desired location. Such maneuvers are a well-established technology with a rich literature. One of us (RW) wrote an automated program that given the current spin axis and the final desired spin axis determines the correct times to activate the torque coils that is routinely used to maintain the ALEXIS attitude. The daily satellite drift is of order 1-5 degrees per day which requires a maneuver every 2-5 days.

This means of maintaining the ALEXIS attitude has proven to work quite well. However, two anomalies were caused by human error when the spin axis precessed significantly away from the Sun instead of towards it due to incorrect command files being sent. Procedures for maneuvering have since become more formalized with several checks and balances being added before the command file is sent. No other maneuvering anomalies have been encountered since the change in the procedures.

4.2 Central processing unit

On 13 October, 1993 during a visit by our primary funders from DOE, the spacecraft configuration at contact was found to be in a state consistent with the 80C86-based central processing unit (CPU) having upset. Upon investigation of the stored data, it was discovered that the reset was associated with a South Atlantic Anomaly (SAA) crossing. The satellite was reconfigured for flight and operations proceeded normally. This is the only incidence of spacecraft CPU resets.

4.3 Radio frequency interface board (RFIB) has problems at elevated temperatures

On 9 August, 1993, contact with the satellite was lost as the satellite slipped into the first dawn/dusk, 100% illumination orbit. After several frantic days of postulating causes (bad ephemeris, ground station malfunction, space debris impact--Perseid meter shower, temperatures out of limits, spacecraft CPU reset that enabled the onboard attitude control software to flip the satellite upside down, etc.) two possible scenarios were considered as viable possibilities:

1) elevated temperatures causing a problem on an undetermined spacecraft component

2) the solar panel voltage regulator (SPVR) was functioning on a 10 Hz cycle, causing noise transients on the bus which results in non-contact. The SPVR's function is to take the solar panels off-line if their voltage goes above 36.5 Volts. This condition was only supposed to occur when the panels initially came into the sun from shadow and were fairly cold. When they are in 100% sunlight, the panels were supposed to be warm enough with enough load to keep the voltage below that point.

The solution for condition 1 is to lower temperature by turning off components while the solution for condition 2 is to turn everything on to use more power to keep the SPVR from tripping. When the next contact was made on 10 August, 1993, solution 2 was chosen due to the data in hand and the commands were sent to raise the heater set points to use more power. However, this quickly proved to be the wrong solution as contact was once again lost until 26 August, 1993 when the satellite slipped back into darkness. Luckily, during the 14 days of no contact, the satellite did not drift far enough to allow sunlight to enter the telescopes. If it had, the detector filters would probably have been damaged due to excess heating.

Since this exercise in stress management, although we do not have thermistors on the RF components of the satellite, it has been hypothesized based upon temperatures from adjacent areas that some component on the RFIB board is sensitive to temperature and a policy of strict temperature management has been invoked. This failure mode was not caught during full up thermal vacuum testing because the transmitter failed early in the test sequence and the remainder of the testing was done with a digital hard link. After the transmitter was repaired, the individual components were thermal vacuum tested, but a second full system test was not done.

To keep temperatures within range, it has become necessary to turn off all telescopes operations 1.5 days before 100% illumination orbits are encountered and wait to turn back on 1.5 days after darkness is again traversed. This means that for the approximately four times per year that we are in the dawn/dusk orbit, all telescope operations cease, although BLACKBEARD operations continue. During these times, only one contact per session is supported which allows us to get down spacecraft state-of-health data as well as BLACKBEARD data with a minimal heat input to the system from the transmitter. The times of 100% illumination, when no telescope data can be acquired, are actually looked forward to with great relief by the small flight team as it is a time to get caught up on sleep as well as other work. If a ground station crash occurs during the 100% illumination orbits, it is rare that we are able to reestablish contact with the satellite as the extra thermal input from the transmitter has increased the temperature enough to cross the thermal threshold.

