

**UTILIZATION OF THE  
MULTIPLE ACCESS COMMUNICATIONS SATELLITE (MACSAT)  
IN SUPPORT OF  
TACTICAL COMMUNICATIONS**

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Two MACSATs were launched on May 9, 1990 on a Scout launch vehicle from Vandenberg Air Force Base, California. After a short on-orbit check-out, these research and development satellites were placed into service providing operational communications support to 2d Marine Aircraft Wing units deployed to the Persian Gulf in support of Operations Desert Shield and Desert Storm. This support was provided from August 1990 until Operation Desert Storm was completed in April 1991. During this time, many lessons were learned that are directly applicable to the design and fielding of future small tactical communications satellites. This paper will highlight some of the lessons learned from supporting Operation Desert Shield, as well as other communications support missions.

**MACSAT, A STORE-AND-  
FORWARD DEMONSTRATION  
SYSTEM**

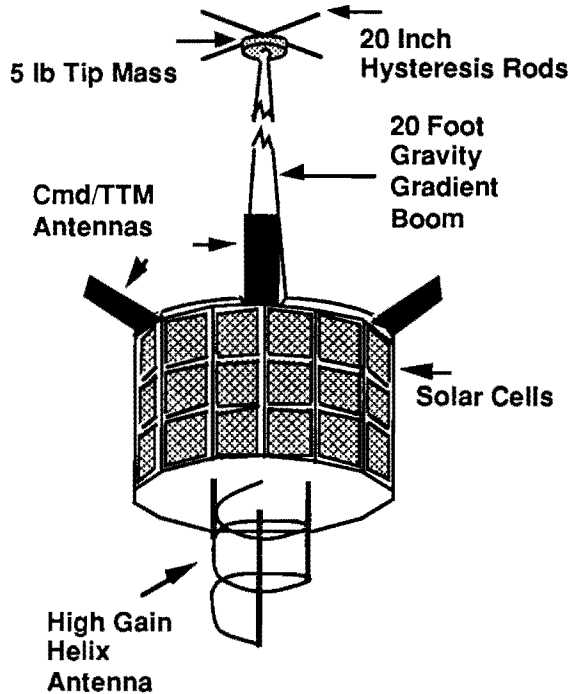
Two Multiple Access Communications Satellites, known as MACSATs, were placed in a 90 degree near-circular polar orbit at an altitude of about 400 nautical miles by a single Scout launch vehicle in May 1990.

The satellites, designated M1 and M2, vary in their orbital phase relationship to each other due to a difference in separation velocity from the bus. After about two-and-one-half years, the satellites will be 180 degrees apart in the

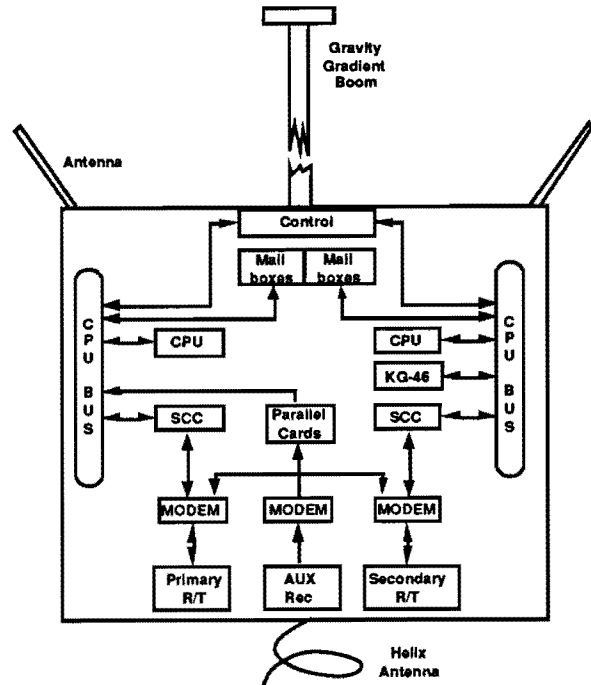
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same orbit plane, but will continue drifting and come back together. The orbit period is about 100 minutes.

MACSAT is a 16-sided truncated cylinder, 24 inches in diameter, 14 inches in height, and weighs 145 pounds. Four UHF blade-type antennas are mounted on top of the satellite. The blade antennas have a gain of 1 decibel (dB) referenced to a circularly polarized isotropic antenna (dBic). A high gain, helix antenna is mounted on the bottom of the satellite that has a gain of 6 dBic. Passive stabilization is provided by a 20-foot gravity gradient boom mounted on top of the satellite. MACSAT has a design life of three years on orbit. This design life was based on the expected lifetime of the batteries and the solar panels



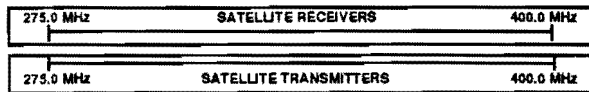
**On-Orbit Configuration of  
MACSAT**



**Functional Block Diagram of  
MACSAT**

The receiver subsystem consists of two frequency-synthesized receivers that operate in the military Ultra High Frequency range (275-400 megahertz (MHz)), tunable in 12.5 kilohertz (KHz) increments. Only one receiver is operated at a time; the other provides redundancy. The receivers have a maximum instantaneous bandwidth of 30 KHz and operate at a data rate of 2.4 kilobits per second (kbps). The receivers have a sensitivity of -120 dB referenced to 1 milliwatt (dBm) for a 10 dB signal-to-noise ratio. The receivers accept  $\pm 7.5$  KHz deviation frequency shift keying (FSK) modulation, and can use either of the two associated antenna systems. There is an auxiliary receiver that is used only by the Master Control Station (MCS) and is protected by special access codes.

