LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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EO SHUTTER CONTROLLER MANUAL

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1 OVERVIEW

The Electro-Optical (EO) Shutter Controller is an integral part of LIGO's length sensing control system. The controller is designed to provide gating signal for a commercial High Voltage (HV) pulse generator used to control the EO Modulator in the servo loop. Signal from a high speed photodetector in the control loop is fed to the unit for processing. When the laser beam intensity exceeds a predetermined level, the controller turns off the gating signal and shuts down the EO modulator. The unit is designed to interface with the LIGO VMEbus. Normally, the unit is under remote VME control. However, most of its functions can also be adjusted locally.

2 SPECIFICATIONS

(A) High Voltage Specification:

Positive High Voltage (+HV) Range:	0 to 10KV
+HV Output Current:	0 to 3 mA
+HV Ripple (Full Load, Max Vout):	.20% Vp-p
+HV Dynamic Load Regulation:	<5.0Vpk
Negative High Voltage (-HV) Range:	0 to 2.0KV
-HV Output Current:	0 to 10 mA
-HV Ripple (Full Load, Max Vout):	.05% Vp-p
-HV Dynamic Load Regulation:	<2.0Vpk

(B) Power Supply Requirement:	+24Vdc @ 800mA
(C) Input Resistance:	50 Ohm
(D) Input Voltage Range:	0 to +/- 5Vpk
(E) Output:	TTL logic
(F) Control logic:	TTL logic

3 THEORY OF OPERATION

The main mission of the controller is to provide gating signal as well as high voltage power supplies to the pulser that controls the EO Modulator. Input signal from the high speed photodetector is first amplified by the non-inverting amplifier U1 with gain determined by the following formula:

$$V_g := 1 + \frac{R_2}{R_1}$$

This amplified signal is then used to compare with the reference voltage (Vref) at the output of unity gain buffer amplifier, U11, by comparator U2. Input to U11 is selectable through front panel switch S1. When the switch is in the REMOTE position, the reference voltage is set by the VME host. When the switch is in the LOCAL position, the reference voltage is set by the front panel THRESHOLD ADJUST knob. Comparator U2 together with resistors R36, R37 and R38 forms a comparator stage with hysteresis. Hysteresis is achieved by shifting the reference voltage at the positive input when the output voltage changes state. Thus, when the signal at the inverting input of U2 is less than or equals to the reference voltage at its non-inverting input, output of U2 switches HIGH (Vcc) and the upper input trip point is given by:

$$V_{Triphi} := \frac{V_{cc} \cdot R_{37} \cdot \left(R_{36} + R_{38}\right)}{R_{36} \cdot R_{37} + R_{36} \cdot R_{38} + R_{37} \cdot R_{38}} \qquad V_{Triphi} = 1.797$$

When the input voltage rises above VTriphi, output of U2 will go low (GND) and the lower trip voltage is now given by:

$$V_{Triplo} := \frac{V_{cc} \cdot R_{37} \cdot R_{38}}{R_{36} \cdot R_{37} + R_{36} \cdot R_{38} + R_{37} \cdot R_{38}} \qquad V_{Triplo} = 1.634$$

