A New TDRSS Compatible Transceiver for Long Duration High Altitude Scientific Balloon Missions

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ABSTRACT

High altitude scientific balloons have been used for many years to provide scientists with access to space at a fraction of the cost of satellite based experiments. In recent years, these balloons have been successfully used for long duration missions of up to several weeks. Longer missions with durations of up to 100 days (Ultra-Long) are on the drawing board. An enabling technology for the growth of the scientific balloon missions is the use of the NASA Tracking and Data Relay Satellite System (TDRSS) for telemetering the health, status, position and payload science data to mission operations personnel. The TDRSS system provides global coverage by relaying the data through geostationary relay satellites to a single ground station in White Sands New Mexico. Data passes from the White Sands station to the user via commercial telecommunications services including the Internet. A forward command link can also be established to the balloon for real-time command and control.

Early TDRSS communications equipment used by the National Scientific Balloon Facility was either unreliable or too expensive. The equipment must be able to endure the rigors of space flight including radiation exposure, high temperature extremes and the shock of landing and recovery. Since a payload may occasionally be lost, the cost of the TDRSS communications gear is a limiting factor in the number of missions that can be supported. Under sponsorship of the NSBF, General Dynamics Decision Systems has developed a new TDRSS compatible transceiver that reduces the size, weight and cost to approximately one half that of the prior generation of hardware.

This paper describes the long and ultra-long balloon missions and the role that TDRSS communications plays in mission success. The new transceiver design is described, along with its interfaces, performance characteristics, qualification and production status. The transceiver can also be used in other space, avionics or terrestrial applications.

1.0 INTRODUCTION

The National Scientific Balloon Facility was established in Boulder, Colorado in 1961 under the auspices of the National Science Foundation. The facility was moved to Palestine, Texas in 1963 and designated as the NSBF in January 1973.

In 1982, sponsorship of the NSBF was transferred from the National Science Foundation to the National Aeronautics and Space Administration (NASA) and the NSBF became a separate entity under the University Corporation for Atmospheric Research (UCAR).

In October, 1987, the NASA contract to operate the NSBF was awarded to the Physical Science Laboratory (PSL) under the auspices of New Mexico State University located in Las Cruces, New Mexico. The contract is administered by Goddard Space Flight Center's Wallops Flight Facility.

The NSBF provides complete balloon operations services and engineering support to the United States and foreign scientific communities. The operations services include inflation, launching of the balloon, tracking and recovery of the payload, and telecommand and data retrieval with reliable electronics systems. Some of the areas of engineering support are design of balloon systems, research in balloon materials, electronics design, gondola design and thermal analysis. Also included are power system design, instrumentation design and integration, and recovery system design.

In over 30 years of operation, the NSBF has launched more than 1700 balloons for 35 universities, 23 other research agencies, and 33 foreign groups. During this span of years there has been a dramatic increase in sophistication of experiments and demands for service. This can best be shown by comparisons of the growth in payload weight, balloon size, and the amount of electronic support provided between 1963 and 1988. The average payload increased from 407 pounds in 1964 to more than 3000 pounds in 1988. Average balloon volume has increased from 2.8 million cubic feet (MCF) in 1964 to over 20.0

MCF in 1988. Today, payloads weighing 5000 pounds are quite common and balloons of 20 to 40 MCF are flown routinely.

In 1988, NASA made a decision to dedicate significant resources toward the development of a Long Duration Balloon (LDB) capability. The objective of the project was to develop global communication systems in order to conduct flights of scientific experiments weighing 1500 pounds or more for durations of up to 3-4 weeks. The longer duration flights allow more scientific data to be obtained in a single balloon flight for basically the same amount of money.

Shown in Figure 1-1 is a Support Instrumentation Package (SIP) that was developed by the PSL, which includes the telecommunications, positioning, data acquisition and storage, solar power, and command control sub-systems required for safe and reliable LDB flights. In order for the NSBF to operationally control the balloon flight and allow for scientific data to be relayed globally, it was necessary to develop satellite communications. The most important of these developments was to use NASA's Tracking Data and Relay Satellite System (TDRSS).

