Lab 2

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Section: 01B

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1 Introduction

This lab deals with three sensors: QEI, ping, and capacitive touch. The QEI sensor is used to control the color of an LED. The ping sensor is used to control the frequency of a sound. The capacitive touch sensor is used to detect if a person is touching the sensor.

2 QEI

The QEI sensor sends two signals when it is turned, A and B. At the rising edge of A, B will either be high or low. If B is high, the QEI was rotated clockwise (CW). If B is low, the QEI was rotated counterclockwise (CCW). By setting an interrupt to trigger on either edge of either signal, software can determine which way the QEI is being rotated.

The color of the LED is changed by varying the duty cycle of three PWM signals. A lower duty cycle results in a brighter color. Red is brightest at 0 degrees and ranges to be off at -120 and 120 degrees. Green is brightest at 120 degrees and ranges to be off at 0 and 240 degrees. Blue is brightest at 240 degrees and ranges to be off at 120 and 360 degrees.

2.1 QEI Software

In the interrupt both the current state of A and the previous state of A are recorded to detect a rising edge. When a rising edge is detected B is sampled to determine if it is high or low. If B is high the current degree is incremented, but if B is low the current degree is decremented. If the angle has changed, the main loop updates the duty cycle for the colors.

2.2 Testing

Testing of this program began by using the interrupt to confirm the that the QEI sensor was outputting both signals. Once the interrupt was triggering and both signals were outputting as intended, logic was implemented to detect the rising edge of A and measure B.

The LED logic was the most complicated part of the QEI sensor. Many if statements were used to handle all the possible values that could result from positive and negative angles. The most troublesome logic dealt with angles that crossed zero. Because the angles roll over at -360 and 360 degrees multiple if statements were required.

3 Ping

The ping sensor has one input and one output. The input is a trigger pin that requires a 10us pulse to activate the ultrasonic signal. The output is an echo pin that remains high until the sensor receives the echo of the ultrasonic signal. In reality the echo signal has a slight offset and will scale approximately linearly with distance.

The sound is output using the speaker circuit designed in the previous lab.

3.1 Ping Software

The ping software includes two interrupts. The first interrupt triggers on a timer. The period of the timer can be changed by manipulating a numerical value in a register. The timer is initialized to trigger every 14us. A the trigger pin is set high between two interrupts. The timer is then set to 60ms. After 60ms the timer is set back to 14us to set the trigger pin high. This happens in an infinite loop to trigger the ultrasonic sensor every 60ms.

Another interrupt triggers on either edge of the echo signal. On the rising edge of the echo signal a timer is initialized. On the falling edge of the echo signal the time between the two interrupts is recorded. The time of flight is linearized as 63.5x + 87 converting cm to us.

In the main loop the sound is output as 293Hz + 10*(distance cm).

3.2 Testing

The timer interrupt was first tested to see which values resulted in a 10us delay. The 10us delay periodically failed to activate the sensor, so a longer time was selected.

The linearization of the sensor was done by testing the time of flight every cm from 1 to 30. The least squares law was then used to determine a slope and offset.

4 Capacitive Touch

The capacitive touch sensor changes its capacitance when touched. By putting the sensor in a low pass RC filter the capacitance was estimated to be 15pF when touched and 63pF when not touched.

4.1 Capacitive Bridge

Both a low pass and high pass capacitive bridge were tested. The low pass bridge provided a more convenient signal for amplifying. The 430$k\Omega$ resistors and 100pF capacitors were used in the bridge. When touched one signal decrease in amplitude. By amplifying the difference between the signal, software can be used to determine when the sensor is being touched.

In the main loop the output from the differential amplifier is continuously read with an ADC pin. Over a period of 100ms the maximum signal is recorded and compared against a threshold. If the maximum is above the threshold the program determines that someone is touching the sensor.

4.2 Relaxation Oscillator

The sensor can also be used to vary the frequency of a relaxation oscillator. The relaxation oscillator has a base frequency of 4.6kHz, and when the capacitor is touched, the frequency is reduced to about 1.2kHz.

4.3 Testing

The capacitive touch sensor was first tested in a low pass RC circuit to find its approximate capacitance. A 3.3V square wave was the input. The output was measured at increasing frequencies until the output decreased by 3dB.

The capacitive bridge was tested by measuring the output from a high pass and low pass configuration. The high pass configuration resulted in a brief spike in the output wavefrom. The low pass configuration produced a smoother waveform. The outputs from the bridge were buffered using voltage followers and input to a differential amplifier described on `https://www.electronics-tutorials.ws/opamp/opamp_5.html`. The resisters used were $50k\Omega$ for R1 and R2 and $150k\Omega$ for R3 and R4. This results in a gain of 3. After inputting the signal to an ADC pin, a threshold of 150 was sufficient to detect a touch.

