Capacitors and Inductors Procedure

Instructional Objectives

- Understand if our measuring equipment affects the circuit being measured.
- Analyze the transient response of a simple RC circuit.
- Analyze the transient response of a simple RL circuit.

Procedure

Parts needed for this lab: 510Ω, 3.3K and 10K resistors, a 0.1uF capacitor and a 10mH Inductor.

For all experiments in this lab you will be using a bread-board, an Oscilloscope and Signal Generator.

Part 1: Measuring the transient response of an RC network.

Review the Oscilloscope Familiarization document if you need to remind youirself how to use the scope.

Before we actually measure the RC time constant there are a few things that need to be determined about the circuit and the measurement instruments.

The theory section talks about the initial and final conditions of the voltage on the capacitor. We will investigate these conditions, since they influence the measured results. The initial conditions are not difficult to set or measure. To make it easy to measure τ we force the initial voltage across the capacitor to a known voltage and change the voltage across the capacitor to the final voltage. With this setup we can use Eq. 7 or 9 (Theory Section) to measure τ with the scope.

IMPORTANT NOTE: We are going to drive the RC with a very slow square wave. Slow is defined as a square wave having a period, T, about 30 times the time constant, τ, of the RC or RL circuit. We do this so that the capacitor (inductor) has time to get extremely close to the final voltage that is driving the circuit. This defines the initial and final conditions for us because we wait long enough before the square wave to change voltage. The square wave is supposed to be close enough to ∞ time. This dictates that we use low frequency square waves to determine the initial and final voltages across the device under test (d.u.t). We will have to zoom into the voltage across the L or C after determining Vinitial and Vfinal to determine τ more accurately.

Another issue we need to deal with is the influence the load resistance of the oscilloscope has on our measurement since we will use it to measure the τ of the RC circuit. The oscilloscope has the input impedance usually marked on the front panel of the scope near the BNC input. This is independent of the scope probe but is important. The impedance of measuring will be the scope input impedance in series with the scope probe impedance. The input impedance of the scope probe changes when you switch between X1 and X10. The switch changes the impedance of the probe. The impedance is mostly resistive and is the resistance from the tip of the probe to the center pin of the BNC connector. The X1 impedance and the X10 impedance are different. Use the input impedance of the scope and the scope probe to check and see if the measurement will affect the time constant measurement significantly. Use the X10 setting if the X1 setting will affect the measured results too much. Find the impedances of the scope probe. Measured from tip to BNC center pin using the DMM. 1X ___1M ohm______ 10X ___10M ohm________

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Look at the front of the scope near the input jacks. It gives the input impedance of the scope. 1MegaOhm and a small amount of capacitance. We will only consider the resistive part for now.

Now that we know the input resistance of the Oscilloscope we can determine if it will influence the measuring of the time constant τ. From figure 5 below we can evaluate whether or not the input resistance of the scope probe discharges the capacitor too much while R1 charges it. Too much means the connected scope probe discharges the capacitor fast enough to change the measured time constant by more than 1% for this lab. Does this input resistance discharge the cap at a rate high enough to influence the measureable charging through R1 by more than 1%?

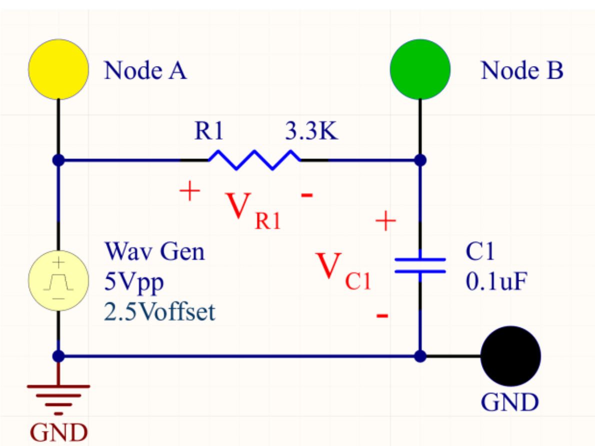
To determine this compare the charging R to the discharging R.