As a result of the thermal management, no contacts have been lost due to temperatures being out of limit high. Figure 1 shows the daily average of both the variation of dark time (number of minutes per orbit of darkness) and the temperature of one of the electronics boxes as a function of time since launch. The times of 100% illumination are

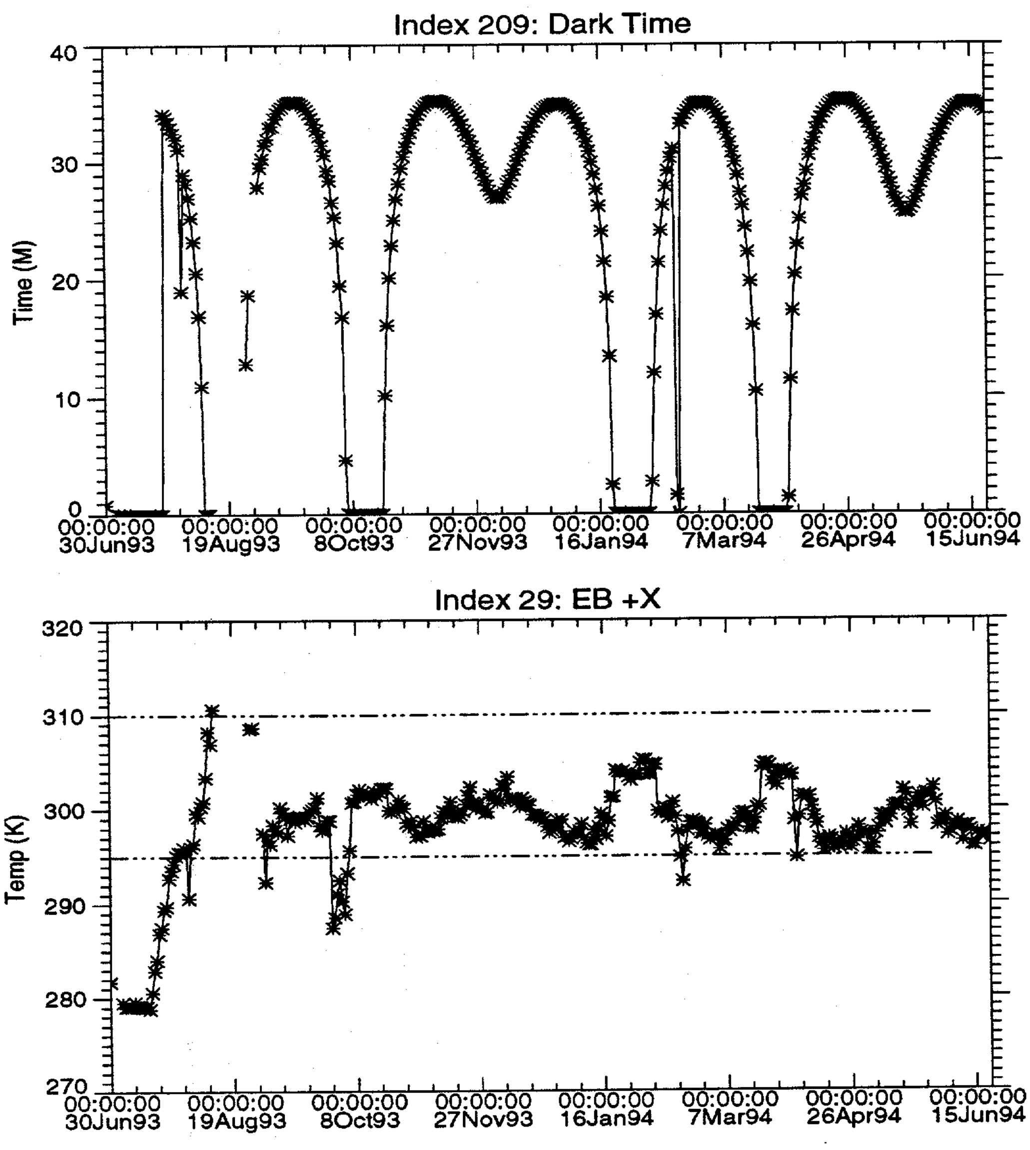

Figure 1: Time history since launch of the orbit dark time and one of the electronics boxes.

