Optical Trigger Box

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September 20, 2018

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Abstract: This System is designed to temporarily turn off a Laser Diode Controller when a signal from a photo diode reaches the Trigger Threshod set by a User Interface. CMS utilizes this system to test the losses of their crystalline mirror coatings. The Trigger Threshold is set using a Teensy 2.0 board and a series of low pass filters. The System will display this set trigger threshold on the user interface. The Teensy will, as well, compare the Photo diode signal to the Trigger Threshold using the comparison modulator in its microprocessor to determine whether or not to turn off the Laser Diode Controller. The Teensy than uses a ADG436 Dual SPDT Switch to control the signal to the Laser Diode controller. The User Interface was designed with QT designer, which then generated code that was converted to python. Further Python code was written to communicate between the User Interface and the Teensy board. This additional code, when paired with the code used for the Teensy, allows the user additional abilities, such as controlling the gain of the incoming photo diode signal using an AD8251 Micro-controller, controlling whether or not signals can be sent to the SPDT switch, calculating the average frequency of triggers over a settable period of time, and measuring the Trigger Threshold. The Serial Port is used as an intermediate between the Python Code and Teensy Board.

1. Background & Summary

An optical ring down is the leakage of the light field out of an optical cavity after its source of light has been turned off. The time constant of the ring down is related to the finesse of the cavity. CMS uses this box to read the output from a cavity that contains their mirrors and sets the box to trigger off a chosen event. After the laser diode is turned off, a ring down occurs. CMS can than determine the finess of the cavity and from there, the losses of their crystalline mirror coatings. Being able to reset this test after the ring down and therefire run it repeatedly allows many tests to be done quickly, which is helpful in establishing a reliable loss estimate. In order to function properly for this

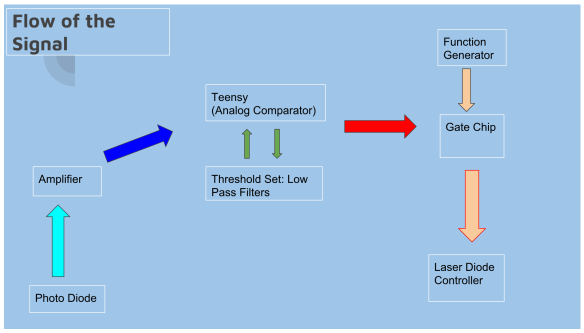

Figure 1: Flow of the Signal

The arrows show the flow of the signals between sources, outputs, and chips within the Trigger Box. The various colors represent different signals, either signal that are created from previous signals or signals that are completely new. Also The Teensy receives commands from the serial port as well. However this is not shown here as the commands are part of the set up of the device, but they are not part of the functionality of the running device.

test, the box must be able to take a signal from the photo detector, compare that signal to a set trigger threshold level, and than send a signal to turn off the LDC. Figure 2 gives an example of how all the signals needed in the box may run. As one can see, when a trigger occurs, where the dotted lines are, different signals react differently and eventually create the outgoing signal that controls the LCD. The Photo Diode and Threshold signal dictate the shape of the Mod Signal and the Mod and Sig signals than dictate the shape of the Out signal.

Low Pass Filters (LPFs) are electrical filters that attenuate the amplitude of AC signals with high frequencies so they can be used essentially as DC signals. These filters are built with a capacitor and a resistor. The circuit of LPFs are set up as shown in Figure 3. An LPF not only changes the amplitude of a high frequency signal, but phase shifts the waveform of the signal as well. The lowest frequency where the filter attenuates the amplitude of the wave is called the corner frequency. This corner frequency can be calculated from the time constant of the capacitor, Tau, as shown in the calculation below:

$$\begin{aligned} f &= \frac{1}{2\pi * R * C} \\ &= \frac{1}{2\pi * \tau} \end{aligned}$$

where R is the Resistance of the resister in ohms , C is the capacitance of the Capacitor in farads , and f is the corner frequency in hertz. τ is the time constant in seconds which is equal to the Resistance times the capacitance(Low).

