TDRSS GROUND SEGMENT PERFORMANCE

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ABSTRACT

About 150 racks of fully-automated equipment provide tracking, user traffic transmission and reception, simulation, and verification services for users of NASA's Tracking and Data Relay Satellite System (TDRSS). Installation of this equipment in the White Sands Ground Terminal Facility is now complete and final testing is nearly complete.

This paper describes the implementation and performance of that portion of the ground segment equipment provided by Harris. Major equipment groups described are 1) antennas, 2) user traffic link forward (transmit) equipment, 3) S-band single-access return (receive) equipment, 4) K-band single-access return equipment, 5) multiple-access RF equipment, 6) range and range-rate equipment, 7) user spacecraft simulation equipment, and 8) system verification equipment.

TDRSS OVERVIEW

Users of TDRSS will be provided with range and range-rate tracking services, forward data relay services and return data relay services. User spacecraft simulation and system verification services are also provided.

The Space Segment consists of three operational geostationary relay satellites. The east and west satellites are dedicated to TDRSS services, while the central satellite is shared with Advanced Westar services and is a spare for TDRSS. Each Tracking and Data Relay Satellite (TDRS) provides five channels--two S-band single-access (SSA), two K-band single-access (KSA), and one S-band multiple-access (MA). The MA forward link channel services multiple users on a time-shared basis using a single-beam phased array. Return links from MA users are handled via a multiple-beam phased array.

The Ground Segment (GS) consists of a single ground terminal located at White Sands, NM. Three 18m (60 ft) antennas provide Ku-band up and down links to the three TDRSs. Matching the three TDRSs are three identical groups of ground equipment. Each group provides forward link service to MA users and both forward and return link service to SSA and KSA users. Equipment groups that are shared by the three TDRSs are MA return link, range and range-rate, user spacecraft simulator, and verification.

All equipment is controlled by computers located in rooms adjoining the communication equipment room. The system is operated primarily via data messages provided by NASA. Manual operation is also possible via operators’ consoles. Most of the communications equipment is free of any local, front-panel controls.

Table I summarizes the services provided by TDRSS.

TABLE I   TDRSS Services

Forward Services	3 MA 6 SSA 6 KSA
Return Services	20 MA 6 SSA 6 KSA
Tracking Services	9 Range 119 Doppler
Simulator Services	1 MA 1 SSA 1 S-Shuttle 1 KSA 1 KSA/K-Shuttle
Verification Services	Automated BER tests Automated power, frequency, and time measurements Manual channel linearity measurements
Frequencies (MHz): MA Users SSA Users KSA Users S/G Uplink S/G Downlink	 2287.5 Rtn/2106.4 Fwd 2200-2300 Rtn/2026-2118 Fwd 15003 Rtn/13775 Fwd 14600-14826, 15150-15225 13405-13731, 13816-14040

ANTENNAS

Prominent at the White Sands Ground Terminal (WSGT) are the three 18m K-band antennas, aligned on a north-south axis. These antennas, as well as the equipment chains connected to them, are designated North, Central, and South (N, C, S). The user spacecraft simulator antennas and a rotating antenna for axial ratio verification are located on the building roof.

The 18m antennas are elevation/aximuth types, using a Harris wheel and plate pedestal. The reflector panels are made up of stretch-formed aluminum skins bonded to kerfed channel frames. The panels are mounted such that no metal-to-metal contact occurs, thus inhibiting generation of intermodulation products. A monopod is used to support the feed and subreflector. Shaped reflectors and subrefletors are used to optimize the aperture gain.

Table II summarizes the performance of the 18m K-band antennas.

TABLE II 18M Antenna

Receive Band	13.4 - 14.0 GHz
Transmit Band	14.6 - 15.2 GHz
Measured G/T	41.0 to 42.9 dB/°K (G ≈ 66 dB, T ≈ 250°K)
Measured Transmit Gain	66.5 - 67.9 dB
Measured Beamwidth	0.1°
Measured Autotrack Accuracy	0.003° (3 sigma)

FORWARD EQUIPMENT

This equipment group consists of the modulators, upconverters, and high-power amplifiers (HPAs) necessary to support forward traffic to user spacecrafts. Figure 1 is a simplified block diagram of a single chain showing how the chains are combined and switched to the three 18m antennas. The 3x3 antenna switch provides redundancy switching. In normal use, data traffic will be input at the NASA Communications Network (NASCOM) interface. The data will then be PN-spread and combined with a PN ranging channel and QPSK-modulated onto a carrier. The carrier frequency can be adjusted to provide forward link Doppler compensation, thus reducing the frequency acquisition problem for the user spacecraft. Forward IF services are also provided to handle users that have unique modulation schemes.

