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ENGR 271

Lab 0xD: Square Wave Circuits

Introduction

In this lab we will be exploring different types of square wave circuits that produce square waves. These are very common in digital switching circuits. We will be exploring Schmitt Trigger oscillator, Two Inverter oscillators, DIY 555 Timers, 555 astable multivibrators and crystal oscillators.

Part A: Astable Inverter Configuration

1. In procedure 1, we are tasked with building the Schmitt Trigger oscillator with Multisim, which can be seen in Figure 1. We are also tasked with measuring the frequency (Figure 2), duty cycle (Figure 3 shows the On Time, and frequency shows the period), rise time (Figure 4) and fall time (Figure 5). We can see that there is a negligible difference in the rise and fall time with this counter. To find the duty cycle, we use the equation
   $Duty\ Cycle\ =\ On\ Time\ /\ period\ *\ 100\%$
   $Duty\ Cycle\ = 25.5\,e - 6\,/\,71.6\,e - 6\ *\ 100\%\ =\ 35.7542\%$
   In the table below, we compile all of our measurements.

Frequency (kHz)	Duty Cycle (%)	Rise Time (ns)	Fall Time (ns)
13.9	35.7542	1	1

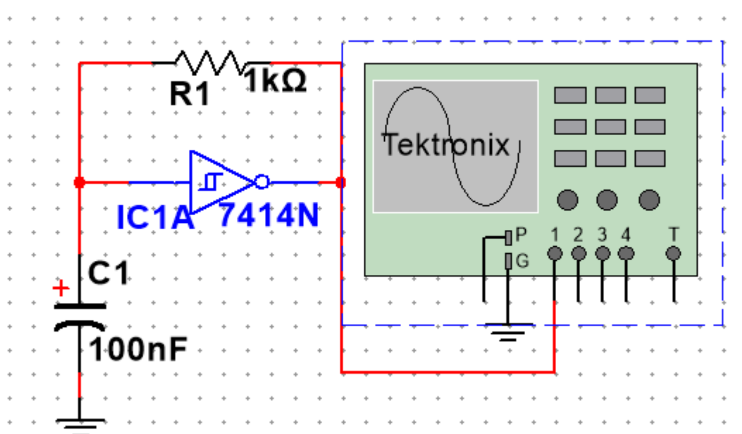

Figure 1: Schmitt Trigger Oscillator Schematic

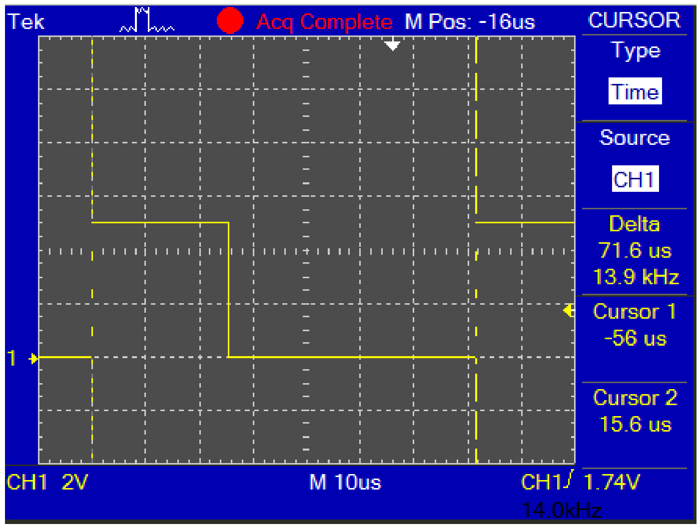

Figure 2: Frequency = 13.9 kHz

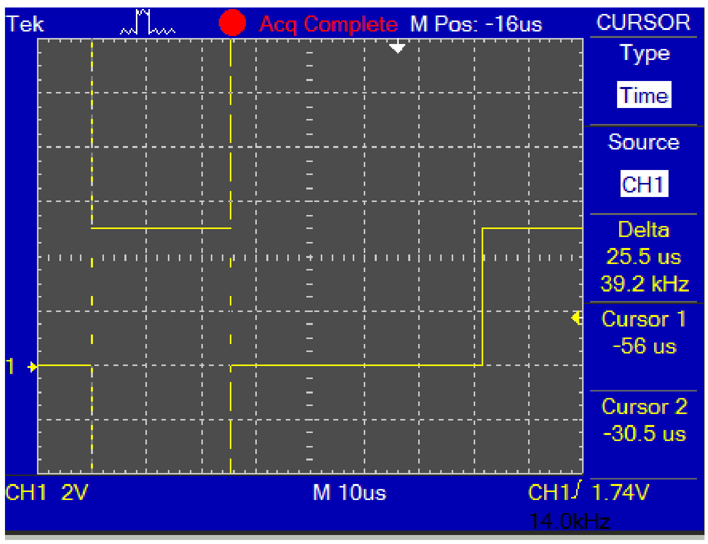

Figure 3: On Time used for Duty Cycle

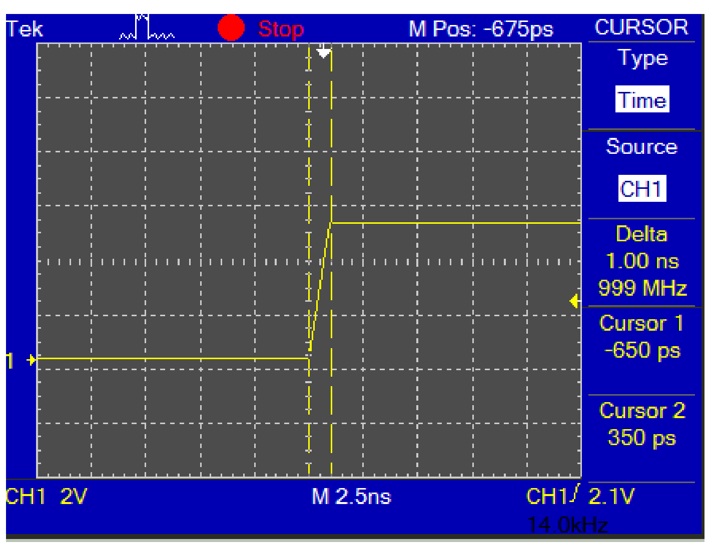

Figure 4: Rise Time = 1ns

