THE RF SYSTEM FOR THE CEBAF POLARIZED PHOTOINJECTOR*

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Abstract

Jefferson Lab's CEBAF electron accelerator has recently begun delivering spin-polarized electrons for nuclear experiments. Spin-polarized electrons are emitted from a GaAs photocathode that is illuminated with pulsed laser light from a diode laser synchronized to the 3rd subharmonic (499 MHz) of the accelerating cavity frequency (1497 MHz). Up to three experimental halls (A, B and C) are served by the photoinjector each with their own beam requirements. To accomplish this, three independent diode lasers are synchronized and combined to illuminate the GaAs photocathode emitting a 1497 MHz pulse train of electrons. In addition an RF bunching cavity approximately 2 m down stream from the photocathode is used to compensate for space charge effects at the higher beam currents. The RF system that controls these elements is a modified VME based system. Custom RF VME modules control phase and amplitude for each laser diode and the bunching cavity. Power requirements were satisfied with commercial RF amplifiers, 5 W for the diode lasers and 10 W for the bunching cavity. Simple software algorithms using the EPICS control system correct phase and amplitude drifts. The RF system is compact, simple and allows for easy hardware or software modifications.

1 INTRODUCTION

The 5.5 GeV CEBAF accelerator at Thomas Jefferson National Accelerator Facility (Jefferson Lab) is arranged in a five pass racetrack configuration, with two superconducting radio-frequency (SRF) linacs joined by independent magnetic 180° transport arcs. The continuous electron beam is composed of three interlaced variable intensity beams that can be independently directed from any of the five passes to any of the three experimental halls. This allows three simultaneous experiments at the same or different energies and currents. Electrons are emitted through a polarized photocathode [1]. All of the experimental halls (A, B and C) are fully operational.

Recently a new laser system for the polarized source has begun operation that allows each of the experimental halls to independently choose current and operational duty factor [2]. Three diode lasers are biased with an RF frequency of 499 MHz. The light from the lasers is then optically combined to form a 1497 MHz pulse train. The light then illuminates a GaAs photocathode, producing polarized electrons. Precise phase control between the lasers is essential for proper acceleration. The 499 MHz laser pulses must be 120° apart to construct the 1497 MHz signal. Amplitude control is also important since each laser's pulse length is determined both by the dc bias and the RF bias. The laser's pulse length determines the electron bunchlength leaving the photocathode. The RF system also includes a bunching cavity to help reduce space charge effects over the wide current range (100's pA to 180 μA) demanded by the users.

Previously a CEBAF RF control module had controlled the laser for the photocathode (single laser) [3]. This system is based around a CAMAC interface and is designed to control a superconducting accelerating cavity. While this control system has been excellent for superconducting accelerating cavities, it has only been marginal for controlling RF systems like laser diodes and normal conducting cavities. Therefore it was decided to design a system that better met the needs of the laser diodes and was compatible with the EPICS/VME interface.

2 LASER RF SYSTEM

The laser RF controls are a VME based system using the EPICS control system [4]. Drifts associated with these RF systems are mostly thermal; thus we chose a rather slow (10 Hz) feedback system. A dedicated EPICS IOC (Motorola MV 167) is used to control the phase and amplitude of the three laser diodes and the bunching cavity. The update rate of the EPICS control system met our need. Should faster update rates be necessary, speeds up to 1 kHz are possible by putting the software into VxWorks directly on the IOC. Choosing the VME bus allowed us to use economical and readily available VME cards. In addition the EPICS collaboration already had the drivers available for the ADC/DAC (VMIVME 4514A) and I/O (VMIVME 2532A) cards and only slight modifications were necessary. The VME crate is a custom crate with a modified P2 backplane to handle the control signals. RF signals are hard wired to the back of the crate. Blindmate™ connectors allow for easy VME module removal.

