**SPDT HV switch and 16dB gain Differential Amplifier**

**Property of**

**ANALOGIC CANADA**


***Written by: MAHBOOB LIAQUAT***

***Supervised by: Salman Arnab Moazzem***

# SYSTEM OVERVIEW

This manual has the information needed to build and properly operate the HV switch and the amplifier that was used for the TOF (Time-of-Flight) and IFTOF (Interrupted Field Time-of-Flight) experiments to measure sample carrier mobility and lifetime.

Figure 1 presents the entire system designed to perform both TOF and IFTOF measurements, utilizing a grounded bridge network to suppress displacement current signals in IFTOF experiments. To balance the bridge, a variable open-air capacitor $C_N$ with a high breakdown voltage was incorporated. We reduced large unwanted electrical noise (common-mode switching transients) by adding two very fast diodes (MUR120) to each resistor in the bridge circuit. A special amplifier (differential amplifier) is used to ignore any remaining noise and only amplify the useful signal (the transient photocurrent).

The voltage bias was supplied by a BERTAN 205B-10R high-voltage (HV) power supply and applied to the sample through HV switch. The trigger signals required for the switches, laser, and oscilloscope were generated by a PCIe-6361 counter board installed in the PCI slot of a Windows 10 PC. The experiment was controlled through a custom graphical user interface developed in LabVIEW, running on the same PC. A Tektronix MDO4104-3 Mixed Domain Oscilloscope was used to digitize and capture the photocurrent signal, with the recorded data stored on a USB drive via the oscilloscope's USB port. Figure 1 illustrates the complete system, including the computer, trigger mechanism, oscilloscope, high-voltage power supply, HV switch, laser, sample, variable capacitor, bridge network, and amplifier.

