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# A VXI-Based, Integrated System of Beam Position Monitoring and RF Measurement for the Advanced Photon Source (APS) Linear Accelerator*

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*Abstract*

A combined system of beam position monitoring and rf measurement has been implemented at the APS S-band linear accelerator (linac) [1]. The linac is subdivided into five sectors and each sector is comprised of a klystron and associated accelerating structures. The instrumentation for each sector is located, together with its processor, in two VXI mainframes. This system has operated successfully for more than a year.

## I. INTRODUCTION

The rf schematic for the APS linac is shown in Figure 1. Drive to the klystron is provided using a pulsed solid-state amplifier. The pulsed amplifier is preceded by a drive line that feeds all sectors, phase shifters, a PIN diode switch used for VSWR protection, and a preamplifier. The VXI-based measuring system for each sector is housed in a separate cabinet, and each system uses the reference line to derive phase measurement standards.

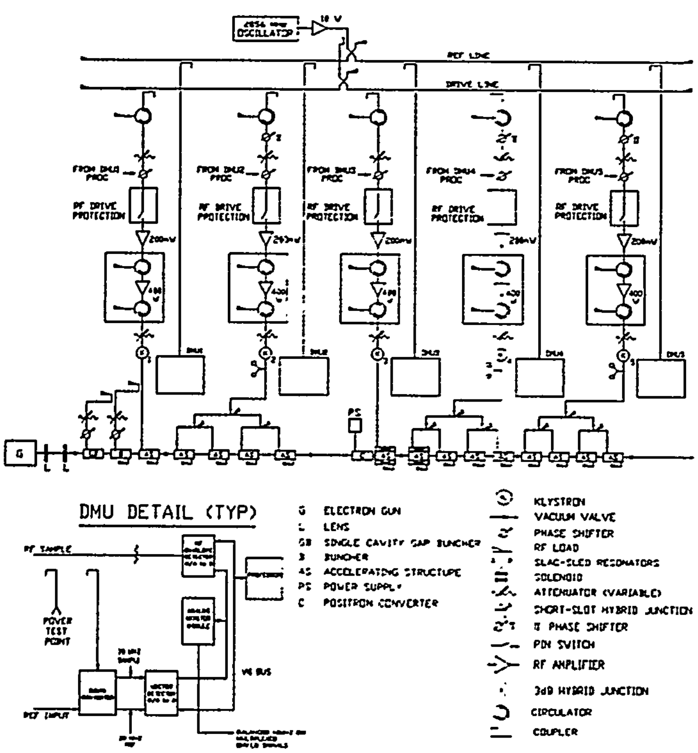


Figure 1: APS linac rf schematic diagram.

Rf for the entire linac is derived from an ovenized, synthesized source and 10-Watt GaAs FET amplifier. Both the drive and reference lines are driven from the amplifier output. The drive and reference lines are integrated into a single temperature stabilized assembly.

## II. SYSTEM CONFIGURATION

The principal parts of each system are located in two C-size VXI mainframes, housed in a single 19-inch rack as shown in Figure 2. MXI modules in slot zero of each of the

