# DESIGN AND USE OF A CCSDS-COMPATIBLE DATA UNIT DECODER

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## ABSTRACT

The Consultative Committee for Space Data Systems (CCSDS) formulates and publishes recommendations for space data system standards. CCSDS Recommendations define a layered data communications network along the lines of the OSI model. In the space link layer (OSI Data Link layer) fixed length blocks of CCSDS Packets are generated and multiplexed into the data field of Virtual Channel Data Units (VCDUs) in the Virtual Channel Access Sublayer. VCDUs with error correction coding become CVCDUs (coded VCDUs). CVCDUs (or VCDUs) with an attached sync marker become Channel Access Data Units (CADUs) which are transmitted on the Physical Space Channel.

This paper discusses AYDIN's DEC012 Data Unit Decoder, a VMEbus circuit card which recovers Virtual Channel Data Units (VCDUs) from corrupted Channel Access Data Units (CADUs) received on the Space Link Subnet of a CCSDS-compatible space datacomm link. The module's design and operation is described along with its use in the X-ray Timing Explorer (XTE) and Tropical Rainfall Measuring Mission (TRMM) science satellite programs run by NASA Goddard Space Flight Center.

## KEY WORDS

CCSDS Data Unit Decoding, Space Data Systems, VCDU, CVCDU, CADU, Viterbi Decoding, Reed-Solomon Decoding, Frame Synchronization.

## INTRODUCTION

AYDIN Computer and Monitor Division developed its Model DEC012 CCSDS Data Unit Decoder for use in integration and test of the NASA X-ray Timing Explorer (XTE) and Tropical Rainfall Measuring Mission (TRMM) science satellites. These satellites, and indeed most of NASA's scientific spacecraft to be launched in the 90's, adhere at least to some extent to CCSDS Recommendations for space data communications.

CCSDS, the Consultative Committee on Space Data Systems, is an international body that formulates and publishes recommendations for space data system standards. NASA and many other of the world's national space research agencies are members or observers in CCSDS.

In an effort to standardize space data communications CCSDS has produced Recommendations that specify a layered communication systems architecture for space data systems. Such systems can include manned and unmanned space vehicles operating at a wide range of user data rates, servicing a large number of users conducting a broad spectrum of scientific, engineering, and commercial investigations. These system characteristics require the flexibility that can only be provided by a packet-based data communication system architecture.

The CCSDS Recommendations define a data communications network along the lines of the OSI model. (See figures 1 an 2.) In the space link layer (OSI Data Link layer) fixed length blocks of CCSDS Packets are generated and multiplexed into the data field of Virtual Channel Data Units (VCDUs) in the Virtual Channel Access Sublayer. The VCDUs are generated by attaching header and trailer and applying error correction to the fixed length blocks. VCDUs with error correction coding are called coded VCDUs (CVCDUs). (See figure 3.)

Error correction includes Reed-Solomon coding (outer code) and convolutional coding (inner code). The bit stream can also be pseudo-randomized to ensure adequate transition density and differentially encoded to provide immunity to transmission link polarity inversion. In the absence of error correction coding the VCDU can have a CRC frame check sequence appended to provide error detection. The last process in the Virtual Channel Access Sublayer makes a Channel Access Data Unit (CADU) from the CVCDU by appending a synchronization pattern (Attached Sync Marker-ASM). A continuous and contiguous stream of fixed length CADUs is transmitted through the physical layer over the Space Link Subnet.

A receiving terminal at a ground station on the space link subnet must decode CADUs by applying a combination of Viterbi and differential decoding, derandomization, and Reed-Solomon decoding. These decoding processes provide error-corrected VCDUs to the OSI Data Link Layer. So-called Level Zero Processing in the Data Link Layer processes the VCDUs, extracting user data packets for delivery.

## DECODER DESCRIPTION

The AYDIN DEC012 CCSDS Data Unit Decoder, figures 4 and 5, is a 6U VMEbus circuit card. It executes decoding functions in whatever combinations necessary to recover VCDUs from CADUs received on the Space Link Subnet. The DEC012 receives coherent NRZ-L PCM serial data and clock from a Bit Synchronizer at rates up to 20 Megasymbols per second, and hands off decoded VCDUs with ASM and appended status trailer to a host processing system for Level Zero Processing.

