A Video Distribution & Analog Monitoring System for the Jefferson Lab FEL*

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Abstract. The Jefferson Lab Infrared Free Electron Laser (IRFEL) has used the 200MHz, 16 x 16 buffered crosspoint switch, AD8116 to implement video and analog distribution. These switches are configured as 64 inputs x 16 outputs packaged into a rack mount chassis, which is used for both the video and analog systems. These systems are controlled through EPICS. This paper describes how the 256 point matrix is implemented to support the electron beam diagnostics for the FEL as well as support for the user lab video demands. A switcher chassis is also connected to three digital oscilloscopes to provide an Analog Monitoring System (AMS). The scopes are in turn connected to the video switcher using a VGA to video adapter. The analog signals can then be viewed on any color monitor connected to the video system. The video switcher feeds a 16 channel 1:4 video distribution amplifier and to a "video-to-fiber" transmitter. All of the 128 video and 128 analog channels are available locally in the FEL building and remotely at the CEBAF main control center.

INTRODUCTION

The Jefferson Lab Free Electron Laser is driven by a recirculating superconducting RF (SRF) CW linac. A key feature of the electron driver (Figure 1) is that it operates with >95% energy recovery by passing the electrons back through the SRF cavities 180 degrees out of phase. This decelerates the bunched electrons after a single pass through the wiggler; the beam is then dumped at 10 MeV.

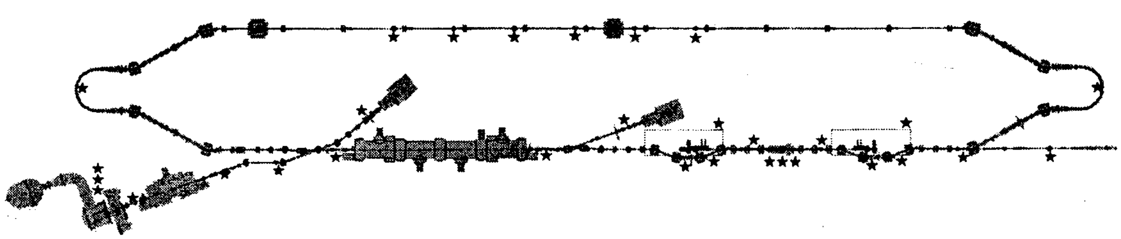

FIGURE 1. This figure shows the layout for the driver accelerator. The * are the 26 beam viewers.

The driver accelerator is operated at various repetition frequencies and pulse widths per the FEL experimenter's requests. The micropulse frequency is up to 37 MHz for

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pulsed beam and up to 75 MHz for CW operation. The macropulse can be adjusted from a single micropulse (10 μSec for lasing - rise time of optical cavity) to CW with beam currents up to 5 milliamp at energies between 25 MeV and 50 MeV. This results in FEL power of up to 1.7 KWatt CW. This power is delivered in sub-picosecond pulses of up to 25 microjoules per pulse.

The FEL output is then transported, under vacuum, upstairs to the Optical Control Room (OCR). Each of the mirrors is monitored with a CCD camera (scattered harmonics are visible). A small portion of the light (0.1%) is picked off for on line diagnostics and the remaining full power beam is available for the six user labs. Each of these labs is equipped with both video inputs and outputs and connections to the AMS.

SYSTEM REQUIREMENTS

The initial requirements for video distribution system were for the 26 beam viewers and a few channels for the HeNe laser alignment beam. In fact there are now 128 video input channels in the completed system. During the first year of operation a single 64 (in) x 16 (out) crosspoint chassis was sufficient, but as the six user labs were commissioned and electron beam studies were moved to the CEBAF Main Control Center (MCC) the requirements evolved somewhat.

The Analog Monitoring System (AMS) is used most often to view beam loss monitor signal levels, RF system phases and amplitudes, and drive laser "health". This system combined two 64 x 16 crosspoint chassis from the beginning to provide 128 inputs and 16 outputs to three, four channel oscilloscopes and the remaining four channels to a fast digitizer.

Video Distribution System

The principle requirement for the video system is that any of the 128 video inputs be available in 12 different machine/experiment control locations. This enables machine operation from the two different control rooms (~1 Km apart), alignment of the FEL mirrors in the tunnel, operations in 6 user labs, and monitoring from optics control and in the drive laser clean room. This is accomplished by connecting the 16 outputs of the crosspoint chassis to multiple Video Distribution Amplifiers (VDA)(1). All of the 40 monitors are labeled with an output number between 1 and 16. The 16 outputs have been arranged as to not conflict with multiple user operation, i.e. the tunnel monitors are common to both control rooms since for beam operation there will not be anyone in the tunnel and one of the two control rooms will have precedence over the other.

