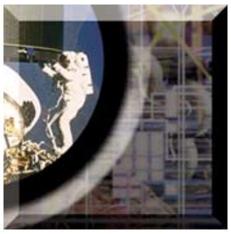

Unattended Satellite Contacts

Glen E. Baer and Steven E. Gemeny

The APL Satellite Communications Facility (SCF) has a 40-year history of conducting spacecraft operations. The facility has evolved over this period into an impressive ground station supporting both internal and external customers through an "unattended contacts" support paradigm. The concept is a proven operational standard within the SCF that results in substantial cost reductions. The capabilities of the SCF represent the key criteria for its success in the new commercial ground station market.

INTRODUCTION

Among the assets most visible at APL are the three antennas of the Satellite Communications Facility (SCF) that are used to communicate with various satellites. Each antenna is a discrete and independent system that provides the gain and pointing accuracy necessary to track and communicate with orbiting spacecraft. Each system is operated and scheduled by a separate suite of equipment within the SCF. Understanding the subtle differences among the antennas' capabilities and the ability to use each system to optimal effect are key criteria for the success of the SCF in the commercial ground station market.

This article describes the SCF and introduces the new concept of "unattended satellite contacts." The 40-year legacy of the SCF has yielded a state-of-the-art ground station with equipment and staff able to meet the needs of any customer. The staffing of the station rather than the program has made the unattended satellite concept as presented here possible.

SCF OVERVIEW

Location is one of the key attributes of any ground station. The SCF's mid-latitude location, at 39°10′ N latitude, 76°53′ W longitude, is ideal for communicating with numerous spacecraft of various orbital inclinations.

The SCF is more than simply a collection of antennas. A complete ground station involves a large amount of control equipment as well as specialized receivers and computers connected by a maze of wiring. Centralizing this equipment is a requirement for ease of maintenance and improved reliability (Fig. 1).

The focal point of all activities in the SCF is the Operations Center.[1] This 6000 ft^2 facility, located in APL Building 36, houses all equipment and personnel necessary to conduct SCF operations. Originally built in 1961 as the Injection Station for Transit,[2] the SCF has continuously been improved and upgraded to maintain its status as a state-of-the-art satellite communications facility.

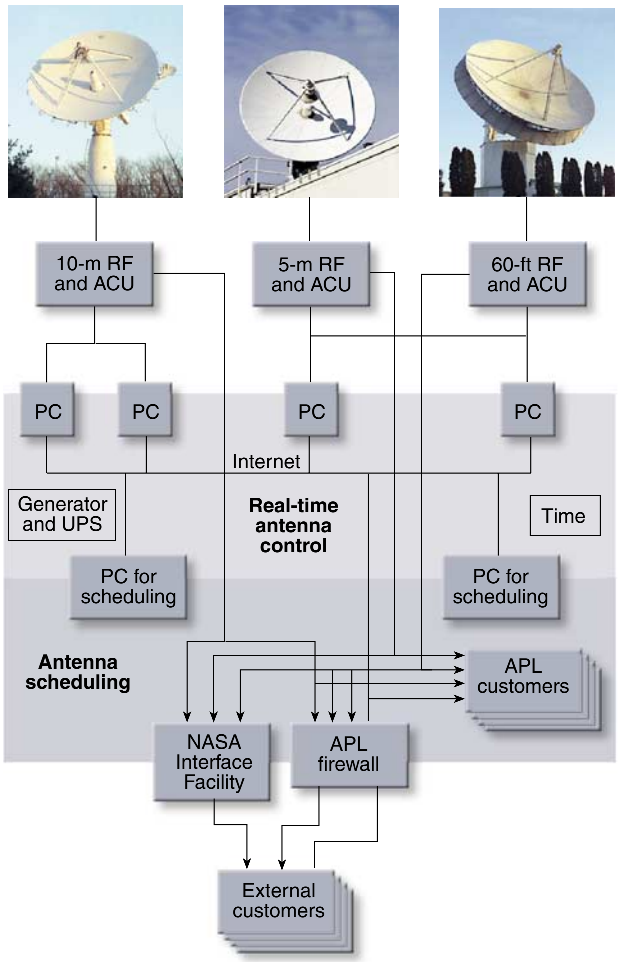

Figure 1. Satellite Communications Facility architecture (ACU = antenna control unit, UPS = uninterruptible power supply).

