# ALEXIS, the Little Satellite That Could--4 Years Later

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Abstract. The 113-kg Array of Low Energy X-ray Imaging Sensors (ALEXIS) satellite was launched from the fourth flight of Pegasus on 25 April, 1993 into a 750 x 850 km, 70 degree inclination orbit. Due to damage sustained at the time of launch, ground controllers did not make contact with the satellite until late June of 1993. 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. Now 4 years later ALEXIS is still collecting more than 100 MB of mission data per day. ALEXIS was originally designed to be a high risk, single string, "Smaller-Faster-Cheaper" satellite, with a 1 year nominal and a 3 year design limit. This paper will discuss how well the various satellite and experiment subsystems are surviving a variety of low and high radiation environments and what improvements have been made to make the operations more autonomous.

ALEXIS has served as a testbed for development of more reliable autonomous operations and a semi-autonomous remote groundstation located in Alaska. Lessons learned from ALEXIS have had direct applications to the next LANL satellite to be launched, FORTE.

## 1. INTRODUCTION

ALEXIS is one of the first modern, sophisticated, miniature satellites, and as such offers a lesson in miniature satellite design and development[1]. 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[2]. In a 113-kg package, ALEXIS includes a six-telescope ultrasoft X-ray array (the ALEXIS experiment)[3,4], 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 but, after the initial recovery effort, this has only mildly compromised the performance, thanks to the dedication of the operations team. 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[5]. A detailed review of the launch, rescue mission and initial flight results was presented last year[6,7]. The purpose of this paper is to review experience gained in the areas of flight operations and the individual system flight performance based upon 4+ years 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 have been presented by Roussel-Dupré[8] and are discussed below:

### 2.1 Operations Team

ALEXIS may be the run by the smallest team with about 10 team members who constitute 6-7 full time equivalent people including managers and science analysts. 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.

--project manager: number people--1
background: astrophysicist
duties: lead interface between team members and upper management, budget management, project implementation

--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 one graduate student
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: astrophysicist
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 scientist number people--3
backgrounds: one astrophysicist and two graduate research assistants
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.

--telescope science analysis: number people 5-6
backgrounds: astrophysicists and computational physicists
duties: telescope performance verification and calibration implementation, point source detection analysis, real time transient detection and detailed analysis of transient behavior[9,10,11]

-- BLACKBEARD duty scientist: number people--1
backgrounds: RF scientist
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: two computer science programmers and Aurora and Antares System Laser Operators
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**

| | program mgmt | satellite flight lead | ground station operator | telescope flight lead | telescope duty scientist | telescope science analysis | 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 | | | | | | √ | | | |
| person #10 | | | | | | √ | | | |

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

It is important to note that of the original team, only 3 team members have remained with the project throughout all phases of the operations. Each team member often has other additional duties in addition to the primary responsibilities. 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.

The graduate students who have worked on the telescope operations usually only remain as part of the team for one year before they move on to other jobs or go back to graduate school. In addition to the longer term graduate students, there have been several undergraduate summer students and more than a dozen students funded by the Department of Energy Science and Engineering Research Semester (SERS) program. In total, the project has benefited from a total of 26 different students, although some students have particpated in several different parts of the project.

## 2.2 General Satellite Operations Center Operations

Because of the ALEXIS' 70 degree inclination, 100 minute 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 was 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 and 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 that the project has 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 of a session 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 with extra time to be utilized for other ALEXIS tasks. As the project becomes more mature and routine, additional automations have been implemented both on the ALEXIS telescope front, where an automated command generation widget tool has been developed, as well as on the overall ground station operation with an improved automated attitude control maneuver generator. The several improvements that have been made on the ground station computer interface include porting the original Apple Macintosh based code to a Sun workstation, adding user configurable "strip chart" state of health displays, developing contact "playback" ability to help with anomaly resolution and operator training and improved automation of the groundstation with additional displays to allow more visibility to a remote "laptop" operator.