clearly visible as times of zero minutes of darkness. Also visible is the loss of contact during August, 1993 where there is a two week gap in the data. When this occurred, the electronics box exceeded 310°C, however, the actual part that was responsible for the lack of contact, was quite probably much hotter than this. The temperature decrease in early October, 1993, is the result of turning off the telescopes a little too early as we were learning to control the satellite temperature as the satellite slipped into the next 100% illumination orbit. This plot demonstrates that we have been successful with the thermal management for the remainder of the mission.

4.4 Batteries/solar cells/charging circuitry

The ALEXIS satellite contains four 1.2 amp-hour, 28 V battery packs built of 23 NiCd cells each. Typical battery usage is on each orbit to cycle the battery depth of discharge between 0-20%; during nighttime contacts when the transmitter is on, the discharge level is allowed to get as low as 25% at which time the contact must be terminated.

Only routine charging and discharging of the batteries has been done; no action to deep discharge the batteries to prevent a '"memory" set has been instigated. An extensive effort to understand the battery discharging/charging curves as a function of season, and effective load, etc. is still in work. Looking at preliminary long term trending plots, it appears that the minimum battery voltages recorded per day may have dropped 0.0-0.5 Volts after one year on orbit. We have considered three possible explanations for the batteries to account for the drop in minimum battery voltage:

1. The batteries internal resistance is slowly increasing as a function of age.
   Options: None

2. The Battery charging capacity is reduced by age.
   Options: None, In fact re-conditioning the batteries could promote a more significant failure.

3. NiCd Memory Effect: In which the Charge vs. Voltage curve is modified to have a "false knee".
   Options: Recondition the Battery

One important point that was brought out in our analysis of the charging system is that the four different battery packs track each other in voltage extremely well. Either they are all OK, all need conditioning, or are all failing in exactly the same manner (the last being highly unlikely). However, since we have not been operationally hindered by the decrease, we have not undertaken any re-conditioning of the batteries and will not until we are severely operationally hampered. An estimated time for the need to recondition the batteries based upon the preliminary, worse case decrease in the minimum battery voltage would result when we lose an additional 0.5 V, at about 1.75-2 years from launch.

4.5 Fine Sun sensor

The ALEXIS Fine Sun Sensor (FSS) is a 4 segmented system with the segments arranged in a square pattern behind a square aperture. Each segment is independently read out and the differences between readings are used to determine the Sun position within the 16° field of view. As originally conceived, the Sun motion in the FSS would be minimized by the on-board attitude software. However, due to the failure of the solar paddle support structure which has altered the spin axis, currently the Sun sweeps through the FSS for 4-5 seconds per spin and is not always centered in the sensor.

During the effort to determine the attitude based upon the on-board sensors, it was determined that the only way to consistently fit the FSS data was to require a relative phase delay between segments; the phase delays are due to slight differences between the different RC time constants for the anti-alias filters on each segment. The phase delays in the FSS required are small and would have been inconsequential if the sun was positioned as designed in the sensor. The largest errors that have been determined are smaller than the original design specification for that sensor, but due to our current usage, it is a significant effect. Therefore, there is a concerted effort ongoing at this time to accurately determine the phase delays as an accurate response is critical to the attitude reconstruction effort.

4.6 Memory boards

The ALEXIS on board memory is comprised of 6 boards each with 16 MBytes of storage locations. The on board algorithm routine checks memory locations and automatically maps out bad sectors as they are located. During integration and testing, one memory board occasionally was mapped out as being bad. We once disassembled the satellite to repair the board, however, once removed from the satellite, it was found to be fully functioning. This board again failed just prior to launch but no corrective action was taken at that time due to severe schedule constraints except to permanently map it out. Recently, in order to get more memory for BLACKBEARD operations, several attempts were unsuccessfully made to try to remap back in this board with the hope that the board might be operational. No further attempts will be made to remap in this board.