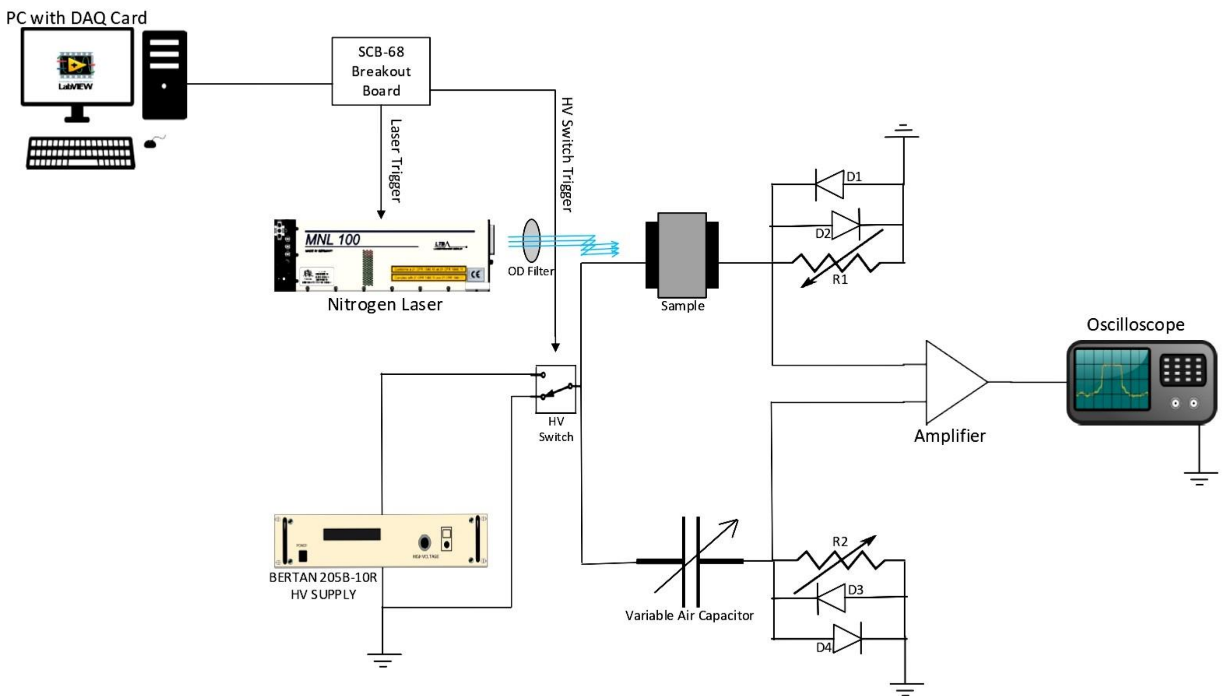


*Figure 1. The schematic of the TOF/IFTOF system for up to 1kV displacement current-free measurements utilizes a grounded bridge network. The timing for the trigger signals is provided by the PCIE-6361 DAQ board, which is connected to the PC's PCI bus. The SCB-68 allows the user to access the outputs from the DAQ in the form of terminal blocks and the trigger signals are transmitted via BNC cables to the laser and the HV switch. The photocurrent is monitored using a digital oscilloscope, and the collected data is retrieved through the oscilloscope's USB port.*

By carefully tuning the variable air capacitor within the bridge, most of the displacement current signal could be minimized. However, the dark current in a-Se samples is not entirely negligible and increases significantly with the applied electric field $F$ . Additionally, this dark current tends to decrease over time.

It is important to understand how the large displacement currents are taken care of using this system. First, when the HV switch is turned ON, a large displacement current signal is produced by the sample as well as the variable air capacitor. Then, these go through the resistors R1 and R2, but since these variable resistors R1 and R2 have the diodes D1, D2 and D3,D4 connected across them, they clip off a large part of the displacement current signal and bring it down to about 600mV. However, for IFTOF, even this is too much and so it needs to be brought even further down. Once the fine tuning of the resistors can no longer reduce those displacement current signals, that is when we have to use Digital Subtraction, by taking one reading by applying the laser and another without laser and then subtract the two. That will give the remaining pure IFTOF result.

# High Voltage Switch

Figure 2 shows the schematic for the HV switch that was designed at built for the experiment.

Following this schematic will be enough to built a replica of the HV switch. The first of the main components in this switch includes the 24V DC-DC converter. In this experiment, every single equipment, electronic component and device has to be grounded to a common point EXCEPT this DC-DC converter. So, it must be

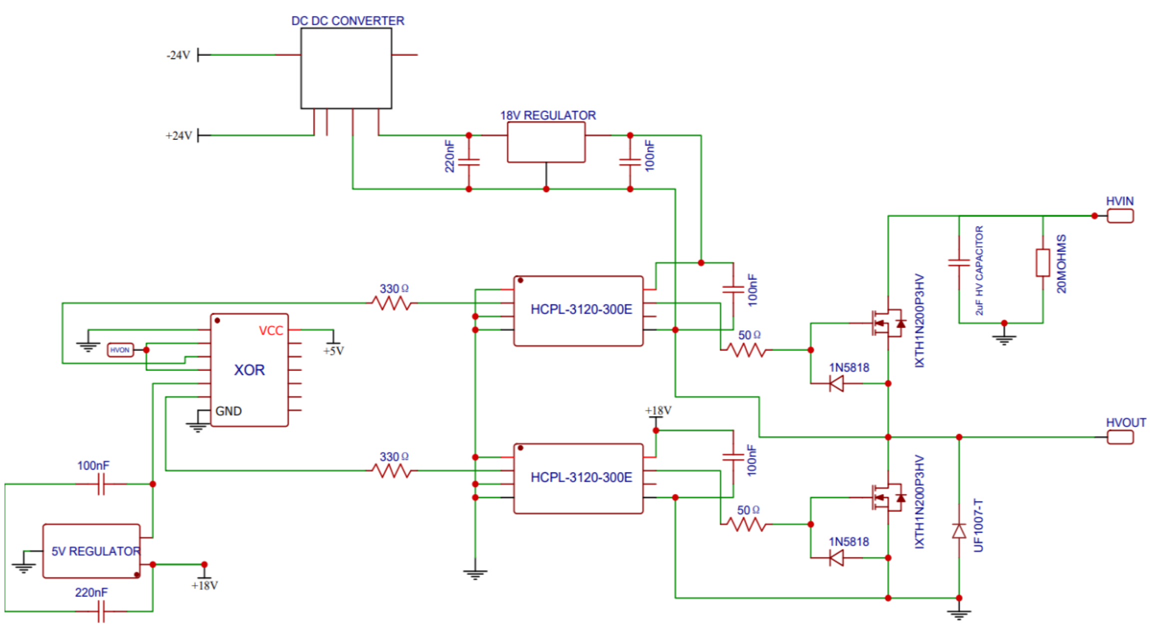


*Figure 2. Schematic of the ultra-fast 1000V HV switch with a switch speed of faster than 100ns built for the TOF/IFTOF experimental setup.*

