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Landsat D Telecommunications Payload: Earth Imaging Data via TDRS

H. B. Poza*
TRW Defense and Space Systems Group, Redondo Beach, Calif.

This paper describes the telecommunications payload for the Landsat D spacecraft. The salient design features of the electronic equipment, as well as the performance requirements that such equipment must satisfy to fulfill communication functions, are presented. Operational characteristics associated with the process of relaying Earth-imaging information to the White Sands Ground Station via the Tracking and Data Relay Satellite (TDRS) are also highlighted.

Introduction

THE Landsat D spacecraft is designed to collect Earth-imaging data and transmit it to domestic and foreign users for processing and evaluation. It will allow assessment of the capability of the Thematic Mapper (TM) to provide improved information for Earth Resources Management and provide a transition for both domestic and foreign users from the Multi-Spectral Scanner (MSS) data to the high resolution and data rate of the TM.

A single Landsat can survey nearly the entire area of our planet every 18 days. The view from one Landsat (through MSS or TM) can cover an area requiring more than one hundred aerial photos and can reveal vast features that may be obscured in mosaics made from aerial photographs. Correspondingly, a complete photomosaic of the United States can be assembled using approximately 570 Landsat images, while nearly 30,000 aerial photos would be needed to cover the same area. Landsat photographic images are taken in the red and green bands of visible light and in near-infrared bands. These images are converted to radio signals that are transmitted to Earth, where computers reconstruct them to produce black and white or colored pictures and bring out features of the observed terrain or vegetation. In this fashion, healthy vegetation may stand out in bright red while diseased or insect-infected plants may appear gray.[1]

The telecommunications payload (Ku-, X-, and S-band equipment) provides the Landsat D spacecraft with the capability of transmitting TM and MSS instrument data to both TDRS and selected ground-based recipients. The image data collected are returned to the ground processing system via two paths. The first, and primary path, is via a Ku-band (15.003 GHz) link through the Tracking and Data Relay Satellite System (TDRSS). TM data are transmitted at 85 Mbps, with MSS data at 15 Mbps, and both are recorded on high-density tape at the TDRSS receiving site at White Sands, New Mexico. The data are then relayed via a domestic communications satellite (DOMSAT). To effectively use the DOMSAT bandwidth, the TM data rate is reduced by one-half to 42.5 Mbps, and the MSS rate is doubled to 30 Mbps. At these rates, the data are recorded in the Landsat D Data Management System (DMS) located at the Goddard Space Flight Center (GSFC). A DOMSAT is also used to transmit processed MSS data from GSFC to the United States Department of the Interior's Earth Resources Observation System (EROS) data center at Sioux Falls, South Dakota. Figure 1 illustrates the Landsat D system and its major interfaces.

The second data path from the Landsat D satellite is a direct link, at the X band (8.212 GHz) for TM and MSS data and at the S band (2.187 GHz) for MSS data, to GSFC. The data are recorded in the DMS at real-time rates: 85 Mbps for TM and 15 Mbps for MSS. The X- and S-band links are also used for direct read-out of image data to foreign ground stations.

The Data Management System satisfies the functions of data quality check, estimation of cloud cover, application of radiometric corrections, and generation of geometric correction coefficients. Selected images have the geometric corrections applied and are converted into products for users. All data are sent to Sioux Falls for further distribution to the general public.

Telecommunications Subsystem Description

The Landsat D communications subsystem consists of the components necessary to accept digital data signals from the MSS and TM sensors, modulate the selected data outputs onto the appropriate RF carriers, amplify the RF signals, and transmit each RF signal from its dedicated antenna to designated receiving terminals. It further provides the spacecraft with the capability of acquiring and tracking TDRSS forward-link emissions at the Ku band.

The telecommunications payload is comprised of a wideband module, an RF compartment, and a gimbal-drive assembly (see Fig. 2). The wideband module attaches to the instrument module and provides mounting for the S-band-

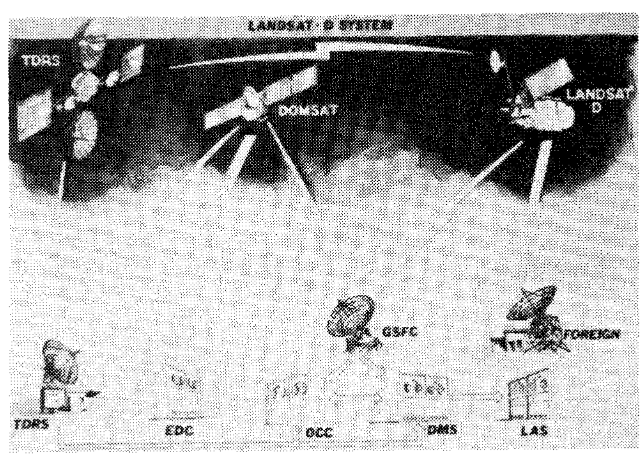

Fig. 1 Landsat D-TDRS information system.

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*Assistant Manager for Projects, Electronic Development Operations.