Several sectors on the other boards were mapped out prior to launch. Since launch, no new sectors have failed. This means that not one bit out of 76 MBytes has failed. As a test, one of the previously mapped out sectors on one of these boards was successfully mapped back in and appears to be fully operational at this time. We currently have 80% of the original memory operational which does not limit data acquisition unnecessarily. If more memory were available, it would theoretically allow for some additional data acquisition, however, it would be difficult to get more data to the ground with the 4 good throughput contact per day that we currently staff.

5. ALEXIS TELESCOPES

The ALEXIS telescope system is comprised of a Data Processing Unit (DPU) which provides the switched and conditioned low voltage power and high voltage power for the ALEXIS telescopes, command decoding, distribution and all onboard data processing, front end electronics (FEE) which does the pulse digitizing and initial processing, and the telescopes containing mirrors, filters and microchannel plate detectors. Details of the telescope design, calibration and performance have been previously reported by Bloch[1,2]. On orbit telescope performance is presented by Bloch[3] at this conference.

5.1 Experiment DPU

During the first 3 months of telescope operations, the operators were besieged daily by both hard (back into bootstrap mode) and soft resets of one or more of the four DPU's. The DPU's would be tripped as the satellite crossed the 1) South Atlantic Anomaly (SAA), a region above the South Atlantic where satellites encounter a swarm of trapped charged particles, 2) the Auroral zones or 3) in the polar cap regions (see Figure 2). Each reset would require a real time reconfiguration of that DPU during already busy contacts. It was eventually determined that the resets were not due to a CPU problem, but rather due to the way EDAC hardware interrupts were being handled in software. Every time a DPU memory fault is detected, and an interrupt routine is called to fix the bit; this never happens on the ground, and was difficult to simulate. A minor software poke solved this problem which greatly simplified daily operations.

After this first fix, other, more extensive fixes were required of the DPU code to accommodate the actual on-orbit performance of the ALEXIS experiment, especially the higher than expected backgrounds over a good fraction of the orbit. The primary difficulty in collecting science data was due to the fact that during a single satellite spin (50 sec), the count rate could vary between 20-20,000 counts/sec, and trigger a software safing mode intended to shut down the HV supply during times of high count rates like in the SAA. Therefore, features that we thought would be "Nice to Have" before launch became essential due to the current operational constraints. A software fix to "throttle" the HV level based on count rates now allows us to collect data continuously over a spin of the satellite. The HV is dropped by 300 volts or so when the count rate gets above a programmable threshold, and goes back to the original level when the rate drops below a second programmable threshold. A second major difficulty due to the background is that in order to keep the detectors healthy, the telescopes are only turned on during times of eclipse. This requires daily uploads of command scripts of more than 500 commands per script to each telescope CPU to turn on the electronics, configure for observations, make the observations and turn off at the end of each orbital eclipse. Originally conceived as a turn-on and stay-on experiment, the originally limited number (200) of allowable stored commands has recently been increased to accommodate greater than 24 hour operations between command uploads which will be required if we eventually go to automated operations over entire weekends.

An additional problem that we have encountered, especially during the past six months, is a corruption of the Alexis telescope commands. The corruptions often occur during times of ground station crashes, although not always. It is unclear whether the problem is with the ground station, the spacecraft or the DPU. Corruptions occur erratically, but

