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HANDLE VIA CONTROL SYSTEM

DATE 15 Nov 1979

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COMMENTS _____

COORDINATION _____
ACTION _____
INFORMATION X

TO: DR. [REDACTED]

SUBJECT: LANDSAT-D Ground Station

Toby,

Here is a package which should form a pretty good point of departure for you. Please note that I have the documents in a particular order which I believe will allow you to make the best sense of each.

[REDACTED]



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Control No. BYE-28438-79
Classified by [REDACTED] Copy 1 of 2
Rev 15 Nov 1999 Page 1 of 1

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HANDLE VIA
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CONTROL SYSTEM

STUDY TASK STATEMENT
FOR
ASSESSMENT OF RISKS
ASSOCIATED WITH PROVISION
OF
A LANDSAT-D GROUND STATION
TO THE PEOPLE'S REPUBLIC OF CHINA (PRC)

- I. This assessment should not consume more than 300 man-hours of work and must be completed on 27 November 1979. The assessment's product should be a study approximately six to twelve pages in length plus supporting chart/table annexes as necessary.
- II. The assessment should examine the following:
- Risk, if any, of the LANDSAT-D technology transfer to the Chinese accelerating the sophistication of target signals environments, outpacing U.S. SIGINT Research and Development progress.
 - Risk, if any, of the LANDSAT-D technology transfer contributing significantly to opposing SIGINT capabilities against U.S. communications (especially space associated) systems as a result of access to LANDSAT-D's high capacity receiver and ground processing technology.
 - 
- III. The above risk assessments should be covered in three principal contexts. The first is the risk (if any) associated directly with provision of the technology to the Chinese; the second is the risk (if any) which would result from Soviet access to any or all of the LANDSAT-D technology provided the Chinese; the third is the extent to which the technologies perceived to be at risk might already be available from US or foreign commercial sources.
- IV. The National Reconnaissance Office (NRO) staff project officer for this assessment is  (202-695-0945/0962, KY-3 2257).

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The LANDSAT-D System

8 June 79

Abstract

The LANDSAT-D satellite, and the communications and processing systems it uses or communicates with, are described. All the data are from unclassified sources, including published literature, and discussions with NASA personnel.

A classified analysis of the impact of exports of the LANDSAT-D system technology is given at the end. Except for that final section, the paper is unclassified.

Contents

1. Conspectus -- and abstract of the LANDSAT system
2. Overview of LANDSAT-D Communication System
3. The TDRS System
4. The White Sands Ground Station
5. Goddard Processing Center
6. The Portable Ground Station
7. Foreign and Domestic Interest in LANDSAT-D
8. The Cryptologic Implications of LANDSAT-D Exports
9. Appendix: Doing SIGINT on LANDSAT-type Signals

(8) (9) are classified.

The LANDSAT-D System

J. A. Meyer

15 May 79

1. Conspectus

The LANDSAT-D is a system for sensing, collecting and processing data about the earth's surface. The sensors look down at a small portion of the earth, and quantify the energy radiated in several bands of the electromagnetic spectrum between infra red and ultra violet. The quantified data are transmitted through a complex wideband communication system to receivers, recorders and processors. Large scale computer processing is used, along with human judgement, to extract information about the earth and its resources.

The complete LANDSAT system is still being developed and extended, but the basic US configuration consists of:

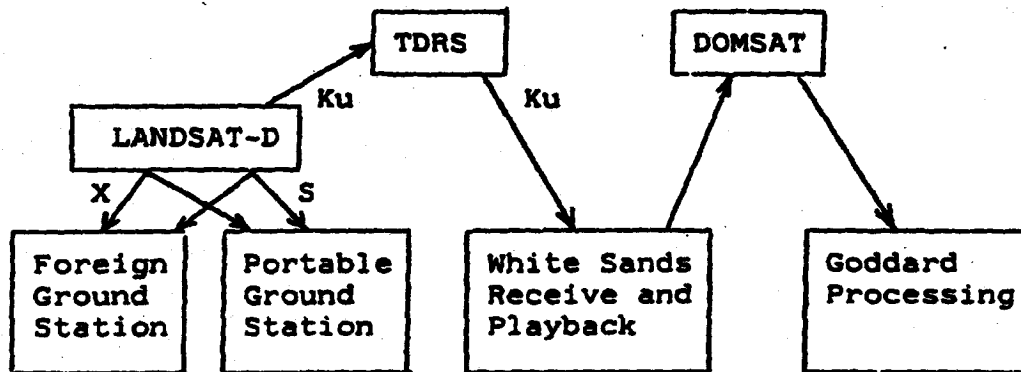
1. The LANDSAT-D low altitude earth resources sensor satellite.
2. The TDRS high altitude geostationary data relay satellites.
3. The ground station at White Sands to receive LANDSAT-D data via TDRS.
4. The DOMSAT geostationary satellite to relay White Sands data to Goddard.
5. The LANDSAT-D processing center at NASA Goddard.
6. The LANDSAT-D portable ground station.

The TDRS and DOMSAT are leased services. There is some discussion of using a COMSAT or INTELSAT satellite for fast retransmission of LANDSAT-D data to foreign LANDSAT processing centers. The other components are owned and operated by NASA. Although LANDSAT-D will not be launched until late 1981 and is not an operational system, there are proposals in Congress and in various Departments to establish and operate several LANDSAT-D satellites in an operational system after 1981.

In addition to the US configuration, some of the existing foreign LANDSAT-C ground stations may be modified to receive and process LANDSAT-D data. Eight foreign countries have expressed an interest to NASA in having LANDSAT-D capabilities, either by upgrading their existing LANDSAT-C stations, or by building new LANDSAT-D stations.

Although the LANDSAT-D/TDRS system can give coverage of almost the entire globe, the foreign LANDSAT users like to have their own processing capability to assure the fidelity of the raw data and the results.

Illustration: US LANDSAT-D System



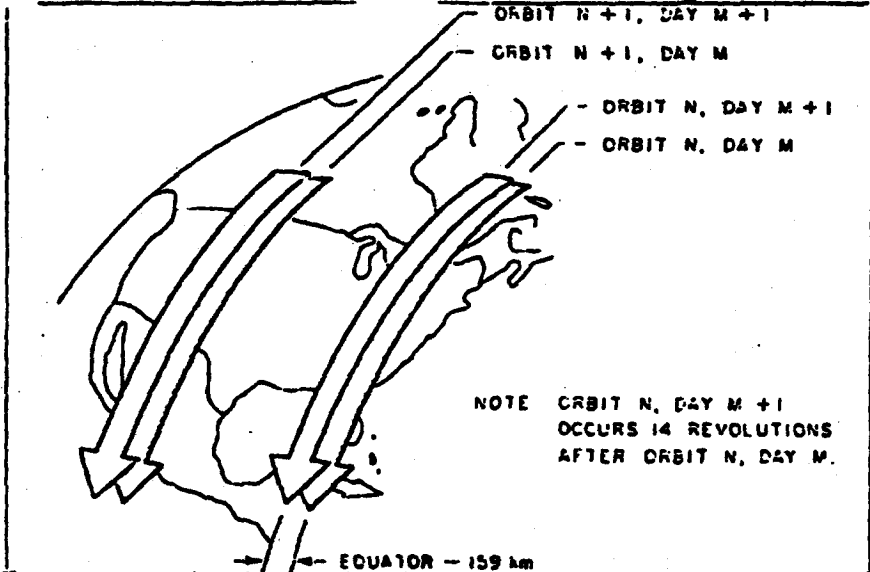
The portable ground station will initially be used by NASA to test the downlink transmission of data from LANDSAT-D on S and X band frequencies, and no data will be used in the portable ground station --- because it will be located at Goddard and will relay its data directly to the Goddard processing center. Subsequently the portable ground station may be transported and set up elsewhere, at which time recording and processing equipment will be associated with the ground station.

2 Overview of LANDSAT-D Communications System

ORBIT

The LANDSAT-D satellite will circle the earth in a "sun synchronous" orbit at 705 Km, with 98.2 degrees inclination. It has a period of 99 minutes and passes over the same swath on earth at the same local time --- at 14 day intervals, after it has scanned the entire earth. The satellite will make 14.4 orbits around the earth each day, and will, for example, make three North to South daylight passes over the US at the same local time (about 0930) mapping parallel swaths 100 miles wide, space about 1500 miles apart. It will also make three South to North nightly passes 12 hours later. On successive days, parallel adjacent swaths can be mapped by the satellite. The current LANDSAT-C satellite has a 912 Km altitude orbit, and completes its survey of the earth in 18 days.

Illustration: LANDSAT Ground Coverage Pattern



SENSORS

Two separate but similar sensor systems, viz: MSS and TM, are used on LANDSAT-D to generate images of the earth under the satellite. MSS (Multi Spectral Scanner) has 4 sensor windows from Infrared to Ultraviolet, and generates a 15.06 million bit per second (MB/s) data stream. Resolution per picture element (pixel) is about 60 meters on the earth's surface, i.e. the energy emitted or reradiated from a 60 x 60 m² area will be quantified as a single pixel in the "picture" obtained by the MSS.

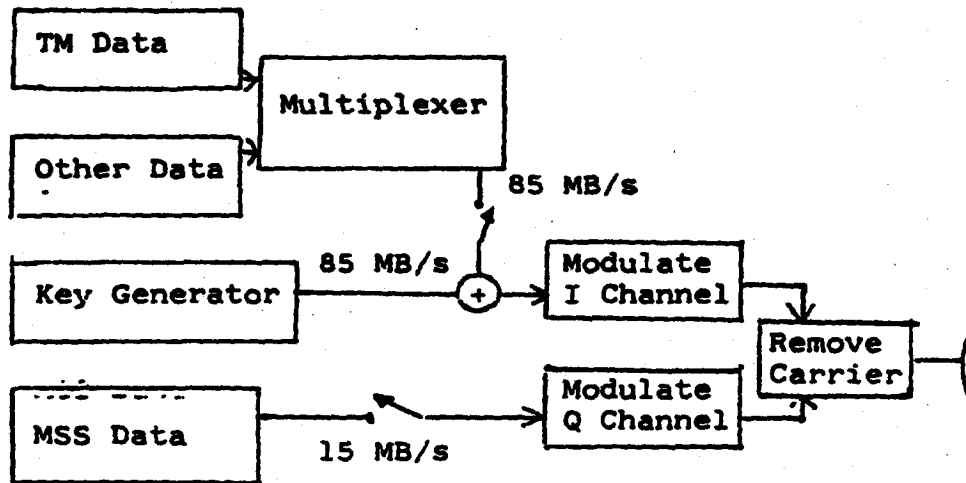
TM (Thematic Mapper) is also a multi spectral scanner with 7 sensor windows from Infrared to Ultraviolet. It generates an 84.903 MB/s data stream. Resolution per pixel is 30 meters. The term "Thematic Mapper" apparently derives from cartographic applications of the multispectral data.

RADIO
LINKS

Three independent radio transmissions can be used to telemeter imagery data from LANDSAT-D, and there are also beacon and telemetry transmissions. LANDSAT-D also receives navigation and command signals.

1. MSS data are transmitted downward at 15 MB/s on a PCM/FM radio link at 2265.5 MHz (S-Band). The power is 10 watts and the spacecraft antenna gain is 2.5 dB in the worst case at maximum range. This will provide data to the existing LANDSAT-C ground stations which only process MSS data.
2. TM data generated at 85 MB/s are added (Mod 2) to binary key generated at the same rate by a 15 stage psuedo random generator on the spacecraft. The "scrambled" data at 85 MB/s are used to modulate the I-channel of a "unbalanced" QPSK signal which is transmitted downward at 8.125 GHz as a spread spectrum PSK signal with the carrier removed. MSS data at 15 MB/s can be combined with the 85 MB/s "scrambled" data, or with the 85 MB/s key stream (no TM data) by modulating the Q-channel of the UQPSK signal. The I-channel uses 80 percent of the power at 85 MB/s and the Q-channel uses 20 percent of the power at 15 MB/s, so the power per bit is about the same in both channels. The "scrambling" is done to provide a high rate of signal transmissions to keep the data stream in synchronization even when the TM and MSS data are featureless. When the carrier is removed, this high transition rate gives a spreading of the signal power over a 170 MHz band to keep signal fluz density low, and to combat fading and signal fluctuations. The combined 85 + 15 MB/s data streams are thus combined on the same spread signal. The 8.125 MHz (X-Band) signal is radiated at 44 watts over a circular pattern about 1500 miles in radius on the earth's surface. The X-Band antenna gain is about 6 dB in the worst case at maximum range.
? What is best case?
3. The 85 MB/s TM data, after scrambling, can be combined with the 15 MB/s MSS data as in (2) above, and transmitted upward to one of the TDRS satellites at 15.024 GHz (Ku Band) as a spread spectrum signal. The bandwidth and modulation of the Ku and X Band signals are the same. LANDSAT-D uses a 6 foot antenna, pointed at TDRS with .8 degree beamwidth, for the 85 MB/s spread spectrum transmission. To assure the 10^{-5} bit error rate (BER) required, the Ku Band uplink is given an extra power margin to compensate for the 10^{-5} BER design of TDRS. 45