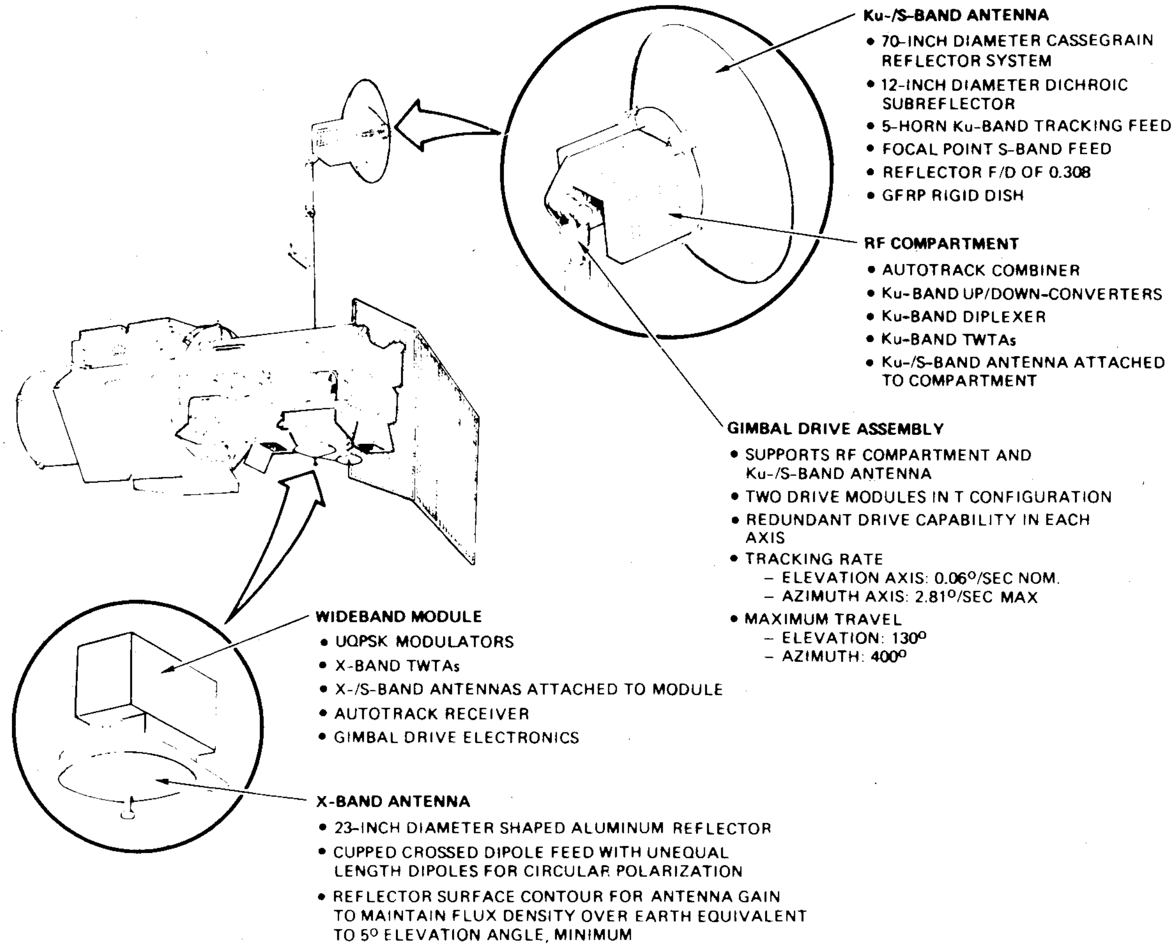

Fig. 2 Landsat D flight segment configuration.

