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Low Earth Orbiter Demonstration Terminal

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The concept of an automated, unattended ground system for low-cost tracking of near-Earth missions has been validated by the successful demonstration of a telemetry receive-only terminal that tracked two NASA spacecraft-of-opportunity in low Earth orbit. The terminal receives, processes, and distributes telemetry data to principal investigators without operator intervention. The validated Low Earth Orbiter Demonstration (LEO-D) terminal is designed around commercial off-the-shelf subsystems and is now available as a low-cost turnkey product from a commercial vendor.

I. Introduction

The idea of an automated, unattended terminal was conceived by the NASA Office of Space Communications to reduce the life-cycle cost of tracking near-Earth missions. JPL was tasked in FY 1994 to conduct a demonstration of the concept. Successful 1-week demonstrations of the automated, unattended operations of the terminal were conducted with the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) in July and with the Extreme Ultraviolet Explorer (EUVE) in December of 1994. Since then, the terminal has been further tested by routinely tracking National Oceanographic and Atmospheric Administration (NOAA) weather satellites for over 2,000 satellite passes. In the August–November 1995 period, the terminal was modified to add uplink command capability for full service (telemetry and command) support of low Earth orbiter missions. This article documents the receive-only terminal and the corresponding tests/demonstrations.

Significant drivers for this work include the need for a lower-cost alternative to the current NASA ground network tracking assets (26-m and 11-m antennas) to serve an increasing number of low Earth orbit (LEO) missions;[1] the desire for and advantages of direct-to-ground tracking [versus the Tracking and Data Relay Satellite System (TDRSS)] [1], facilitated by low-cost onboard solid-state memory; and the goal of "pushing" data to the principal investigator (PI) over commercial communications services to further reduce operations cost.

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[1] R. J. Cesarone and R. L. Horttor, *Integrated Ground Network Design for Near-Earth and Deep-Space Mission Support*, JPL D-12819 (internal document), Jet Propulsion Laboratory, Pasadena, California, August 1995.

The availability of commercial subsystems for the building of reliable automated ground stations provides the enabling environment for realizing the goals quickly and cost effectively. In particular, the automation, integration, and networking capabilities available with modern workstations provide the opportunity for a major paradigm shift: simply to view the ground station as a workstation that happens to have specialized hardware (antenna, receiver, etc.) as its peripherals.

II. Demonstration Concept and Approach

The demonstration concept and approach were driven by the following sponsor directives: a quick, low-cost demonstration with an existing small explorer (SMEX) mission, use of a receive-only terminal, autonomous terminal operations, and use of commercial telephone lines for all terrestrial communications, including automated data delivery to the science investigators.

A. Demonstration Concept

The demonstration concept focused on operating an automated telemetry receive-only terminal in a remote, unattended mode to track low Earth orbiter spacecraft of opportunity for intervals of approximately 1 week. As shown in Fig. 1, remote access to the terminal is used to select spacecraft to be tracked, when to track each spacecraft, and where and when to send the processed data to participating PIs for the mission. The processed data are analyzed by the PI to verify the quality of the data. The uplink to and operation of the spacecraft are provided by collaborating missions. As requested by the sponsor, use of commercial telephone lines for data communications between the telemetry terminal, remote control terminal, and the PI facility were integral parts of the demonstration.

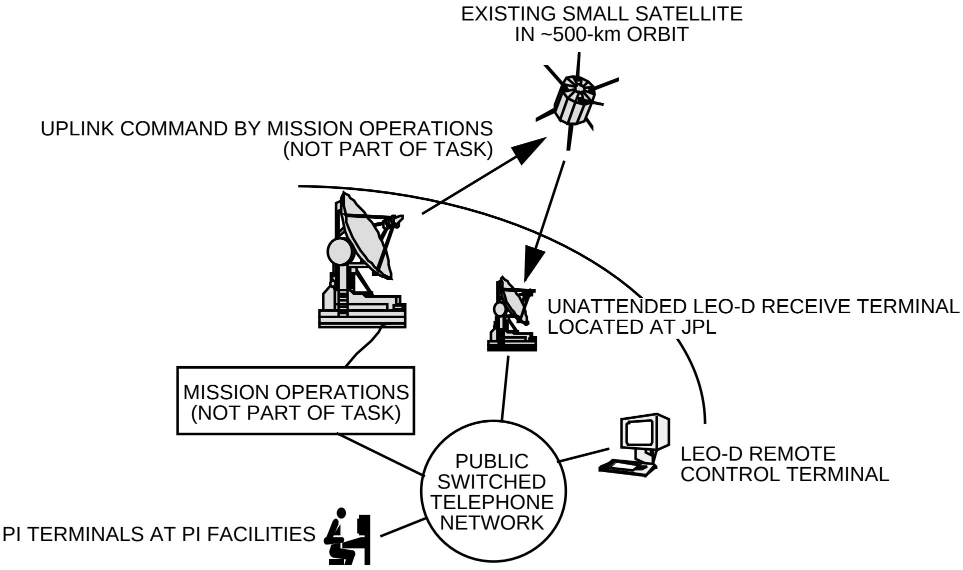

Fig. 1. The LEO-D terminal demonstration concept.

