Summary of Key Electrical Hazards at LIGO
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1. **Overview:** The following document describes the more commonly encountered electrical hazards at LIGO. The list is obviously not intended to be all inclusive, but should provide a good starting point.

   The purpose of the note is to aid in selecting electrical safety training that will be made available in the future. No attempt has been made to cover work on the facility AC power distribution (120VAC and higher), as that type of work is typically performed by electricians under subcontract hire.

2. **Hazard Scenarios:** The hazardous devices most commonly encountered at LIGO can be broken up into the following groups:
   a. Piezo Electric Transducers
   b. Suspension Electrostatic Drives
   c. Vacuum Ion Pump and Vacuum Gage Power Supplies
   d. High Power RF (Radio Frequency) Sources
   e. Suspension Bias Voltages
   f. Silicon Photodetector Bias Voltages
   g. Forklift Battery Maintenance

3. **Detailed Descriptions**
   a. As shown in figure 1, the LIGO Piezo Electric Transducers (PZTs) consist of small (approximately 1 inch in diameter), cylindrical devices with metallization applied to the opposing surfaces. In a typical application, a DC bias is applied to the PZT. Portions of the PZT are often exposed, and can present a shock hazard during testing. Table 1 has a summary of electrical characteristics. It is not uncommon to require direct measurement of the voltages on the plates of a PZT as a performance verification.

Figure 1

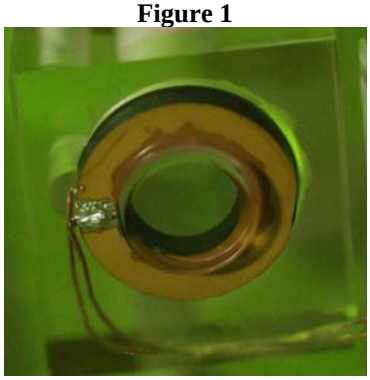

Table 1 PZT Electrical Characteristics

Voltage	Up to 400 volts DC
Current	The power supplies are typically capable of greater than 10 milli-Amperes, generally less than 100 milli-Amperes
Capacitance	Capacitance values (for stored energy calculation) can range from a few pico-farads, up to a micro-farad.
Miscellaneous	There is not typically much AC content riding on the DC bias for a PZT. A few volts peak to peak are normal.

b. **Electro Static Drive:** In Advanced LIGO, the optical suspension system will likely use an electro-static drive system. This system is still in a development phase, but some of the preliminary characteristics are summarized in Table 2.

Table 2 Electro-static Drive Electrical Characteristics

Voltage	Up to 850 volts peak to peak AC at frequencies up to ~40kHz or so
Current	The power supplies are likely to be capable of greater than 100 milli-Amperes
Stored Energy	While the capacitance of the electrodes may be small, there could be significant capacitance in the transmission cables or driver amplifiers. This is still under development
Miscellaneous	A DC bias could also be present in this system

c. Vacuum Ion Pump and Vacuum Gage Power Supplies: These are commercial products that are usually carefully designed to avoid electrocution hazard. It's not uncommon for the larger devices to have full interlock systems that sense if the system integrity has been violated and shut down the high voltage supplies automatically. Table 3 has a summary of the characteristics of these devices at LIGO

Table 3 Vacuum Equipment Electrical Characteristics

Voltage	Up to 7000 volts DC
Current	The power supplies for these devices are able to supply a few milli-Amperes, but often have a current limit that can be programmed into the device
Stored Energy	The intrinsic capacitance of the in-vacuum component is usually small, but there could be significant capacitance in the transmission cables.
Miscellaneous	There should be no need to directly perform measurements of the high voltage portions of these devices. The devices are usually capable of displaying operating voltages and currents.

d. **High Power RF (Radio Frequency) Sources:** Carbon Dioxide (CO2) lasers used in the LIGO Thermal Compensation System (TCS) utilize a Radio Frequency (RF) drive. The RF power levels used to excite a CO2 laser can be quite high ranging from tens to hundreds of watts. Table 4 brackets some of the parameters used at LIGO

Table 4 Thermal Compensation System RF Characteristics

RF Power Level	The RF power level required for a CO2 laser is approximately ten times the laser optical power. Advanced LIGO TCS system optical power is of order a few tens of watts, leading to an estimate of RF power of several hundred watts.
Frequency	The RF drive frequency of a CO2 laser is set by the resonant frequency of the plasma tube. 45 MHz is common for Synrad Inc. lasers.
Miscellaneous	It is not known at the time of writing whether or not there are hardware interlocks to shut down the system if the RF drive cable is disconnected.

e. **Suspension Bias Voltages:** For Initial and Advanced LIGO, DC biases are applied to control points in the Optical Suspension System. These voltages are deliberately filtered such that they have little or no AC content, but the voltage levels can be dangerous. Table 5 summarizes the characteristics of the suspension biases.

Table 5 Suspension Bias Voltage Characteristics

Operating Voltage Range	Minus 300 to plus 300 volts DC
Current	The power supplies used to drive the bias circuitry are capable of supplying in excess of 10mA
Miscellaneous	The need for such high voltages has its origin in electrical noise. The high voltages don't actually have to leave the circuit board and propagate down a cable to the suspension system. This will help with safety somewhat.

f. **Silicon Photodetector Bias Voltages:** In Initial LIGO there was a need to utilize silicon based photodetectors. In order to meet performance requirements, DC biases were applied. For the future, it is likely that there will be no need to use these devices, but for the sake of completeness, they will be described. From the standpoint of safety, they are very similar to the PZTs described earlier in this note. Table 6 summarizes the characteristics.

Table 6 Silicon Photodetector Bias Voltages

Operating Voltage Range	Up to 150 volts DC
Current	The power supplies used are capable of supplying in excess of 10mA
Miscellaneous	A shift from silicon diodes to InGaAs removes the need for high bias voltages in the future

g. **Forklift Battery Maintenance:** Forklifts and Man-lift type machinery are commonly used at the LIGO observatories. The hazards associated with maintaining the lead-acid batteries in these machines go beyond electrical safety to include the proper handling of the acid as well as the considerable weight of the batteries – estimated at 2000 lbs. Table 7 summarizes the electrical characteristics of the batteries. No effort is made to address the other safety hazards in this document.

Table 7 LIGO Lead-acid Battery Characteristics

Forklift Battery Voltages	36 volts DC formed by 18 volt cells
Genie Man-lift Battery Voltages	24 volts total formed by 6 volt cells
Current	Hundreds of amperes
Miscellaneous	Battery maintenance is usually a matter of disconnecting and reconnecting to a charger