The transmitter subsystem consists of two 10-watt transmitters and one 60-watt power amplifier that operate in the military UHF range tunable in 12.5 MHz increments.



## MACSAT Frequencies

The MCS sends two types of commands to the satellite over the command data link: schedule information commands that instructs the satellite to conduct communication events and housekeeping commands.

MACSAT has two redundant Complementary Metal Oxide Semiconductor (CMOS) 80C86 central processing units (CPUs). Each CPU is coupled through a Serial Communications Controller (SCC) to both data receivers and to both transmitters. The CPUs perform the following functions:

- Storage and execution of uplinked schedule information
- Control of the receiver and transmitter for store-and-forward operations
- Activation of receivers and transmitters on command or schedule
- Screening of incoming messages for correct access codes
- Storage of incoming messages for retransmission
- Transmission of stored messages
- Monitoring of satellite status
- Formatting and transmission of telemetry data

Each CPU has 1.2 megabytes of non-radiation hardened random access memory that can be configured as variable capacity mailboxes in 8192 byte increments. The smallest mailbox is 8 kilobytes and the largest is 64 kilobytes; however, the largest block of data that can be relayed is 56 kilobytes due to the size of the receive buffer. Messages sent to MACSAT during a scheduled receive event are stored in a mailbox dedicated to that event.

A total of 54 solar cell panels, capable of producing 67 watts of electric power, cover each of the 16 sides of the satellite and the top and bottom face plates. Depending on the Beta angle (the angle between the sun/earth axis and the plane of the satellite's orbit), 14 watts of power are generated on average per revolution of the satellite around the earth. The battery system consists of a +18 volt bus, dual temperature-compensated charge regulators, and dual nickel cadmium

(NiCd) battery packs. The batteries are connected to a set of DC (direct current) to DC converters that provide switched  $\pm 15$  volts of electrical power to operate the transmitters and receivers, and unswitched +5 volts of electrical power to operate the dual computer system.

Passive thermal control is achieved through gold tape applied to the outside of the satellite. The temperature of the bottom plate, to which most electronic subsystems are mounted, is about +10 degrees centigrade (C), with excursions of only about 20 degrees C about this mean. Temperature swings of the side panels are larger. Temperature fluctuation is kept within acceptable limits by the thermal conductivity of the heat paths through the top and bottom plates and the aluminum stringers that form the structural supports along the cylinder's axis.

The MACSAT demonstration system consists not only of the MACSATs, but also the MCS, ground user terminals, software, and operators. MACSAT is the element of the system that has received the most visibility, however, the performance of all parts of the system must be considered to evaluate the true capability of the system.

Master Control Station: The MCS, located in McLean, Virginia (near DARPA headquarters), schedules and controls all MACSAT operations, and is capable of sending message traffic to user communications terminals via the satellites in unencrypted form. MCS equipment includes a modem, microcomputer, graphics display monitor, keyboard, and printer. The MCS uses a high gain antenna that is capable of tracking the satellites.

User Equipment: A major objective of the MACSAT design was to enable the satellite to interoperate with communications equipment typically found at a military unit, thereby avoiding the necessity of fielding new equipment. As a result, a frame formatter and special connecting cables are the only non-standard UHF satellite terminal components a user needs to operate a MACSAT link. DARPA provides these items to MACSAT users as required.

The frame formatter enables military communication equipment already in the inventory to be compatible with MACSAT by performing the protocol conversion between the users data terminal equipment and the satellite. The data conversion process consists of implementing the synchronous datalink communications protocol and Manchester encoding the data.

DATA DEVICE	CRYPTO DEVICE	RADIO SET
GRID PC	KG-84A	AN/PSC-3A
ZENITH PC	KG-84C	AN/LST-5B/C
AN/UGC-74A/B		AN/HST-4
FACSIMILE		AN/ARC-187
IMAGERY		AN/WSC-3
		AN/URC-110

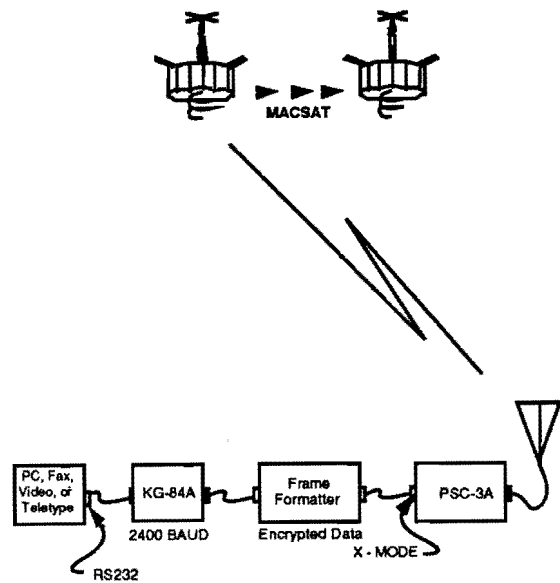
### MACSAT User Terminal Equipment

Selection of the input/output data device depends upon the type of information the user wishes to transmit. The most versatile input/output device is the personal computer (PC), which functions as a user-friendly interface for computing and displaying satellite schedules, as well as a data communications device. Software supplied for PC operations consists of MSSATERM, developed by DARPA to enable automated communications to take place, and GRAFTRAK II, produced by Silicon Solutions, Inc. to provide satellite schedules and to provide a graphic display of the satellite location.