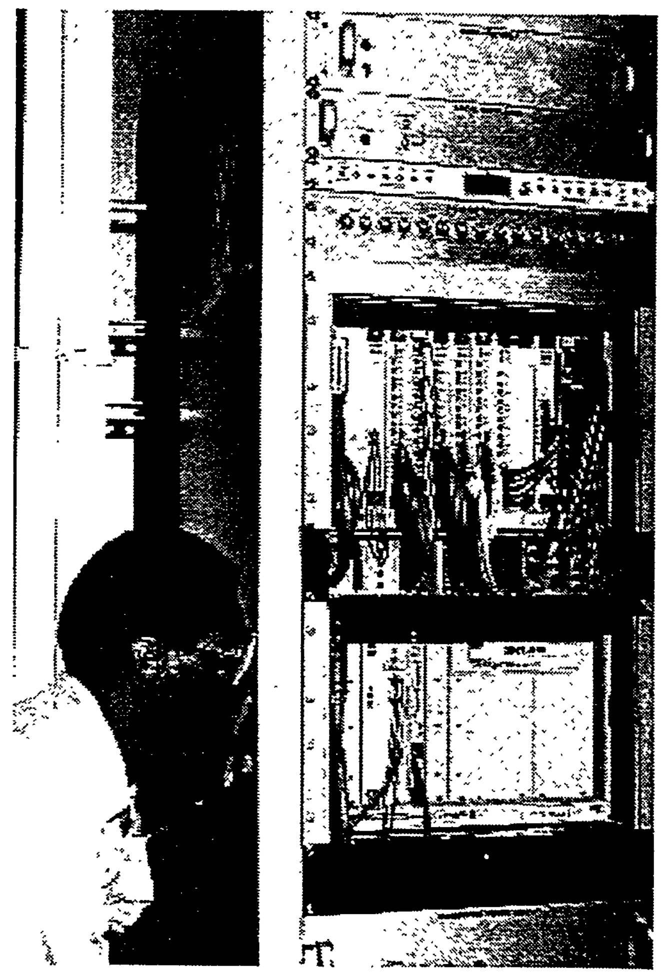

Figure 2: The two VXI mainframes are in one rack.

two mainframes provide links between them. The first mainframe contains a Motorola 68040 processor, an Ethernet link, and an Allen-Bradley Remote Interface link. The processor and the Ethernet link are contained in the VXI CPU Module that is shown in Figure 3. Additional slots in the mainframe allow for miscellaneous functions and future growth. EPICS-based software [2], developed by a multi-laboratory collaboration to support real-time control system applications, runs on the processor.

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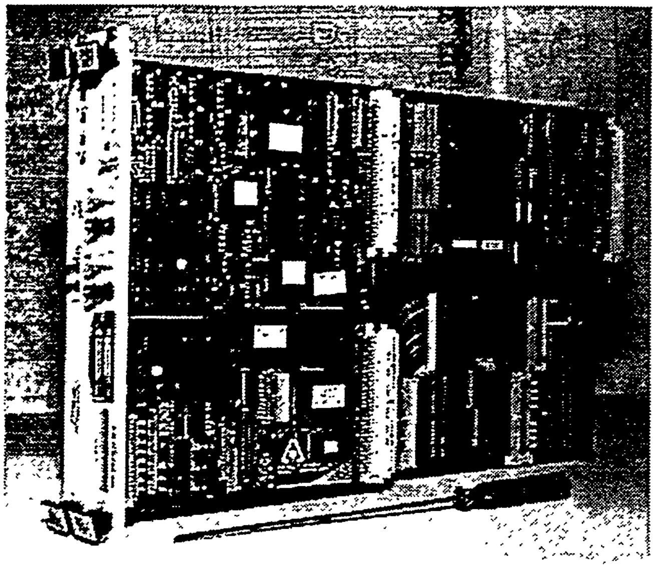

Figure 3: The VXI CPU module.

The second mainframe contains four types of VXI data collection and conversion modules, an analog link transmitter module, and a MUX module. It also contains the trigger module, shown in Figure 4, that drives all ten trigger lines on the VXI backplane.

## III. REMOTE INTERFACING

The Allen-Bradley Remote Interface link is used for control and monitoring of the klystrons, pulse modulators, and low-level rf drive. Long-term phase control is also implemented via the remote interface. This interface includes all functions necessary for normal sequencing and operation.

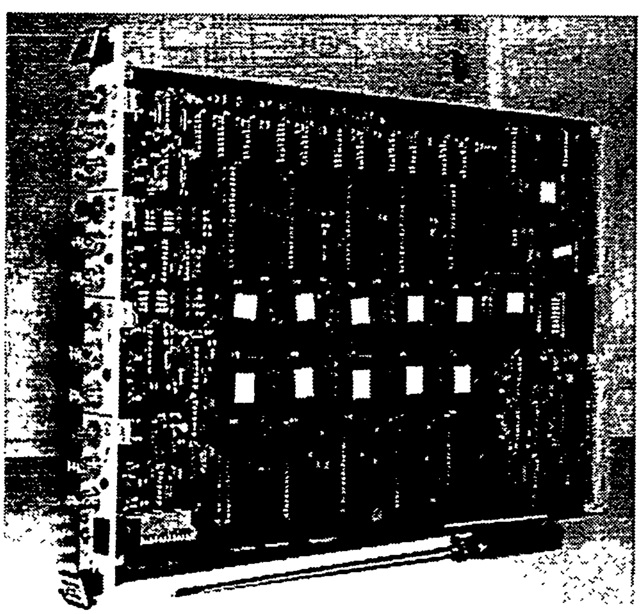

Figure 4: The trigger module.

