GROUND SUPPORT FOR THE SPACE-BASED RANGE FLIGHT DEMONSTRATION 2

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ABSTRACT

The primary objective of the NASA Space-Based Range Demonstration and Certification program was to develop and demonstrate space-based range capabilities. The Flight Demonstration 2 flights at NASA Dryden Flight Research Center were conducted to support Range Safety (commanding and position reporting) and high-rate (5 Mbps) Range User (video and data) requirements. Required ground support infrastructure included a flight termination system computer, the ground-data distribution network to send range safety commands and receive range safety and range user telemetry data and video, and the ground processing systems at the Dryden Mission Control Center to process range safety and range user telemetry data and video.

KEY WORDS: Tracking and Data Relay Satellite System, Flight termination system, Launch head, Range Safety, Range User

INTRODUCTION

The objective of the Space-Based Range Demonstration and Certification (SBRDC) Flight Demonstration 2 (FD2) [formerly Space-Based Telemetry and Range Safety (STARS)[1]] was to develop and demonstrate a space-based range capability. In order to meet the objective, ground-based infrastructure was required to support flights utilizing the Range Safety (RS) and Range User (RU) systems. The RS ground systems were required to support the validation of 840-bps forward links to an F-15 (McDonnell Douglas, now the Boeing Company, Chicago, Illinois) airplane for flight termination system (FTS) commands and a 10-Kbps return telemetry link from the F-15 airplane for monitoring the RS parameters in the Dryden Flight Research Center (DFRC) (Edwards, California) Mission Control Center (MCC). The RU ground systems were required to support an increased telemetry data rate of at least 5 Mbps, and the processing and display of an Internet protocol (IP) -based data stream and video. Figure 1 shows the F-

15 airplane and the associated assets used to support FD2. This paper will primarily discuss the ground infrastructure used to support the RS and RU ground tests and flights.
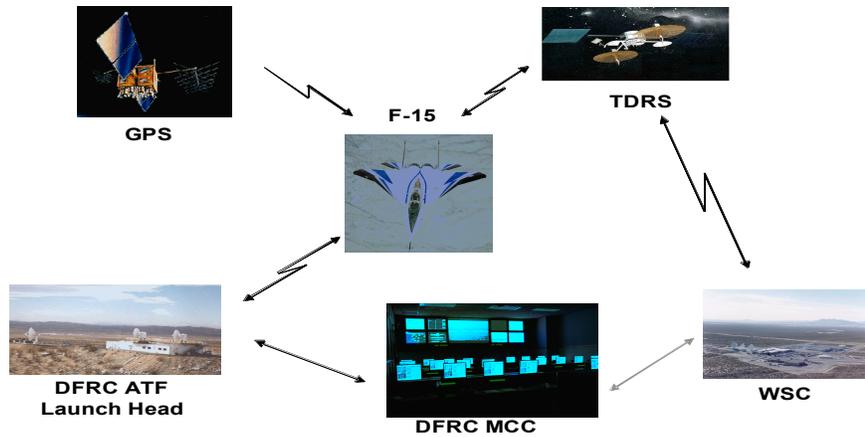

Figure 1. Overview of Space-Based Range Demonstration and Certification Flight Demonstration 2.

RS SYSTEM

The RS ground systems consisted of the flight termination system (FTS) computer and a Telemetry and Radar Acquisition Processing System (TRAPS) located in the DFRC MCC, the launch head located at the DFRC Aeronautical Tracking Facility (ATF), the Tracking and Data Relay Satellite System (TDRSS)[2] ground terminals located at the White Sands Complex (WSC) (White Sands Test Facility, Las Cruces, New Mexico), and the data distribution links at DFRC and between the DFRC MCC and the WSC.

The FTS computer was developed by Kennedy Space Center (KSC) (Kennedy Space Center, Florida) personnel to be used in the DFRC MCC during the FD2 flights. The computer was used to generate the RS forward link commands providing encryption and Reed Solomon (30, 16) encoding on a 64-bit data packet. The 64-bit packet included bits for a check channel, range identification (ID), transmit ID, vehicle ID, counter, FTS commands, and user defined commands. In front of the 64-bit packet were a 16-bit frame synchronization pattern and 70 Reed Solomon parity bits and 2 fill bits after the packet.

