Design and Features of the EIC-DIRC Laser Lab's Laser Interlock System

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This note discusses the design and features of the laser interlock system for the laser lab, a controlled area, built for testing the reflectivity of the quartz crystal bars that are to be used in the Detection of Internally Reflected Cherenkov-light (DIRC) detector of the Electron-ion Collider (EIC).

Cherenkov-light in the EIC-DIRC detector is generated by quartz bars and directed to the electronic array by total internal reflection. To check whether the bars reflect greater than 99% of the light, they will be tested using a 325-nm/442-nm dual-wavelength laser, which will be located in the laser lab, a controlled area, Fig. 1.

Jefferson Lab's safety requirements for the laser lab are that it must have an interlock system to ensure that the area's occupancy is controlled, that the laser can be quickly and easily disabled in case of an emergency, and that the designed interlock system does not rely on software. To comply with these requirements, an interlock circuit was designed and prototyped, Fig. 2.

The interlock circuit uses 5-VDC logic where 0 V indicates the low logic level and 5 V indicates the high logic level. The interlock inputs to the circuit, red highlighted portion of Fig. 2, are all passed to two eight-input NAND gates combined with one OR gate, effectively creating one 16-input NAND gate. NAND logic was selected to ensure each input is correctly connected to the circuit because each input expects a high logic level to indicate that the interlock input is okay. If an input is not connected or does not receive a signal, or there is a power distribution issue, the circuit will fail to a safe state.

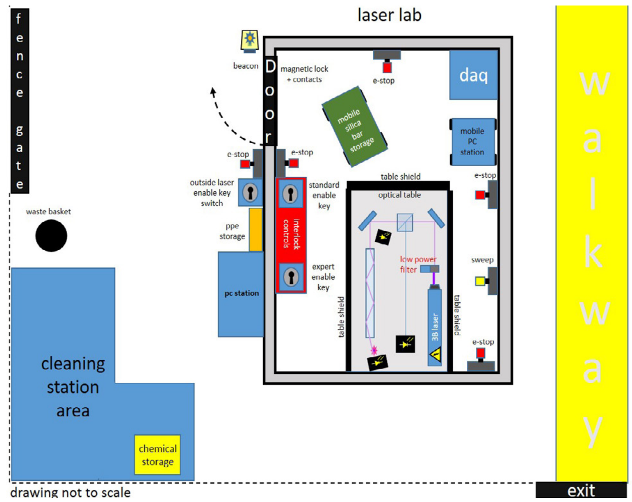

FIG. 1. Controlled area for laser testing.

To protect the circuit from over or under voltage conditions, inputs to the circuit (whether an interlock or a status input) are connected to a series of Schottky diodes. These circuit segments ensure that the inputs remain within 0–5 V. Additionally, logic gate inputs are pulled down to ground by 10-kΩ resistors to ensure that the gate inputs do not float to an unknown level.

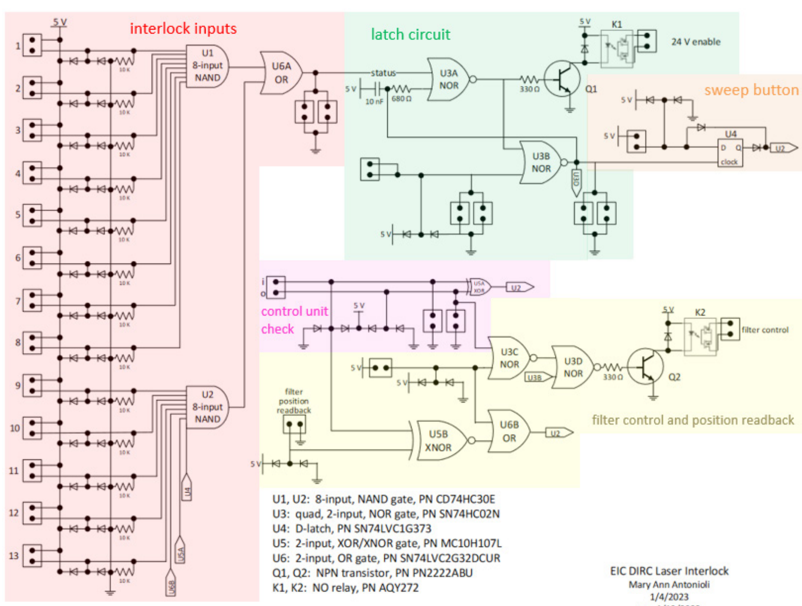

FIG. 2. EIC-DIRC laser interlock circuit diagram.

Users will operate the laser interlock system from one of two keyed control units. One keyed control unit placed outside the laser lab allows full power laser operation when the lab is vacant. The other control unit placed inside the laser lab has two keys; one key allows operation of the laser with reduced power using a filter; the other, the expert key, allows the override of filter installation, enabling full-power laser operation by experts.

