PTP EX:
HIGH-RATE FRONT-END TELEMETRY AND COMMAND PROCESSING SYSTEM

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ABSTRACT

This paper describes the PTP EX, a 160 Mbps Telemetry and Command front-end system, which takes advantage of the state-of-the-art in networking and software technology, and the rapid development in PC components and FPGA design. Applications for the PTP EX include High-rate Remote Sensing Ground Stations, Satellite/Payload Integration and Testing, High-rate Bit Error Rate Test (BERT) System and High-rate Digital Recorder/Playback System.

The PTP EX Interface Board, the MONARCH-EX PCI High Speed Frame Synchronizer/Telemetry Simulator with Reed-Solomon Encoder/Decoder, is designed with the following key capabilities:

- 160 Mbps serial input for CCSDS Frame Processing (Frame Synchronization, De-randomization, CRC, Reed-Solomon decoding, time stamping, quality annotation, filtering, routing, and stripping);
- 160 Mbps disk logging of Reed-Solomon corrected CCSDS frames with simultaneous real-time processing of spacecraft engineering data and ancillary payload data;
- Onboard CCSDS Telemetry Simulation with 160 Mbps serial output (Sync Pattern, background pattern, ID counter, time stamp, CRC, Reed-Solomon encoding, Randomization, and Convolutional encoding);
- Bit Error Rate Testing up to 160 Mbps (Pseudo-random transmitter and receiver with bit error counter).

The innovative architecture of the MONARCH-EX allows for simultaneous logging of a high-rate data stream and real-time telemetry processing. The MONARCH-EX is also designed with the latest in field-programmable gate array (FPGA) technology. FPGAs allow the board to be reprogrammed quickly and easily to perform different functions. Thus, the same hardware can be used for both Telemetry processing and simulation, and BERT applications.

The PTP EX also takes advantage of the latest advances in off-the-shelf PC computing and technology, including Windows NT, Pentium II, PCI, Gigabit Ethernet, and RAID subsystems. Avtec Systems, Inc. is leveraging the PTP EX to take advantage of the continuous improvement in high-end PC server components.

KEY WORDS

CCSDS, Reed-Solomon Coding, Data Logging, and Level-Zero Processing.

INTRODUCTION

Avtec Systems, Inc. PTP EX is a High-rate CCSDS Front-end Telemetry and Command Processing System. Applications for the PTP EX include High-rate Remote Sensing Ground Stations, Satellite/Payload Integration and Testing, High-rate Bit Error Rate Test (BERT) System and High-rate Digital Recorder/Playback System.

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- 160 Mbps serial input for CCSDS Frame Processing (Frame Synchronization, De-randomization, CRC, Reed-Solomon decoding, time stamping, quality annotation, filtering, routing, and stripping)
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- Bit Error Rate Testing up to 160 Mbps (Pseudo-random transmitter and receiver with bit error counter)

The PTP EX also supports CCSDS Telecommand (including COP-1), however this paper focuses on the Telemetry Processing capabilities of the system.

CCSDS PACKET TELEMETRY OVERVIEW

The Consultative Committee for Space Data Systems (CCSDS) has outlined a series of recommendations designed to promote standardization between missions, spacecraft, and member organizations. The recommendations on Packet Telemetry promote standardization in the end-to-end transport of mission data from application processes in space to distributed user application processes in space or on Earth.

In Packet Telemetry, multiple spacecraft processes generate data packets. The size and rate at which these packets are generated can vary depending on the requirements of the on-board process. A packet identifier header is then prepended to the data packets, and the variable size packets are inserted into fixed length Transfer Frames. Packets may span multiple Transfer Frames, up to the maximum allowed packet size.

Each Transfer Frame has a header containing a frame identifier field and frame sequence count information. The frame identifier field is used to define which Virtual Channel group that a particular Transfer Frame belongs. Virtual Channelization provides a method for organizing and prioritizing Transfer Frames. A particular Virtual Channel (VC) can be assigned for a specific type of data. For example, VC 0 is typically used for real-time, mission-critical and spacecraft housekeeping data. Other VCs can be assigned for playback telemetry or image data.

Once the Transfer Frame is created, it can optionally be encoded prior to transmission over a RF link. CCSDS defines a concatenated coding scheme with an inner Convolutional code and an outer Reed-Solomon code with block interleaving. Additionally, a CRC checksum can be added, and the data can be Randomized prior to transmission. **Figure 1** is a diagram of an encoded Transfer Frame with Packets.