made sure that this converter, or isolator, is completely isolated from the rest the of the setup. It acquires +24 and -24 from the +ve and -ve terminals of a DC power supply, say for example, CH 1 of the DC supply. However, since the Opto-Coupler (HCPL-31200-300E) requires 18V, an 18V regulator is connected at the output of the 24V DC DC converter to bring down the voltage to 18V and then supply it to the top HCPL-3120. The 0.22 uF and 0.1 uF capacitors are connected according to the datasheet of each component. Next comes the two Opto-Couplers, one on top and the other at the bottom. The bottom one is grounded to the common ground of the entire system, while the top one is not. The top Opto-Coupler should never touch the ground other wise the switch cannot give any voltage as output and a large amount of current could flow leading to failure of the MOSFETS or even burning them. The switching of these HCPL-3120 is controlled by the logic XOR gate to the left of the schematic in figure 2. At the extreme bottom left is just a 5V voltage regulator, since the XOR device needs to be powered up by 5V, else it won't work. The 2MOhms resistor and the 2uF HV capacitor (these are rated for 1000V) act as filter for the voltage input. Finally the main workers of the switch are the MOSFETs, top and bottom configured in a totem-pole arrangement. The 1N5818 diodes are just for protecting the MOSFETs to make sure in case of any sudden voltage surges of more than the breakdown voltage of those diodes (typically around 30V) the diodes will burn out and save the MOSFETs. The MOSFET used in this setting can handle voltages upto 2KV, but it will not work because the Opto-Couplers, HCPL-3120 cannot handle voltages that high. The HCPL-3120 can handle continuous voltage supply of 630V, but 1181V is possible if the ON time of the switch is less than 1 second. **Therefore, it is recommended not to keep this HV switch ON for more than one second if the applied voltage is more than 630V**. **Also, Do not exceed 1181V when using this switch.**

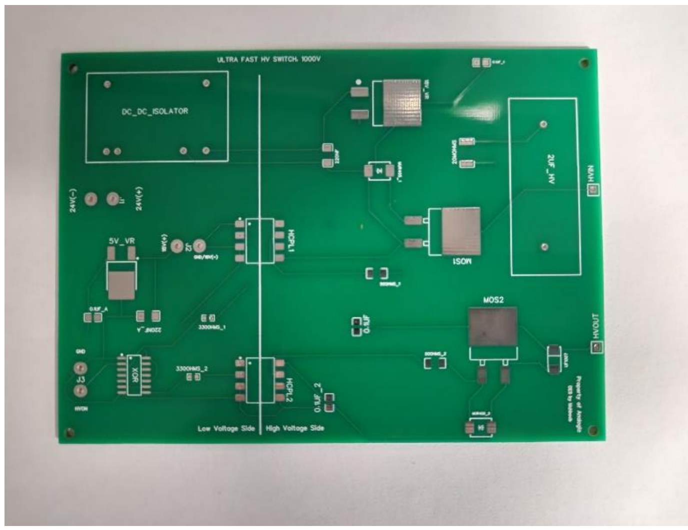


*Figure 3. HV Switch bare PCB without any of the components soldered. Each component footprint is specified which needs to be placed and soldered onto the PCB. The major components are the(from the Top Left) DC-DC isolator, 5V regulator, XOR Logic gate, HCPL1 and HCPL2 Opto-Couplers, 18V regulator, MOS1 and MOS2 HV MOSFETs and the 2uF HV Capacitor. The rest of the footprints include capacitors, input/output pins, diodes and power supply pins.*

The HV switch is designed to apply **only positive bias** to the sample. When a positive bias is applied to the top electrode, holes drift toward the lower electrode, generating a hole transient photocurrent signal. For electron measurements, the sample connections are simply reversed while all other experimental procedures remain unchanged. Make sure **Safe High Voltage (SHV) cable connectors are used** at the input and output side of the switch. **The switch must be properly sealed in an enclosure** with the ground connections properly made. Otherwise, the obtained signal will not be clear and have interferences with the signal output.