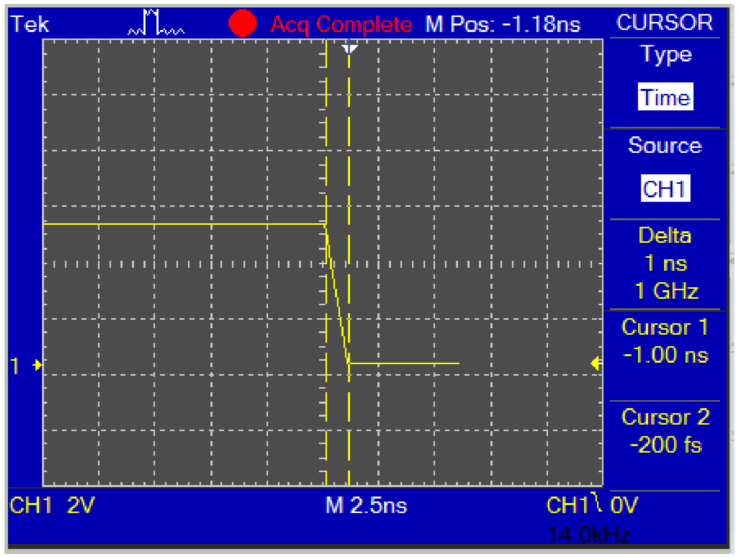

Figure 5: Fall Time = 1ns

2. In this procedure, we are tasked with modifying the Schmitt Trigger Oscillator to have a variable resistor to enable the frequency to be variable. In Figure 6, we can see the base circuit that utilizes a 100k variable resistor. In Figure 7 we can see the variable resistor at 0% and in Figure 8 we can see the variable resistor at 100%. The effective frequency range is 142 Hz - 5.89 Mhz when using a 100k variable resistor.

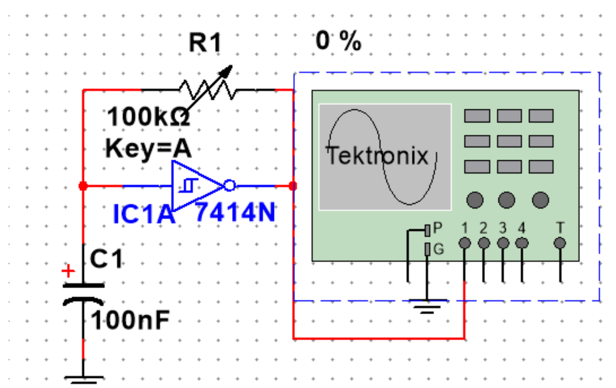

Figure 6: Schmitt Trigger Oscillator with 100k variable resistor

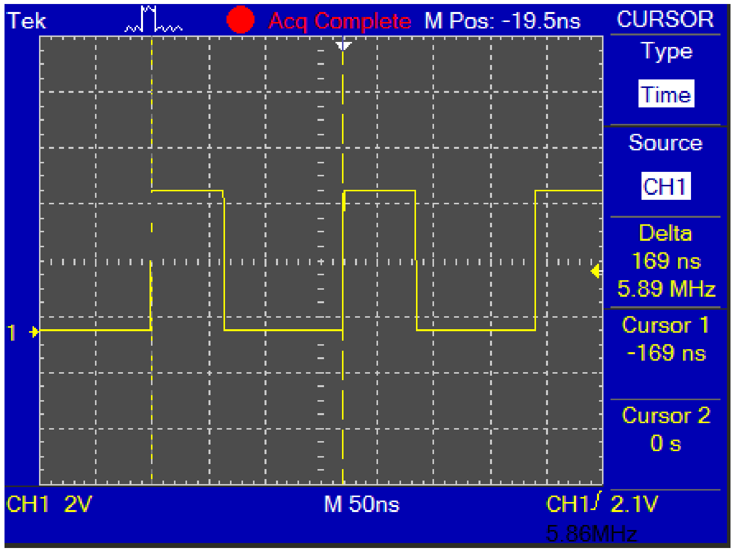

Figure 7: Schmitt Trigger with variable resistor at 0%

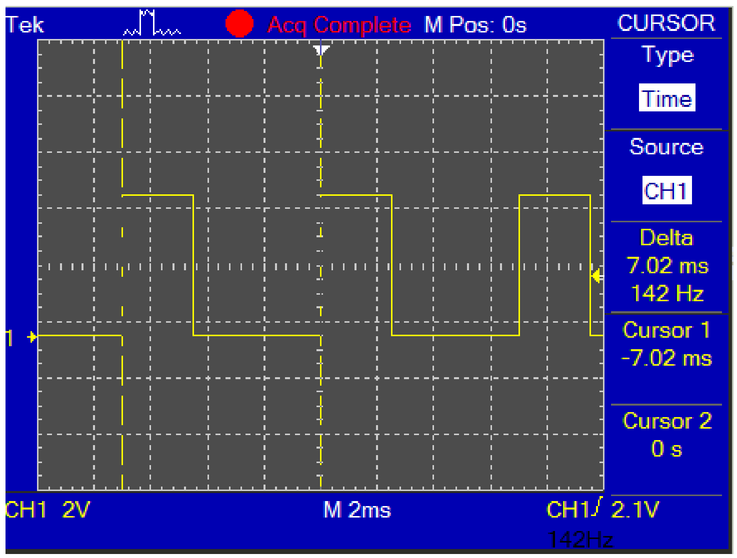

Figure 8: Schmitt Trigger with variable resistor at 100%

3. In procedure 3, we are tasked with building and simulating the Two Inverter oscillator. In Figure 9, we can see the base schematic. We are tasked with measuring the frequency (Figure 10), duty cycle (Figure 11), rise time (Figure 12) and fall time (Figure 13). We use the same equation from procedure 1 to find the duty cycle, which yields
$Duty\ Cycle\ = 84.8e - 3\ /\ 169e - 3\ *\ 100\%$
$Duty\ Cycle\ = 49.8817\%$
In the table below, we can see a compilation of all our measurements. The rise and fall time should be equal. We can account for the difference due to the Multisim oscilloscope cursors errors and how "touchy" they are.