Within the Operations Center, each antenna is supported by a separate complement of telemetry and command equipment, including antenna controllers, telemetry receivers, demodulators, bit synchronizers, carrier and subcarrier generators, as well as telemetry and command processing equipment. Furthermore, reconfigurations within the SCF are enabled by the use of various electronically controlled switching matrices. These switching systems make it possible to reroute signals from one antenna to telemetry or command processing equipment normally used by another. In this manner it would be possible, for example, to use the Consultative Committee on Space Data Systems (CCSDS)[3] processing capability of the 60-ft system to process the telemetry received from the 5-m antenna at L band. Likewise, S-band telemetry being processed from the 60-ft system can instead be received by the 5-m system in the event of a short-term outage of the 60-ft antenna.

To provide a more cost-effective service to external (as well as internal) customers, the SCF operates under the paradigm of "unattended contacts." The strategy works by staffing the station rather than staffing for individual contacts (passes). Station staff are available to perform preventative maintenance, implement station improvements and upgrades, and work on other programs while they also address issues specific to an individual pass that might behave anomalously. This results in a vast reduction in overhead and mission-specific manpower costs associated with the need for an operator to monitor a specific spacecraft contact (typically 15 min of work) occurring 2 to 3 times during an 8-h shift.

The unattended contacts paradigm has been demonstrated effectively in the SCF since 1995 by the 5-m system in support of approximately 15 contacts per day with various NOAA spacecraft. The paradigm has also been embraced for the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED)[4] Program. TIMED, to be launched in August of this year, will be supported by the 60-ft antenna for up to six contacts per day during normal operations.

THE ANTENNAS

60-ft Antenna

The SCF commenced routine operations in the early 1960s when the 60-ft antenna became operational as the Injection Station for Transit, the Navy's first satellite navigation system. Over the years this antenna has been upgraded, enhanced, and maintained, not only for its historical value, but also as a unique asset providing a critical communications capability.

As the first system installed at the SCF, this is the largest and perhaps the most versatile of the facility's three antennas. It is equipped for S band (2025 to 2300 MHz) and VHF (150 MHz) operation.

The system's antenna gain in S band exceeds 48 dB (an amplification factor of over 50,000). This high gain is achieved at the expense of reducing the beamwidth of the antenna to 0.25°. This narrow beamwidth dictates extreme accuracy in both the pointing commands sent to the antenna and the timing of the commands. Also, during periods of closest approach, the predicted position of the spacecraft (calculated from its orbital element set) may introduce additional errors sufficient enough to cause loss of signal. This type of tracking error is eliminated by the use of an autotracking system that senses any misalignments between the antenna and the spacecraft and compensates automatically to keep the spacecraft centered in the antenna's beam.

The 60-ft system is one of the few hydraulic-driven antenna systems still in use. One distinct advantage of hydraulics is the available tracking rate. In the case of this antenna, a moving mass of nearly 30 tons can be driven at a rate in excess of 5°/s. The challenge of using hydraulics is the fine control of this large force. This is accomplished by limiting the maximum velocity in the 60-ft system to 2°/s and by using a microprocessor-based controller designed and fabricated by APL in the mid-1980s to "close the loop" on the hydraulic control.

Telemetry processing is accomplished using a high-speed, real-time, UNIX-based front-end processor, which is capable of processing telemetry at rates of up to 20 Mbits/s. The system is reconfigurable under software control to support up to 100 different spacecraft. These configurations can support a multitude of data rates, telemetry formats, and delivery options. The most significant among these formats have been published by the CCSDS. The basic design concept of the CCSDS capability was patterned after the LEO-T[5] ground station concept promoted by NASA Wallops Flight Facility.

When tracking spacecraft that are designed following CCSDS recommendations, the front-end processor used by the SCF can separate telemetry into virtual channels (up to 63 per mission) for immediate delivery over Transmission Control Protocol/Internet Protocol (TCP/IP) sockets, or selectively store the data for later delivery via File Transfer Protocol (FTP). The integrity of the data is preserved during the downlink process using a Reed-Solomon error correction code. For further protection against possible data corruption during the ground transport and archival processes, a spacecraft-generated cyclic redundancy check sum can be added. This check sum can be verified after the Reed-Solomon correction and preserved as part of the telemetry frame as it is transmitted on to the end-user.

During a contact, the front-end processor opens a socket connection to the customer's host for real-time telemetry and commands. Dump telemetry is separated within the front-end and stored for postpass FTP. The front end can also be configured to send station status telemetry over an additional socket connection.