The DEC012 Data Unit Decoder module was designed by Aydin Corporation's Computer and Monitor Division in response to a specification written by the Electrical Engineering section, code 733, at NASA Goddard Space Flight Center (GSFC). DEC012 modules are in use at GSFC where they support Integration and Test of the XTE and TRMM science satellite programs. DEC012 modules are also in use at Johns-Hopkins Applied Physics Labs and at Telenetics supporting the ACE (Advanced Cosmic Explorer) and NEAR (Near Earth Asteroid Rendezvous) science satellite programs.

The hallmark of the DEC012 is the sheer amount of error detection and correction, synchronization, and decoding power provided in a 6U x 160mm VMEbus module. These functions involve Viterbi decoding, frame synchronization, derandomization, Reed-Solomon decoding, and CRC checksum verification. Each of these functions is individually programmed into the process so as to accommodate wide variations in the encoded bit stream format.

## DEC012 OPERATION

Viterbi decoding provides error correction for convolutionally-coded data. The DEC012 processes rate 1/2, constraint length 7 convolutionally-coded bit streams. It accommodates alternate symbol inversion and affords programmable metric normalization rate settings for symbol node synchronization. The Viterbi decoding process also calculates bit error rate for the received bit stream.

Frame synchronization is necessary for derandomization, Reed-Solomon decoding, and CRC checking as these are all frame synchronous processes. The DEC012 incorporates AYDIN's full-featured frame synchronizer on a chip. This ASIC provides frame synchronization pattern correlation for patterns of up to 64 bits and with error tolerances of up to 25%. Frames can be up to a million bits in length. (CCSDS CADUs however are limited to a maximum size of about 16,000 bits.) Programmable synchronization strategy allows balancing synchronization decision time and decision confidence. Bit stream inversion is detected and corrected automatically by the ability to recognize complemented synchronization patterns.

Bit stream derandomization is provided. This feature would be invoked to remove a cover sequence applied in the spacecraft data system to insure a minimum transition density in the transmitted bit stream.

Reed-Solomon coding of the baseband bit stream provides powerful burst error correction to protect the transmitted data from the effects of a burst-noise space channel. The Reed-Solomon code specified by CCSDS for Virtual Channel Data Units corrects up to 16 symbol errors in a codeword size of up to 255 eight-bit symbols. The trailing 32 symbols in the transmitted codeword are check symbols computed by the Reed-Solomon coding algorithm. Where the space channel burst error characteristics might overwhelm even this level of error correction codeword symbol interleaving is employed to provide greater levels of burst error protection. Codewords can be interleaved symbol-by-symbol to a depth of up to eight. The interleave depth used for XTE and TRMM is five which means that error bursts of up to 80 symbols (640 bits) can be tolerated.

The DEC012 provides Reed-Solomon decoding for codeword sizes of from 228 to 255 symbols and interleaving depths of from 1 to 8. The DEC012 deinterleaves the symbol stream before applying Reed-Solomon decoding and reinterleaves the decoded codeword symbol groups to recover the transmitted symbol ordering. (The spacecraft interleaving process does not actually change the order of the baseband data octets but merely routes each octet from every group of I octets to a different R-S coder. The output port of each R-S coder is tapped in turn to generate the transmitted symbol stream.)

Note that the R-S code is a systematic code which means that the data octets applied to the coder appear at the coder output port unchanged. The coder merely computes and appends check symbols to octet groupings of from 196 to 223 symbols. The DEC012 removes the check symbols after codeword correction and passes the corrected data stream with R-S status bytes in place of the check symbols. The status bytes tell how many symbols were corrected in each codeword, or whether the codeword was uncorrectible (more than 16 symbol errors).

When the space data system constraints do not allow the use of error correction, CRC error detection might be employed to flag VCDUs that are corrupted in transmission. The DEC012 can compute a CRC on the received frame including transmitted CRC to detect errored frames. It will flag the errored frame in the appended status trailer and report a running count of errored frames.