As originally designed, the ground station operation was to be completely autonomous after the initial checkout period. However, due to the launch problems, the project supported all contacts out of concern for the safety of the satellite even after the original anomaly was resolved. Occasional autonomous contacts were made during the first 4 years over major holidays and on two separate occasions when team members were married. However, as the funding support has declined, there has been a push for more autonomous contacts. There has also been the development of a remote, completely autonomous groundstation located in Fairbanks, Alaska to support both ALEXIS and the next LANL satellite FORTE. Thus, the most recent automation advances for the ground station has lead to the ground station being an automated facility operational via a remote laptop computer. Currently, there is a plan to go 48 hours between manned contacts with only automated contacts in between the manned contacts in the near future. There is also the 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 during fall 1997. However, this might prove difficult as battery capacity degrades with age.

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 fifteen 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 4+ years 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
>
> --the time to train new operators to full competency is quite extensive which has lead us to require at least a years commitment of new team members
>
> --it is difficult to both operate a small satellite and analyze the data and write scientific papers with a team of 10 or fewer full time people
>
> --because of the small team nature of this project and the fact that many team members change on a yearly basis, it is easy to "misplace" notes, reports and other pertinent documentation and thus some rigor about reporting is necessary. A web archive of project reports and notes has been successfully implemented to archive such information

## 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 National Laboratory 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 initially experienced with the Mac IIfx computer, this hope has not been realized as mentioned above. A later effort (part of an advanced ground station technology initiative for the follow-on LANL FORTÉ and MTI small satellite programs) ported the Mac code over to a Sun workstation which resulted in a much more stable system. The ground station hardware has been previously summarized by Priedhorsky[1,2,6]. 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 computer using the satellite ephemeris information and Universal time (which is read automatically from a WWV 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, only 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.

--Dish Positioner Control Box

-The positioner control box has been the most problematic of the whole ground station system. The problem is usually simple to diagnose and a spare swapped in its place. It has been sent back for repair 3 times.

--Dish Positioner

-The positioner drive mechanism on the dish started to have problems tracking during the summer of 1996. The symptom was that the dish was unable to track rapidly enough under automatic control to keep up with the satellite during the contact and occasionally, the operator had to give manual assist. The original positioner was removed and sent to Telonics for repair after being swapped for a spare. The problem was traced to an alignment problem that was easily fixed.

### 3.2 Control Computers

Originally, the ALEXIS ground station control computer system had 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. Because the control computer system was the most persistent failure mode of the entire satellite system, an effort was made during the second year of the mission to replace the Mac IIfx, which had 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, was completely successful resulting in ground station code that was much more reliable, and to which several new features had been added. As mentioned above, some of the extras that were included in the new code were adding user configurable "strip chart" state of health displays, developing contact "playback" ability and improved automation of the groundstation with additional displays to allow more visibility to a remote "laptop" operator. The task of operating the tracking dish was also moved off of the Dell computer such that all control room activities are now being performed by the Sun workstation. Ground station crashes and corrupted commands were the only remaining hardware obstacle to automated operation. As user confidence in the new ground station performance increased, unattended and remotely manned passes have proved possible.

Problems that have been encountered by the control computer system components are noted below:

--Dell computer

Driving computer for the Telonics tracking dish was a DOS based Dell computer. Except for an occasional reboot, this computer had run without any problems until 3 years into the mission when the power supply failed just minutes prior to a contact. The first contact was missed, but the power supply was replaced before the second contact of a session so only one contact was missed.

--Mac IIfx

The telemetry interface board originally connected to a Macintosh IIfx computer which handled 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 was running Mac operating system v6.0.5 just prior to being replace by the Sun workstation. Problems encountered with this system are as follows:

-Repeated 20" monitor failures

The large screen monitors failed three times within two months during 1995. 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 did not seem to be able to keep up with both Doppler calculations and data-down/commands-up tasks. The separation of tasks successfully corrected the drop out problem.

-Frequent ground station computer crashes
Ground station crashes usually occurred during command upload for reasons unknown, which was traced to a bug in the Mac groundstation code. The occurrence of crashes tended to be erratic and unpredictable. At times there was only one ground station crash per week while at other times there were one or two per day. When a crash occurred, it took 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 was insufficient time to recover. This resulted in a loss of 3 minutes of down load data time that could usually be recovered on the next pass. During the port of the code to the Sun workstation, several minor bugs were found in the code and corrected.