The FTS computer generated two 840-bps non-return to zero-mark (NRZ-M) transistor-transistor logic (TTL) (RS-422 option available) outputs. A transmit ID was used to identify the source of the forward link commands: either the launch head located at the DFRC ATF or from a TDRS. The manual FTS commands sent to the F-15 test airplane were monitor, arm, or terminate. The computer could also be set up to auto-sequence through the commands. Figure 2 shows the setup window used to set up the FTS Computer commands.
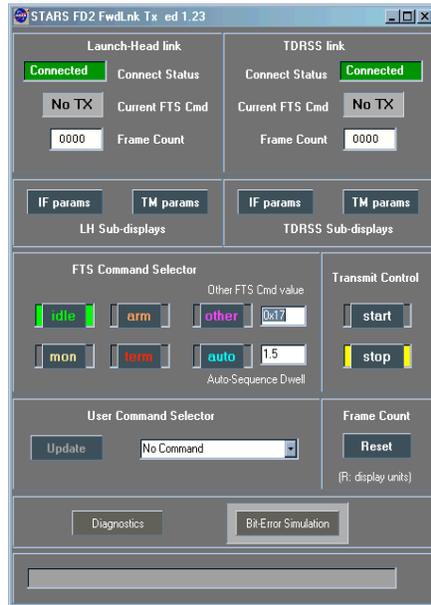
Figure 2. The command setup of the flight termination system.

One of the FTS computer outputs was sent to the launch head system located at the ATF site via a dedicated multi-mode fiber optic link. The second output was input into a video distribution amplifier to provide two outputs for the missions requiring two tracking and data relay satellites (TDRSs). The two TDRS outputs were sent to the DFRC Communications Building over dedicated multi-mode fiber optics links and from the Communications Building to the WSC via two dedicated 56-Kbps circuits.

The launch head system included the use of an ATF 7-meter uplink/downlink antenna to provide a method to simulate the S-band forward link from a TDRS by providing S-band spread spectrum bi-phase shift keying (BPSK) modulation with pseudonoise (PN) encoding, and also received the 10-Kbps BPSK return telemetry link. This system allowed ground checkout to occur with the RS system hardware onboard the F-15 airplane without having to schedule the TDRS assets. Radar data was provided to the launch head system to allow automatic adjustment of the output power based on the range to the F-15 airplane. Figure 3 includes the onboard RS flight hardware that was interfaced with the ground systems. The commands sent via the launch head were received by the Range Safety System (RSS) low-power transceiver (LPT) and processed by the RSS command and data handler (C&DH) for Reed Solomon decoding and decryption. The two S-band radio frequency inputs to the LPT allowed two signals each, one from the launch head and one from the TDRSS. A command from the FTS computer initiated recording on the C&DH to record the commands that were received from the ground systems. Pseudonoise codes 11 and 12 were used during the flight tests and a command could be sent to the LPT to configure pairs of receiver channels to look for either code.
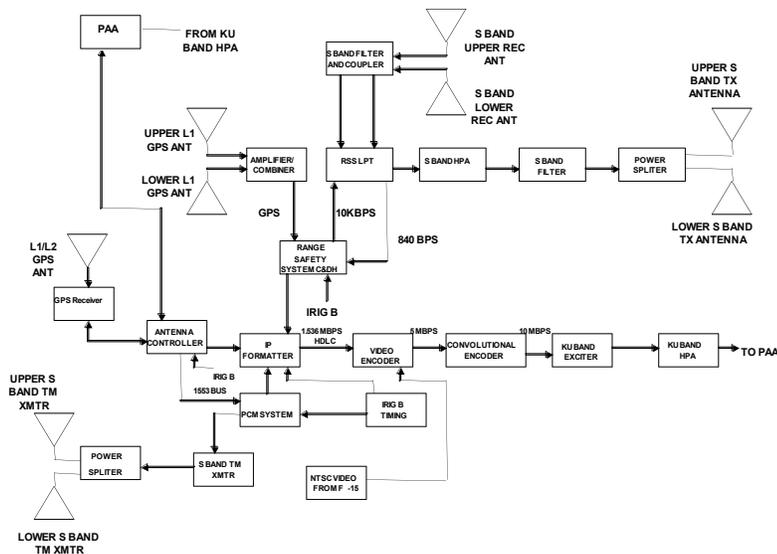
Figure 3. Range Safety and Range User flight hardware.

