A GROUND STATION FOR USE WITH SMALL SATELLITES

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NASA has plans to initiate a new series of inexpensive, Scout-sized Explorer satellites to be placed in service starting in the early 1990's. Today's computer technology makes it feasible and economical to build such a satellite so that it can be operated from a single, small ground station. This station would be located at the satellite user's facility and it would operate autonomously. Except for launch and support during operational emergencies, no NASA facilities would be required. We show this way of operating will result in a lower cost mission with no performance penalty.

INTRODUCTION

Small Scout-class satellites usually carry only one scientific instrument (or perhaps a small set of related instruments) controlled by one person called the Principal Investigator, or PI. The usual operating relationship between the PI and NASA has been that the PI requests that NASA take certain data. Then NASA, operates the satellite, acquires the data and transmits it to him. He then processes the data and publishes the results.

This paper proposes a major change in this operation: give the PI direct and complete control of the spacecraft and the instrument. Our initial evaluation shows that this mode of operation will be less expensive and more responsive than our past practice. This paper describes a portable ground station that would make this possible. There should be no performance penalty since we can revert to the NASA system in an emergency.

THE SPACECRAFT'S CHARACTERISTICS

When studying a new satellite for NASA, a communications question is: Can it use the Tracking and Data Relay System (TDRSS) ? For the kinds of Scout-class Explorer mission orbits we've considered, the maximum satellite weight ranges from about 150 kg to 225 kg. The largest Scout shroud limits the satellite volume to 0.96 cubic meters. These numbers make it almost impossible to fit in a TDRSS communication antenna and have enough weight and volume left for the payload. The conclusion is that we must communicate with ground stations.

Having decided to communicate directly with ground terminals, the next question is: How many contacts per day are required to operate the satellite? The answer has a direct bearing on the operations cost for these satellites. The remarkable performance improvements of flight computers has made it feasible to build satellites that operate for one day (or more) without human intervention. This means that an operations staff working part time could operate the satellite. A corollary is that a world-wide distribution of ground stations is not required; a single ground station can do the job.

The satellite will be built with sufficient computing power to facilitate a one contact a day operation. The flight command computer will have sufficient memory to hold somewhat more than a day's operating schedule. To make the operations easy and reliable, standard sequences of operations can be initiated with just one macro. It will be programmed as an expert in the safe operation of the satellite so that no command will cause damage to the satellite. The telemetry system will be controlled by a computer. This will make it easy to configure the satellite for each new application without making hardware changes. The data storage function will be handled by a computer with a memory large enough to store a day's worth of data. For most of the missions we studied, the average data rate fell between 0.5 kbps and 10 kbps. For a given mission, the memory capacity would be adjusted in increments of 64 megabits up to more than a gigabit. It will use hardware error correction coding for low error rates and software to exercise the memory in a self-checking mode. If any bad memory devices are found, it will skip them.

A TRANSPORTABLE GROUND STATION

NASA has closed ground stations and has shifted new satellites to TDRSS. This is a more cost effective method of operating while providing near-global communications coverage to large, low altitude satellites. This is a good solution to the communication problems of this class of satellite, but as discussed above, it is not practical for a Scout-class Explorer. NASA has been criticized for taking too long to get data to the user. New satellites are being designed with Packet Telemetry systems so that data delivery can be accomplished rapidly.

We propose a transportable ground station design for use in operating a Scout-class Explorer. It would be located at the PI's facility thereby eliminating any data delivery delay. The station itself is inexpensive -- we estimate less than $ 750K. Unlike NASA's network stations, it uses a small antenna (three meter diameter) and has no redundant hardware. Figure 1 is a block diagram of the station and Figure 2 shows the transportable radio frequency (RF) equipment. It will receive data playbacks from the satellite at 2 Mbps and to send commands at 1 kbps. The antenna will be pointed using predicted angles generated by the central computer. This prediction, in tern, depends on one-way doppler orbit determination also performed by the central computer.