FIGURE 1-1. LDB SUPPORT INSTRUMENTATION PACKAGE WITH THE TDRSS TRANSCEIVER COMMLINK SHOWN.

At this stage in the LDB development, TDRSS provides the most reliable and constant communication to the balloon payloads in order to operationally maintain safe flights. Future developments include using the transceiver with a high gain antenna, which will allow data rates approaching 150 kbps. Shown in Figure 1-2 are two typical ground tracks of flights in Antarctica with and without TDRSS coverage. Other types of satellite communication equipment haven't proven as reliable or near real-time as the TDRSS link.

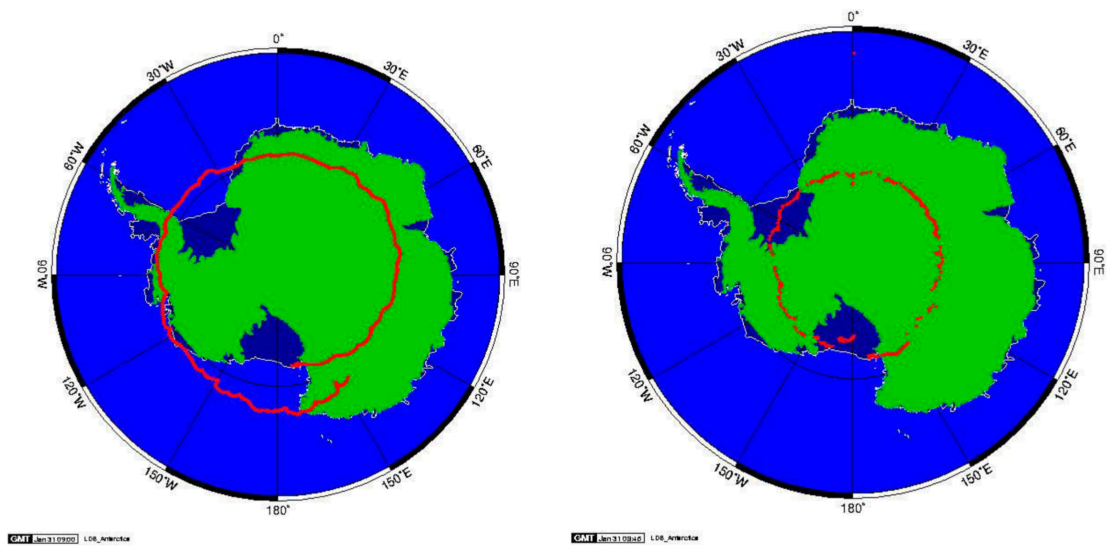

FIGURE 1-2. THE GROUND TRACK ON THE LEFT SHOWS THE CONTINUOUS REAL-TIME CONTROL AND TELEMETRY COVERAGE PROVIDED BY THE TDRSS FOR A RECENT ANTARCTIC SCIENTIFIC BALLOON MISSION. THE GROUND TRACK ON THE RIGHT SHOWS THE COMMUNICATIONS OUTAGES THAT OCCURRED WITH PRIOR SYSTEMS.

Typical science disciplines flown on LDB flights include, x-ray/gamma ray astronomy, upper atmospheric research, solar physics, high energy astrophysics, and infrared astronomy. With the TDRSS link, important science data can be relayed to the ground real-time nearly continuously.

2.0 TRANSCEIVER OVERVIEW

A functional block diagram of the transceiver is shown in Figure 2-1. The primary function of the receiver is to demodulate control command data and present it to the command decoder. The transceiver provides redundant command data, clock and lock indication interfaces for this purpose. Command data rates can be customized via firmware. For TDRSS mode operation, the transceiver design currently features eight data rates (125, 250, 500, 1000, 2000, 4000, 8000 and 16000 bps) but data rates up to 512 kbps are possible.

The transmitter accepts data from the balloon's data encoder and will phase modulate it (either QPSK or BPSK) on the downlink signal. Redundant interfaces are provided. The data is modulo-two added to the internally generated TDRSS PN spreading codes prior to the modulator for TDRSS transmissions.