The commands sent from the FTS computer at the DFRC MCC to the WSC over dedicated 56-Kbps full-duplex circuits were uplinked to the F-15 airplane via TDRSS. Dedicated circuits were used for FD2 to limit the latency of the ground portion of the link to send commands via the forward link and to receive telemetry data on the return link.

In Flight Demonstration 1 (FD1)[3] nondedicated circuits were used, which had more latency because the link was shared with other users. The average round trip delays using a bit error rate test set at DFRC (using 2047 pattern, delay function, and circuits in loopback at WSC) for the ground links for the 840-bps channels and the 10-Kbps channels was 146 milliseconds and 34 milliseconds, respectively. The average delay from DFRC to TDRS and back to DFRC was approximately 600 milliseconds. The 10 Kbps return link telemetry data sent via the LPT was received at the WSC using the S-band single access (SSA) return link service. The 10-Kbps telemetry data was sent to DFRC via the dedicated 56-Kbps circuits. This return link data was also routed to the Wallops Flight Facility (WFF) (Wallops Island, Virginia) and KSC through the use of the NASA Integrated Services Network (NISN) nondedicated circuits. Figure 4 shows the forward and return link data distribution for the RS flights.

Figure 4. Flight Demonstration 2 Range Safety data distribution.

The FTS computer was also used to display telemetry data from the RSS. It had the ability to receive one 10-Kbps non-return to zero-level (NRZ-L) TTL input and to perform Reed Solomon decoding. The launch head, TDRS 171/174 or TDRS spare return link data was monitored on the computer display. There were one return link main display and three subpanel displays. The main display showed the status of telemetry frame synchronization, IRIG-B time, forward link status for each of the four channels, status of C&DH logging and recording, and LPT transmit power. The LPT subpanel displayed the energy per bit to noise power spectral density ration (Eb/No) (normalized signal-to-noise ratio) and automatic gain control (AGC) values for each of the four receiver channels, carrier lock, PN codes received, and temperatures of the RSS hardware. The forward link subpanel was important for displaying the transmit ID received on each of the four channels as launch head or TDRSS. The last subpanel was the global positioning system (GPS) display to show the status of the number of satellites in view of the GPS receiver and horizontal dilution of precision (HDOP), vertical dilution of precision (VDOP), and time dilution of precision (TDOP) values.

The TRAPS was used to record the two forward link 840-bps streams output from the FTS computer for postflight analysis to determine the latency that occurred from the time a command was issued to the time it was processed onboard with the C&DH. It was also used to record the 10-Kbps return links from the launch head and up to two TDRSs, and to provide the telemetry data lock status.

The ground equipment required for the 840-bps forward link to the F-15 airplane and the 10-Kbps return link from the F-15 airplane worked successfully to provide support for the RS flights which were high dynamic maneuvering flights. The launch head system