If the input resistance of the probe is >> than the charging R, R1, there won't be a problem unless you are trying to measure with incredible accuracy. For example, 100:1 ratio of Rin / R1 yields a 1% error. 1000:1 ratio a 0.1% error etc. It all depends on the accuracy you need for your tests. You should consider to 1% accuracy to be good enough for this lab.

Do you need to worry about the oscilloscope + probe input resistance when determining τ For R1 = 10K? ___No, Rin/R1gives only a 0.1% error _____

0. Parts: 1 - 0.1uF Film Cap, 1 - 10mH Inductor, 1 - 510Ω, 1 - 3.3KΩ, 1 – 10KΩ

1. Measure the charging of a capacitor to determine τ_{Charge}: Build the circuit shown in Figure 5 below. R1 is 3.3K and C1 is 0.1uF. Note the labeled nodes are where you will make your measurements with the CH1 and CH2 inputs.



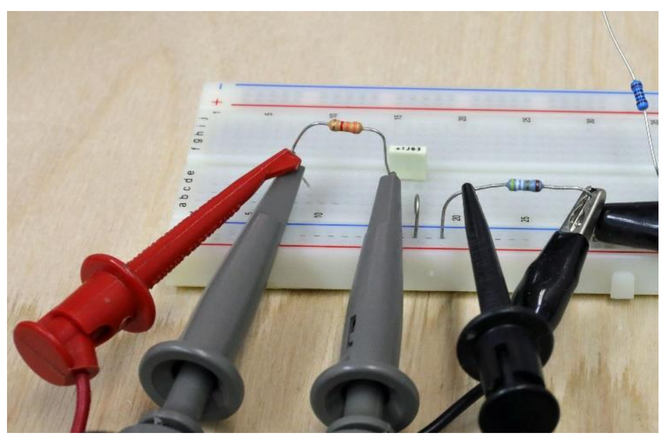


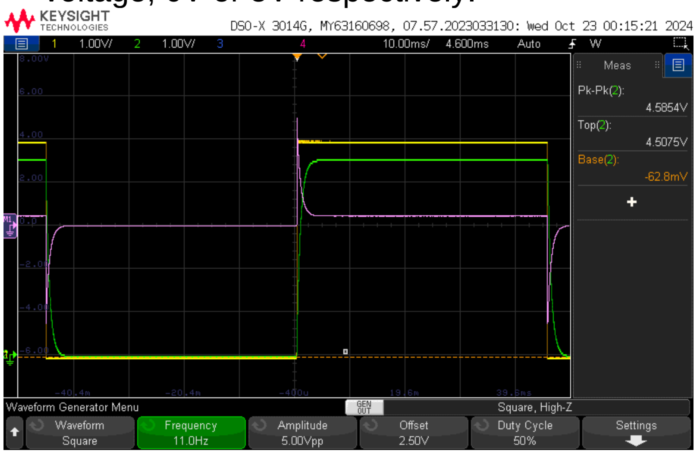
Figure 5: RC circuit with breadboard example.

What is the theoretical τ for this RC circuit? ___0.00033__________ S

General Setup:

- Connect the scope signal gen output to the circuit at Node A and GND.
- Setup the Wave Gen source to put out a 5V$_{PP}$ square wave with 2.5V offset at a frequency low enough that lets the voltages across the capacitor reach the initial or final values. A frequency with a period of about 20 or 30 times τ in time is a good start. Remember freq = 1/Period. This low frequency will be used to determine the initial and final voltages across the D.U.T. (Device Under Test). You can tell if the frequency you choose is low enough by looking at the voltage across the

capacitor and seeing if it approaches a constant voltage, 5V or 0V, before it changes to the other voltage, 0V or 5V respectively.



Frequency too Low and too high. Just right is shown in Figure 6.

- Start the Oscilloscope.
- Trigger on the ‘WaveGen’. Enable Averaging (8) using the Acquire key.
- Set the time base (Horizontal Control) to an appropriate uS/ or mS/ (time per division) which allows you to see both the charging and discharging of the capacitor on one screen and also shows the initial and final voltages. This will show about 2 cycles of the square wave.