The health and status information of the transceiver can be read serially via a NASA standard serial digital interface. Discrete bi-level status and analog telemetry is also provided. The transceiver design is tolerant of input power variation and will operate within specifications at any voltage between 21 to 35 volts DC.

Control of the transceiver operating modes is accomplished using discrete RS-422 line receivers. The line receivers must be driven to a logic one or zero condition and held in that state to retain the mode selection. The commands available include:

- PN codes ON/OFF (transmitter spreading codes enabled or disabled)
- Transmitter ON/OFF (turns the transmitter on and off)
- A/B Select (select which of two redundant data sources are to be transmitted)
- Data Rate HI/LO (choose from two forward link command data rates)

The transceiver is packaged as three modules (RF module, Digital Processor Module and Power Amplifier Module), which are stacked horizontally to form a rugged mechanical assembly. A photo of the transceiver is shown in Figure 2-2 and a system block diagram is shown in Figure 2-3.

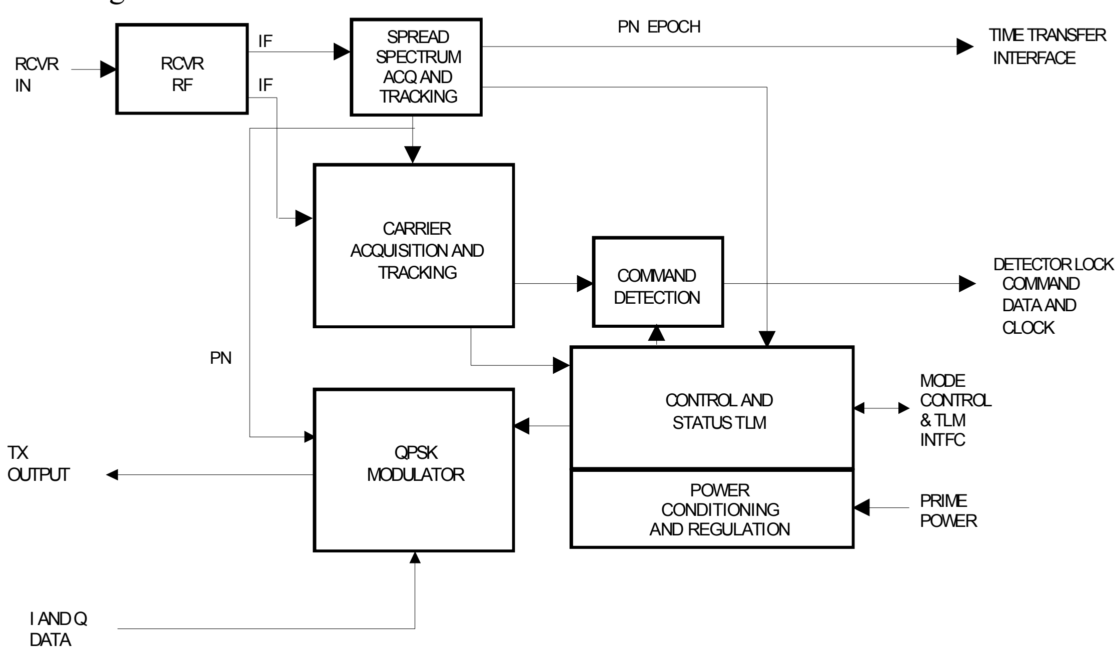

FIGURE 2-1: TRANSCEIVER FUNCTIONAL BLOCK DIAGRAM

2.1 RF MODULE DESIGN

The RF module is the top module in the stack and contains all of the radio frequency circuitry for the receiver and transmitter with the exception of the high power amplifier. The transceiver derives all of its internal frequencies from a single temperature compensated crystal oscillator (TCXO) located in the RF module. The oscillator frequency stability is better than 1 ppm from –15 to +55 degrees C. Good frequency stability allows the TDRSS ground station to accurately compensate the forward link signal for Doppler shift and oscillator uncertainties, which simplifies the signal acquisition process. The transceiver transmits and receives at the S-band frequencies allocated for space use.