B. Mission Selection

The selection of candidate missions was based on the following criteria: availability for demonstration in calendar-year 1994, viability of telemetry reception by small, low-cost terminals, ease of demonstration coordination, and willingness on the part of the mission's PI to assist in validation of the delivered data. Figure 2 shows the terminal G/T (ratio of the antenna gain over the antenna system temperature) requirements for telemetry reception from five missions that meet the first two criteria. Discussions with mission operations and PIs for SAMPEX and EUVE, two low Earth-orbiting missions operated by

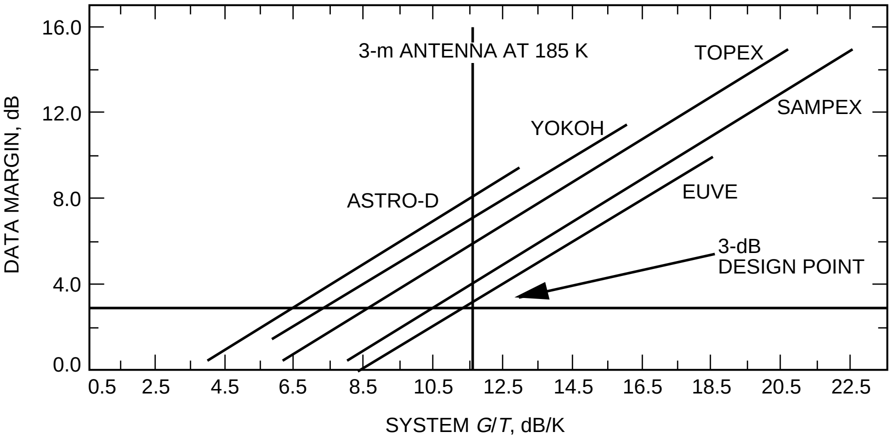

Fig. 2. The telemetry data margin as a function of terminal *G*/*T* for LEO missions of opportunity (calculated at a satellite elevation angle of 10 deg and assuming the terminal is 80 deg of the spacecraft antenna boresight).

NASA's Goddard Space Flight Center (GSFC), resulted in agreements to conduct the demonstrations with these two missions. The PIs for both SAMPEX, at the University of Maryland, and EUVE, at the University of California, Berkeley, agreed to analyze the telemetry data to validate their quality.

III. LEO-D Terminal

A. Terminal Requirements and Selection Approach

Orbit and link characteristics for SAMPEX and EUVE are summarized in Table 1. As shown in Fig. 2, the terminal G/T requirement for telemetry reception from these missions could be satisfied with a 3-m antenna. A survey of commercially available terminal systems indicated that automation and autonomy requirements of the terminal can be met by commercially available, low-cost weather satellite tracking stations; however, hardware modifications to these terminals would be required to accommodate the operating frequency, G/T, and multifunction capability for demonstration with SAMPEX and EUVE. Further survey of the commercial market indicated that the necessary hardware modifications to the weather satellite terminals could be accomplished quickly and at low cost using commercial off-the-shelf (COTS) equipment.

The Low Earth Orbiter Demonstration (LEO-D) terminal was competitively procured as a turnkey system and installed at JPL in July 1994. SeaSpace Inc., a weather satellite terminal manufacturer in San Diego, California, provided the terminal per upgrade requirements defined by JPL for tracking telemetry data from NASA satellites. This modified system is referred to hereafter as the LEO-D terminal. Table 2 lists the terminal subsystems, all commercial products, and their vendors.

B. Terminal Characteristics

Figure 3 presents a block diagram of the LEO-D terminal. The terminal consists of a 3-m aluminum mesh antenna enclosed in a fiberglass radome and a 1.2-m rack that houses the station electronics. Figure 4 shows the antenna system installed on the rooftop of Building 260 on the Mesa at JPL, while Fig. 5 shows the electronic rack housed inside a small room in the same building. The radome protects the antenna RF front-end and tracking mechanism from rain, winds, and other environmental conditions. This results in a low-cost, low-maintenance tracking antenna system.

The electronics rack includes the telemetry receiver, bit synchronizer, antenna controller, and a SPARC 10 workstation, all of which are commercial equipment. The workstation provides the automated,

Table 1. Summary orbit and telemetry characteristics for SAMPEX and EUVE.

Characteristic	Mission	
	SAMPEX	EUVE
Apogee, km	675	532
Perigee, km	550	500
Inclination, deg	82.2	28.2
Downlink frequency, MHz	2215.0	2287.5
Polarization	Left-hand circularly polarized (LCP)	Right-hand circularly polarized (RCP)
Maximum data rate, kbps	900	1024
Baseband signal	Biphase	Biphase
Modulation	PM	PM
Convolutional coding	Rate 1/2	None
Maximum Doppler shift, kHz	60	64
Maximum Doppler rate, kHz/s	0.80	0.85

Table 2. LEO-D terminal turnkey vendor and commercial subsystems.

System	Vendor	Model number
LEO-D system integrator and software	SeaSpace	LEO-D terminal
Subsystems		
Radome, antenna, front end	SeaTel	SAR 1200
Tuner, receiver	Microdyne	MR 1400
Bit synchronizer	Decom Systems, Inc.	DSI 7000
Workstation	SUN Systems	SPARC 10

unattended operation of the terminal, including autoscheduling, calculation of orbital trajectories, control of the antenna positioner for spacecraft tracking, and automated telemetry operations, as well as the processing and distribution of spacecraft engineering and science telemetry data to mission operations and the science users of the data.

Table 3 provides performance data on the LEO-D terminal. In its current configuration, the terminal operates in the 2210- to 2295-MHz band. The antenna and its associated feed and low-noise amplifier (LNA) have a combined G/T of 11.5 dB/K in this band. The antenna system can track Earth-orbiting spacecraft at rates up to 5 degrees per second in both azimuth and elevation.