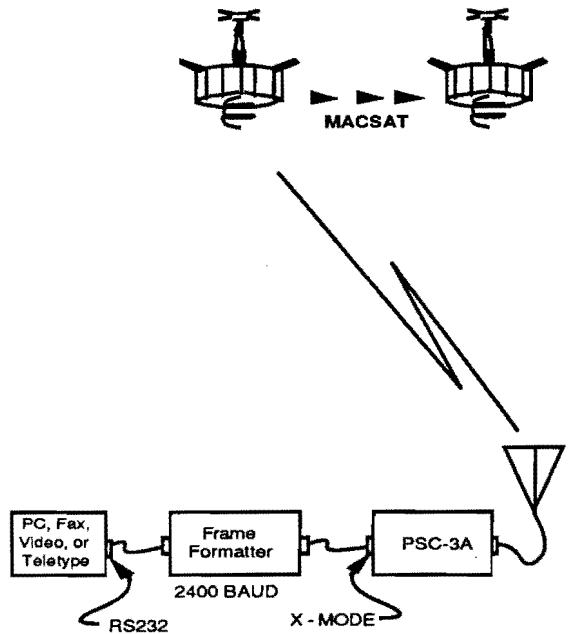
Pre-launch testing identified the AN/PSC-3A satellite radio as the baseline MACSAT ground radio. The AN/PSC-3A is a battery operated, manpack transceiver that operates in the UHF range. There are other radios that are compatible as well, although some require a minor signal level modification to function properly.

The ground antenna is typically the Dorne and Margolin DMC-120 collapsible, medium-gain, directional antenna. The DMC-120 can be remoted 25-150 feet from the radio, and has 6 db of gain and an 85 degree beamwidth.

The communications terminal can be operated in the secure as well as the nonsecure mode.



Typical Secure Data Terminal Configuration



Typical Non-Secure Data Terminal Configuration

The TSEC/KG-84A is the baseline communications security equipment for MACSAT use. The KG-84A connects the data terminal equipment and the frame formatter. A representative configuration for relaying non-secure data through MACSAT is basically the same as for relaying secure data, except the crypto device is deleted and the data terminal equipment is connected directly to the frame formatter.

When passing secure data via MACSAT, the user communications terminal consists of a data device, cryptographic device, frame formatter, radio and antenna.

Imagery transmissions can be relayed via MACSAT. There are a number of methods that can be used for relaying this type of data. A typical equipment configuration is represented by the Remote Image Transceiver (RIT). This equipment, manufactured by Phototelesis, Inc., enables images to be stored on a PC disk and relayed as a normal data file through the satellite. Images that contain as much as 56 kilobytes of data may be relayed. This capability is useful for transmitting maps, overlays, or other pictorial material.

## DEMONSTRATION PARTICIPANTS

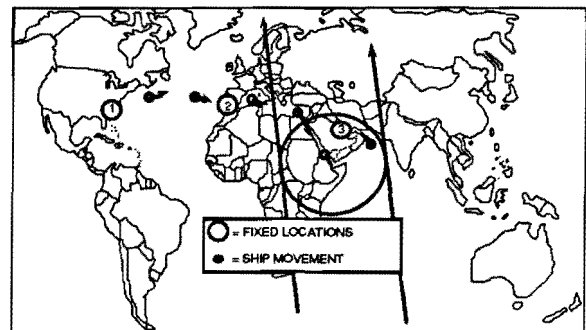
MACSAT has supported a large number of operational, training, and exercise requirements in the past year. The support provided to Operations Desert Shield and Desert Storm has been the most highly publicized and resulted in the most valuable lessons learned. This support is the center piece of the discussion in this paper. In addition to this support, other significant support was provided to the Navy and National Science Foundation summer and winter missions to Antarctica and to Army Special Forces activities. These missions are also discussed in terms of the lessons learned from their network configurations and types of data relayed.

## MACSAT SUPPORT TO OPERATIONS DESERT SHIELD AND DESERT STORM

One of the envisioned missions for MACSAT was support of tactical contingency operations. Within hours of

President Bush's announcement of the commitment of U.S. forces to the Persian Gulf, DARPA alerted the members of its LightSat User Coordination Group (LUCG) to inform their respective Services of the quick reaction availability of MACSAT for long haul message relay. Working through their LUCG representation at Naval Space Command, a communications support request was received from the 2d Marine Aircraft Wing (MAW).