and the total hysteresis of the circuit is given by

$$\Delta V_h := V_{Triphi} - V_{Triplo}$$

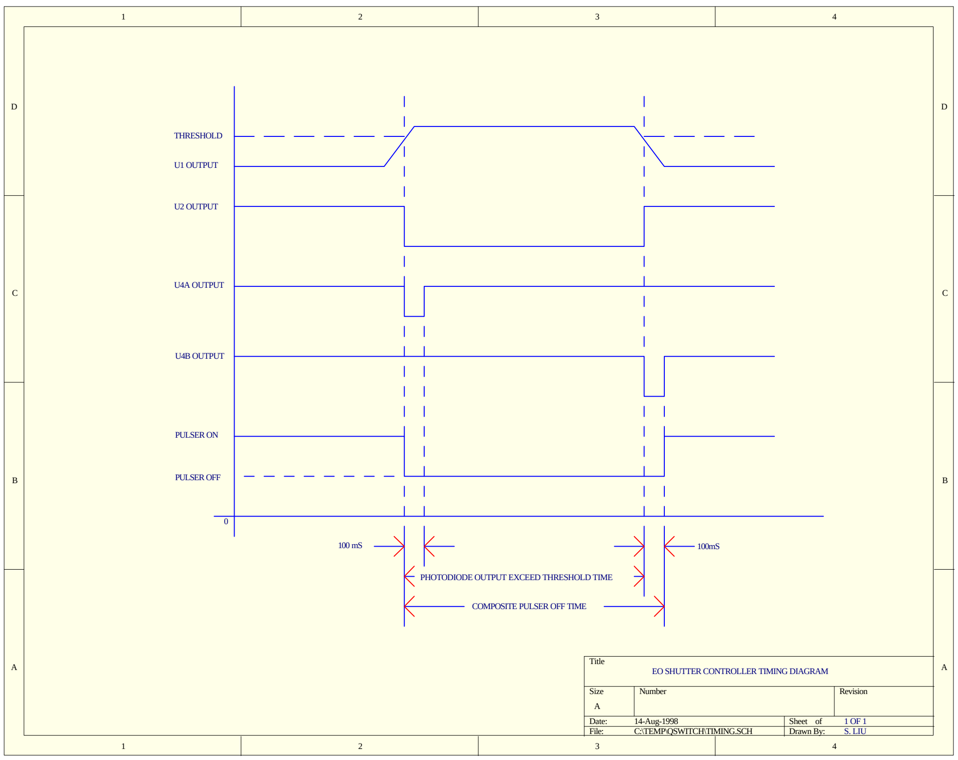
$$\Delta V_h = 0.163$$

Output of U2 is then branched out to three different places. One output goes to the input of AND gate U6B directly. The rising edge of U2 output is used to trigger a 500 nS pulse generator (U5) used to provide proper setup time for the main 100 mS Monostable Multivibrator (Mono) U4B. The duration of the mono is given by:

$$t_w := R_{28} \cdot C_{28}$$

$$t_w = 0.1$$

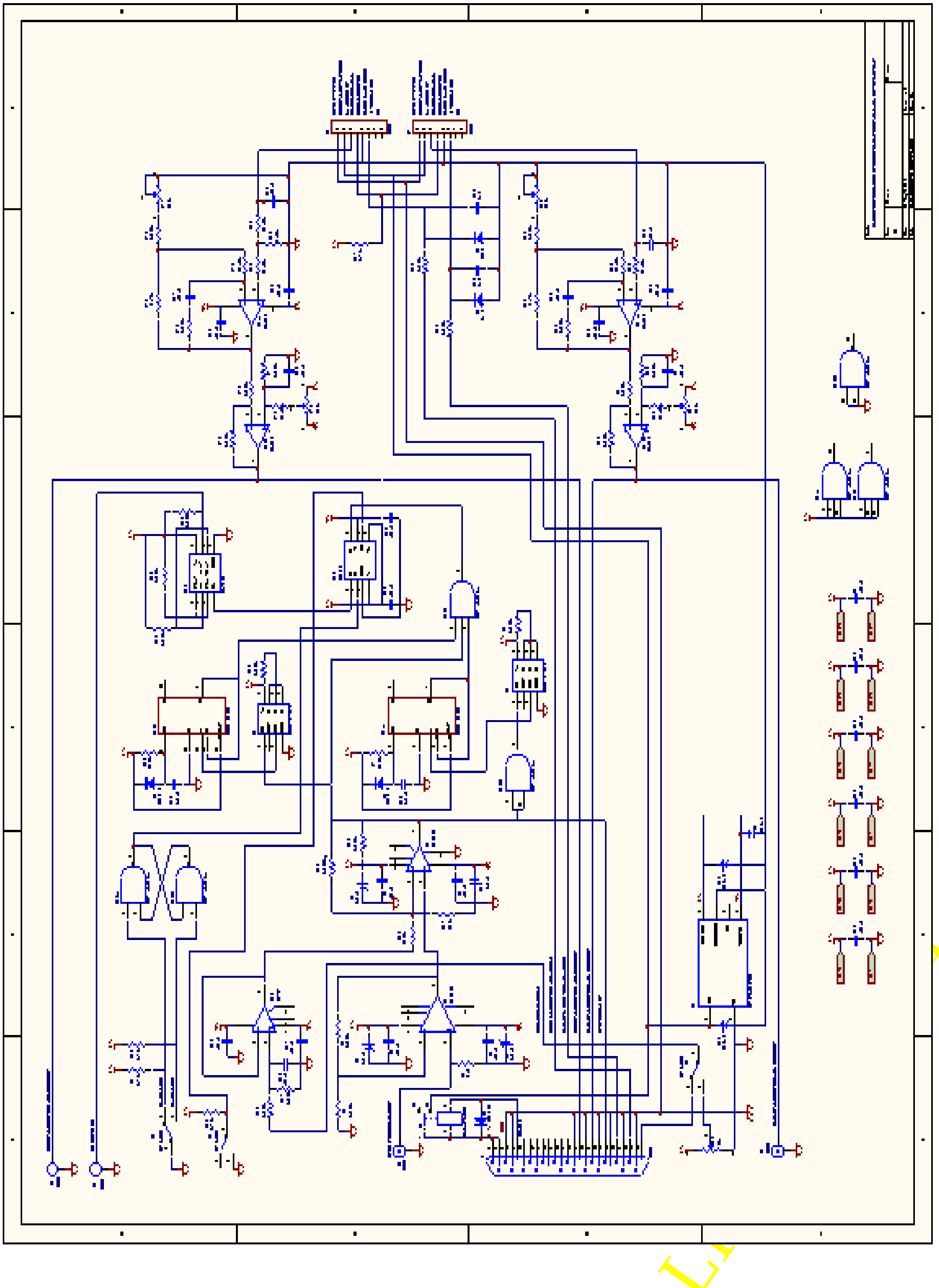
Similarly, the falling edge of U2 output goes through an inverter, U12C, to provide positive trigger for U3 which in turn triggers U4A. Output of U4A is a delayed mono with the same pusle-width as U4B. AND gate U6B sums up all these outputs to form a composite gate signals as shown in the diagram below:



When switch SW3 is in the AUTO mode, this composite gate signal passes through solid state switch U13 to the output driver U10. When switched into the MANUAL mode, front panel switch SW2 is used to simulate the gate signal for turning the high voltage pulser on or off manually. NAND gates U12A and U12B form a debouncer for the contact of SW2 to prevent multiple triggering.

Op Amp U7A and U7B convert the Iout monitor current of the positive high voltage power supply into a voltage for checking the status of the power supply. Op Amp U9A and U9B perform the same function for the negative high voltage power supply used.

The following is the complete schematic of the controller:



High Voltage Power Supplies

One positive 10KV high voltage regulated DC-DC converter (Ultravolt Inc.10A24-P15-M-C) and one negative 2 KV high voltage regulated DC-DC converter (Ultravolt Inc.2A24-N20-M-C) were used to generate the positive and negative high voltage power supplies for the DEI GRX-10K-H 10KV Pulse Generator. The converters uses the +24Vdc input power supply to generate oscillation frequency near 100 KHz for the voltage multiplier to generate the required high voltages. Each unit has an internal precision reference so that remote control can be used to program the power supply of a specific voltage. For the positive DC-DC converter, programming is done with 0 to +5 Vdc to produce 0 to 10 KV output voltage. For the negative DC-DC converter, the programming voltage goes from +5 Vdc to 0 to produce 0 to -2KV output voltage.

Output current of the DC-DC converter is monitored by reading the voltage appearing between pin 3 and signal ground return pin 5 for each of the converters. The positive 10 KV high voltage power supply has a scaling factor of 1.5mA/8.0V. C41 together with the internal isolation resistor (~15K) of the high voltage power supply to forms a low pass filter to convert this AC signal to a "DC" voltage. Because U7 is operating on +/- 5Vdc power supplies, this input voltage is first scaled by resistors R51 and R52 to within U7's input range. U7A then provides a DC gain and AC suppression to further clean up this signal for outputting. Potentiometer R47 is used to fine adjust the gain of this stage. Op Amp U7B is used to null out offset from the sensing circuit and provide proper signal polarity at the output.