The relaxation oscillator was implemented using the astable configuration from the LM555 datasheet. RA was chosen to be $810k\Omega$ and RB was chosen to be $3M\Omega$. The capacitor was a 22pF capacitor in parallel with the capacitive touch sensor.

Reversing the polarity of the capacitive touch sensor resulted in the sensor switching which side was affected by touch.

The following are images from the oscilloscope showing various stages of the capacitive touch sensor. In the Figures 1 and 2, notice the change in frequency. In Figures 3, 4, 5, 6, 7 and 8, notice the change in amplitude in the green waveform. In Figures 9 and 10, notice the change in frequency in the yellow signals.

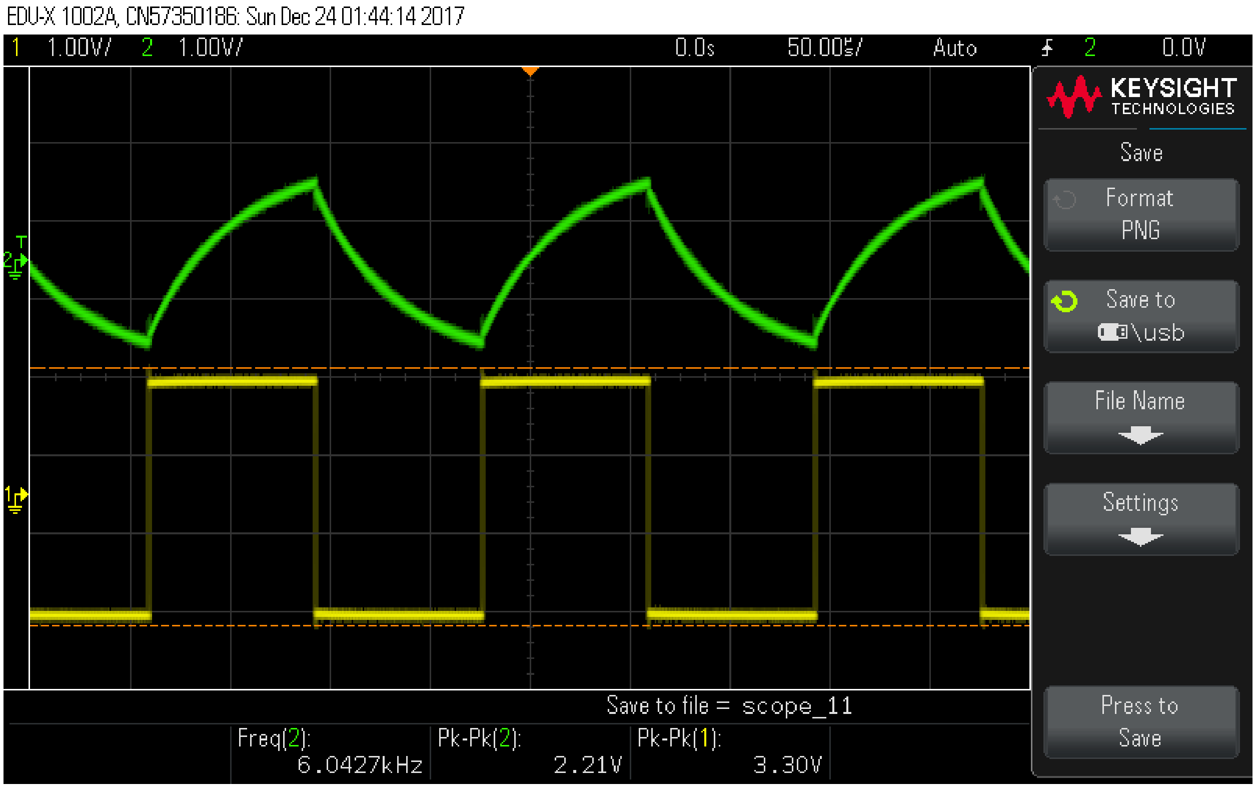

Figure 1: This is the touched sensor in a simple RC circuit.