MACSAT began providing support to Operation Desert Shield on 20 August 1990 and to Operation Desert Storm on 17 January 1991. This support continued until 5 April 1991 when the 2d MAW personnel returned to Marine Corps Air Station (MCAS) Cherry Point, North Carolina. The 2d MAW MACSAT network consisted of stations at MCAS, Cherry Point (Station 1) and at a Southwest Asia (SWA) location (Station 3). A shipboard station onboard the USS Nassau and a station at Rota, Spain (Station 2) participated in the network during initial deployment. The Rota, Spain station was established to support aircraft deployments. After four days of operation, this station was deactivated and the personnel and equipment deployed to the Persian Gulf area.



Operation Desert Shield MACSAT Network

Since MACSAT is an experimental research and development satellite that began supporting operational requirements after only a short, on-orbit checkout period, operational procedures had not been fully developed and only a limited number of personnel had been trained.

MACSAT support began within 48 hours of notification that 2d MAW elements were deploying to the Middle East. DARPA sent

personnel to Cherry Point to train personnel to communicate via MACSAT, and provided frame formatters, cables, communication terminal software, planning assistance and satellite scheduling.

After only eight hours of overnight training, one group of operators flew to Rota, Spain and another group deployed onboard the USS Nassau. A third group of Marines flew to SWA. The SWA and MCAS, Cherry Point stations remained in operation until 5 April 1991.

For approximately 30 days after arrival in SWA, there was no full-service communications center available to 2d MAW, and MACSAT provided the most expeditions service available. Approximately 40 kbytes of logistical, personnel and administrative messages were relayed through MACSAT between SWA and Cherry Point each day. Initially, MACSAT provided the primary route for message relay between MCAS, Cherry Point and SWA. Writer-to-reader time was typically two to six hours. Although other communication systems were placed into service, MACSAT continued to provide a valuable augmentation capability throughout the deployment and was used almost daily.

The efficiency of the network was determined by the number of messages acknowledged by addressee within 48 hours. The SWA station experienced monthly efficiency rates of 60-100 percent with an average of 96 percent. The Cherry Point station experienced monthly efficiency rates of 8-87 percent with an average of 52 percent. The higher efficiency rates were experienced in the last four months of support. The difference in station efficiency was due to the SWA station being operated by personnel having communications center message handling experience.

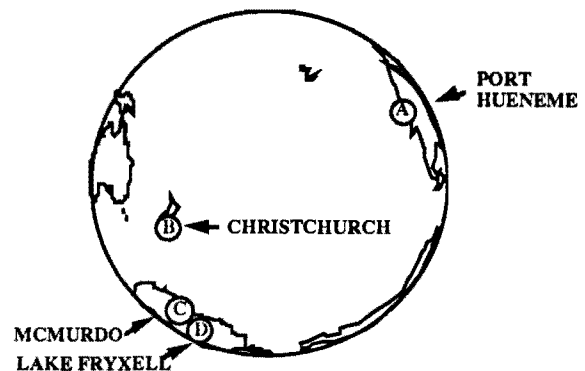
Initial low efficiency and problems that prevented the Marines from achieving a consistent 100 percent efficiency rate were attributable to initial timing anomalies, ground equipment malfunctions, and operator inexperience or equipment unfamiliarity. The initial inability to use the KG-84A (which has since been corrected) prevented more widespread use of MACSAT. Most problems were corrected through experience and training. This opportunity to use

MACSAT in support of operational requirements provided many lessons learned that have already been applied to enhance MACSAT operations. Other lessons learned will be valuable when designing future small satellites.

Support of Operations Desert Shield and Desert Storm demonstrated that MACSAT provides a quick reaction capability for expeditionary units for which there is no immediate access to a full-service communications center. MACSAT provided a capability for advanced parties and those that remained behind to tear-down and back-load.

### MACSAT SUPPORT TO THE NAVY AND NATIONAL SCIENCE FOUNDATION ANTARCTICA MISSIONS

In September 1990, a representative of the Naval Space Command asked DARPA to provide MACSAT support for the National Science Foundation's summer mission to Antarctica. This mission is supported by the Navy from Point Hueneme, California. A staging base is in Christchurch, New Zealand. The forward operating base is located at McMurdo Station in Antarctica, with mobile remote parties at various locations on the ice in Antarctica including Lake Fryxell



Antarctica Network

Originally, the concept envisioned three types of support. One support requirement was to use MACSAT to relay weather information from McMurdo Station to the C-130 aircraft when half way from

Christchurch. Another element was to provide a data relay capability from McMurdo Station to Point Hueneme. The third element was to provide data relay from remote parties beyond line-of-sight to McMurdo Station.

This support involved the use of radio equipment including the AN/ARC-187 (onboard the C-130), the AN/URC-110, and the LST-5B. Interfaces had been established for the LST-5B, but not for the other radios. Therefore, cables and interface modifications were quickly developed for these radios. Before deployment, the systems were tested with the satellite, operators were trained, a satellite schedule was planned, and the necessary equipment was provided to the operators.

The most significant modification involved the frame formatter. This device was originally designed to interface with the baseline equipment, i.e., the AN/PSC-3A and the LST-5B. During check-out of the additional radios, it was found that different signaling and keying levels were required and that some radios require a preamplifier to have sufficient link margin with the satellite for operation.