Another reason for the low price per station is that we expect as many as seven of these systems will be built. The exact number will depend on the number of satellites that must be operated at any one time. We expect that when a mission is finished, the station would be moved to support another PI.

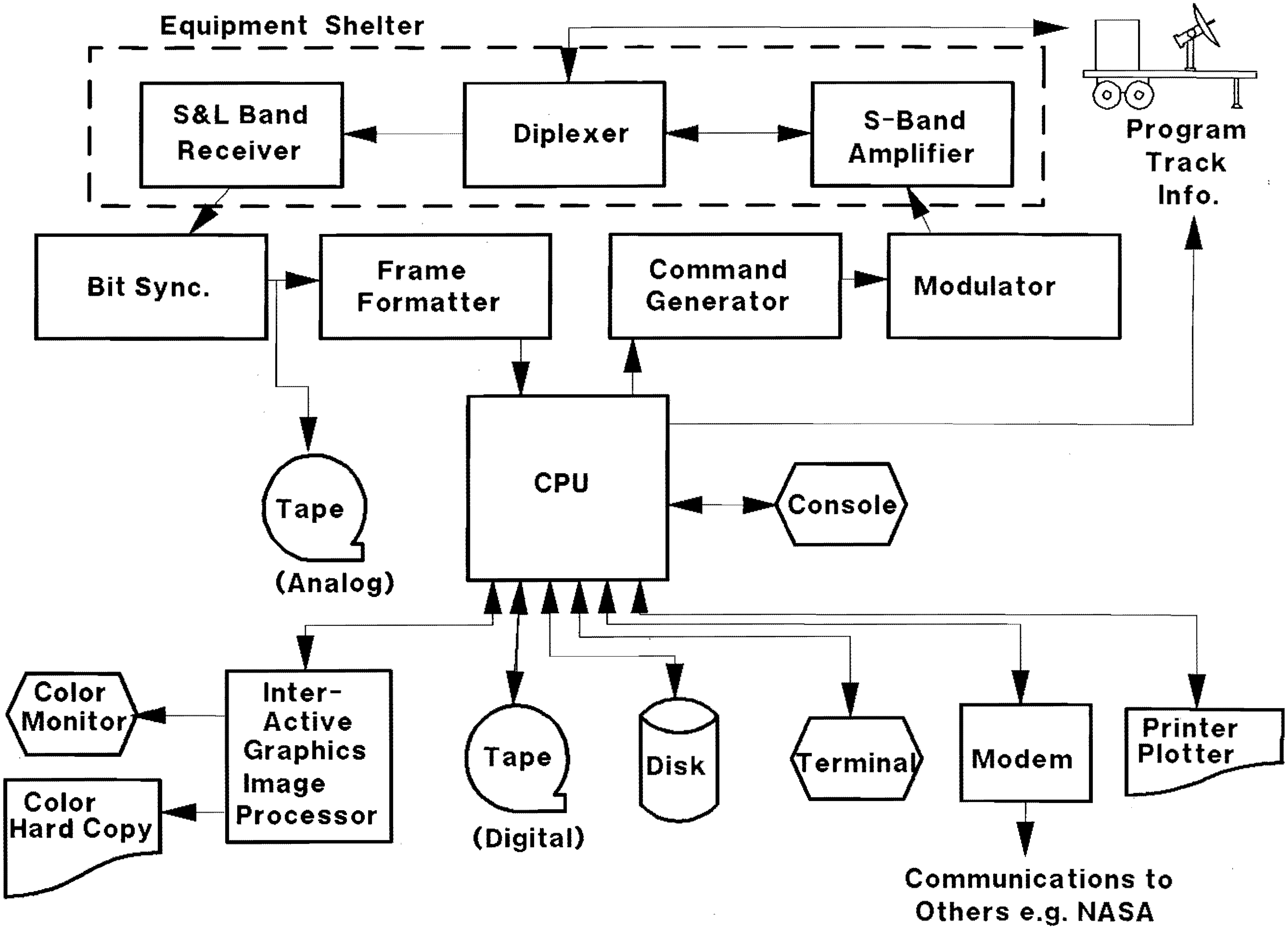


Figure 1 PORTABLE GROUND SYSTEM CONFIGURATION

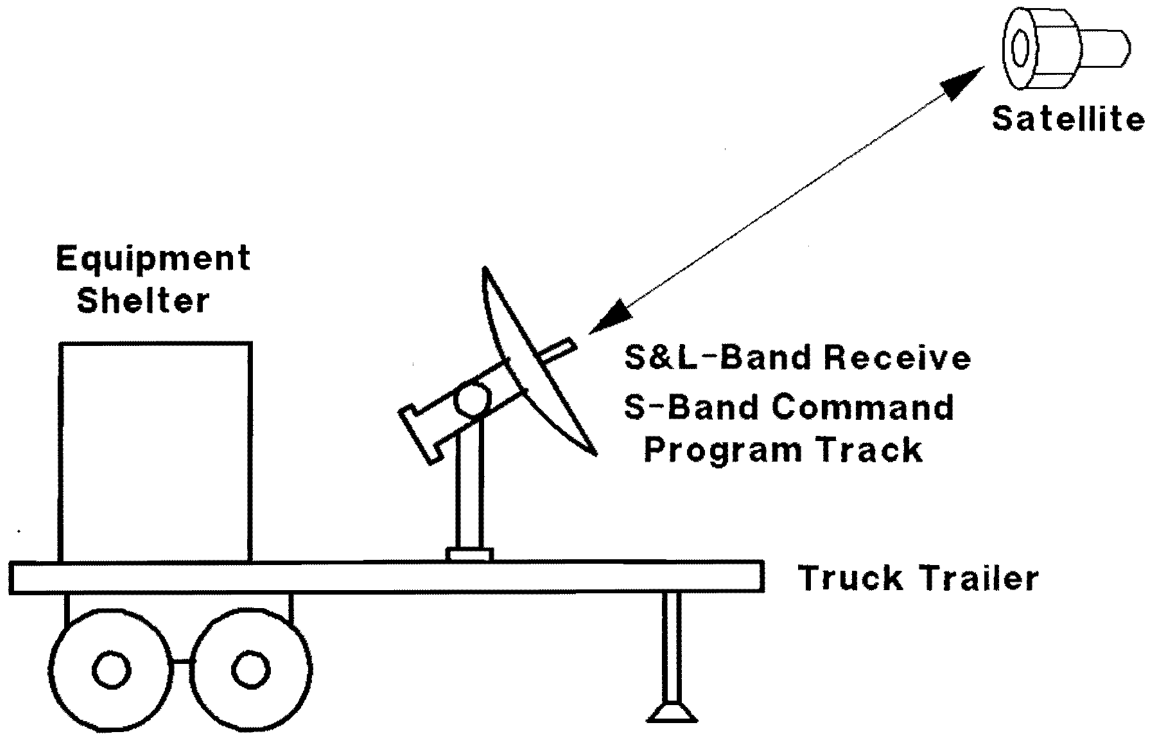
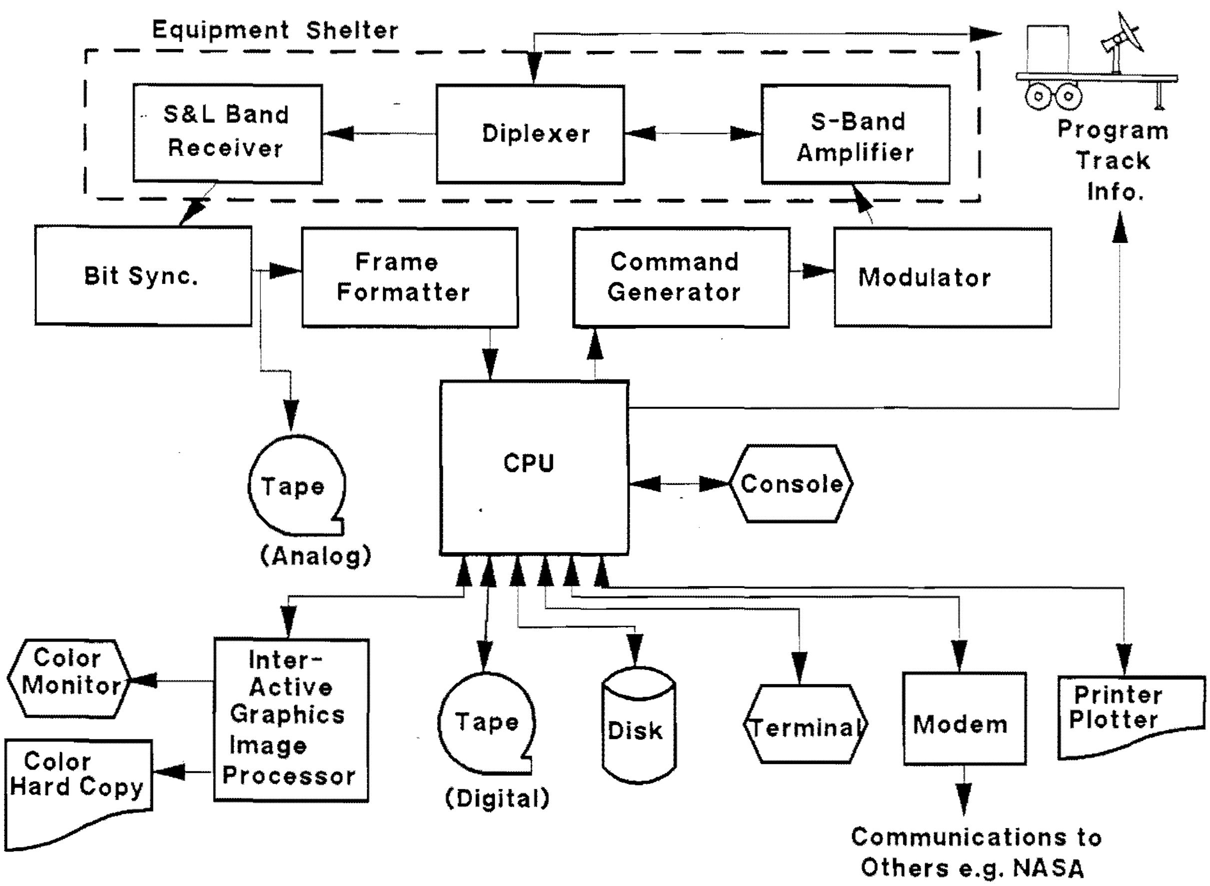