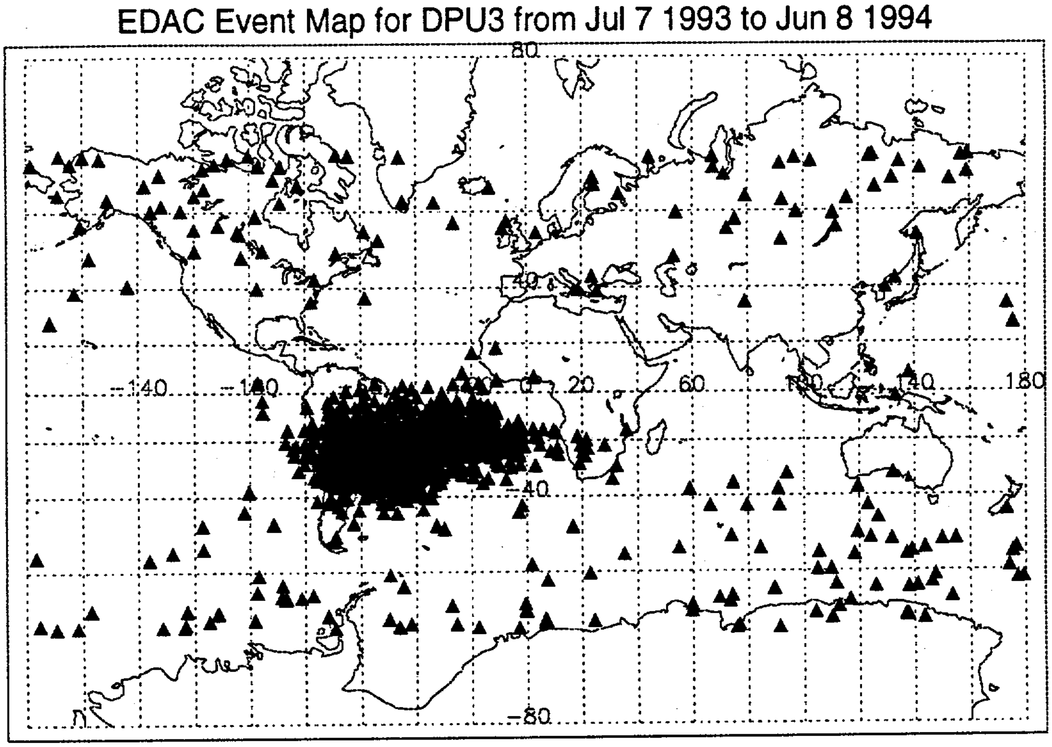

Figure 2: DPU3 soft and hard reset locations before software fix.

on average one occurs every two days. The commands are packetized before upload with 3 commands per packet. The nature of the corruption is that some where a pointer to the packet locations becomes confused and reads the same packet twice and misses another command. When this occurs, the solutions is to disable stored telescope commands on the DPU for which there was a corruption and upload the commands again. There is no verification that there was a corruption during a contact; the post past processing printouts must be searched for the corruption signature. To minimize the effect of the corruption, we now upload telescope commands on the first pass of a session to allow us the second pass to correct a corruption if it occurs.

Due to the extensiveness of the modifications to the DPU code and the inability to fully test every possible scenario, especially the extreme high and low count rates per spin, the only real test of the software is to upload it to the satellite after it passes ground testing. Several iterations of the code have been required. Although initially, the first version of code was programmed into the 64K-16 bit word EEPROM, later, to minimize the number of times we reprogrammed the EEPROM, new code was first programmed into the on-board, 256Kwords of EDAC RAM and then transferred to the EEPROM when it appeared to be working correctly. Each code upload requires either 1) re-programming the 64Kwords of code or 2) in simple cases such as changing HV ramping speeds, etc., only reprogramming a few words. For unknown reasons, reprogramming has often times required uploading the same files 1-3 times before a successful upload is obtained. To date, we have tested 3 versions of code in RAM and have fully reprogrammed 5 versions into EEPROM. Most of this code testing was done with telescope pair number 2 which was the least efficient of the three pairs of telescopes. At the current time, the code appears to be working very well, greatly improving the amount and quality of data from what was originally collected.

One major concern with regards to the uploading of new DPU code has been the determination that the EEPROMS have a finite programmable lifetime of 1-2 years due to radiation damage. These concerns are based upon radiation testing at SNLA that has determined that after a certain level of radiation exposure, the voltage pumps become damaged on the chips which precludes additional re-programming. Given ALEXIS' orbit and a worst case analysis for the radiation exposure for the EEPROMS, the EEPROMS can probably be reprogrammed for up to 18 months (J. Griffee, SNLA, private communication). Therefore, there is a concerted effort to complete all DPU modifications before time runs out.