### **MACSAT SUPPORT TO THE ARMY SPECIAL OPERATIONS MISSIONS**

The Army Space Command and the Army Space Institute working through the LUCG assisted the 1st Special Operations Group at Fort Lewis, Washington, organize and conduct demonstrations using the MACSATs. Although these units established multiple networks at various times, the network of greatest significance was between units deployed to Thailand and units at Fort Lewis, Washington.

A several-week exercise began in May 1991. A second demonstration of this network is being conducted 5 June through 5 September 1991. These networks involve the use of a typical secure data terminal configuration using the TSEC/KG-84A, the HST-4 radio, the frame formatter, and a personal computer. Scheduling was accomplished by the MCS and the schedule distributed to participants as a MACSAT broadcast message. This was the first long-term use of the MACSAT network secured



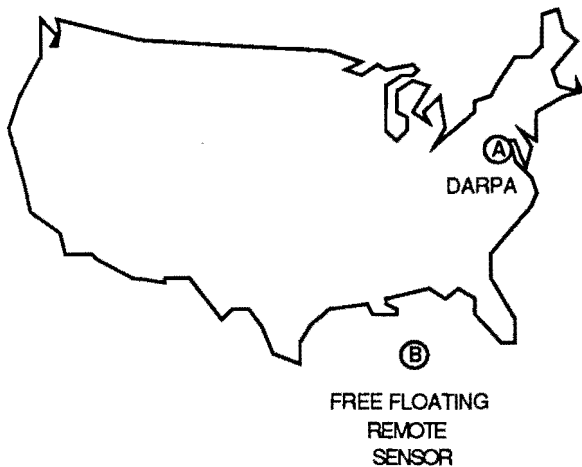
### **Special Forces Thailand Network**

with KG-84A communications security devices. The networks were used for relay of low volume data and success rates of about 95 percent were achieved. Success for this demonstration was determined by the percentage of available satellite passes during which message data was received or transmitted. The amount of time typically required for relay of data between Thailand and Fort Lewis was about four to six hours.

Planning for these networks implemented a new training method that has proven to be very effective. This method is referred to as "train the trainer". Personnel from the Army Space Institute trained a limited number of personnel from Fort Lewis, who then trained other operators without assistance from the Army Space Institute. This cadre training method has enabled MACSAT network operations to experience a very high success rate.

### **MACSAT SUPPORT TO THE NAVY REMOTE SENSOR MISSIONS**

The first military service demonstration of the MACSAT capability occurred in July 1990. This was a demonstration of the ability of MACSAT to interrogate a remote sensor and command the sensor to send data to the satellite for storage and relay to the MCS. About 32 kilobytes were successfully decompressed when processed by the receiving terminal. Due to the large earth area serviced by the satellite, it was not necessary to know exactly where the sensor was located for the data exchange to take place. At a zero



### Remote Sensor Network

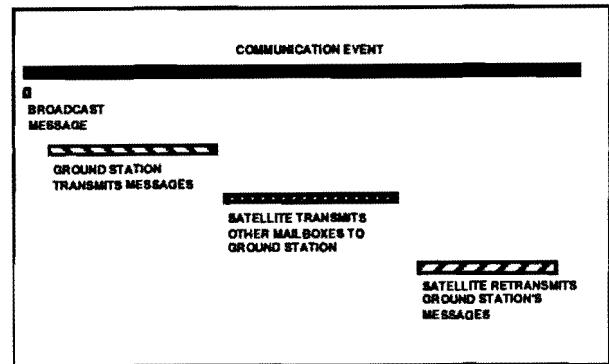
degree look angle, the communications coverage of the satellite covers a 3000 nautical mile swath of the earth's surface.

This demonstration led to the development of a capability for the satellite to interrogate a typical user terminal and enable unattended transmit and receive operations to take place. This concept proved most valuable during Operation Desert Storm when SCUD attacks were taking place. The operator would place messages in a file for transmission and leave the terminal unattended. If MACSAT made a pass over the site during the SCUD attack, the data exchange would be initiated by the satellite and the data relayed without operator intervention.

### LESSONS LEARNED

Lessons learned are discussed with regard to the MCS, satellite, user communications terminal equipment, software, and operators.

MCS Lessons Learned: All satellite actions during a communication event must be scheduled by the MCS. Scheduling involves determining the usable passes each day for each of the network users including the MCS and scheduling the satellite's actions accordingly. After the usable passes are determined, the MCS operator prepares a master schedule of events to be executed by the satellite for the next three to four days.



Sequence of Action During a Communication Event

MACSAT was scheduled to execute a specific sequence of events for each user.

This figure shows the duration of the communications window and the events that were executed during that window. This schedule was designed to allow the relay of about 32 kbytes of data during the satellite's pass over the user's location. The sequence of events and the actions accomplished during each event are shown in the table.

EVENT	ACTION
1	The satellite transmits for five seconds to cue the user and start the sequence.
2	The user begins transmitting messages and continues for two to three minutes.
3	The satellite transmits data stored in a mailbox to the user.
4	The satellite transmits data stored in the local user's mailbox for confirmation.