SCF enhancements to the LEO-T telemetry system include the addition of a second redundant stack of telemetry processing equipment. This second stack can be used to seamlessly support a change of downlink mode or data rate caused by spacecraft autonomy. Also added to the basic LEO-T is the ability to support differentially encoded quadrature phase shift keying (QPSK) data. This data format, adopted by the TIMED Program as the primary high-rate mode, relies on differential encoding to resolve the four-way ambiguity inherent in QPSK. Traditionally, Viterbi encoding has been used prior to QPSK modulation, which would eliminate the ambiguity on the ground side after the receiver. The disadvantage of this approach is increased bandwidth of the downlink signal, which has an adverse effect on system performance for low-level signals. By adding the differential QPSK capability to the SCF, superior performance is maintained while minimizing downlink bandwidth for those missions designed to take advantage of the capability.

The SCF 60-ft system is also configured to support CCSDS commanding. Adherence to CCSDS recommendations allows the SCF front end to monitor the status of the spacecraft receiver for carrier and bit lock. This capability enables the SCF systems to detect possible command link failures and reestablish the spacecraft uplink without loss of any commands and without operator intervention.

SCF enhancements to the LEO-T command subsystem include multiple redundant command uplink chains. These uplinks consist of a pair of Microdyne TSS-2000 signal simulators used as an S-band source driving a pair of Logitmetric 50-W power amplifiers. The two uplink chains are cross-configurable, with redundant cabling to the antenna feed. This configuration of uplink equipment is capable of an effective isotropic radiating power (EIRP) equal to nearly 1 MW within the narrow beam of the antenna (59 dBW EIRP).

The VHF capability of the 60-ft antenna is an artifact of its original purpose in support of Transit. In this band, antenna gain is a more reasonable 25 dB (an amplification factor of nearly 325) and the beamwidth is a manageable 7°. Few, if any, of today's spacecraft use this band for command or telemetry. Possible uses for this VHF capability (now largely allocated to the Amateur Radio Service) may be limited to supporting crew morale and educational outreach programs with the International Space Station in conjunction with the APL Amateur Radio Club.

5-m Antenna

As APL and the SCF evolved through the late 1960s and 1970s, the need to support other missions developed. Enhancements to the 60-ft antenna alone could not meet the changing mission requirements for ground contacts. It therefore became necessary to add another system, the 5-m antenna, which was affixed to the roof of the then-new Kershner Space Integration and Test Building.[6]

This antenna, installed in 1985 as a backup to the 60-ft ground station supporting Geosat, is configured as a receive-only system. It is equipped to support reception in three bands, S (2025 to 2300 MHz), L (1650 to 1750 MHz), and X (8000 to 8500 MHz). Its S-band feed is equipped with autotrack capability. In this mode the 5-m system can be configured to feed pointing angles to the 60-ft system, but this capability is rarely used as it introduces another set of latencies to the 60-ft control subsystem.

The 5-m system has been the SCF workhorse for proving the unattended contacts concept. Since 1995 it has been conducting 12 to 15 unattended passes per day for an internal APL program. These passes have involved the automatic tracking, acquisition, and reception of signals from three different NOAA spacecraft and the reliable transmission of imagery for postpass processing. It also serves as a backup for the Midcourse Space Experiment (MSX)[7] Program run for the Ballistic Missile Defense Organization (BMDO) and the Air Force by APL since the launch of the MSX spacecraft in 1996. The experiences gained from these passes, now totaling nearly 50,000, form the basis of the current paradigm of unattended contacts now envisioned for future contacts at the SCF.

10-m Antenna

Following the success of the Geosat Program and a new national awareness of the need for space-based defense systems, APL began work on the MSX spacecraft. Supporting the ground contact requirements for MSX required yet another addition to the SCF antenna arsenal. This resulted in the installation in 1992 of the 10-m antenna at the north end of Building 23 to support MSX command and telemetry requirements. The system is the only space/ground-link subsystem (SGLS) command station in the United States not under exclusive DoD utilization. It is capable of reception in both S and X bands and is supported by a fleet of telemetry receivers and bit synchronizers handling rates in excess of 100 Mbits/s. The antenna gain at S band is 43 dB. At X band, the gain is over 55 dB (a factor > 400,000 times), making the 10-m antenna the highest-gain system at the SCF.

The system can transmit through either a 200-W solid-state power amplifier or a 2-kW klystron amplifier in the limited L-band range of 1763.7 to 1839.8 MHz. With an antenna gain of 42 dB in the uplink band, its EIRP (in the 1° beam) is in excess of 3 MW (75.5 dBW EIRP). Although this extreme transmit capability is rarely used, it provides just the type of superior performance that allows the SCF to support the special needs of damaged or failing on-orbit spacecraft.

THE OPERATIONS CENTER

Infrastructure

The SCF requires a reliable infrastructure to support operations. Most significant to its routine operations are electrical power, network connectivity, and, oddly enough, knowledge of time. The loss of any of these services, unless properly planned for, would cause the loss of critical spacecraft data.