The receiver can demodulate binary phase shift key (BPSK)-modulated and quadrature phase shift key (QPSK)-modulated signals as well as phase-modulated (PM) or frequency-modulated (FM) signals with arbitrary modulation indices. The bit synchronizer can synchronize on nonreturn-to-zero (NRZ) and biphase (Manchester-coded) data and, if needed, can also provide for soft decoding of rate 1/2 constraint-length-7 convolutionally encoded data. The bit synchronizer can operate at input symbol rates of up

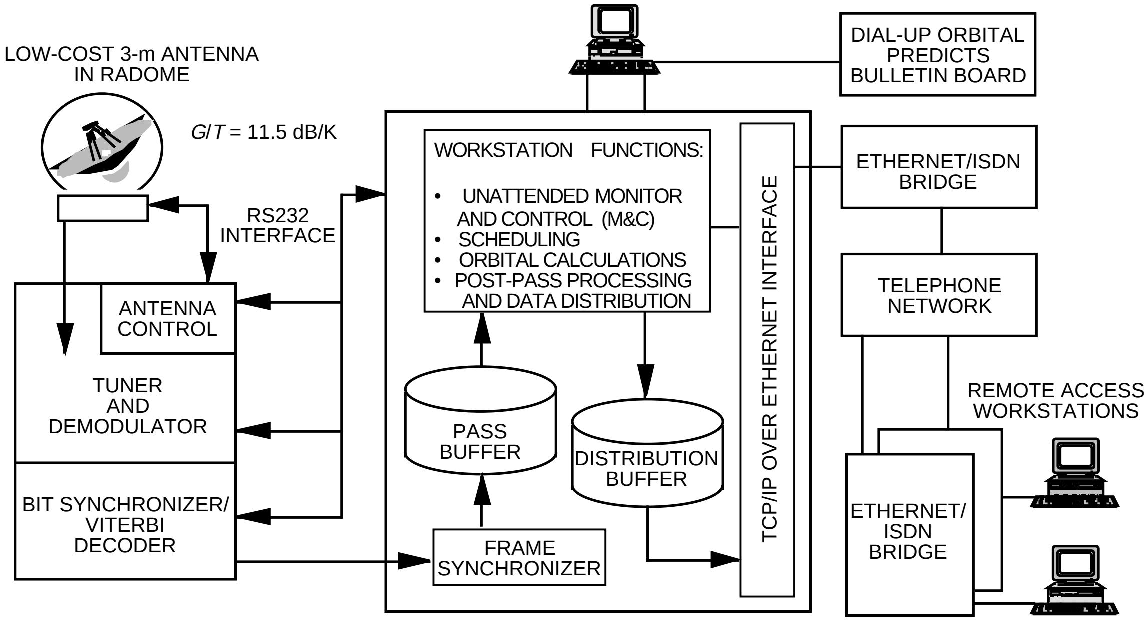

Fig. 3. The LEO-D terminal system design based on commercial hardware and software.

Fig. 4. The LEO-D radome/antenna assembly installed on Building 260 on the JPL Mesa during SAMPEX and EUVE demonstrations. (The assembly was moved to the rooftop of Building 238 in April 1995).

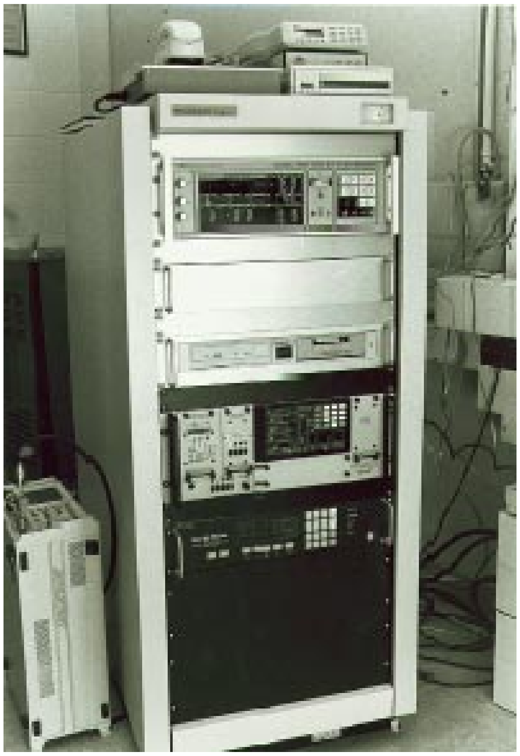

Fig. 5. The 1.2-m LEO-D terminal rack housing the control workstation, communications interfaces, antenna controller, and the entire receiver.

Table 3. LEO-D terminal performance summary.

Characteristic	Performance
Allowable spacecraft inclination, deg	0–180
Maximum azimuth tracking rate, deg/s	5
Reception frequency, MHz	2210–2295
G/T, dB/K	11.5
Polarization	LCP and RCP, remotely selectable
Baseband signal	NRZ, biphase, remotely selectable
Modulation	FM, PM, BPSK, QPSK, remotely selectable
Convolutional decoding	Rate 1/2 (on/off)
Maximum symbol rate, ksps[a]	4800
Maximum data rate for NRZ data, kbps[a]	2400 ($R = 1/2$ coded), 4800 (uncoded)
Maximum data rate for biphase data, kbps[a]	1200 ($R = 1/2$ coded), 2400 (uncoded)
Maximum Doppler shift tracked, kHz	100
Maximum Doppler rate tracked, kHz/s	1.0

[a] Subject to availability of adequate telemetry data margin.

to 4.8 Msps. This translates to an effective telemetry reception rate of 1.2 Mbps if the data have been biphase and rate 1/2 convolutionally coded, as is often the case with most NASA near-Earth missions.

The operating frequency and the ceilings on telemetry rates of the terminal can be modified easily by replacing the appropriate modules of the terminal with other commercially available equipment consistent with the desired data rates and operating frequencies.