Table III lists some of the performance characteristics of the GS forward equipment. Of primary significance to users is the high quality of the forward link signals.

TABLE III Forward Equipment

Number of Equipment Racks	17
Range Channel	PN only PN rate ≈ 3 Mchip/sec
Command Channel	Data modulo-2 added to PN code
Command Channel Data Rates	MA: 0.1 - 10 kbps SSA: 0.1 - 300 kbps KSA: 1 kbps - 25 Mbps
Command/Range Power Ratio	10 dB
Nominal HPA Power Output	200 W
Measured Performance:	
Modulator phase imbalance	±0.9°
Modulator gain imbalance	±0.13 dB
Relative phase I/Q	±1.6°
Data asymmetry	±0.8%
Data transition time	3 ns
PN chip jitter	0.2° rms
Spurious PM	1° rms
Incidental AM	1.15%
Gain flatness	±0.3 dB
Phase nonlinearity	±1.80°
AM/AM (linear mode)	0.92 dB/dB
AM/PM (linear mode)	3.3°/dB

SINGLE-ACCESS RETURN EQUIPMENT

Figure 2 shows one SA return equipment chain and how it interfaces with the antennas. An SA chain consists of a downconverter, demodulator, bit synchronizer, and decoder. The decoder is bypassed for uncoded data. Carrier Doppler compensation, based on user spacecraft ephemerides, is done in the downconverter. Compensation for Doppler on the PN rate is done in the demodulator by biasing the PN clock oscillator.

Table IV summarizes the performance of the SA return equipment.

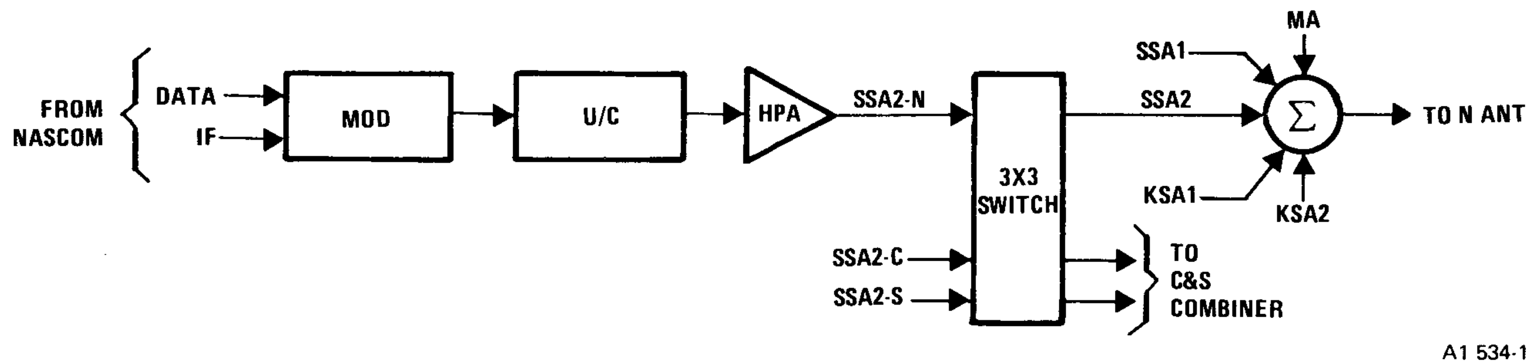

Figure 1 - Forward Equipment Chain.

