NEAR REAL-TIME TELEMETRY UTILIZING SATELLITE COMMUNICATIONS

Ricky L. Maurer
Electronics Engineer
Naval Air Warfare Center Aircraft Division
Atlantic Ranges and Facilities Dept.
Patuxent River, Maryland 20670

ABSTRACT

Satellite transmission systems have proven themselves very effective in a variety of applications. One such application is the transmission of telemetry (TM) data and associated information in a near real-time environment. This paper describes the satellite data relay system currently utilized by the Telemetry Data Center at Patuxent River, Maryland and the corresponding remote receiving site, and discusses the performance of this system.

KEYWORDS

Near Real-Time Telemetry, Satellite Communications

INTRODUCTION

Over the past 25 years, satellite communications has experienced an extraordinary amount of development and growth and has become an important part of our daily lives. In the 1970s, it was first realized as a practical way of getting information from one point to another over long distances. The 1980s was a decade in which great strides were made in the development of satellite technology as a highly reliable transmission medium. Now, in the 1990s, satellite communications is an indispensable tool in our daily world of communication.

In the realm of telemetry processing, satellite communications has become a proven method of transferring data from one location to another in a near real-time environment. The term “near real-time” is used because there is a small delay ($\approx 1/4$ second) between the time of transmission from the test site to the time of reception at the receiving facility due to the satellite distance. Commercial satellite communications also lends itself very easily to protection using NSA-approved hardware. This helps provide a layer of security around sensitive information that is virtually transparent to system operation.

Another benefit of satellite communications lies in the fact that movement of personnel can be minimized because the data can now be sent directly from the test site to the facility where it is to be processed and analyzed. This is especially advantageous for long duration projects where it would be highly inconvenient for project personnel utilizing the data to move to a new location while the project is in an active state. In addition, the expense of moving the personnel and equipment to the test site is very high and requires long lead time planning and coordination. The benefits of satellite communications are therefore obvious, and once a satellite communications system is installed it can prove to be a great asset for many years.

HISTORY

The Telemetry Data Center (TDC) at the Naval Air Warfare Center Aircraft Division (NAWC-AD) at Patuxent River, Maryland has been using commercial satellite communications as an effective way of transmitting telemetry project data to off-site telemetry processing facilities since 1989. An initial concept validation test phase was performed between May 1982 and January 1983. This test was prompted by a requirement to send real-time telemetry flight data acquired at NASA Dryden on Edwards Air Force Base, California to the NAWC-AD TDC. Telemetry data from 16 F-14 and AV-8B flights was successfully relayed via existing NASA video earth stations from EAFB to NASA Wallops Flight Facility (WFF), Virginia. The data was microwaved from WFF to the NAWC-AD TDC for processing. This initial testing validated the concept and helped justify funding for a permanent satellite communications capability. Shortly after the Dryden test, Grumman Aerospace Corporation (GAC) installed satellite communications facilities at Dryden and Calverton, New York and used this system to conduct X-29 flight tests.

The first dedicated satellite link used by TDC was a full duplex circuit to Grumman at Calverton, New York for the F-14D program. This link had a data bandwidth of 3.152 Mbps (DS-1C) on the link to GAC and 256 kbps on the return link to TDC. This circuit was used on and off for a period of 4 years from 1989 to 1993. Various aircraft projects were conducted over this period with test flights approximately totaling 175. The information transmitted over the satellite link simultaneously included 3 to 4 streams of aircraft and missile data, Time Space Position Information (TSPI) data and a voice communications circuit which enabled all the players to talk on the same network. There was a large learning curve during the initial installation and testing, but after confidence was developed in the satellite communications system and the usage of it, the system performed reliably and with minimal failures throughout the years of flight testing.In late 1992, an urgent requirement arose to demonstrate that telemetry and other related project data could be transmitted real-time from NAWC-AD to the Naval Air Warfare Center Weapons Division (NAWC-WD) China Lake, California. China Lake did not own a satellite communications system; however, there was one at Edwards Air Force Base (EAFB) in California with some capacity available, dependent on scheduling and installation of special equipment. After much initial planning and preparation, equipment was installed at EAFB and test data was successfully transmitted to the satellite system located there and relayed via existing microwave links the remainder of the distance to China Lake. The total process of special equipment installation and successful testing was all accomplished within a day's time. The system configuration is depicted in Figure 1, NAWC AD to NAWC WD Satellite Telemetry Relay Demonstration.