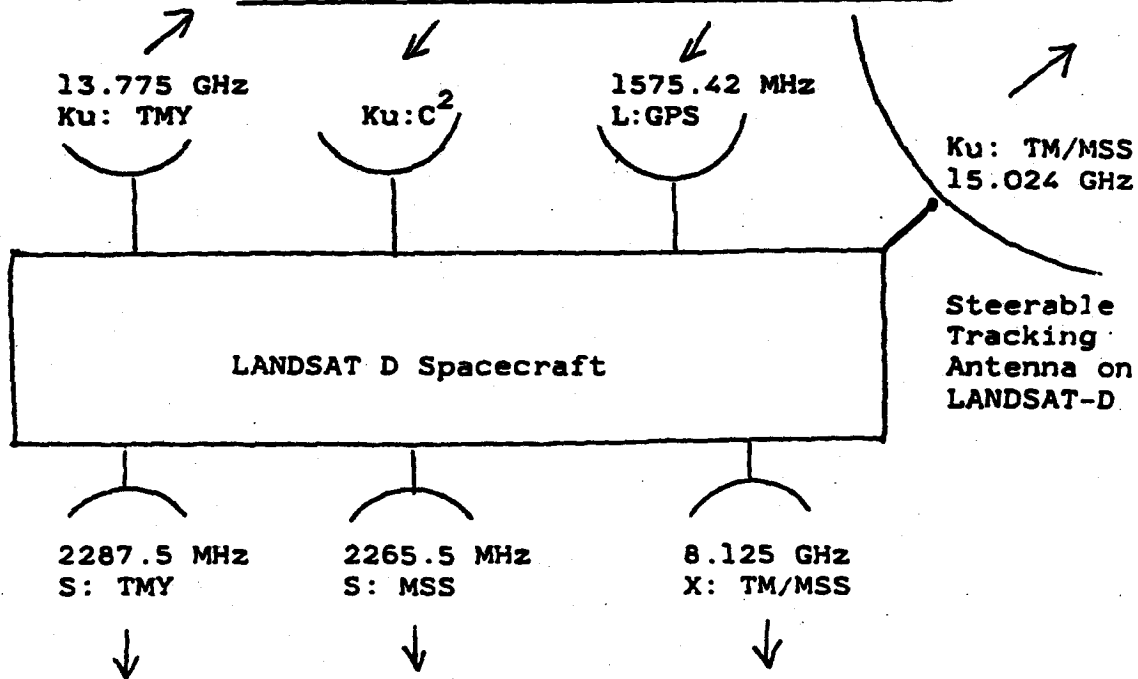
Illustration: X Band / Ku Band Transmission



*chip rate -
chip coded spread
spectrum.*

4. Spacecraft telemetry is radiated downward on a PSK subcarrier at 1.024 MHz transmitted at 2287.5 MHz (S-Band). 20 percent of the signal carrier is left as a residual, and this telemetry signal can be used by a ground station to acquire the LANDSAT-D for initial antenna pointing.
5. A "standard Shuttle" spread spectrum signal of 3 MHz "chip rate" is radiated upward at 13.775 GHz (Ku Band), and this is used by TDRS as a beacon to find and track LANDSAT-D and to point the 12 foot (possibly 16 foot) Ku Band TDRS receiving antenna at LANDSAT-D.
6. Command/control signals from NASA via TDRS to LANDSAT-D are transmitted by a "standard Shuttle" spread spectrum Ku Band signal with 3 MHz chip rate coding, and are received on LANDSAT-D. These signals turn the satellite imagery and transmitters on and off, and perform other functions.
7. Navigation data are received from the GPS (Global Positioning System) at LANDSAT-D via a GPS standard spread spectrum transmission in L Band

Illustration: LANDSAT-D Communications



ACQUISITION

The "standard Shuttle" communication link used to send command/control traffic to the LANDSAT-D spacecraft operates in two modes, viz: acquisition mode and normal mode. During acquisition mode the TDRS sends a psuedonoise coded signal with 3 Mbps code rate, which is "frequency hopped" at a rate of about 5000/second, to enable the user spacecraft (LANDSAT-D) to acquire the signal carrier and to get synchronized to the psuedonoise sequence. After acquisition of the preamble, the communication takes place at a 6 Mbps code rate.

TRACKING

The Ku Band TM uplink antenna tracks the TDRS satellite, while the TDRS antenna tracks the LANDSAT-D, and both antennas are required to give adequate signal accuracy.

GPS DATA

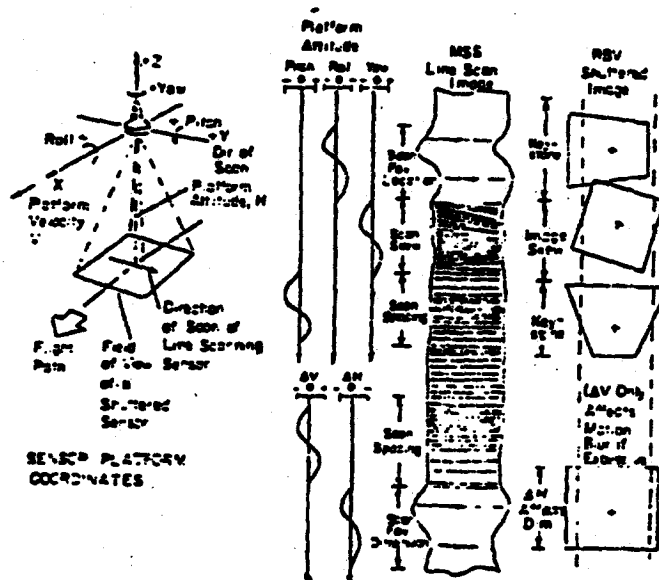
The GPS navigation satellite system transmits two downlink signals from each of the GPS satellites. The L₁ channel at 1575.42 MHz sends a BPSK signal modulated with two different codes. The clear/acquisition (C/A) code is modulated as a psuedo random noise (PRN) at 1.023 MHz, to enable the signal to be acquired by the GPS receiver on LANDSAT-D. A protected (P) code is modulated as a PRN waveform at 10.23 MHz. The C/A signal is modulated in phase quadrature to the protected signal. In this context, "protected" means encrypted. Both C/A and P signals carry information to give location data at the receiver, but the

protected signal gives higher resolution, viz: 10 meter accuracy in 3 dimensions, compared to the 100 meter resolution given by the C/A channel. The 10.23 MHz PRN modulation gives the L₁ GPS downlink channel a radio bandwidth of about 20 MHz. The L₂ downlink sent at 1227.6 MHz carries either C/A or P (protected) signals with constant envelope properties. The pair of channels is used to enable the receiving GPS station to correct for signal delay through the ionosphere. The "chipping rate" for the C/A signal is 1.023 Mbps, and for the P signal is 10.23 Mbps. Spread spectrum modulation is used to keep radio flux intensity on the ground at a low level, to prevent interference with terrestrial services.

CORRECTION DATA

The GPS receiver on LANDSAT-D enables the satellite to continuously determine its position in 3 dimensions to about 10 meters accuracy, and this position data is interleaved in the TM data stream. The timing and position data from GPS are then recovered in the demultiplexing operations at the ground station, and used to compute the parameters for geometric and radiometric correction of the imagery data of the 'scene' which the TM generates. For example, by knowing precisely how high the satellite was, and its exact position over the ground, and any pitch, roll or yaw parameters, the projection of the TM scanner onto the earth's surface can be computed, and from this the correction computations are defined.

Illustration: TM Scene Distortions

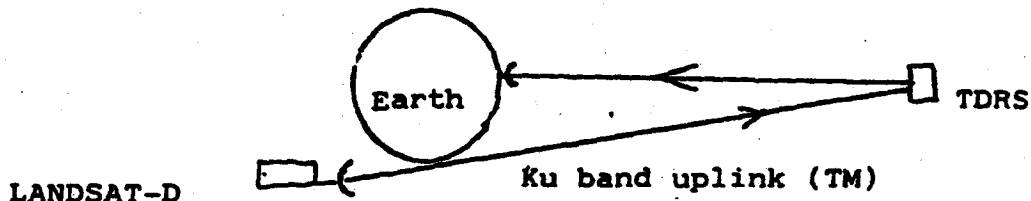


F-B-1 Effect of Platform Dynamics on Image Geometry.

**UPLINK
DATA**

The reduction of radio flux intensity at the earth's surface was also the principal reason for the choice of spread spectrum on the Ku band uplink. At extreme range, the low altitude satellites which send data up to the TDRS are almost over the earth's horizon as seen by the TDRS. While the main lobe of the radio signal up to the TDRS does not actually graze the earth, some of the front lobe energy is expected to reach the surface at the same angle as a line of sight radio relay system. To prevent interference with possible terrestrial services, the signal waveform is spread out by the data scrambler, and the signal carrier removed (probably by a Costas loop) before transmission.

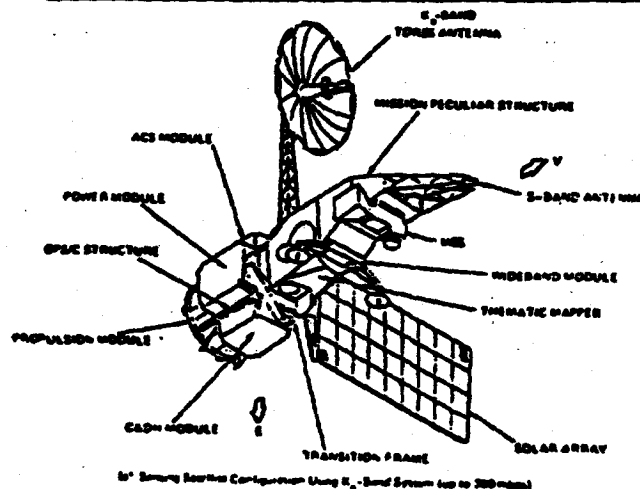
Illustration: TM Data link to TDRS at long range



The data transmission system is designed to operate at much higher bits rates than 85 MB/s. NASA projects data rate requirements for sensing up to 500 MB/s by the late 1980's, and the TDRS can relay at 300 MB/s as now designed, using the same QPSK transmission system. NASA expects that by using polarization diversity on an "advanced" TDRS they can achieve data rates of 600 MB/s from TDRS to the White Sands ground station.

The 6 foot Ku band uplink antenna on LANDSAT-D has a main lobe beamwidth of 0.7 degrees at 3 dB points, and hence it must be accurately pointed at TDRS.

Illustration: LANDSAT-D Configuration



DOWNLINK
DATA

The S-Band 15 MB/s MSS downlink signal will be received by a 30 foot antenna, and current LANDSAT-C stations could receive it, as well as the S-Band telemetry signal. The X-Band TM or TM+MSS signal will also be received by a 30 foot antenna. A single 30 foot antenna can operate at both X and S bands if it has suitable receiving horns, and the antenna is physically accurate and smooth enough for the X Band operation.

When receiving X Band TM or TM/MSS data the antenna pointing must be controlled by X Band autotracking, because of the narrow beam (0.3 degrees) of the antenna at X Band. The nominal maximum slant range occurs when the ground station is at a 5 degree angle, and this slant range is 2573 Km (1599 miles), which is less than the LANDSAT-C slant range because of the lower orbit. The 30 foot antenna can be pointed even lower because of the power margins provided in the satellite, but usually this is not practical because of terrain blocking.

The S-Band 15 MB/s data down link operates with an expected 10^{-5} bit error rate (BER). The PCM/FM signal has nominal frequency excursions of + 7.5 MHz with an 0.5 modulation index. Reception of the signal depends on recovery of the signal carrier. The X-Band 85 MB/s data link is designed to operate with 10^{-6} BER. The Ku Band TM 85 MB/s uplink is also designed to operate with 10^{-5} BER, but TDRS itself is only designed for a 10^{-5} BER, so NASA has put more RF power onto the LANDSAT uplink to compensate for this. The S-Band telemetry from the LANDSAT-D has a 20 percent residual carrier power, so that a coherent detection of that 2287.5 MHz telemetry link can be done by an S Band ground station.

One of the problem in any spread spectrum system is the initial acquisition of the signal and getting synchronized with the code stream. In the LANDSAT-D, the TM (Thematic Mapper) must be switched on for 4 minutes to warm up before taking pictures, and the X band transmitter must also be warmed up, so there is a transmitting preamble of pseudo random key for several minutes which repeats the code sequence before TM data are available. This long preamble can be used by a ground station to acquire and synchronize to the spread spectrum signal, and to home in on the X band autotrack, before the TM data are sent.

ANTENNA
FOOTPRINTS

The S Band and the X Band space craft antennas both have large "footprints" ---they reach to the earth's horizon, a circle of over 1600 miles in radius --- and any ground station or stations within the "footprint" can receive whatever the LANDSAT-D transmits.

TELEMETRY
DATA

The MSS data stream carries space craft telemetry data interleaved with the sensor and synchronizing data. The TM data stream carries spacecraft telemetry data, sensor calibration data, timing data and navigation data from the GPS system, interleaved with the sensor and synchronizing data. When they are sent over the X Band or the Ku band, both the MSS and TM data streams are differentially encoded, and the TM data are then also "scrambled" by adding key (mod 2) at 85 MB/s.

A ground station can request that MSS data be sent on the S Band or the X Band link, or on both. The LANDSAT-D is commanded only by NASA over the Ku band links which are relayed by TDRS, and these commands are sent as spread spectrum signals. The ground stations cannot send commands to the LANDSAT-D directly.

COMMANDS

According to the commands it receives, the LANDSAT-D can transmit over the S Band, X Band or Ku Band data links, or over any combination. Ordinarily only one transmitter will be used to save spacecraft power and to avoid overheating. The LANDSAT-D is designed to send TM data for about 15 minutes on the X Band and about 15 minutes on the Ku Band in an orbit. In extremis these episodes can be doubled on one orbit, but this tends to run the battery power down so that succeeding orbits must do very little transmission. The principal power drain comes from the X Band TM link at 44 watts. If the Ku link and the X Band link are both on, at least 54 watts must be expended, and the spacecraft tends to heat up. At the beginning of its life the LANDSAT-D will be able to recharge its batteries in one normal orbit, but as the spacecraft ages after a few years, the solar cells deteriorate and the effective duty cycle must be reduced.