--Sun SPARC 20 Workstation

No problems have been encountered with the Sun workstation system.

## 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[1,2]. 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 thanks to the on-board spacecraft software developed by AeroAstro. Details of the rescue mission have been discussed by Priedhorsky[6,7]. Details of how the horizon crossing indicator, fine and coarse sun sensors are used to determine the precise attitude knowledge required for skymap processing has been recently presented by Pskaiki[5]

### 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[6,7], the ALEXIS attitude is routinely adjusted from the ground to keep the spin axis within 15° 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. Richard Warner of AeroAstro wrote the automated program that, given the current spin axis and the final desired spin axis, determines the correct times to activate the torque coils. This program is routinely used to maintain the ALEXIS attitude. Former team members Sean Ryan and Stephen Stem wrote a program to automatically scan the most current spacecraft attitude data upon download and when necessary to automatically run the original program from Mr. Warner and generate the required command sequence autonomously for upload on the next contact. 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 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's 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 5-7 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 could be 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.

In addition to the delay detailed above, we think another type of FSS delay is responsible for occasional 0.3 degree jumps of the apparent satellite spin axis over the course of about an hour. This tends to increase the size of the point source region and thus diluting the count rate and minimizing the potential for detection. 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. This effort has produced optimal delays and sensor alignment twist for one "hot" time orbit when the Sun was continually observed. But it was noted that when these results were used for a different hot time that large than expected attitude errors were calculated indicating that it may be necessary to have a time dependent value for these two parameters.

### 4.3 Coarse Sun Sensor

The ALEXIS satellite has 12 coarse Sun sensors distributed around the satellite to help determine the satellite orientation. These sensors are simple solar cells which have a cosine theta solar response. In late November of 1994, Coarse Sun Sensor #2, which is located on the broken +Y paddle, became intermittent in operation. The data drop-outs appear very regularly about 10 minutes after the satellite comes back into sunlight from eclipse, as if a thermal threshold is involved. It is usually out for the rest of the orbit, but sometimes comes back just before eclipse entry. No other signals from the broken paddle appear affected. It is possible that this sensor has become a 1 bit motion indicator for the paddle. Since this sensor is not used for any attitude issues, there is no direct mission impact.

### 4.4 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. During the four plus years of the mission to-date, this was the only incidence of spacecraft CPU resets.

### 4.5 Problems with Radio Frequency Interface Board (RFIB) at Elevated Temperatures

On 9 August, 1993, contact with the satellite was lost as the satellite slipped into the first operational 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