In 1993 the Navy/Marine/Bell/Boeing V-22 program arrived at a financial crossroad: concurrent flight testing at both contractors' facilities was very expensive, overall program cost was a serious concern, and a new approach was needed. The program office decided to consolidate the test program at NAWC-AD, using an Integrated Test Team approach. Special telemetry data analysis facilities at the Bell Helicopter/Textron Inc. (BHTI) in Arlington, Texas were considered crucial to the program, therefore a method was needed to transfer telemetry data in real-time to that facility. Use of the satellite link was proposed and equipment was installed at both ends to accommodate an aggregate bandwidth of 6.312 Mbps (T-2). This would provide for two streams of aircraft data, time, voice and some overhead necessary for data integrity information. A return link from BHTI to TDC was established at a data rate of 56 kbps to provide a full duplex circuit. This return link to TDC was required for data integrity checks which help provide optimum performance from the link. Since its installation in August 1993, this system has been used on all V-22 test flights conducted at NAWC-AD and is still being used for all test flights and extensive playbacks of telemetry test tapes recorded during flight testing. It has been a highly reliable transmission medium for hundreds of flights and playbacks and accomplished this with minimal delays to the V-22 program.

SYSTEM ARCHITECTURE

The satellite communications system located at TDC is composed of three main subsystems: The telemetry front end multiplexing equipment, the fiber optic components and the satellite earth station hardware. The system located at BHTI is very similar except the multiplexing equipment is replaced by demultiplexing equipment. Figure 2, the System Block Diagram, illustrates the basic architecture of the satellite communications system configured from commercially available hardware.

TELEMETRY FRONT END MULTIPLEXING EQUIPMENT

The front end multiplexing equipment located at TDC consists of two separate multiplexers. The first of these is an MA1142 Analog Multiplexer made by Loral Data Systems. This unit provides for digitizing of 1, 2, 4, 8 or 16 analog parameters, with bandwidths up to 32 kHz for 1 parameter and 2 kHz for 16 parameters. The output of this device is an NRZ-L PCM data signal accompanied by a separate clock. The data rate can be selected as 7.8, 15.6, 31.2, 62.5, 125, 250, 500 or 1000 kbps depending on the bandwidth required by the input channels. The input and output voltage ranges are also jumper selectable for adaptation to the hardware being used.

The key component in the satellite communications system is the second multiplexer, an EMR 8210 High-Rate Intelligent Asynchronous Multiplexer also made by Loral Data Systems. This device provides for simultaneous acquisition of up to 12 independent serial digital inputs (channels) in a variety of configurations. The first two channels are reserved for T-1 Alternate Mark Inversion (AMI) encoded data streams where the clock signal is embedded in the data. The remaining ten inputs accept NRZ-L data streams, selectable among TTL, RS-232 or RS-422 (differential) interfaces, and having bit rates varying between 250 bps and 11.63 Mbps. Each data channel must be accompanied by a separate clock input. The EMR 8210 output trunk rate is jumper selectable among DS-1 (1.544 Mbps), DS-1C (3.152 Mbps), DS-2 (6.312 Mbps) and DS-A (12.928 Mbps) operating modes, with the aggregate data rate being 90 percent of the output trunk rate selected. The output signal interface is also selectable among fiber optic (TTL), AMI (bipolar) or KG (differential) levels, and can be randomized for better transmission of low density or fixed patterns.

TELEMETRY DEMULTIPLEXING EQUIPMENT

The corresponding demultiplexers located at BHTI also consist of two separate units. The counterpart to the MA1142 is a Loral Data Systems Model MA1233 Analog Demultiplexer. This unit restores the 1, 2, 4, 8 or 16 parameters digitized by the multiplexer to their original analog form. The demultiplexer's bit rate, number of channels and output channel levels correspond to the same specifications as the multiplexer, and the input PCM voltage can be jumpered for various levels. Output channel cards provide either a filtered, smoothed signal or an unsmoothed signal.