The VDAs are connected to a "video-to-fiber"(2) driver/receiver set that connects the FEL building to the Main Control Center (MCC). During construction four 24-fiber optic cable bundles were installed of which less than half are currently in use. There are cameras that monitor both control rooms so one is aware of who is at the other end.

Analog Monitoring System

The original requirements for the AMS were quite modest (BW>100 KHz) and 128 input channels. It was envisioned that the signals would be switched and routed to either of the control rooms to a patch panel and one would connect to and adjust the scope settings by hand. With the advent of the modern digital scope equipped with a VGA output we opted to use a video black box (3) to convert the VGA to composite video and then connect the scope to the video system. This allowed for an increase in system bandwidth of two orders of magnitude, a real reduction in hardware costs due to dedicated scopes verses scopes in multiple locations, and completely eliminated the need for any dedicated cables (copper or fiber) from the FEL to the MCC.

SYSTEM PERFOMANCE

The core of both systems is the AD8116 that is a high speed 16 X 16 video crosspoint switch matrix. This device offers 0.1 dB flatness out to 60 MHz, differential gain and phase errors of better than 0.01% and 0.01°, and channel switch times of 50 ns with 0.1% settling. There is -60 dB of crosstalk between adjacent channels and -105 dB of isolation (@ 10 MHz) for the AD8116. Additionally the AD8116 includes output buffers that can be placed into a high impedance state for paralleling crosspoint outputs so that off channels do not load the output bus.

Analog Devices offers this chip in a four layer evaluation board (EVB) (3) for ~$500, complete with 16 input BNCs, 16 output BNCs, and windows based software. We have packaged four of these AD8116EVBs into a single chassis with a digital interface to form the 64x16 switch matrix. These chassis can be used separately or daisy-chained together.

Since we are using an evaluation board that was designed for 75Ω inputs and outputs, an input and an output buffer chassis is required. The input chassis can be fitted with either a high impedance differential amp or a 50Ω loaded front end. The input signal is attenuated by a factor of 5 to reduce the input $\pm$ 10 Volt signal to $\pm$ 2 Volts which is then sent to the switch matrix.

SYSTEM LAYOUT

The video system resides, for the most part, in the center of the linac gallery. The AMS system is distributed through out the building; each of the RF zones holds a 16 channel input buffer chassis, the output buffer chassis and scopes are located in a rack in the control room, and the switch matrixes are located together with the video switchers in the middle of the linac gallery. See figure 2.

Video Layout

Although the outputs of the video system are distributed throughout the facility, every input to the system is routed to a central location where the core elements of the