## IV. VXI DATA COLLECTION MODULES

The VXI data collection modules were designed by Los Alamos National Laboratory (LANL) [3] with upgrades accomplished collaboratively by LANL and Argonne National Laboratory (ANL). A common digital interface exists on all modules, while three types of on-card signal conditioning allow measurements of rf amplitude, rf phase, and beam position. Each channel digitizes a single measurement during each linac pulse, and the exact time of the sample can be adjusted by the operator. Each module can also be commanded by software to put analog signals onto either or both sets of designated local bus lines on the backplane.

The four types of VXI data collection and conversion modules are described below:

- Envelope Detector Modules (EDMs) provide eight channels of diode-detected signals. Linearized values for each possible raw output value from the analog-to-digital converter, interpolated from calibration of 88 points per channel, are stored in an EEPROM. Rf samples are available at the input (both forward and reflected) and output of each accelerating structure. Envelope detector channels have been provided for almost all of these signals.
- A Down Converter Module (DNM) driving a Vector Detector Module (VDM) produces two channels of I and Q waveforms and digital data. The VDM operates at 20 MHz. A photograph of a VDM is shown in Figure 5. The

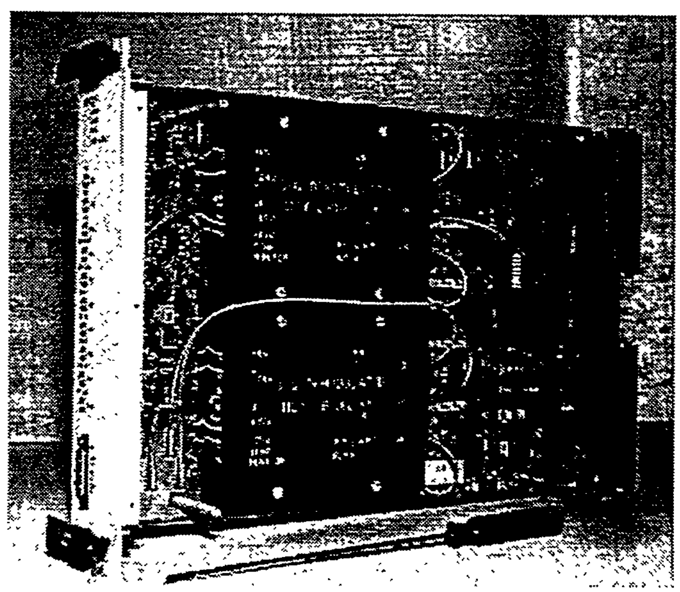

Figure 5: The vector detector module (VDM):

VDM utilizes two insulated, ovenized, I/Q demodulator assemblies that can be seen in the figure. Phase is calculated by software and can be plotted by on-line sweeping of the sampling time. Phase is measured at the input to each sector (at the output of the klystron and SLED) with a single sample each pulse. Multiplexed phase measurements are available for other forward power samples. A phase between -180° and +180°, with a resolution of 0.01°, is computed from measured I and Q data. The smaller in magnitude of I and Q is always used as the

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED numerator in the computation to avoid losing precision near the sine wave maxima. Line-stretcher type phase shifters are included at the reference inputs of each sector's phase measuring modules. These phase shifters are set so that the phase reading of each sector can be set to approximately +90° at maximum energy conditions for electrons. There are two advantages to this choice. +90° is a point where phase is calculated as:

$$\cos^{-1}\left(\frac{I}{(I^2+Q^2)^{1/2}}\right)$$

where I is near zero and the I channel has a lower noise level than the Q channel. In addition, the readings for electrons at +90° and positrons at roughly -90° will not fall near the point of discontinuous readings located at ± 180°. Figure 6 is an example of the on-line window for phase control as it appears during positron runs.