The demultiplexer used with the EMR 8210 is a Loral Data Systems EMR 8220 Asynchronous Demultiplexer. This unit reconstructs the data to the original form it was received in at the TDC before it was multiplexed by the EMR 8210. Its inputs are selectable to conform to the EMR 8210's trunk outputs and the 12 channel outputs can be selected to the same interfaces as the EMR 8210's inputs. The channel PCM outputs are accompanied by bit rate clocks, allowing direct connection to a PCM decommutator.

FIBER OPTICS COMPONENTS

The fiber optic links at both TDC and BHTI are identical to each other in all aspects except the length of the fiber optic cable between each facility and its earth station. Since both earth stations are located 1000-2000 feet away from the telemetry front end equipment, the satellite modems were moved from the earth stations into the telemetry facilities. On the NAWC-AD uplink, the Intermediate Frequency (I.F.) outputs (70 MHz $\pm$ 18 MHz) from the satellite modems are fed into fiber optic video transmitters which accept an incoming electrical video signal with a bandwidth of up to 120 MHz. The signal is then converted into a lightwave signal and sent over multimode fiber to the fiber optic video receiver at the earth station. There the receiver converts the lightwave signal back into the 70 MHz I.F. signal for connection to the earth station hardware. The downlink is similar to the uplink with one exception. The receive I.F. signal routed from the earth station via fiber is split into two signals 3db down and connected to a pair of satellite modems. The inputs to the fiber optic transmitters must be adjusted to video specifications (1 volt p-p at 75 ohms) for minimum bit error rate on the optical link.

SATELLITE COMMUNICATIONS EARTH STATION HARDWARE

The earth station located at NAWC-AD TDC incorporates a 12 meter C-band reflector and is termed the Satellite Communications Data Relay System (SATCOM DRS). The uplink digital data rate is currently T-2 but can be changed within two hours time to a T-1C rate. The SATCOM DRS also provides receive (downlink) capability for reception of test data from other sites. The main components of the system are the antenna and electrically-driven pedestal, the shelter with its support equipment, and the electronic hardware within the shelter. The antenna incorporates a dual polarization feed and redundant 80 ^{o}K low noise amplifiers.

The hardware within the shelter is fully redundant and has a microprocessor-based monitor and control unit for detecting faulty equipment and switching to a backup device in case of failure. This unit incorporates a dial-up modem which is utilized to report status to the satellite network control facility, as well as allowing remote transmitter control. The following redundant items are located within the shelter: Two crystal-controlled frequency upconverters with individual synthesizers, two 125 watt high power amplifiers (HPAs), and two crystal-controlled frequency downconverters with individual synthesizers. An antenna control unit is the final item located within the shelter. The satellite modems and modem redundancy switch were moved into the

TDC facility for ease of operation and remoted by the fiber optic transceivers which send/receive the IF signals to/from the TDC facility.

The earth station located at the BHTI facility in Arlington, Texas is very similar to the SATCOM DRS located at NAWC-AD in Patuxent River, Maryland. The antenna at BHTI is only a 5 meter dish and cannot uplink the data rates the SATCOM DRS can transmit, but it can easily receive the data transmitted to it by the distant system. The current uplink digital data rate for the BHTI system is 56 kbps (T-1 is possible) which is easily received by the 12 meter system at Patuxent River. The HPAs at BHTI are also smaller with a 75 watt power output rating. The other minor difference is that the upconverters and downconverters at BHTI have internal frequency synthesizers while the units at the NAWC-AD earth station are external. Both earth stations are configured from commercial hardware and maintained and operated by GTE Government Systems.

THEORY OF OPERATION

Telemetered data from the aircraft is routed from the receiving antennas to the front end processing equipment at TDC. This data is conditioned by bit synchronizers and input to the EMR 8210 Multiplexer as NRZ-L data signals and corresponding 90^{o} clocks. Up to 10 channels of data can be input to the EMR 8210 as long as the total aggregate bandwidth does not exceed 90% of a T-2 signal (5.68 Mbps). One of these channels is connected to the MA1142 Analog Multiplexer which digitizes two voice circuits and two redundant IRIG-B time code signals, and converts them to a 500 kbps NRZ-L data and clock signal. Also input to the EMR 8210 is a 56 kbps output of a test pattern receiver. This device provides a bit error rate test signal for a Telecommunications Techniques Corporation (TTC) FIREBERD 6000 Communications Analyzer at the distant end. The test pattern receiver was built in-house as a useful tool in logging the performance of the link.