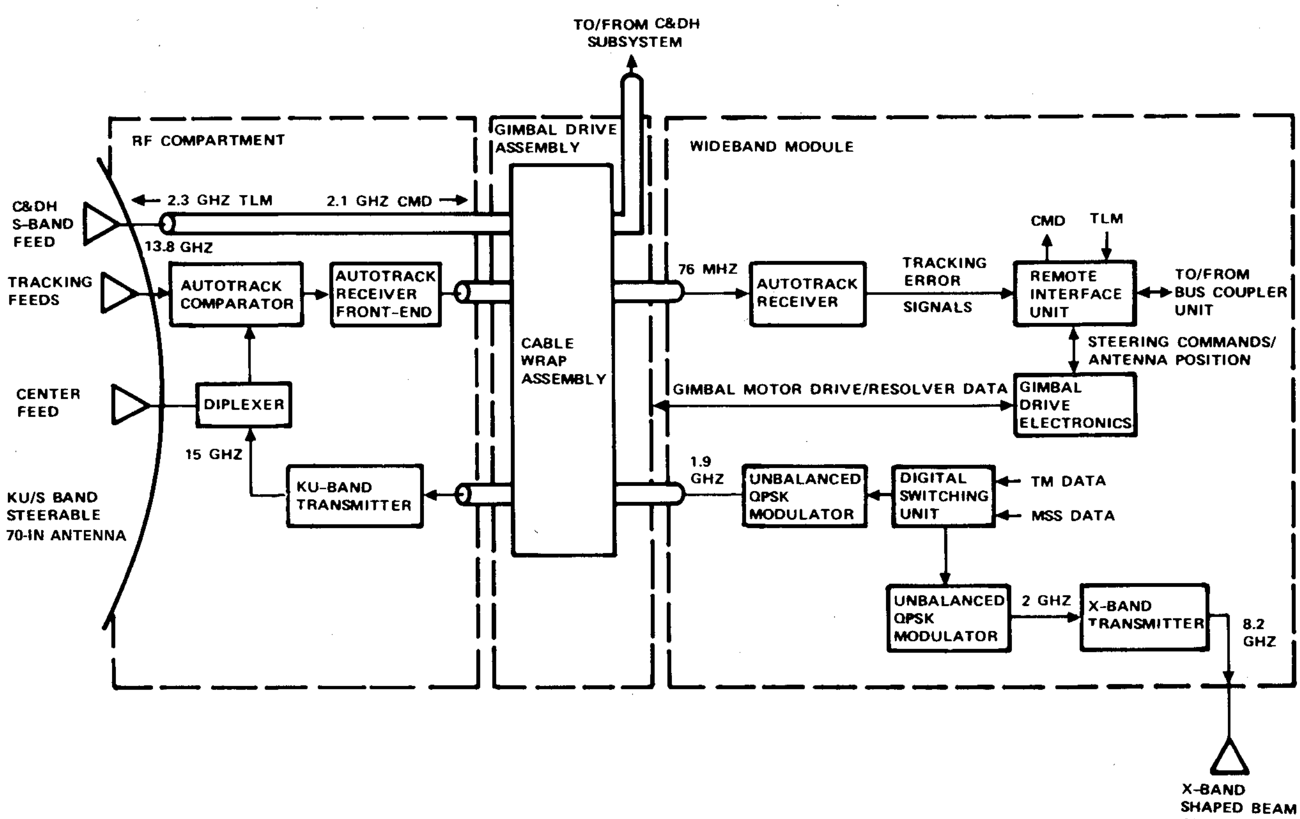

Fig. 3 Landsat D telecommunications subsystem.

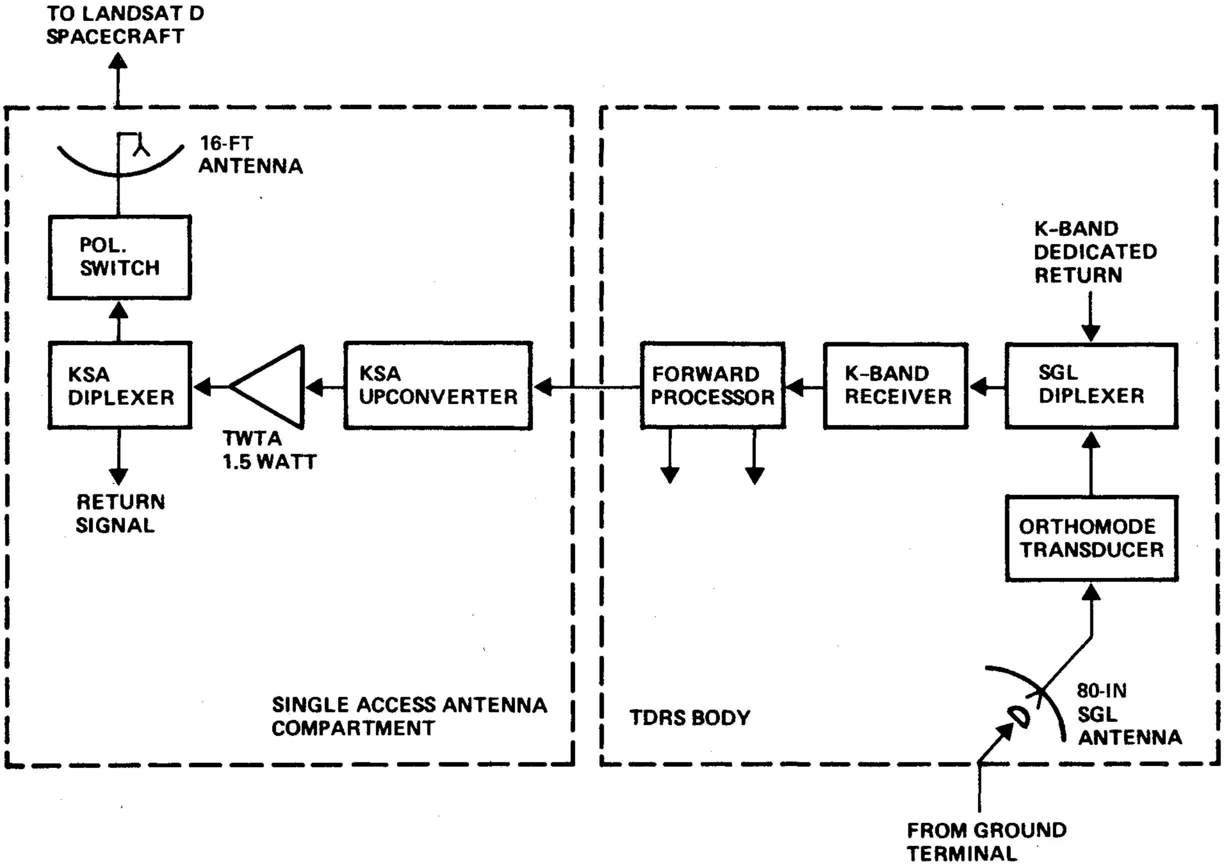

Fig. 4 Forward-link signal flow-through TDRS.

shaped beam antennas and the X-band antenna. This module contains the X-band transmission link equipment, signal and power control electronics, gimbal-drive electronics, the modulator portion of the Ku-band transmission link equipment, and the autotrack receiver.

The RF compartment contains the Ku-/S-band antenna, the switching, diplexing, upconversion, and power amplification components (TWTAs), and the downconverter for the autotrack system. The RF compartment and Ku-/S-band antenna are attached to the spacecraft articulated boom by means of the gimbal-drive assembly, a two-axis rotary mechanism consisting of an elevation-over-azimuth mount. A simplified functional block diagram of the Landsat D telecommunications subsystem is shown in Fig. 3.