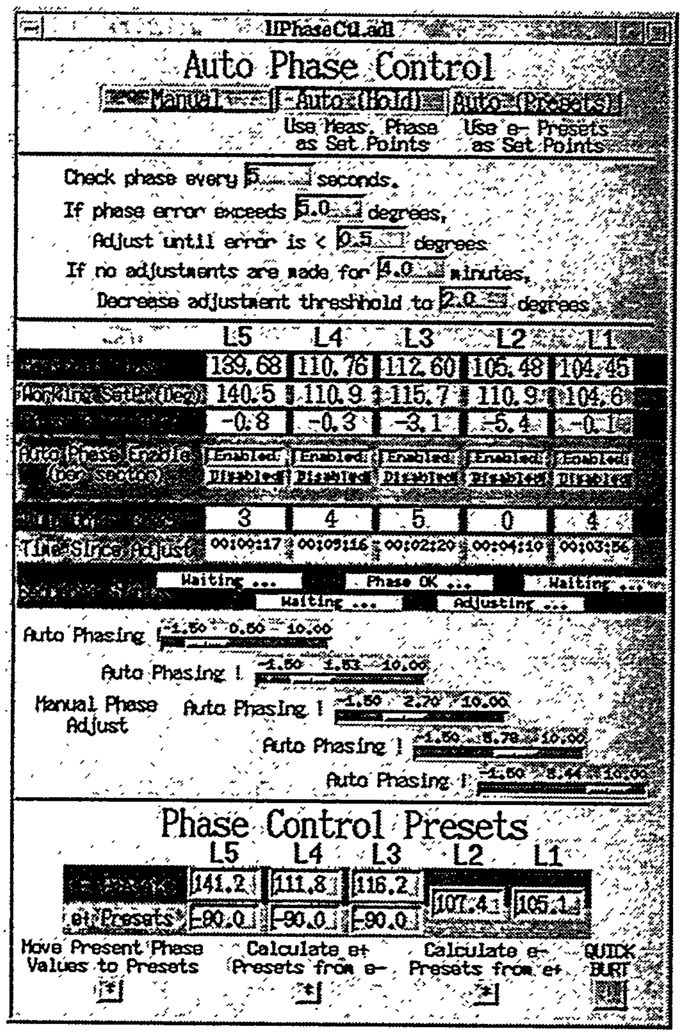


Figure 6: Autophase control screen.

- An external eight-channel, downconverter feeds each 70-MHz Beam Position Monitor (BPM) Module, to accommodate two sets of horizontal and vertical stripline signals. A BPM Module is shown in Figure 7. The downconverter includes a bandpass filter in each channel that stretches the 30-nsec pulse to around 200 nsec. Each of the eight BPM channels uses two AD640 demodulating logarithmic amplifiers. Beam position is calculated from the relative stripline signal amplitudes [4].

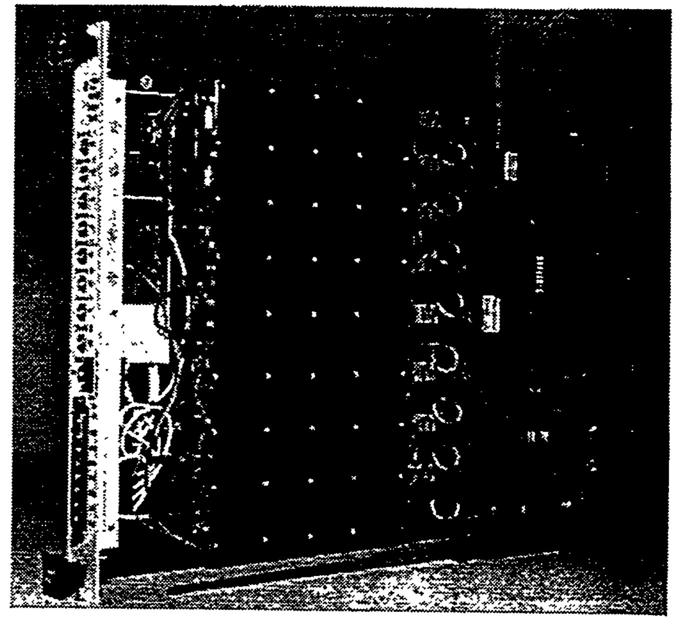

Figure 7: A beam position monitor module.