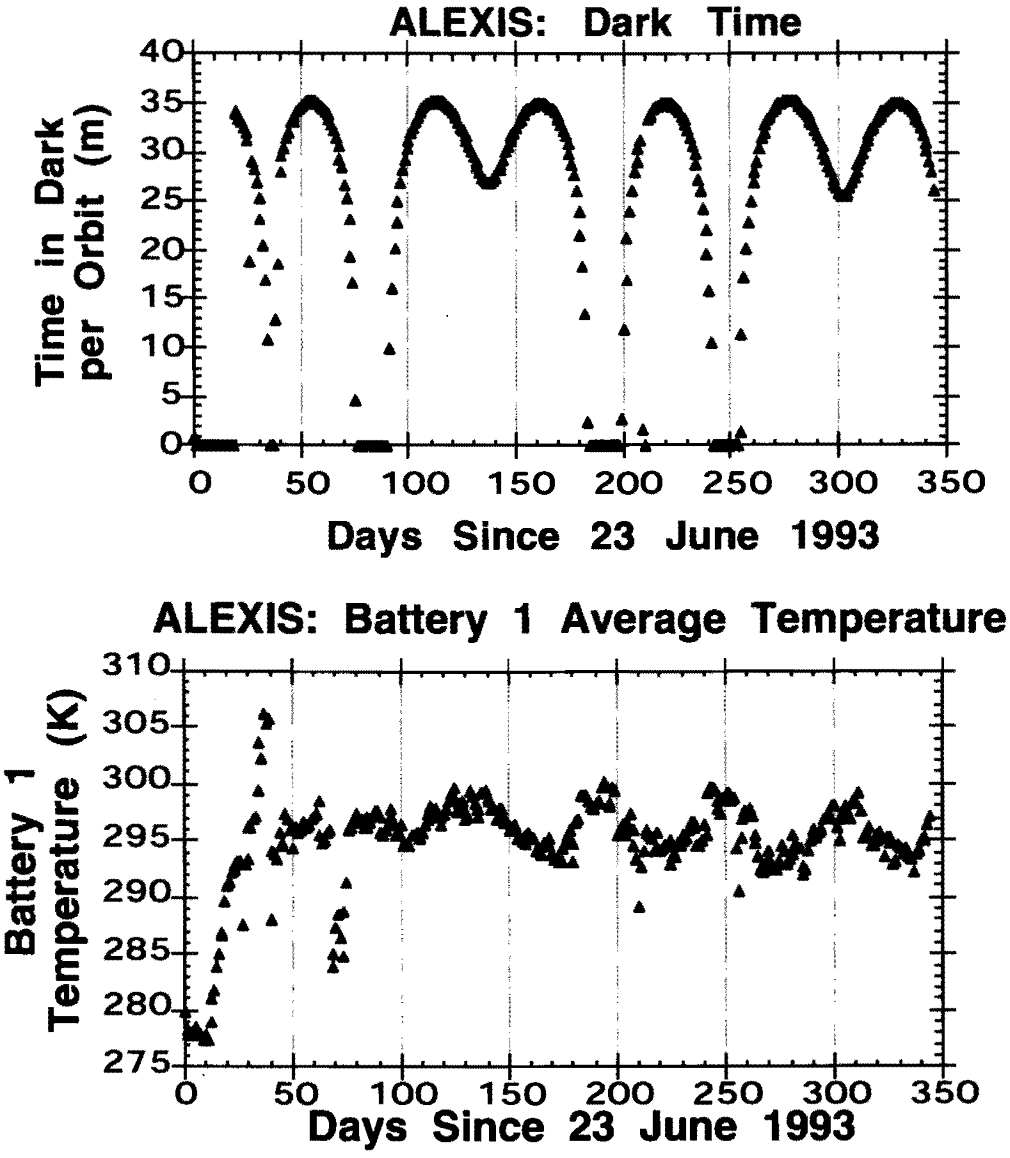
2) the solar panel voltage regulator (SPVR) was functioning on a 10 Hz cycle, causing noise transients on the bus which results in non-contact. The SPVR's function is to take the solar panels off-line if their voltage goes above 36.5 Volts. This condition was only supposed to occur when the panels initially 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 day before 100% illumination orbits or "hot times" are encountered and wait to turn back on 1 day 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 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.

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 battery boxes (which tracked essentially the same as the offending electornics box) as a function of time for the



Fiqure 1: Time Historv of Orbit Dark Time and Batterv 1 Temperature

first year of operation. The times of 100% illumination are 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°K, 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 our success with the thermal management post-August, 1993.

### 4.6 Batteries, Solar Cells and Charging Circuitry

The ALEXIS satellite contains four 1.2 amp-hour, 28 V battery packs built with 23 hand-picked commercial Gates NiCd cells each. The batteries are maintained at full charge by means of an on-boardvoltage-temperature relationship to insure that the batteries reach full charge without potential for thermal runaway. Only a single V-T curve can be uploaded at a time and it is used by all four of the battery packs. Because of the passive thermal design of the satellite, the average temperature of the batteries has been 293° K for batteries 1 & 3 which trend together and 298° K for batteries 2 & 4 which trend together during eclipse times and between 300 to 305° K but occasionally as high as 310° K during hot times throughout the duration of the mission. Figure 1 shows the temperature variations of battery 1 for the first year of operation. This variation is representative of the variations observed for the other three batteries. 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 according to procedure.