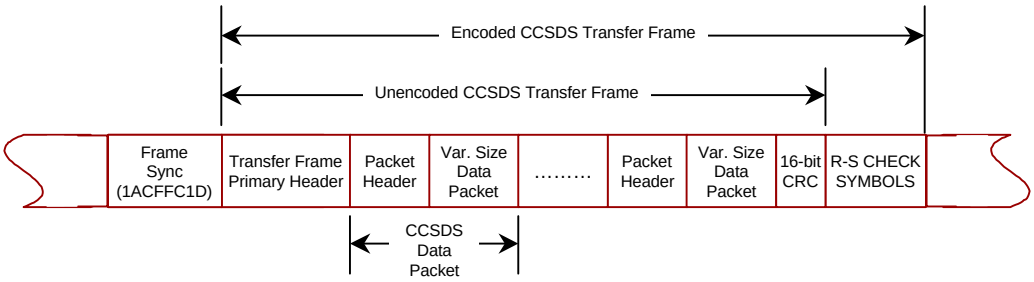

Figure 1: CCSDS Transfer Frame

As shown in **Figure 1**, the CRC checksum is calculated and appended to the end of the Transfer Frame. The Reed-Solomon codeblock is then generated and appended after the CRC. After the Reed-Solomon code is added, the Transfer Frame can be Randomized and Convolutionally encoded.

PTP EX SYSTEM ARCHITECTURE

The PTP EX System is based on the architecture of a standard PC server. A block diagram of the PTP EX system is shown in **Figure 2**. The standard PC architecture, Windows NT operating system, and the PCI bus allow for upgrade of all peripherals. No proprietary bus, CPU, or system architecture is used except for the MONARCH-EX PCI-based Frame Synchronizer/Telemetry Simulator with Reed-Solomon Encoder/Decoder.

The PTP EX system contains dual Pentium II 400 MHz processors with 256 MB SDRAM, built-in 10/100 Base T Ethernet, a 2 GB Ultra/Wide mirrored SCSI system hard drive, a CD-ROM drive, and a 1.44 MB floppy drive. The system's dual processors, mirrored system hard drive, and redundant hot swap power supplies provide high availability for mission critical applications.

The PTP EX system is configured with the Windows NT operating system and Avtec's PTP NT software. The PTP NT software controls all aspects of the PTP EX system.

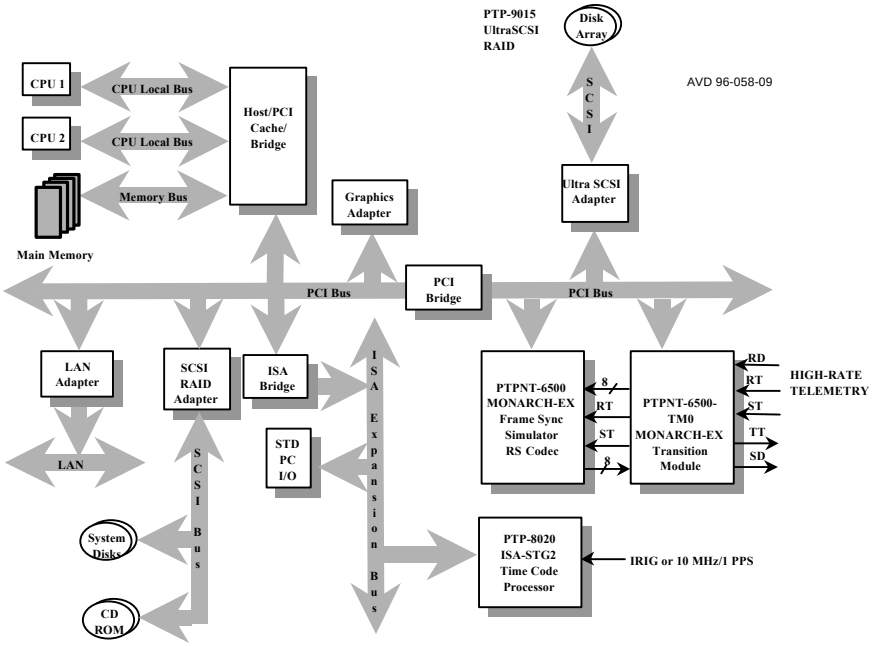

Figure 2: Block Diagram of PTP EX System

PTP NT SOFTWARE OVERVIEW

The PTP NT software controls all aspects of the system, including data flow and board configurations, via software modules. Each module represents physical interfaces including the network, disk, and Frame Synchronizer/Telemetry Simulator, as well as software processes such as the CCSDS Virtual Channel Processor, Packet Processor, and the File Recorder. All modules are loaded onto the PTP NT Desktop. **Figure 3** is a sample PTP NT Desktop with modules loaded and configuration windows open. Each module has its own configuration and status windows, specific to the component it represents. Once loaded, the modules can be connected in various ways to control data flow and input/output via the easy-to-use Graphical User Interface (GUI). The PTP NT can be controlled locally or remotely via a network socket interface.