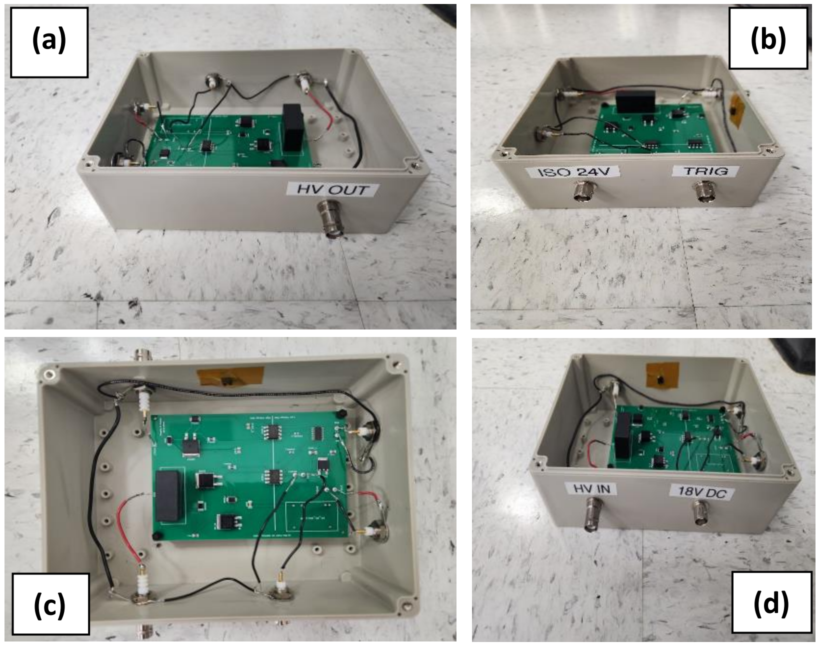


*Figure 4. This image shows the HV switch after soldering all the components and placing it inside the enclosure. (a) is the Right View where the HV cable is to be connected as the output voltage to reach the sample which is inside the sample enclosure box. (b) shows the Rear View containing the connection from the 24V isolated power supply and next to it is the trigger signal connector. (c) This is the Top View showing the internal connections. (d)The Left view has a knob which is the HV input which is the connecting cable coming from the HV power supply and the 18V DC supply connector*

The bias voltage is supplied by a BERTAN 205B-10R high-voltage power supply, which is connected to the HV switch input (HVIN). To apply a positive bias for transient photoconductivity measurements, the HV switch output (HVOUT) is connected to the sample's top electrode. Functioning as a single-pole double-throw (SPDT) switch, the HV switch normally grounds its output through the lower MOSFET. A +5V pulse at the trigger input (HVON) activates the upper MOSFET, connecting the high-voltage supply to the sample for the duration of the trigger pulse. Since the HV switch operates only with positive voltage input, electron transient photoconductivity measurements require connecting the switch output to the sample substrate, while the top electrode is linked to the sampling resistor and signal electronics**. This switch has a switching speed of less than 300ns.**

## Amplifier

A wide-bandwidth, two-stage differencing amplifier was designed to amplify the differential photocurrent signal while rejecting the common-mode displacement current. The schematic of this amplifier is shown in Figure 3. The AD830ARZ is the differential amplifier and the AD827 is the operational amplifier. Both of them require +15V and -15V supply in order to function. Suppose you have a DC power supply with 2 channels, CH1 and CH2, in order to obtain negative voltage, -15V, short the positive terminal of CH1 of the DC power supply with the negative terminal of CH2 of the same DC power supply. This shorted path is now the common ground that can be connected with the HV switch ground, sample ground and even the grounded bridge network ground. Basically it is the ground for the entire experimental setup. After shorting these two, now your CH2 positive terminal will supply +15V and the CH1 negative terminal will supply -15V. Make sure to measure using a DMM each time before conducting experiments. Now you can easily supply +15V and -15V to your amplifiers. I have chosen 15V, but you can supply higher or lower, given that it does not go beyond the functional range of the amplifiers according to their datasheets. The 0.1 uF capacitors are just decoupling capacitors that help filter any noisy signals so that it doesn't interfere with the amplification process.