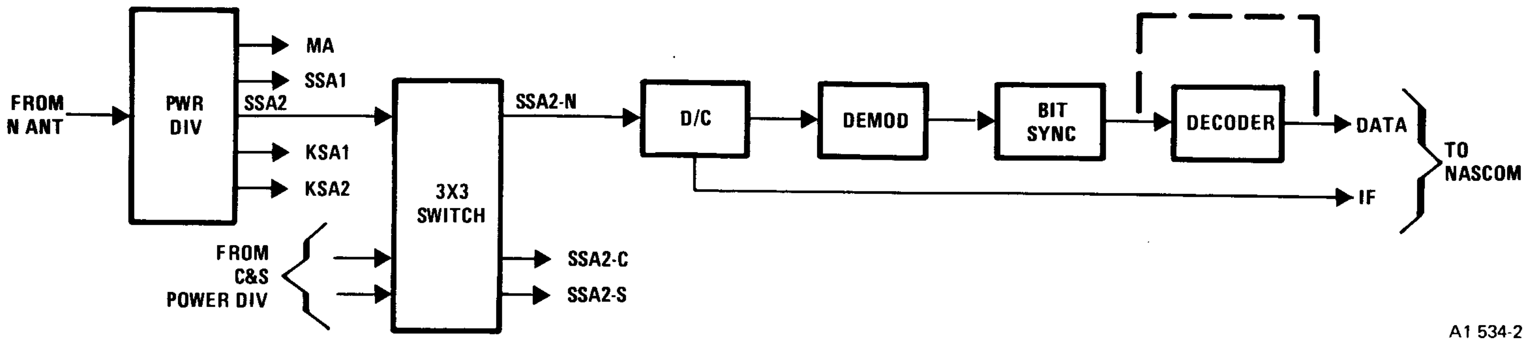

Figure 2 - Single-Access Return Equipment Chain.

TABLE IV Single-Access Return Equipment

Number of equipment racks	51
Data rate capability (per I/Q channel)	SSA: 100 bps - 6 Mbps KSA: 1 kbps - 150 Mbps
Modes and Characteristics	Coded (R 1/2) or uncoded PN spread or unspread BPSK or QPSK NRZ or Biphase formats
Measured E_b/N_o for BER = 10^{-5}: @ 150 Mbps, coded @ 6 Mbps, coded @ 3 Mbps, uncoded @ 100 kbps, uncoded, PN spread	 7.9 dB 5.3 dB 10.1 dB 11.1 dB
SSA Services to Shuttle: Characteristics Measured E_b/N_o for BER = 10^{-4}	 BPSK, 96 or 192 kbps Rate 1/3 coded 5.2 dB
KSA Services to Shuttle: Characteristics Measured E_b/N_o for BER = 10^{-5} @ 50 Mbps rate 1/2 coded	 3 channels QPSK or Analog FM 2 - 50 Mbps on high rate channel 4.2 MHz video bandwidth 7.0 dB

The significant parameter is bit-error-rate (BER). Listed in the table are the results of the acceptance tests for BER conducted on the installed SA return equipment groups. The BER tests were run using test signal distortions that approximated the worst-case user signal, and channel distortions (both linear and nonlinear) that approximated the distortions allocated to the TDRS. Analysis shows that the BER results could be degraded by an additional 1 to 2 dB if all user signal distortions and the TDRS channel distortions were simultaneously at their worst-case limits.

MULTIPLE-ACCESS RETURN EQUIPMENT

As many as 20 MA return links can be handled simultaneously by TDRSS. The 20 links may be apportioned in any manner to the three operational TDRSs. All 20 users could be assigned to one TDRS, or they could be distributed through all three; for example: 5 through the east TDRS, 2 through central, and 13 through west.

The MA return signals are handled by a multiple-beam phased array, in which the array elements are on the TDRS and the multiple-beam power dividers, weighting networks, and control processor, are all located on the ground. A frequency multiplexing/demultiplexing process is used to keep the individual element signals separated on the downlink.

Figure 3 gives a simplified block diagram of the MA return equipment, showing how the 20 beams are formed and how any one beam can be allocated to any one of the three TDRSs. Harris provided the MA RF equipment, which includes the frequency demultiplexers (for element signal separation), the power divider/switch matrix, weighter/combiners, and Doppler correctors. Some of the key characteristics of the MA RF equipment are provided in Table V.