Of the 5.68 Mbps bandwidth allowed by the EMR 8210, 5.124 Mbps is left available for the remaining 8 channels of input data. The V-22 aircraft data rate is 2 Mbps, which allows two aircraft to fly simultaneously and still provides over 1 Mbps of bandwidth for other purposes (tape playbacks, etc.). The EMR 8210 provides a T-2 composite data stream and associated clock signal as balanced differential outputs. These signals are then connected to the EF Data Corporation model SMS-651 Modem Switch as RS-449 levels. The modem switch is connected to two EF Data SDM-8000 Satellite Modems which contain built-in scramblers/descramblers, differential encoders/decoders, transmit and receive frequency synthesizers and multi-rate Forward Error Correction (FEC) convolutional encoders-Viterbi decoders. The modems are full-duplex, QPSK digital modulators/demodulators that operate at data rates from 9.6 kbps to 8.448 Mbps.

The SMS-651 checks both modems for faults and switches to the unfaulted modem if a failure occurs. The transmit I.F. signal it receives from this modem is then routed to the fiber optic transmitter for transmission to the fiber optic receiver located in the earth station. This signal is then input to the upconverters which shift the I.F. frequency up to C-band (5.9-6.4 GHz). From here, the HPAs boost the power to the level necessary for transmission, and the antenna/feed assembly radiates the carrier to the satellite. The transmit power level received by the satellite transponder is carefully controlled to minimize interference with other users.

The downlinked 3.7-4.2 GHz RF carrier received by the BHTI earth station's antenna/feed assembly is fed to LNAs which provide amplification with minimum noise addition. The downconverters then shift the receive RF carrier down to the 70 MHz I.F. signal and send it to the fiber optic subsystem for transmission to the BHTI TM processing facility. There the I.F. signal connects through a 1-to-2 splitter to both SDM-8000 Satellite Modems. The BHTI system does not have an SMS-651 Modem Switch, so the data input/output is hard-wired from a specific SDM-8000 and in case of failure must be manually switched to the backup modem. An SMS-651 Modem Switch is eventually planned for this system.

The SDM-8000 modem demodulates the I.F. carrier and outputs the reconstructed T-2 signal to the EMR 8220. The EMR 8220 Demultiplexer breaks out the individual channels into their original form, PCM data accompanied by clock. The aircraft 2 Mbps TM data is fed into the BHTI TM processing system for analysis and display. The 500 kbps analog multiplexed signal is inserted into an MA1233 Analog Demultiplexer which reconstructs the two voice channels along with the two channels of time. The other channel inserted into the EMR 8210 Multiplexer which carries the 56 kbps test pattern can be attached to a FIREBERD 6000 for bit error rate and system performance analysis.

The uplink from BHTI to NAWC-AD is initiated by a device built in-house for the purpose of providing a full duplex link capable of data integrity tests at the NAWC-AD end of the link. This device generates an NRZ-L test pattern at RS-449 levels and is sent to the satellite modems for transmission. The uplink from BHTI is very similar to the uplink from NAWC-AD with the exceptions that the data rate is lower and no modem switch is used. The downlink to NAWC-AD follows a similar route as the BHTI downlink except that it runs through the SMS-651 Modem Switch. The SMS-651 selects the modem that is not in fault and sends the 56 kbps data and clock signals to the test pattern receiver which synchronizes to the test pattern generated at BHTI and provides data integrity information which can be analyzed by a FIREBERD 6000.

SYSTEM PERFORMANCE

The satellite link between the TDC and BHTI facilities has operated very reliably from the beginning of operation. It has maintained average bit error rates in the range of 10^{-9} errors/second and has operated with a very minimal amount of down time. Each site has two predictable outages per year which occur for 20 to 40 minutes a day for a period lasting about 3 to 4 days. These are solar-related outages and occur when the sun's path crosses directly over the feed of the earth station's antenna. The other sources of down time have been split between scheduled preventative maintenance and the occasional equipment failure. The satellite communications equipment used at both the TDC and BHTI facilities is fully redundant, therefore link downtime occurs only if one of the multiplexing or fiber optic components experiences a failure. Typical contractor site maintenance visits only average about once per month. Both earth stations operate unmanned.