- Analog-to-digital conversion in all modules is done by a Datel SHM-49 hybrid track/hold amplifier and an AD574 monolithic analog-to-digital converter, yielding a 10-MHz bandwidth.

## V. TIMING AND SOFTWARE PEAK DETECTION

A different trigger timing system than the one used at LANL is used for most measurements in the APS linac and improves resolution and jitter by more than an order of magnitude. The upgraded LANL modules allow any of the VXI backplane triggers to be directly selected, or the LANL default triggering system can still be used. A VXI trigger module, designed at ANL, contains a set of eight-bit programmable delay lines that can be used to select sample time in increments of 5 nanoseconds. A separate delay line controls each of the two ECL triggers and eight TTL triggers on the VXI backplane. Software peak detection by scanning is available for all signals. Time scans are automated for use with BPMs, and replace the hardware peak detecting circuits that are commonly used. A BPM readout screen is shown in Figure 8, and a typical BPM time scan is shown in Figure 9. Beam steering is easily performed by observing the graphical display of beam position shown in Figure 10 and adjusting steering magnets as required. Operators get an overview of the linac's rf status, including alarms and abnormal conditions, from a single screen, 20% of which is shown in Figure 11. Operators can easily perform scans and set peak times for rf measurements. A typical time scan of a SLED waveform is shown in Figure 12.

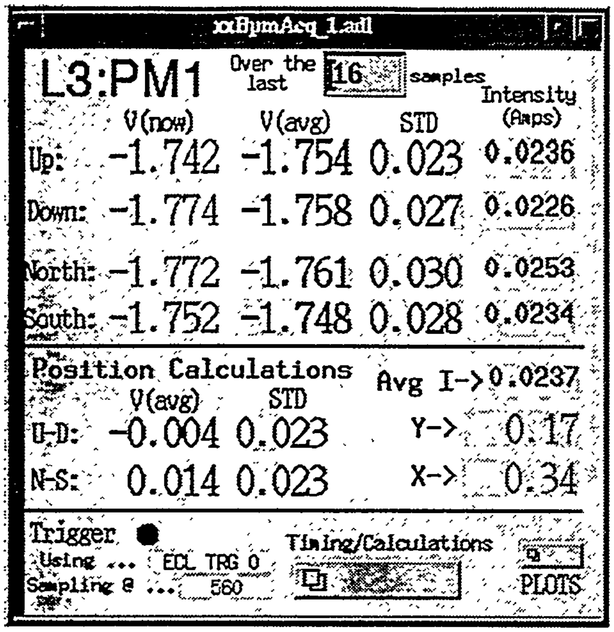


Figure 8: BPM readout screen.

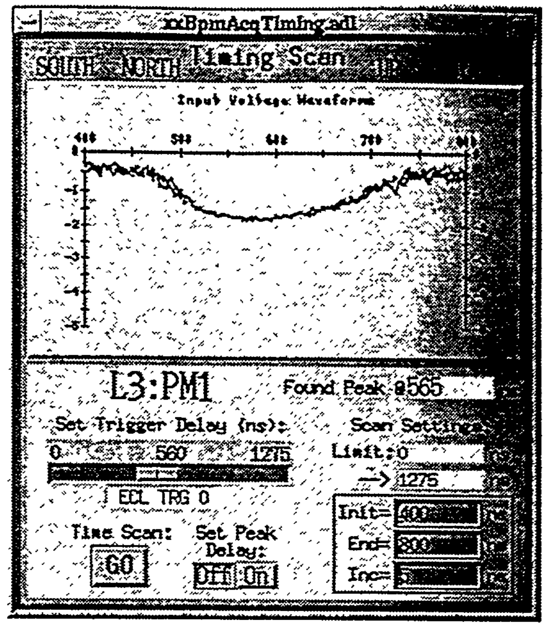


Figure 9: BPM time scan.