Oscilloscope inputs.

Use all scope probes on 1X. If you use 10X then calibrate the probes. This is explained in the Oscilloscope Familiarization … document. You also need to set the probe setting on the scope to 10:1 to get the measurements to read the correct values.

- Connect the CH1 tip to Node A and the alligator clip to GND.
- Connect the CH2 tip to Node B and the alligator clip to GND.
- Turn on the MATH channel and set it to CH1-CH2.

I got a scope image that looked like figure 6.

First of all what is CH1 measuring? CH1 measures the input voltage of the square wave.

What is CH2 measuring? CH2 measures the voltage across capacitor.

What is Math measuring?The voltage difference between CH2 and CH1

Which curve(s) can you measure the time constant from? CH2, the green curve.

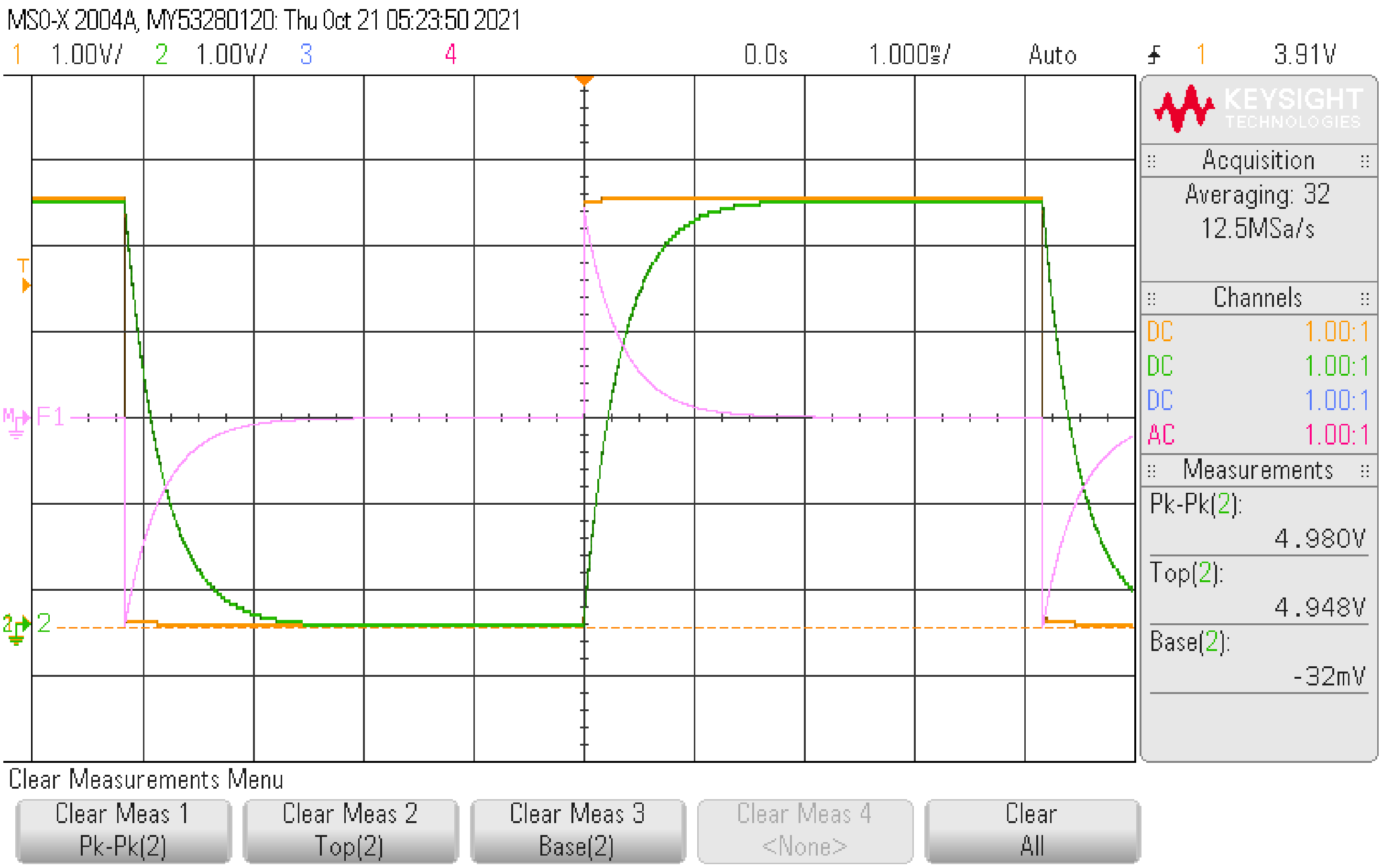


Figure 6: RC time constant measurement traces.

- I added some measurements that we will use to determine some of the charging and discharging parameters.
- Use the Base and Top measurements on CH2, the initial (about 0 V for charging) and final (about 5V for charging) voltages across the capacitor. If there are peaks that are present on the trace you should not use Min and Max but rather use Base and Top because they ignore any spikes that may be in the curve which are just noise for our measurements.

  V_{INIT} __10mv_____, V_{FINAL} __4.94V_____ across the capacitor.

  Make sure you are convinced the waveform is done rising or falling.

2. Use the cursors (preferably Tracking) to measure the time constant τ_{Charge}