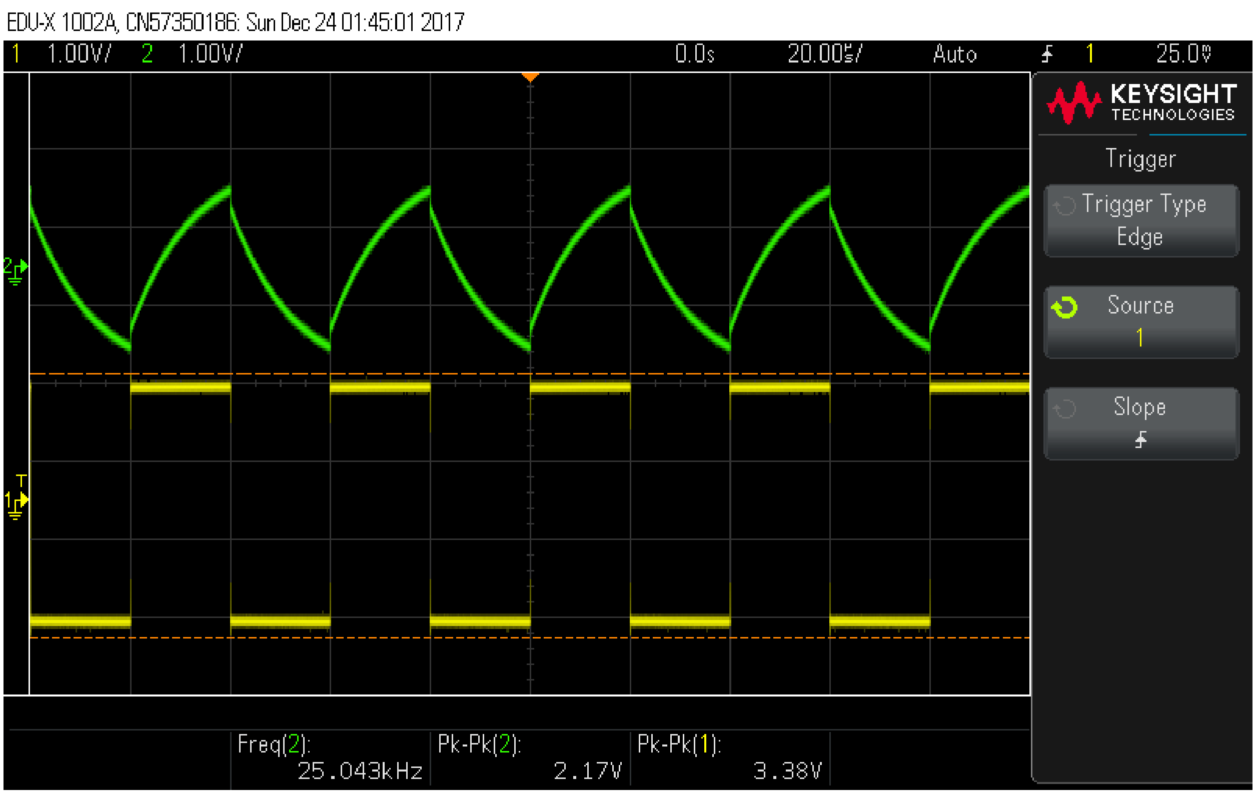

Figure 2: This is the untouched sensor in a simple RC circuit.