Decoded, corrected (or flagged) VCDUs are passed in 16-bit parallel, word serial form through a FIFO-buffered DEC DR11W-compatible interface to a host computer or workstation for processing of the packets transported by the Virtual Channel Data Units.

The DEC012 keeps running counts of such things as Viterbi decoder node sync losses, errored frame sync patterns, frame slips, uncorrectible R-S codewords, and CRC errors. These can be read by the VME host CPU over the VMEbus. The DEC012 will alert the VME CPU to signal input loss, loss of frame synchronization, and FIFO overflow conditions by asserting a VME IRQ.

The DEC012's capabilities described above allow the coding gain that can be achieved by the use of concatenated Reed-Solomon and convolutional coding to be realized in a compact, economical manner in the space subnet ground station. It merges decoding, synchronization, error detection and correction, quality annotation, FIFO-buffering and computer interface in a compact 6U VME card. This high level of integration allows the use of less sophisticated bit synchronizers, does away with the need for a separate frame synchronizer, and relieves the processing software of having to compute quality indicators for the received VCDUs as this information is provided by the DEC012.

## USE OF THE DEC012 IN SATELLITE INTEGRATION AND TEST

The DEC012 is used in the Front End Data System (FEDS) in the XTE and TRMM Integration and Test (I&T) Ground Support Equipment (GSE) to receive, decode, error-correct, and annotate CCSDS VCDUs. (See Figure 6.) In the context of the FEDS the DEC012 is referred to as baseband equipment (BBE) since it brings the coded symbol streams back to baseband.

The FEDS is a component of the spacecraft GSE and provides the telemetry downlink and command uplink interface to the spacecraft. The FEDS is responsible for receiving and decoding CCSDS VCDUs received in CADUs, extracting packets from the VCDUs, and distributing the packets to the various users. The users in this case are Test Conductor Workstations (TCWs) and instrumenter GSEs (IGSEs). The operators of the TCWs and IGSEs monitor specific telemetry points, and send commands to the spacecraft in support of spacecraft I&T and during launch activities.

The FEDS includes a VME crate, a UNIX-based workstation, and support networking equipment as shown in Figure 6. The VME crate contains five Single Board Computers running the realtime operating system VxWorks, 192 MB RAM, two DEC012 decoders, and two DR11W parallel interfaces. The VME crate performs the more critical realtime functions of the FEDS including telemetry decoding, error correcting, data annotation, data buffering, sorting and pre-screening of VCDUs. The UNIX-based workstation (250 SpecMark DEC Alpha) performs packet extraction by Virtual Channel and distributes the packets to the TCWs and IGSEs. All packets or a subset of packets may be distributed to the users in realtime based on their requirements.

In support of spacecraft I&T it was required that the FEDS be capable of changing decoder modes and frame lengths on the fly in order to match all the possible spacecraft encoder modes. Frame acquisition strategy varied depending on tests being performed. Because of these requirements, the decoder cards needed to be closely coupled to the computers performing data processing and had to be capable of being reconfigured and reset with little or no operator intervention. The capabilities of the DEC012 described in this paper provide all the necessary programmable features required to support I&T of the XTE and TRMM spacecraft.