The scaling factor for the negative 2KV high voltage power supply is only 10mA/90mV. Therefore, no divider network is used at U14's input and the processed signal is further amplifier by a gain of 10 before being sent to the output.

Low Voltage Power Supply

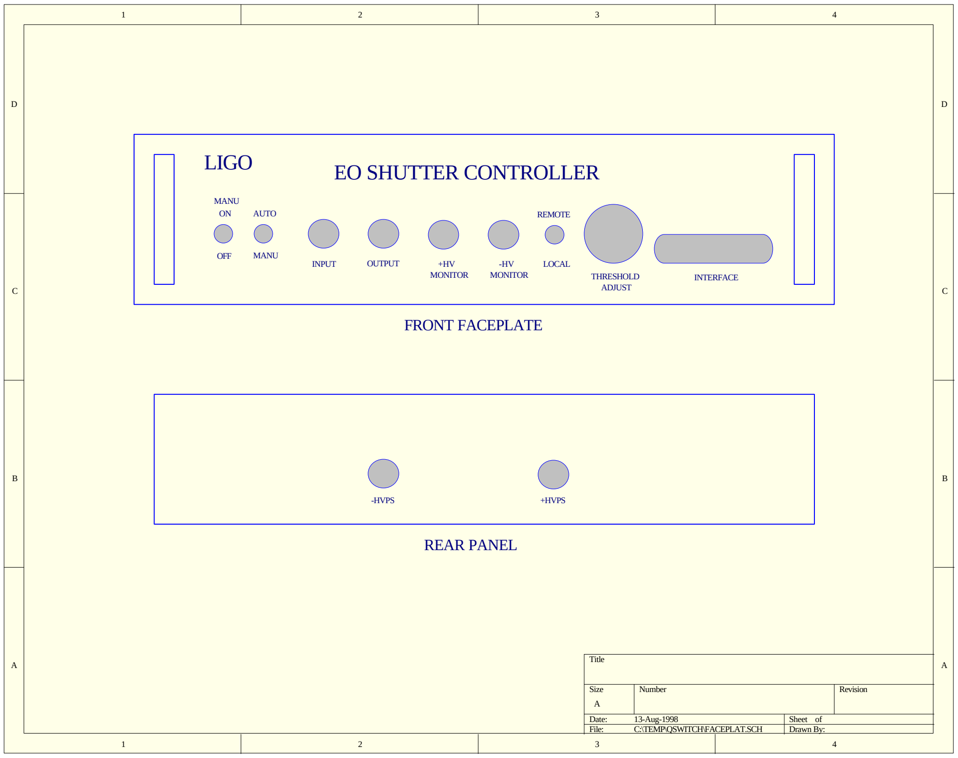
A miniature DC-DC converter (Datel BWR-5/500-D24 DC-DC) is used to convert the +24 Vdc input power supply to +/- 5 Vdc power supplies for both analog and digital circuits on board. Power to the unit can be remotely controlled by grounding pin 3 of the interface connector.

VME Interface

A front panel DB25 connector is used to interconnect the unit to the VME crate. Through this connector, the VME host can set the threshold level and adjust the positive or negative high voltage level through three DAC(Digital-to-Analog) channels from a remote site. Similarly, the VME host can use three channels of ADC(Analog-to-Digital) to monitor the controller's high voltage levels as well as its trip condition.

Mechanical Drawings:

The following are the mechanical drawings of the front panel, rear panel and the component layout in the chassis.