and one TDRS were used simultaneously for the forward link generated by the FTS computer for some of the flights and two TDRSs were used simultaneously for some flights to verify an all-space-based RS capability. Two flights were flown to simulate the handover from the launch head system to a TDRS. The 10-Kbps return link received via the launch head and two TDRSs simultaneously was successfully distributed via the ground links to the DFRC MCC for RS data displays to monitor the performance of the RS system. Figure 5 shows the distribution required for the forward and return links using two TDRSs.
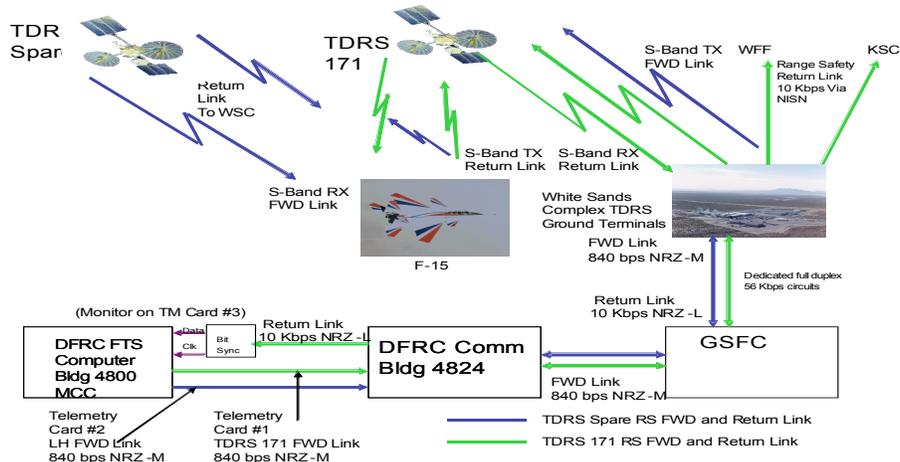
Figure 5. Range Safety forward and return links using two Tracking and Data Relay Satellites.

RANGE USER SYSTEM

The RU ground system consists of the video decoder, router, TRAPS, and Flexible Acquisition Processing System (FLAPS) located in the DFRC MCC, the TDRSS ground terminals, and the 5-Mbps data distribution link between the DFRC MCC and the WSC. Figure 3 includes the RU flight hardware that was interfaced to the ground systems.

The RU FD2 hardware provided the capability to test at a high data rate of 5 Mbps using a phased-array antenna (PAA)[4]. The IP formatter was used as a proof of concept to relay IP-based data to the ground, which data would be compared with a traditional pulse-coded modulation/frequency modulation (PCM/FM) 800-Kbps telemetry link. The IP formatter was configured to accept user data protocol (UDP) antenna controller data at 72 Kbps, RS 10-Kbps PCM data, and 800-Kbps F-15 PCM data. The output of the IP formatter was packetized UDP data at 1.536 Mbps in a high-level data link control (HDLC) synchronous serial RS-422 format. These data, along with National Television System Committee (NTSC) cockpit video, were combined in a video encoder; the 5-Mbps output was input into a convolutional encoder. The PAA used the Ku-band single access (KuSA) with BPSK modulation return link service to interface with the WSC.

At the TDRSS ground terminal the signal was processed before it was sent to DFRC. The data were then input into a serial to packetized data router in order to send the 5-Mbps data to DFRC for processing. The data were routed from WSC to the Jet Propulsion Laboratory (JPL) (Pasadena, California) and from JPL to DFRC on existing circuits. The packetized data arrived in DFRC Communication Building 4824, which is the interface for NASA Service Assurance Plan Technical Refresh (NTR) circuits. The RS-530 serial 5-Mbps output of the router was sent over a RS-422 multi-mode fiber optic modem link to DFRC Building 4800 for processing at the TRAPS.

In DFRC Building 4800 the data were processed for display and recorded for postflight analysis. The RS-422 output of the fiber optic modem was input into the video decoder to separate the video and IP data and another output was created via a video distribution amplifier to provide a source for recording the combined stream. The video was input into the video switch for distribution of the video into the MCC for display during the missions. The router was used to locate HDLC frames, remove framing, and forward IP packets to destination over a 10-Mbps Ethernet, one frame per packet. The Ethernet output was processed and displayed with a laptop running display software. Another option was to use FLAPS software to read in the UDP/IP packets, extract frame telemetry, and pass telemetry data to a front-end processor in engineering units (EU) tag/data format.