Unbalanced quadriphase shift keying (UQPSK) modulation is utilized for transmission of TM and MSS data at both Ku and X bands.† For the Ku-band transmission link via TDRS, the UQPSK signal is properly upconverted and amplified by a 22-W traveling wave-tube amplifier (TWTA) prior to being transmitted via the Ku-/S-band antenna. The Ku-/S-band antenna is composed of a 70-in. diameter Cassegrain reflector, a five-horn Ku-band tracking feed, a 12-in. dichroic subreflector (resonant at the Ku band, transparent at the S band), and a focal-point S-band feed. This Ku-/S-band steerable antenna also receives the forward-link signal from TDRS by way of its five-horn feed. The center horn is utilized for the primary transmit/receive function, while the four small monopulse horn feeds surrounding it provide the autotrack capability. The closed-loop monopulse tracking system accepts the autotrack signal and drives the gimbal motors to position the antenna in a direction that minimizes the angular error between the antenna boresight and the TDRS signal line-of-sight.

In addition to allowing transmission to and reception from TDRS at the Ku band, the Ku-/S-band antenna also contains an S-band feed which provides a high-gain antenna receive/transmit capability for S-band command reception and telemetry data transmission. Command/telemetry functions are performed onboard the spacecraft by the Communications and Data Handling (C&DH) module.

For the X-band direct-access downlink, modulated signals from the UQPSK modulators are upconverted and amplified by means of a 44-W TWTA prior to transmission to GSFC or desired foreign users. The TWTA drives a 23-in. shaped-beam X-band antenna which provides essentially constant EIRP over the illuminated surface of the Earth.

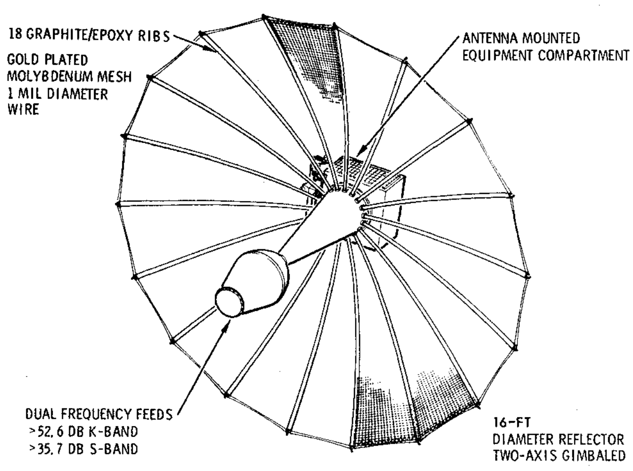

Fig. 5 TDRS single-access antenna.

†The unbalanced nature of this modulation scheme results from using the in-phase (I) channel for transmission of TM data (85 Mbps), while the quadrature (Q) channel accommodates the MSS data (15 Mbps). A 4:1 power ratio in favor of the I channel is maintained.

Table 1 Ku-band autotrack channel: key components

Items	Description	Important parameters	
Antenna	70-in. diameter Cassegrain reflector system	Peak gain	45.5 dBI
		Axial ratio	1.2 db
	12-in. diameter dichroic subreflector	3 dB beam width	0.72 deg
	Five-horn Ku-band tracking feed	Scale factor at boresight deg	0.78 V/V
	Reflector F/D of 0.308		
	Aluminum core/graphite-epoxy facesheet		
Autotrack combiner	Two ferrite phase shifters	Insertion loss	0.6 dB
	Two hybrid tees		
	Redundant control unit	AZ/EL isolation	>32 dB
	Combines azimuth and elevation signals	Phase variation	4 deg/°F
Down-converter	Downconverter 13.775 GHz to 76.5 MHz IF	Noise figure	9 dB
		Bandwidth	10 MHz
	Establish autotrack noise figure	Conversion gain	37 dB
	Provides preselection filtering and amplification	Gain stability	±0.4 dB
Receiver	Fixed frequency AM receiver with AGC	AGC loop	15 Hz
		IF BPF BW	4 MHz
	Provides noncoherent detection of error signals	Output BW	1 Hz
		Receiver scale factor	2 V/10% AM
	Demultiplex and demodulate AZ/EL signals	Long-term offset	±50 mV
	Provides lowpass filtering and amplification		
	Output signal, signal strength signal		