However, the actual attenuation of the signal comes from the capacitive reactance of the capacitor, which is dependent on the frequency of the signal

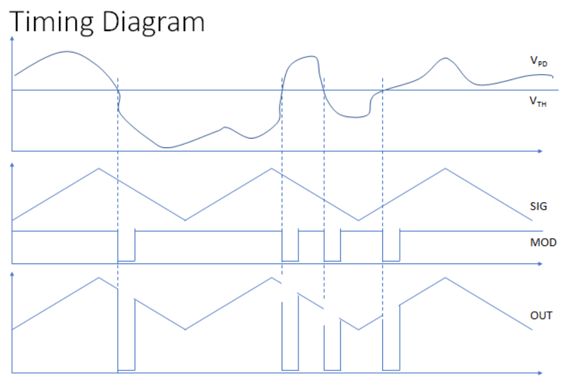

Figure 2: Signals within the Box

The signals in the diagram show examples of the different signals in Figure 1. The different signals are placed in an order that helps show how the signals are related. This graph was used as a guide when creating the box. The V_{PD} label indicates the signal from the photo diode, the The V_{TH} label indicates the Threshold level signal, The SIG label indicates the signal from the function generator, the MOD label indicates the signal that the Teensy outputs to the SPDT switch, and the OUT signal indicates the signal output from the box to the LCD.

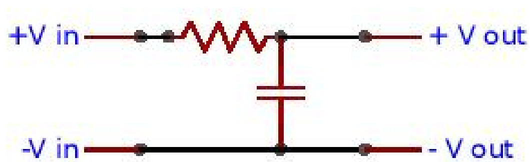

Figure 3: Diagram of Low-Pass Filter

This diagram shows the general outline of a low pass filter. The two red parallel lines represent a capacitor. The red zig-zagged line represents a resistor. The Voltages at each corner of the diagram represent either an input voltage, indicated by "in", or an output voltage, indicated by "out".The positive and negative leads are indicated by "+" for positive and "-" for negative.

running through the filter. The capacitve reactance is a measurement of how resistive a capacitor is to AC currents. This resistance prevents AC currents from running down the capacitor directly to ground instead of running to the circuit. Capacitve reactance decreases with an increase of frequency because higher frequency signals have a greater rate of change of voltage, which means they can drive more current onto the capacitor. The capacitve reactance of the capacitor can be calculated using the formula below:

$$X_{\mathrm{C}} = \frac{1}{W * C}$$

where X_C is the reactive capacitance of the capacitor in ohms, W is the angular frequency of the signal in hertz, and C is the capacitance if the capacitor farads. To summarize, a higher frequency signal entering the capacitor means a smaller capacitive reactance and a larger voltage drop over the capacitor. This behavior can be modeled with bode plots, as pictured below in Figure 4, that model both the phase shift and signal attenuation due to the filters on a log-log plot. The voltage change over a filter can be calculated with the equation below:

$$V_{\mathrm{out}} = \frac{X_{\mathrm{C}}}{\sqrt{X_{\mathrm{C}}{}^2 + R^2}} * V_{\mathrm{in}}$$

where V_{out} in the voltage out of the circuit in volts, V_{in} is the voltage into the circuit in volts, R is the resistance of the Resistor in the filter in Ohms, and X_C is the reactive capacitance of the capacitor ohms(AC).

2. Teensy

The Teensy 2.0 board runs an Arduino Program that takes a message from the Serial Port. This message can be one of several commands: "Set", "Enab", "Gain", and "Freq". Any non-recognized command will return an error code, indicated by a specific negative number based on the type error as shown in Figure 5.

"Set" followed by a threshold value between zero and five tells the Teensy to output a Pulse-Modulated Signal (PWM), that has an average value of the given threshold value, into the LPF circuit as shown in Figure 8. The signal from the circuit is than read and returned to the Serial Port to be read by the Python code. Set followed by a question mark tells the Arduino to read the input from the LPF circuit and report it back to the Serial Port without modifying the output from the teensy to the LPF circuit. For either command, the returned threshold level may be between .05 V below and .05 V above the set threshold value.