Typical Events During a Communications Window

With simultaneous worldwide networks in operation, it was typically necessary to schedule the satellite to perform these four events for each user. At one time, each of four users were scheduled for four passes each day, for a daily total of 66 events. An additional two events were scheduled for the MCS each day. Since a total of 255 events can be stored on-board the satellite, this number of satellite events was depleted after three or four days. The amount of time required between events for the satellite to process the next instruction became a problem that could be controlled by reducing the event list to about 130 events. In



addition, the amount of time required by the MCS operator to schedule the events was a problem resolved through the use of data base templates. Both of these problem areas were resolved and are discussed below in more detail.

Initially, the time required for the MCS operator to put together a full satellite schedule for several days required an excessive amount of time (on the order of 40 hours). To reduce this preparation time, the MCS operators developed the capability to use a template of standardized events based on schedules developed and refined as the Desert Shield network matured. These templates are now used for all other MACSAT demonstrations and have reduced the schedule preparation time by approximately two-thirds.

The MCAS, Cherry Point station and the MCS are in the same satellite footprint. One to two of the four to six usable passes each day were reserved for the MCS to control the satellite, i.e., receive telemetry data from the satellite and update the master schedule.

Frequently, several East Coast users in the same footprint as MCAS, Cherry Point needed periodic access to MACSAT to conduct communication tests. Multiple East Coast users reduced each user's network access due to the need to share passes.

This contention was reduced by assigning low elevation passes to the MCS after a high-gain tracking antenna was installed for communications with MACSAT.

To reduce the impact of multiple users in one geographic area, a centralized station concept was developed with Headquarters, Marine Corps. This concept would use only one MACSAT station in a large geographic area capable of interfacing with other users through an electronic mail system. The use of a central station would increase the data relay capacity of MACSAT.

Satellite Lessons Learned: The M2 MACSAT was used to support Operations Desert Shield and Desert Storm. No significant problems were experienced. Lessons were learned with regard to schedule execution, the use of a cueing signal, and satellite timing.

When the network began operation, a broadcast message was routinely used that

contained only random data that provided nothing more than an audible cue to an operator. The MCS operators began placing a condensed schedule in the broadcast mailbox. The broadcast message contained condensed schedule data such as time, azimuth, and elevation of the satellite's passes over that ground station for the next 24-48 hours. MACSAT ephemeris data was updated in this same manner that enabled the users to determine their schedule independently using GRAFTRAK II software.

As experience was gained, it was noted that satellite events did not always occur when scheduled. Through investigation it was determined that the satellite requires about 45 seconds to empty its receive buffer of data just before going to the first transmit event. Other timing anomalies were due to the satellite requiring 20-30 seconds to sort through the list of scheduled events in the data base to determine which one was to be executed next. These effects were cumulative, and the fifth event in a sequence could occur about 2.5 minutes behind schedule. Part of the problem stemmed from the amount of schedule data being loaded into the satellite's memory. Initially, the MCS scheduled 255 communication events for a three- to four-day period and loaded this data into the satellite's memory. When the timing problem became apparent, the MCS began creating two- to three-day schedules -- about 130 events. Having fewer events programmed caused the satellite event timing to be more accurate.

Communications Terminal Equipment Lessons Learned: Ground station equipment used by most users includes a portable personal computer (PC), a frame formatter, and an AN/PSC-3 satellite radio with a Dorne and Margolin DMC-120 antenna. Lessons were learned with the operation of each of these devices.

Most operators used the PC as their input/output device. On one occasion it was discovered that the frame formatter was incorrectly connected to the PCs COM2 port instead of the COM1 port, resulting in no data being sent or received during that communication event. The problem was

eliminated with the use of an operator check list.

The frame formatter performed its function without any reported problems. However, the low voltage light that indicates when the batteries are low was inoperative. Operators sometimes neglected to turn on the frame formatter's power, which prevented messages from passing between the input/output device and the radio. Again, the user checklist resolved this problem. In addition, instructions were provided on methods to connect a 9-volt power supply to the frame formatter to eliminate the possibility of dead batteries.

During pre-launch testing, the AN/PSC-3A radio was identified as the baseline MACSAT ground radio. A number of lessons have been learned regarding operations of this radio.

Obtaining at least one AN/PSC-3A radio for each of the 2d MAW stations was not an easy task, and backup radios were out of the question. Radios to operate this network were obtained not only from Marine Corps channels, but also from Army and Air Force resources. Lack of backup radios caused stations to be inoperative for extended periods while the cause of an outage was being determined. If spare equipment had been available, outages would have been reduced to a minimum.

The AN/PSC-3A radios drain batteries very quickly. A major problem was finding a suitable power source in SWA for the radios. The AN/PSC-3A radio operates off two +24 volt dc 2.4 ampere-hour rechargeable NiCd batteries, or two +24 volt dc non-rechargeable lithium batteries. The supply of both batteries was very limited in SWA, and a charger for the NiCd batteries was not available. After an extended period of time, a power supply was obtained. However, it operated on 110 volts 60 hertz current and the only electrical source available was 220 volts 50 hertz. The Marines located a 110 volts 60 hertz electrical source to operate the power supply.