The pseudo random key stream is always sent on the X or Ku bands, if the transmitters are on, whether or not TM or MSS data are sent, to assure that the radiated power is spread over the entire \pm 85 MHz bandwidth, and to give numerous transitions to maintain receiver synchronization.

3 The TDRS System

There are two TDRS (Tracking and Data Relay Satellite) satellites, which are located in high altitude geostationary orbits over the Atlantic and Pacific Oceans respectively.

Illustration: TDRS System

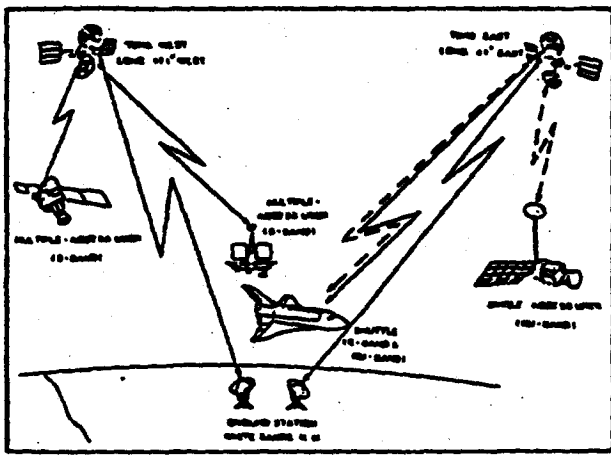


Fig. 7 Operational TDRS System

The TDRS system is scheduled to be operational in late 1980. It represents the result of studies and developments that began in the mid 1960's, and included the solution of many technical problems, including the steerable antennas on the TDRS and user spacecraft. The current spaceflight tracking network consists of 16 ground stations distributed around the world. When TDRS becomes operational, many of these stations will be phased out.

The first significant studies of a space-based tracking system were initiated by NASA in 1966, and the resulting system was called Orbiting Data Relay Network (ODRN). After definition phase studies in 1971, the "bent pipe" mode of operation was adopted, where all data would be relayed through TDRS from a user satellite in real time.

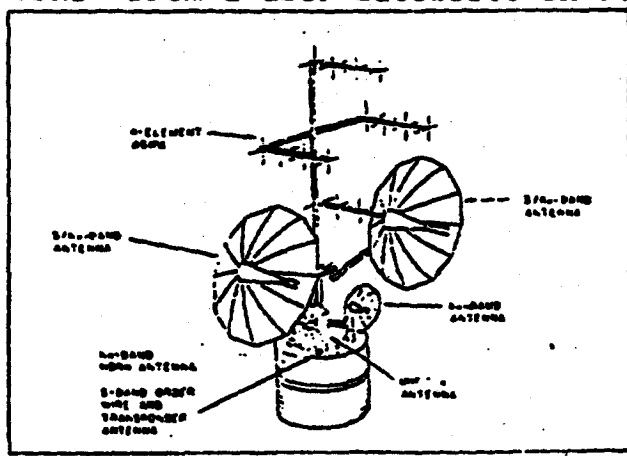


Figure 3. Hughes Aircraft Company Baseline

TDRS
SATELLITES

The TDRS system consists of two geostationary relay satellites located a minimum of 130 degrees apart in longitude, and a single ground terminal located at White Sands Test Facility (WSTF), New Mexico. The system includes two additional satellites, both in orbit, with one in a configuration as a rapid replacement and the other in a commercial configuration. The TDRS system was originally planned as a NASA operational system, and hence received considerable engineering support from NASA during its design and development. It has been changed to a privately owned system, which Western Union will lease to NASA for LANDSAT-D and Shuttle operations. TDRS will also be leased for communications with the payloads launched by the Space Shuttle. To simplify the leasing and using arrangements, the operations of the TDRS have been standardized as much as possible.

MODES

The TDRS will operate in three modes, viz: (1) Multiple Access (MA), at S-Band, (2) Single Access at S-Band (SSA), and (3) Single Access at Ku-Band (KSA).

MA
MODE

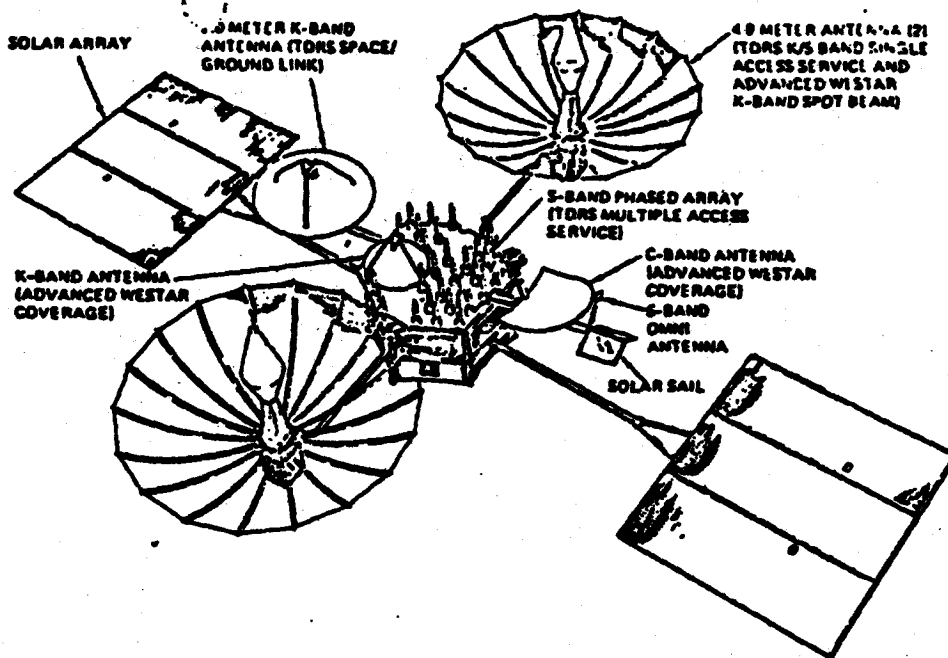
The Multiple Access (MA) communication service system is designed to provide simultaneous real-time and dedicated return link service to low earth orbiting user spacecraft with real-time data rates up to 50 Kbps. Uplink data rate requirements from 100 bps to 50 Kbps can be satisfied by the S-Band links for up to 20 users at once. Each user will be within view of a TDRS at least 85 percent of the time, although technical restraints may reduce this access. A TDRS can command one user spacecraft at a time via MA with a variable transmitted data rate of 100 bps to 10 Kbps.

KSA/SSA
MODES

The Single Access service can operate on both S-Band (SSA) and Ku-Band (KSA) simultaneously, if both data uplink sources lie within the beamwidth of the 16 foot diameter antenna on TDRS. (note: in 1974 the TDRS antennas for Ku/S band operation were planned as 3.8 meter diameter, but since then antenna size has been increased to 16 feet. This gives better signal to noise performance, but requires more accurate pointing and tracking). Ordinarily one of the 16 foot Ku/S Band antennas will track a single low altitude user satellite such as LANDSAT-D, while the other will be pointed toward the White Sands ground station. The data from the user satellite will be transmitted as a pseudo noise QPSK signal in which each phase can be modulated at rates from 1 Kbps to 150 Mbps on the Ku Band link or 0.1 Kbps to 6 Mbps on the S-Band uplink.

Table: TDRS Data and Command Rates

	Channel 1	Channel 2	Total	Command
MA	0.1-50 Kbps	0.1Kbps-50Kb	0.1-50 Kbps	0.1-10 Kbps
SSA	100 bps-6 Mbps	100 bps-6Mbps	1K-12 Mbps	0.1-300Kbps
KSA	1 Kbps-150Mbps	1 Kbps-150Mbps	1K-300Mbps	1K-25Kbps



TDRSS/ADVANCED WESTAR SHARED SATELLITE

Figure 4.26 The Western Union Tracking and Data Relay Satellite System TDRSS will perform three functions:

- i. Data relay services to and from low-orbit NASA satellites including the space shuttle.
- ii. Supplementing the 4-6 GHz communications service between large earth stations provided by WESTAR.
- iii. 12-14 GHz service between rooftop and parking lot antennas for voice, video and data signals with transmission speeds up to 250 Mbps.

The solar arrays on TDRS provide 1700 watts of power. There are six antennas, three steerable by commands from earth, viz:

1. A 30 element S-Band phased array for space operations.
2. Two 16-foot steerable umbrella-like antennas for S-Band space operations and Ku-Band data relay.
3. A 6.6 foot steerable antenna for Ku-Band data relay.
4. A 4.8 foot fixed antenna for C-Band(4,6 GHz) WESTAR-type communications.
5. A 3.7 foot fixed antenna for terrestrial communication with rooftop antennas at Ku-Band.

In some modes of operation, both 16 foot Ku/S band steerable antennas can track space vehicles, and provide two simultaneous Single Access (KSA/SSA) operations. In this mode of operation the 6.6 foot steerable antenna provides the downlink to the White Sands ground station. When very high data rates are sent, one of the 16 foot antennas can be used to track the space vehicle (e.g. LANDSAT-D) while the other 16 foot antenna is used for data relay down to White Sands --- to give more accurate relay operation.

The command and forward link signals are standardized for TDRS user satellites, e.g. LANDSAT-D, Space Shuttle, etc. and are chip coded spread spectrum signals with chip rates of about 3 Megachips/sec. The wideband SSA and KSA uplink data signals are not standardized on data rate or coding, although they all use the same general QPSK spread spectrum modulation scheme.

TDRS will provide a number of telecommunications services under lease arrangements.

Table: TDRS Telecommunications Services

- Forward link services (to user spacecraft)
 - S-band Multiple Access (MA)
 - S-band Single Access (SSA) and S-band Shuttle
 - Ku-band Single Access (KSA) and Ku-band Shuttle
- Return link services (from user spacecraft)
 - S-band MA
 - SSA and S-band Shuttle
 - KSA and Ku-band Shuttle
- Tracking services*
 - One way range rate
 - Two way range and/or range rate
- Simulation services
- Verification services.

The two TDRS satellites will provide continuous coverage of satellites in orbits between 1200 and 12000 km altitude, with decreasing coverage (a gap in earth coverage) for orbits below 1200 km and above 12000 km altitude.

Illustration: TDRS Geographic Coverage

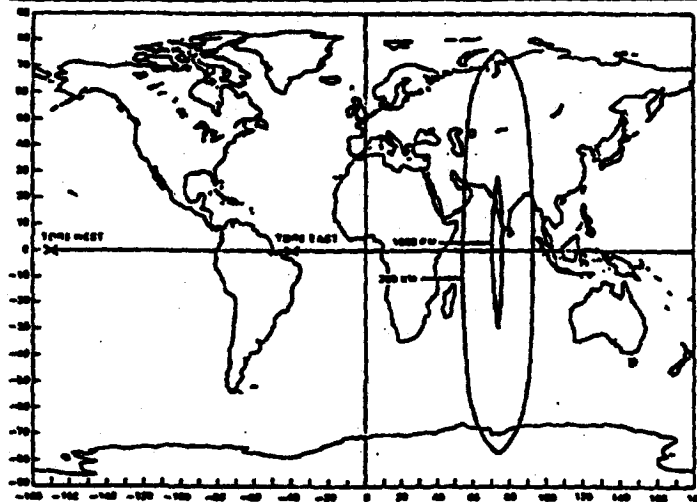
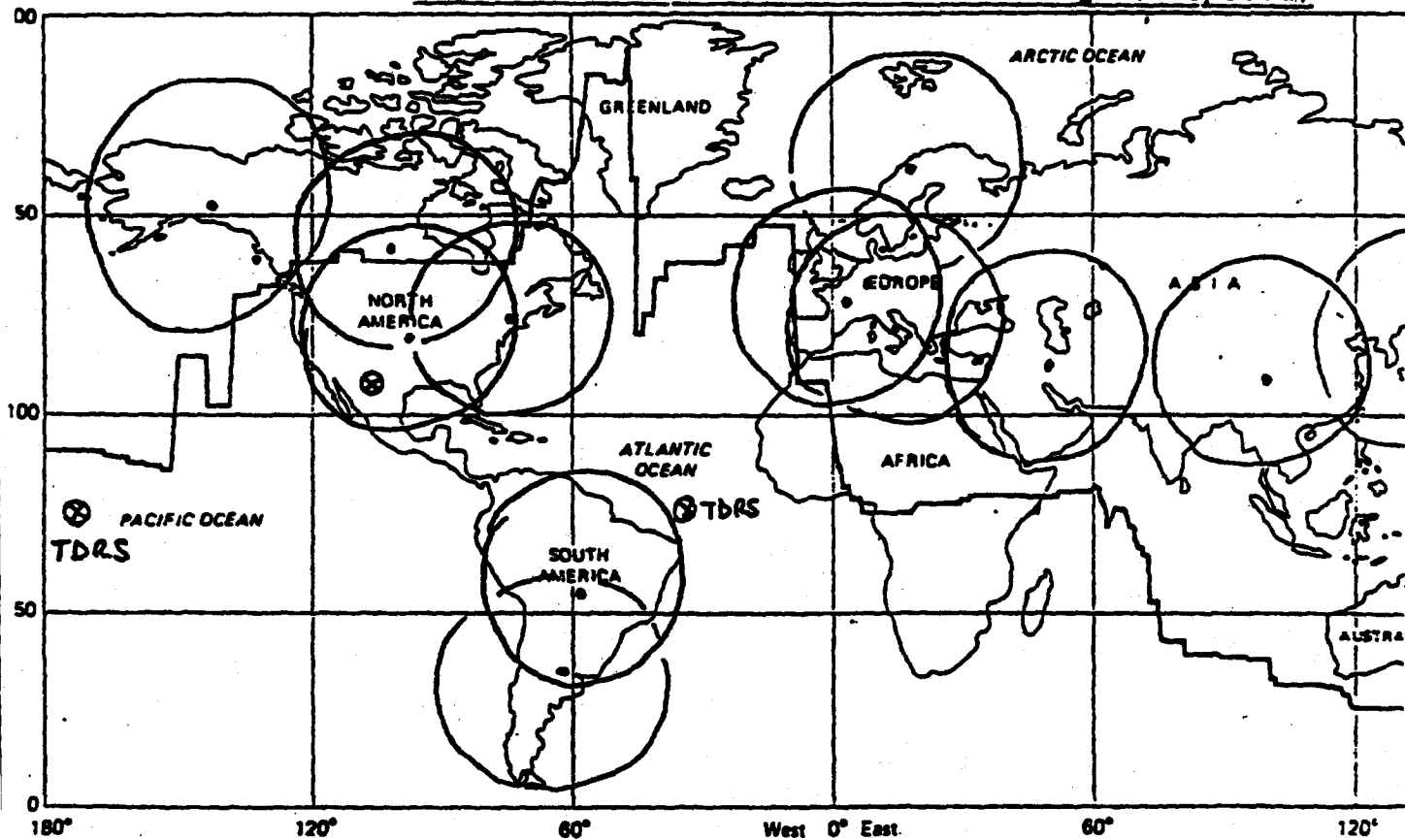


Figure 6 TDRSS No Coverage Zone

The operational concept that was planned in the LANDSAT-E use of TDRS was to have only one ground station, at White Sands, to receive the LANDSAT-D data from all over the world. This would eliminate the need for any foreign based and foreign owned ground stations for operation of LANDSAT-D, the Space Shuttle, and various other satellites.