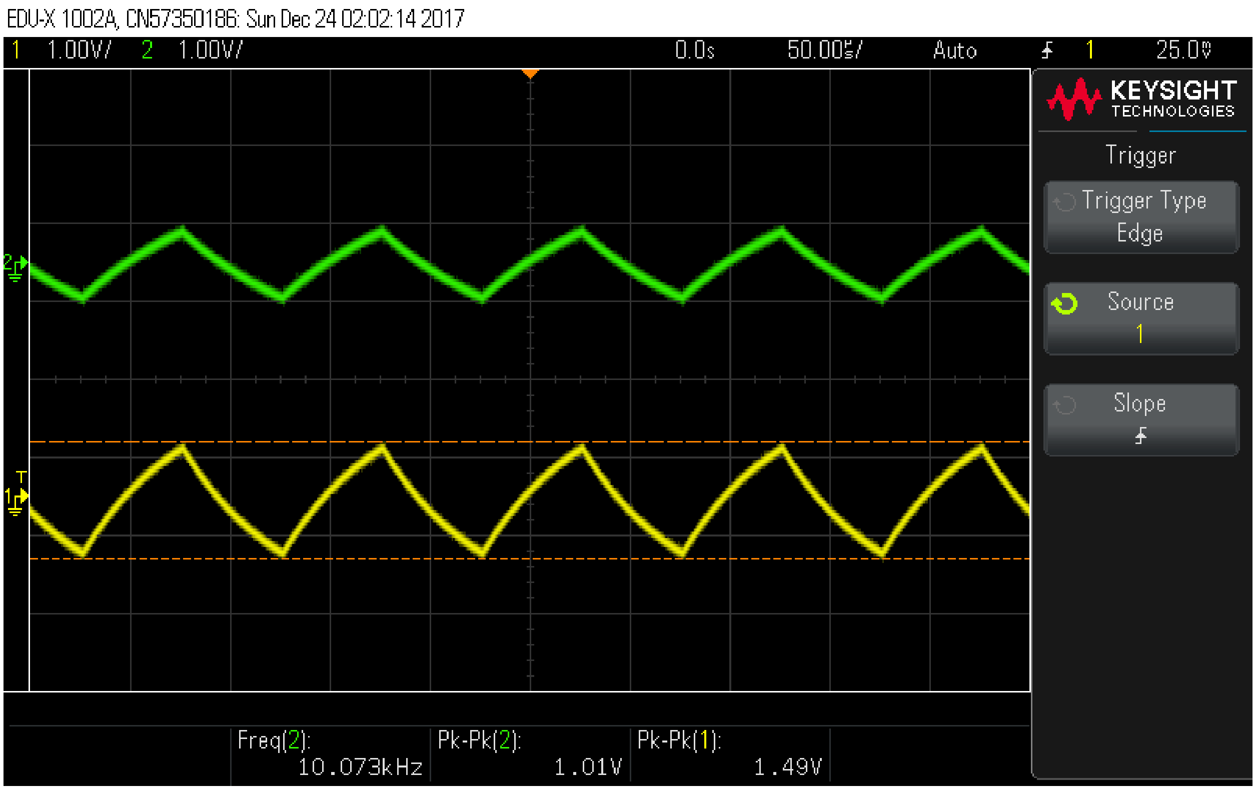

Figure 3: This is the touched sensor in a low pass bridge configuration.

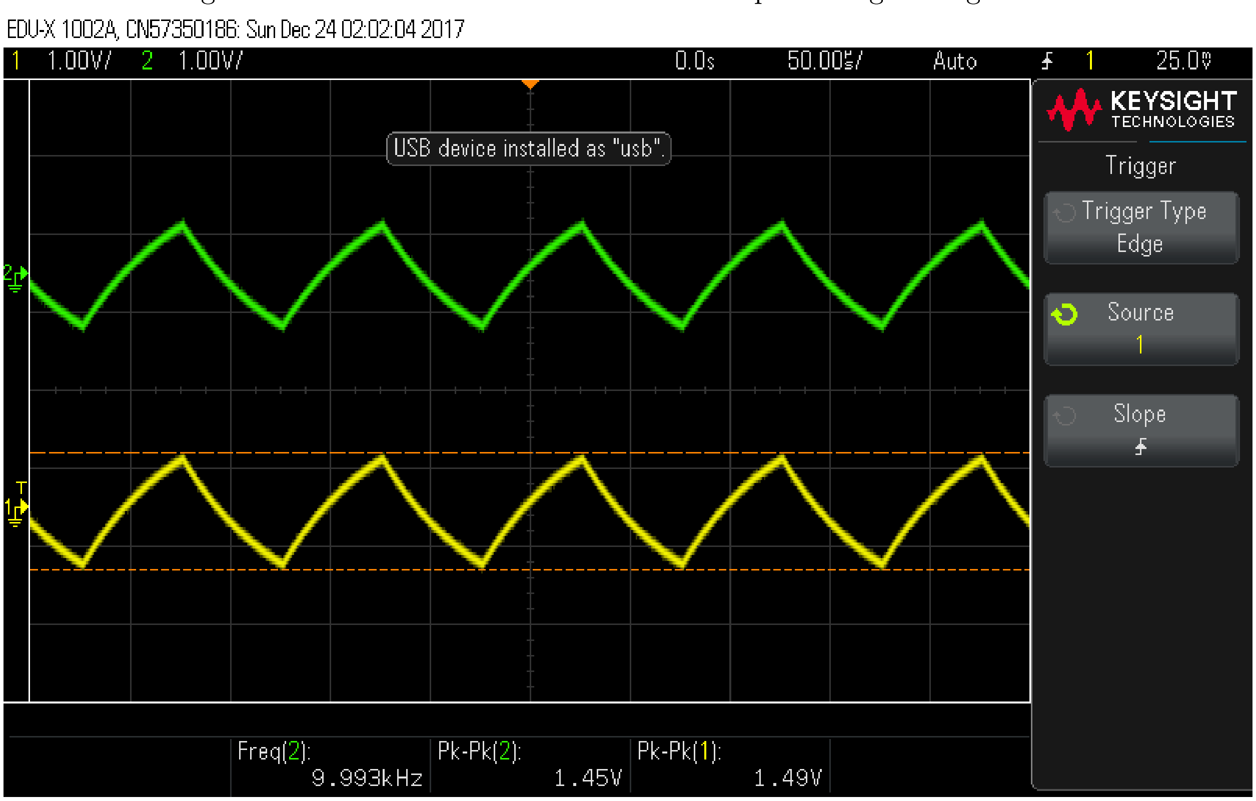

Figure 4: This is the untouched sensor in a low pass bridge configuration.