TABLE V MA Return RF Equipment

Number of equipment racks	15
Signal characteristics	30 frequency mux channels, spaced 7.5 MHz, 13405 - 13622.5 MHz
Frequency demux reference	13731 MHz (TDRS telemetry carrier)
Measured performance: Gain tracking Time delay tracking Differential phase stability Complex weight quantization Weight vector error, rms Amplitude flatness (±2.4 MHz) Phase nonlinearity (±2.4 MHz)	 ±0.9 dB ±3.8 ns ±6° over 4 hours 32 amplitude levels on I and Q vectors 3.5% of full scale ±0.2 dB ±1.8°

TRACKING EQUIPMENT

User spacecraft range and Doppler-shift are measured by a shared set of equipment.

Figure 4 illustrates the basic approaches used in the measurement of range and Doppler. Range (time) is determined by measuring the elapsed time between the transmitted PN epoch and the received PN epoch. Doppler shift is determined by beating the down-converted received carrier frequency against a predetermined, programmable reference frequency. The Doppler output is multiplied by 1000 for S-Band, or by 100 for K-Band, and fed to a counter. Each second the Doppler count is readout by the system computer.

The reference frequency is setup such that the Doppler count will be biased around 240 MHz. Thus the signal to the counter is 240 MHz+1000 fd for S-Band, or 240 MHz+100 fd for K-Band, where fd is the user's Doppler shift.

Table VI summarizes the tracking equipment performance. The dominant source of range measurement error is system thermal noise. At low data rates (i.e. low SNR in the carrier recovery loop bandwidth), thermal noise is also the dominant contributor to the Doppler phase noise. At higher data rates, however, the 5 MHz cesium-beam frequency standard becomes the dominant source of Doppler phase noise.

TABLE VI Tracking Equipment

Number of equipment racks	5
Estimated performance:	
Doppler phase noise, low data rates	0.3 rad, rms
Doppler phase noise, high data rates	0.2 rad, rms
Range (time) measurement random error	18 ns, rms
GS delay calibration error	+20 ns

SIMULATION EQUIPMENT

Five User spacecraft simulators are provided: SSA, S-Shuttle, MA, KSA, KSA/K-Shuttle. Figure 5 shows how the five simulators share the one S-Band and the one K-Band antenna. All five simulators can be used simultaneously. Each simulator provides the capability to simulate all specified modes of a user spacecraft. Power output of the HPA's can be controlled via computer commands to simulate the complete range of user spacecraft return link EIRP. Similarly, in the forward link direction, the complete range of user spacecraft G/T can be simulated by controlling the amount of thermal noise injected into the receiver frontend. Return link Doppler, range delay, and I/Q power ratio can also be varied under computer control.

Table VII summarizes the significant characteristics of the simulation equipment.

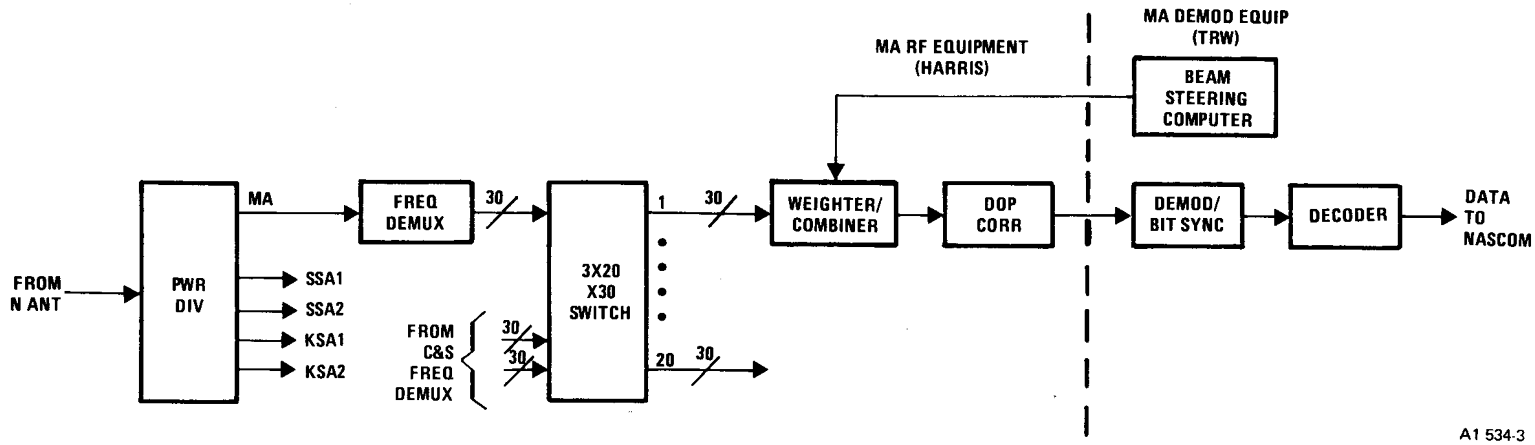

Figure 3 - Multiple-Access Return Equipment Chain.