Figure 2 PORTABLE TRANSMIT/RECEIVE EQUIPMENT FOR SCOUT-CLASS EXPLORER MISSIONS



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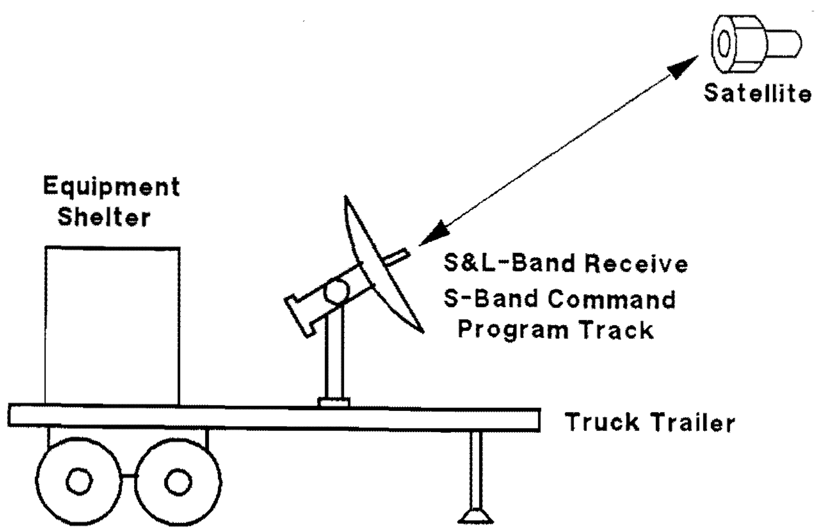