The SCF is a fully autonomous self-contained facility capable of sustaining operations in the absence of commercial electrical service. All critical equipment is located inside the Operations Center and is powered via a 200-kW uninterruptible power supply (UPS). In the event of a commercial power outage, the UPS maintains operations during a transition to backup power, a 750-kW diesel generator. The transition to backup service is accomplished autonomously in less than 15 s. Again, the SCF is capable of full operations in excess of 72 h in the absence of commercial power, and substantially longer with regular refueling.

All data transfers between the SCF and the end-user are passed through the APL primary Internet access point. Internet access consists of a 10-Mbit connection to Digex into Mae-East along with a 12-Mbit connection to Internet II through the main Hopkins campus. Additionally, the SCF may, under certain conditions, be able to route connections through the NASA Interface Facility (NIF) located at APL. The NIF is currently used to support several APL missions, with excess capacity to support SCF utilization.

To acquire and accurately track orbital objects, a precise knowledge of time is required. All times in a ground station environment are specified in Universal Coordinated Time (UTC). Timing signals within the SCF are locally generated and synchronized with UTC via a highly stable disciplined time and frequency standard[8] which is measured against either of two external sources (Fig. 2). A Global Positioning System (GPS) station clock is installed in the SCF to serve as the backup source for comparison timing, while the primary source is received from the APL Time and Frequency Laboratory (TFL). The TFL operates a set of ultrastable disciplined time and frequency standards, which contribute to the Bureau International de l'Heure for maintaining UTC. It is equipped with three hydrogen masers that are used as short-term frequency references. Frequency stabilities of better than 1×10^{-10} are achievable via the TFL. By using the TFL, the SCF can maintain local time code generators synchronized to UTC to within 1.0 μs.

Scheduling Capabilities

Having laid the framework for a technologically advanced satellite ground station capable of independent, unattended, and autonomous support of satellite

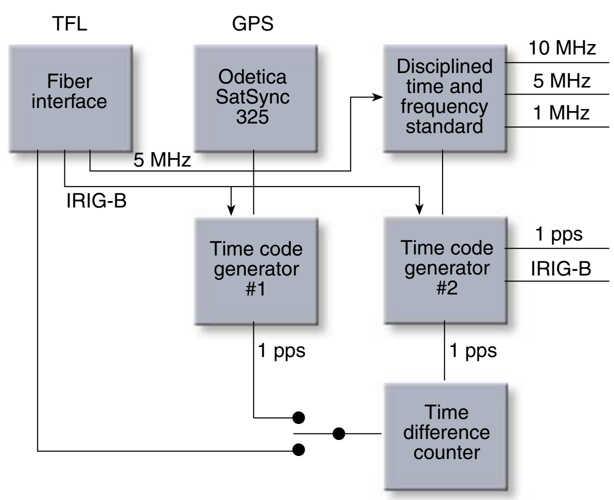

Figure 2. Timing signal generator within the SCF (pps = pulse per second).

ground contacts, the SCF must provide access to its assets while preserving the integrity of the overall station. To accomplish this, the SCF must allow users of the systems to schedule contacts with spacecraft on an “as needed or available” basis. One of the most recent upgrades to the SCF, conceived and implemented using only SCF staff, is the addition of an integrated Web-based scheduling system, which permits the outside user to perform any function related to scheduling a contact (Fig. 3).

One of the first steps in scheduling a contact is to upload current spacecraft element sets (ELSET), which provide a concise description of the spacecraft’s movement in time and space using a well-established format. Scheduling with an out-of-date ELSET would cause the contact to be late relative to the correct position of the spacecraft. (As counterintuitive as it may seem, atmospheric drag on an orbital object causes it to arrive *sooner* than expected, since slower, lower objects have less far to travel per orbit.)

Another feature required for scheduling contacts is the ability to query the system for possible passes during a programmable number of days, beginning on a selected day. Thus, users have maximum flexibility as to when to schedule future contacts that may occur during their absence (a weekend or vacation). Perhaps most crucial is the need to identify any passes that are blocked by a previously scheduled pass. Since the antennas are scheduled on a “first come, first served” basis, the system must know when *not* to allow new passes that are in conflict with a previously scheduled pass. In the case of a partially conflicted pass, users may elect to modify the start and stop times of their passes to prevent blockages.

Users are enabled in the Secure Server System based on their IP address and are given unique user names and passwords. They can view the details only on their own spacecraft; for other spacecraft, only the asset used and the start and stop times are visible. This scheduling system has been under development for the past year and has recently been successfully brought online.