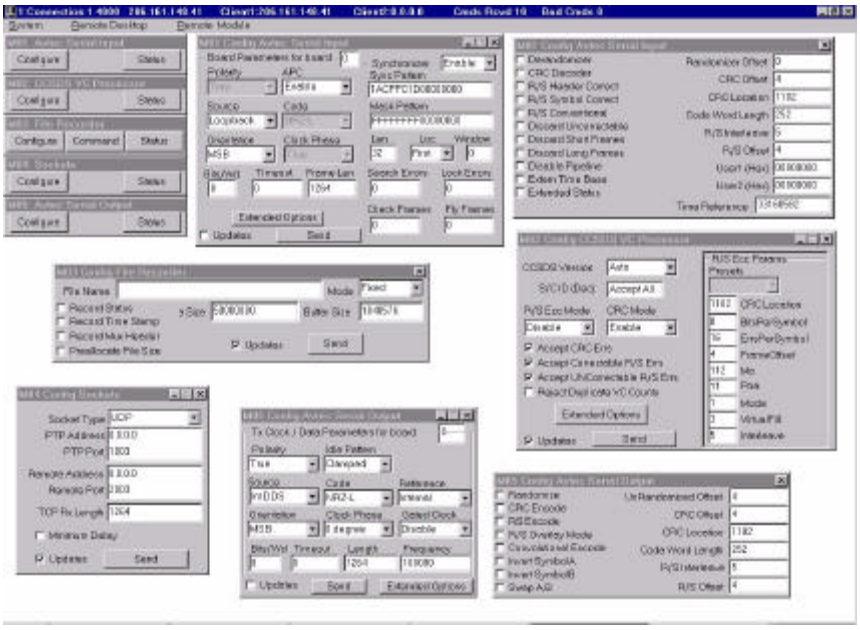

Figure 3: Sample PTP NT Desktop

MONARCH-EX OVERVIEW

The MONARCH-EX Frame Synchronizer/Telemetry Simulator with Reed-Solomon Decoder/Encoder is a two PCI board set. The MONARCH-EX baseboard performs all frame processing including Frame Synchronization, Derandomization, Reed-Solomon decoding, and Data Sorting based on Spacecraft ID and Virtual Channel ID at rates up to 160 Mbps. The MONARCH-EX baseboard also performs Telemetry Simulation at rates up to 160 Mbps. The MONARCH-EX is a bi-directional board, and as such, can simultaneously receive and process a 160 Mbps data stream, while simulating telemetry using onboard memory.

The MONARCH-EX accepts clock and data inputs via a differential ECL interface. The input/output interface on the MONARCH-EX is provided through a Transition Module, which resides in an adjacent PCI slot. The MONARCH-EX Transition Module is connected to the MONARCH-EX baseboard via two 8-bit parallel mezzanine busses. A block diagram of the MONARCH-EX is shown in **Figure 4**. The Transition Module provides the differential ECL serial interface and a Frequency Synthesizer for generating an internal transmit clock. The Transition Module converts the serial input stream to a parallel data stream and passes the parallel data to the MONARCH-EX base board for frame processing. The Transition Module accepts a parallel data stream from the MONARCH-EX baseboard and converts the data to a serial stream for output.