The TRAPS front-end processor received the tag/data, and passed the data to the MCC display systems. This is the first time the MCC was used to process IP data from a test airplane. Figure 6 shows the data distribution for the RU data.
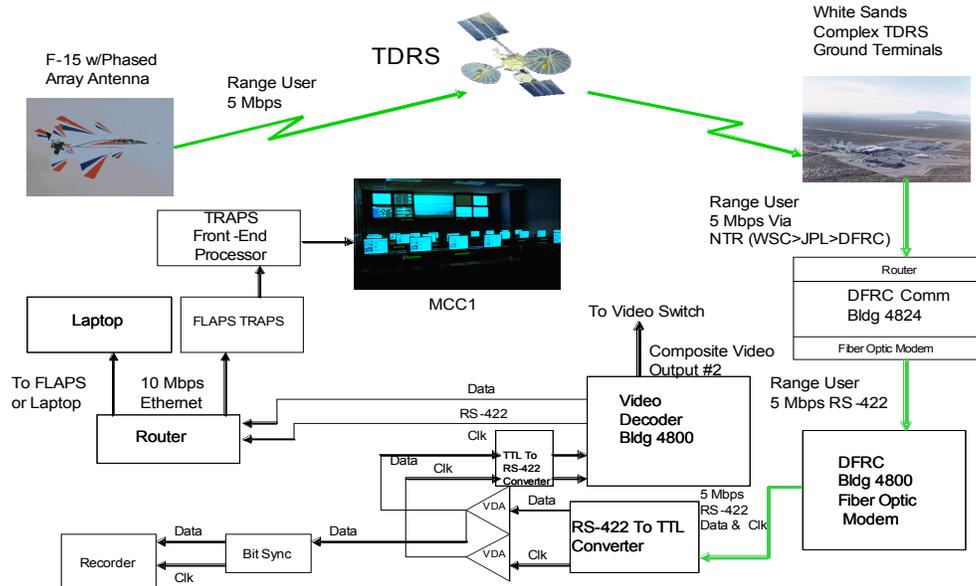

Figure 6. Range User data distribution.

Data displays were important in helping to monitor the RU flights and for comparing traditional PCM displays with IP-based displays. The two critical displays used were the SBRDC Enhanced GPS/INS (EGI) instrumentation and the SBRDC RU Antenna Display. An IP and PCM version of each display were made available for use in the MCC. It was critical that information on the EGI was available in the MCC to ensure the system was aligned and available to provide information for the algorithm necessary to provide pointing angles for the PAA to point toward the TDRS antennas. The RU Antenna Display provided critical information on command, elevation, and azimuth status; GPS positions; and commanded elevation and azimuth of the PAA to help determine when data should be received and at what pointing angles good data were received. These displays are shown in Figures 7 and 8.
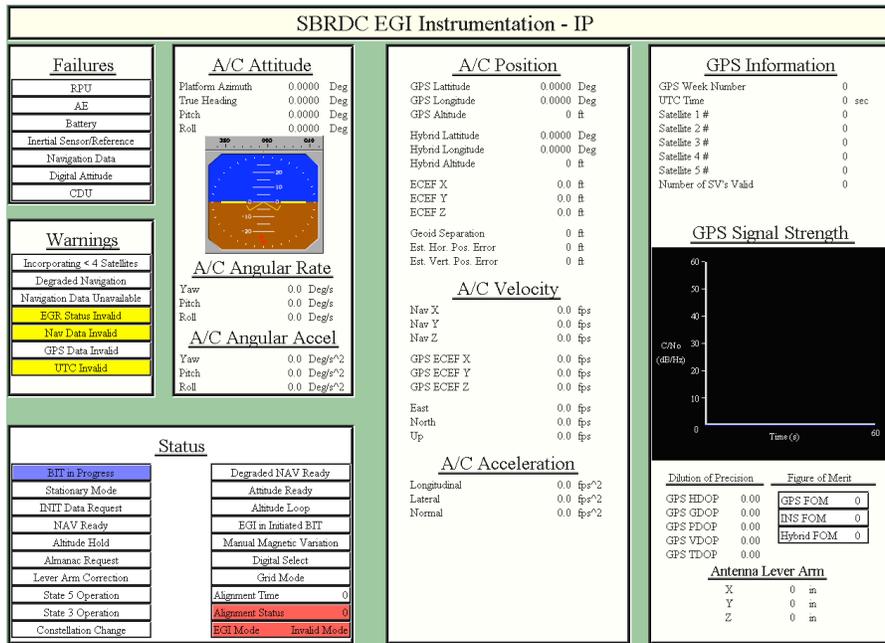