This concept has now been modified. While TDRS will be used for tracking and command/control of LANDSAT-D, the data transmission through TDRS may be much less than originally planned, because foreign users prefer to keep their ground stations (LANDSAT-C stations) operating and receive direct downlink data for LANDSAT scenes that they are interested in. As a result the TDRS may be used primarily for LANDSAT-D imagery of US territory (in which case TDRS is not really needed), while non-US territory may be scanned and downlinked directly on X-Band to various foreign ground stations --- although simultaneous uplink through TDRS is possible.

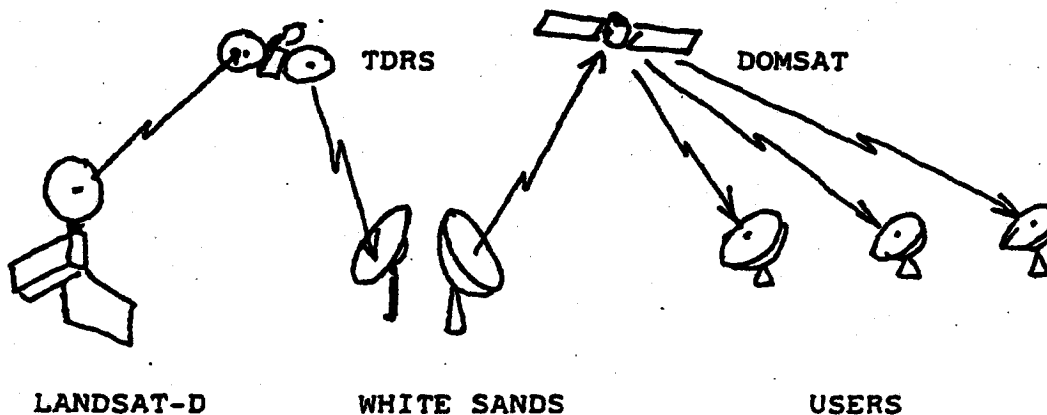
Illustration: X-Band Downlink Coverage (Proposed)



The circles represent coverage possible by X-Band downlink to existing or planned LANDSAT-D ground stations. TDRS could cover almost all of this, but may be avoided by foreign parties for data privacy reasons.

Although the initial TDRS operation will record the LANDSAT-D/TDRS downlink data at 85 Mb/s at White Sands, and then relay it through a domestic satellite link to Goddard after some delay, plans for on line retransmission and distribution of TDRS data by domestic satellite are being pursued.

Illustration: TDRS/DOMSAT Receiving/Distribution



Currently, DOMSAT transponders cannot carry the bit rate, but use of multiple transponders, or new transponders may resolve this.

Future Advanced TDRS systems will employ laser links to augment the data relay capability of the radio links. The optical telescopes will be pointed and tracked (by a double beacon system) to an accuracy of 5 micro radians, and the laser links will carry data at a gigabit/sec rate.

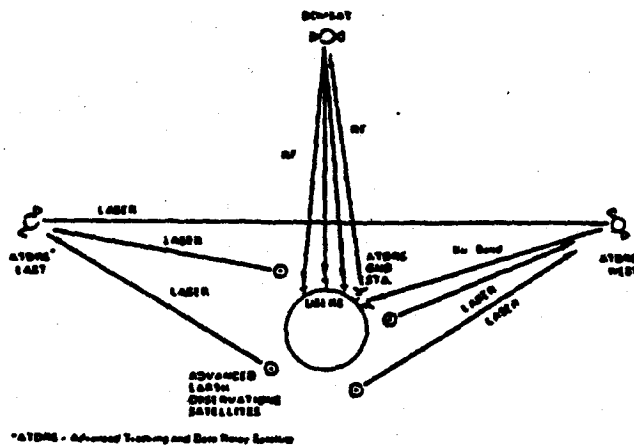


Figure 2. Earth-Sensing Satellite Relay System Concept for the Late 1980's.

(Note: The subsequent description of TDRS is more detailed, and may be skipped by the non-technical reader.)

S/Ku
ANTENNAS

The S-Band antenna and the Ku-Band antenna are colinear, and they use the same 16 foot reflector. The S-Band and Ku-Band autotrack nulls remain within approximately 0.1 degree of each other. It is intended to align the S-Band and Ku-Band tracking feeds within 0.1 degree, to result in a relative pointing error of less than 0.2 degrees between S-band and Ku-Band. With this small pointing error, the S-Band tracking system can be used to autotrack and lock onto the user satellite. e.g. LANDSAT-D, and then hand over to the Ku-Band autotrack. The beamwidth of the 16 foot antenna at S-Band is 2 degrees, while the beamwidth of the same antenna at Ku band is 0.3 degrees. The "programmed" pointing of the TDRS antenna is at least 0.7 degrees because of a combination of altitude errors and mechanical errors in the antenna support mechanism, so that the Ku Band autotrack cannot even find the user satellite (e.g LANDSAT-D) within its main lobe by programmed pointing. Although the S-Band main beam is 2 degrees wide, the actual tracking error is less than 0.2 degrees, and since the misalignment and pointing error between S and Ku Band feeds is around 0.1 degree, the S-Band autotrack will keep the user satellite within the main beam of the Ku-Band autotrack system, and handover is feasible.

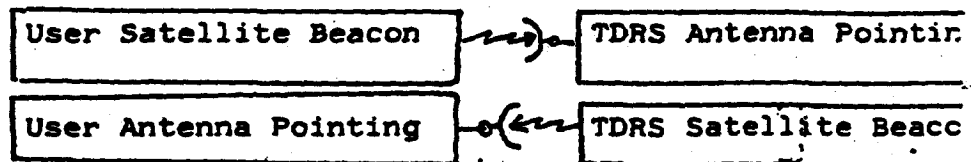
To summarize the acquisition and tracking scheme, the programmed tracking steers the antenna toward the user satellite closely enough so that the S-Band autotrack can acquire and lock onto it. This puts the user satellite within the mainbeam of the Ku-Band autotrack which then converges precisely onto the user satellite.

The user satellite will steer its own antenna onto the TDRS in a similar way, using a signal radiated by the TDRS as a beacon to establish autotrack in the Ku Band.

DOUBLE
BEACON
TRACKING

In effect, the TDRS/User two way communications are based upon a "double beacon" cooperative tracking system in which both satellites focus on each other's "beacon" radiations to point their antennas at each other. Actual command and data communication (wideband) cannot flow until the antennas are tracking correctly, and the spread spectrum signals are synchronized.

Illustration: "Double Beacon" tracking system



When TDRS tracks LANDSAT-D it acquires autotrack on the satellite by first pointing its 16 foot antenna to where LANDSAT-D is supposed to be. This predicted position is computed on the ground from knowledge of the LANDSAT-D orbit, but it will generally not allow pointing to better than 1 degree accuracy. Since the beam of the 16 foot TDRS antenna is less than 0.3 degrees, the "programmed tracking" is followed by a search for the power envelope of a "Shuttle Standard" 3 megachip coded spread spectrum signal radiated at 13.775 GHz by LANDSAT-D which is used as a "beacon".

MA
FORWARD
LINK

In normal "forward link" communications from TDRS down to the user satellite, command signals are sent to activate certain functions on the spacecraft. IRAC restrictions on the flux density of the forward link S-Band and Ku-Band signals require that all MA, SSA and KSA forward link signals be transmitted with spread spectrum modulation. This in turn required a design in which the forward link signals operated in two modes, viz:

- (1) Acquisition Mode -- a frequency hopping (FH) preamble
- (2) Normal Mode -- A non-hopping spread spectrum command link.

The frequency hopping is done to enable the receiver on the user spacecraft (e.g. LANDSAT-D) to acquire the synchronizati quickly with the psuedo noise (PN) code used to generate the spread spectrum transmission. The user spacecraft receiver gets partial synchronization from the FH transitions and then does a correlation search to complete synchronizatio

Illustration: Signal Acquisition (simplified)

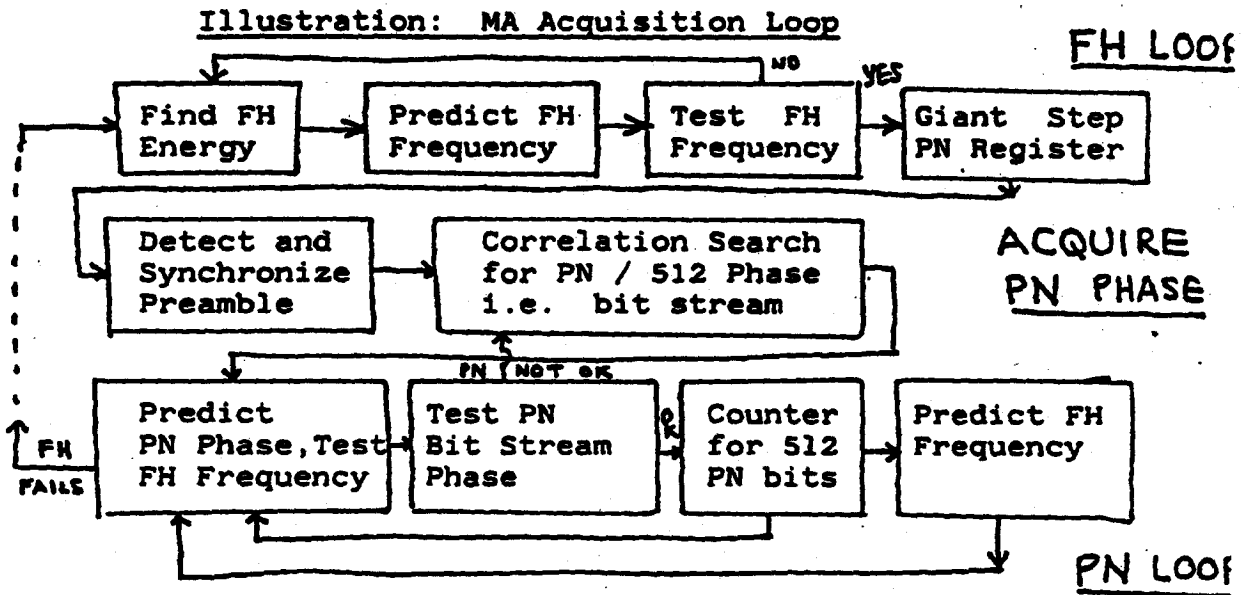


MA
FREQUENCY
HOP
LOCK

To see this acquisition procedure in more detail, the MA signal, which is transmitted at S-Band, has a psuedo random frequency hopping (FH) code length of 2^8 . Depending on the register state, the preamble signal is frequency hopped to one of 256 frequency values. The 256 frequency values are spaced 12 KHz apart, so that during the preamble the signal energy is spread over 3 MHz. The MA acquisition preamble is transmitted at the same chip rate as the subsequent command signal, with "coherent frequency hop modulation" (which presumably means that the energy is concentrated in a narrow channel so that M-ary detection of the frequency hopping can be done). The user spacecraft receiver acquires this "acquisition preamble" --- usually in about 15 seconds --- and at that point is partially synchronized to the long 2^{18} psuedo noise (PN) code period within $\pm 1/512$ of the PN period. The remaining timing

MA
PSUEDO
NOISE
LOCK

uncertainty is resolved by a sliding correlator search over the subsets of the PN period.



(Note: This diagram is derived from some published technical data on TDRS, but it is constructed, not copied, based on 1975 data)

When the PN search finds the expected match of the on board PN generator and the received signal data, the space craft receiver is completely synchronized with the PN code generator at the signal source (which is apt to be a ground station). The FH acquisition preamble reduces the time to acquire PN synchronization by more than 100 to 1, compared to a "brute force" sliding correlation search on the PN sequence. When the forward link switches to normal mode the code synchronization is maintained without any further adjustment. The KSA and SSA acquisition is done the same way, with about 4 second acquisition time.