The first stage utilizes a high-CMRR, wide-bandwidth video amplifier (AD830ARZ) from Analog Devices, configured as a unity-gain differential amplifier. This amplifier has a unity gain bandwidth of 85 MHz and a common-mode rejection ratio (CMRR) of 60 dB at 4 MHz.

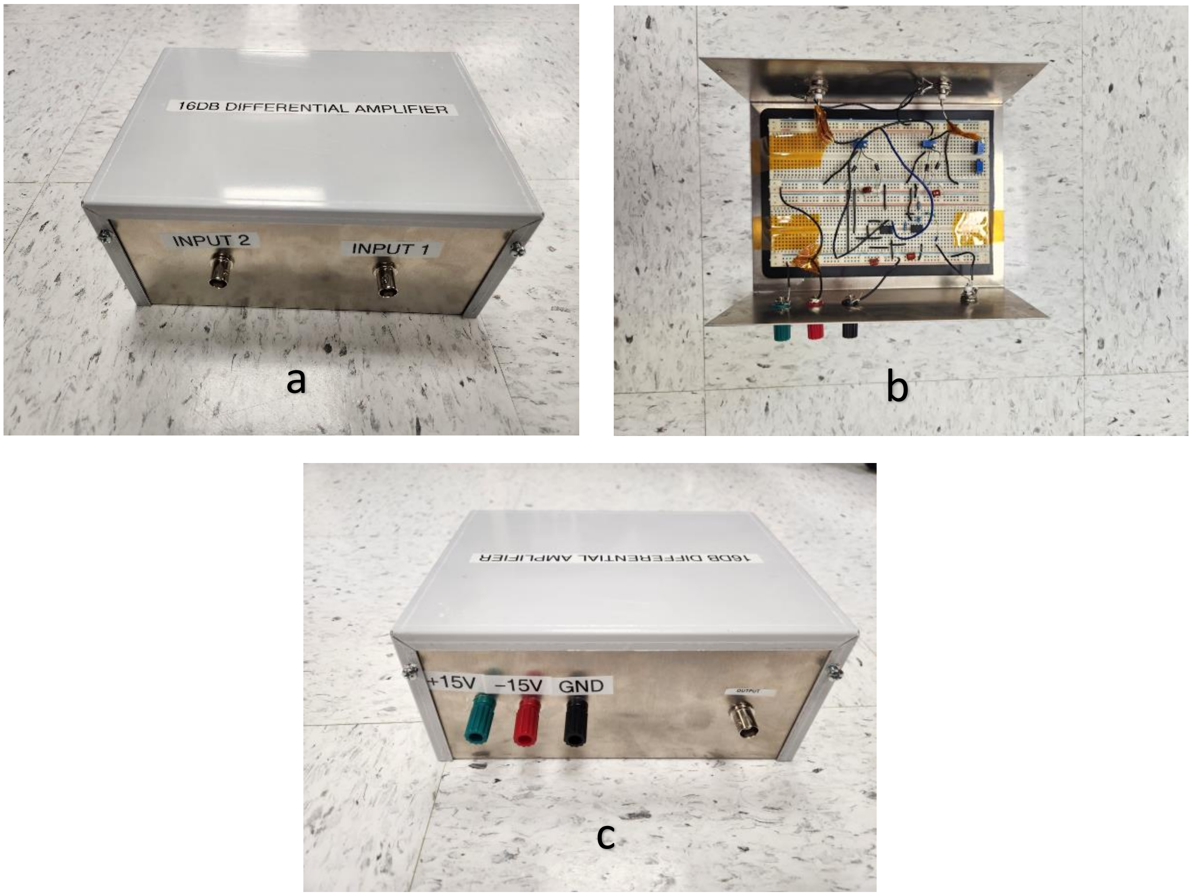


*Figure 5. Images showing the Amplifier enclosed in a shielded box. (a) shows the front view of the Amplifier with the INPUT 1 and INPUT 2 terminals which are the connections for the output signal that is collected from the sample in the sample box and the Air Capacitor output signal displacement current signal respectively. (b) shows the internal connections of the amplifier inside the enclosure. (c) is the Rear View containing the connections for the 15V power supply, ground and the Output knob at the far right.*

The second stage is a non-inverting amplifier, built using a high-speed operational amplifier (AD827) from Analog Devices. This stage provides a gain of 16 dB (based on what the resistor value is in the feedback path), ensuring that the photocurrent signal is amplified above the noise floor of the digital oscilloscope. To measure the output, if you have an oscilloscope probe with a hook and a sawtooth grabber, then place the hook after the 50Ohms resistor, which is the output of course, and then connect the sawtooth grabber on the common ground. **If all your connections are power supply is fine but you still don't see an output, then it is probably because either your R1 value or R2 value is too high or too low, which could cause a huge offset and remove the base signal of the oscilloscope from its zero position**. Moreover, make sure the timescale is right and the trigger is placed properly in the oscilloscope to capture the signal.