In the RF module the S-band RF input to the receiver is amplified with a low noise amplifier (LNA) and bandpass filtered before undergoing a double RF downconversion to a second intermediate (IF) frequency. The local oscillator signal for the first downconversion is generated from the TCXO using a Phase Locked Loop (PLL) multiplier. This feature allows the receiver frequency to be changed easily via software. The PLL frequency is programmed by the microprocessor in the digital processor module via a three wire serial interface. The second IF frequency is output to the digital module for signal processing along with a buffered output from the oscillator which is used as the digital processor's system clock.

FIGURE 2-2 THE MULTIMODE TRANSCEIVER IS PACKAGED IN A LIGHT WEIGHT, RUGGEDIZED, MODULAR CONFIGURATION TO WITHSTAND THE HARSH ENVIRONMENTS OF HIGH ALTITUDE BALLOONING.

The receiver is able to accommodate over 90dB of input dynamic range (noise floor to max signal level) by leveling the second IF output power via a non-coherent AGC loop. The AGC control voltage is provided to the digital processor module for signal strength telemetry.

The transmit frequency is generated by a second PLL frequency synthesizer. The TX synthesizer consists of the PLL IC, the loop filter and a voltage controlled oscillator (VCO). The range of the VCO is sufficient to enable the synthesizer to generate all of the allowable TDRSS transmit frequencies. The output of the VCO drives the LO port of a Vector Modulator where the QPSK modulation takes place. The module receives I and Q baseband data signals to be transmitted from the digital processor module. These signals are low pass filtered prior to being applied to the modulator. This pre-modulation filtering limits the frequency spectrum of the transmit output to meet the power spectral density requirement imposed by the TDRSS specifications. The modulated output of the Vector Modulator is amplified prior to being sent out to the Power Amplifier module.

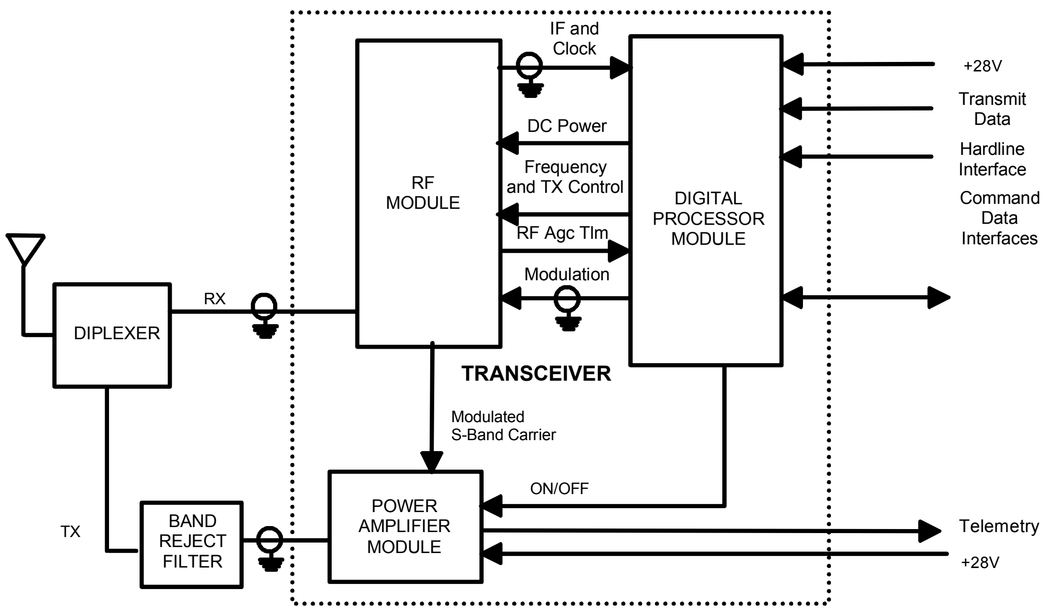

FIGURE 2-3 THE TRANSCEIVER CONSISTS OF THREE MODULES. A SEPARATE DIPLEXER AND FILTER ARE USED TO TRANSMIT AND RECEIVE ON A COMMON ANTENNA

2.2 DIGITAL PROCESSOR MODULE

The Digital Processor Module (DPM) provides the digital signal processing functions and also contains a DC to DC power converter, which converts the prime power input voltage to regulated secondary voltages for the transceiver's digital and RF circuits.