Table: Acquisition Mode Parameters

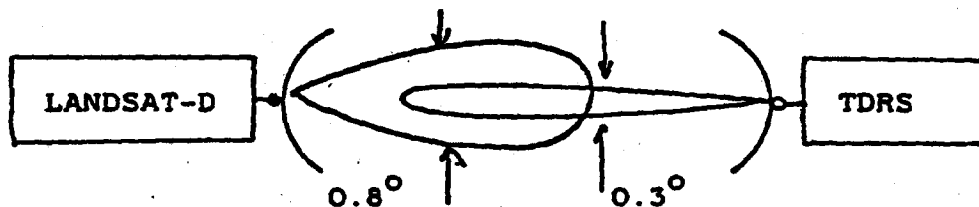
	PN Period	FH Positions	FH Rate	FH Increment	FH
MA	2^{18}	256	~ 3000/sec	12 KHz	3 MHz
KSA/SSA	2^{19}	512	~ 6000/sec	12 KHz	6 MHz

SA
TRACKING

The high precision auto-tracking by both spacecraft antennas, viz: LANDSAT-D and TDRS, is essential for the high data rate transmissions, for unless both antennas are pointed accurately at each other, the wideband data transmission cannot be accomplished with sufficient accuracy to make the TM (thematic Mapper) data useable.

Since the low altitude LANDSAT-D satellite is orbiting at about 18000 MPH, and will pitch and yaw and move around from various causes, the technical problem of keeping both antennas continuously pointed within a few tenths of a degree is critical.

Illustration: Intersecting Antennas Beams



Since the -3dB (half power) beamwidth is only a fraction of a degree for both antennas, tracking must be much closer than that, e.g. beamwidth/10, to maintain a good signal path. This is especially critical at extreme range where the signals "graze" the earth and hence experience the greatest atmospheric and ionospheric effects, while their path loss is greatest. Because the high altitude TDRS satellite is not subjected to the random accelerations which perturb LANDSAT-D, it can use a larger antenna with a narrower beam.

The central concept in the precision tracking between TDRS and LANDSAT-D, as noted earlier, is that both vehicles emit signals which serve as "beacons" to locate and lock onto each other. (This same "double beacon" technique is also used for intersatellite laser links which are planned for an Advanced TDRS where optical antennas of 40 microradian beamwidth must be kept pointed at space or ground stations with 5 microradian accuracy!)

In addition to the pointing and tracking requirements, there are also technical problems in keeping the surfaces of the unfurlable 6 foot and 16 foot antennas smooth enough to give the necessary power concentration at the short 2 cm Ku Band wavelengths. Physical experiments have uncovered surprises. A number of experiments have been conducted using ATS-6, NIMBUS-6, GEOS-3, and APOLLO-SOYUZ to prove the concept

**TDL
CHIP
LOCK**

PN synchronization is then achieved with a non-coherent Tau-Dither Loop (TDL) --- which is a sophisticated search algorithm that "dithers" back and forth in aligning the waveform of the arriving signal with an expected waveform in the receiver.

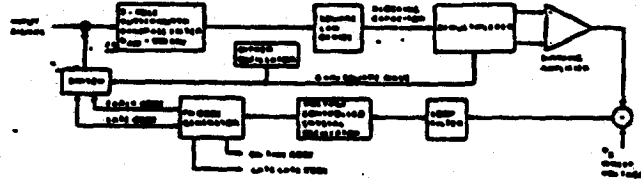


Figure 14. Tau-Dither PN Tracking Loop

The forward link signal from TDRS (to Shuttle) is a 216 Kb/s data stream which is "chip coded" at a 3.028 031 megachip rate to produce a 6 MHz spread spectrum signal. The PN chip code is 1023 long, generated by a Gold Code sequence. The PN waveform is modulated so that an "early" code is $\frac{1}{2}$ chip ahead of the "on time" PN code. There is also a "late-late code" which is $1\frac{1}{2}$ chips behind the "on time" code, and is also needed by the "code lock" detector.

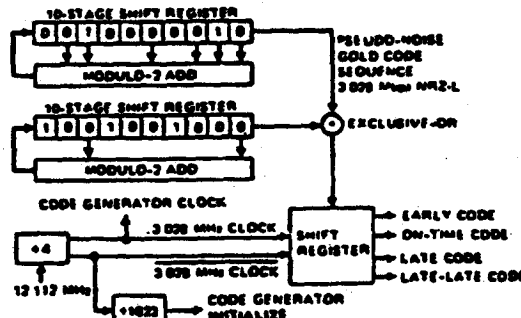


Figure 8. Gold Code PN Generator

The PN lock detector executes a brute force search of the 1023 chip code at a rate of 256 chips/sec, so that a full sweep of comparing the arriving waveform with the code sequence is made in about 4 seconds. The particular Gold Code chosen has several false peaks, i.e. places where the code correlates with itself, and hence "false lock" was found to be one of the most important design problems.

**BIT
LOCK**

When the chip code synchronization is established, the receiving system then synchronizes to the 156 Kb/s bit stream with matched filter detectors. A Costas Loop running at twice the bit rate is used for bit synchronization.

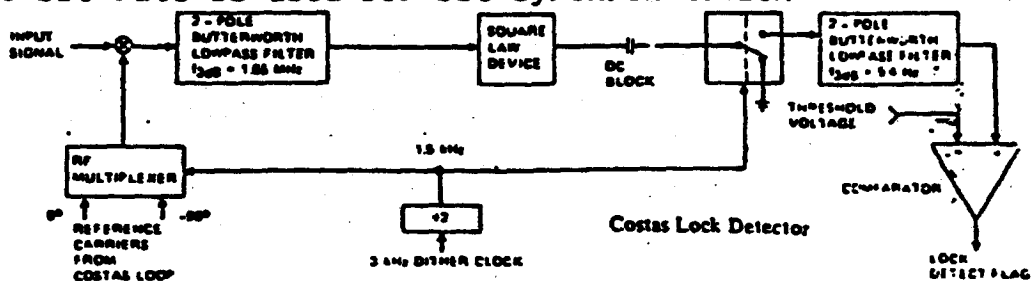


Illustration: Bitstream Synchronization

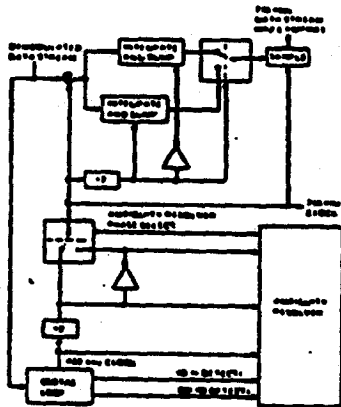


Figure 23. Bit Synchronizer and Bit Detector

FRAME
LOCK

A frame synchronization subsystem operates in a 3 mode sequence: search, acquisition test, and lock verification, to acquire and maintain synchronization with the (Shuttle) 32 bit frame synch which is the prefix of the 9 x 48 bit frame. With frame synchronization attained the data stream is demultiplexed and used on board the low altitude spacecraft.

Illustration: Frame Synchronization/Demultiplexing

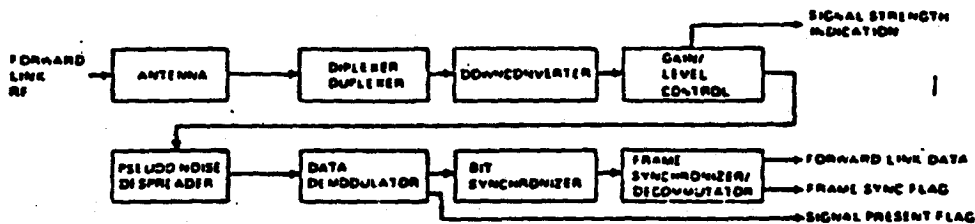


Figure 7. Forward Link Functions

Ku
RETURN
LINK

The Shuttle return link Ku-Band system transmits a 50 Mb/s signal from the Shuttle up to TDRS at 15.0034 GHz by an unbalanced QPSK PN spread spectrum modulation, which is essentially the same system used on LANDSAT-D. The 50 MB/s signal is convolutionally encoded at a $\frac{1}{2}$ rate to produce a 100 Mb/s bit stream before it is used to key the I Channel of the QPSK modulator. This differs from LANDSAT-D which does not use convolutional coding on its 85 MB/s data. The Shuttle convolutional encoder is based on a 31 stage shift register.

Ku
FORWARD
LINK

Although the MA forward link described in 1975 literature used an FH acquisition mode for S-Band synchronization to a PN coded signal, the Ku-Band forward link designed to operate via TDRS to the Space Shuttle has a completely different acquisition system based on a "Tau-Dither" loop (TDL), and it does not use frequency hopping.

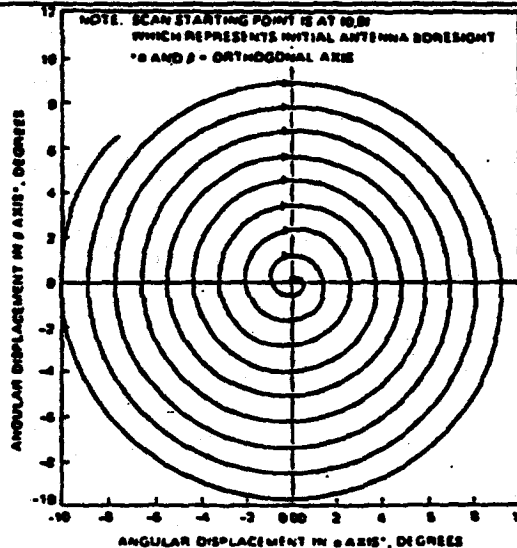
Table: TDRS Ku Band Forward Link

FORWARD LINK RF SIGNAL CHARACTERISTICS	
Carrier frequency	13.775 GHz \pm 10 kHz
Received wave polarization	Right hand circular
Received wave axial ratio	1 dB max
Dynamic range of incident flux density	-113.5 dBW/m ² max -126.9 dBW/m ² min
PN code length	1023 symbols
PN code rate	3.028 031 megachips/sec at chip/sec
PN code format	NRZ-L
Mode 1 data rate	216 kbps \pm 22 bps
Mode 2 data rate	32 or 72 or 96 or 216 kbps
Data format (all modes)	Biphase-L (Manchester)
Modulation (when present)	Biphase

Ku
ANTENNA
LOCK

The Space Shuttle will use a 3 foot Ku-Band antenna, compared with the 6 foot antenna on LANDSAT-D, for its 50 Mb/s uplink data transmission. This antenna begins its search for the TDRS 13.775 GHz Ku-Band forward link signal by pointing the antenna within \pm 10 degrees of the TDRS and then executing an inward spiral search until it locks onto the 13.775 GHz signal. The tracking accuracy after lock is acquired is about $\frac{1}{2}$ the antenna beamwidth, at the 3 sigma level, i.e. 99.7 percent of the time within $\pm \frac{1}{2}$ BW.

Illustration: Antenna Search Pattern



The various operations of dithering, code generation, code matching, and loop tracking are combined in the signal acquisition and tracking loop, once the antenna tracking has converged sufficiently on the signal.

Illustration: TDL Acquisition and Tracking

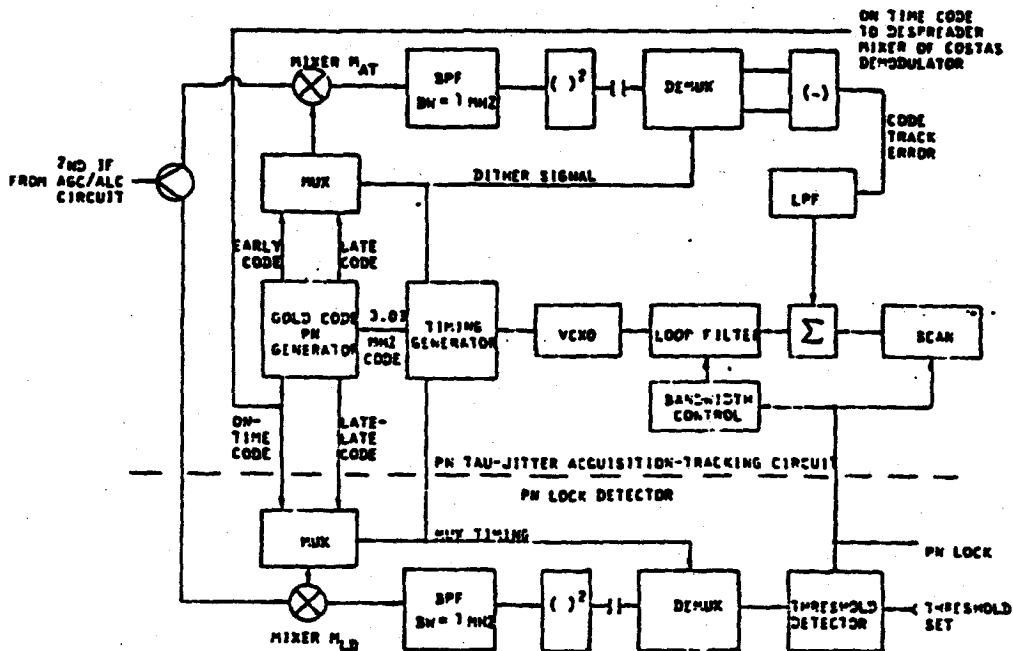


Figure 12. Ku-Band PN Tau-Jitter Acquisition-Tracking and PN Lock Detector Functional Block Diagram

All of this spread waveform processing results in the extraction of a string of despread pulses, which must then be detected and synchronized to give a bit stream output.

Like the FH (frequency hopping) system, the Tau-Dither Loop must acquire the PN spread spectrum quickly, i.e. in about 4 seconds. The S-Band and Ku-Band despreaders operate somewhat differently, although both use Tau Dither Loops to lock on the spread waveforms.

Although the command and forward link signals are standardized for TDRS user satellites, the wideband SSA and KSA omlink signals are not standardized on data rate or coding, although they all use the same general QPSK modulation scheme.