LIGO
EO SHUTTER CONTROLLER
MANU
ON
OFF
AUTO
MANU
INPUT
OUTPUT
+HV MONITOR
-HV MONITOR
REMOTE
LOCAL
THRESHOLD ADJUST
INTERFACE
FRONT FACEPLATE
-HVPS
+HVPS
REAR PANEL
Title
Size
A
Number
Revision
Date: 13-Aug-1998
File: C:\TEMP\QSWITCH\FACEPLAT.SCH
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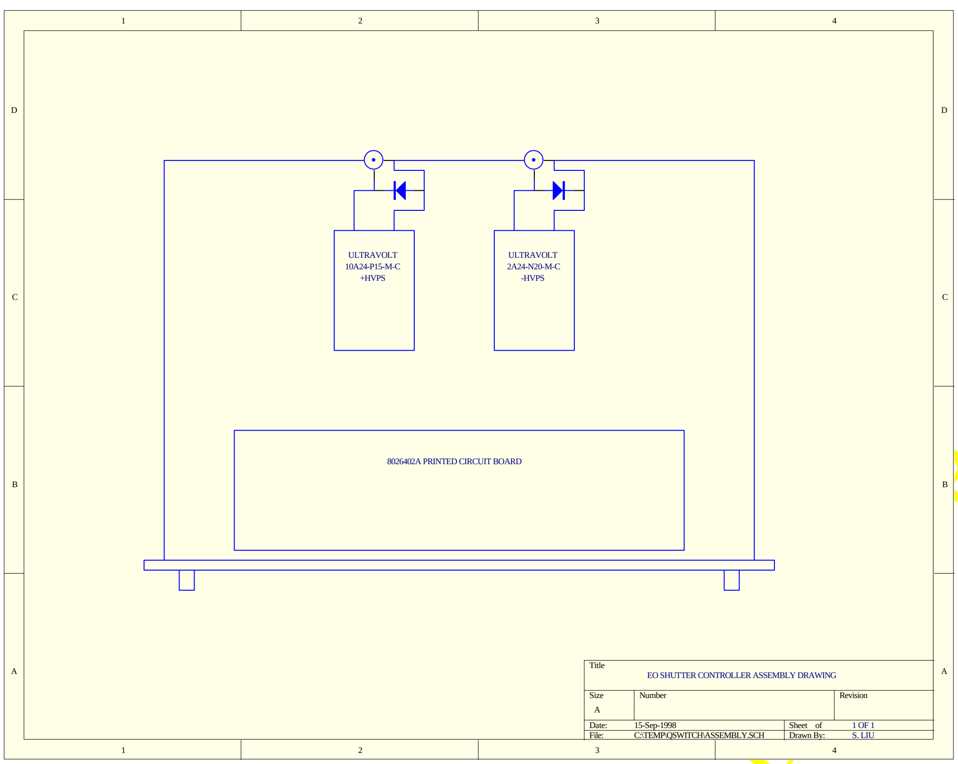
ULTRAVOLT
10A24-P15-M-C
+HVPS
ULTRAVOLT
2A24-N20-M-C
-HVPS
8026402A PRINTED CIRCUIT BOARD
Title
EO SHUTTER CONTROLLER ASSEMBLY DRAWING
Size
A
Number
Revision
Date: 15-Sep-1998
File: C:\TEMP\QSWITCH\ASSEMBLY.SCH
Sheet of 1 OF 1
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APPENDIX 1 PHOTODIODE SIGNAL ANALYSIS

The following represents two of the most commonly used configurations for photodetector operating in the photoconductive mode. Both are reverse biased and operate in the current-to-voltage conversion mode.