## ACKNOWLEDGEMENTS

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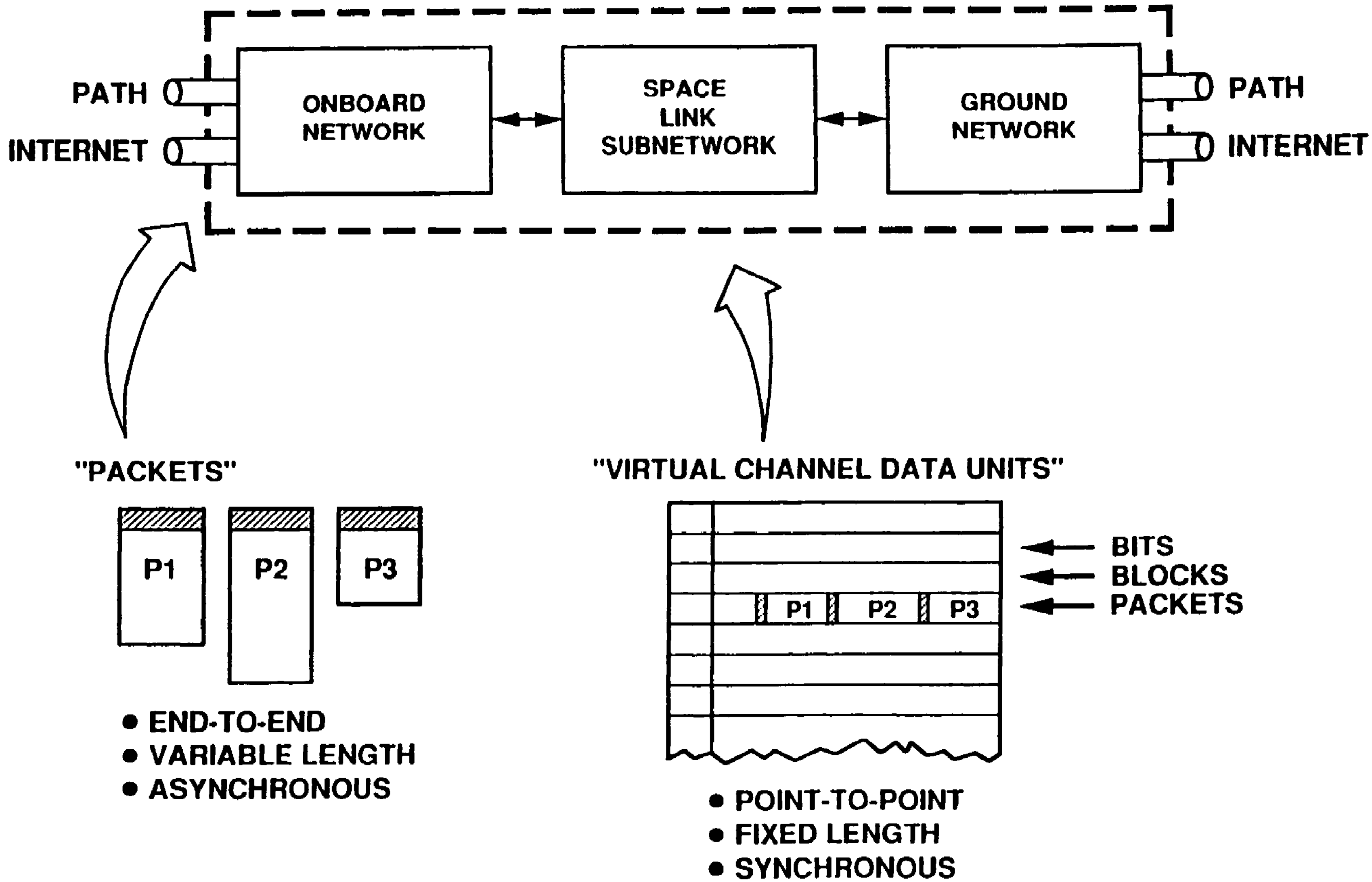