Until 1996, only routine charging and discharging of the batteries has been done, however, occasionally, the BLACKBEARD experiment gets caught in a high power state even though it was commanded to a low power state which resulted in the payloads having to be load shed by the on-board software. Load shedding starts at energy levels of 64% and has a somewhat similar effect as reconditioning for the batteries.

After a preliminary look at the first year long term battery trending data, it appeared that the minimum battery voltages recorded per day may have dropped 0.0-0.5 Volts after one year on orbit. Three possible explanations for the batteries to account for the drop in minimum battery voltage were proposed at that time:

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

It has been determined that the four different battery packs track each other in voltage extremely well. Either they were all OK, all needed conditioning, or were all failing in exactly the same manner (the last being highly unlikely). However, since we were not operationally hindered by the decrease, we did not undertaken any re-conditioning of the batteries choosing to wait until we were 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.

After a 100% sunlight orbit in October, 1995 the satellite temperatures were higher than had been previously experienced which was originally thought to be a fluke of the orbit. However, the satellite temperatures remained 2-5 degrees higher even after ALEXIS was again in orbits with eclipse durations of 26 minutes. After looking in detail at the battery data, it was determined that the total orbit average power dissipated by the batteries was different from similar averages a year prior by about 10 Watts which was enough to account for the excess temperatures. It was determined that due to battery aging that the V-T curve that was used was higher than the batteries could reach resulting in the battery heating and a near thermal runaway. To reduce the heating, a V-T curve which had a decreased step at higher temperatures was uploaded. This modification of the V-T curve appeared to be completely successful. After this event, it then became nominal procedure to lower the modified slope V-T curve just prior to a hot time and then to raise it afterwards as a means to minimize the battery temperatures.

A second modification to the onboard software was required in July, 1996 when it was determined that the solar panels didn't have the same current capacity that they did three years before. Right after launch they could provide up to 3.5 Amps while in July, 1996 the maximum current capacity was 3.0 Amps. The voltage that the batteries achieve when fully charged under fast charge is a function of the current available for charging, but the algorithm used to terminate fast charging had been using a fixed voltage setting as a function of temperature only. When the payloads are turned on, there is less current available to charge the batteries, so the maximum voltage that the batteries can achieve during charging is less. If a fixed charge termination voltage table is used, the batteries can be overcharged during times of heavy payload operations and cause battery overheating. To reduce this effect, a new code which measures the current being drawn by batteries in fast charge, and adjusts the voltage cutoff table appropriately was written and uploaded.

By July, 1996, more than 3 years into the mission, the battery performance, especially battery #1, during night time contacts was becoming marginal and it wasdecided that it would be finally necessary to attempt reconditioning the batteries. At the time of this decision, each of the batteries had neared or exceeded 250-500 Amp*Hrs of use. As it turned out, this was to the be first ever battery reconditioning attempted on the ALEXIS batteries with the flight software. Due to schedule constraints pre-launch, battery reconditioning was never tested to completion. The optimal time to do the reconditioning is during the 100% sunlight orbits when power requirements can be supplied by the solar cells. Thus, during the August, 1996 "hot time" the first reconditioning was attempted. Unfortunately, the reconditioning did not go as expected as there was a minor error in the reconditioning software that did not allow the battery voltage to be drawn down as required; instead, the battery charging was put into both discharge and slow charge. Modified code was successfully tested on the ALEXIS spacecraft simulator and then uploaded to the satellite and tested during this "hot time", however, time ran out before a complete set of batteries could be reconditioned.

The final reconditioning was then attempted on the next 100% sunlight orbit in October, 1996. Prior to the reconditioning, the V-T curve was lowered to keep the non-discharged batteries from becoming too hot. We had expectedeach battery to take upwards of 33 hours to discharge, followed by a slow recharge period based upon pre-flight bench testing. Instead, each battery took an average of about 20 hours to discharge and half as long to recharge. At first, we were excited that this shorter than expected refresh duration would allow us to complete a discharge-recharge cycle on each battery within a week. But later, we were not so elated.