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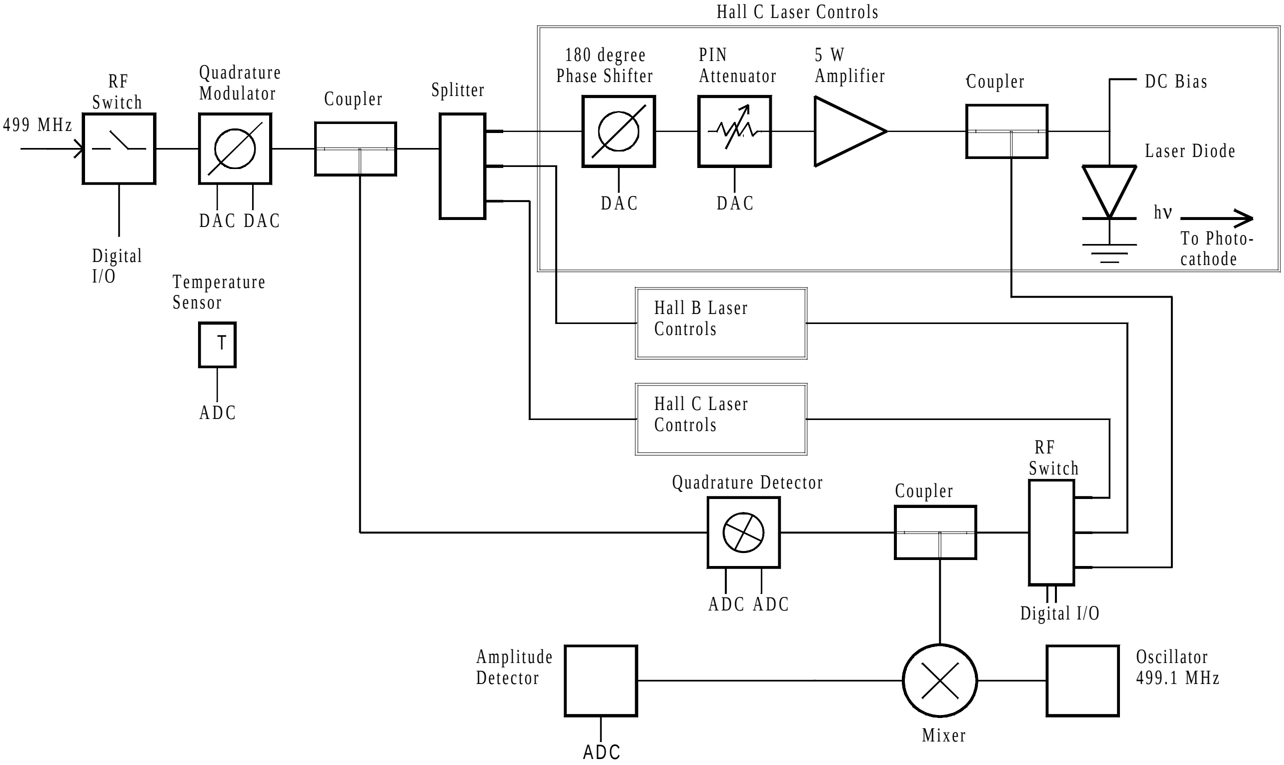

Figure 1 Block diagram of the laser diode RF system.

Figure 1 shows a block diagram of the RF system. The specifications for phase and amplitude control are 1^o and 1% respectively. Considering the relaxed control specifications it was decided to do the entire signal processing at the operating frequency of 499 MHz. This also allowed the system to use one of the pre-existing 499 MHz chopping cavities as a reference; the cavity is located less than 3 m away. The controls are divided into three VME modules: Reference Drive, Phase Shifter Module, and Detector Module. The reference module consists of a 360^o (I/Q) phase shifter for global phase adjustments and a 3-way splitter to supply the RF to the individual laser diodes. In addition it provides a coupled signal to the detector module. The phase shifter module consists of three 180^o varactor capacitor phase shifters (Synergy Microwave) used to align the phase between the three laser diodes. The phase between the lasers is coarsely (+/- 5^o) set using hard-line. The varactor phase shifters were chosen over I/Q phase shifters for cost reasons and since it was not necessary to have 360^o of phase shift capability. The phase shifters are controlled by 12 bit DACs. 5 W solid state amplifiers (Microwave Power Equipment) are used to RF bias the laser diodes. Inside each amplifier a voltage controlled PIN attenuator is used to control the RF bias on the laser diode. Approximately 1 W of RF power is needed for the laser diode RF bias. The detector module detects drifts due to cable or components (most notably the amplifiers). An RF signal is coupled back from each laser diode to the detector module. To economize on RF parts the three RF signals are muxed through an RF switch into a 360^o phase detector (quadrature detector) and amplitude detector. The EPICS control software continuously switches among the three RF signals. The error signals are then fed through the VME back plane to the ADC. The amplitude detector is an Analog Devices RMS to DC converter operating at an IF of 100 kHz. This was chosen over a typical Shottky diode because it is less susceptible to temperature drifts.