- You need to determine what voltage is 63% from initial to final to make this measurement.
- You will use the Cursors for this. Click on the Cursors button.
- Use the Tracking Mode. Set the Source to CH2 (V_C). We will use this trace to find the time constant. We could use the MATH trace as well.
- Move the X1 cursor using the Cursors control to put the Y1 cursor at the INITIAL voltage on CH2. (About 0 volts) right before it starts to rise quickly.
- Move the X2 cursor to put the Y2 cursor to the FINAL voltage of the CH2 trace (About 5V).
- Calculate the voltage which is $(1 - e^{-1})$~0.63 the way to from V_{INIT} to V_{FINAL}. This is 63% from V_{INIT} to V_{FINAL} = V_{INIT} + 0.63(V_{FINAL}-V_{INIT}) ____3.162__________V. From Eq. 9 in the theory section.
- Move the X1 cursor to the point in time where the CH2 trace starts rising from $V_{INITIAL}$ if it isn't already there.

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- Make the Horizontal Time Base faster about 2 clicks. Fast enough so you can still see the CH2 trace where 63% occurs.
- Move the X2 cursor to the time where Y2 is at the 63% Voltage value (V_C).
- Now you can read the ΔX value of the cursor data in the lower right portion of the screen. This is the time constant, τ, for the circuit.
- Capture the resulting display and put it in the report instead of the plot I captured. Make sure your plot has CH1, CH2 and MATH. Also have the cursor menu showing your ΔX as well.

$\tau_{ChargeRC}$ = _____335 mu S____________________.