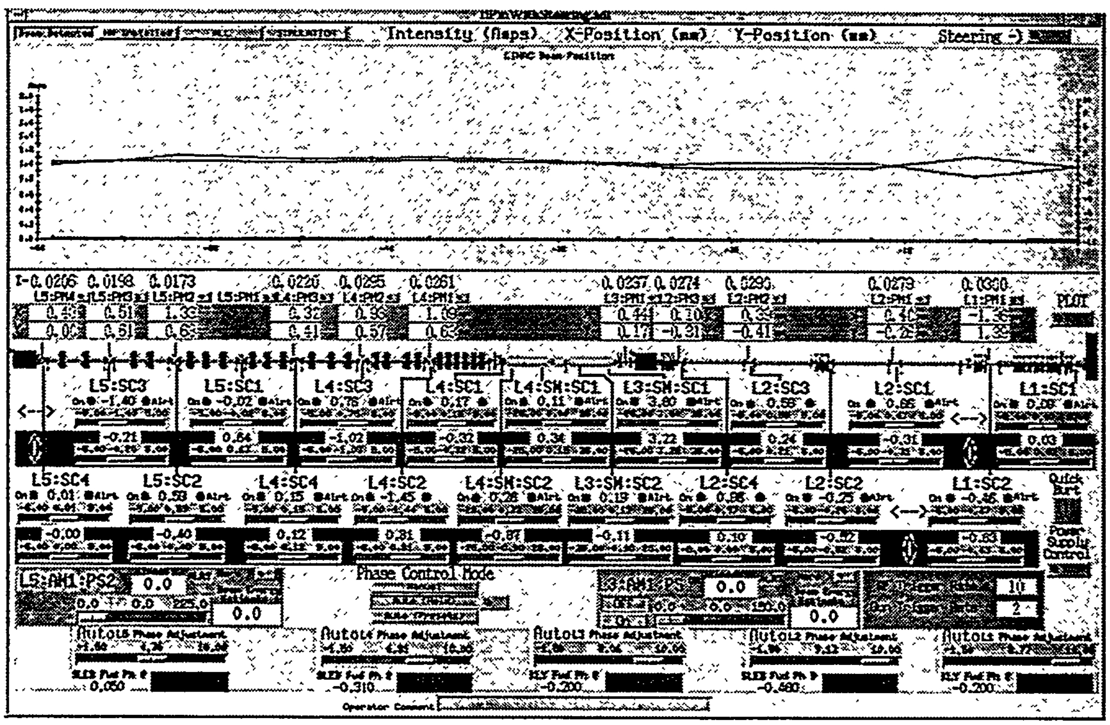


Figure 10: Graphical display of beam position.

## VI. INSTALLATION AND TEMPERATURE CONSIDERATIONS

A major consideration is to ensure sufficient flow of air that is cool enough to maintain a safe operating temperature on all modules. This equipment is located in a non-air conditioned environment, and operating ambient temperatures as high as 40°C are considered normal. The maximum permissible temperature rise from gallery ambient to VXI module exhaust air is 15°C in order to stay below the 55°C maximum temperature that is standard for VXI modules. Conventional enclosed relay rack cabinets cannot be expected to meet this requirement (a 20°C worst case rise for air within the rack is a standard assumption). These considerations led to a requirement for ducting of outside air (i.e. not heated by other equipment in the rack cabinet) directly to the VXI mainframe air intakes. Bids were solicited for VXI mainframes mounted in pairs in relay rack cabinets with ducts. The successful bidder was Hewlett Packard, using the E1401A mainframes mounted in an E3662A cabinet with a custom designed duct assembly. The somewhat unconventional rear air intakes of these VXI mainframes proved to be advantageous in this case by allowing a simple duct assembly to direct air from a louvered rear