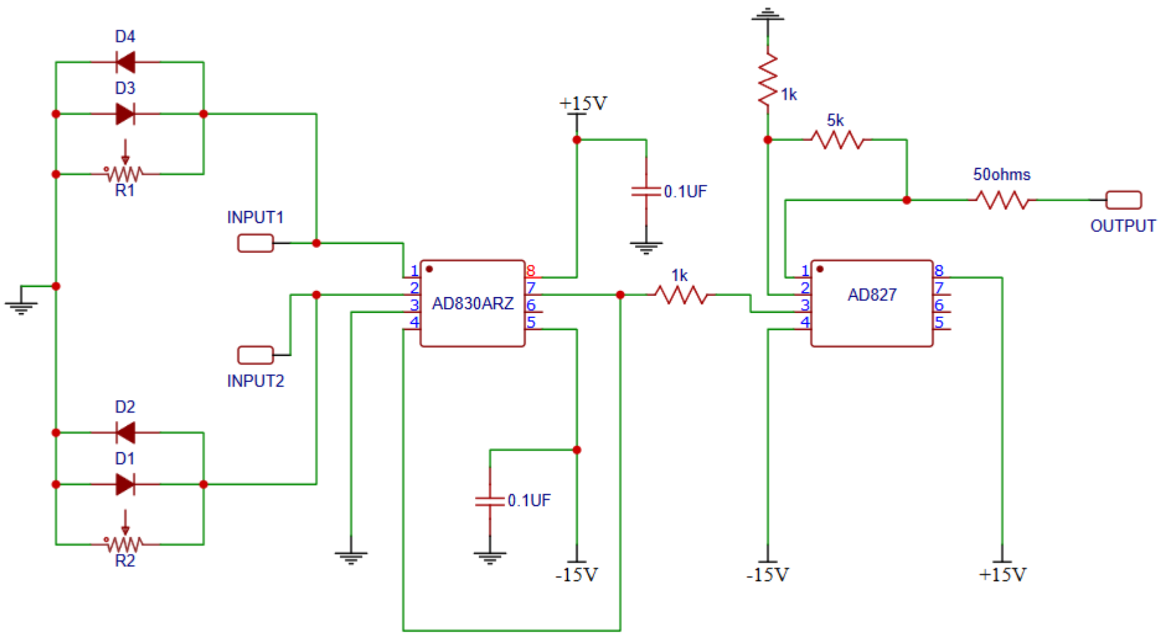


*Figure 6. A cascading 2-Stage system of amplifiers consisting of a differential amplifier and a 16dB gain amplifier. The two grounded bridge networks are at the left most of the schematic.*