Each control unit has sets of LEDs connected in parallel to display the actual status, the latched status, whether the circuit's reset is active, and which control unit is active (outside or inside the lab).

To ensure that only one control unit is active in the control system, an XOR circuit is used, pink highlighted portion of Fig. 2. The inputs to the XOR gate are the enable signal from the two control units' keyed switches. The output of this circuit portion is used as an interlock input and will be high (good) if and only if one key is present in the system.

The inside control unit will automatically install the power-reducing filter depending on which of the two inside keys is being used, the standard or the expert enable key.

The power-reducing filter is a 2.0 optical density, absorptive filter that reduces the power of the laser by a factor of 100. With this filter, the ~45 mW laser's power is reduced to that of a Class 2 laser, making the laser safer to operate by occupants of the laser lab.

The power-reducing filter is mounted on a Thorlabs motorized flip-mount that is controlled and monitored by the interlock circuit portion highlighted in yellow in Fig. 2. The filter control uses the readback signal from the standard or the expert enable key inside the laser lab and the enable key outside the laser lab to install or remove the filter. The flip-mount has a readback that indicates the filter-installed status. The flip-mount and the inside control unit status signals are combined into a filter-in-place interlock input, which initiates an interlock if the filter is removed when the standard enable key is used.

To ensure that the laser is blocked from operators, sidewalls on the laser lab's optical table are used as shields. On the sidewalls, contact sensors detect whether the sidewalls are in place. These normally-open contact sensors are connected to an input of the interlock circuit.

To control occupancy, door contact sensors and a sweep button are used. The door contact sensors are magnetic contacts where one portion is fastened to the door frame of the laser lab's entry door and the other portion to the door. When the door is opened, the magnetic connection between the two portions is broken, pulling the input signal low.

The sweep button, orange highlighted portion of Fig. 2, requires the user to press a button inside the laser lab and then reset the system within a preset time period (Jefferson Lab safety requirement is at least 10 s), effectively forcing users to perform a sweep of the laser lab within the preset time period to ensure that the lab is vacant

The circuitry used for the sweep button is a D-type latch, which passes its input through to its output as long as the input signal to the clock (control) is held high. If the input signal to the clock is low, output is maintained at the previous input value, i.e. before the input signal value to the clock changed to low. For the laser lab's interlock system, the overall latched status is used as the input signal to the clock, the actual sweep button is used as the latch input, and the latch output is used as an interlock input. With this configuration, if the system is not reset within the time period allowed by the sweep button timer, the system will return to an interlock state. If no other interlocks are present, the sweep button is pressed, and the system is reset, then the overall latched interlock will be cleared.

The interlock system maintains its interlocked status until it is reset, a capability achieved using a NOR gate in a set-reset latch circuit, green highlighted portion of Fig. 2. The inputs of the set-reset latch circuit give the present status from the NAND gate and a reset signal from the keyed control units. With the configuration of the control units and their respective reset buttons, only the reset button on the control unit that is active can clear the interlocks. Using an RC circuit, the set-reset latch is initialized to the latched interlock state upon power up, preventing the system from enabling the laser in the event of a power glitch. The outputs of the set-reset latch are the latched status and the inverted latch status. The latched status is indicated with LEDs on the control units. The inverted latched status is used in the relay circuit that enables 24 VDC to power the laser lab's yellow laser beacon, the laser lab door's magnetic locks, and to the relay with a 10-s delay timer to enable the laser.

To allow quick and easy disabling of the laser, two inputs of the interlock circuit are for the emergency stop button chains. One emergency stop button chain will be placed outside the laser lab so the laser can be disabled from outside if personnel need to quickly enter the laser lab. The other emergency stop button chain will be inside the laser lab. The inside emergency stop chain consists of four buttons in series, with each button placed on one wall of the laser lab to ensure that a button is easily accessible.

The developed interlock circuit was prototyped on a breadboard and tested with emergency stop buttons and door contacts. Figure 3 shows a photo of the testing of the prototype.

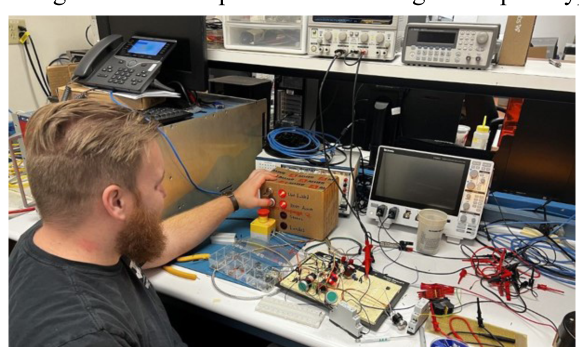

FIG. 3. Tyler Lemon operating breadboard prototype of the laser interlock circuit.

In summary, the EIC-DIRC laser lab requires a hardware-based interlock system. Such a system that meets Jefferson Lab's safety requirements for safe operation of the Class 3B laser was designed and prototyped.