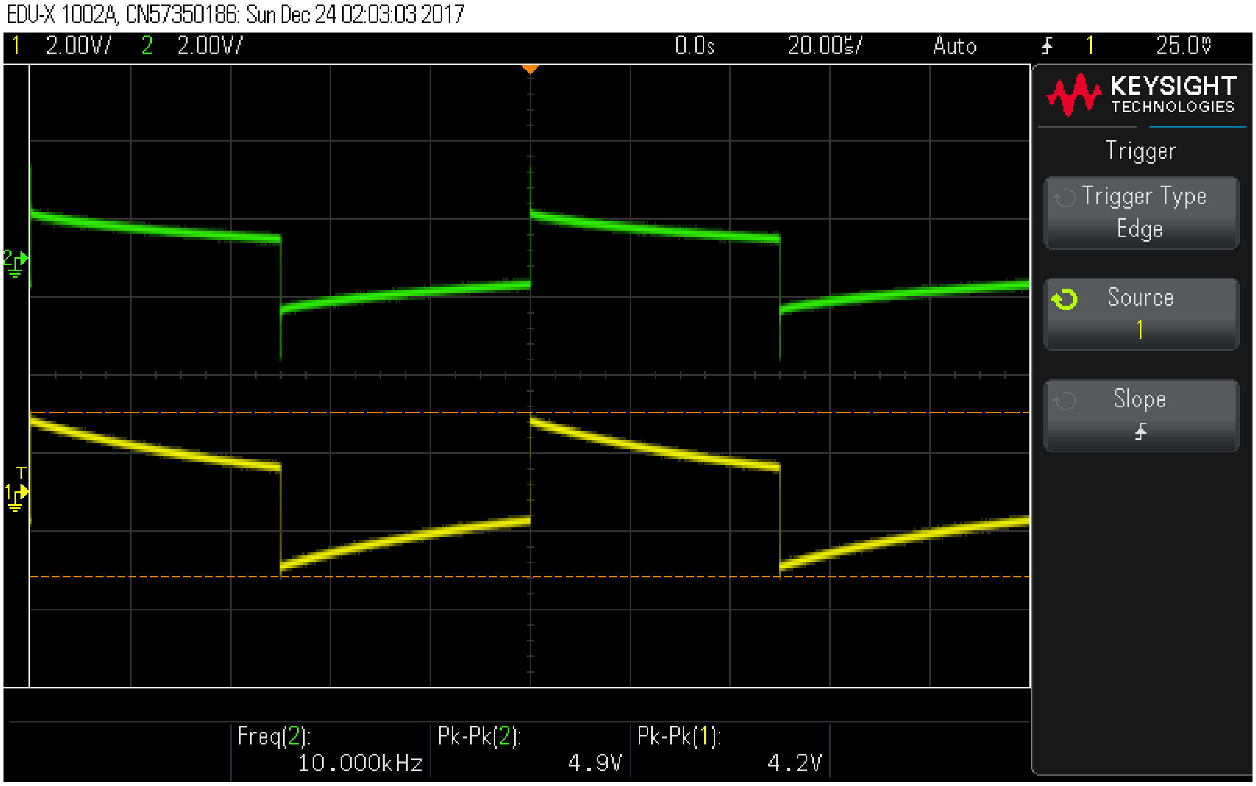

Figure 5: This is the touched sensor in a high pass bridge configuration.