Frequency (Hz)	Duty Cycle (%)	Rise Time (ns)	Fall Time (ns)
5.91	49.8817	1.24	1.22

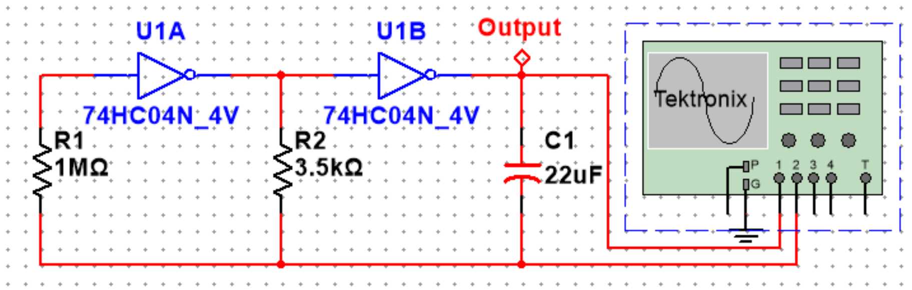

Figure 9: Two Inverter Oscillator

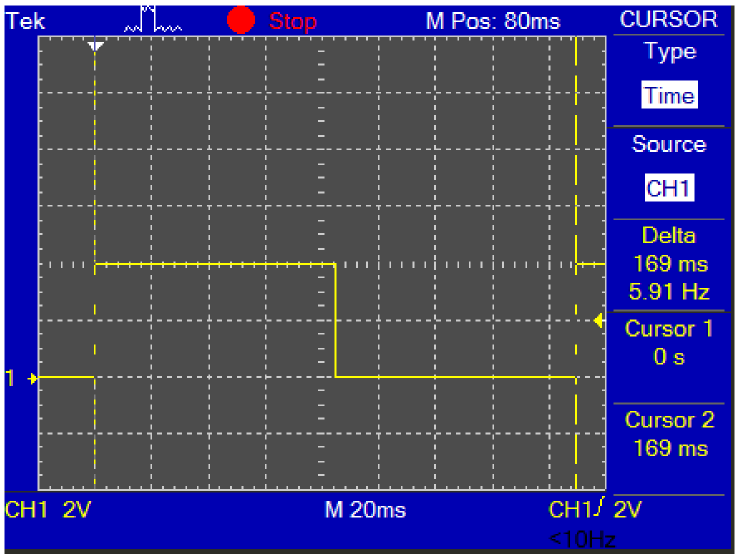

Figure 10: frequency = 5.91 Hz

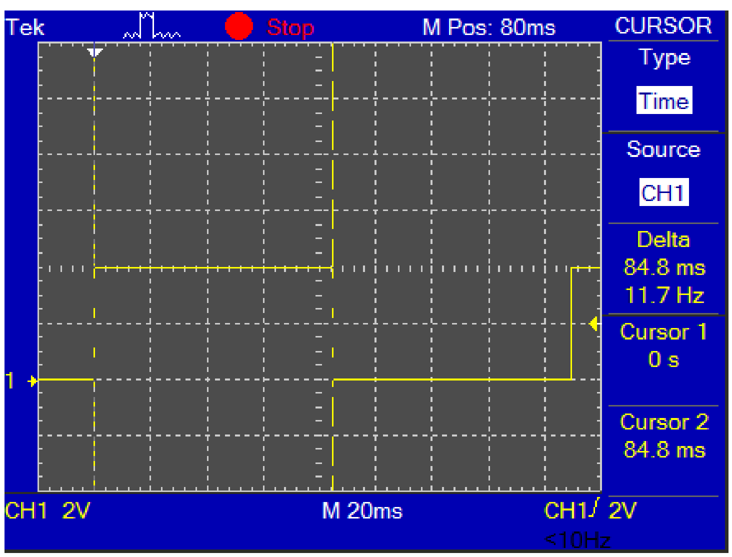

Figure 11: on time used for Duty Cycle

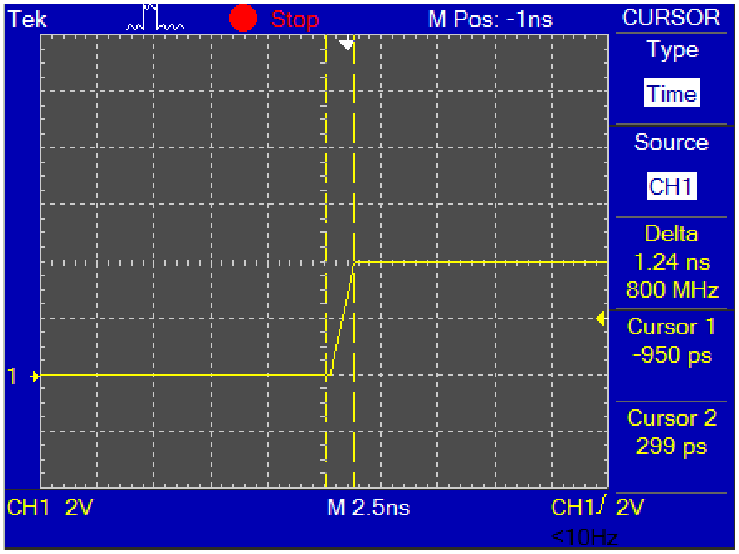

Figure 12: rise time = 1.24ns

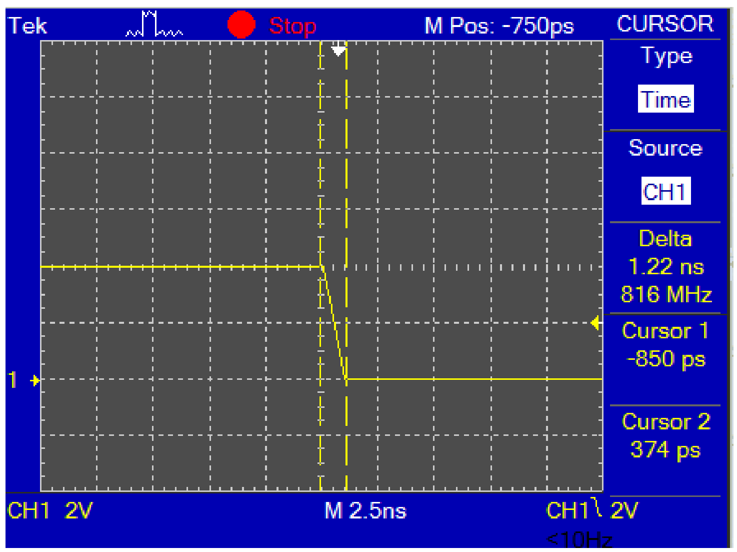

Figure 13: fall time = 1.22ns

4. In procedure 4, we use the same circuit from procedure 3, but we are changing the temperature coefficient (TC1) to 0.001 and simulating a linear temperature sweep at 0°C, 50°C and 100°C. Below, we can see our results, 0°C (Figure 14), 50°C (Figure 15) and 100°C (Figure 16). Below, we compile all of our measurements. The math for finding frequency can be found in the description of each Figure in this procedure. This makes sense, that we are seeing as the temperature goes up, the frequency value gets smaller (or slower in the time domain). This is a concept we learn in physics, that as electrical systems are warmer, the speed of the flow through them increases. This is why superconductors only work at extremely low temperatures.