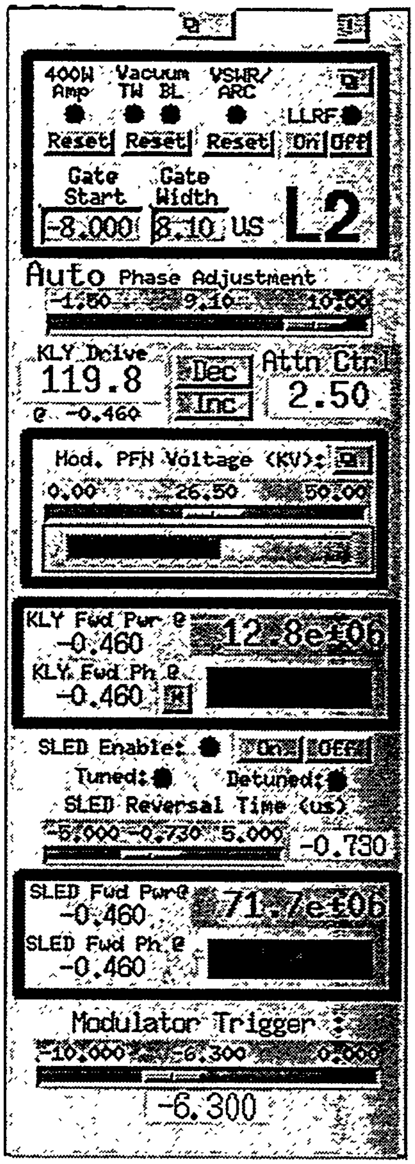


Figure 11: Rf master control screen for a single sector.

door to the air intakes. Operating experience has shown this solution to be quite successful in controlling temperature rise. As long as the air filters are kept clean, temperature-related operational problems are the same in the VXI modules as in other linac equipment.

## VII. CONCLUSION

The combination of rf measurements and BPMs using software peak detection via control of VXI backplane triggers works efficiently for the APS S-band linac, where the number of independent signals per mainframe is dictated by practical cable lengths. Machines with more densely packed BPMs would likely become limited by trigger availability.

This system has operated successfully for more than a year and has achieved phase repeatability to within a $\pm 2°$ window. The phase stability has been verified by regular correlation with linac energy. The system has also achieved a good and still improving level of reliability on-line. Basic performance has been at a level that has readily supported commissioning and operation, but further refinements are still being pursued. More details of the linac's recent performance are given in [5].

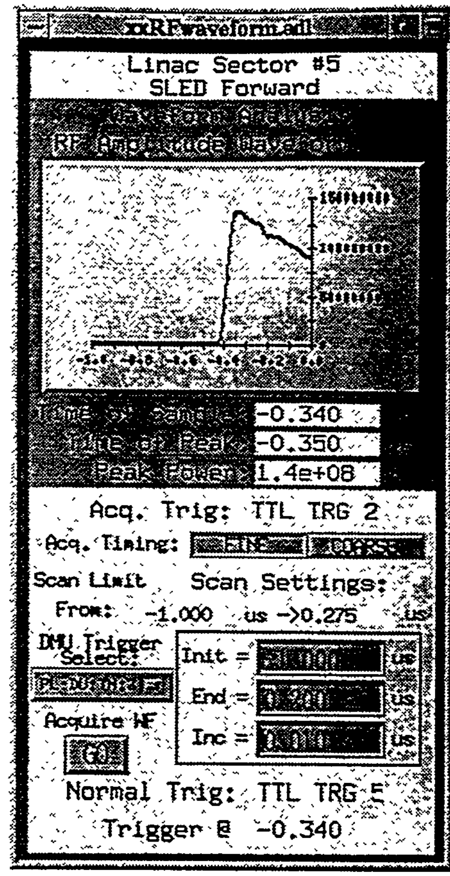


Figure 12: SLED time scan.

## VIII. ACKNOWLEDGMENTS

We would sincerely like to acknowledge the efforts of Messrs. C. Gold, D. Jefferson, R. Koldenhoven, and J. Hawkins, whose efforts in support of the linac low-level systems were instrumental to the successful results.

## IX. REFERENCES

[1] 7-GeV Advanced Photon Source Conceptual Design Report, ANL-87-15, April 1987.

[2] W. P. McDowell, et. al., "Status and Design of the Advanced Photon Source Control System," 1993 Particle Accelerator Conference Proc., Washington, DC., May 1993, pp 1960-1962.

[3] S. P. Jachim, et al, "The Los Alamos VXI-Based Modular RF Control System," 1993 Particle Accelerator Conference Proc., Washington, DC., May 1993, pp 1154-1156.

[4] R. E. Fuja and M. White, "Performance of the Advanced Photon Source (APS) Linac Beam Position Monitors (BPMs) with Logarithmic Amplifier Electronics," 1995 Particle Accelerator Conference Proc., Dallas, TX, May 1995, to be published.

[5] M. White, et al., "Performance of the Advanced Photon Source (APS) Linear Accelerator," 1995 Particle Accelerator Conference Proc., Dallas, TX, May 1995, to be published.