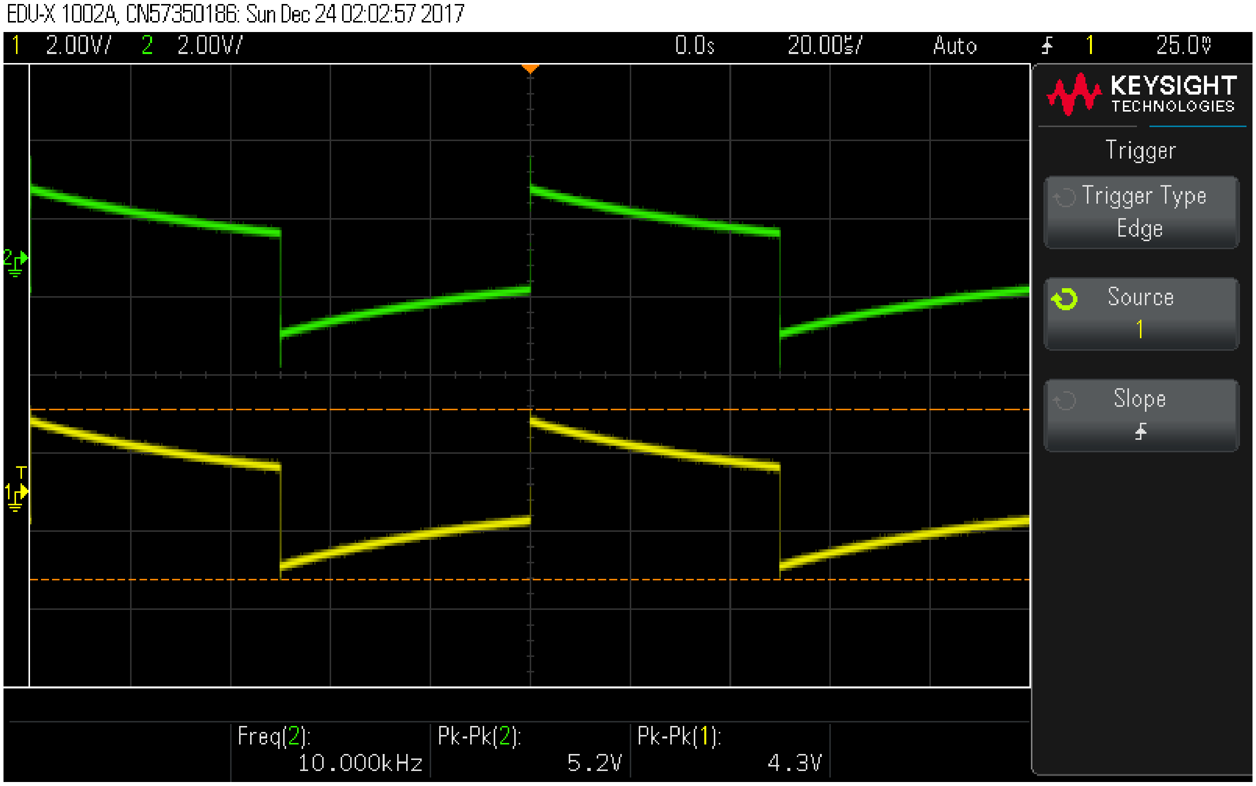

Figure 6: This is the untouched sensor in a high pass bridge configuration.

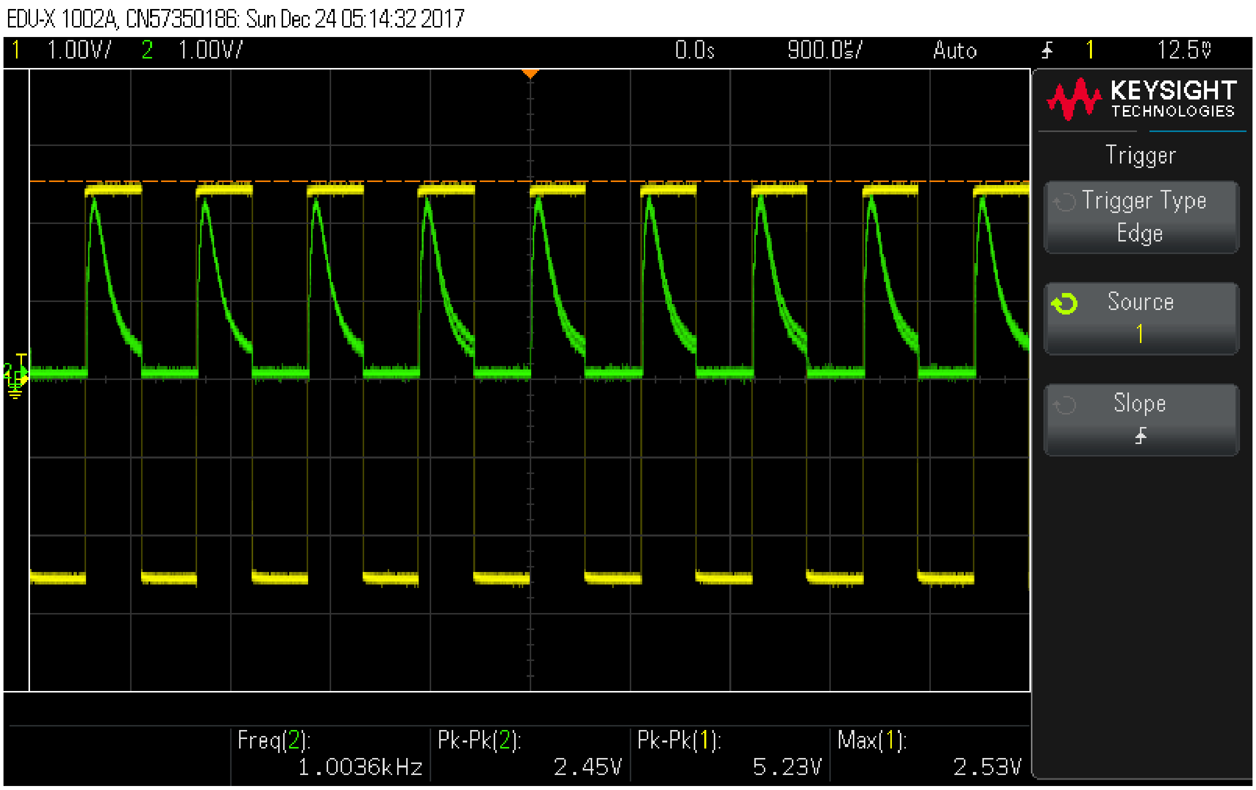

Figure 7: This is the amplified differential signal when touched.