During the first round of reconditioning, we observed that batteries 1, 2, and 4 exhibited what appeared to be a depressedknee in the discharge voltage vs. discharged capacity curve (See Figure 2). It was believed that the batteries were probably suffering from voltage depression or "memory effect". We proceeded with a

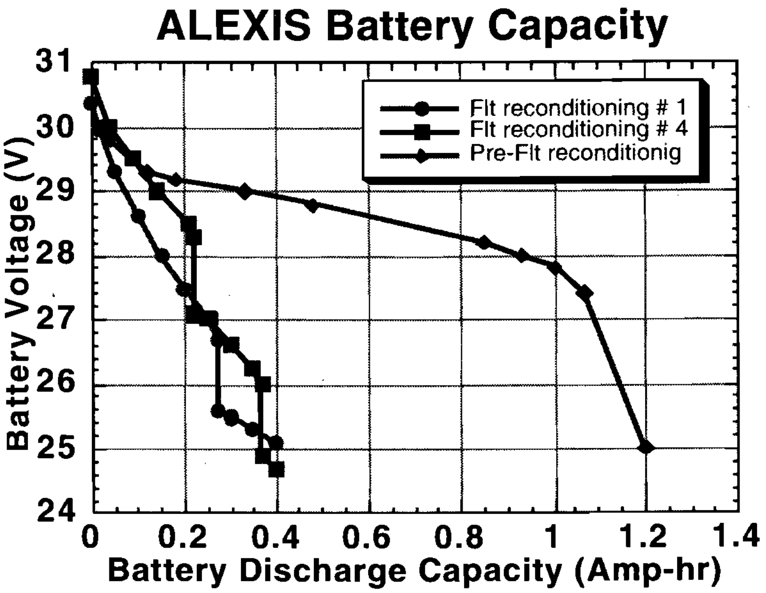


**Figure 2: Plot of battery #1 capacity for 11 August, 1992 pre-flight and October, 1996, post-flight reconditioning.**

second round of reconditioning, then a third, expecting the depressed knees to disappear or move further to the right on the discharge voltage vs. discharged capacity curve. Instead, the depressed knees moved slightly up the discharge curve, including the knee for battery 3, which had been thought to be the normal knee of its discharge curve. One possible explanation for the move of the "knee" to the left in the voltage vs. capacity curve was that the V-T curve was too low and, thus, did not allow full battery charging.

The nominal operation of the solar panel voltage regulator (SPVR) confuse matters even more. The SPVR acts to regulate the spacecraft voltage in such a way that if there is a light load on the panels (i.e.. can't load the panels below 36V) then the panels are disconnected from the system and the spacecraft obtains power from the batteries. We had noticed this behavior during the previous hot time when we were troubleshooting the software problem, but temporarily forgot about it during the October, 1996 reconditioning exercise. It appeared that since there was no load on the panels due to only survival spacecraft functions being load (i.e. no telescope data processing units on to minimize spacecraft temperature) that the batteries did not reach a real full charge. Thus, because of this and because the V-T curves were lowered during the "hot time", we summarized that when the second reconditioning cycle was done, the batteries started out with less charge than the first time and it was assumed that the depressed knee was observed sooner.

Finally, in another attempt to increase the charge on the batteries before starting a fourth reconditioning of battery 1, we raised the V-T curve to slightly above the nominal curve that had been used previously. However, when we observed two "depressed knees" on the last battery 1 discharge cycle, we realized we could not be seeing a "depressed knee". We now believe that the "knees" observed are consistent with cell reversals, and not voltage depression. From the last discharge curves we conclude that each battery has at least one lower capacity cell with battery 1 having at least two bad cells. We have also determined that our battery capacity is now around 0.4-0.6 Amp*Hrs per battery. This is about 1/2-1/3 of the original capacity of the batteries and explains the decreased discharge time previously noted. This result was surprisingly low. However, some aging is to be expected after about 5.5 years of use (ground test and in-flight), with an average temperature in flight of about 20° C, and a severe overheating event in 1995.