Frequency at Specific Temperature Sweep Values		
0°C	**50°C**	**100°C**
6.07 Hz	5.775 Hz	5.05 Hz

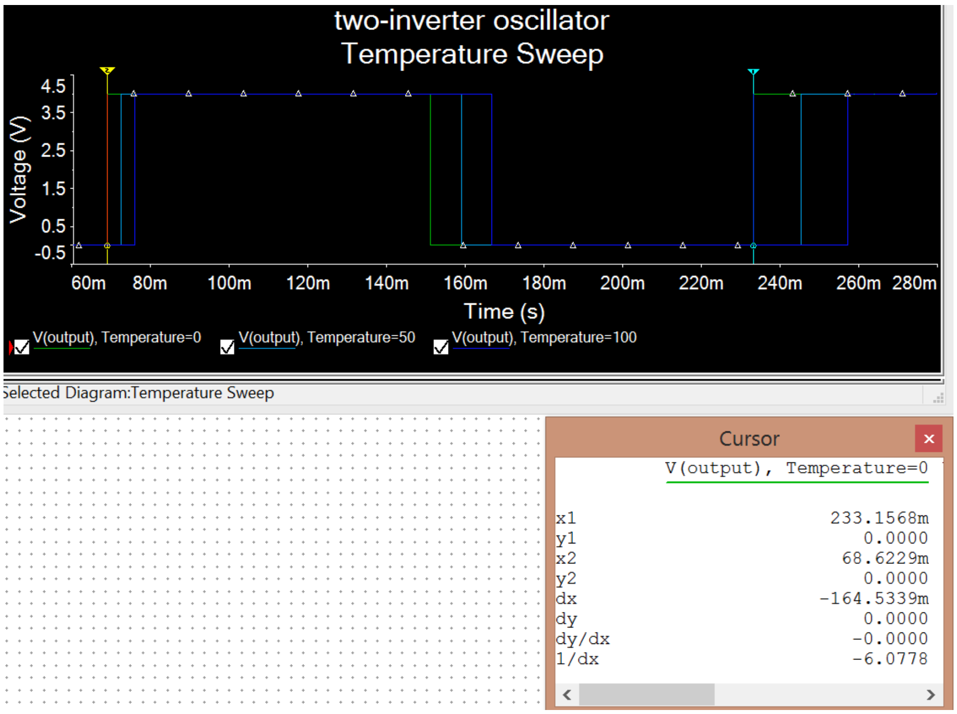

Figure 14: 0C (Frequency = 1/ 164.5339e-3 = 6.07 Hz)

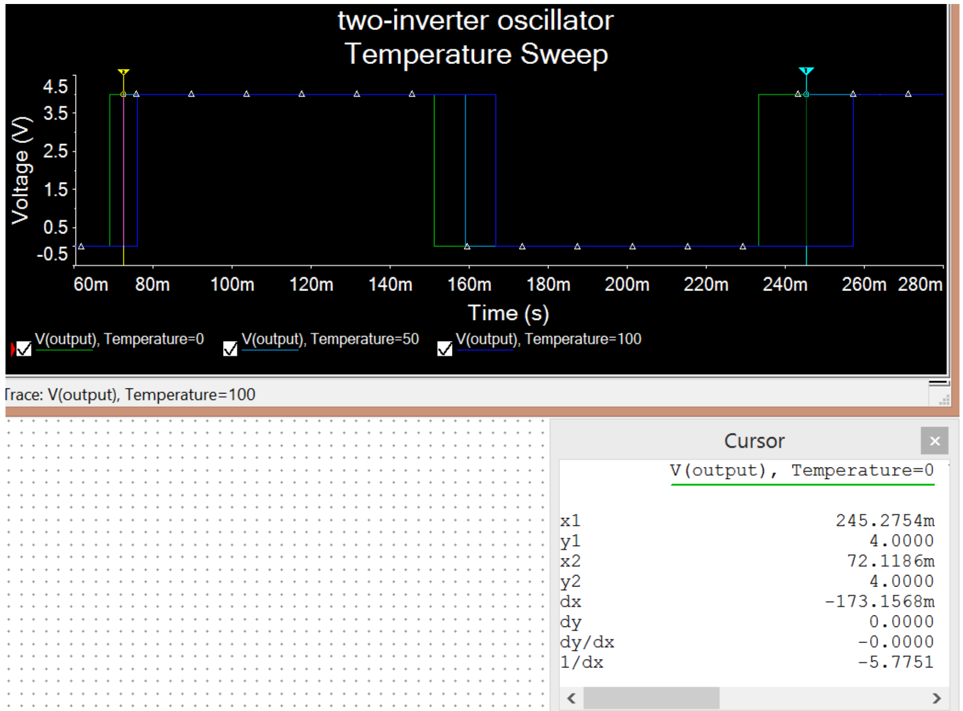

Figure 14: 50C (Frequency = 1/ 173.1568e-3 = 5.775 Hz)

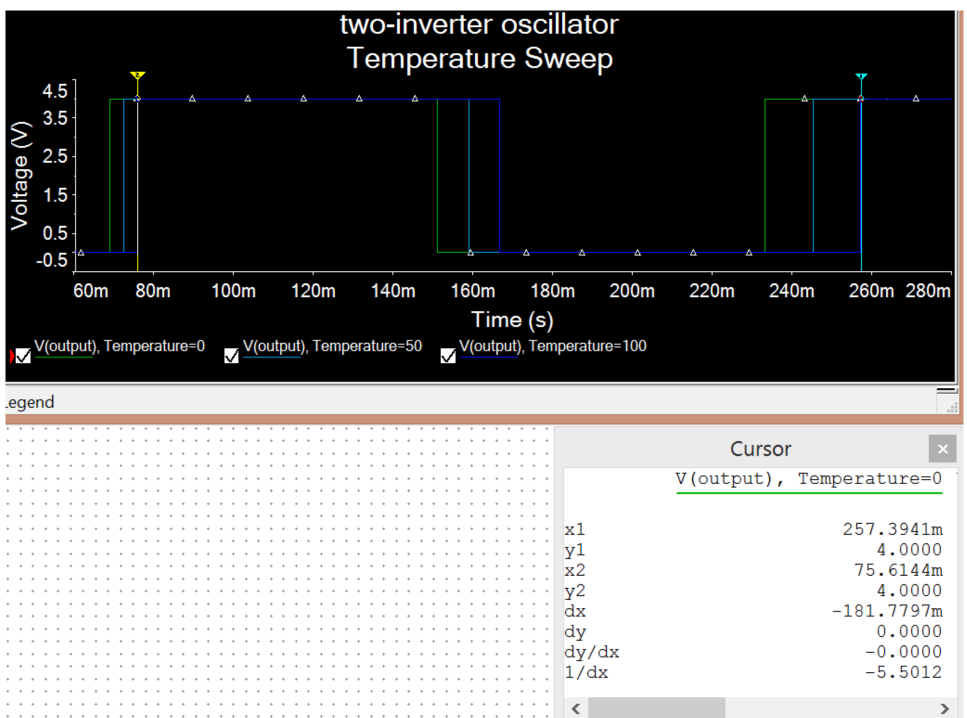

Figure 14: 100C (Frequency = 1/ 181.7797e-3 = 5.05 Hz)

Part B: 555 Timers

5. In procedure 5, we are tasked with building the DIY 555 timer in Multisim, that is given to us in the lab instructions. In Figure 15, we can see the finished circuit and in Figure 16, we can see that it operates in the expected way that a 555 timer does. We have seen these in previous classes and we can use the data sheet of a 555 timer to compare. We know that when RST is high, CON is high, THR is low, we should always see a high OUT, no matter what TRG is. Whenever RST is low, OUT is always low. This is why digital inputs are connected, to test all possible combinations, which was successful.

