THE DESIGN OF A VIDEO ACQUISITION SYSTEM FOR JSF

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ABSTRACT

The F-35 program, known as the Joint Strike Fighter (JSF), is the largest DOD program ever awarded. There are three F-35 variations, each intended to meet the specific needs of the Air Force, Navy, Marine Corps, and Allies. The F-35 Joint Strike Fighter represents the newest advanced military aircraft to make use of Fibre Channel as its primary avionics information transport network. In addition to its use for carrying tactical information systems data, the Fibre Channel network will also transport the real-time digital video used in the cockpit; primarily the pilot's helmet mounted display (HMD) and the high-resolution configurable panoramic cockpit display (PCD). In addition to the fighter's instrumentation configuration for orange wire and avionics data, the aircraft will carry a separate instrumentation package to allow for both the recording and telemetry of either high-resolution Fibre Channel digital video or standard resolution analog video inputs during flight tests. This multiplexer is designed to record cockpit video and audio data, while supporting an option for the test engineer to select up to three out of eight video and audio inputs for real-time telemetry to the ground. This paper describes the architecture of this system, along with the techniques used to reduce the 5 MBps Fibre Channel digital video to a bandwidth acceptable for telemetry.

KEYWORDS

Video, Instrumentation, Recording, MPEG-2, Cockpit, Telemetry

INTRODUCTION

The F-35 Joint Strike Fighter represents the newest advanced military aircraft to make use of Fibre Channel as its primary avionics information transport network. In addition to its use for carrying tactical information system data, the Fibre Channel network also transports the real-time digital video used in the cockpit; primarily the pilot's helmet mounted display (HMD) and the high-resolution configurable panoramic cockpit display (PCD). As an element of the flight test program for the aircraft, it is required that these three video sources are included as part of the instrumentation's recording capabilities. An additional goal of the program is to provide real-time telemetry of a subset of this display data to the ground for analysis and interpretation. Given the data rates involved and the immaturity of the technology being proposed, this task has proven to be difficult to accomplish. Specialized hardware and software, both in the air and on the ground has been developed to accomplish this objective. This paper will examine, in detail, the top-level constraints and requirements of the project, the system architecture developed to implement the program requirements and an overall description of each of the individual components of the solution.

AIRCRAFT ARCHITECTURE

The pilot's primary display on the F-35 is the Panoramic Cockpit Display (PCD). This display is composed of left and right components, referred to as the display management computer (DMC) left (DMCL) and right (DMCR). In addition, the pilot will wear a helmet mounded display (HMD) referred to as the Enhanced Helmet Display Processor (EHDP) or DMC-Helmet (DMCH). In this paper, the terms DMCL, DMCR and DMCH will be used to refer to each of these components. The visual displays on the F-35 are capable of displaying graphics, digital video and digital video with a graphic overlay. In order to record the information as it is presented to the pilot, the composite display information must be monitored after all the graphics overlay processing is complete. This can be done by recording output of the graphics processor to the aircraft's Portable Memory Device (PMD) or with the onboard instrumentation. A high-level system diagram for the components associated with each display is shown below:

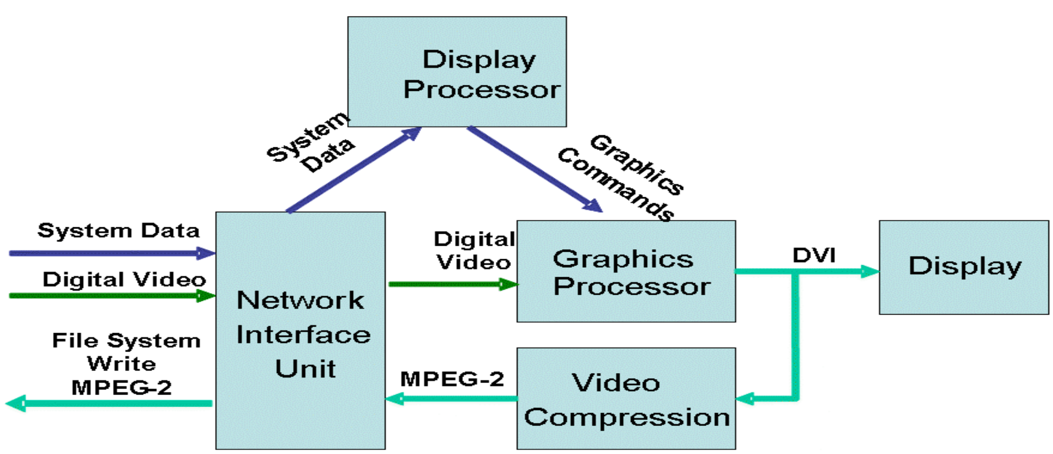

Figure 1: JSF Video Display Data Flow

Each display (DMCL, DMCR, and DMCH) is built from either real-time digital video (such as that generated by an on-board sensor or camera) and/or real-time system data from the aircraft (such as speed and direction). Both kinds of information arrive at the display network interface through the aircraft Fibre Channel switched network. The digital video is passed directly to the graphics processor, while the system data is sent to the display processor. This will then generate a set of commands to be used by the graphics processor for constructing a real-time overlay for the digital video. The output of the graphics processor is sent through a digital video interface (DVI) to the LCD display for direct viewing by the pilot (either as part of the panoramic display or through the helmet) and additionally to a MPEG-2 video compression unit. The output of video compression engine is encapsulated into Fibre Channel frames and re-transmitted back into the network for recording by the aircraft or for use by the flight instrumentation system. In addition to the digital video component of the aircraft, digital audio (from the cockpit microphone) is also transmitted on the Fibre Channel network in its raw form. The JSF program also requires that conventional analog video and audio inputs into the instrumentation system are available. The specifics of each of the six types of input sources that can be presented to the video instrumentation system are as follows:

Type	**Resolution**	**Bandwidth**	**Depth (bits)**	**Bit Rate**
DMCL	1280x1024	40 Mbps	24	Variable
DMCR	1280x1024	40 Mbps	24	Variable
DMCH	1280x1024	20 Mbps	8	Variable
Digital Audio	NA	240 Kbps	16	Constant
Analog Video	640x480	2 Mbps	24	Constant
Analog Audio	NA	192 Kbps	16	Constant

Table 1: JSF Video Input Sources

REQUIREMENTS

The top-level systems requirements for the JSF video instrumentation system include:

- Accept up to five independent video input streams
  - Two conventional analog video input streams
  - Three MPEG-2 high-resolution compressed digital video input streams
    - Available through a single Fibre Channel optical interface
- Accept up to Three independent audio input streams
  - Two independent analog audio input streams
  - One independent digital audio input stream
    - Available through single Fibre Channel optical interface
- Single removable recording media cartridge
  - Two hours recording capacity
- Six discrete control/status input/output lines
  - Record Start/Stop Control
  - Record Ready Indicator

- Record Active Indicator
- Low Memory Indicator
- Event Marker Control
- Media Cartridge Interlock Indicator

- Telemetry output (clock and data)
  - Selectable any two out of five source video streams
  - Selectable any one out of three source audio streams
  - Programmable from 1 Mbps to 20 Mbps
- CAIS programming interface
- IRIG-B time input
- Chapter 10 compatible

A high level diagram which depicts the aircraft system requirements is shown below:

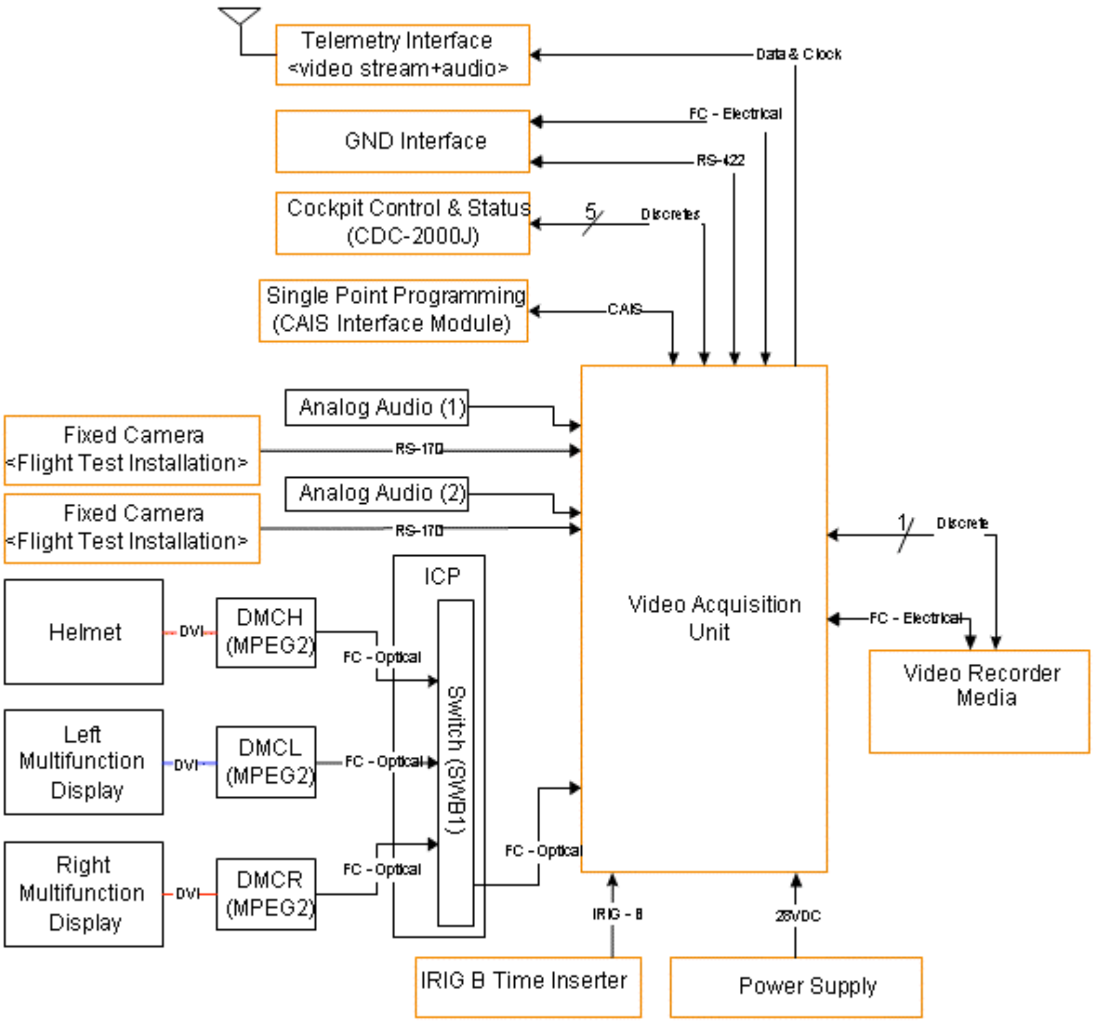

Figure 2: JSF Video Instrumentation System Diagram

SYSTEM DESCRIPTION

What follows next is a step-by-step discussion of the processing procedure used by the instrumentation system on the video and audio data as it is acquired in the aircraft and delivered to both the aircraft recorder and the ground reproducer.

Recording

Each DMC outputs its compressed video data into the Fibre Channel network using a pre-assigned Anonymous Subscriber Messaging (ASM) label. Each network node in the aircraft is required to actively solicit its packets from the Fibre Channel switch by using a JSF-specific protocol called Selective Message Routing Capability (SMRC). The instrumentation unit uses its programming to instruct its Fibre Channel interface card to send frames to the attached switch and setup a path through the network such that the video data from each DMC is routed to the instrumentation port. The data appears at the port as a Fibre Channel File System Message. This is the native format used by the aircraft to store the display data into the operational recorder. The instrumentation recorder will directly embed this format into its Chapter 10 file as a message packet. Additionally, the instrumentation system is required to strip this message format from the raw video data to enable its use elsewhere in the unit for telemetry. The analog video and audio inputs to the system are handled by a separate card which provides four independent inputs that are each processed by a MPEG-2 video and audio encoder. The output of each channel is also sent to the on-board recorder to be stored as conventional Chapter 10 video packets, while a copy of the data is sent to the telemetry card for processing. In order to allow the user to select any video or audio input for telemetry, every video and audio stream is compressed and processed as a separate transport stream.

Telemetry

The telemetry portion of the instrumentation system is handled by a specifically designed card which implements similar functionality to a pre-existing TTC product, the MARM-2000. Its purpose is to accept one or more input streams and dynamically allocate time slots in its pre-defined PCM format to carry data in the PCM output stream. Each input stream is assigned transmit bandwidth based on the customer's specification. The card multiplexes the input streams into a single output bit stream for transmission, each input channel being assigned timeslots based on how much data is actually queued waiting for transmission. The task of the card is to assign timeslots in a manner such that the reproducer on the ground does not underflow or overflow while recreating the output stream at the programmed bit rate.