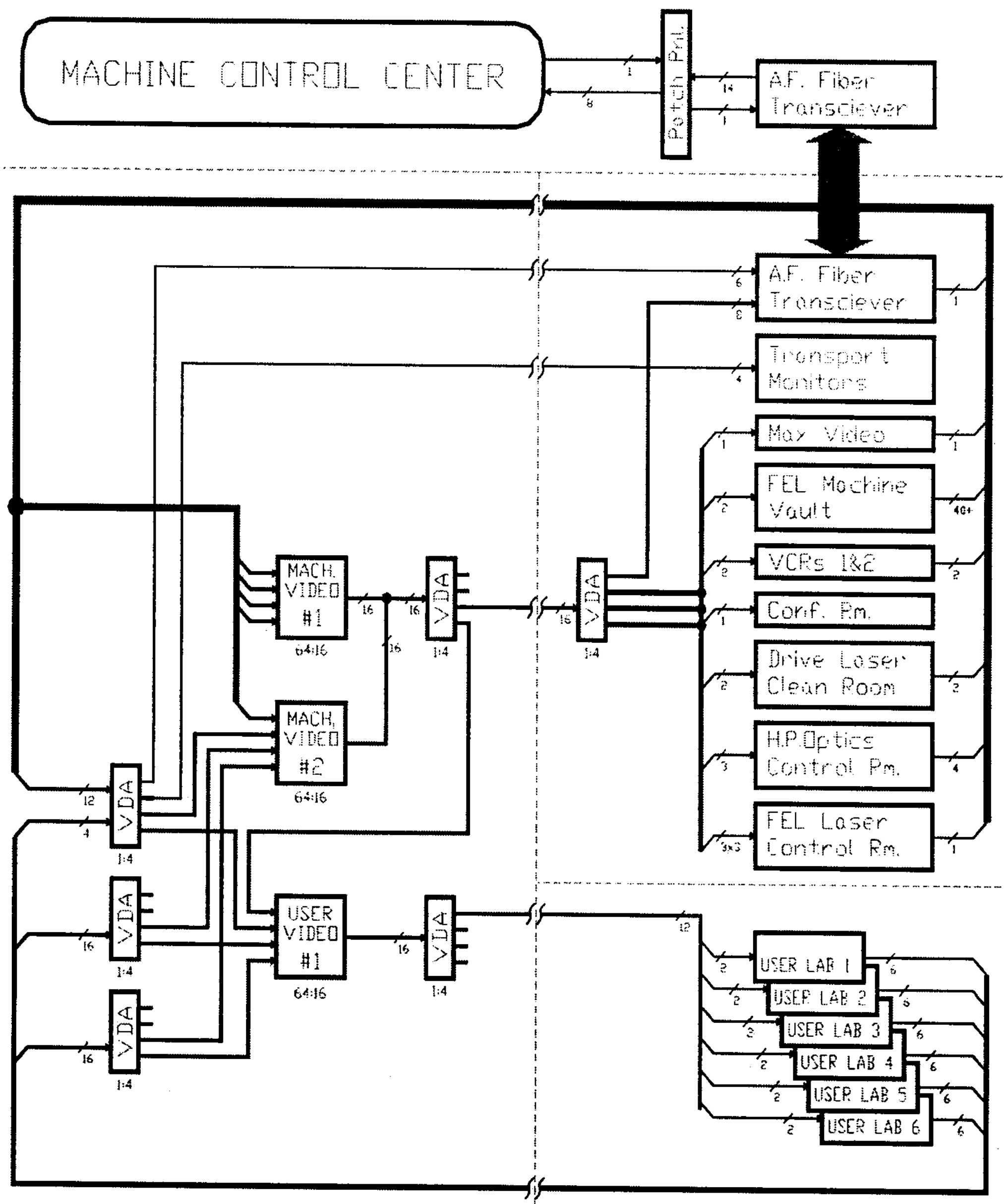

FIGURE 2. FEL Video System Layout

system are integrated in an adjacent set of control racks. As mentioned earlier, the 64 input/16 output cross-point chassis are the heart of the system and all video source signals are provided to them. However, many of these inputs signals are needed continuously by other devices in the system (ie: multiple crosspoint switchers, video quad systems, dedicated monitors, etc...). To facilitate this demand, the system utilizes rack-mountable video distribution amplifiers. These VDA chassis provide 4 separate outputs for each of its 16 inputs. The use of the VDA chassis on the inputs to the system makes it possible to conserve the number of "switchable" outputs that are provided to certain operation locations and yet still provide the required signals for viewing without having to rob the switcher of any of its inputs. Currently, the laser facility has more than 40 destinations to which video must be supplied with and the number seems to be growing daily. Although TVs make up a large number of the video output destinations, there is an increasing number of devices which perform measurements based on video signals. A VME based video acquisition card (Max-Video 200) provides a means of measuring beam profiles from the electron machine and a PC based card allows for intensity profiling of the high power laser light produced by the FEL. As the video switcher chassis is limited to 16 outputs, the system again utilizes a VDA chassis to provide these destinations with a separate output signal from the switcher chassis. Implementing VDAs on both the systems inputs and outputs has made it possible to custom configure each of the 12 machine control locations with a unique combination of both fixed and switchable video output signals which is optimized for the nature of work done at that control location.

Analog Monitoring System Layout

The AMS input chassis are located in close proximity to the equipment that is to be monitored these are then run up to 30 meters to the switch matrix. Each of the input chassis has 16 BNC inputs and 16 BNC outputs. The outputs are 75Ω and connected to the switch matrix with RG59. The 16 switch matrix outputs are also 75Ω back terminated; these outputs are routed, 30 meters, to the control room on RG59. The output buffer chassis has a gain of 5 to restore the signals to ± 10 Volts. This output is back terminated in 50Ω so one could terminate the scope input to 50Ω for enhanced high frequency (pulse) response while sacrificing half the signal level.

Signal Chain typical of ALL Signals sent through the Analog Monitoring System

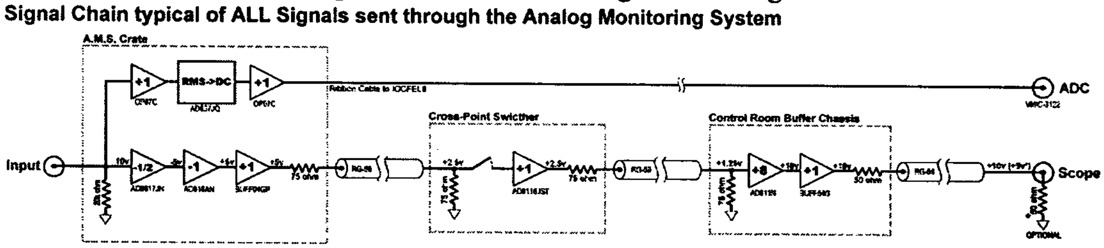

FIGURE 2. Analog monitoring signal path.