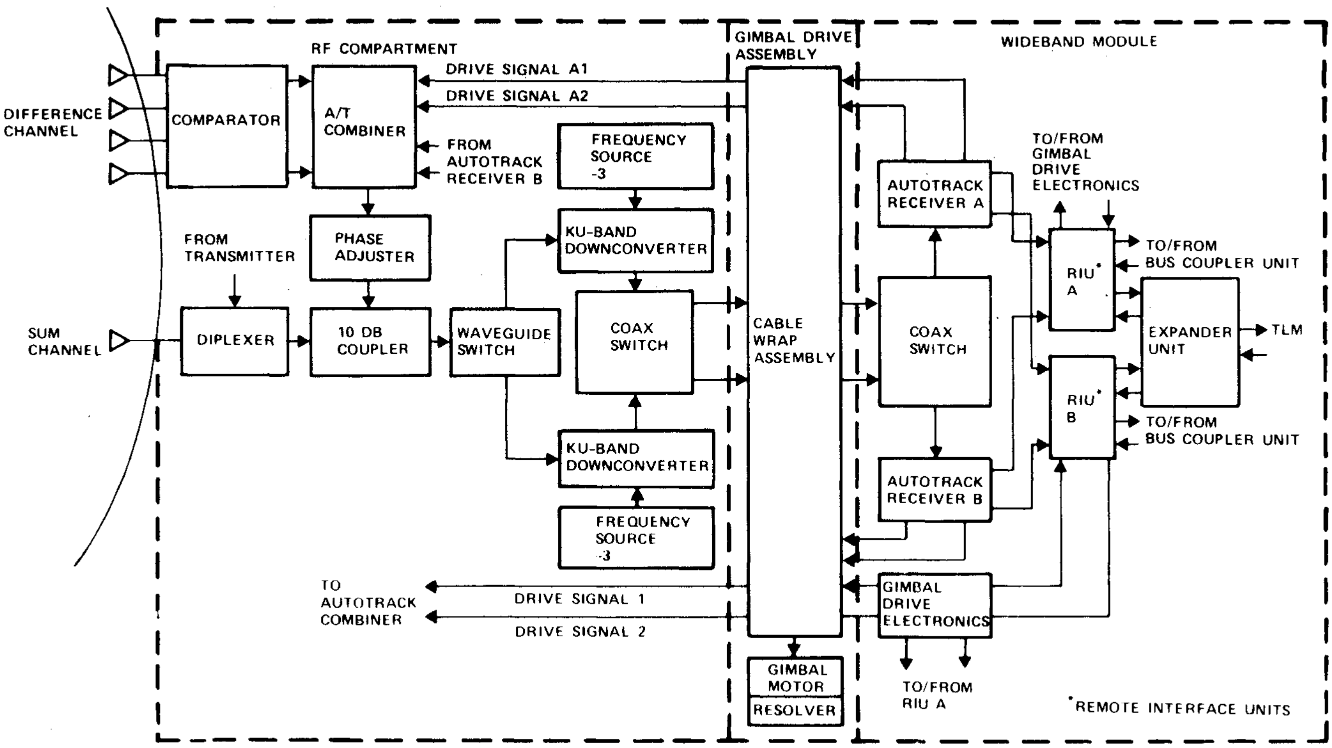

Fig. 6 Landsat D autotrack system block diagram.

The balance of this paper will concentrate primarily on the Ku-band links through TDRS utilized by Landsat D for transmission of its collected imaging data and reception of ground signals. These links constitute the Ku-band return and forward channels, respectively.

Ku-Band Forward Link

The TDRSS ground terminal at White Sands transmits a composite signal that contains, among others, the Landsat D K-band single access (KSA) signal. This composite signal is received at the TDRS by the 80-in. space/ground link (SGL)

Table 2 Ku-band return channel: key components

Items	Description	Important parameters	
Digital switch unit	Low-power Schottky TTL design High-speed switch utilizing MECL 10 K/MECL III Provide data mode selection, input/output Differential encoding/reclocking PN code for spectrum spreading	Bit transition time Bit phase jitter Data asymmetry PN code	2 ns 0.8% 3% $2^{15}-1$
Unbalanced QPSK modulator	Double-balanced mixer for I/Q channel biphase modulation Modulation at frequency 1875.4 MHz 6 dB power division between I and Q channel Provide linear amplification over 170 MHz BW	Output level Phase unbalance Amplitude unbalance Phase Linearity Gain flatness	11 dBM ±3 deg ±0.25 dB ±2.0 deg ±0.2 dB
Upconverter	Translates 1.8754 GHz to 15.0034 GHz Perform channel spectrum and noise bandwidth control with 5-pole output filter Perform amplification and multiplication of local oscillator for low-side injection	Data BW Conversion gain AM/PM Gain flatness Phase linearity Phase noise enhancement	170 MHz −8 dB 1 deg/dB ±0.2 dB ±1.5 deg 18 dB
TWTA	Integrated amplifier package with input isolator Dual collector design with multiple tapered helices Expected efficiency of better than 25% Utilizing mode voltage control for mode switching	Power output Frequency range Gain (SAT) AM/PM Gain flatness Phase linearity	22 W 14.9-15.1 GHz 54 dB 4.5 deg/dB ±0.2 dB ±2 deg
Antenna	70-in. diameter Cassegrain reflector system 12-in. diameter dichroic subreflector	Peak gain Polarization Axial ratio Power handling	46.9 dBI RHCP 1.2 dB 35 W