Figure 1 CCSDS Principal Network *

* Workshop for CCSDS Implementors, November 1992, GSFC

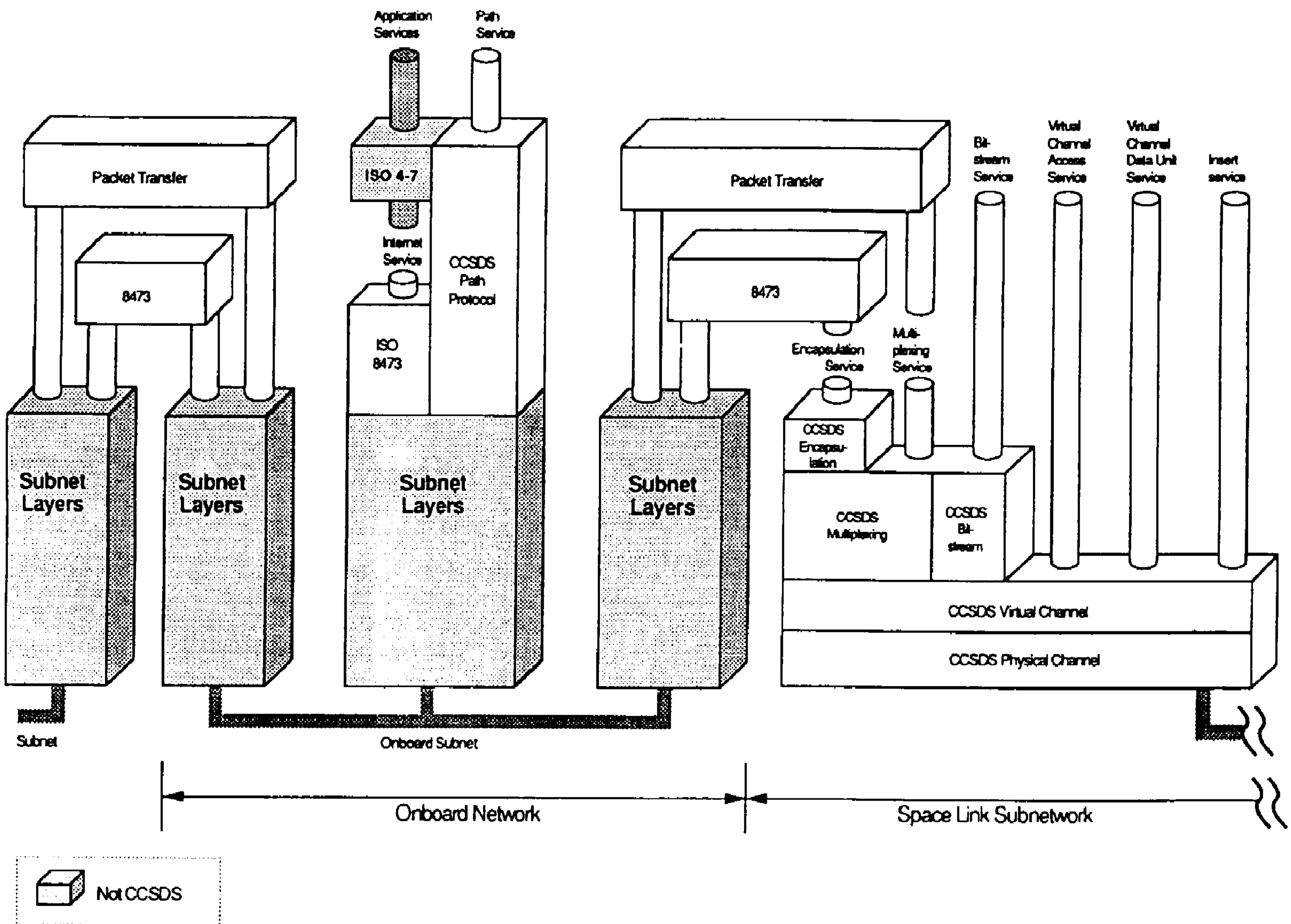


Figure 2 CCSDS Principal Network Service Model-Space Segment *