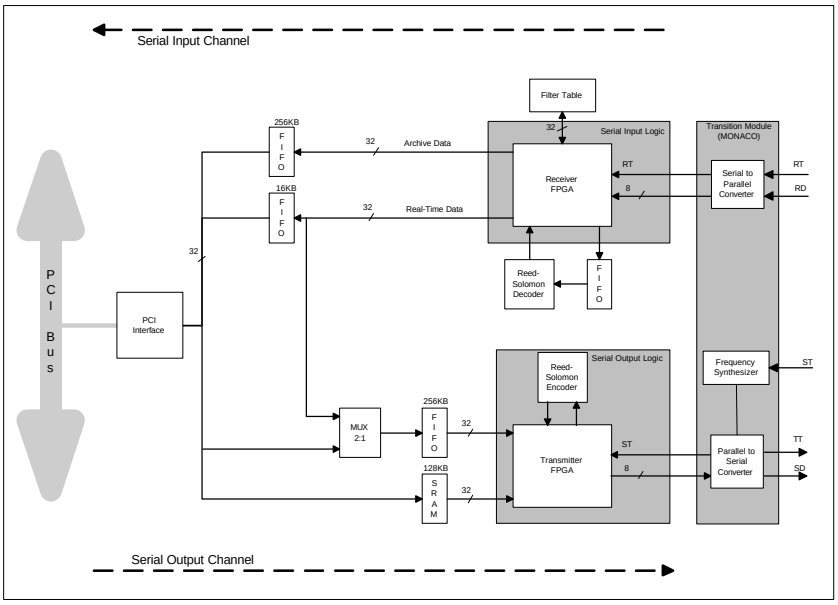

Figure 4: MONARCH-EX Block Diagram

PTP EX TELEMETRY PROCESSING

Figure 5 outlines the PTP EX System's CCSDS Telemetry Processing capabilities. The Coding Layer and Transfer Layer (Virtual Channel filtering) functions are all performed in hardware (MONARCH-EX). Packet Layer processing and data distribution is accomplished by the PTP NT software. Optionally, Transfer Layer functions can be performed in software.

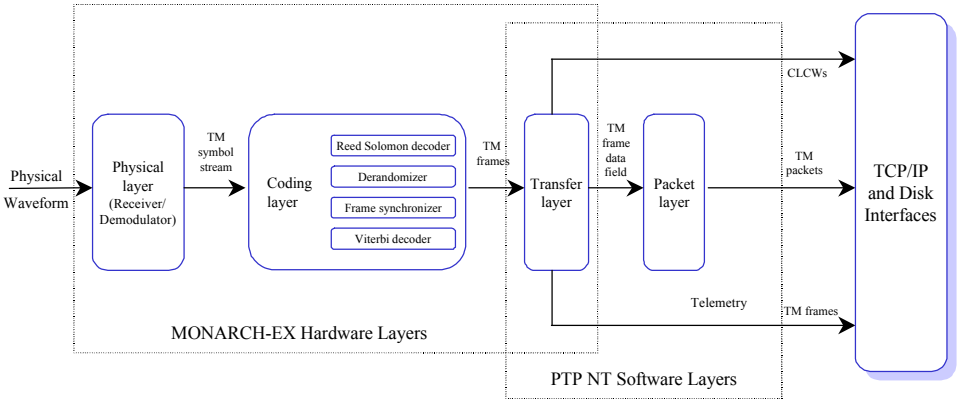

Figure 5: PTP EX CCSDS Telemetry Processing

HIGH RATE TELEMETRY ACQUISITION

The MONARCH-EX accepts high rate serial data in NRZ-L, S, or M format at rates up to 160 Mbps. It performs frame synchronization with auto-polarity correction, de-randomization, and Reed-Solomon error checking and correction (including VCDU header), and CRC error detection. The MONARCH-EX supports CCSDS Version 1 and

Version 2 frame formats and service grades 2 and 3. All of the Frame Synchronizer, De-randomizer, and Reed-Solomon decoding and error correction parameters are user programmable and can be bypassed. The MONARCH-EX appends a time tag with 1 microsecond accuracy and quality annotation to each frame that is received. The quality annotation includes the following fields: Frame Sync State, Autopolarity Flag, Bit Slip Flag, Loss of Sync Flag, CRC Check Flag, and Reed-Solomon Error Detection/Correction statistics.

The MONARCH-EX routes frames of data to the Archive path and/or real-time path based on a user specified field in the frame header. The MONARCH-EX contains a programmable filter that can be used to route frames of telemetry based on any 32-bit field within the first 16 bytes of the frame. For CCSDS frames, this allows filtering based on a combination of Spacecraft ID (SCID) and Virtual Channel ID (VCID). For non-CCSDS frames, this filter can be used to route based on sub-frame ID, or any other 32-bit field. Frames can be routed to the real-time path or the Archive path, both paths, or discarded. The data routing is accomplished using a Filter Table located in a Content Addressable Memory (CAM), which offloads a large portion of work from the CPUs. The Real-time telemetry is then passed along the real-time data path and taken in by the PTP NT for software processing. This includes AOS service processing and encapsulation for network transmission via TCP/IP.