Figure 2 PORTABLE TRANSMIT/RECEIVE EQUIPMENT FOR SCOUT-CLASS EXPLORER MISSIONS

A typical deployment might be as follows:

A) One at each of two or three PI locations to support two or three operating satellites.
B) One at the satellite builder's factory.
C) One at each of one or two PI instrument development facilities. These would not include the RF equipment until needed a few months before launch.
D) One at the launch site. This one would not have RF equipment because adequate RF equipment already exists there.

The station can be run by just one operator because the station computer will automatically control the station during the pass. (For safety reasons, a second person should be nearby, but he need not be involved with the pass.) It is anticipated that the central computer will be of the Micro Vax class. To aid the PI and the operator prepare for each pass, it will contain expert software to help them prepare only safe command loads. For most missions, these command loads can be prepared a few days in advance. During the pass, it will send the next day's command load. At the same time the bit synchronizer will lock up on the received telemetry data and store it on tape for later processing. The computer will review health and safety telemetry data as it is received. The computer also updates the orbit based on the received carrier doppler and commands the antenna to follow the satellite. Between passes, the computer will be used by the PI to process his data. For most instruments, this computer will be quite adequate. For a few demanding instruments, a mainframe computer system may be needed. In this case, the transportable system will still do all its normal command, telemetry reception and orbit determination functions. Its data processing function might be limited to being a "front end processor" for the mainframe.

The system at the manufacturer's plant and the system at each PI instrument development facility will be used as Ground Support Equipment (GSE). GSE is used to test the satellite or the instrument separately. When the instrument is integrated with the satellite, it also tests that everything works together as desired. Note that during instrument integration, the manufacturer's station will run both his spacecraft and the instrument. All that is needed is software written during instrument development. When everything works well at the factory, it should also work well in orbit. There should be no surprises after launch because identical hardware and software will be used to operate it.

During instrument development, the PI's operating personnel will become very familiar with the computer and its operation. Then they will participate in the integration and test of the instrument with the spacecraft. During this time, they will be taught the spacecraft operation. In this way they will be given "hands on" operations experience with their satellite long before they see it in orbit.

When it comes time for launch, the software for that mission will be installed in the same equipment at the launch facility. Again, there should be no surprises during the prelaunch checkout.

RELIABILITY OF THE GROUND STATION AND SATELLITE

To keep the ground station and satellite costs low, no redundant hardware will be provided. This means that the ground station may be out of operation for one or more days while repairs are made. This outage will not be a problem to the satellite since it will automatically go into a safe mode when it runs out preprogrammed things to do. If the station is going to be out of service for an unacceptably long time, the PI can request ground station support from NASA. Any of the NASA ground stations and any of the other transportable stations can be used. For most station failures, the PI could still control his satellite by sending his commands via the modem. When this is not possible, control could be passed to any of the other portable stations. These sites already know how to operate a similar satellite and would insure its continued health. If the PI had prepared a few days worth of commands and had made a back up copy, he could use any available computer to send these to the alternate control site and not lose any science.