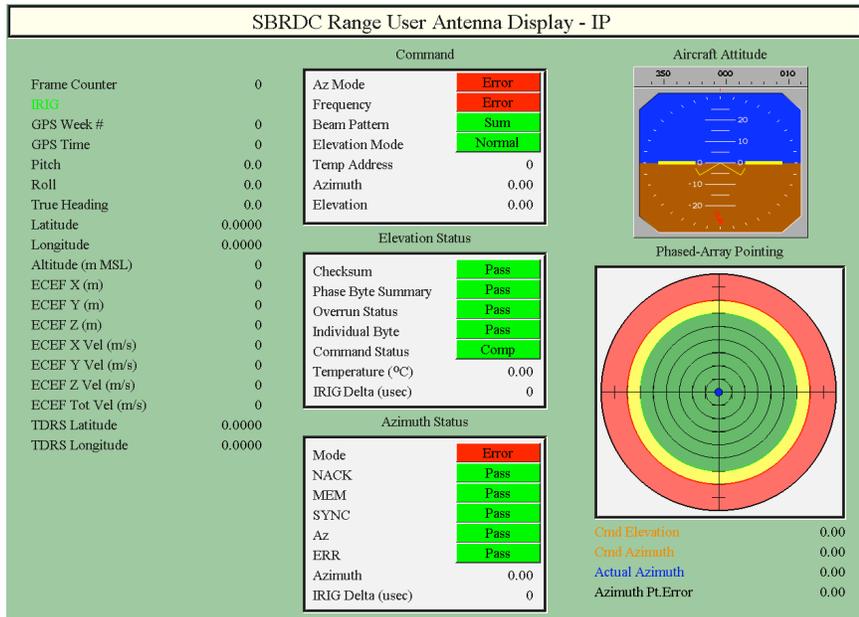Figure 7. Space-Based Range Demonstration and Certification enhanced GPS/INS instrumentation.

Figure 8. Space-Based Range Demonstration and Certification Range User antenna display.

There were some problems with the 5-Mbps data link between WSC and DFRC with the routers that were used to take in the serial data and packetize the data. There were problems with the optimum clocking mode (internal or external) and the optimum buffer size to use on the routers. The settings that worked with the original router did not work with the replacement routers. The original routers were replaced because the decision was made by the NTR network personnel to go to the new routers for the NISN upgrade for all NASA centers. When the tracking of the TDRS antenna by the PAA was lost, the data link did not work when the tracking was reestablished. There appeared to be a problem with correct clocking on the router output port. Resetting the router ports helped to reestablish a good data link, but it made it very difficult to complete the test points for the RU flights. Some data were lost, and test points had to be reflown because of the problems with the data link. Also, WSC was not able to record the 5-Mbps stream before it was shipped to DFRC. It was a programmatic decision to accept this risk because of the cost and effort required to provide this capability. In hindsight, utilizing this capability would have helped to recover the lost data.

The TDRSS also functioned more effectively when the system was set up for program track, which pointed the antenna toward a fixed point instead of allowing the antenna to track automatically. In autotrack mode, the system did not always regain track after tracking was lost, and the TDRS antenna was pointing incorrectly.

After successfully completing the test points required for the 5-Mbps flights, the data rate was increased to 10 Mbps to see whether it was possible to maintain a good link margin at that higher data rate. The router and link bandwidth between the WSC and the DFRC Communications Building, and the fiber optic modem link between the DFRC

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Communications Building and the DFRC MCC, were configured for the higher data rate. The buffer and clock settings used for the router at 5 Mbps did not work well for the 10-Mbps data rate after tracking was lost and reestablished, but excellent data were obtained when the link was reestablished. Resetting the router ports helped to establish good data link connectivity between the WSC and DFRC, but resetting had to be performed each time after tracking was lost.