CONCLUSION

Commercial satellite communications has proven itself to be a reliable and economical method for transmitting high data rates between widely separated aircraft test locations. It is a mature technology, and for the Telemetry Data Center, has become a routine method of relaying telemetry, space position and voice data to another test range or aircraft contractor site where special purpose analysis facilities and data analysis specialists exist. The ease with which it is protected adds a layer of security to sensitive information and appears almost transparent to the data transmission process. Furthermore, with the advancements of technology in the field of fiber optics and the development of more robust multiplexing techniques, and improvements in data compression techniques and error correcting codes, satellite communications should be considered as an invaluable tool in aircraft flight testing for many years to come.

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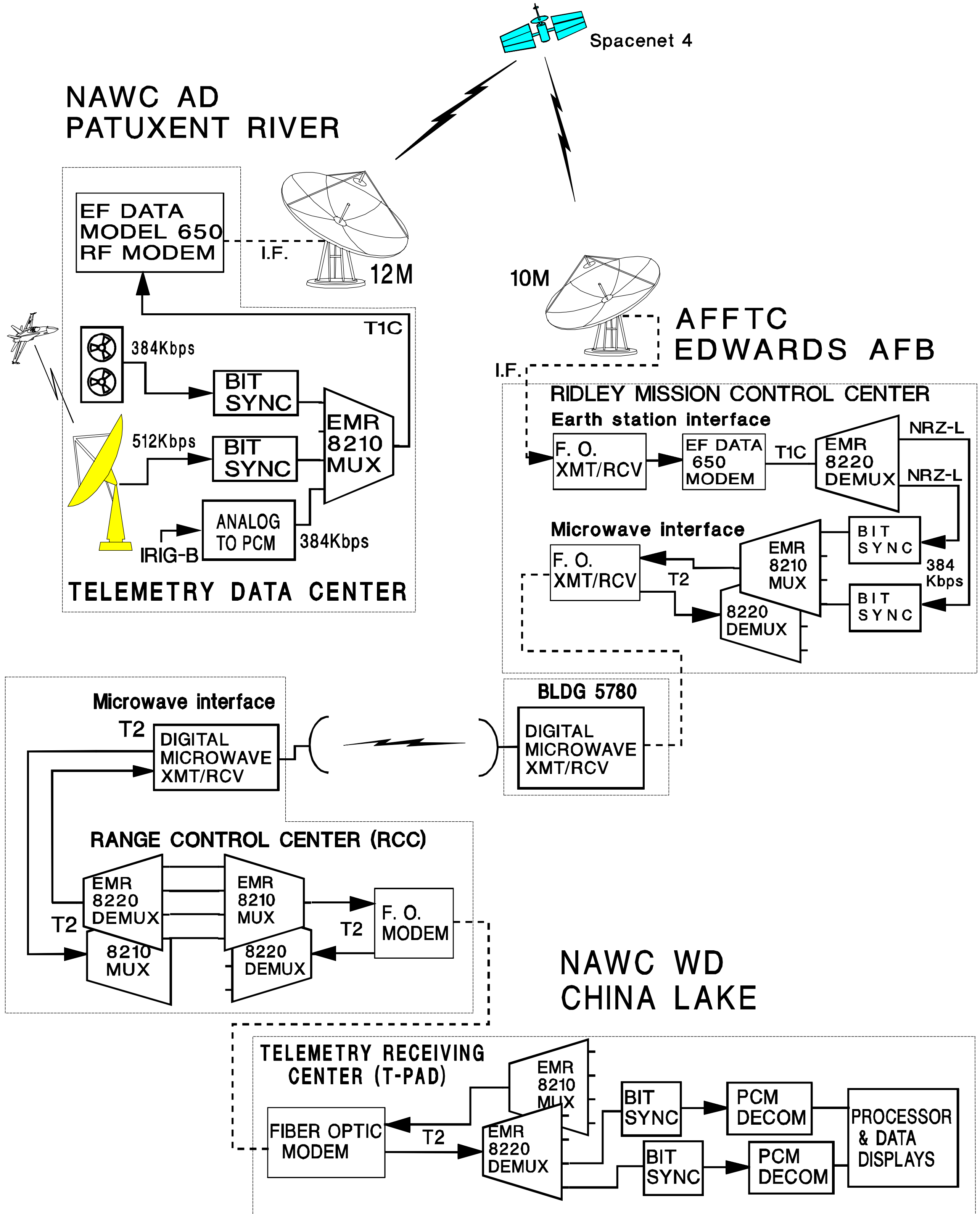