The archive data is transferred directly from the MONARCH-EX to an UltraSCSI controller in a peer-to-peer fashion without CPU intervention. The Archive telemetry with quality annotation and time tag is logged to a single file on the UltraSCSI RAID system at rates up to 160 Mbps. The data file can be processed post pass to sort service data units into separate files for distribution.

The PTP maintains cumulative data quality statistics, including: count of frames received, frames archived, frames sent to the real-time path, frames with CRC errors, frames with RS errors, uncorrectable RS errors, bit slips, and dropouts.

SOFTWARE TELEMETRY PROCESSING (PTP NT)

The PTP NT software performs real-time service processing and network transmission. The PTP NT software can also be used to perform service processing and network data transfer on archive data post pass. The PTP EX real-time service processing data rates vary based on frame length, packet length, and the type of processing required (Virtual Channel processing and/or Packet processing).

The PTP provides support for both Version 1 (Conventional) and Version 2 (Advanced Orbiting Systems) of the CCSDS recommendations for packet telemetry. The PTP supports the following Conventional CCSDS services: Source Packet, Privately Defined

Data, Frame Secondary Header, and the Operational Control Field. The PTP supports the following CCSDS AOS services: Encapsulation, Multiplexing, Bitstream, Virtual Channel Access (VCA), Virtual Channel Data Unit (VCDU), and Insert.

The PTP supports service data unit processing using a collection of software modules. For example, the CCSDS Virtual Channel Processor Module de-multiplexes a data stream based on Virtual Channel ID. The sorted outputs of the Virtual Channel Processor module can be routed to File Recorder modules so that each individual virtual channel can then be logged to independent binary files. Selected service data units can also be transmitted in real-time over a TCP/IP socket to the local or remote host computers using the Network Sockets Module. PTP NT also provides a Packet Processor module that extracts CCSDS packets from selected VCDUs for network transfer or archive. These packets can then be written to independent, binary files based on APID (Application Process Identifier). The Bit Stream module extracts bit stream service data units from selected VCDUs for network transfer or archive. Each service processor module provides quality annotation based on the operations performed. The PTP service data processing and routing is completely user definable.

The PTP provides several ways to send data over a TCP/IP network. The PTP will autonomously send selected real-time telemetry to a TCP/IP (client or server) or UDP/IP socket port. The PTP also supports IP Multicast so that real-time telemetry data can be sent to multiple hosts simultaneously. A number of encapsulation modules are available to format the data prior to network transmission, including NASCOM RTP, IPDU, SFDU, LEO-T, and EDOS. The PTP's 100 Mbps Ethernet interface supports network transfer rates up to 10 Mbytes/sec. The actual network transfer rate depends on the selected protocol (TCP or UDP), the amount of network congestion, and the distance to the remote host (TCP acknowledge delay).

SIMULATION AND TESTING

The PTP provides the capability to simulate telemetry data for testing. The PTP can generate a CCSDS or TDM telemetry streams based on user definable parameters for the header fields and source data. The PTP can also transmit a stream read from hard disk or received from the network. The telemetry simulator parameters can be programmed via the local interface or by the host controller.

The MONARCH-EX generates telemetry frames and outputs serial clock and data at rates up to 160 Mbps. The MONARCH-EX Telemetry Simulator can read frame data from the PCI bus, or build frames from host provided data that is stored in onboard memory (CAM). The MONARCH-EX can overlay a sync pattern, ID counter, and time stamp before passing the frame to the encoders. The output channel performs CRC encoding, Reed-Solomon encoding, pseudo-randomization, and convolutional encoding.

The MONARCH-EX can be equipped with an optional Bit Error Rate Tester module. The Bit Error Rate Tester (BERT) provides the capability to transmit and receive pseudo-random number codes for end-to-end system testing. The BERT supports 160 Mbps full duplex operation. The BERT module supports the following pseudo-random patterns:

127 bit:	$x^7 + x^6 + 1$
511 bit:	$x^9 + x^5 + 1$
2047 bit (forward):	$x^{11} + x^9 + 1$
2047 bit (reverse):	$x^{11} + x^2 + 1$
32K bit:	$x^{15} + x^{14} + 1$
1M bit:	$x^{20} + x^{17} + 1$
8M bit:	$x^{23} + x^{18} + 1$

The BERT receiver uses a digital correlator to synchronize to the input data stream. This technique reduces sync loss due to noisy data. The receiver maintains the following statistics: computed bit error rate, bits received, bits in error, bit slips, and dropouts.