5.2 Front end electronics

The front end electronics (FEE) digitize the pulses created by the detectors. To date, there has been only one type of problem associated with the FEE and that is once every 3 months or so, one of the three ADC's latches and becomes stuck in the digitizing mode. This latch up results in the ADC temperature increasing from a nominal working temperature of 35-40^{O}C to 60^{O}C. Due to the fact that the power to the FEE is cycled every orbit as a result of the observing scenario, when a latch up does occur, the condition is cleared by the power cycle.

5.3 High voltage power supply

The high voltage power supplies contained in the DPU box provide the correct power for the ALEXIS detectors and are protected by in-line circuit breakers. On one occasion only, the circuit breaker to one telescope pair was triggered and needed to be reset by a power cycle after an inadvertent high voltage spike occurred during DPU software operational testing. Ever since the circuit breaker has been reset, nominal operations have continued through the present.

5.4 Sensor system

5.4.1 Filters

The ALEXIS detectors are limited to the 66 to 95 eV bandpass regime by the reflective properties of the mirrors as well as thin film filters supported on wire mesh in front of the detector. The filters that were flown for the 66 and 71 eV ALEXIS telescopes are comprised of 1200Å of aluminum and 600 Å of carbon while the filters for the 95 eV telescopes are comprised of 1500Å of Lexan, 200Å of titanium and 900Å of boron.

Early in the mission, it was discovered that the filters were not optimized for daylight, earth looking operation. This, plus the unexpectedly large background, required a significant change to operation plans; instead of turning on the telescopes and leaving them on for all time, to assure the safety of the detectors as well as the electronics, scripts were required to be written to only turn on the detectors during the eclipse part of the orbit.

After first light through all telescopes, it was determined that one telescope had acquired three pinholes which appeared as three small donut shapes. Although it is not possible to now use these portions of the detector for cosmic observations, the actual percentage of the total detector area is small, so it is only a minor impact to the observing program. These areas can be used, however, to try to determine the nature of the UV background.

5.4.2 Microchannel plate detectors

The ALEXIS detectors are double plate, curved front faced, microchannel plates (MCP's) paired with wedge and strip resistive anodes designed to operate near 4000 V. The detectors were fully calibrated in the lab at UCB by Oswald Siegmund's group before delivery. After delivery to LANL, they were installed in the telescope bodies and calibrated again. During this second calibration, the detectors were run at several different voltages and a final set of "flight" voltages was determined based upon optimal detector performance.

The ALEXIS telescopes were launched at a near vacuum with the last pumping occurring 2.5 days before launch. The telescope bodies were not perfectly leak proof; preflight testing indicated that they either leaked or outgassed at 200-300 mTorr per day, therefore, there were expectations that there would be a small partial pressure in them at launch. The original operations plan, a compromise between adequate time for spacecraft outgassing and door open operation to allow for detector outgassing, called for the detector doors to be opened one at a time, two per day starting on the fifth day after launch . The primary concern was some residual outgassing of the spacecraft might contaminate the telescope mirrors and thus destroy the 304Å anti-reflection coating. After the doors were opened, a two day wait would occur for the telescope bodies and especially the microchannel plates to outgas before HV would be turned on.

In actuality, due to the launch problems, the detector door opening did not start until 22 July, 1993 after initial contact and recovery with first HV operations starting on 27 July on one of the detectors. By this time, the satellite was well outgassed and any concerns about contamination of the mirrors was no longer an issue. For the most part, the door opening activities were straight forward with the doors opening on the first or second try except for telescope 3B. All doors were opened by a sliding wedge pushed by the plunger of a hot wax accuator. The door open commands specified how long to turn on the heaters to the wax for which initially the successful ground test times of 2-3 minutes were used. Repeated attempts to open 3B proved unsuccessful until the open command was sent for 10 minutes.