* CCSDS 700.0-G-2

# VIRTUAL CHANNELS

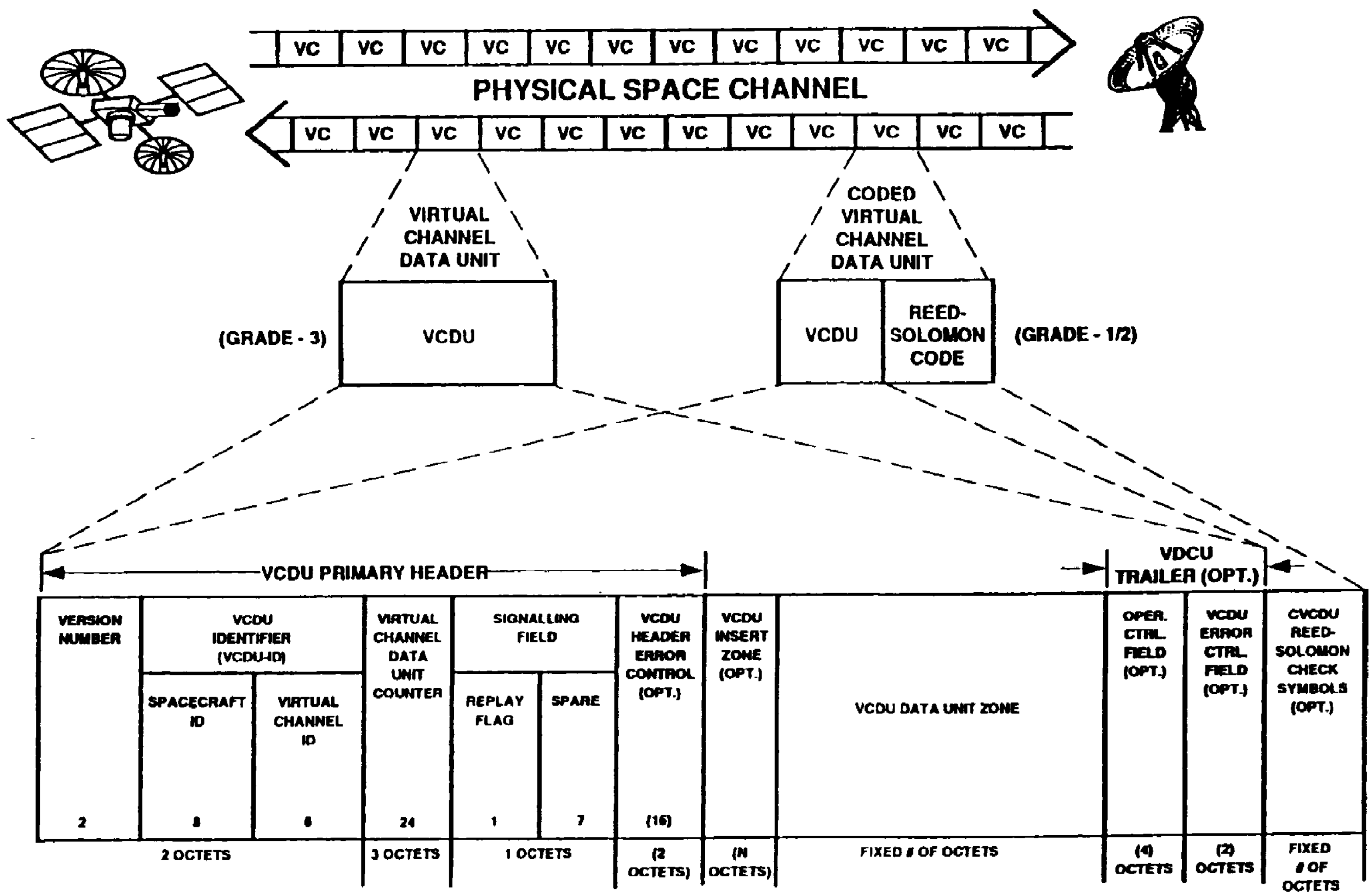


Figure 3 CCSDS Space Link Subnetwork *
* Workshop for CCSDS Implementors, November 1992, GSFC