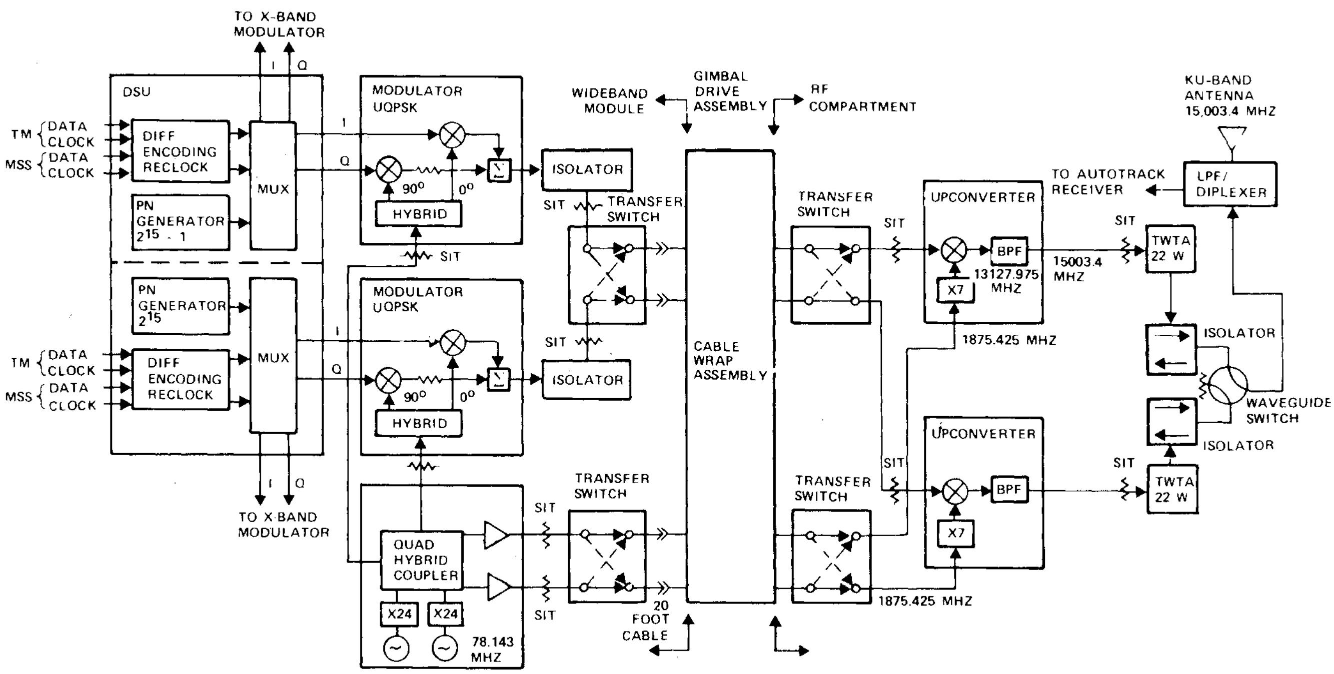

Fig. 7 Landsat D Ku-band return-channel block diagram.

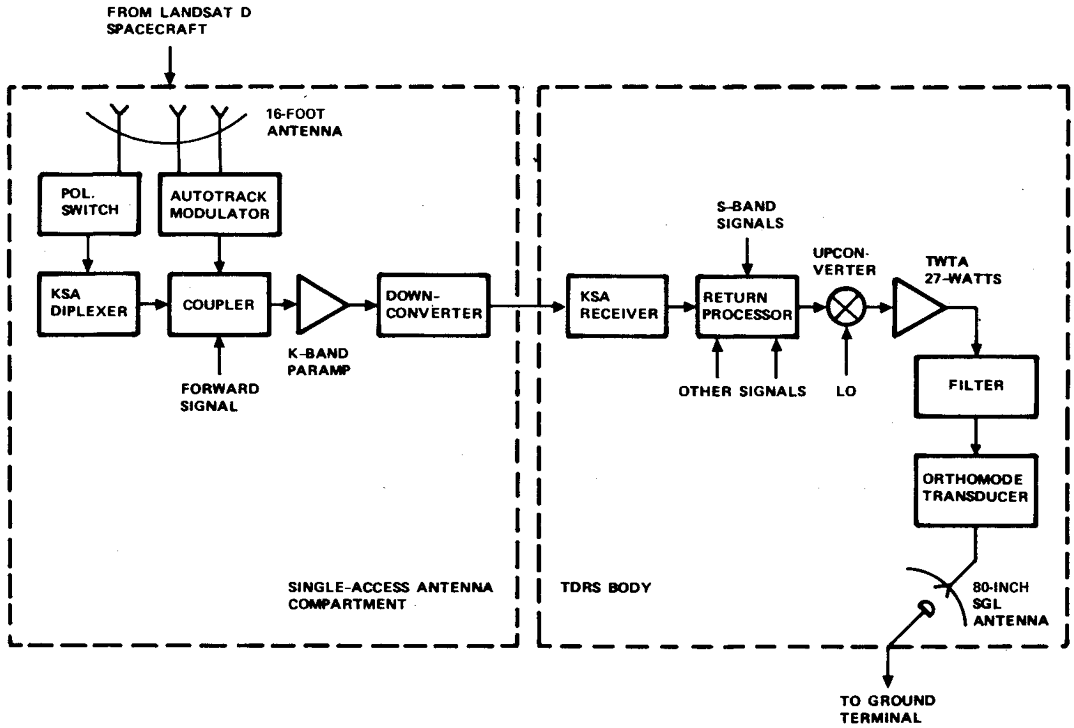

Fig. 8 Return-link signal flow-through TDRS.

antenna (Fig. 4). The TDRS K-band receiver (Fig. 4) translates the uplink signal to an intermediate frequency, amplifies it, and sends it to the forward-processor assembly. The forward-processor assembly filters and demultiplexes this composite signal into the separate signals that were multiplexed at the ground terminal. The Landsat D KSA signal is sent at an intermediate frequency (IF) from the forward processor to the single-access antenna compartment where a KSA upconverter converts it to the Ku band. A 1.5-W TWTA amplifies this signal for transmission to the Landsat D spacecraft via a 16-ft steerable antenna (see Fig. 5). Additional details on the TDRS forward-link communications payload are contained in Ref. 2.