Not having test equipment for the radios and other components in the user terminal configurations made trouble-shooting very difficult. When the MACSAT station was established in Rota, Spain, one of the AN/PSC-3 radios would not process the

signals from the satellite. Local tests with the control tower indicated the radio receiver was operative. In an attempt to resolve this problem, DARPA loaned the Marines another AN/PSC-3A, which was sent to Rota, Spain, and restored the network to operation. The faulty radio was returned for repair. After trouble-shooting, it was found that the receiver sensitivity was not adequate to work with the satellite. This problem would have been more quickly resolved if spare equipment had been available.

The AN/PSC-3A uses a collapsible, medium-gain, directional antenna. Generally, the user points the antenna in an easterly direction and toward the highest elevation angle for a satellite pass to the east. A similar westerly orientation is used for passes to the west. This type of antenna orientation is made possible by using the high-power amplifier and the high-gain helix antenna on the satellite, which provide adequate link margin and reduces pointing accuracy requirements. Lessons were learned regarding the antenna and the antenna coaxial cable.

During the early days of MACSAT use, the users occasionally failed to point the antenna correctly for the pass. In addition, it was difficult to position the antenna to prevent blindspots when the satellite passed behind a building or other obstruction. An unobstructed view of the satellite was obtained by locating the antenna on the roof when possible.

Computer Software Lessons Learned: DARPA provided software consisting of two separate programs. The programs are used for satellite orbit prediction and communications, respectively.

Using GRAFTRAK II, operators can predict communication opportunities when a master schedule has not been received from the MCS. Routinely, DARPA received updated ephemeris data for MACSAT from the United States Space Command and relayed the data to all user ground stations to ensure that accurate communication event information would be calculated by GRAFTRAK II.

This pass prediction capability has proven to be a valuable operator aid.

DARPA developed MSATTERM, a communication software program specifically for use with MACSAT. A number of lessons were learned as a result of using this software.

When the network began, the user would type the messages on the PC and store them in the "FILES" subdirectory.

After the transmit event began (following receipt of the initial broadcast message), a message to be sent was highlighted on the menu with the cursor, and the operator pressed the PC's ENTER key to send the message to the satellite. There was about a ten-second delay before the message left the radio, caused by the processing (or formatting) of the message that took place in the frame formatter. The longest delay was caused by having to select and transmit each message individually and waiting until it had left the radio before selecting the next message for transmission. Operators developed procedures for accommodating the timing delays and DARPA revised the software to reduce the effect of these delays.

Due to the lack of a bit error correction feature on MACSAT, incorrect data was sometimes received. These bit errors not only limited the types of data that could be relayed, but created data processing problems. When a large number of bit errors were experienced during a communication event, new binary data combinations were created resulting in numerous "Control-Z" function characters. "Control-Z" is an "end of data" indicator and should appear only at the end of a message. The PC stopped receiving each time a data combination equating to "Control-Z" was received. Whenever the PC hung up, it resulted in a loss of message data. Software changes eliminated this problem.

As a result of these operational experiences, the software was rewritten to correct these problems and to implement other features.

Normally, only two minutes of the MACSAT pass was allocated to the ground station for transmitting data to the satellite.

DATE	AOB	MAX	LOS	DX/EL	AZ	ORBIT
11 SEP 90	003637	003841	004244	2 EL	290	1841
11 SEP 90	081353	082025	082658	18 EL	80	1846
11 SEP 90	105158	105914	110633	49 EL	280	1847
11 SEP 90	123300	123630	124000	3 EL	294	1848
11 SEP 90	202204	202451	202738	2 EL	84	1853
11 SEP 90	215513	220208	220903	44 EL	74	1854
11 SEP 90	234438	234933	234707	18 EL	282	1855

LEGEND:  
 AOB = Acquisition of Signal. Zulu time (hours, minutes, seconds) satellite enters field of view  
 MAX = Maximum. Zulu time satellite reaches maximum elevation of pass  
 LOS = Loss of Signal. Zulu time satellite departs field of view  
 DX/EL = Degrees of Elevation. Highest point of pass above horizon  
 AZ = Azimuth. Direction from ground station to highest point of pass  
 ORBIT = Number of revolutions around earth since launch

### Communication Opportunities Predicted by GRAFTRAK II

the 56 kbyte receive buffer.

These timing issues were accommodated by making schedule changes and establishing automated message queues. This increased the number of outgoing messages that could be transmitted during a communication event.

#### Message Handling Lessons Learned:

Support of SWA operations has shown that a good understanding of message handling procedures and accountability is of great importance for efficient operation of the network.

Initially, MACSAT user terminal operators were accustomed to local area network operations. When a message was transmitted on this type of network, the operator had assurance that the message was correctly received by the addressees because of error corrections built into the system. Since MACSAT does not make use of error correction, the send and forget procedures were not adequate.

Message accounting procedures were implemented by SWA operators that required all messages to be acknowledged by a service message. In addition, an analysis was performed to ensure that all messages were received. A file copy of all messages was kept for 30 days to enable messages to be resent if not acknowledged by the addressee. These procedures ensured that all messages reached their destination.

### FUTURE APPLICATIONS

MACSAT has proven that the satellite store-and-forward communications concept provides tactical users with timely, assured space capabilities. Data can be relayed from any point on the earth to any other point on

the earth without an intermediate relay. Polar users above 70 degrees north or south receive good coverage from MACSAT. In these locations, MACSAT is visible every 90 minutes.