The primary obstacle to providing the high-resolution video on the ground from the high resolution displays aboard the aircraft is their bandwidth. Even after MPEG-2 compression, each display processor on the aircraft produces data at 40 Mbps. This far exceeds the total available bandwidth allocated for video telemetry. The only way to accommodate these input sources is through a form of video bit rate decimation. The approach used by the video instrumentation system is as follows:

1. Fibre Channel frames sent to the telemetry card will be inspected to determine if they are carrying JSF video.
2. A video extraction algorithm will be used to recover raw MPEG-2 elementary stream data. This is done by parsing the Fibre Channel frame and stripping off the Fibre Channel headers and File System headers and trailers.
3. The resulting MPEG-2 elementary stream data is sent to a second filter stage.
4. The second stage filter attempts to locate and remove the non I-frames present in the elementary stream.
    a. The elementary MPEG-2 stream is parsed looking for I frames.
    b. The complete I-frame is extracted.
    c. The I-frame is dropped or kept depending upon the bit rate of the assigned channel.
    d. The I-frame is re-embedded into a full MPEG-2 transport bit stream
    e. The bit stream is passed on to the card for its normal multiplexing functions

Each compressed video stream from an aircraft display consists of MPEG-2 I and P frames. Removing all of the P frames, reconstructing a transport stream and restricting the resulting transport stream to 1 FPS is estimated to reduce the original 40 Mbps output rate down to a telemetry output rate of 2.5 Mbps.

Reproduction

On the ground, a de-multiplexer separates each video and audio channel and feeds them into a dedicated MPEG-2 decoder. The hardware is designed to handle MPEG-2 high-level main-profile transport streams. Each video stream is output through a digital video interface onto a high-resolution LCD. A total of three video and/or audio streams can be decoded simultaneously. In addition, the de-multiplexer is capable of dynamically switching between one out of a possible eight configurations (a different mix of three out of the possible eight possible input sources) based on changing the mode of operation in the aircraft.

Analysis

Once the aircraft has landed, the cartridge can be removed from the instrumentation system and reviewed on the ground. Each file created contains a Chapter 10 Index which can be used to quickly locate portions of the video for analysis by using an IRIG timestamp. In addition, the pilot can create Chapter 10 Event Markers using an input discrete connected to a cockpit control panel. Once the cartridge is loaded on the ground, it can be quickly swept for event packets and output to the user to aid in selecting portions of the file for analysis. Once the portion of video of interest has been identified, the playback software extracts the MPEG-2 elementary stream from the embedded Fibre Channel frames and displays it for analysis and review.

An end-to-end overview of the JSF video acquisition is shown below:

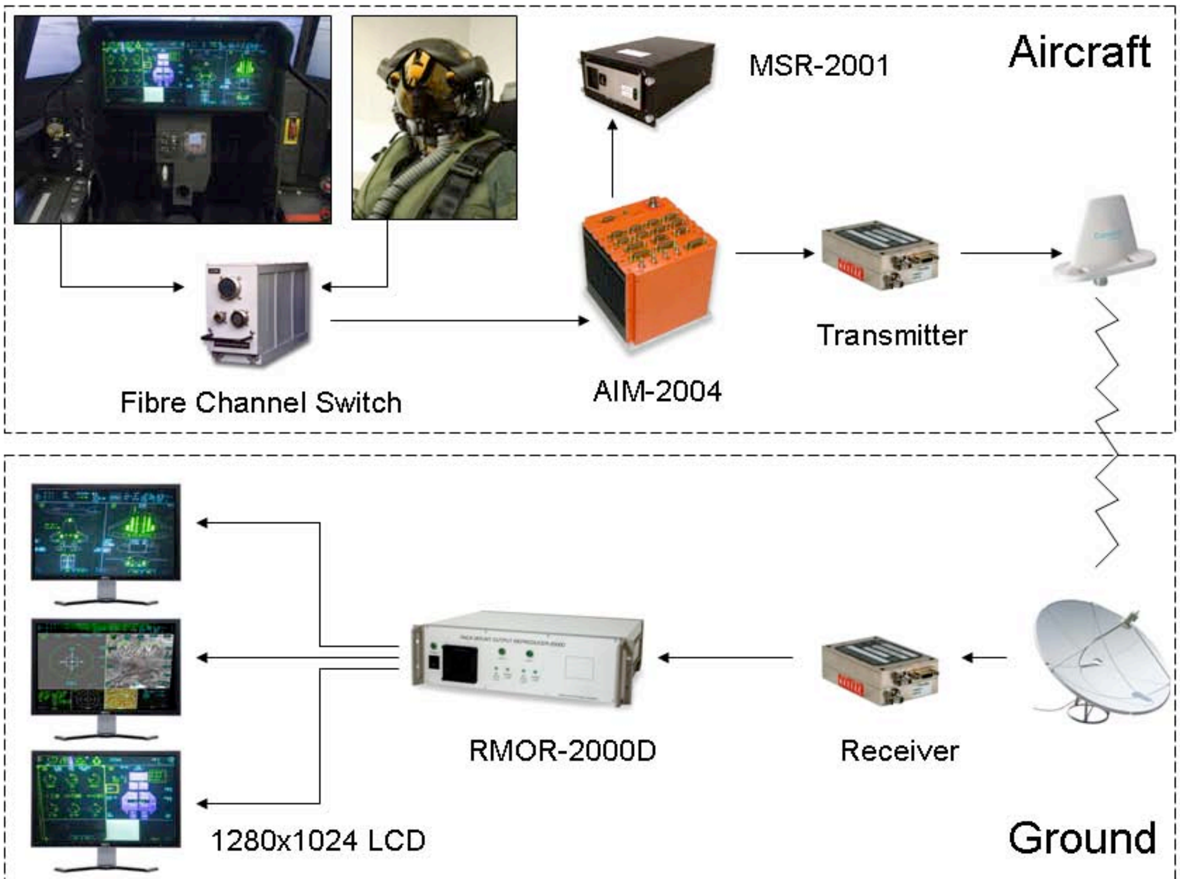

Figure 3: JSF Video System Overview

SYSTEM COMPONENTS

The video acquisition system is based on the AIM-2004 Airborne Instrumentation Multiplexer which has already been used in the JSF program for sensor and avionics acquisition. The unit is configured with various I/O cards to acquire four Fibre Channel optical video/audio streams, two RS-170 video streams, two audio inputs, and one IRIG time input. The multiplexer output is routed to the MSR-2001-PS solid-state recorder via an electrical Fibre Channel bus for recording. The media cartridge is fully compatible with existing recording equipment currently being used with the JSF program. The function of each of the individual components in the system is highlighted below.

AIM-2004

This unit is a four slot chassis designed to provide data multiplexing for recording of up to 100 MBps. It contains a PowerPC processor running a real-time embedded Linux operating system supporting a variety of system software services and tasks. Each unit is configured with 256 MB of RAM and 64 MB of non-volatile memory for software and configuration data. IRIG B AC or DC can be used for timestamping and a CAIS bus interface allows the unit to act as a CAIS bus remote.

ARM-301A

The ARM-301A is a one-channel PCM output card for use in the AIM-2004. The card is designed to emulate an existing TTC product, the MARM-2000. This emulation function is required in order to reconstruct real-time video using the existing TTC's RMOR-2000 system on the ground. The card provides PCM clock and data outputs in either single-ended (TTL) or RS-422 differential format at NRZ-L or RNRZ-L rates up to 20 Mbps. A programmable 6-pole Bessel response pre-modulation filter is also provided for the telemetry output.

VID-304

The VID-304 is a four channel MPEG-2 audio/video encoder interface card for use in TTC's AIM-2004 products. The card accepts RS-170 composite or S-video on a per-channel basis (in either NTSC or PAL video formats). Each video channel can be multiplexed with a corresponding audio channel, compressed into an MPEG-2 transport stream, and packetized per IRIG-106 Chapter 10 format. Each channel within the VID-304 card has the flexibility to acquire video, audio, or combined video and audio. For this application, two channels will be used to acquire and encode the two RS-170 video channels into MPEG-2 transport streams, while the other two channels can be used for analog audio. All of the acquired video and audio data will be transferred to the Chapter 10 recorder while only selected channels will also be sent to the telemetry output for transmission.

FCH-304L

The FCH-304L is a quad-optical Fibre Channel interface board for use in TTC's AIM-2004 products. The FCH-304L provides four full-duplex optical Fibre Channel interfaces that adhere to the Fibre Channel standards set and maintained by the American National Standards Institute (ANSI) Task Group X3T11. Each full-duplex Fibre Channel interface is capable of data rates up to 2.125 Gbps. The four optical Fibre Channel interface pairs are accessible at the FCH-304L faceplate via a fiber optical D-Subminiature receptacle. This card was developed using parts from the JSF program which are designed to provide an aircraft-specific Fibre Channel switched network based on the ASM protocol.