However, not all of the results were bad news. The discharge curves for the batteries were shallower after the first reconditioning cycle. Also, when the batteries were recharged after the hot-time, they were qualitatively observed to be more balanced, and could run longer through the darkness. This indicates that there was some improvement due to the exercise which was observed during nighttime operation. However, it has been noted that battery 1 continues to have the worst performance of the 4 batteries which might be attributed to poor capacity due to the 2 cells observed in cell reversal during the reconditioning exercise. Because of the observed cell reversal during reconditioning, future battery recondition will not be attempted since it will only continue to exasperate the bad cell problem in the batteries. Degrading battery performance and solar cell output will eventually limit ALEXIS future operations.

## 4.7 Memory Boards

The ALEXIS on board memory is comprised of 6 boards each with 16 MBytes of storage locations. The memory is made up of Dense-Pac DPS256Q8 modules which use Hitachi 256K CMOS SRAM. 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. After the first year of the mission, 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 have been 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 after four plus years of being on orbit. 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 contacts per day that we currently staff unless the Alaska ground station is utilized.

## 4.8 Failed Spacecraft Commands

Once and only once has it been noted that commands sent to the spacecraft were not executed. This occurred during the first attempt at battery reconditioning when power off commands were sent to DPU's 1 & 2.

Confirmation of commands sent was observed in the telemetry log, but repeated tries for a day failed to turn off DPU 1 & 2. Due to the concern about the battery reconditioning, not much attention was paid to this event, and then oddly both DPUs powered off together two days later. After the odd shutdown, DPU1 turned on and off when commanded. Fortunately, this behavior has not repeated.

## 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[3,4]. On orbit telescope performance has been presented by Bloch[9] previously.

### 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. 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 PCU problem, but rather due to the way Error Detection and Correction (EDAC) hardware interrupts were being handled in software. Every time a DPU memory error is detected an interrupt routine is called to correct and report the bit error. A fault in this routine would cause a processor reset. This fault was missed by software testing since Single Event Upsets (SEUs) are infrequent on the ground and the simulation method proved inadequate. A minor software poke corrected this fault which greatly simplified daily operations.

After this 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 280 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 48 hour operations between command uploads which will be required as we eventually go to more and more automated operations.

An additional problem that we have encountered, during the first year of operations, was a corruption of the ALEXIS telescope commands. The corruptions often occurred during times of ground station crashes, although not always. Initially it was unclear whether the problem is with the ground station, the spacecraft or the DPU. Corruptions occurred erratically, but on average one occurred every two days. The commands are packetized before upload with 3 commands per packet. The nature of the corruption was that somewhere a pointer to the packet locations became confused and read the same packet twice and missed another command. When this occurred, the solution was to disable stored telescope commands on the DPU for which there was a corruption and upload the commands again. Since there is no verification that there was a corruption during a contact, the post pass processing printouts must be searched for the corruption signature. After the groundstation code was ported the Sun workstation, the corruption problem disappeared. However, to minimize the possible effects of the corruption, we always 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 initial 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 later 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 required 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. Although care was taken to assure that no code was uploaded in regions of high particle background like the northern auroral region, for unknown reasons, reprogramming often times required uploading the same files one to three times before a successful upload was obtained. In the end, eight to ten versions of code were uploaded to DPU2 before all of the changes were working optimally of which five versions were uploaded into EEPROM. Telescope pair number 2 was the least efficient of the three pairs of telescopes and thus, chosen for this risky operation. Only one or two additional code uploads were required for DPU's 1 & 3. After several years of use, the code appears to be working very well, and has greatly improved the amount and quality of data from what was originally being 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 Sandia National Laboratory 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 was a concerted effort to complete all DPU modifications before time ran 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 observed anomaly associated with the FEE and that anomaly nominally occurs a couple times per year since the initial operations began (Table 2). From the data obtained, we have concluded that the ADC appears to malfunction possibly due to a latch-up condition which interferes with the output of digitized data. This apparent latch-up results in the ADC temperature increasing from a nominal operating temperature of 50°C to 60°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 nominal per orbit power cycle.