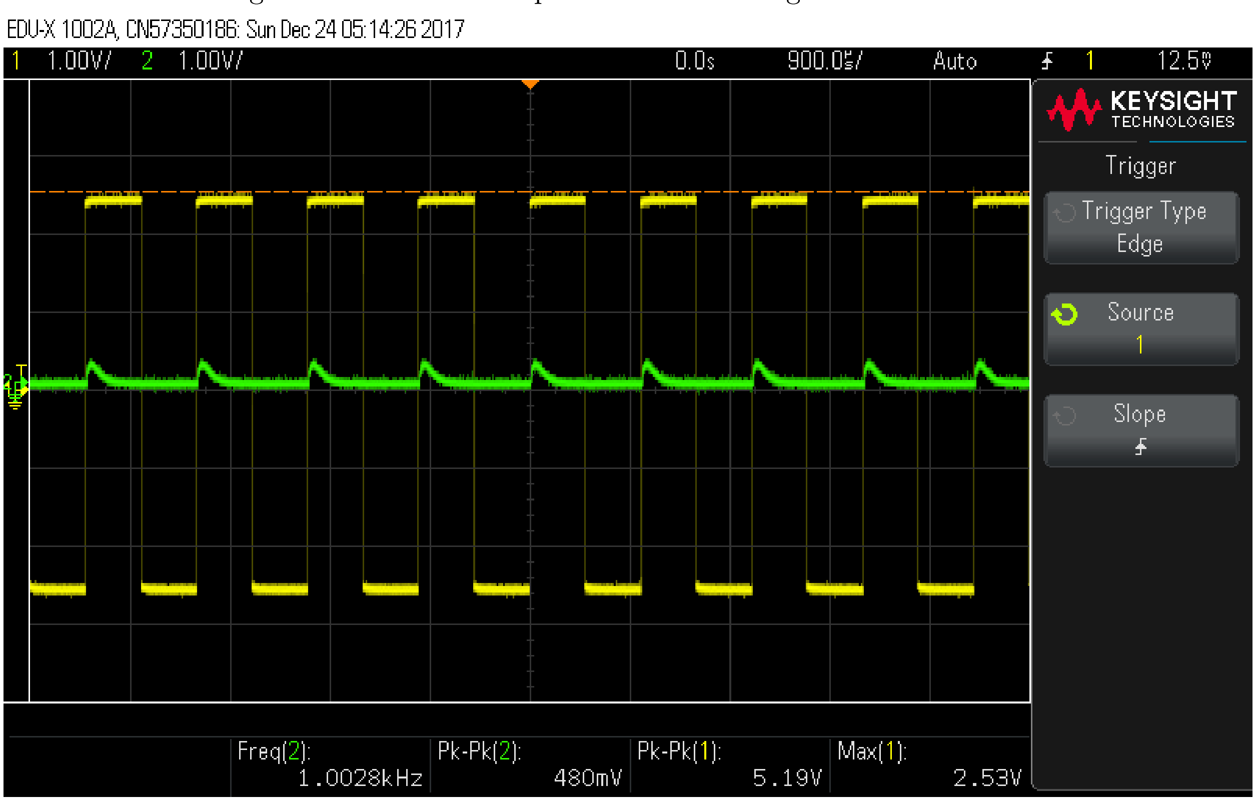

Figure 8: This is the amplified differential signal when untouched.