Figure 1. NAWC AD to NAWC WD Satellite Telemetry Relay Demonstration

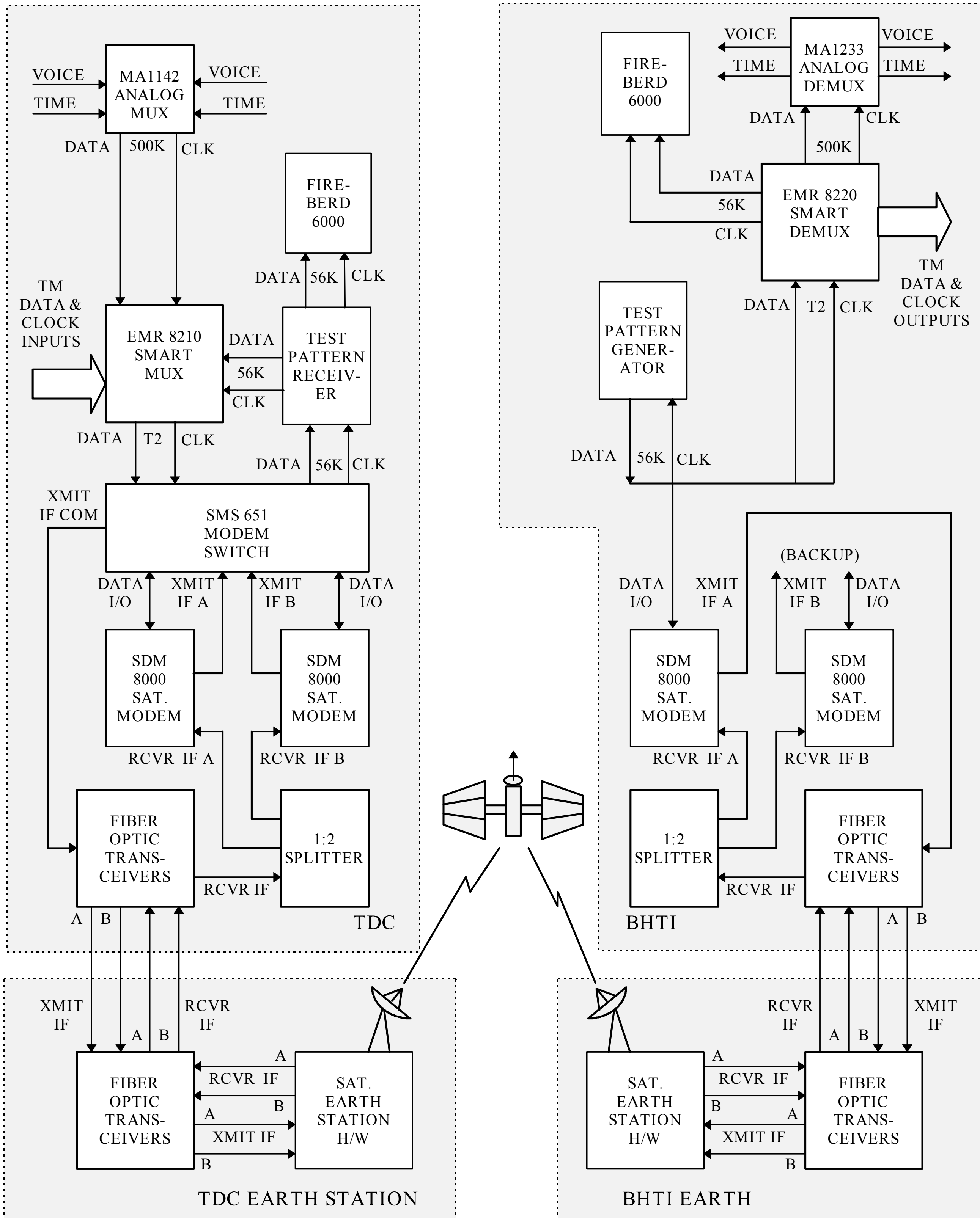

Figure 2. System Block Diagram