The Marine Corps has recognized the potential of MACSAT when augmented with earth-based gateway terminals. They identified a concept for supporting forces deployed aboard ships for extended periods of time and forces located in northern areas. This concept calls for activating centralized MACSAT communications terminals at locations such as on the east and west coasts of the United States. Stations at these locations would interface with the Marine Corps Digital Network for the purpose of relaying messages via MACSAT to remote units with poor communications support. Using a few central stations, message delivery time could be reduced to less than one hour and any location on the earth could be serviced with highly portable data terminals.

## SUMMARY OF CAPABILITIES

MACSAT can support many simultaneous worldwide users due to its large mailbox storage capacity and the low battery drain by the transmitters. The amount of data relayed by MACSAT is not limited by storage capacity, but rather by the amount of data that can be uplinked from a given footprint during a single satellite pass. A central station in each operational area connected to users through a local area network would provide a more efficient data relay capability using MACSAT.

There is sufficient margin to operate the satellite link without precisely pointing the antenna toward the satellite if elevation angles above 15 degrees are used. For lower elevation angles (below 15 degrees), a directional antenna and satellite tracking capability is useful. A satellite tracking capability also allows bit errors to be reduced for low elevation angle passes and allows a station to communicate with the satellite for the longest possible time.

Traditionally, communications systems are configured with redundant equipment; this was not possible for MACSAT user terminals due to the nonavailability of UHF

radio equipment. Without spare radio equipment, it is very time-consuming to isolate and correct link problems.

Communication terminal operations should be automated as much as possible to reduce errors, and the time required for data relay, and to increase the amount of data that can be relayed from a given geographic location.

Having excess link margin is more important when operating with low earth orbiting satellites than with geosynchronous satellites because, as the satellite moves across the sky, it passes behind trees, buildings, hills, and other obstructions.

Procedures are important for MACSAT store-and-forward type of network due to the need to manually acknowledge received messages.

The amount of time required to relay data between the Persian Gulf area and the continental United States was competitive with low priority messages sent via other communication systems. The time could have been reduced to about 30 minutes if a station had been established on the West Coast to augment the East Coast station.

Operating at 2400 bits per second, about 64 kilobytes (32 pages) of data can be relayed from a given footprint during one satellite pass. This capacity must be shared by all users in a footprint. A central station in each operational area connected to users through a local area network (e.g., MILNET) would have provided for prioritization and more efficient message relay.

MACSAT can support quick reaction requirements since the satellite can be scheduled within two to ten hours. User support can begin immediately after the satellite is scheduled and user equipment is in place. The user communications terminal is portable and can be easily relocated as requirements change.

Training can be accomplished in a few hours. Once trained, cadre personnel can be used to train other personnel.

A wide variety of UHF satellite radios are compatible with MACSAT, and any MS-DOS compatible microcomputer can be used as a communication terminal. This interoperability is made possible by the small, battery-powered frame formatter and communication terminal software.

MACSAT can support multiple worldwide networks. For example, during Desert Shield/Desert Storm operations, MACSAT supported SWA users as well as various CONUS users and a Navy/National Science Foundation mission to Antarctica.

### SUMMARY OF LIMITATIONS

MACSAT can store about 255 satellite events. It was determined that MACSAT requires several seconds to process each event if the total number of events is greater than 130. This limitation was resolved by reducing the events to 130 and uplinking a new schedule more frequently.

The use of operator checklists and automated communications terminals is necessary to ensure a high degree of error-free data relay. Initially, operation of the communication terminal was manually intensive and allowed errors to occur. These errors disappeared with increased automation of communication terminal functions. Many other common operator errors were corrected by the use of an operator checklist.

When communication outages occurred, a high percentage were caused by inoperative terminal equipment. When this equipment was replaced, the outages ceased. The availability of spare equipment would have reduced these outages to a minimum.

Initially, there was no assurance that a transmitted message was received by the addressee due to the half-duplex store-and-forward nature of MACSAT and the lack of error correction. Implementation of procedures requiring the addressee to acknowledge receipt by a return message on the next pass resolved this problem. These procedures were implemented by personnel experienced in communications center operations.

Lithium batteries were initially used to power the UHF radios, which quickly drained the batteries. The use of power supplies instead of batteries resolved this problem.

On-board timing and the amount of processing time required by MACSAT were issues that had to be accommodated through operational procedures.

### GENERAL CONCLUSIONS ON LESSONS LEARNED

The lessons learned indicate that MACSAT provided a valuable capability for tactical units. Once personnel experienced in the operation of communications centers began operating the terminals, network efficiency approached 100 percent.

Network efficiency was initially low, but increased rapidly to 100 percent with experience and improved procedures. Experience and procedures would normally have been fully developed prior to beginning operational support. Since it is an R&D system, the MACSAT demonstration program would have discovered and corrected most of the deficiencies encountered during Desert Shield.

Operation of the MACSAT system has now become routine and daily provides valuable communications support users.

Implementation of centralized communications terminals will further enhance MACSAT support by enabling any remote worldwide location to be supported with a one hour message relay capability.