SA
HIGH
DATA
RATES

The LANDSAT-D data signal is an 85 Mb/s spread spectrum signal transmitted up at 15.024 GHz, while the Shuttle sends 50 Mb/s at 15.0034 GHz. Because of the unbalanced QPSK modulation, and the inclusion of the 15 Mb/s MSS data on the Q channel, the actual data rate of the LANDSAT-D signal is 85 + 15 + 100 Mb/s. The Shuttle signal on the other hand is convolutionally encoded to give 100 Mb/s on the I channel and a 4.5 MHz analog signal plus other data can be modulated onto the Q channel at the same time, giving a further increase in the information rate of the signal. The Shuttle uplink signal may range from 2 Mb/s to 50 Mb/s, with convolutional coding at the same rate, so the signal waveform (spread spectrum) can vary over a wide range.

Illustration: Shuttle Convolutional Encoder

SA
ERROR
CODED
DATA

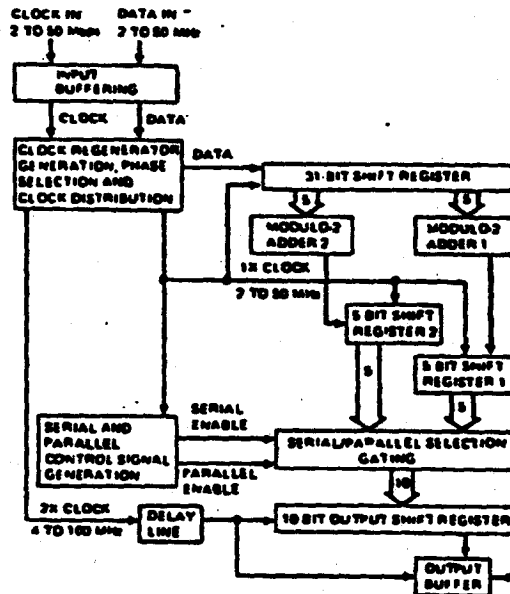


Figure 33. Convolutional Encoder

SPREAD
SPECTRUM
RELAY

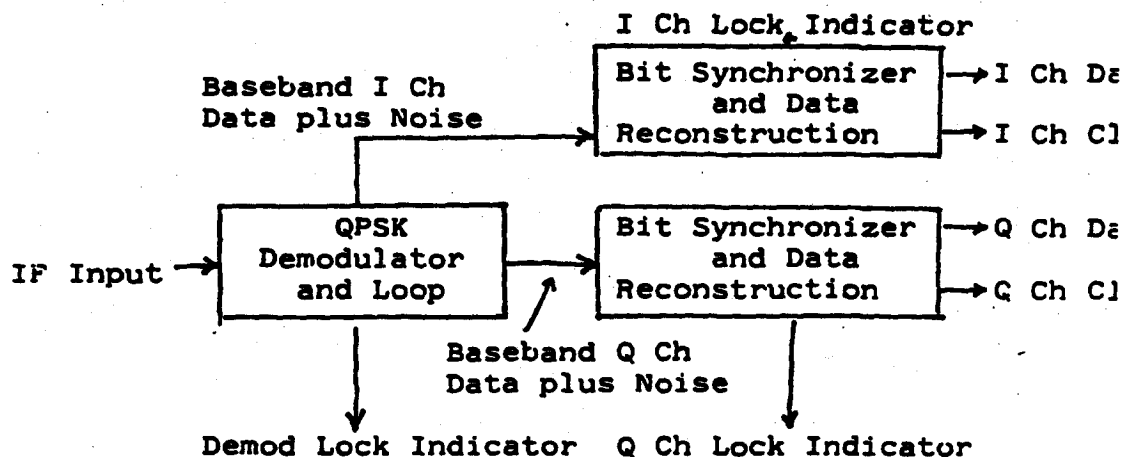
The TDRS is designed to relay a spread spectrum signal in Ku Band (KSA) which is modulated at rates as high as 150 Mb/s on both I and Q channels of a QPSK transmission. The TDRS ground station, receiving two TDRS satellites, can accept two KSA channels at up to 300 Mb/s each, on the spread spectrum waveform. The LANDSAT-D data signal has an RF bandwidth of + 85 MHz, but the TDRS Ku Band transponder has an RF bandwidth greater than 300 MHz. Because TDRS operates as a linear transponder, any spread spectrum waveform or combination of waveforms can be relayed through it.

4. The White Sands Ground Station

RECEIVING
SA
DOWNLINK
DATA

At the White Sands ground station a 60 foot antenna is used to receive the spread spectrum Ku Band 13 GHz TDRS downlink signal from each TDRS. The antenna at 13 GHz has a beamwidth of 0.08 degrees. The received spread spectrum "unbalanced" QPSK signal is heterodyned down to an IF stage, where a special demodulator is used to separate the I and Q channels. The I channel contains the 85 Mb/s scrambled TM data, and the Q channel contains the 15 Mb/s MSS data. These channels are then run through separate synchronizers to synchronize on the bit streams and reconstruct the data.

Illustration: Preliminary Demodulation of UQPSK Data



BENT
PIPE
MODE

The White Sands ground station will be "transparent" to data, i.e. it will relay or store and forward the received bit streams without any regard to content or format.

BIT
SLIP
CONTROL

A particular problem at this stage is "bit slip" in which the channel separation may get one bit out of phase, and start demodulating the Q channel as the I channel. This would mutilate both data channels, and make subsequent descrambling impossible. To determine that the I and Q channels are correctly "locked", the signal power in both channels is sensed. Because the I channel is 4:1 stronger than the Q channel in the UQPSK waveform, a bit slip error can be quickly detected and corrected from this power measurement. (These are the I/Q lock indicators in diagram above). This is a fairly sophisticated demodulator, since signal carrier (which is removed aboard LANDSAT-D) is never regenerated. The X-Band reception of the portable ground station will use the same demodulation scheme.

DATA
RECORDING
85 Mb/s

The 85 Mb/s scrambled TM data are recorded at White Sands on a 42 track (Bell & Howell) tape recorder. The psuedo random key will not be stripped off at this point, and hence the data will not be demultiplexed for a "quick look". The MSS data are recorded at 15 Mb/s on the same type of recorder, but at a lower tape speed. The 85 Mb/s recorder is capable of recording 2 million bits per second per track at full speed. Ordinarily at LANDSAT-C ground stations the MSS data are recorded on a 28 track HDDT recorder which can store 600 000 bits/sec per track (10 000 bpi) at full speed.

OFFLINE
DEMUX

Although the descrambling, decoding and demultiplexing of the TM and MSS data will not be done in real time at White Sands, the quadriphase receiving system is capable of performing these operations on line. (see block diagram for the quadriphase receiving system). Presumably the portable ground station will be equipped to do that demultiplexing when it is located somewhere else than Goddard.

DOMSAT
RELAY

After the reels of tape have recorded approximately 8 hours of downlink data from TDRS (which may take a while because the LANDSAT-D is only expected to transmit on Ku Band for about 15 minutes per 99 minute orbit), the tapes will be played back and the recorded data will be retransmitted over a US DOMSAT to Goddard where they will be rerecorded.

Illustration: Data Relay from White Sands to Goddard

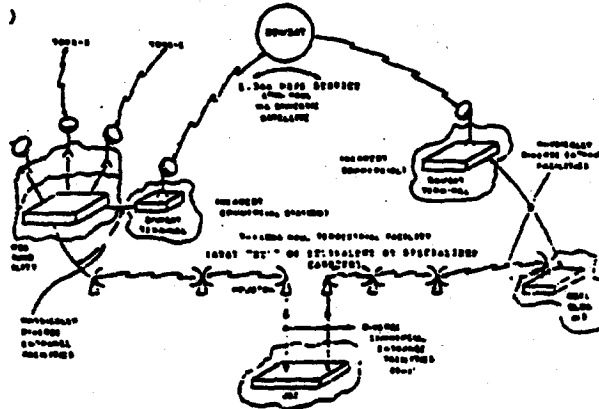


Figure 4. Preliminary Baseline NASCOM/TDRSS Diverse Facility Concept

PACKET
ERROR
CODING

Because US DOMSAT transponders can only pass 36 MHz the data relay via DOMSAT is limited to about 50 Mb/s. The 85 Mb/s data tapes are played back at lower speed, and the data are coded before transmission to combat errors. Packet transmission will be used with BCH (Bose-Chaudhuri-Hocquenghem) block coding to reduce undetected error rates

below 10^{-11} .

Currently NASA is considering a DOMSAT arrangement which would permit the full 85 Mb/s data stream to be relayed from White Sands to Goddard at full speed, and this would make real time display and interactive use of LANDSAT-D possible. (The matter is reportedly under contract study).

REAL
TIME
RELAY

There are proposals to do real time data relay and distribution from White Sands to multiple users via a DOMSAT. This broadcast distribution would be applicable to various TDRS SA and MA data streams besides LANDSAT.

Illustration: DOMSAT Distribution of TDRS Data

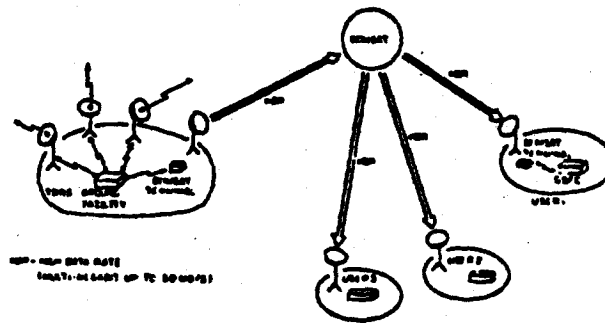


Figure 6. Broadcast Distribution of Multimegabit Data to Users Through DOMSAT

MA
SERVICES

In addition to the KSA and SSA services which the White Sands ground station provides, it can also receive and distribute up to 20 MA (multi access) users. The multiplexed data from the phased array S Band antenna on the TDRS are processed by 30 S Band receivers, and combined in a network processor to extract and demodulate the various MA signals, each separately chip coded at independent data ra:

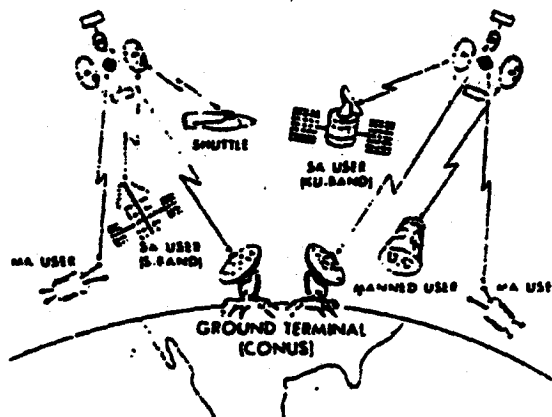


Figure 5. TDRS Concept

This MA service is applicable to LANDSAT-D, because the forward link is used to command the LANDSAT, and the MA return link carries information about the spacecraft location and status which is necessary to schedule and command its operations.

Illustration: MA Ground Terminal Processor

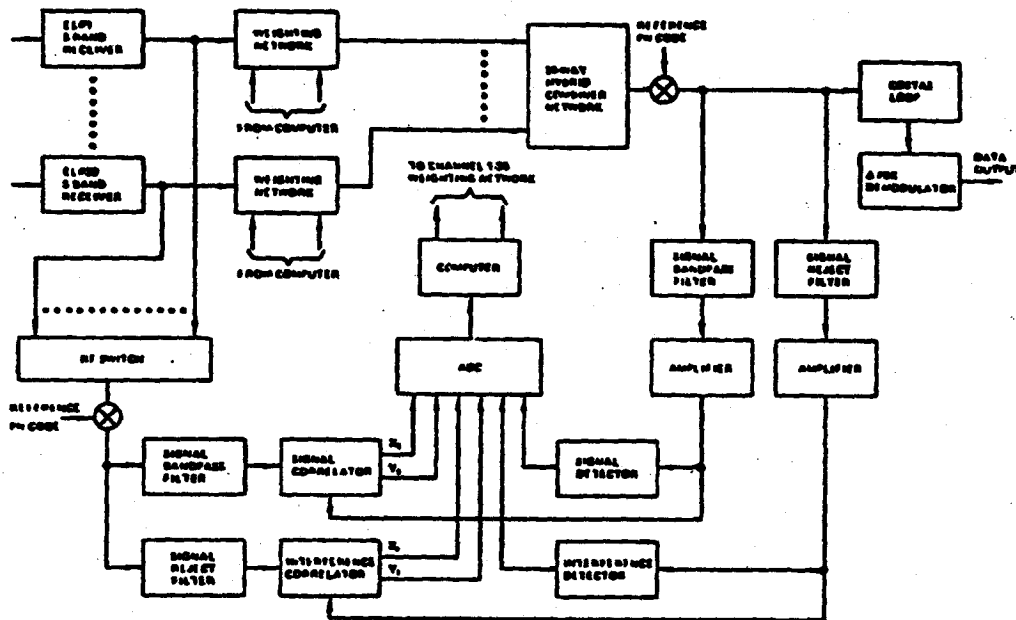


Figure 12. Dedicated Adaptive Array Ground Terminal Equipment in Support of a MA User

FUTURE
WHITE
SANDS
ROLE
?

The role of the White Sands ground station in the LANDSAT-D operations will depend to a large extent on whether the data are downlinked on X Band to various national ground stations, without simultaneous uplink on Ku Band to TDRS. The original concept was to use TDRS for all data return, but the dozen LANDSAT users apparently want the data transmitted directly to them, to assure fidelity --- and possibly to get exclusive access. The user preference may reduce the role of White Sands for data return. However, the White Sands station will still be the conduit for the command, tracking and forward link communications for LANDSAT-D.