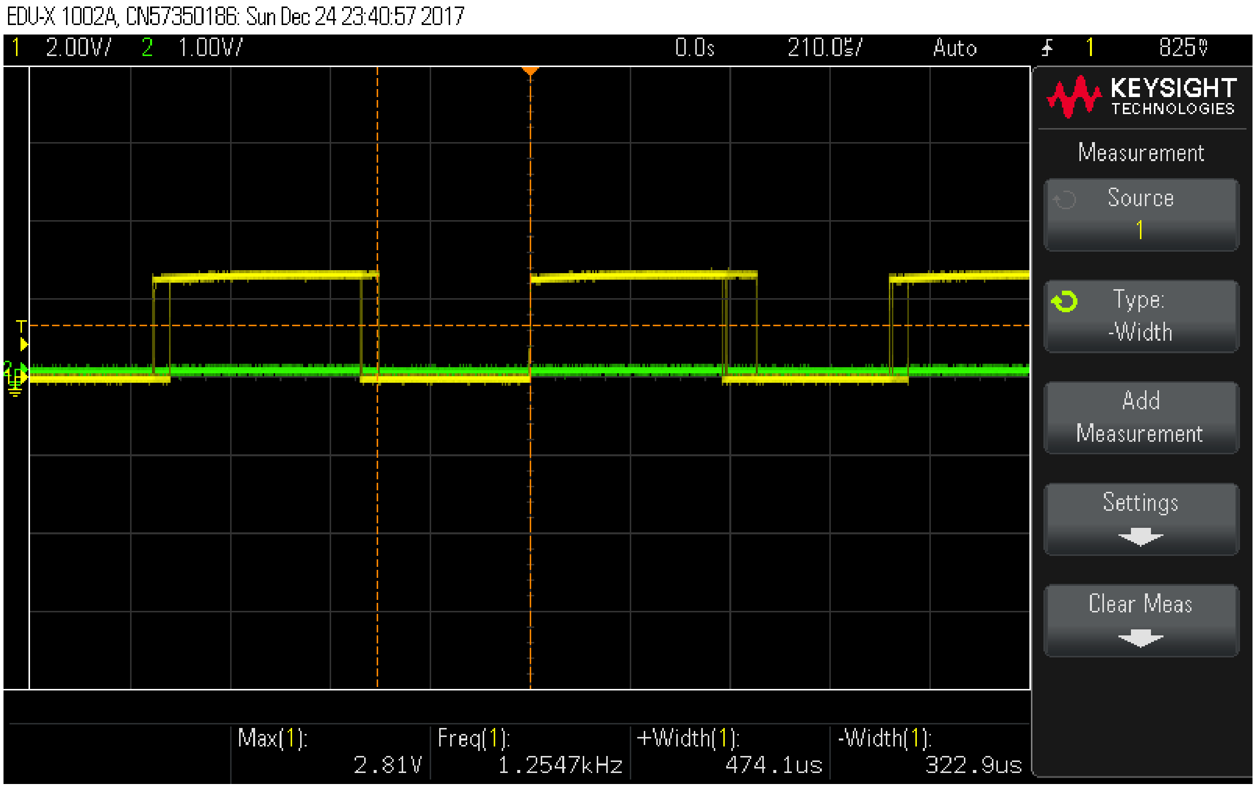

Figure 9: This is the relaxation oscillator when touched.

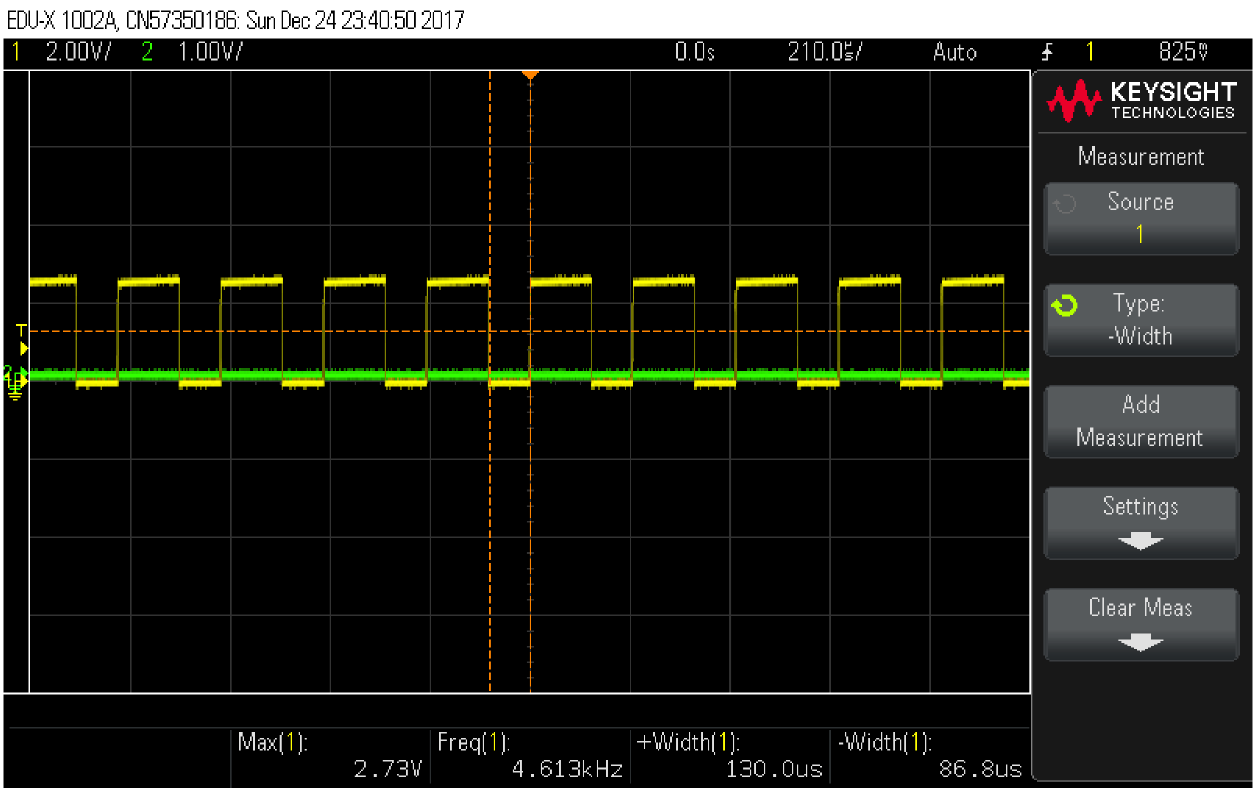

Figure 10: This is the relaxation oscillator when untouched.