C. Telemetry Processing

Telemetry data processing is performed by software residing in the LEO-D terminal workstation. Figure 6 shows a block diagram for the data-processing capabilities of the LEO-D terminal. The bit stream from the telemetry channel passes through the frame synchronizer and is buffered on a dedicated disk (pass buffer). The quality of the data is verified by executing a cyclic redundancy check (CRC) on each frame; the CRC statistics are recorded in a log file for each telemetry dump to document the quality of the received telemetry data. Depending on the mission requirements, the telemetry data can be either sent directly to the end user, stored for subsequent transmission to the user, or processed further and then forwarded to the user. The first two options were used when demonstrating the terminal with EUVE and the third option with SAMPEX. Further details of the data-processing and distribution configuration for the demonstrations with the two missions are given in Sections IV and V of this article. It should be noted that the terminal is capable of providing customized data processing for multiple missions. Based on the instructions given to the terminal through the autoscheduler, the automated "data handler supervisor" activates the customized data-processing routine to process the telemetry for the specific mission.

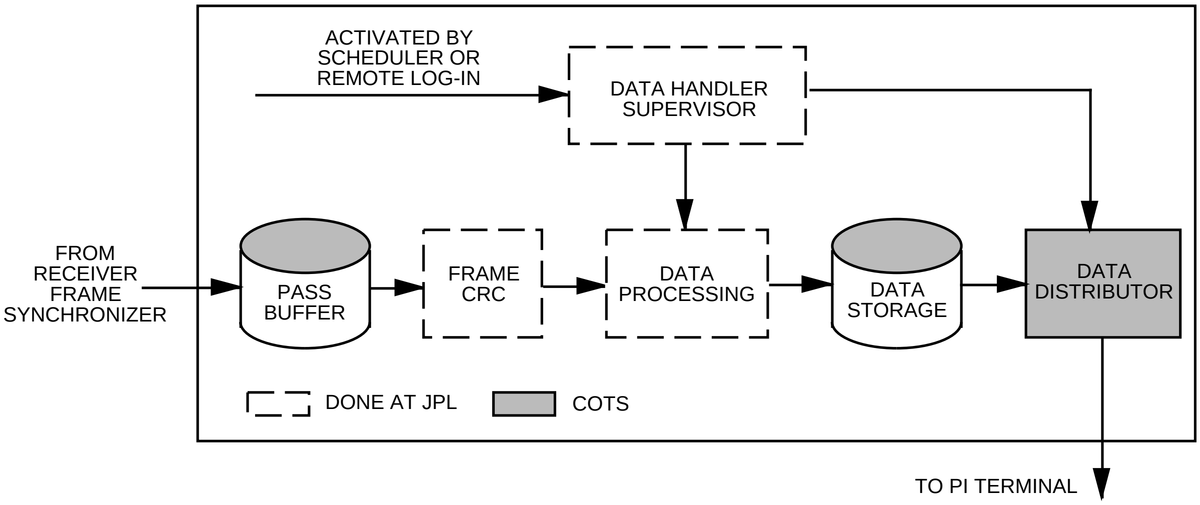

Fig. 6. The Leo-D terminal data processing and distribution.

D. Communications Interface

A switched integrated service digital network (ISDN) provided by phone companies over regular phone lines is used for ground communications. The terminal SPARC workstation has a standard ethernet interface that is connected to two ISDN lines through the same number of ethernet–ISDN bridges (see Fig. 3). The duplicate ISDN lines allow two simultaneous connections with the terminal; this configuration can be scaled to allow a larger number of simultaneous connections. The same arrangement, but with one ISDN line connection per site, is duplicated at the facilities of the PI and other authorized users of the LEO-D terminal. For reliable communication, the terminal and the remote users employ transaction control protocol/internet protocol (TCP/IP). This particular networking arrangement has proved to be low cost and very effective during the LEO-D terminal demonstrations. The ethernet–ISDN bridges provide good security as they are programmed to accept calls from specific parties. The bridges also provide for lossless data compression for transmission across the ISDN lines. Telemetry data contain considerable repeating patterns and are very good candidates for lossless data compression. A compression ratio of approximately 4:1 was achieved when sending processed SAMPEX science data to its destination.

E. Automated Autonomous Operation of the Terminal

The terminal workstation provides for automated, unattended operation of the terminal. After the initial setup, the terminal automatically dials an electronic bulletin board on a daily basis and retrieves orbital elements, supplied by the Naval Space Surveillance Center, for Earth-orbiting spacecraft. Based on these orbital elements, the terminal automatically generates satellite view periods and antenna-pointing predicts. The autoscheduler uses the view periods and user-defined tracking priorities to continuously track multiple spacecraft of interest. For every scheduled pass of the spacecraft, the autoscheduler wakes up the terminal one minute before the spacecraft appears over the horizon. The terminal then executes the automated, unattended telemetry reception routines, after which it waits for the next scheduled spacecraft.

When the terminal is waiting between scheduled passes, it processes the telemetry data and then sends the data to the destination designated for each spacecraft, using file transport protocol (FTP) over predesignated communication links, such as ISDN lines.

IV. Demonstration With SAMPEX

A. The SAMPEX Spacecraft

SAMPEX is a small explorer-class mission that is operated by GSFC's SMEX Office. The spacecraft is in a near-circular orbit at an altitude of approximately 600 km and an orbital period of 94 min at an inclination of 82 deg; the orbit is not sun synchronous. The spacecraft spins around its longitudinal axis at a rate of one turn per orbit. The spin axis and the solar panels are kept facing the sun. The spacecraft has two low-gain antennas 180 deg apart and perpendicular to the spin axis. A NASA SMEX transponder with a 5-W S-band transmitter is used for communications with the ground. The power is split equally between the two low-gain antennas. Allowing for the cable losses, power splitting, and radiation pattern of the antenna, the effective isotropic radiated power (EIRP) is about 31 dBm at the boresight of the low-gain antennas, dropping to 24 dBm at an angle of 80 deg away from the antenna boresight. At angles further than 80 deg from the antenna boresight, the gain pattern becomes very erratic because of interference between the radiation patterns of the two low-gain antennas and the body of the spacecraft. Depending on the orientation of the orbit with respect to the Sun, the attitude of the antenna with respect to the subsatellite point can vary from 0 to 90 deg.