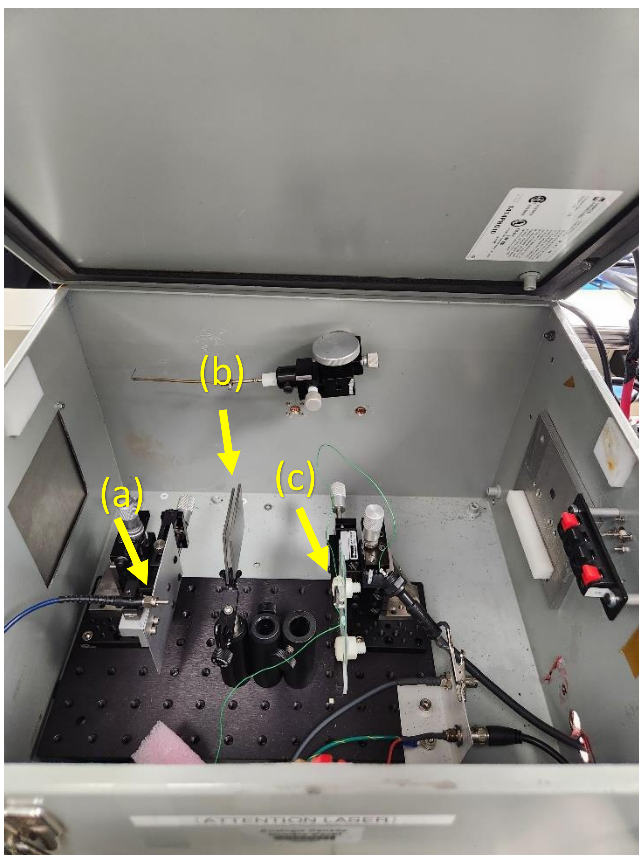


*Figure 7. Sample box enclosure. This box is made sure to prevent external light from interfering with the experiment. The Nitrogen Laser head is at the left most of the image labelled as (a). (b) is the OD filters which are used to reduce the intensity of laser light falling on to the Sample and there are two of them in this image. (c) is the sample held tightly with the sample holder and screwed in place. Two thin green wires can be seen coming out of the sample. One of these is for the HV bias (from the HV OUT knob of the HV switch) and the other is for the charge collection (which comes out and is connected to the INPUT 1 of the amplifier)*

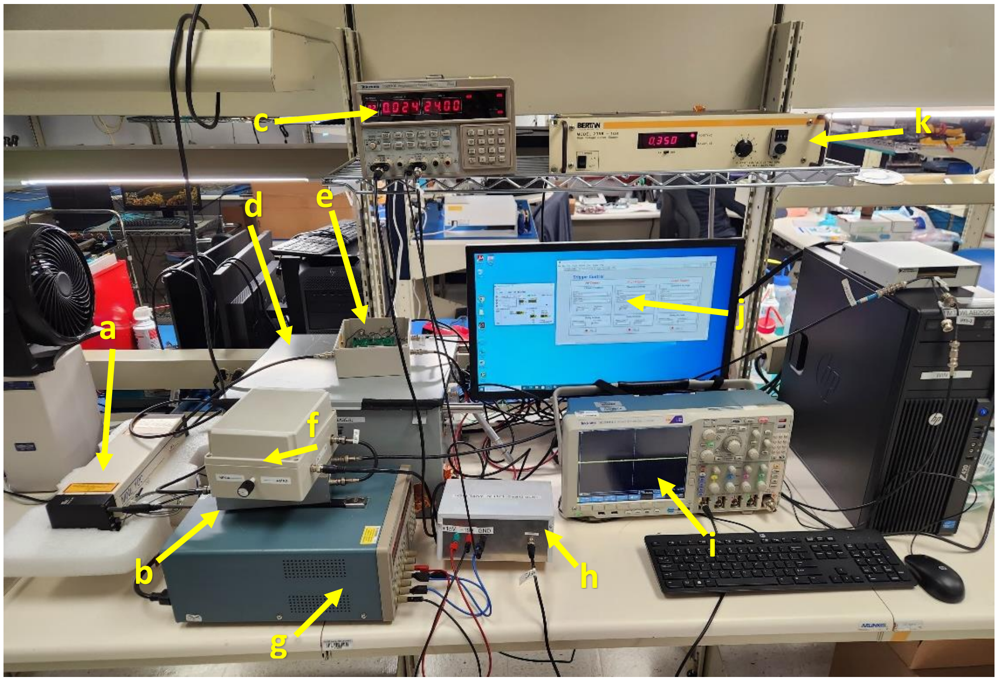


*Figure 8. The entire experimental setup view. All the Equipment used are shown here. (a) Nitrogen Laser. (b) HV Splitter box with one HV input and two HV outputs, one going to the HV switch and the other going to the Air Capacitor. (c) DC Power supply for the HV switch with Channel 1 being 24V and Channel 2 is 18V. (d) Sample box enclosure. (e) HV switch. (f) Air Capacitor enclosed. (g) DC power supply for powering up the amplifier. (h) the 16 dB differential Amplifier. Note that the grounds are made common from CH2 of (c), both channels of (g) and the GND terminal of the amplifier in (h). (i) Digital Oscilloscope. (j) PC with the LabView GUI and the Interphase for controlling the Laser. (k) BERTAN HV power supply.*