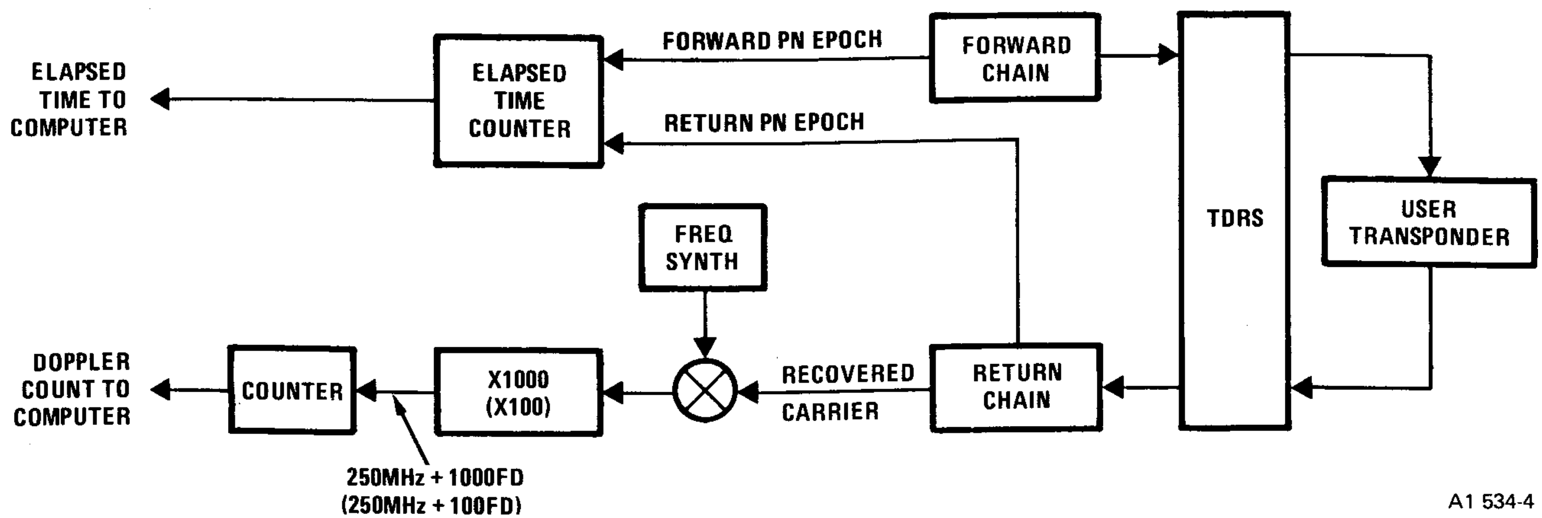

Figure 4 - Tracking Equipment

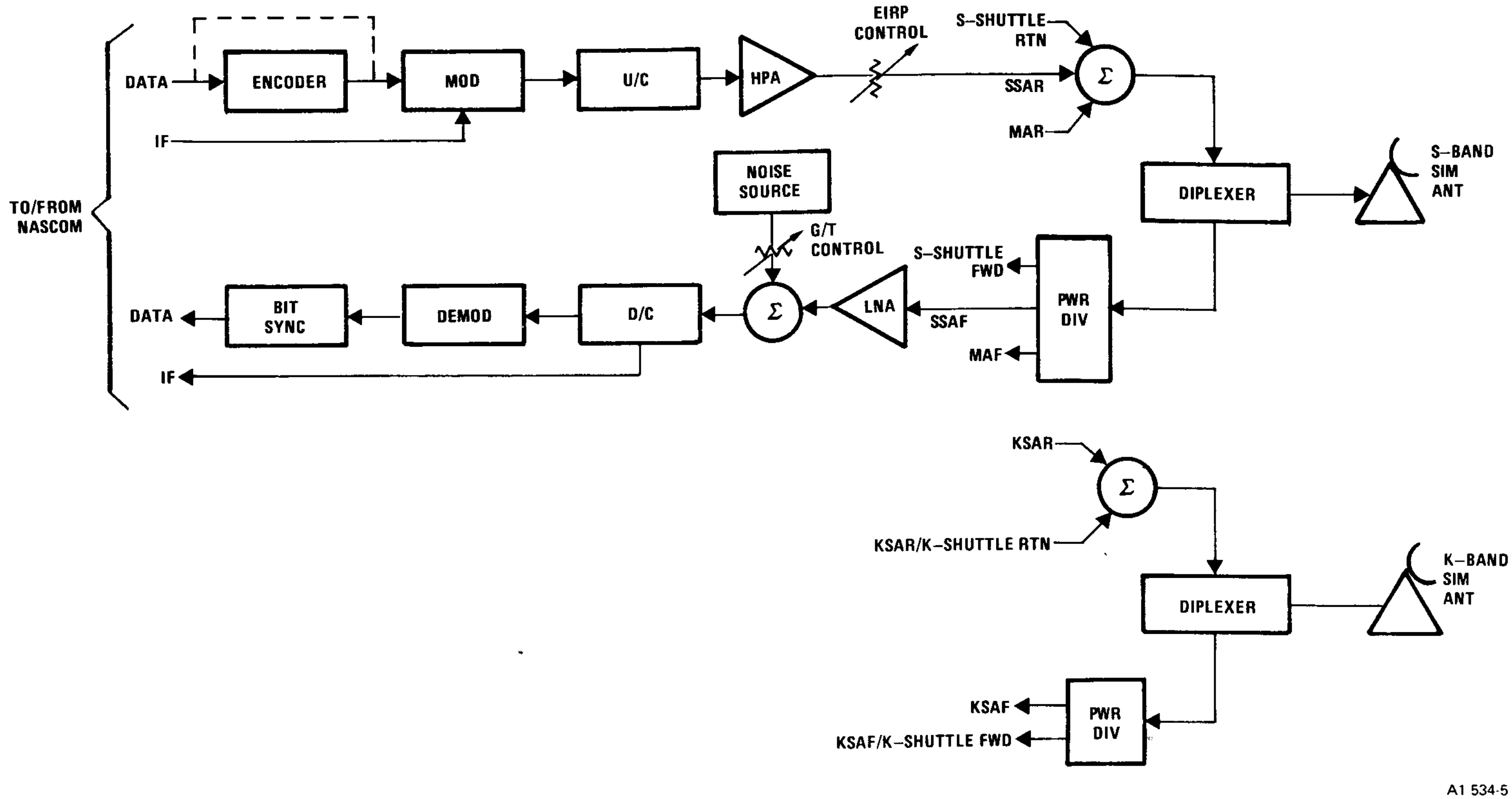

Figure 5 - Simulation Equipment

TABLE VII Simulation Equipment Characteristics

Number of equipment racks	16
Range of EIRP available	MA: -11 to +33 dBw SSA: -10 to +45 dBw KSA: -3 to +60 dBw
Range of G/T available	MA: -40 to -15 dB/°K SSA: -50 to -10 dB/°K KSA: -27 to +21 dB/°K
Range of I/Q power ratio available	-6 to +6 dB
Range of simulated Doppler available	MA, SSA: ±230 kHz KSA: ±1.6 MHz
Range of simulated range delay available	0 to 85 ms (1 PN code length)

VERIFICATION EQUIPMENT

Overall system performance can be verified by this group of equipment. Figure 6 shows the various components of this equipment group. The primary component is the test traffic generators and bit-error counters. Bit error counts can be made via the TDRS for both forward links to and return links from simulated user spacecrafts. The test traffic generators can be varied over data rates of 100 bps to 150 Mbps. Data frequency jitter of 0.1, 0.5, 1, and 2 percent can also be simulated by the test traffic generators. Other automated verification tests can be done using a microprocessor-controlled power meter and counter. Forward and return link channel linearity (amplitude and differential group delay flatness) can be measured manually using a microwave link analyzer. The analyzer receiving unit is coupled with a calculator and X-Y plotter to provide convenience and accuracy in the calibration and recording of the data.