The Ku-band forward-link signal (3 megachips/second PN spread spectrum) from the TDRS is received at the Landsat D spacecraft by the five-horn feed assembly of the 70-in. Ku-/S-band steerable antenna. Four small monopulse horn feeds, which surround the sum-channel feed horn, and the autotrack comparator synthesize the azimuth and elevation difference signals. These signals are proportional to the angular error between the antenna boresight and the received TDRS signal line-of-sight. They are biphase-modulated (A/T combiner) time-multiplexed, and added to the reference sum-channel received signal by means of a 10-dB coupler to generate the amplitude-modulated autotrack signal. As shown in the block diagram of Fig. 6, the sum-channel signal is fed to the downconverter via the diplexer/filter which provides received-band selection in addition to attenuation of the receiver-image band and Ku-band TWTA broadband noise.

The composite single-channel AM autotrack signal is downconverted and routed through the cable wrap assembly and down the boom to the autotrack receiver located in the wideband module. Coax switches provide cross-strap redundancy between the downconverters and the autotrack receivers. The signal is amplified by an automatic gain-controlled IF amplifier prior to square-law detection to remove the amplitude modulation representing the normalized azimuth and elevation error signals. Separation of the azimuth and elevation error signals is accomplished by a demultiplexer contained within the autotrack receiver. The demultiplexing waveform that separates both these signals is identical to, and synchronized with, the multiplexing

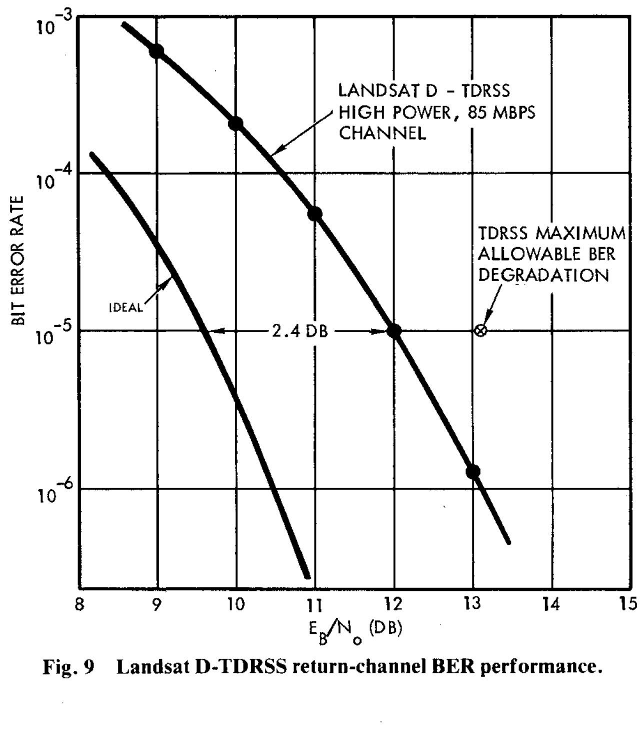

Fig. 9 Landsat D-TDRSS return-channel BER performance.

waveform. A low-frequency filtered dc signal derived from the AGC control circuit provides signal strength indication. The two pointing error signals, together with the signal strength signal, are digitized by the Remote Interface Units (RIUs) and provided to the onboard computer via the spacecraft multiplex data bus. The signal strength signal is processed by the onboard computer to activate the autotrack mode and is also telemetered to the TDRSS ground station via the C&DH subsystem to verify that the TDRS-to-Landsat link has been established. Table 1 depicts the main unit elements comprising the Landsat D autotrack channel and their key features.

The autotrack receiver, antenna, gimbal-drive assembly, and onboard computer form a closed-loop monopulse tracking system. The azimuth and elevation error signals are processed by the onboard computer to generate appropriate command signals that, in turn, are fed back through the RIUs to the gimbal-drive assembly. In response to these signals, the gimbal motors position the antenna in a direction that minimizes the angular error between the antenna boresight and the TDRS signal line-of-sight.

In addition to the autotrack mode of operation, the steerable high-gain antenna also operates in a program track mode. Position feedback to the onboard computer via the RIUs is provided by azimuth and elevation gimbal resolvers.

Ku-Band Return Link

The collected Earth-imaging data (TM and MSS) is first routed to the digital switching unit in the wideband module where it is reclocked by means of associated clock signals prior to mode selection. Independent mode selection is provided for both X-band and Ku-band operation, activating 1 of 15 data output combinations for the two links. Mode selection is implemented in a manner that precludes ground demodulator data dropouts and violations of power flux-density limitations. The outputs from the digital switching unit, consisting of differentially encoded TM and MSS data on separate inphase (I) and quadrature phase (Q) lines, are provided as inputs to unbalanced quadrature phase-shift keyed (UQPSK) modulators. The UQPSK modulators modulate the selected TM and MSS data onto S-band RF carrier references.

For the Ku-band transmission link via TDRS, the UQPSK-modulated S-band signal is routed up the boom on redundant coaxial cables and through the cable wrap assembly to redundant Ku-band upconverters in the RF compartment (Fig. 7). The upconverters, driven by frequency sources in the wideband module, translate the modulated S-band signal to the Ku band. The upconverter output is amplified by one of two redundant 22-W traveling-wave-tube amplifiers (TWTA) prior to being transmitted via the diplexer/filter and Ku-/S-band antenna.

The lowpass filter portion of the diplexer/filter attenuates the TWTA second harmonic to a level compatible with radio astronomy power flux density constraints. A transmit band-pass filter, also part of the diplexer/filter, attenuates TWTA regenerated signal components and tube broadband noise to a level that is not only compliant with power flux density requirements but is also below that required to degrade the autotrack system performance. The output from the diplexer/filter drives the 70-in. high-gain antenna. A description of the key Landsat D return link components is contained in Table 2.