"Enab" followed by a zero turns off interrupts from the analog compactor, which is responsible for sending the pulse to the SPDT switch as well as making the LED blink. Enab followed by a one turns these interrupts on. Enab followed by a question mark reports whether these interrupts are turned on and off by reporting back a zero or one.

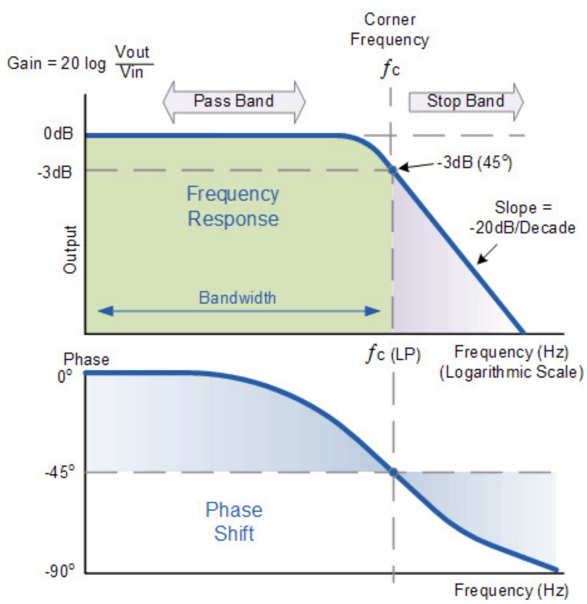

Figure 4: Bode Graph Example

This Graph demonstrates the frequency response and phase shift of an AC signal passing through a Low Pass Filter. These graphs show the Transfer Functions of these changes. This graph was taken from the article "Low Pass Filter - Passive RC Filter Tutorial" as to demonstrate the general form of a bode graph and the transfer functions of frequency response and phase shift of a AC signal through a LPF.

Error Code	Error
-20	No argument
-21	Requested Threshold Level outside of acceptible range
-31	Improper Enab arguement
-41	Improper Gain Argument
-51	Zero or Negative Time (Freq)
-1	Invalid Command

Figure 5: Error Codes for Interface
This chart shows the possible error codes that may show on the User Interface if there is a problem in the Optical Trigger Box.

"Gain" followed by "1","2","4", or "8" sets the gain on the amplifier chip; therefore multiplying the signal from the photo diode by the set amount before it is read by the Teensy. This can help the Teensy read small signals, especially when there is little variance within the signal as well.

"Freq" indicates commands for measuring the average frequency over a period of time. If "Freq" is followed by an "S", the Arduino resets its variables and starts the measurement period. If "Freq" is followed by an"M" than the measurement period is ended and the average frequency is reported. The "Freq" command was used test the Teeny's trigger speed as well as over what time scales average frequencies could be accurately measured. Various frequencies where fed into the Box to trigger the Teensy. The average frequencies where measured over different time scales. The results are represented in Figure 6.

Both Arduino and Python coding where used in order to take advantage of the benefits of both programs. Arduino was used due to its capability to interface with the Teensy and its speed. Hardware functions where set up in the Teensy using Arduino that can react much faster than software. Fast reaction speeds are important when dealing with measurements that occur on the scale of 10 milliseconds. The Arduino code is also always active and looking for triggers or commands due to its looping code structure. This helps it react faster than Python. Python, however, can preform more complex functions as well as interact more easily with other Python code, such as the User Interface and the code controlling the rest of the quality control system for CMS. This functionality, from the Python code, eases user control of the Tigger Box as well as aids in the creation of an automatized quality control system for CMS.