PTP EX CCSDS TELEMETRY PROCESSING PERFORMANCE

The PTP EX system performance varies based on several parameters. The first parameter being the type of data processing required – archiving only, archiving and real-time routing, Virtual Channel processing, Packet processing, and/or Network distribution. The other parameters include transfer frame length (for Virtual Channel processing), and packet length (for Packet processing).

The direct archiving capability of the PTP EX has been tested at rates up to 200 Mbps. Since data is passed directly between the MONARCH-EX and the RAID Controller, with the CPU only responsible for setting up the DMA transfers between the two, CPU utilization (averaged between two processors) is limited to 10-15% at 200 Mbps.

The PTP EX can perform real-time Virtual Channel processing in hardware or software. The PTP EX can process frame telemetry (i.e. filter based on VCID) at rates exceeding 9,000 frames per second. The rate varies based on the size of the transfer frame. **Figure 6** graphs the performance of the PTP EX versus frame length. The frame lengths used were derived from varying levels of interleave of the Reed-Solomon codeblock. An interleave depth of 1 is used for the 259 byte frame, up to an interleave depth of 8 for the 2044 byte frame.

The PTP EX can also perform real-time Packet processing in software (PTP NT). Packet processing involves extracting the multiple packets that may be embedded within each transfer frame. Each packet's header contains an Application Process Identifier (APID).

The PTP NT filters and sorts packets based on APID. The PTP EX can perform real-time Packet processing at rates up to 85 Mbps.

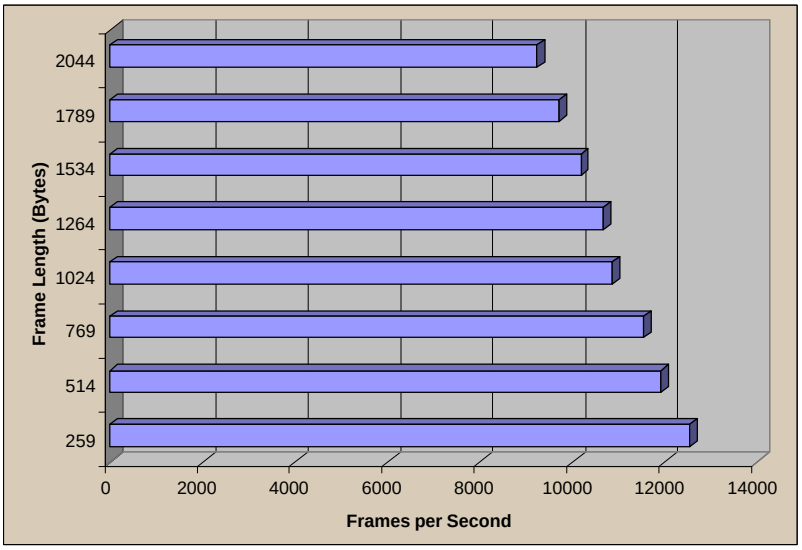

Figure 6: PTP EX Frame Processing Performance

Additionally, once the data has been processed at the Virtual Channel or Packet level, the data can be distributed via a network sockets interface. The PTP NT provides the built-in capability to transmit and receive data via TCP/IP, UDP/IP or Multicast. Processed frames and packets can be transmitted real-time via UDP at up to 40 Mbps on a Fast Ethernet (100 Mbps) network. All network transfer rates are limited by the amount of available bandwidth on a particular LAN. **Table 1** outlines these results.

Table 1: PTP EX Telemetry Processing Performance Specifications

Direct RAID Archiving	Up to 200 Mbps
Virtual Channel Processing	>9,000 frames per second
Packet Processing	Up to 85 Mbps
Network Transfer	Up to 40 Mbps

SUMMARY

The PTP EX High-rate CCSDS Front-end Telemetry and Command Processing System is based on Avtec's field-proven PTP NT software and next generation CCSDS board, the MONARCH-EX. The standard system architecture allows for ease in upgrading and keeps overall cost down.

The MONARCH-EX board architecture offloads processes from the system CPUs and uses the PCI bus at maximum efficiency. This is accomplished by sorting the real-time data and payload data onboard, providing a direct route from the MONARCH-EX to the

Ultra/SCSI RAID subsystem for archiving the payload data via the PCI bus, and passing only the low-rate real-time data to the system for further processing.

The above features allow the PTP EX to be ideally suited for High-rate Remote Sensing Ground Stations, Satellite/Payload Integration and Testing, High-rate BERT and High-rate Digital Recorder/Playback System applications.