Table VIII summarizes the key features of the verification equipment.

TABLE VIII Verification Equipment

Number of equipment racks	7
Test traffic generators: Quantity provided Data rate range Data bit jitter range	 3 100 bps - 150 Mbps Δf = 0.1, 0.5, 1, 2% fm = 0.1, 0.5, 1, 2%
Bit error counters: Quantity provided Data rate range Bit count capacity Bit error count capacity Measurement accuracy (set by EIRP or G/T simulation accuracy)	 5 100 bps - 150 Mbps 2^{28} 2^{21} ±1 dB
Other measurements available: Command/range power ratio Forward link signal EIRP Forward link carrier suppression Forward link PN/carrier coherence Forward link carrier frequency Forward/return link signal acquisition time Forward/return link amplitude/phase linearity GS transmit signal spectrum analysis	

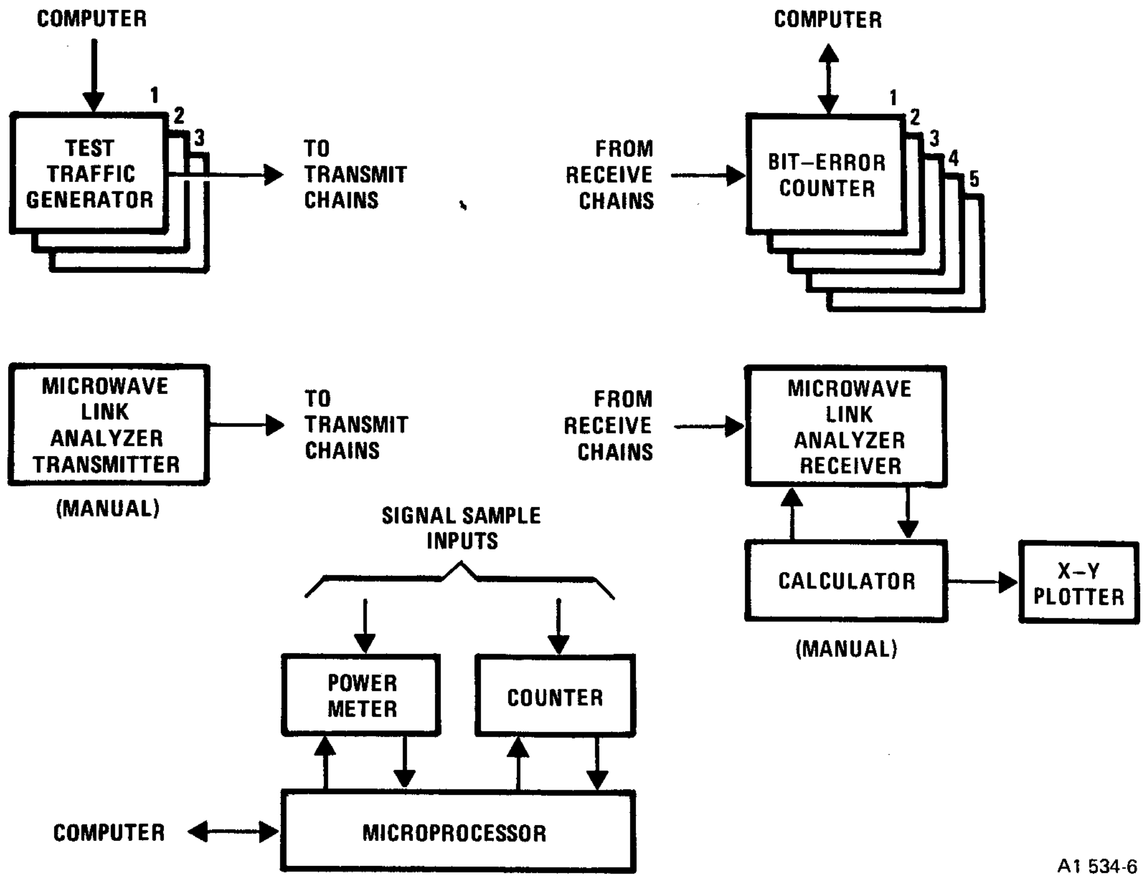

Figure 6 - Verification Equipment