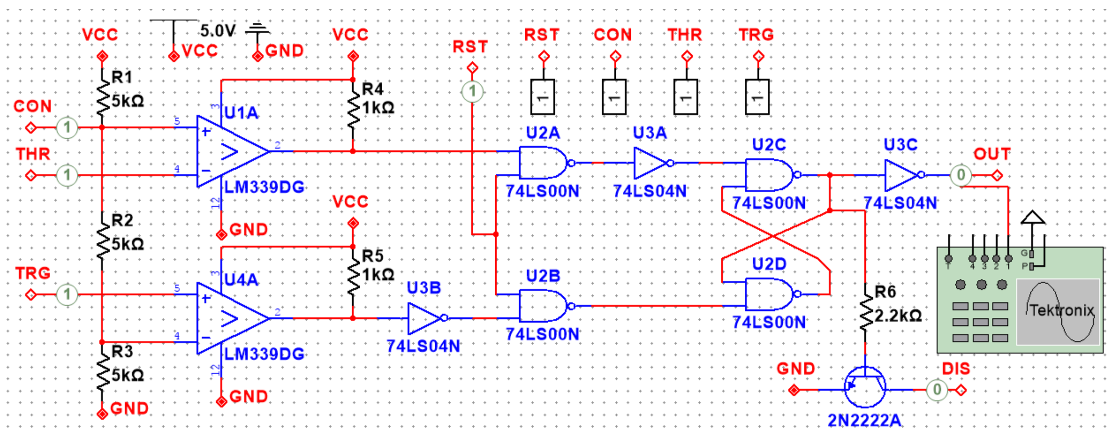

Figure 15: DIY 555 Timer Circuit

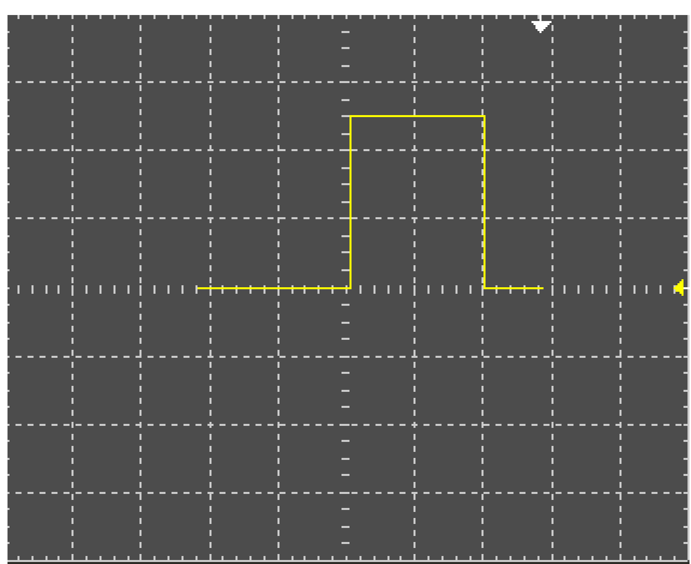

Figure 16: DIY 555 Timer Circuit Output

6. In this procedure, we are tasked with building an astable multivibrator with Tinkercad, using a 555 IC. In Figure 17, we can see the Tinkercad circuit, along with the oscilloscope output. To find the frequency, we multiply the Time Per Division (50ms) by the number of squares inside the wave form, which is ~2.75. This gives us 137.5 ms. Then we convert time => frequency, which is Frequency = 1/time => Frequency = 7.272 Hz

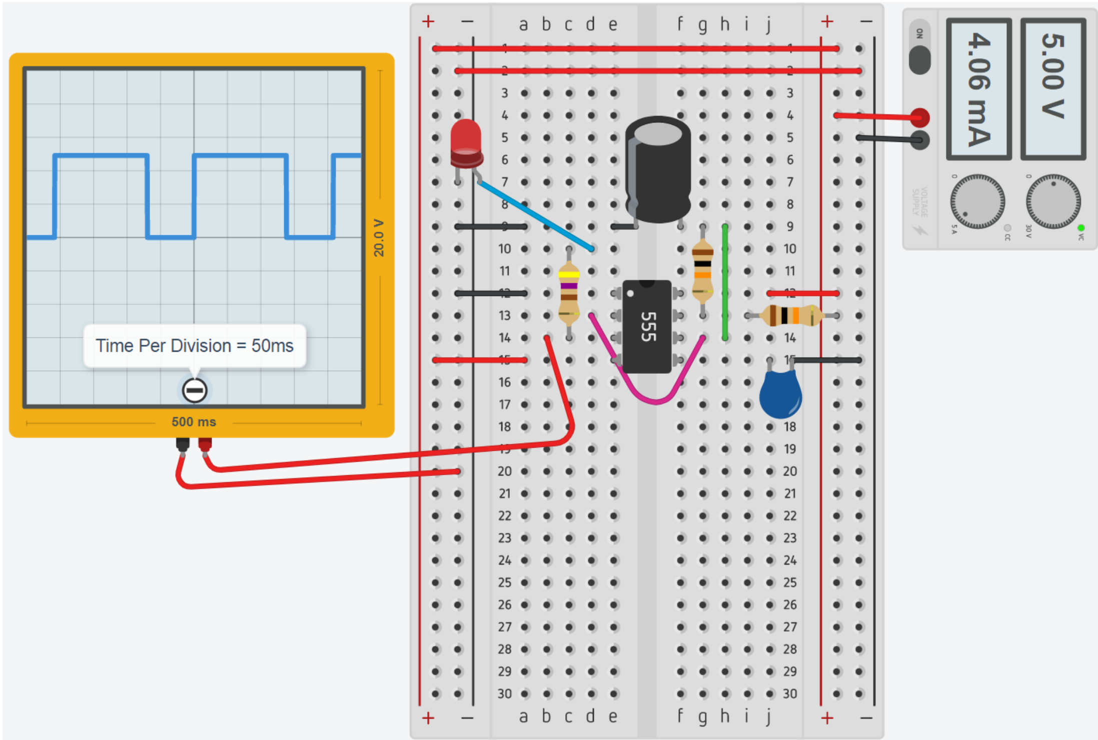

Figure 17: Tinkercad Circuit with oscilloscope output

7. In procedure 7, we are tasked with building the astable multivibrator from procedure 6, in Multisim. The circuit can be seen in Figure 18. Figure 19 shows the output waveform. From this, we can see the frequency = 4.77 Hz. Our value is different from our Tinkercad results, which could be because of the component differences from Tinkercad to Multisim. We played around with this for a while and could never figure out why there was such a big difference, outside of component differences or a Tinkercad -> Multisim conversion issue.