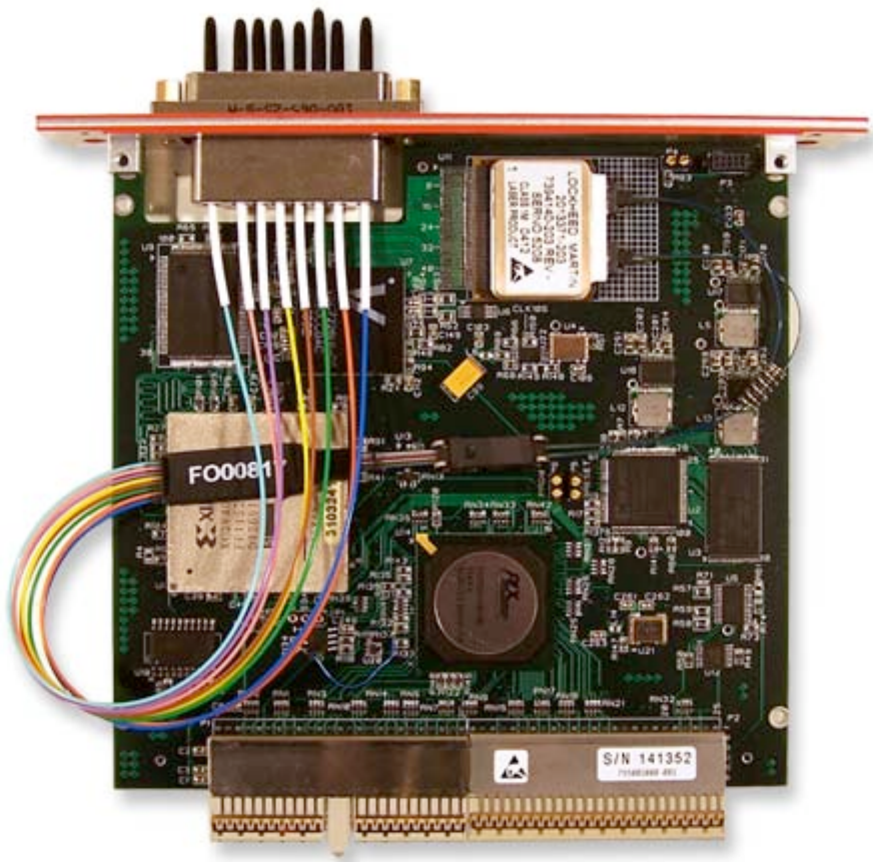

Figure 4: JSF Fibre Channel Card for ASM

RMOR-2000D

The RMOR-2000D Rack Mount Output Reproducer unit is a 19" rack mount assembly used for recovery and regeneration of interleaved data. The RMOR-2000D accepts a high-speed, serial-composite input, de-commutates this input with the DMX-100E card, and regenerates original data channels for real-time monitoring and display. Various plug-in cards can be included in the chassis to handle the required data types including PCM, voice, and video. The system is fully programmable by the user.

DMX-100E

The DMX-100E de-multiplexer card provides the central de-multiplexer function for TTC's Rack Mount Output Reproducer series products. The card is used with various output cards such as the DVC-101H to regenerate video, and voice for real-time analysis. The DMX-100E's inter-leaver format and channel block characteristics are programmed by the user using TTC's TTCWare software tool set. The DMX-100E supports a maximum aggregate data rate of up to 20 Mbps.

DVC-101H

The DVC-101H is a plug-in card for the RMOR-2000 rack mount output reproducer designed to regenerate one channel of compressed MPEG-2 Video/Audio. It supports both standard resolution (NTSC and PAL) composite video in addition to computer video input resolutions of VGA (640 x 480 at 60-85 Hz) up to SXGA (1280 x 1024 at 60-75 Hz). The card decodes a standard MPEG-2 transport stream and can regenerate video, MPEG2 Layer 2 & 3 audio, or uncompressed 16-bit linear audio. The card is capable of handling incoming compressed video and audio bit rates of up to 10 Mbps.

Figure 5: High-Resolution MPEG-2 Decoder Card

CONCLUSION

Our approach to the problem of addressing the needs of the JSF program for an instrumentation video acquisition system is based on maximizing the use of existing COTS products that are configured and/or modified to meet the specified requirements of the program. We believe our solution is uniquely capable of supporting their required flight test video acquisition, recording and real-time telemetry needs. Our novel approach of using real-time decimation of cockpit display video in the air allows the system to provide users on the ground with real-time access to data that has previously been unavailable.