All telescopes when first turned on had high counts rates which gradually decreased over several days of operation at reduced HV, some more quickly than others. Telescopes 3A, 2A and 2B, the first telescopes to be turned on, were left at reduced HV settings for numerous days while the flight team acquired full understanding of what flight threshold settings to use to accommodate the large background. In the midsts of this operation, contact with the spacecraft was lost between August 9-26, 1993 due to temperature effects as discussed in section 4.3. Telescope pair 1 was allowed to outgas the longest before HV operations were commenced; it is interesting to note that these were the easiest to configure, but it is unknown whether or not it is due to the longer outgasing times. The telescope door open—HV on sequence is summarized in Table 2.

Table 2

	door open	first HV	HV at reduced setting	HV at full flight	Final Flight HV
1A	8/7/93	9/3/93	9/3-11/93	9/11/93	4320
1B	8/7/93	9/3/93	9/3-11/93	9/11/93	4400
2A	7/25/93	7/31/93	7/31/93-8/9/93 9/1-11/93	9/11/93	4550
2B	7/25/93	7/31/93	7/31/93-8/9/93 9/1-11/93	9/11/93	4250
3A	7/22/93	7/27/93	7/31/93-8/9/93 9/1-11/93	9/11/93	4450
3B	8/31/93	9/5/93	9/6-11/93	9/11/93	4450

The detectors were brought up to flight voltage in steps to assure safe operations and the final flight settings were those determined in the laboratory pre-flight. Two of the detectors, however, would only run stablely at a slightly reduced flight voltage (50 V lower). Initially, one or two of the detectors which were known to be problematic would go into a self scrub mode, but lowering the voltage 500-1000 V for 1-3 days seemed to cure the problem. However, in mid-November, 1993, several of the detectors went into self scrub mode simultaneously, an effect that we later attributed to the 1) orbit and running the detectors during times of higher particle flux because they were turned on for long periods in the northern auroral zone which was in darkness and 2) the solar wind was greatly enhanced due to a well placed coronal hole which increased the number of particles in the auroral zones. After several weeks of running at lower voltage, we were able to regain normal operations of these detectors, however, it was determined to be necessary to lower flight voltage on two of the detectors by 50-100 V to assure stable operation. Decreasing the working voltage did not significantly effect the operation of these detectors.

5.4.3 On orbit calibration and throughput calculations

Preflight, there was a concern that 1) the ALEXIS mirrors might be significantly impacted by atomic oxygen which would change the reflective properties even though the top mirror surfaces were designed with some oxidation in mind and 2) the long delay in opening the ALEXIS doors therefore subjecting the MCP's to a small partial pressure of gas might have significantly changed the detector sensitivity. The only way to determine whether or not there is any degradation on orbit of any of the telescope components is to monitor a calibrated cosmic source and check to see if there has been any change in the total throughput of the system since final calibration in the laboratory. To this end, the brightest cosmic, non-solar system source, HZ 43, was observed by the ALEXIS telescopes in April, 1994 and preliminary aspect solutions for those days were determined. Based upon 4 days worth of observations it was determined that the throughput corresponds to 60 and 86% of the known source flux in the 71 and 66 eV telescopes, respectively.

5.5 Anomalous background

At first light, the ALEXIS background was observed to be much brighter than predicted pre-flight, more than 10,000 counts per second instead of 30 counts per sec. It was originally thought, before the first attitude solution, that the source of the background was the bright earth in the ALEXIS bandpasses as the background was modulated with the spin period and present for about 50% of the spin period. However, this was eventually proven to be an incorrect assessment when the first attitude solutions became available. A detailed summary of the background as it is understood to-date is presented by Bloch[4], however, the salient features of the background are detailed below.

Due to the varied character of the background, it appears that the background has several different components:

1) A hemispherical enhancement, modulated with spin period, is observed simultaneously in all 6 telescopes throughout a major portion of the eclipse part of the orbit. Initially, we thought that the spin modulated background was the bright earth as observed in the ALEXIS energy bands, however, with the availability of several aspect solutions, it has been determined that it is not always the earth that is bright, but in fact often times, it is a significant portion of the sky.