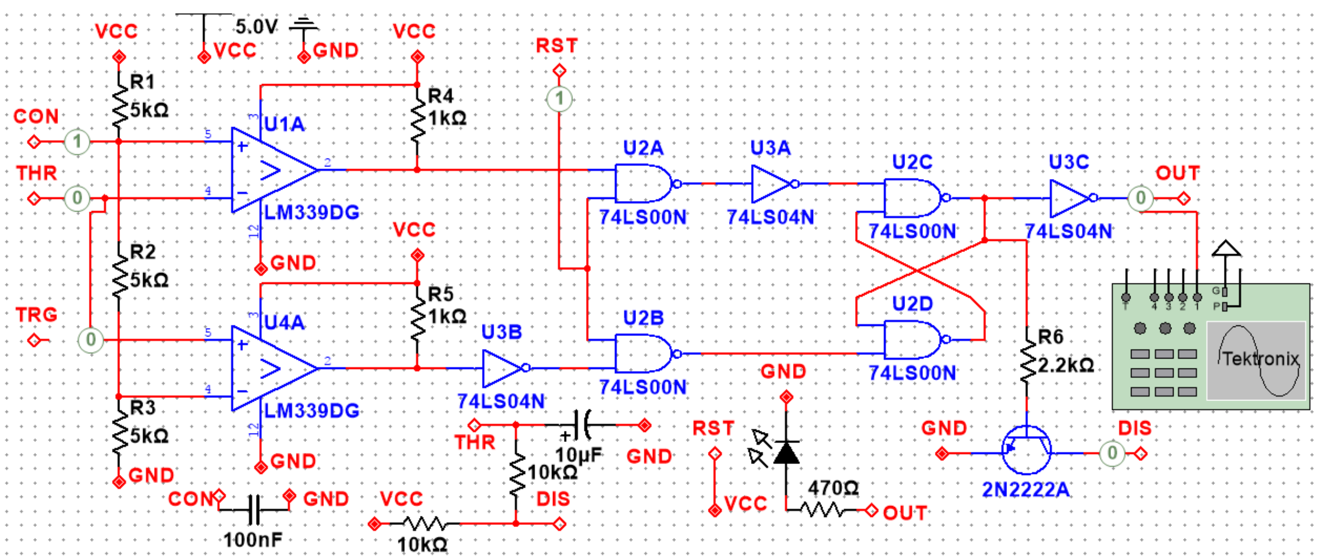

Figure 18: Astable Multivibrator Circuit with 555 DIY Timer

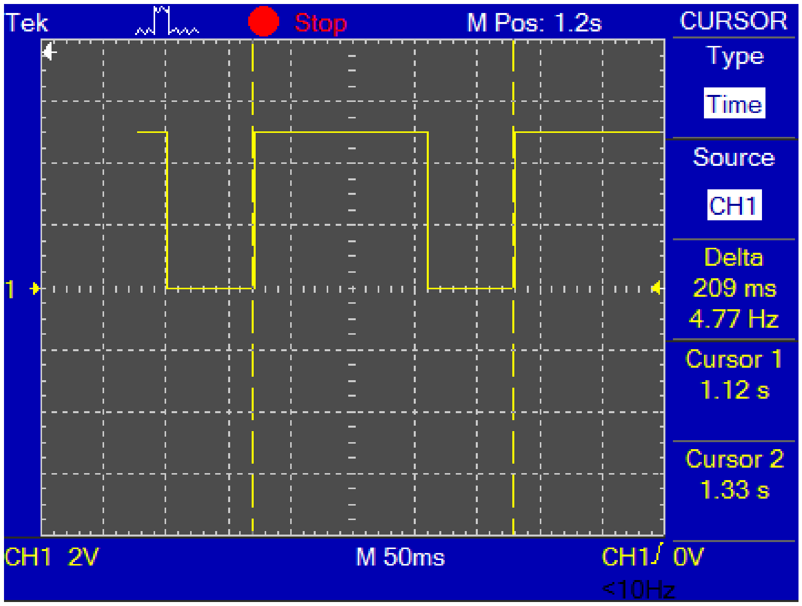

Figure 19: Oscilloscope output, Frequency = 4.77 Hz

8. In this procedure, we are tasked with finding another way to use a 555 timer. We chose a voltage doubler circuit. Theoretically, this circuit will double the input voltage. In our results, we achieved about a 50% gain on the input voltage. We played around with this for a while and could never figure out why it would only produce a 50% gain. We tried different component values on the voltage doubler circuit and different input voltages, and they all resulted in a 30-50% gain. The way voltage doublers work, this could be from the current through the load resistor being too high. Figure 21 shows our Multisim circuit and Figure 20 shows the voltage divider circuit we adapted from (https://www.electronics-tutorials.ws/waveforms/555-circuits-part-2.html).