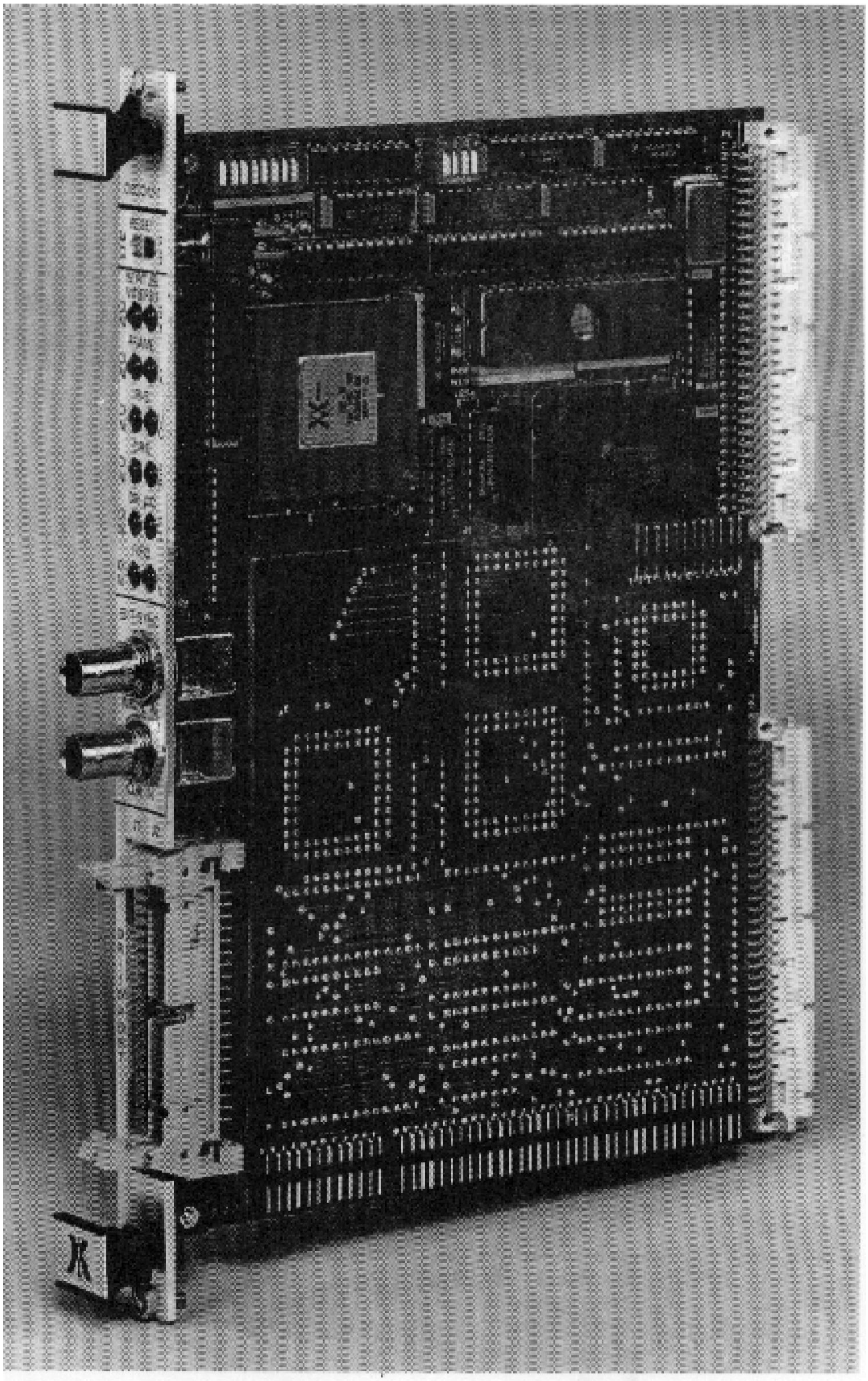

Figure 4 DEC012 Baseband Decoder Module, 3/4 View

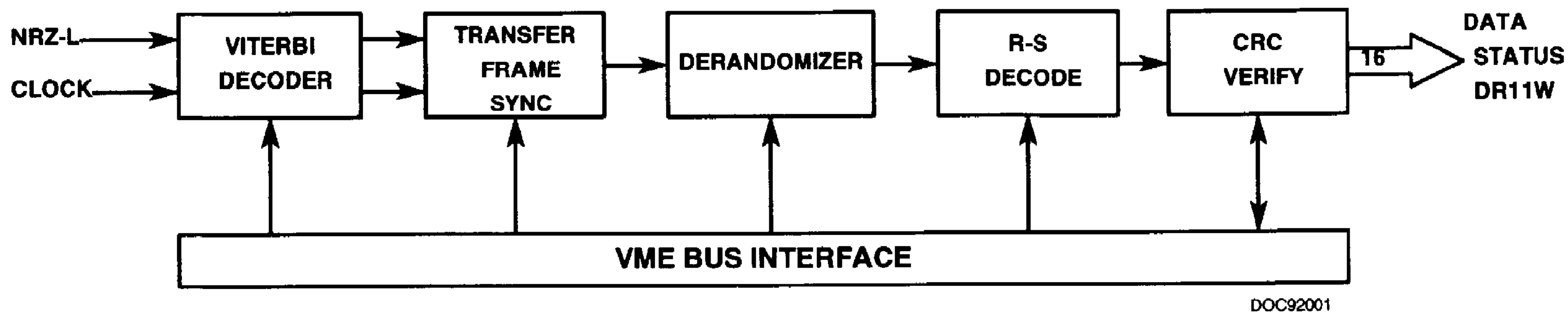