The spacecraft telemetry downlink can be operated either at 16 kbps (real-time data) or 900 kbps (playback from solid-state memory merged with real-time data). At transmission, the telemetry data first are convolutionally encoded at a rate of 1/2 and then Manchester coded (biphase data), resulting in a symbol rate of 64 kbps for real-time data and 3600 kbps for playback. The 64-kbps or 3600-kbps symbol stream phase modulates a 2215-MHz carrier at a modulation index of 1.1 rad.

B. The SAMPEX-to-LEO-D Data Margin

The SAMPEX-to-LEO-D terminal data margin is highly variable during the satellite pass, due mainly to rapid variation of the range and the orientation of spacecraft attitude with respect to the receiving station. Figure 7 shows predicted dynamic link margins for telemetry dumps at 900 kbps during four SAMPEX passes over JPL on August 11, 1994. The dynamic link margins have been calculated by modeling of the spacecraft (S/C) orbit and spacecraft antenna orientation with respect to the ground station.[2] Particularly troublesome for telemetry operations are the deep signal nulls, lasting several

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[2] A. Kantak, "On Site Performance Estimate for SAMPEX Spacecraft Tracking," JPL Interoffice Memorandum 3396-94-25 (internal document), Jet Propulsion Laboratory, Pasadena, California, May 4, 1994.

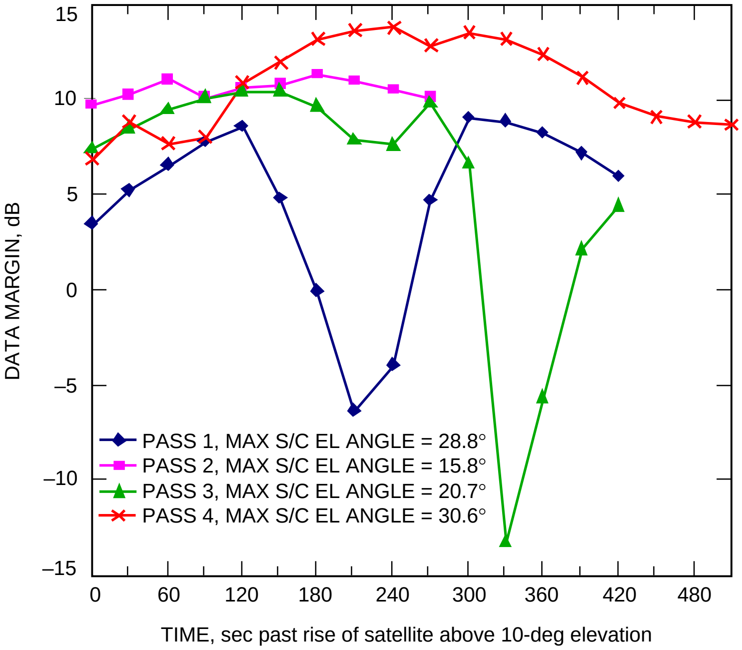

Fig. 7. Estimated data margins for 900-kbps SAMPEX telemetry reception by the LEO-D terminal for four satellite passes over JPL on August 11, 1994.

seconds in the middle of some passes (passes 1 and 3 on this particular day). These signal nulls occur when the orientation of the spacecraft antenna with respect to the ground station is in the 80- to 90-deg range. Similar nulls but of shorter duration also occur at the 9-m ground station at Wallops Flight Facility (WFF), used to support the SAMPEX mission in normal operations. Fortunately, the volume of science data stored on board the spacecraft is small enough such that the stored telemetry data can be dumped twice during most passes, allowing the recovery of almost all of the telemetry data. The same technique was used during the LEO-D SAMPEX demonstration. As an added measure, an exercise was carried out to implement automated dynamic link margin prediction as part of the scheduling process. A number of tests indicated that the model correctly predicted the time of occurrence of signal nulls with an accuracy of 15 s. This allowed for an intelligent selection of data dump windows during the scheduling of telemetry data dumps for the 1-week demonstration; consequently, the percentage of data recovery by the 3-m LEO-D terminal was as good (and actually slightly better than) the performance of the 9-m ground station.

C. The Demonstration Setup

Figure 8 shows the SAMPEX–LEO-D terminal demonstration configuration conducted in collaboration with the SAMPEX operations office at GSFC and the PI at the University of Maryland. A 1-week demonstration window was selected in August 1994 at the convenience of all parties. One week before the start of the demonstration, the LEO-D terminal autoscheduler was used to generate a list of SAMPEX-in-view periods and dynamic data margins for SAMPEX–LEO-D terminal telemetry dumps. The best two passes per day were selected for the 1-week demonstration period, and the schedule was forwarded to SAMPEX operations at GSFC. During the 1-week demonstration period, the spacecraft dumped its stored telemetry science data twice per day to the 9-m station at WFF as part of its routine operations. After the dump to WFF, the same data would be retained in the spacecraft solid-state data storage and dumped to the LEO-D terminal when the spacecraft passed over JPL. The data dumped to WFF would follow its normal routine, i.e., the raw data would be transferred as NASA communications (NASCOM) blocks to the data-processing facility at GSFC for level-zero processing, then formatted