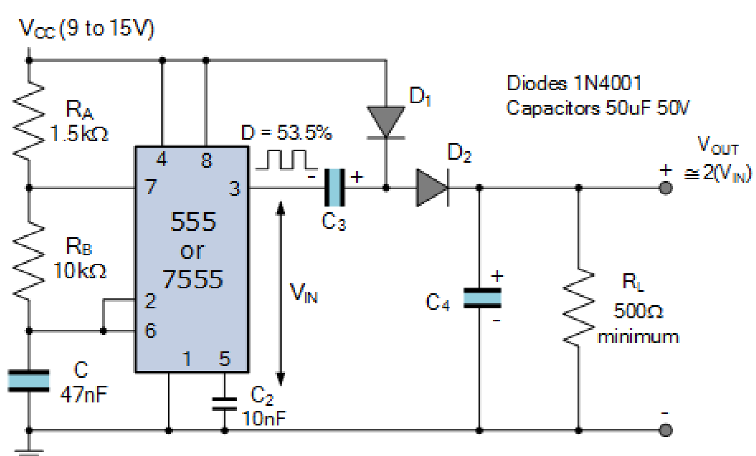

Figure 20: Voltage Doubler circuit from Electronics-Tutorials

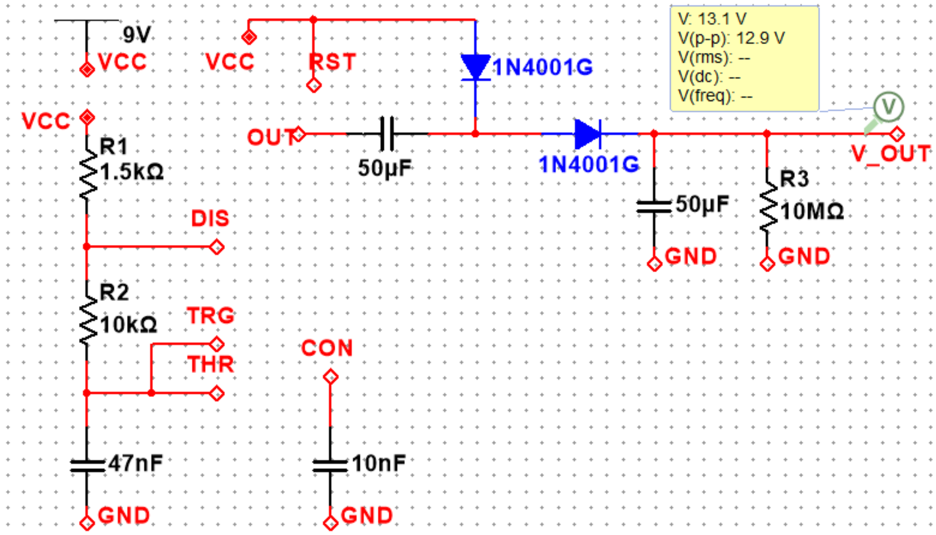

Figure 21: DIY 555 Timer and Voltage Doubler Circuit with results

Part C: Crystal Oscillators

9. In this procedure we are tasked with building a crystal oscillator. In Figure 22, we can see the finished circuit. We are tasked with measuring the frequency (Figure 23), duty cycle (Figure 24), rise time (Figure 25) and fall time (Figure 26). We calculate the duty cycle the same way as previous procedures, therefore Duty Cycle = 44.8e-9 / 93.6e-9 *100% = 47.8632%.