The majority of signal processing functions are contained in complex microcircuits. These circuits include the microprocessor, RAM, PROM and a CMOS Receiver Signal Processing ASIC (RX ASIC). The DPM also provides nearly all of the interfaces to the host vehicle including command data, serial telemetry, discrete control, transmit data, analog telemetry and bi-level telemetry.

The transmitter circuitry includes RS-422 differential line receivers for the data to be transmitted, a control circuit to select between the redundant data inputs, PN code generators and Exclusive OR gates to modulo-two add the data to the PN sequence and drive the vector modulator interface in the RF module. The DPM also provides control inputs and outputs for turning the transmitter circuits and the power amplifier on and off.

The receiver section of the module samples the second IF signal from the RF module with an analog to digital converter. The resulting digital signal samples are input to the RX ASIC for processing. The AISC implements the high clock rate functions that are too fast to be handled by the microprocessor. It:

- Generates a digital clocking signal for the PN code generators.
- Produces the PN codes for the receiver and transmitter.
- Despreads the PN spread TDRSS signal.
- Performs the final downconversion to baseband using a numerically controlled oscillator
- Includes Bit synchronizer loop, data detection and lock functions.
- Provides a digital AGC multiplier to scale the loop error signals.

The code and carrier tracking loops and the lock detector functions are implemented in the microprocessor's software allowing the flexibility of tailoring loop characteristics to mission unique requirements.

The DPM also contains a DC to DC power converter section that receives the prime input voltage (28VDC nominal) and generates the required DC voltages for the DPM and RF modules. Isolation of greater than 1M ohm between primary and secondary (chassis) is provided by a power transformer. A current limiter on the front end of the power converter limits in-rush current upon initial application of prime power.

2.3 POWER AMPLIFIER MODULE

The Power Amplifier (PA) module amplifies the modulated S-band TDRSS transmitter signal output from the RF module to a minimum of five watts. The transmit signal enters the PA module through an SMA connector passes through an input isolator and is amplified by a modular class A/B FET power amplifier which includes an output isolator which protects the PA against shorts or opens at the output. The output RF power is detected and conditioned to provide a "Forward Power" telemetry signal

The Power Amplifier module is turned on and off by the Digital Processor module via an optical isolator interface. It also contains its own DC to DC power converter. These features allow the Power Amplifier module to be remotely mounted near the antenna if desired to reduce cable losses in the RF output path. Temperature Telemetry is also provided via a thermistor that is mounted next to the power amplifier. The PA module is the highest power dissipator of the three modules and is placed at the bottom of the stack to facilitate the removal of heat through conduction in the vacuum environment encountered at high altitudes.

2.4 DIPLEXER AND BAND REJECT FILTER

In addition to the three transceiver modules, two external microwave filter assemblies complete the system configuration. The diplexer allows the transmitter and receiver to share a common antenna for simultaneous full duplex operation. It consists of two bandpass filters, one from the transmitter to the antenna port and the other from the antenna port to the receiver port. The Band Reject Filter (BRF) prevents desensitization of the receiver by rejecting broadband noise that the transmitter produces in the receive frequency band. The BRF is placed in series with the transmitter output and the diplexer's transmit input. The receiver relies upon the preselector filter in the diplexer to provide a portion of the required image and spurious rejection. For users with separate transmit and receive antennas, the receiver may need an external preselector filter if the diplexer is not used.

3.0 CONCLUSIONS

The National Scientific Balloon Facility provides scientists with the opportunity for high altitude research at a fraction of the cost of a scientific satellite mission. The TDRSS communications equipment supplied by General Dynamics Decision Systems allows the investigator to have continuous real time control and transmission of the science data during the NSBF missions. To learn more about the NSBF visit http://www.nsbf.nasa.gov/. General Dynamics information can be found on the web at http://www.gd-decisionsystems.com/space/.