The data are still being analyzed to determine more accurate latency measurements, but the approximate round-trip latency for data and video was between 300-400 milliseconds. Also, the data shown on the IP-based range user displays compared with that shown on the range user PCM displays lagged by approximately 1 second.

SUMMARY

The ground-based systems used for the Range Safety and Range User demonstration flights were successful in supporting the completion of several ground tests and 10 demonstration flights. The Range Safety ground systems supported the validation of an 840-bps forward link to the F-15 airplane using a launch head system and up to two tracking and data relay satellites. A 10-Kbps return link was also validated using a launch head system and up to two tracking and data relay satellites. The data from the Range Safety flights is still being processed toward publishing the final results for latency, link margins, and quality of data. The goal of increased telemetry data rates was met during the Range User flights with the original goal of a 5-Mbps stream being telemetered through the tracking and data relay satellite to the ground via the phased array antenna. Also, adequate link margin enabled the Range User system to support the transmission and reception of a 10-Mbps stream. The processing and display of Internet protocol-based data was also successful. The data for the Range User flights is also still being processed toward publishing the final results. More analysis must be performed to determine the best type of router and setup configuration to support the transmission of packetized data. Both the Range Safety and Range User ground infrastructures assisted in developing and demonstrating a space-based range capability.

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NOMENCLATURE

A/C	aircraft
ANT	antenna
ATF	Aeronautical Tracking Facility
auto	automatic
Az	azimuth
BIT	built-in-test
BPSK	bi-phase shift keying
bps	bits per second
C&DH	Command and Data Handler
Clk	clock
Cmd	commanded
Comm	communications
DFRC	Dryden Flight Research Center
ECEF	Earth-centered, Earth-fixed
EGI	enhanced GPS/INS
EGR	embedded GPS receiver
Est	estimated
FD2	Flight Demonstration 2
FLAPS	Flexible Acquisition Processing System
FOM	figure of merit
FTS	flight termination system
FWD	forward
GDOP	geometric dilution of precision
GPS	global positioning system
GSFC	Goddard Space Flight Center
HDLC	high-level data link control
HDOP	horizontal dilution of precision
Hor	horizontal
HPA	high-power antenna
ID	identification
IF	interface
INIT	initiate
INS	inertial navigation system
IP	Internet protocol
IRIG	Inter-range Instrumentation Group

JPL	Jet Propulsion Laboratory
Kbps	kilobits per second
KSC	Kennedy Space Center
LH	launch head
LPT	low-power transceiver
m	meters
m/s	meters per second
Mbps	megabits per second
MCC	Mission Control Center
mon	monitor
MSL	mean sea level
NASA	National Aeronautics and Space Administration
NAV	navigate
NISN	NASA Integrated Services Network
NRZ-L	nonreturn to zero-level
NRZ-M	nonreturn to zero-mark
NTR	NASA Service Assurance Plan Technical Refresh
NTSC	National Television System Committee
PAA	phased-array antenna
PCM/FM	pulse-coded modulation/frequency modulation
PDOP	position dilution of precision
PN	pseudonoise
Pos	position
Pt	pointing
REC	receiver
RS	Range Safety
RSS	Range Safety system
RU	Range User
RX	receive
SBRDC	Space-Based Range Demonstration and Certification
SV	space vehicle
TDOP	time dilution of precision
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
Temp	temperature
term	terminate
TM	telemetry
Tot	total
TRAPS	Telemetry and Radar Acquisition Processing System
TTL	transistor-transistor logic
TX	transmit
UDP	user datagram protocol
usec	microseconds
UTC	Universal time coordinated
VDA	video distribution amplifier
VDOP	vertical dilution of precision

Vel	velocity
Vert	vertical
WFF	Wallops Flight Facility
WSC	White Sands Complex
X	x-coordinate
XMTR	transmitter
Y	y-coordinate
Z	z-coordinate