Figure 5 DEC012 Baseband Decoder, Simplified Block Diagram

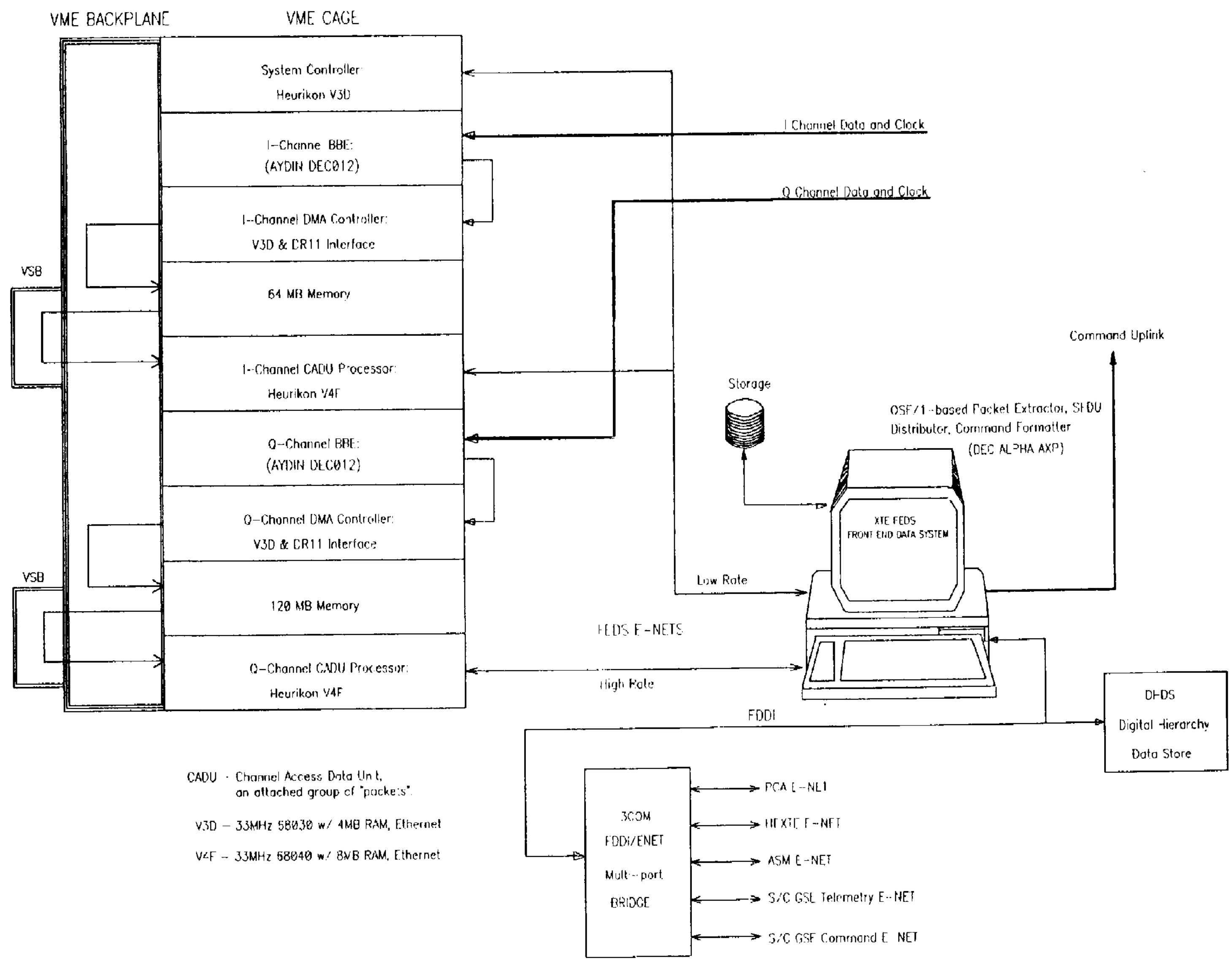


**Figure 6 XTE Front End Data System**