Key to the design process was minimization of thermal drifts. All RF electronics is next to the laser diodes in the tunnel (previously the RF electronics had been located up in the klystron gallery, 10 m above the tunnel). Temperature sensors on the VME cards are continuously monitored for any abnormalities. All the RF components on the VME cards and components were thoroughly characterized in an environmental chamber. It was intended to use the temperature sensors to provide a mechanism to remove thermal drifts using the component characterizations. This was deemed unnecessary after measurements in the CEBAF tunnel showed that temperatures vary less than 2^o C over long periods of time (weeks).

The feedback for the system presently only includes the cables to the laser diodes. Drifts across the laser diodes and optics are assumed to be minimal (< 0.5^o). If tighter tolerances are needed in the future, a laser diode detector can be incorporated in the optical path and the signal fed back into the controls.

3 BUNCHER RF SYSTEM

The buncher cavity is a pillbox design with reentrant nosecones that is operated in the TM_{010} mode at 1497 MHz. The cavity is constructed from stainless steel with copper plating on the RF surfaces, a process with which we have had good success at Jefferson Lab [5]. Three equally spaced ports located around the circumference of the pillbox cylinder are used to interact with the magnetic field of the TM_{010} mode. Manual adjustment of the resonant frequency is achieved via a micrometer controlled plunger mechanism, which is attached to the first port. RF power is delivered to the cavity via a critically coupled inductive coaxial loop probe located at the second port. A small undercoupled loop probe mounted on the third port samples the field for feedback and control. The cavity loaded Q is approximately 2500 and the R/Q is 125.

The cavity is designed to operated between 1 kV/m and 35 kV/m. Since power requirements are small, less than 5 Watts, heating from conductive losses is not a concern and so no internal cooling is necessary. Temperature stabilization is realized through the use of an external water jacket and insulating blanket. The RF phase and amplitude regulation requirement for the cavity control system is 1^o and 1%. As with the laser diodes the feedback takes place through EPICS. Phase control is provided by an I/Q phase shifter (IF Engineering) operating at 1497 MHz and, similarly, phase detection is performed using an I/Q phase detector. Amplitude control is accomplished using a pin attenuator (Anaren) and diode detector in a similar fashion as with the diode laser controls. The reference frequency (1497 MHz) is provided from a pre-existing bunching cavity located further downstream. A single VME card controls the buncher cavity and it is housed along side the other cards for the diode laser controls.

4 SOFTWARE

The software is a low-level application built on the EPICS control system. The interface to the VME hardware is via specifically written EPICS device support that communicates with the commercially available boards. This is mostly a straightforward EPICS database application, using standard records. It uses 12 Capfast database schematics with about 270 records, 26 ".c" subroutine files, and 2 ".st" sequencers. Most of the database records scan at 1 Hz, with the feedback loops running at 10 Hz.

The feedback loops are implemented in software, using the standard feedback control model (i.e. compare the measured hardware value to the user requested value, and vary the hardware set point to drive this comparison toward zero). Each of the three seed lasers and the buncher has independent feedback loops, a phase loop and gradient loop for each. Temperature regulation can be handled by these loops using a 1 Hz scan rate. However, for the buncher beam loading effect, a 10 Hz rate was needed. If a higher rate is desired, then part of the EPICS database will need to be converted into ".c" code to be run as a VxWorks task.

The software incorporates alarms and addresses trouble shooting. The feedback loop parameters can be altered for diagnostics (e.g. variable scan rates, free running or manual trigger modes, and hardware simulation). The user's interface to the alarms and troubleshooting begins with a basic set of good-bad indicators. The top indicator is for the combined status of both subsystems (three laser and buncher). If it shows good, then there is no need to look further. The rest of the basic indicators show more specific status. If an indicator shows bad (warning or fault), then the user can bring up various screens that show the specific problems (e.g. analog value out of range, loss of communication). The built-in troubleshooting screens provide condensed information of what needs to be done and by whom and in what order, and gives reference to the full troubleshooting guide document.

5 SUMMARY

The system has been operational since March of 1998 and has had no major problems. During commissioning of the system, a bug in the phase feedback algorithm caused the systems to run off crest, but this was quickly discovered and fixed. The decision to go with the VME platform over existing CEBAF RF controls has made the system much easier to upgrade and maintain, especially considering the compatibility with the EPICS control system.

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