Table 2: Number of FEE Latch-up

| year | DPU1 | DPU2 | DPU3 |
|---|---|---|---|
| 1994* | 3 | 3 | 2 |
| 1995 | 5 | 1 | 6 |
| 1996 | 8 | 3 | 10 |
| 1997* | 5 | 3 | 7 |

*partial years

### 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 LUXEL 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 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 (2A) had acquired three pinholes near the edge of the filter support ring which appeared as three small donut shapes in the detector image. 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 except for the effect on the count rate. Since the detector electronics is only capable of digitizing 200 counts per second, UV photons which are detected due to the pinhole leaks compete for the digitzable data budget, thus, reducing the number of EUV photons detected. These areas were used once, however, to try to determine the nature of the UV background but the data was marginal with no real conclusions possible.

After the December, 1994 "hot time", first turn-on data showed that the filter for telescope 3A had developed pinhole leaks near the edge of the filter support ring. These new pinhole leaks in 3A were the first filter degradation since launch. The cause of the pinholes creation is still unknown. 3A runs the coolest due to the fact that it looks nearly along the spin axis which would seem to rule out thermal stress and it also sees less background due to RAM, so atomic oxygen erosion is unlikely. The best guess is that the pinholes were created due to thin film stress failure. Luckily, unlike TP2A which has pinhole in the high gain region, the pinholes in TP3A are at the bottom of the low gain region. It appears that these pinholes do not contribute a significant amount to the total count rate, therefore, they do not significantly degrade the acquisition of good science data.

In addition to the above mentioned pinhole filter leaks, additional UV leaks have been detected in the ALEXIS data which is either due to micro-pinhole production or thin film surface crazing. The filters were designed to eliminate light from bright early type B stars. However, during the second and third year of the mission, it was noted in composite sky maps of a month or more that the brightest of these stars were detectable at a low level in one of the detectors. Detailed detector images have shown that only localized regions of the filter are responsible for the leak. Since that time, it appears that all filters have developed regions of enhanced B star detection. While not important for point source detection efforts, these regions of weakly leaking filters may be an issue for the EUV diffuse background studies.

### *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 laboratory 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.

**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<br>9/1-11/93 | 9/11/93 | 4550 |
| 2B | 7/25/93 | 7/31/93 | 7/31/93-8/9/93<br>9/1-11/93 | 9/11/93 | 4250 |
| 3A | 7/22/93 | 7/27/93 | 7/31/93-8/9/93<br>9/1-11/93 | 9/11/93 | 4450 |
| 3B | 8/31/93 | 9/5/93 | 9/6-11/93 | 9/11/93 | 4450 |

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 midst 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 outgassing times. The telescope door open and HV on sequence is summarized in Table 2.

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 stably 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. After nearly 3 years of operations, however, we again increased the voltage by 100 V to regain the lost detector gain.

### *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, has been observed by the ALEXIS telescopes for long periods of time twice a year in all three telescope pair. The source count rate has remained constant and is consistent with preflight estimates.

### 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 has been presented by Bloch[9] and Roussel-Dupré[10], 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 10 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. 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. The magnitude of the overall enhancement is orbit dependent. It is minimized in all three telescope pair but nearly absent in telescope pair 3 which looks nearly along the spin axis just after the orbit has precessed out of 100% sunlight and maximizes by the time the orbit precesses to become noon-midnight. 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 has helped to understand and characterize the ALEXIS background. This information is used by the ALEXIS telescope planners to optimize the best times to make ALEXIS observations. The information gleaned from this characterization is 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 and has served as an important pathfinder experiment for the next LANL satellite, FORTE, which a larger version of the BLACKBEARD experiment. FORTE is scheduled to be launched 28 August, 1997. Additional information about the BLACKBEARD experiment and the most current findings have been summarized by Holden[13].

## 7. SUMMARY

Although only designed for a one year lifetime, the ALEXIS satellite and experiments are working with only some degradation of the batteries, solar cells and detector filters. Despite problems encountered since launch, we have been operating in an extended mission for several years. The first year was very eventful filled with joys and fears, and extreme fatigue. 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 workarounds. Although initially flight operations could be likened to holding a tiger by the tail, now as each problem encountered is surmounted, we have been almost enjoying the rut of routine operations for several years. And as the funding decreases, we are actively pursing trying to do more automated contacts, working only normal working hours and hoping to be able to focus more attention to the data.

## 8. ACKNOWLEDGMENTS

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