5, Goddard Processing Center

At the Goddard processing center the MSS and TM data are run through "pipelines" of processes and computers to demultiplex and decode the data, and to make various geometric and radiometric corrections to the "pictures". After these corrections, about half the scenes will be discarded because of cloud cover, bad data transmission, or other random causes. Processing is a major bottleneck, and Goddard will be equipped to accept and process about 100 scenes of 100 x 100 mile "pictures" (on seven different spectral windows) in a day. The coverage is potentially global, but most of the processing at Goddard will probably be of US territorial images. By contrast, the Canadian and Italian LANDSAT-C stations, which are well equipped facilities, ordinarily process about 10 MSS scenes per day.

LANDSAT-C has a capability to collect and telemeter 'ground truth' data from various 'platforms' at the earth's surface, and these ground truth data are used in MSS processing to provide correction parameters. The atmosphere varies and changes the way the sunlight is transmitted and reradiated from one satellite pass to another, and the ground truth data allow these effects and scene distortions caused by satellite movement, etc. to be compensated. Ground truth data are also crucial to interpreting what the imagery data actually mean, e.g. in agriculture or geology, etc. and without such ground truth data all imagery interpretation is relative.

The volumes of data are very large. A TM scene takes about 26 seconds to transmit at 85 Mb/s, yielding over 2 million bits. The 100 TM scenes/day which NASA expects to process represent only a fraction of what the satellite could produce. The LANDSAT-D spacecraft is designed to produce up to 15 minutes of X Band and 15 minutes of Ku Band transmission in a 99 minute orbit. Ordinarily only one of the TM data transmitters will be on at a time. It is possible to double this transmission to 30 + 30 minutes on a single orbit, after which the LANDSAT-D must rest for a while to recharge its batteries and cool off. At 15 + 15 minutes, this would give about 70 TM or TM/MSS scenes per orbit, and in a day would produce $14.4 \times 70 = 1008$ scenes. If two satellites are put into operation, they could double this and yield about 2000×2 billion = 4 trillion bits of data per day --- although there is no way to process this at present.

The radiometric and geometric processing of the scenes require two successive passes of the data through a computing complex, but they are preceded by operations which decode the data, including correcting bit slips that resulted at White Sands. The offline decoding at Goddard will subtract the psuedo random scrambler key, reformat and demultiplex the data, and extract radiometric calibration parameters. The GPS timing and navigation data received on the LANDSAT, and interleaved into the data format before transmission, are extracted and associated with the pixel sequences, because the precise data about satellite altitude, location, pointing, pitch, roll and yaw and sensor status are needed to perform the radiometric and geometric corrections.

After these corrections, various "image enhancement" processes are run on the "pictures" or on parts of them, to "classify" or "extract" certain kinds of earth resource information which are implicit in the "pictures". Typically the processing uses vectors of pixels from different spectral regions because spectral contrast is a key element in identifying or classifying specific resources. Image processing has become a career field and the computing techniques for doing it are considered high technology --- most of which, like the hardware, stemmed from classified military projects. Over 25 books have been published in the field, specialized journals have appeared, and the literature is extensive.

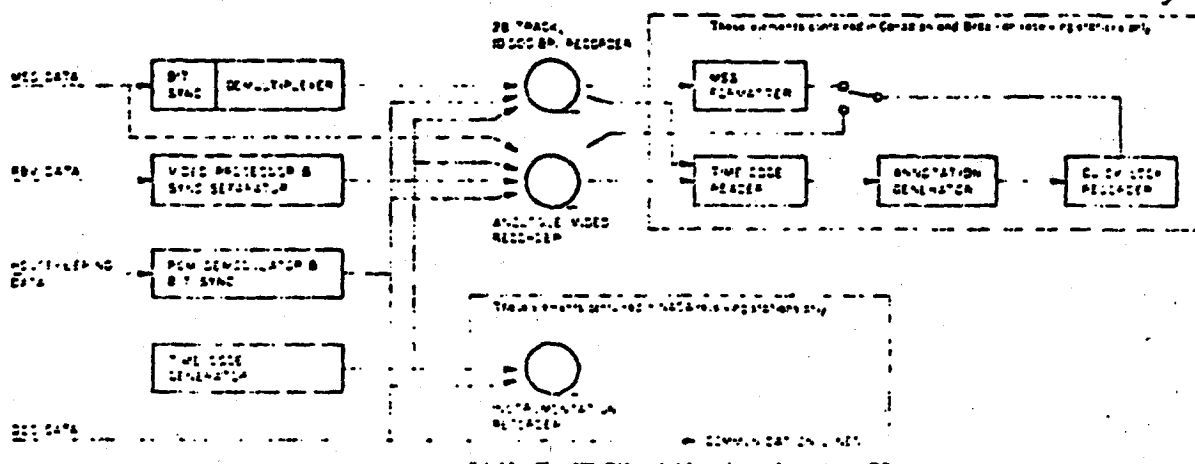
A TM scene or picture represents an area of about 100 x 100 miles coded in an array of about 6000 x 6000 eight-bit pixels. (A line is 6320 pixels). The TM will produce 6 or 7 such arrays, for the different spectral windows, to constitute the "scene". The processing usually combines the data from 2 or more spectral images to obtain the quantitative contrasts which enable classification, segmentation, pattern recognition, and quantitative assessment of the many different kinds of information obtained from a scene.

To do this "image enhancement" and "scene correction" processing, computers and special processors are used. For LANDSAT-C some special processors were developed, e.g. DIGICOL and the ISI System, both complex analog machines, and hybrid analog/digital machines such as the BENDIX M-DAS, GE IMAGE 100 and ESL IDIMS. These processors, supported by second generation computers such as IBM 360/50, 65, 75, have given a 100 fold improvement in processing over manual methods.

For LANDSAT-D TM data, NASA has developed a processing complex which uses VAX 11780 computers and special GE FFP (Federated Functional Processors). The VAX computer and the GE FFP each has a processing capability approximately equal to a CDC 6600.

Processing of raw LANDSAT-C data usually took many weeks before results were obtained, but techniques of generating "quick look" color photographs were developed so that good scenes could be screened for priority processing. Final results were recorded in standardized photographs and computer tapes.

Illustration: MSS Quick Look System



F-21 Elements of data processing subsystem located at receiving stations

For LANDSAT-D the processing systems will be capable of real time display of images on video screens. The results of the processing will be represented on standardized CCT (Computer Compatible Tapes) and on 241 mm film, which will be distributed through the Sioux Falls center.

The use of "image enhancement" processing allows increased resolution of the images, recognition and location of specific features and structures, and recognition and measurement of various earth resources data and other surface effects. The Goddard Facility is designed to do image enhancement on about 100 scenes per day. Typical time to process a TM image on the Goddard VAX 11780/FFP complex is:

Table: Image Enhancement Processing Times

(1) geometric correction using cubic convolution

2 seconds/ spectral band for 512x512 subscene

2 minutes for correction of a full 6000 x 6000 scene (for one spectral channel)

(2) Maximum Likelihood Classification for 6 Spectral Bands into 10 Classes

27 seconds for a 512 x 512 subscene

64 minutes for the full TM scene on all 6 spectral channels.

The necessary but routine work of geometric correction of a six band scene can be done in about 12 minutes, and 100 scenes per day would take about 20 hours on the 11780/FFP complex. Goddard will undoubtedly have more than one such 11780/FFP complex. However, they will not have nearly the capacity to process the 100 scenes per day the LANDSAT-D could give them. NASA will do some image enhancement, but many of the prime customers are universities and laboratories in the US and abroad who have their own processing systems. Most of the image enhancement processes are proprietary, and the highly developed software is also proprietary. The products produced by the proprietary image enhancement are sold as property by the commercial and university producers. No surprisingly, a number of foreign countries have undertaken the development of their own receiving and processing capabilities for LANDSAT-C and may do the same for LANDSAT-D.

Some authorities believe the earth resources systems can provide benefits worth billions of dollars annually to agriculture, geology, and other fields. An example of the economic and political impact of LANDSAT is the discovery by South African researchers of the largest uranium ore despoits in the Free World in Namibia, from computer processing of LANDSAT data. This, plus the enormous wealth of other minerals in the vast geologic system known as "high africa", led to a political decision by South Africa to maintain a presence in Namibia. Mining companies are now beginning to construct facilities to exploit these LANDSAT discoveries, against a background of high international interest.

6 The Portable Ground Station

For several reasons, NASA has designed a portable ground station which can obtain data directly from LANDSAT-D. In the initial operation of LANDSAT-1 (ERTS), scenes from any area could be stored on the spacecraft recorder, and "dumped" to a US ground station for processing. However, this caused quite a lot of delay and there were fears that the on-board recorders would fail. A small number of foreign ground stations, capable of receiving data from the LANDSATs and processing the data, were established in Canada, Brazil, Italy, and West Germany. These stations generally adopted the designs and some of the hardware and software of the NASA ground stations which had preceded them.

Currently there are US LANDSAT-C ground stations at Goldstone CA; Goddard MD, and Fairbanks Alaska. The Alaska station will be modified to receive LANDSAT-D data.

Since the success of the LANDSAT program, a number of foreign countries have expressed interest in upgrading their existing LANDSAT-C stations to receive and process LANDSAT-D data, while other may want to obtain ground stations that will work directly with LANDSAT-D. From a purely technical and economic standpoint this is unnecessary since the TDRS link would allow the White Sands station to receive as much as 1000 to 2000 scenes per day, and these could be corrected and formatted and distributed through Sioux Falls with resulting economies of scale and utilization.

The geometric correction on 100 full TM scenes would only take about 3-4 hours on a 11780/FFP complex. NASA estimates that foreign users needs may aggregate to as many as 150 foreign scenes/day, but the preliminary recording and processing could be done in the US. The intensive work of image enhancement, even in the US, is done in many different centers from the corrected data and thousands of technical and scientific personnel in universities and laboratories are employed full time in analyzing the information extracted from the LANDSAT-C system. However, foreign countries like to have their own receiving and processing capabilities, not only to avoid delays in getting the corrected data, but because they like to keep up with the technology --- in spite of the expense.

The NASA portable earth station will be initially located at Goddard, to allow system testing of the S and X band downlinks, and it will transmit data directly to the Goddard processing center over a short dedicated radio relay link. Subsequently, NASA may relocate it to Lincoln, Nebraska.

where it will be able to receive LANDSAT-D earth resources data at a single point for the entire US (south of Canada). The main LANDSAT data center at Sioux Falls is north of Lincoln, and it too can receive data from LANDSAT-D for the entire US from the S and X Band downlinks. When the portable ground station is located at Lincoln, it will be provided with recording and processing equipment to enable it to collect the TM and MSS data. NASA intends to build only one portable ground station for its own domestic use, but the engineering data and supporting equipment for the ground station will almost surely provide the model from which other ground stations will be derived --- as happened with LANDSAT-1.

The LANDSAT-D portable ground station will use a single 10 meter dish with feeds for both S Band and X band downlink signals, and it will have tracking systems that operate at S band and at X Band. The LANDSAT-D S Band downlink at 2265.5 MHz is compatible with the LANDSAT-C ground stations which already operate in the US and abroad. LANDSAT-D will have only 4 spectral bands in its MSS, compared with 5 in LANDSAT-C, but despite this the MSS data will still be useable to the MSS processes. The LANDSAT-D X Band downlink at 8.125 GHz will carry both the 84.903 Mb/s TM data and the same 15.06 Mb/s MSS data which can be sent on the S band at 2265.5 MHz. The ground station will also receive the S Band telemetry sent at 2287.5 MHz on a PSK subcarrier at 1.024 MHz.

The 10 meter transportable antenna, built by Scientific Atlanta, is considered inferior to the fixed 10 meter antennas which NASA uses at Goddard. It is an AZ/EL antenna, rather than the much more expensive X-Y antennas used as fixed stations at Goddard. As a result it has a blank spot in its coverage when it tries to track a satellite passing directly overhead, while the X-Y antenna has no blank spots. NASA intends to mount the portable antenna at a 4 degree angle (like the Tower of Pisa) to enable the continuous tracking of LANDSAT-D when it directly overhead.

The system noise of the antenna is:

	5° pointing	90° pointing
S Band	125° K	100° K
X Band	200° K	170° K

The S and X band feeds are arranged in a radially symmetric array, and are located at the focal point of a Cassegranian reflector.

(note: 8 June 79. Insufficient time to finish typing description of ground station, and its tracking. will complete later..)

7 Foreign and Domestic Interest in LANDSAT-D

There are proposals in Congress and elsewhere to establish LANDSAT as an operational system, for it has remained in an experimental status for the last seven years. The first LANDSAT-D will be launched in late 1981 and the original plan was to have a backup copy in case of a launch failure. If the 1981 launch was successful the backup LANDSAT-D would have been launched in 1984-5 when the first copy was suffering from dwindling solar power cell output. However, the scheme for going operational would see two LANDSAT-D's in orbit in 1982, with a third copy as a backup. This would give a capability of taking more than 2000 pictures a day, which is much more than the 100 scenes/day that NASA Goddard can process. However, if the basic decoding and geometric and radiometric corrections are done in a pipeline of processors, a much larger number of scenes can be taken, and then most of the image enhancement and image processing would be done by users with specialized interests.

Several Government departments, including Agriculture and Interior, are interested in taking over LANDSAT. There have been several bills in Congress to build a third LANDSAT-I but they got nowhere. Congress is also considering giving LANDSAT to some department, and if that happens then the policy making power which now resides in NASA will presumably pass to the Department which get the operational role.