In the event of trouble on the spacecraft, the PI could ask for support from this same set of ground stations. They would provide the extra contact time needed for diagnosis of the problem and taking corrective actions. If the subsystem experts at the satellite manufacturer's plant are needed, they can get data via a modem from these sites or directly from the satellite using their RF ground equipment

LOW INCLINATION ORBITS

When the inclination of the satellite is less than the latitude of the PI's facility, the satellite will not fly over the PI's facility even once a day. To handle this special case, the PI would still be supplied the portable ground station but not the communications hardware. Using a modem, he would send his commands to a NASA ground station or another portable station that could see his satellite. His data would return to him over the same path after being stored at the receiving site.

THE PI's BENEFITS AND CONCERNS

The PI's benefits are that he will experience a minimal delay in receiving data and he will have full control over his mission. There will be a minimum of dependence on people, equipment and institutions outside of his control.

His concern with this operating mode will be that he doesn't inadvertently kill the mission or accidentally lose a lot of data. Another concern would be that he might get too bogged down in operations to concentrate on the science. We expect to minimize the possibility of failure and to simplify the operation by relying on expert systems in the ground and flight software. It should be noted that an autonomous PI operation will not be forced on any PI. Any mission can be run in the traditional way if that is preferred.

Some of the PI's work will not change one way or the other. Even if NASA takes care of the spacecraft and the communications, the PI will still have to maintain his instrument's health and safety, develop a daily instrument operating command list and process his data.

A side benefit for the PI's institution is that the portable ground station can be used for other purposes. At a university, it can be used to give student engineers and scientists hands on experience with space missions. The receiver and antenna feeds will also cover the frequencies used by various weather satellites. Software to display the data will also be available. This is possible because this station has evolved from a station designed to receive data from these satellites.

THE NASA's BENEFITS AND CONCERNS

The benefit for NASA is that this mode should save money. We have not done a detailed cost analysis, but a qualitative discussion of cost will make the point.

Satellite/Instrument Development Costs

When the NASA does not furnish GSE to a satellite manufacturer, he must design and build whatever he needs. Similarly, unless we supply it, each PI's instrument builder will build whatever he needs for GSE. This will be repeated for each payload in the series. By supplying a transportable ground station for this function, this design and hardware cost is incurred only once. The software cost for satellite development and the several instrument developments will be similar no matter who builds the GSE hardware. However, by using the same hardware for operations, this software can be used as is. It will not need to be modified or rewritten to run on some other hardware.

Operating Costs

If we operated three Scout-class Explorer missions in the usual NASA way, there would be four cost items. First, we would need a highly reliable operations center with its software and one shift of three people a day. Second, we would need the use of one highly reliable ground station with its staff for perhaps an hour a day. The third cost covers communicating the data to the PI and getting his instrument observing commands. Lastly, the PI is paid to process his data and write up his results.

The portable ground stations combine all four of these items into one package. During a pass, it functions as a control center and it transmits commands and receives data with its own antenna. A few wires handle the distribution of this data and the commands. When the station is not involved in running a satellite contact, it performs the PI's data processing function. Since this capability is required in either operating scheme, the computer and its peripherals is a cost that is common to either operating mode. The only incremental hardware cost is the communication equipment. Even if three satellites are being supported by three portable ground systems, this communications hardware would be less than our share of cost of a highly reliable operations center and ground station.

NASA's Concerns

NASA's concerns are similar to the PI's concerns. Can we trust that the mission will go well and not fail prematurely? Aside from the hardware and software safeguards that will be built in, we should recognize that all the people at the PI's facility will be highly motivated to do well. Their reputations and jobs directly depend on their satellite functioning well.

SUMMARY

An inexpensive, portable ground station is described that will autonomously support a proposed series of Scout-class Explorer missions. This station will reside at a PI's institution until his mission is finished. It will then be moved to another PI's institution where it will operate his satellite. Even though each portable station will not include redundant hardware, backup systems will be available to maintain adequate mission reliability. It is also shown qualitatively that this mode of operating will be somewhat less expensive than our usual institutional approaches.