EPICS INTERFACE

During the design of the FEL it was clear that we had a variety of devices that we needed to connect through VME to the control system. In response we designed a general-purpose input/output VME interface. The EPICS interface is essentially the same for both the video and the AMS; both systems have the same "feel".

VME Interface

Each of these interface boards uses 16 bit address space and 16 bit data transfer with the memory address set by dipswitches. All application I/O is buffered by TTL transceivers; this is arranged in 8 banks of 8 bits. External connections to this card are made through the P2 connector. We have designed a collection of interface boards that plug into the rear of the VME crate (P2 Connector only). The module we use in the case is an optocoupler board.

Software

The video switching system is controlled through the Experimental Physics and Industrial Control System (EPICS)(4). This system consists of a set of software tools which are installed primarily on Unix workstations and allow efficient design, compilation and downloading of application programs onto VME IOCs using the VxWorks operating system. The IOCs are in turn interfaced through a VME bus with various custom and commercial cards and chassis which allow remote control and data acquisition from the hardware components. The control and hardware readback data flows between Unix workstation GUIs and IOCs through a high speed network.

The software for the video switcher talks to an in-house designed, 64 bit digital I/O card, which in turn communicates with the crosspoint chassis. When a connection is requested, the software in the IOC determines the addresses of the desired input signal and monitor and sends the appropriate clocked serial stream through the I/O card to all the AD8116s in the crosspoint chassis; based on the address, only the appropriate AD8116 responds to make the connection. Since each AD8116 handles 16 inputs, the address of the proper AD8116 is obtained simply by dividing the input number by 16 and truncating to an integer. To communicate with the setpoint chassis, the Chip Enable (CE) line is held high and the connection data is clocked through one bit at a time. Eighty bits are sent for each user connect command. The data is formatted into 16 5-bit blocks, 1 block for each possible output. The 5 bits in the block have the following meanings; see table 1.

TABLE 1. Bit Definition

Bits 0-4	Bit 5
Relative position number (0-15) of the input to be connected.	Enable/disable (0/1) the output corresponding to this block.

Early versions of the software had code for reading back the 80 bits from the VME card and comparing them to those in the transmit buffer, to ensure data correctness before actually making the connection. This was removed after initial system testing, as it was never needed.

The speed at which the 80-bit stream is sent is only limited by the speed of the IOC, since the VME bus can handle speeds up to 40 Mbytes/ sec. Connection times are typically instantaneous from the standpoint of the user. During early testing it was found that delays on the order of milliseconds had to be artificially inserted by the software between each bit transmission to ensure reliable connections. This was found to be due to the slowness of the opto-isolators being used. When this was corrected, the delays were removed.

A video connection is requested through an EPICS Unix-based GUI which is very simple and intuitive. From it users select any desired input on the menus, select the desired monitor from 16 buttons, then push a connect button which causes the image to appear on the monitor instantly. Which signal is currently on the monitor is indicated by the signal name in the status boxes. Each of the 8 input menus is expandable at the click of a mouse into 16 individual signals. The signal names reside in a data base which can be updated on the fly to allow for changing needs.

In addition to the generic video switcher screen shown, the switching concept is used in many of our other applications. For example, in our viewer program, whenever a viewer is inserted in the beamline, the program automatically calls on the video switcher program to make the appropriate connections, so that at the same time as the viewer is inserted, its image appears on a TV monitor.

A duplicate instance of the switching software is used for the AMS system. Using both systems, we can switch an analog signal to a scope channel through AMS, and then view the scope remotely on a TV monitor using the video switcher. All with a few mouse clicks.

CONCLUSIONS

The video and AMS systems have been in operation for two years now with no significant interruptions in service once commissioning was complete. There are ample spare video inputs (and outputs for monitors) located through out the facility. When one needs a signal sent somewhere for a test plan, a camera is set up on a tripod and connected to the system. This has proven exceptionally useful in the case of FEL users bringing in equipment for a week of running. In many cases the user must operate the experiment remotely because of the laser hazards.

With little effort the complexity of the video system has tripled to include 128 inputs for machine operations and 64 inputs dedicated to user operations with 16 separate outputs. This latest upgrade will be available for the summer 2000 run.

As with the video system the ability to instantly connect any of 128 analog signals, with bandwidth in excess of 10 MHz, to a high speed scope and view that scope on any of 40 different monitors in any of 12 locations has greatly reduced the time to commission and troubleshoot machine problems.

ACKNOWLEDGMENTS

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