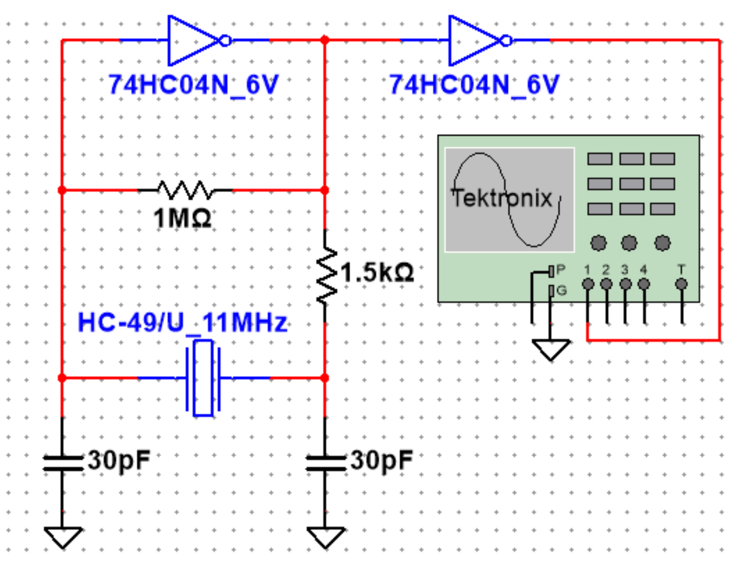

Figure 22: Crystal Oscillator

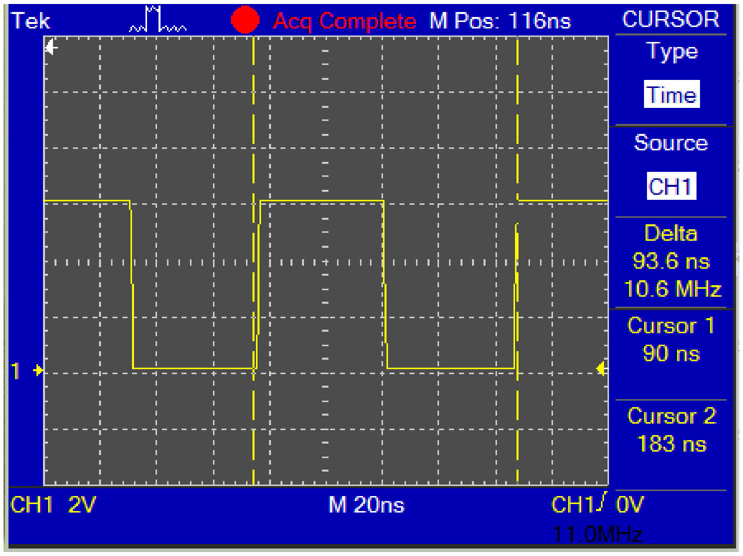

Figure 23: Frequency = 10.6 MHz

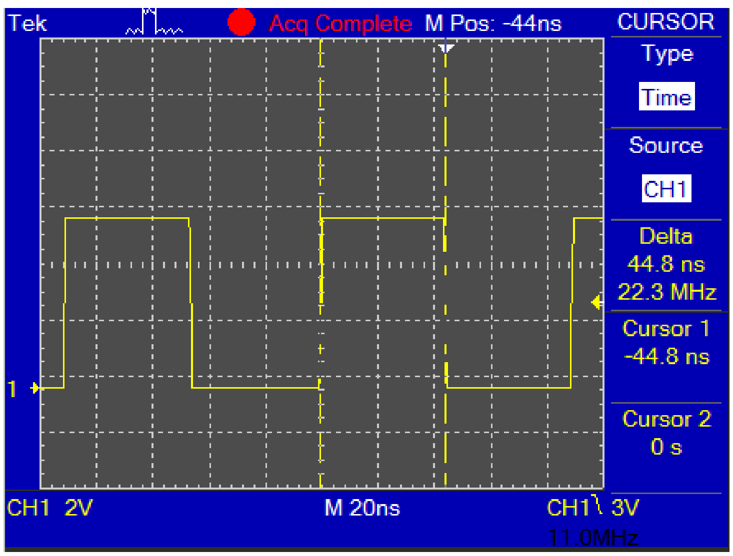

Figure 24: Duty Cycle On Time

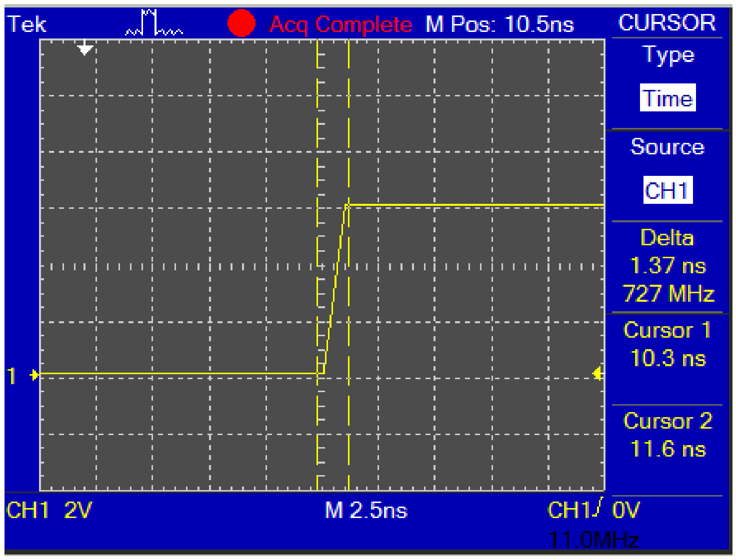

Figure 25: rise time = 1.37ns

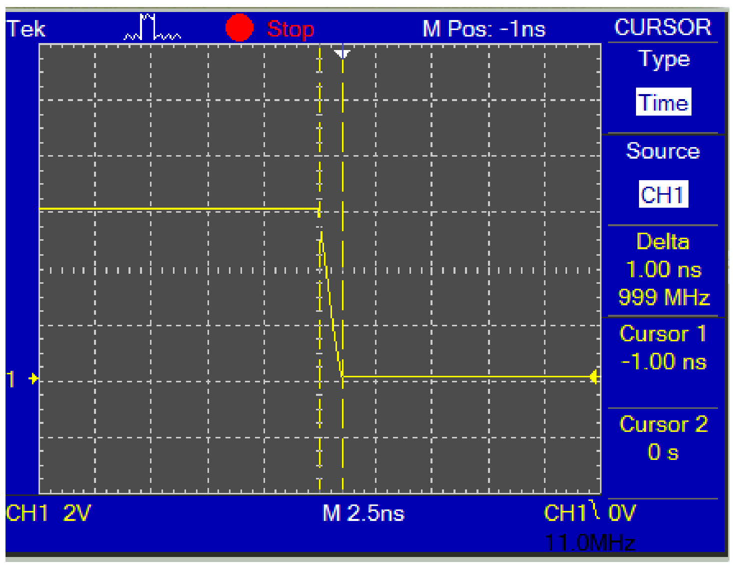

Figure 26: fall time = 1ns

10. In procedure 10, we are tasked with measuring the circuit with the crystal removed (Figure 27) and when the crystal and capacitors are removed (Figure 28). The crystal seems to hone in on the exact frequency that we expect from this type of circuit and “smooths” it out. When it is removed, we see the frequency is slightly slower. When we remove both the crystal and capacitors, we see the frequency almost double. The crystal seems to filter out the frequencies we don't want, and that is based on the 1.5k resistor and 30pF capacitor.

W/ Crystal and Cap	W/o Crystal	W/o Crystal and Cap
10.6 Mhz	11.4 MHz	23.4 Mhz

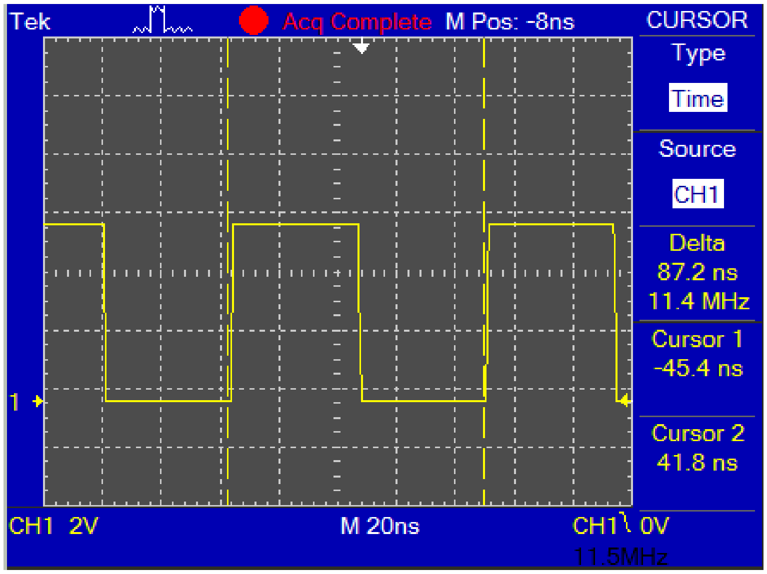

Figure 27: Crystal removed, Frequency = 11.4Mhz

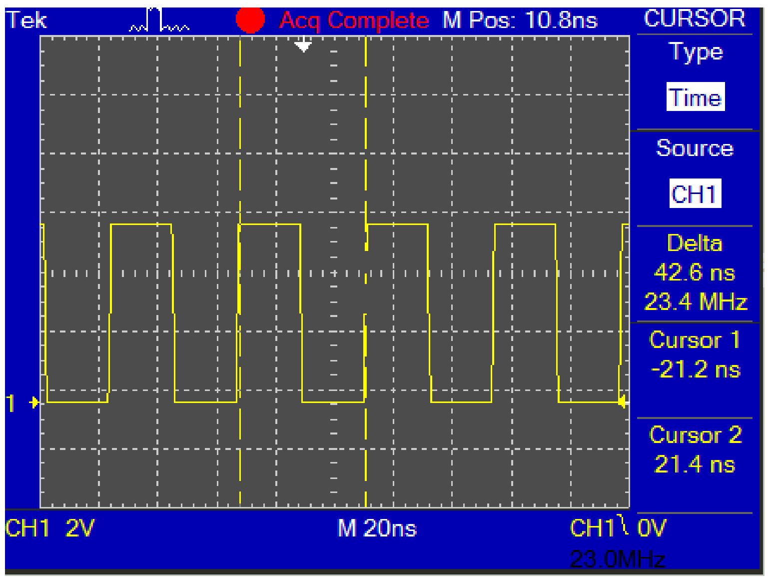

Figure 28: Crystal and Cap removed, Frequency = 23.4MHZ

Conclusion

This lab was very interesting to see how we can build our own timers and adjust them to produce different frequencies and how we can build other circuits to produce an array of square waves with different duty cycles and frequencies. It seems all of the rise and fall times are very close, within a negligible error amount. It was also interesting using Tinkercad. That is a simulation program I have never used before.