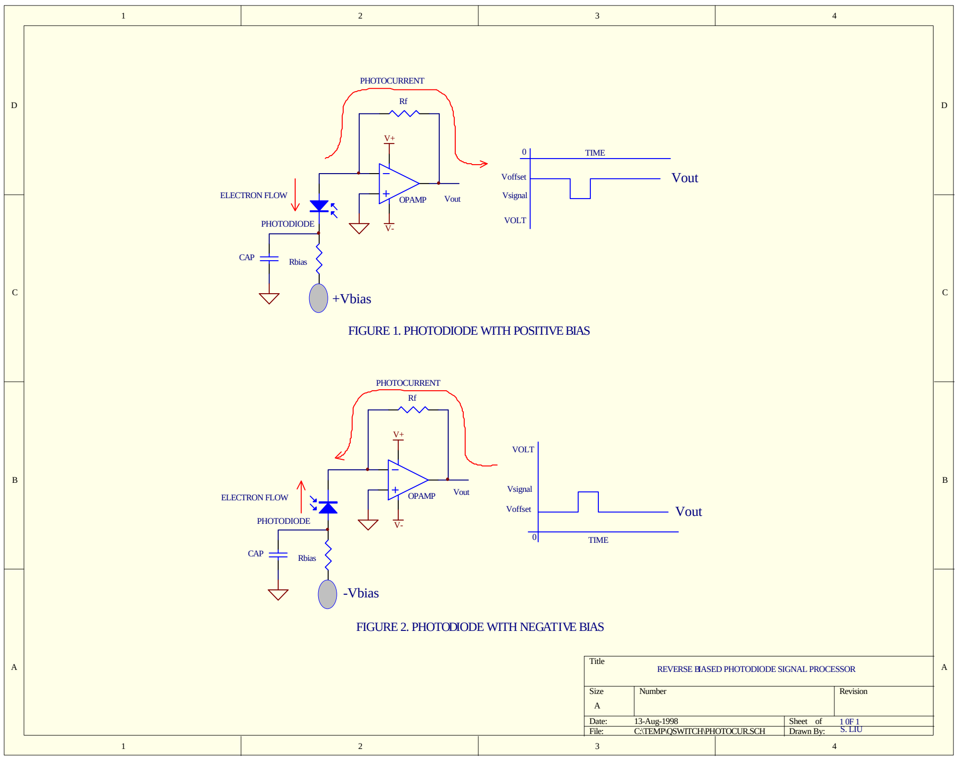

FIGURE 1. PHOTODIODE WITH POSITIVE BIAS

FIGURE 2. PHOTODIODE WITH NEGATIVE BIAS

In Figure 1, the cathode is made positive with respect to the anode. Electrons flow from the P-type region to the N-type region inside the photodiode and the photon generated current flows from the P-type region to the N-type region through the external circuit. In Figure 2, the anode is made negative with respect to the cathode. Electrons still flow from the P-type region to the N-type region inside the photodiode and the photocurrent from P-type region to the N-type through the external circuit. The fundamental difference between the two is their output signal polarity. The accompany plots in each of the above diagrams depict their expected outputs.

In both circuits, Vos is a function of detector and preamplifier noises. The presence of Vos limits their response as well as sensitivity. Except for their output polarity difference, both circuits should work equally well in the scheme of simple threshold detection. Their small difference in signal risetime and amplitude due to electron and holes mobility difference inside the diode material should not be a problem for our present application.

Assuming that the incident power of the 1.06um laser on the detector is in the range of 0.2 to 8.0 was and the optical path attenuation to be 0.00085, output signal from the photodetector can be estimated using:

Symbols and Definitions

Plank's Constant in J*S

$$h := 6.626 \cdot 10^{-34} \qquad J \cdot s$$

Electron Charge in Coul

$$q := 1.60 \cdot 10^{-19} \qquad Coul$$

Speed of Light in Vacuum

$$c := 2.998 \cdot 10^{8} \qquad \frac{m}{s}$$

Wavelength of Incident laser in meters

$$\lambda := 1.06 \cdot 10^{-6} \qquad m$$

Frequency of incident Laser in Hz:

$$\nu := \frac{c}{\lambda}$$

$$\nu = 2.828 \cdot 10^{14} \qquad Hz$$

Photon Energy @ 1.06um in eV:

$$E := \frac{h \cdot \nu}{q}$$

$$\frac{h \cdot \nu}{q} = 1.171 \qquad \text{eV}$$

Let the Optical Path Attenuation be

$$\gamma := (.85) \cdot (.001)$$

and the Detector Quantum Efficiency be

$$\eta := .3$$

For the 0.2w output laser, the incident laser power on the photodetector is given by

$$P_{0.2} := 0.2 \cdot \gamma$$

and the maximum photocurrent can be calculated using:

$$I_{0.2} := \frac{P_{0.2}}{\left(\frac{h \cdot \nu}{q}\right)} \cdot \eta$$

$$I_{0.2} = 4.354 \cdot 10^{-5} \qquad \text{A}$$

Similarly, the maximum photocurrent at 8 w is given by

$$I_{8.0} := \frac{8.0}{\left(\frac{h \cdot \nu}{q}\right)} \cdot \gamma \cdot \eta$$

$$I_{8.0} = 0.002$$

If we use a 1 K Ohm load resistor to convert these currents into voltage, the expected values are 43.5 mV + Vos to 2.0 V + Vos respectively. These are the values used to calculate the approximate gain needed for the input amplifier.