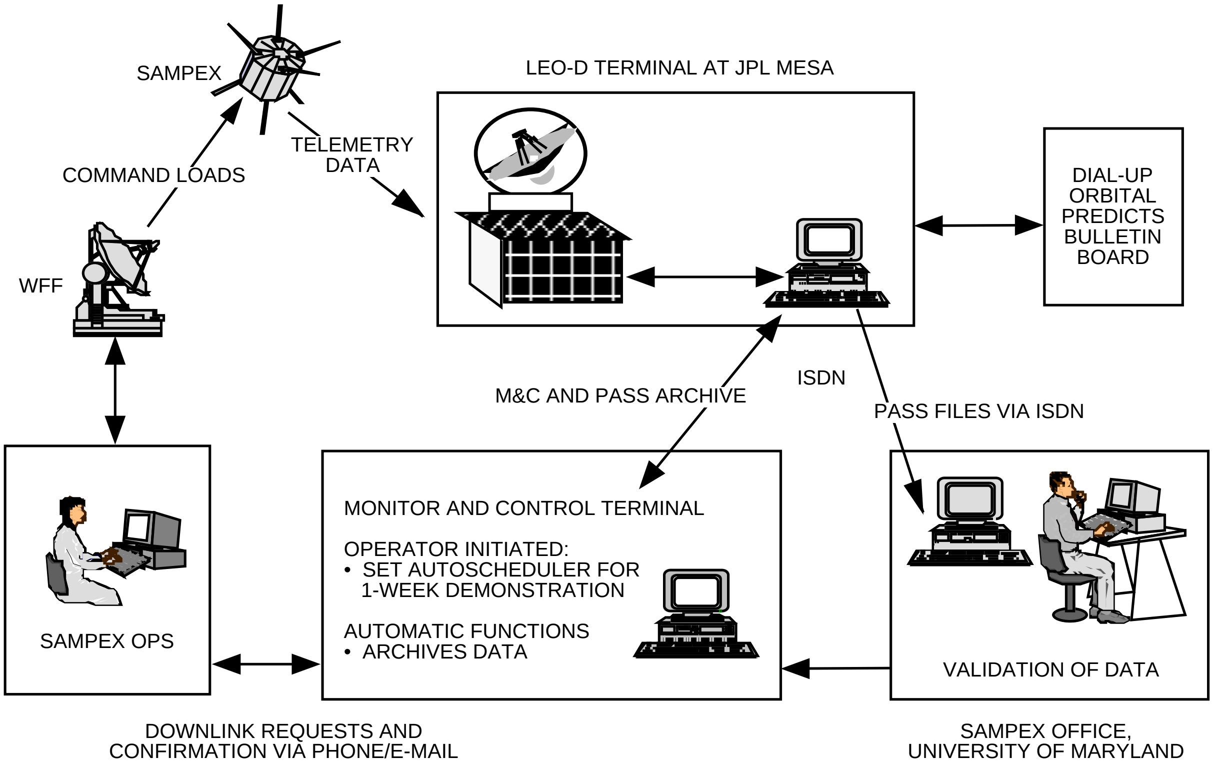

Fig. 8. The LEO-D terminal demonstration with SAMPEX (August 8–15, 1994).

into distinct instrument files, and finally transmitted as NASCOM blocks to the PI at the University of Maryland for value-added science processing.

Figure 9 shows a block diagram of the approach used by the LEO-D terminal to process SAMPEX telemetry data. SAMPEX telemetry follows Consultative Committee for Space Data Systems (CCSDS) standards [2]. The telemetry stream is structured into frames with 8 virtual channel designations and packets marked by 48 application process identifiers (APIDs). Telemetry processing starts with the reading of the telemetry data from the pass buffer, followed by verification of the quality of each frame by CRC. This is followed by virtual channel extraction (SAMPEX has 8 virtual channels), which is followed by packet extraction. SAMPEX has 48 categories of packets that are designated by 48 distinct APIDs. APIDs 1–18 are for science and 19–48 for engineering data. One index file per APID is used to record pointers to each recovered packet belonging to the particular application.

Once packet extraction and indexing have been completed for one telemetry dump, the process waits until data from the next telemetry dump from the same spacecraft become available. The data from the second dump are processed and the recovered packets and their pointers added to the packet buffer and the packet index files. For each APID, the packet index from passes 1 and 2 are merged, sorted, and purged of duplicate packets. This process continues, and new packets are continuously added to the packet buffer and recorded in their index files for subsequent telemetry dumps. Once science packets bearing satellite time stamps for a 24-hour period have accumulated in the buffer, the science packets corresponding to the 24-hour period are separated from the buffer and formatted into 18 PI files (one file per science APID).

The telemetry science files (PI files) were sent to the PI on a daily basis via FTP using TCP/IP protocols over the ISDN line. Over the 7-day demonstration period, quality checks were performed on