Round-the-Clock Support

Spares Inventory

The ability to support round-the-clock operations for customers requiring high-reliability contacts with their space-based assets ultimately comes down to keeping every piece of equipment running at peak performance. This challenge can only be met with ready access to spare parts and knowledgeable, experienced personnel.

The SCF maintains an in-house spares inventory of any component previously identified as “long lead.” This inventory includes major components needed to effect rapid repairs on antenna systems such as drive motors, brakes, and key hydraulic subsystems. All electronic systems are spared as a unit or at the subassembly level.

Staff

The SCF has seven full-time employees: three administrative personnel and four staff members who function

REV	SAT	USER	ANTENNA	SETUP	START	STOP	MAX ELEV	AZ START	AZ END
49878	NOAA-12	NOAA	5 Meter	00355 19:50:03	00355 19:53:03	00355 20:04:20	9	104	10
30804	NOAA-14	NOAA	5 Meter	00355 20:05:21	00355 20:08:21	00355 20:22:30	29	135	357
49879	NOAA-12	NOAA	5 Meter	00355 21:26:52	00355 21:29:52	00355 21:45:31	74	160	349
30805	NOAA-14	NOAA	5 Meter	00355 21:46:32	00355 21:49:32	00355 22:03:18	36	186	337
49880	NOAA-12	NOAA	5 Meter	00355 23:08:50	00355 23:11:50	00355 23:24:28	12	215	324
23764	MSX	MSX	5 Meter	00355 23:37:34	00355 23:40:34	00355 23:55:32	24	128	358
23765	MSX	MSX	5 Meter	00356 01:18:15	00356 01:21:15	00356 01:37:36	47	180	340
23766	MSX	MSX	5 Meter	00356 03:05:14	00356 03:08:14	00356 03:16:20	3	245	306
30811	NOAA-14	NOAA	5 Meter	00356 08:27:42	00356 08:30:42	00356 08:43:37	12	35	144

Figure 3. Screen shot of a typical SCF schedule for the 5-m antenna.

in a technical and operational role to provide round-the-clock station coverage. Combined, the SCF staff represents nearly 85 years of expertise in the field of satellite communications, with a median service time of more than 7 years. This level of staffing is augmented by other professional staff at APL that are available on extremely short notice to provide in-depth technical assistance covering a broad spectrum of disciplines.

Through the use of this well-trained and practiced technical staff, 24/7 coverage, a proven spares philosophy, and an available pool of "expert knowledge," the SCF is fully able to meet the reliability and mean-time-to-repair requirements necessary to provide valuable services in the commercial ground station market.

SCF CUSTOMERS

The SCF supports six users (the first three, mentioned briefly earlier, are considered to be APL internal programs for other sponsors). The customers are as follows:

1. MSX: The SCF is currently supporting up to six contacts per day for the MSX spacecraft, which was built at APL and launched in 1996. MSX contacts are supported primarily by the 10-m antenna using SGLS commanding, with the 5-m antenna system serving as backup.
2. NOAA: The facility is supporting up to 15 passes per day for various NOAA spacecraft using the 5-m system. Data from these contacts are processed to determine sea-surface temperature trends and to post real-time weather maps on the Web.
3. TIMED: The SCF will be the primary ground station for the TIMED Program being managed by APL for NASA. TIMED is planned to be launched in 2001. The SCF will be scheduling up to six contacts per day using the 60-ft antenna with the CCSDS telemetry suite.
4. Universal SpaceNet (USN): The SCF is under contract to USN, a commercial ground network provider, to support NASA's Triana mission as a primary East Coast station using the 60-ft system and to provide on-demand scheduling of the antennas via task orders.
5. Lockheed Martin: The facility is under contract to Lockheed Martin as part of the Consolidated Space Operations Contract (CSOC) to provide on-demand scheduling of the antennas via task orders.
6. Honeywell: The SCF is under contract to Honeywell to provide on-demand scheduling of the antennas via task orders.

THE FUTURE OF UNATTENDED CONTACTS

As APL and the SCF move into the new millennium, both are strategically well positioned to take advantage of new, emerging business opportunities. The standard of unattended contacts places the SCF in the marketplace with economically priced contacts. These reliable, low-price contacts are a highly sought commodity.

By opening the SCF to use by commercial customers, APL is leveraging a 40-year legacy of high-reliability spacecraft support into the new business of "satellite ground stations for hire." To survive in this new environment, the SCF is guarding against the complacency caused by a history of successes and is ever vigilant in seeking improvements and enhancements to remain on the vanguard of technology. With this focus, both the SCF and APL are anticipating many years of new and challenging work from business associations that are developing daily in the commercial space age.

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