The Landsat D K-band single access (KSA) return signal is received at the TDRS by the 16-ft antenna. This signal is isolated from the transmit signal by a diplexer, amplified by a parametric amplifier, downconverted to an intermediate frequency, and sent to the return processor assembly (Fig. 8). The return processor assembly accepts the incoming Landsat D KSA signal and performs either of the following functions: 1) multiplexes this signal with other incoming S-band signals—the TDRS telemetry and the downlink pilot tone—prior to upconversion or 2) routes this signal to a separate (dedicated) K-band upconverter. Signal transmission to the White Sands ground station is accomplished in either case by means of a 27-W TWTA and an 80-in. antenna. Additional details on the TDRS Ku-band return-link communications payload can be found in Ref. 2.

Performance Requirements and System Capabilities

The overall performance requirements for the Landsat D Ku-band telecommunications equipment return and forward links are contained in Tables 3 and 4, respectively. The expected flight performance for each of the link parameters, based on finalized breadboard/development model tests and detailed analyses performed as part of the Landsat D program, is also included. A more complete evaluation of payload performance and presentation of test results is contained in Ref. 3.

The expected bit error rate performance of the Landsat D-TDRSS return link is illustrated in Fig. 9, based on the parameters of Tables 3 and 4 and the detailed computer

Table 3 Landsat D Ku-band return channel critical parameter performance

Parameter	Requirement	Estimated capability
Transmit frequency	15003.4 ± 0.76 MHz	15003.4 ± 0.2 MHz
Polarization	RHCP	RHCP
Antenna gain	≥46.2 dBI	46.9 dBI
Axial ratio	≤1.5 dB	<1.2 dB
Link margin (BER 10^{-6})	≥4.7 dB	TM 5.2 dB MSS 6.9 dB
Gain flatness	≤ ±0.3 dB over 170 MHz	±0.18 dB over 170 MHz
Phase linearity	≤ ±3 deg over 170 MHz over 170 MHz	±3.1 deg 170 MHz
I/Q power ratio	6±0.4 dB	6±0.2 dB
I/Q relative phase	90±3 deg	90±3 deg
Data transition induced PM	≤6 deg rms	5.8 deg rms
Phase imbalance	≤ ±3 deg	±1.5 deg
Gain imbalance	≤ ±0.25 dB	±0.15 dB
Data asymmetry	≤ ±3%	±2.5%
Data transition time		
I channel	≤2.3 ns	2.0 ns
Q channel	≤3.3 ns	<2.0 ns
Phase noise		
1-10 Hz 1-10 Hz	≤15 deg rms	<14.8 deg rms
10-100 Hz	≤7.5 deg rms	<7.4 deg rms
0.1-1 kHz	≤2 deg rms	<2.0 deg rms
1 kHz-150 MHz	≤2 deg rms	<2.0 deg rms

Table 4 Autotrack link critical parameter performance

Parameter	Requirement	Estimated capability
Receive frequency	13.775 ± 0.7 MHz	13.775 ± 0.7 MHz
Polarization	RHCP	RHCP
Antenna gain	≥44.7 dBI	45.5 dBI
Axial ratio	≤1.5 dB	<1.2 dB
Dynamic range	−163 to −158 dBWI	−168 to −153 dBWI
Pull-in range	≥0.4 deg	0.45 deg
Pointing error (A/T mode)	≤0.1 deg	0.08 deg
A/T scale factor (minimum)	≥0.087 V/V/deg	0.11 V/V/deg
A/T scale factor variation	≤12.0 db	9.6 dB
Σ-channel to mechanical Z-axis alignment	0.08 deg (3σ time varying)	<0.08 deg
A/T null to Σ-channel electrical alignment	0.02 deg (3σ time varying)	<0.02 deg
Minimum scale factor signal strength	≥1.0 dB/V	3.0 dB/V
A/T error voltage SNR at pull-in	≥35.0 dB within 1 Hz	40.0 dB within 1 Hz
Channel gain stability	≤ ±0.4 dB	±0.25 dB
RMS A/T noise jitter at boresight	≤0.002 deg within 1 Hz	0.0015 deg within 1 Hz
Signal strength SNR	≥60 dB within 1 Hz	70 dB within 1 Hz

Table 5 Landsat D weight and power breakdown

		K and X band	K band only
Weight (lb)			
RF compartment		156.5	156.5
WB module		153.5	65.9
	Total	310.00	222.4
Power (watts)			
RF compartment		69.5	69.5
WB module		169.0	54.7
	Total	238.5	124.2

model of the TDRS contained in Ref. 5. Table 5 summarizes the weight and power breakdown for the Landsat D wideband communications subsystem.

Conclusions

This paper has described the design features, operational characteristics, and performance requirements associated with the Landsat D telecommunications subsystem. The communications payload depicted herein is projected to meet or exceed all performance requirements. Moreover, it is expected to provide greater than 5-dB margins for both the Ku-band downlink through TDRS and the X-band direct-access downlink for transmission of either TM or MSS data.

Breadboard testing of units has provided initial verification of the excellent performance expected of the Landsat D communications hardware. This data, combined with TDRS channel test data[4] and computer-simulation results now available,[5] support the claim that extremely high-quality Earth-imaging data will be collected throughout the 1980s via the Landsat D-TDRS information system.

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