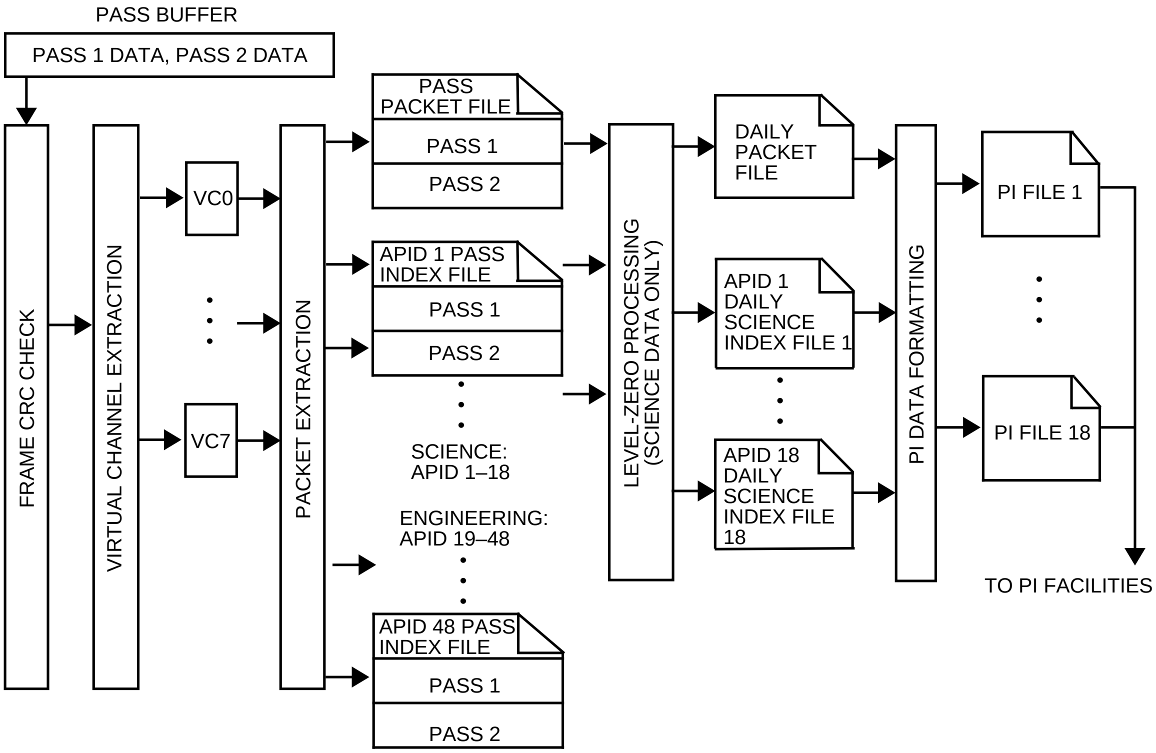

Fig. 9. Packet extraction, level-zero processing and data formatting performed by the LEO-D terminal for the SAMPEX demonstration.

the data, initially at the LEO-D terminal as part of the data-processing procedure described above, and then reconfirmed by the PI. The percentage of science data packets missing in the final instrument data files was used as a quantitative measure of the success of the telemetry reception by the LEO-D terminal. For the data collected by the LEO-D terminal, the percentage of missing science data packets was in the 1-percent range (see Table 4). This compared favorably with the 1- to 2-percent miss rate of the same science data recovered through the normal operations of the mission during the same period.[3] The main cause of data loss is link outages caused by the spacecraft antenna pointing away from the ground station during portions of the satellite pass.

This successful 1-week demonstration validated the automated, unattended operation of the LEO-D terminal for reception, processing, and distribution of telemetry data from low Earth-orbiting missions.

V. Demonstration With EUVE

The EUVE is an explorer-class mission that is operated by GSFC. The spacecraft is in a circular orbit at an altitude of 500–550 km and an orbital period of 92 min at an inclination of 28 deg; the orbit is sun synchronous. The spacecraft is spin stabilized. The mission's telecommunications needs are normally supported by TDRSS through a gimbaled high-gain antenna on board the spacecraft. The spacecraft has a low-gain antenna for emergency support by the NASA Deep Space Network (DSN). The initial planning for the EUVE–LEO-D terminal demonstration was centered around the use of the spacecraft's low-gain antenna. However, this plan changed drastically when one of the two transmitter power amplifiers on board the spacecraft failed in March 94. The mission determined that it was unsafe

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[3] G. Mason, personal communication, SAMPEX PI, University of Maryland, Greenbelt, September 1994.

Table 4. Performance summary of the LEO-D terminal demonstration with SAMPEX.

UTC date, yr/mo/day	Pass summary (2 passes/day)			Daily performance summary	
	Pass beginning, h:min:s	Pass duration, min:s	Maximum elevation angle, deg	Science packets received	Packets missing, percentage
94/08/08	06:09:10	8:40	76	71,124	1.09
	18:34:40	6:40	65		
94/08/09	06:19:00	8:20	43	78,212	0.92
	18:44:40	6:20	79		
94/08/10	06:29:00	7:20	26	70,100	0.85
	18:53:00	7:30	48		
94/08/11	06:39:39	5:22	16	82,912	1.19
	19:01:20	8:20	31		
94/08/12	05:10:45	9:59	48	69,026	0.78
	19:11:51	6:56	20		
94/08/13	05:20:20	7:12	84	64,314	1.18
	17:46:00	6:00	52		
94/08/14	05:30:08	7:55	55	89,822	1.03
	17:55:29	6:22	84		
94/08/15	05:40:04	7:13	32	76,432	0.89
	18:05:09	6:20	61		

to switch the remaining transmitter power amplifier on the spacecraft between the TDRSS-tracking high-gain antenna and the ground-mode low-gain antenna. At the same time, tests indicated that when the spacecraft is transmitting telemetry data at 32 kbps to TDRSS, the side-lobe power transmitted in the direction of the ground at intermittent times will be of sufficient strength for reception of the telemetry data by the LEO-D terminal over periods lasting 20–30 s at a time. After considerable deliberation, it was decided to go on with limited tests/demonstrations with the EUVE with the configuration shown in Fig. 10.

Using its autoscheduler, the LEO-D terminal was set to track the EUVE whenever it was in view and to monitor the telemetry link for useful telemetry data from the spacecraft. As the spacecraft high-gain antenna was not trained on the location of the LEO-D terminal, telemetry data would be collected only when the spacecraft antenna happened to be in a direction such that some of the signal transmitted through the side lobe would reach the LEO-D terminal.

The collected telemetry data were frame synchronized and then transmitted to the EUVE PI facilities at the University of California, Berkeley, over ISDN lines using FTP. The automated, unattended operations of the terminal and its data distribution capabilities worked flawlessly during the test/demonstration period [1]. Statistics on the quality of the telemetry data are given in Table 5. It should be pointed out the errors appearing in the data are an artifact of the spacecraft's lack of pointing of its high-gain antenna towards the terminal on the ground and not a result of terminal under performance. A number of EUVE-class missions are considering the use of LEO-D-class terminals (with uplink capability) for support of their missions [1].