Private industry has also put out proposals to take over LANDSAT as a commercial venture, now that NASA has developed it. The Senate Subcommittee on Science, Technology and Space recently held two days of hearings on legislation to establish an operational remote sensing satellite system. Most industry witnesses recommended that the acquisition and dissemination of earth resources information be handled by private companies rather than by government agencies. COMSAT and LOCKHEED indicated that they were ready to take on this information brokerage at once. Two bills were considered, viz: S. 663, the Earth Data and Information Service Act of 1979 and S. 875 the Earth Resources Information Satellite Act of 1979. Representatives from Federal and State agencies, industry and quasi-government agencies testified on both bills. Senators Stevenson and Schmitt are trying to goad NASA and the Executive Branch into more aggressive action to exploit this economically significant technology.

Frank Press of OSTP testified that the Administration had interagency task forces trying to define the institutional, financial, technical and marketing activities of an operational remote sensing service. S. 663 defines a 7 year interim period to do this. Press felt the bill had been anticipated by Executive Branch activities. COMSAT wanted the role as the operator of the satellite system, and the producer of basic

data products, e.g. the preprocessed but unanalyzed scenes. Specialized users would buy these and do the value-added processing to classify and extract information and value-added data. The lure of profits from a remote sensing monopoly has awakened business appetites --- but the monopoly itself may soon disappear in the face of foreign competition.

NASA, during this time, has been active in negotiations with various foreign countries. There are 11 foreign nations which have established LANDSAT ground stations, and a total of 110 countries have purchased LANDSAT data (from LANDSAT-C and its predecessors). There are no definite commitments but a number of countries have expressed interest in retrofitting existing LANDSAT-C stations to receive LANDSAT-D data, or in acquiring LANDSAT-D stations. NASA has had a team in Japan in early May 1979 discussing a "D-upgrade" of the Japanese LANDSAT-C station. The Japanese apparently want to use Mitsubishi to modify their ground station, rather than arranging for the purchase of a US station through NASA, but they may want some technical help from NASA.

Brazil is considering either upgrading its LANDSAT-C station at Cuiaba, or getting a complete LANDSAT-D station, but because of the shorter slant range from LANDSAT-D they may need more than one ground station. Argentina, which has no LANDSAT station, has expressed interest in getting a LANDSAT-D station, complete with 85 Mb/s recorder, VAX 11780 computer, GE FFP processor, and other equipment --- but the status of the station and the whereabouts of the equipment are unknown. Italy has a big LANDSAT-C station and currently does a lot of processing and data collection for European and neighboring countries. It is probable that Italy will want to upgrade its station to LANDSAT-D operations, with tape recorders, processors, etc. West Germany also has a LANDSAT station and will probably upgrade it.

NASA has developed a number of interesting techniques for retrofitting antennas and receiving stations originally built to work in one frequency band, so they can operate simultaneously in two bands --- principally by use of dichroic subreflectors --- which will probably be adopted by foreign countries. The foreign countries which have engineering resources prefer to operate their own ground stations so they can keep up with the technology --- by having it transferred to them --- and also control the acquisition of data over their own territories, and do their own processing without letting a foreign government (the USA) screen or alter the raw data.

THE
FRENCH
CONNECTION

The French Government has shown great interest in the LANDSAT-D technology. They do not want a LANDSAT-D ground station. But they do want to acquire all the technical know how necessary so that they can make their own SPOT earth resources satellite, now in development, interoperable on the radio system and the data processing system with LANDSAT-D, so that SPOT data can be received and processed at the foreign LANDSAT-D stations. Although the French usually show a willingness to go their own way and set their own standards, they encountered severe buyer resistance to the SPOT service they are setting up to compete with LANDSAT. The potential customers, most of whom already have LANDSAT-C stations, told the French that they did not want to pay the cost and confusion of having two different X-Band radio receiving systems and, more important, two completely different data processing systems which would frustrate cross comparisons between SPOT and LANDSAT-D data. As a result, the French are now trying to make SPOT interoperable with LANDSAT-D radio and data processing systems.

SPOT

SPOT has 10 meter resolution, which is three times finer than LANDSAT-D, and the French hope to compete with NASA by offering this higher grade data, relying on NASA to provide the technical data on the radio and data processing systems to make the SPOT interoperable.

The SPOT satellite will provide stereo imagery as well as high resolution. A proposed future US satellite called STEREOSAT is intended to give stereo imagery by using three multispectral cameras, one looking forward at 30 degrees, one looking backward at 30 degrees, and the third looking straight down, as LANDSAT-D does. The US Geological Survey has strongly recommended this. The STEREOSAT orbit would be the same as LANDSAT-D to provide the maximum comparability of the stereo data with LANDSAT-D data. The swath width would be one-third the LANDSAT-D swath and the resolution would be 15 meters .

Illustration: STEREOSAT



The three successive images could be taken at intervals of about 1 minute, so the illumination and cloud cover

of the "scene" will not have changed much. In late 1978 this STEREOSAT was only a concept, while the French SPOT is already under development. Hence in this project the French have actually moved ahead of the US in space technology. NASA is very wary of the political problems of collecting imagery data at resolutions higher than 30 meters, because of their policy of public access to all data collected, while the French have simply adopted a different policy for SPOT --- which apparently will offer greater data privacy.

The current struggle to control LANDSAT-D is likely to slow down the technologic development, which has already been affected by Shuttle costs. If private industry takes LANDSAT over they will freeze the technology as they did in COMSAT's when NASA was ordered out of the COMSAT area in the early 1970's. The foreign surveillance satellite developers will rush into this opportunity and the US will almost surely be pushed into a second rate status in remote sensing technology. The problems of catching up will then arise.

Since the French will want to operate the SPOT data processing on their own computers, this presumably means that they will want the software development technology transferred to them, as well as any necessary radio and recorder technology. European companies do not hesitate to buy up or set up US companies to get such technology without having to go through any export control process.

The French Embassy in Washington has been in correspondence with the NASA technical people about this, and NASA engineers have been in Paris earlier this year to discuss the technology transfer.

SPOT will be under the operational control of the French Government. It will presumably have a swath 25 miles wide, and generate 25 x 25 mile scenes, assuming its data rate and spectral decomposition is similar to LANDSAT-D TM. If the French export SPOT ground stations to countries which the US would not export LANDSAT-D stations to, the SPOT stations will be able to receive all LANDSAT-D data which is within their radio range (when LANDSAT-D downlinks on X or S Band). In order to make SPOT interoperable with LANDSAT-D, the French will have to acquire the technology for 85 Mb/s data encoding by a pseudorandom scrambler, and the SPOT ground stations will also have to have the 85 Mb/s descrambling capability. The pseudo random generator used in LANDSAT-D is a 15 stage device but the LANDSAT-D manufacturer (TRW apparently) has provided no other information about the generator. The French will have to incorporate an identical scrambler in SPOT or they cannot interoperate with LANDSAT-D ground stations. However they can also incorporate a second

psuedo random generator of their own design for the exclusive use of the SPOT ground stations. This could then provide data privacy from any unauthorized recipient unless the French choos to reveal all the functional details of the SPOT scrambler, including its state and how to acquire it on each transmission. If they hold anything back, SPOT data will be encrypted.

CRYPTOLOGY

The issue of satellite reconnaissance of economic or military data of a country is a very topical political issue. SPOT at 10 meters resolution will be in the center of that, and cryptology --- viz: the encoding, privacy and public access by interception, to SPOT data ---- will be the key policy/technical factor in future earth resource operation and experiments, and in the trans-border data flow that results from these operations.

USSR FRENCH JOINT PROJECT

Even though SPOT will be a French project, and the French may decree that it is not subject to COCOM, the French have an existing international agreement with the USSR to jointly develop an earth resources satellite which will presumably be launched by the USSR. It seems likely that the French will have a material interest in making the joint satellite compatible with SPOT to some extent, and this would almost inevitably lead to certain technology transfers to the USSR, after the French re-engineer what they get from NASA. Hence, 85 Mb/s scrambling and 85 Mb/s spread spectrum transmission are likely candidates for this two step export to the USSR.

The competition between the US and France to sell LANDSAT-D compatible ground stations is almost certain to intensify the export problems. Because the French do not have a TDRS system, they must either record at 85 Mb/s on the SPOT spacecraft, or else downlink data directly to foreign ground stations. If LANDSAT-D and SPOT ground stations can interoperate with either satellite, then US LANDSAT-D ground station manufacturers will try to sell ground stations to all the countries who might want SPOT or LANDSAT data. If SPOT provides data privacy that LANDSAT-D does not, the French may find this a selling point. This could lead to a rapid proliferation of high technology satellite receiving and processing stations which are apt to have both cryptology and military implications. Ironically, NASA is apparently helping further this technologic competition by helping the French on the technology level without visibly having analyzed all the consequences.

LANDSAT
AGING

One of the ironies of the foreign acquisition or retrofitting of LANDSAT-D ground stations is that by the time they are operational, the first LANDSAT-D will be aging and losing power, and hence be unable to provide as much service at the very time when the foreign demand for data will be mounting. The French, or the French and Russians jointly, could find a well prepared and equipped market for satellite services they could schedule at that time, and effectively push NASA out of its own market ---- while offering special benefits such as data privacy which NASA is committed never to do.

UNDER
SELLING
LANDSAT

If LANDSAT is converted to a commercial operation run by corporations, the foreign satellites can easily undersell them because in the first place they have not had to bear the cost of the development, and in the second place the foreign government can find ways to establish price levels and other financial arrangements which will give them a market advantage.

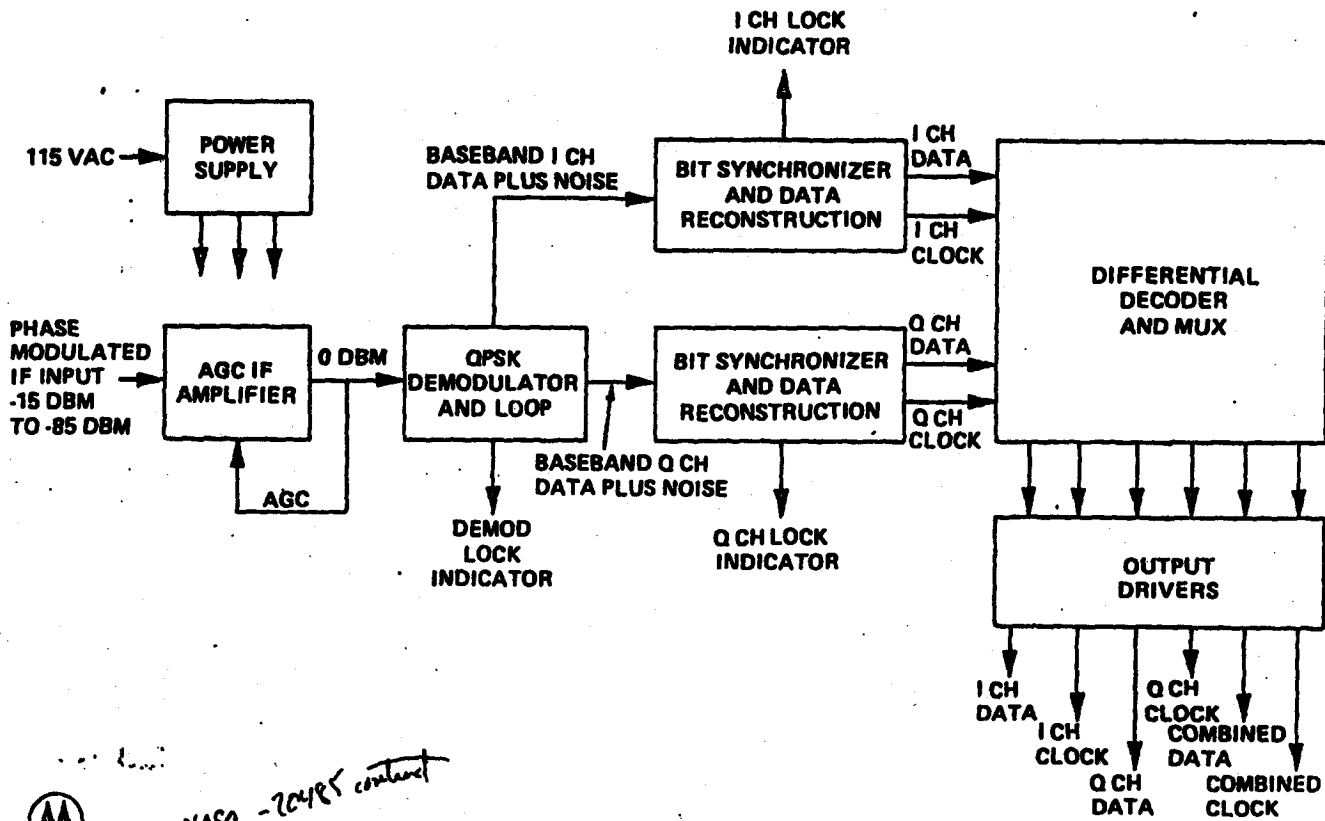
The obvious consequences of this are that the US will have considerable difficulty maintaining a primary position in this area of space technology --- just as Canada and other countries have moved ahead of the US in COMSATS --- and once the lead is lost, the investment will be further cut back according to standard business practices that demand return on investment and short term profitability.

COMPETING
LANDSAT
COMPANIES

Another possibility that can result from making LANDSAT into a commercial venture is an "open skies" policy, as has happened in DOMSATS, where anyone can put up a satellite and the commercial companies compete. This same principle applied to remote sensing would produce the same kind of overcapacity that the DOMSAT decision has produced. Without a monopoly to keep the prices up, a great deal of competition in satellite data products will result, and competitors will offer special features such as higher resolution, encryption, realtime interaction, camera pointing, and other features --- shifted over from the classified satellite programs and put on the open market. If those satellites are operated by US companies for foreign customers, some interesting problems in export of information and services will arise.

FUNCTIONAL BLOCK DIAGRAM FOR THE QUADRIPHASE RECEIVING SYSTEM

MANUAL CONTROLS



1974
NASA - 20485 contract

QPSK DEMODULATOR AND LOOP