2) A broad, bell shaped, spin modulated enhancement of on average 8 minutes has been observed located centered near the equatorial regions. This enhancement persists from revolution-to-revolution, day-to-day and month-to-month and is a nominal feature of the ALEXIS count rate curves. During February, 1994, it was observed at least 50-60% of the time while during April it was observed during 80% of the orbits. It is observed in all 6 telescopes simultaneously which is difficult to understand if the background is due to particle events as telescope pair 1 and pair 3 have look directions separated by more than 60 degrees. Occasionally, this enhancement is absent only in telescope 3A which looks nearly along the spin axis. It is often associated with bright transient events of duration <45 sec which cause FEE resets. Variability in the bell shaped envelope is also infrequently observed.

3) Occasionally, a two minute enhancement that is not modulated with spin period is observed located at +45 and -30 degree latitude. Similar features are also observed by the gamma-ray detectors on the DMSP satellite near the same times at similar latitude bands and with similar duration (Klebesadel, private communication). DMSP sees these features only in the lowest energy channel (50-100 keV).

An extensive effort is now underway to try to understand and characterize the ALEXIS background. Once characterized, the information will be used by the ALEXIS telescope planners to optimize the best times to make ALEXIS observations. Also, when we are finally able to fully characterize the observed ALEXIS background, the information gleaned will be of tremendous value for the future design of near UV, "solar blind" detectors.

6. BLACKBEARD

The BLACKBEARD payload is designed to make radio frequency observations in the VHF band. It consists principally of two selectable monopole antennas, a band-selectable receiver, and a broadband (150 MS/s) digitizer. Other components of the payload include narrowband channels, a broadband trigger circuit, and two simple photodiode arrays. The primary mission of the BLACKBEARD experiment is to measure the effects of the ionosphere on the propagation of impulsive radio signals such as those that might emanate from lightning or possibly from an electromagnetic pulse (EMP) from a nuclear device. Part of the experiment is to transmit a calibration pulse from the ground and record its time-domain signature on the spacecraft, to measure the filtering effects of the ionosphere from the local facility called the Los Alamos Portable Pulser (LAPP).

BLACKBEARD software is designed as a state machine system. Each state is entered at a preprogrammed Universal Time. Only 2 of these states need to be entered at a millisecond accuracy time and then only if we are doing timed events (pulser shots). After launch, and for most of this year, the timing of these states has been exactly what we observed during ground testing - timing was +- 1 millisecond for the critical states and +0 to +7 for the rest of the states (the DPU has an 8 millisecond clock that causes a CPU interrupt).

After discovering and mapping trans ionospheric pulse pairs (TIPP) events (these are event driven as opposed to time driven), interest has once again been focused on doing pulser shots. From a close scrutiny of the pulser data, it appears that something seems to have changed as now the timing is considerably off; a given sample ranges from -17 milliseconds early to 53 milliseconds late. We are currently looking for the cause of this timing problem. However, what makes troubleshooting very difficult is the lack of prototype hardware on which to do any testing as, unfortunately, BLACKBEARD never really had a prototype and lacked any integrated test setup. It is important to note that at the present time, BLACKBEARD does works very well doing event or survey operations where millisecond timing is not critical, but pulser experiments will continue only by using long record lengths until the source of the timing problem can be determined. Additional information about the BLACKBEARD experiment and the most current findings are summarized by Holden[5].

7. SUMMARY

Although only designed for a one year lifetime, the ALEXIS satellite and experiments are working without any significant degradation despite problems encountered since launch and we are now looking at an extended mission. The past year has been very eventful filled with joys and fears, extreme fatigue and now almost boredom. But for as complex a system that the ALEXIS satellite is, there have been few problems other than those associated with the initial launch failure. Typically, the problems that have been encountered in each subsystem have been minor with easy work arounds. Although initially flight operations could be likened to holding a tiger by the tail, now as each problem encountered is surmounted, we are almost enjoying the rut of routine operations. And as the new ground station nears completion, we are looking forward to the possibility of automated contacts, working only normal working hours and being able to focus more attention to the data itself.

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