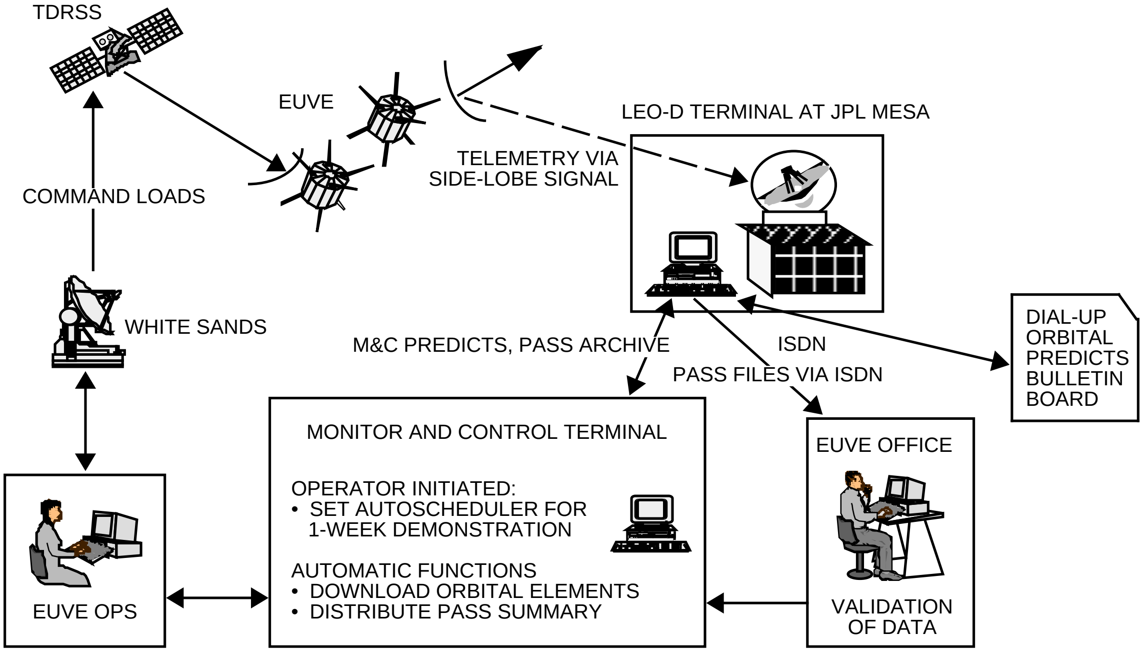

Fig. 10. The LEO-D terminal demonstration with EUVE (November–December 1994).

Table 5. Performance summary of the LEO-D terminal demonstration with the EUVE.

UTC date, yr/mo/day	Pass summary			Pass performance summary	
	Pass beginning, h:min:s	Pass duration, min:s	Maximum elevation angle, deg	Frames received per pass	Frames with CRC errors, percentage
94/11/20	15:03:10	12:30	35	3584	0.6
94/11/21	13:03:00	11:30	24	5632	5.7
94/11/22	14:22:10	12:20	36	1280	5.8
94/11/23	12:22:40	12:10	27	2080	5.1
94/11/23	15:43:50	11:30	24	1024	4.9
94/11/24	13:42:00	12:25	35	1024	3.1
94/11/25	11:42:10	12:20	30	2304	2.8
94/11/25	13:22:10	12:25	34	1024	1.1
94/11/26	11:22:06	12:10	31	2560	0.7
94/11/27	09:22:00	11:30	17	4352	0.9
94/11/27	11:01:00	12:10	32	3072	1.1
94/11/28	09:01:00	11:30	19	3840	0.8
94/11/28	10:41:00	12:10	33	3072	2.4
94/11/29	08:41:00	11:30	20	4096	1.6

VI. Longevity Tests on the LEO-D Terminal

In order to get long-term statistics on its operation, the LEO-D terminal has been autoscheduled to track three NOAA weather satellites (NOAA 11, 13, and 14) on a continuous basis since installation in July 1994. The only exceptions have been a two-week period in April 1995 when the terminal was relocated from the JPL Mesa to a rooftop position on JPL's Building 238 and an accumulation of 60 days when the terminal was being upgraded with uplink capability in the August–November 1995 time frame. During this period of almost 14 months of operation, the LEO-D terminal has worked trouble-free for over 2,000 satellite passes, corresponding to an accumulation of 330 hours of tracking.

VII. Conclusions and Follow-Ups

The LEO-D terminal demonstration has successfully validated the feasibility of automated, unattended operation of low-cost terminals for telemetry support of low Earth-orbiting missions. This marks an important milestone in efforts to reduce the life-cycle cost of tracking NASA satellites in near-Earth orbits. In addition to a low acquisition cost ($300 k for the 3-m option), the terminal is highly automated and operates autonomously, resulting in a low operations cost.

A separate study commissioned by the NASA Office of Space Communications has shown that from 55 to 70 percent of NASA near-Earth missions can be supported by 3- to 5-m terminals if uplink capability is added to the terminal.[4] This new class of low-cost Earth stations can be used as dedicated terminals to support individual missions, or several stations can be networked to provide ground support to a large number of near-Earth missions. JPL was tasked to upgrade the terminal with uplink capability and validate its autonomous, unattended operations in calendar year 1995 as a proof-of-concept demonstration prior to implementation of this capability by WFF as part of NASA's ground network [3]. Another aspect of the JPL challenge was to demonstrate that this class of terminals can reconfigure themselves without operator intervention to serve as "virtual dedicated terminals" while being time shared by several missions. This second phase of validation demonstration was successfully accomplished in December 1995 as this article was being completed. This second phase will be reported upon in a future article.

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