3. User Interface

The user interface has multiple functions. The interface has a slide bar and a spin box to set the threshold voltage. These two threshold setters have been programmed to change when the user changes their input or the other threshold setter is changed, i.e the spin box value will change when the slider is moved or when its value is changed. These two actions send the "Set (threshold in volts)" command to the serial port and are marked by the "Level Set" title. The "Read" Push button sends the "Set ?" command to the Serial port. All three of these actions then adjust the spin box to the value returned to the serial

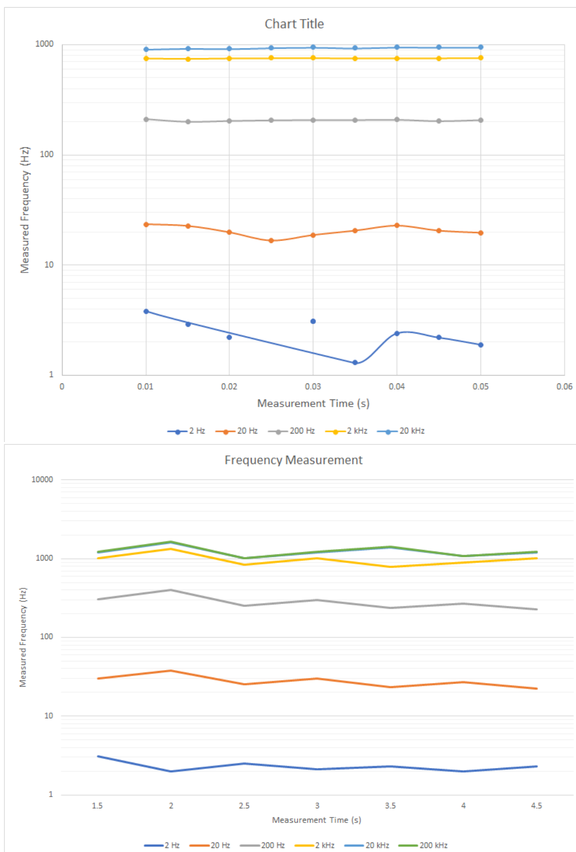

Figure 6: Results of the Speed Test of the Optical Trigger Box

These tests show the average frequency over a given amount of time for different frequencies. These results shows how successful the optical trigger box is at triggering at each frequency for different measurement times. The results show the mean of twenty trials. The closer the measured frequency is to the input frequency, the more successful the box is at triggering at each trigger event. A function generator was used to create a mock signal for these tests.

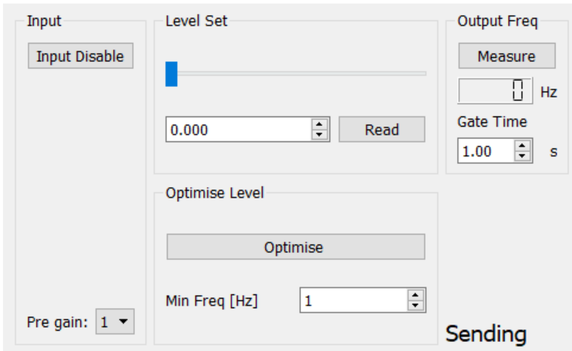

Figure 7: Picture of User Interface
This picture shows the User Interface that is used for the system.

port from the Teensy, the set Threshold Level.

To measure frequency, the user uses the functions in the upper right hand corner of the user interface that are labeled "Output Freq". The user enters a time in seconds in the double spin box below the label "Gate Time". Then the user presses the button that is labeled "Measure". This button is then disabled while the measurement is taken. After the measurement is taken for the amount of time entered by the user, the frequency is reported in Hz in the lcd under the push button and the button becomes active again. The other functions are able to be used during the measurement. The measurement time may be changed as well, but it will not affect the current measurement of the frequency.

In the top left corner is a button that enables and disables interrupts in the Teensy, which sends pulses to the SPDT switch. The label represents if the "Input", these interrupts, is enabled or disabled and whether or not pressing this button will enable or disable it. In the bottom right hand corner next to the "Pre Gain:" label is a drop down box that allows the user to select the gain on the amplifier that amplifies the photo diode signal. In the bottom right hand corner where the label says sending is where either the sent confirmation "Sent" will appear, if a command successfully works on the Teensy, or the appropriate error code will appear, if it does not. The "Set" commands do use this confirmation label as either a threshold value or an error code will appear in the spin box after a "Set" command is given, which will indicate the success of the command without the use of the confirmation label.

4. Hard Ware

The circuit built for the Trigger Box is shown the in Fig. 7. As shown in the diagram. Two low pass filters are placed in series between the input and output pin. Note the output pin must be capable of outputting a PWM signal and the input pin must be capable of the analog read function. Two filters where used to provide a greater attenuation of the amplitude of the PWM signal quickly without decreasing the corner frequency of the LPFs, as this can slow

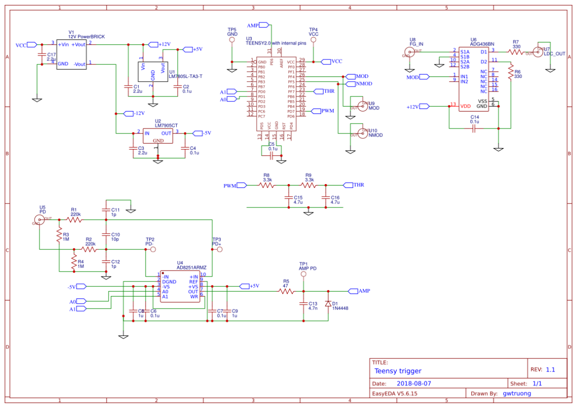

Figure 8: Circuit Schematic of Hardware Circuit

This diagram shows the components found on the PCB inside the Trigger box and the connections between the chips, inputs, outputs, and the filters, that are used for functionality as well as to reduce noise. The resistors and capacitors are labeled with a name as well as their value.

the adjustment time of the Threshold value, or increasing the corner frequency, as this can lead to a less attenuated signal outputted from the circuit. The Teensy receives power and signals from the computer.

The photo diode first runs though two low pass filters with a bypass capacitor between them, which increases the capacitance of the filters. These filters reduce noise, but also reduce the amplitude of high frequency signals as a side effect. The filters than feed into the amplifier. The positive and negative inputs of the amplifier are grounded with large resistors to allow a leakage of current that stabilizes the input of the amplifier with little change to the voltage. The gain of the amplifier is set by the Teensy. The power for the amplifier comes from two linear power supplies that are powered by the Teensy VCC. The power lines are filtered before and after the linear power supply with bypass capacitors. The output of the amplifier is filtered as well to reduce noise before the signal enters the Teensy. A reversed biased diode prevents negative signals from the amplifier from entering the Teensy as negative signals would run down the diode to ground rather than enter the Teensy, but positive signals would enter the Teensy. Negative signals are outside of the range of voltages allowed to enter the Teensy and may possible damage it.

The Threshold signal and the amplified photo diode signal both enter an analog comparator in the microprocessor of the Teensy. The comparator sets an interrupt flag in the Teensy each time the detector value crosses the threshold level. This flag than triggers an interrupt in the Teensy. When the interrupt occurs, the Teensy sends a pulse in the MOD and NMOD outputs as well as the signal to the SPDT switch. The Mod signal and signal to the SPDT Switch branch off from the same pin on the Teensy. The SPDT switch produces a signal that is a mix of the FGEN IN input mixed with the MOD signal. This signal goes to the Laser Control Diode. The SPDT switch is powered by a 12 V power block that gets power from the Teensy. The power to the SPDT Switch is filtered with bypass capacitors.

Creators

System Created by Dr. Gar-Wing Truong and Blake Haist

Citations

1.“AC Capacitance and Capacitive Reactance in AC Circuit.” Basic Electronics Tutorials, 31 May 2018, www.electronics-tutorials.ws/accircuits/ac-capacitance.html.

2. Low Pass Filter - Passive RC Filter Tutorial. (2018, May 15). Retrieved from $https://www.electronics-tutorials.ws/filter/filter_2.html$

Versions

This document refers to specific versions of the described software:
User Interface: TeensyTriggerSoftwareUI_a6_2.py
Python: TeensyTriggerSoftware_a6_2.py
Arduino: TeensyTriggerSoftwareUI_v_a6_2