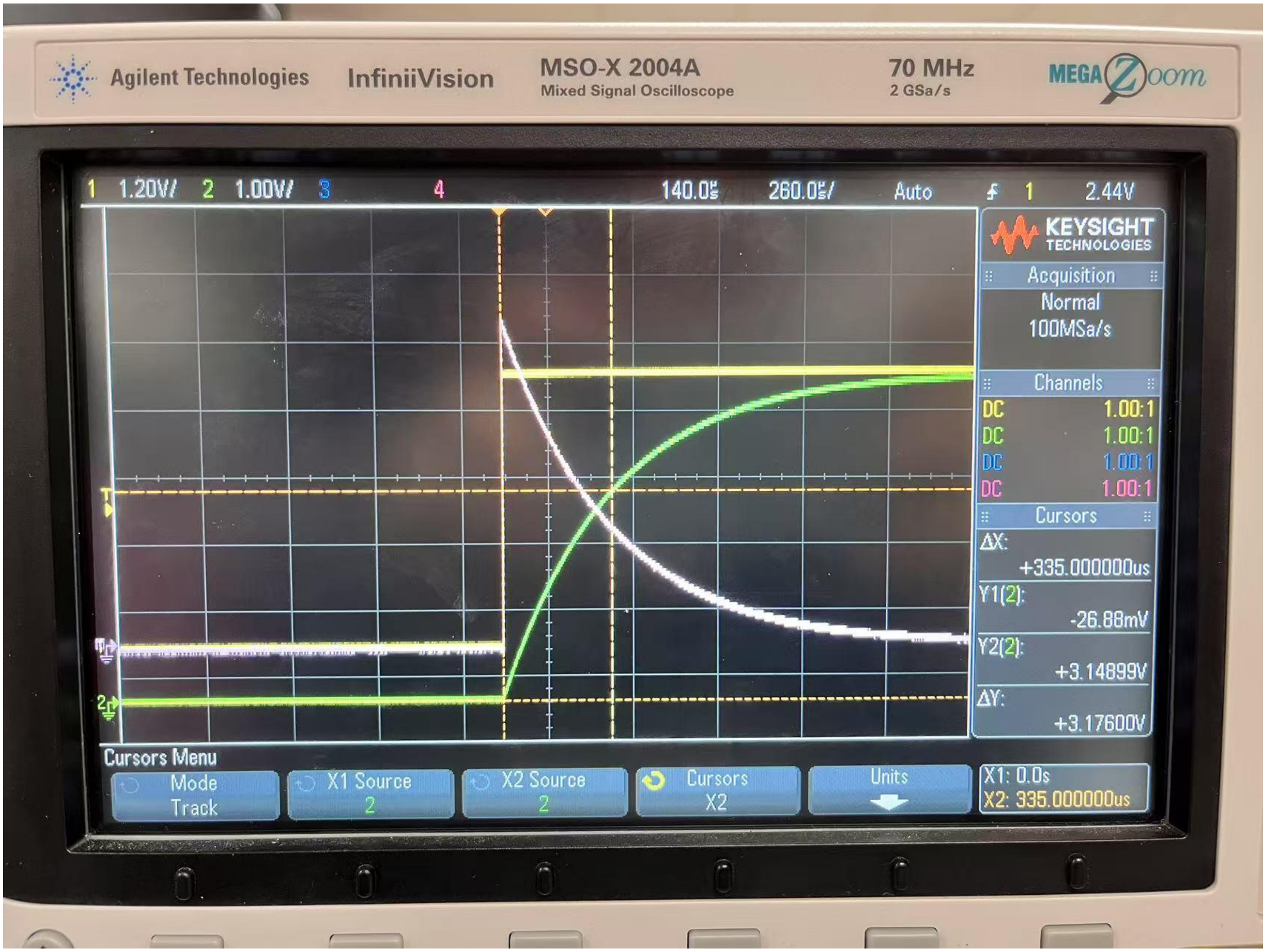

Figure 7: My plot of the time constant zoomed in.

3. Use the cursors to measure the time constant $\tau_{Discharge}$. This is when the voltage starts high and goes low.

- Change the horizontal position control to get this done.
- Now you need to calculate the voltage that is 63% down from the 5V initial value to the 0V final value.
- The vertical voltage you need this time is $(1 - e^{-1})$~0.63 the way to V_{FINAL}. This is 63% from V_{INIT} to V_{FINAL} = V_{INIT} + 0.63(V_{FINAL}-V_{INIT}) ____1.898________V. From Eq. 9 above. V_{FINAL}-V_{INIT} should be negative. This is not the same voltage as the first one. It should be closer to 0V than to 5V.

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- Capture the resulting display for your report.

$\tau_{DischargeRC}$= _____318 mu S_______________________.

4. Measure the peak current values during charge and discharge cycles. The current starts at 0 and either increases or decreases depending on whether the capacitor is charging or discharging.

a) You use MATH to measure the current. The voltage across the resistor is CH1-CH2. V_{POS} ___4.92_v_____, V_{NEG} ___-4.85v________.

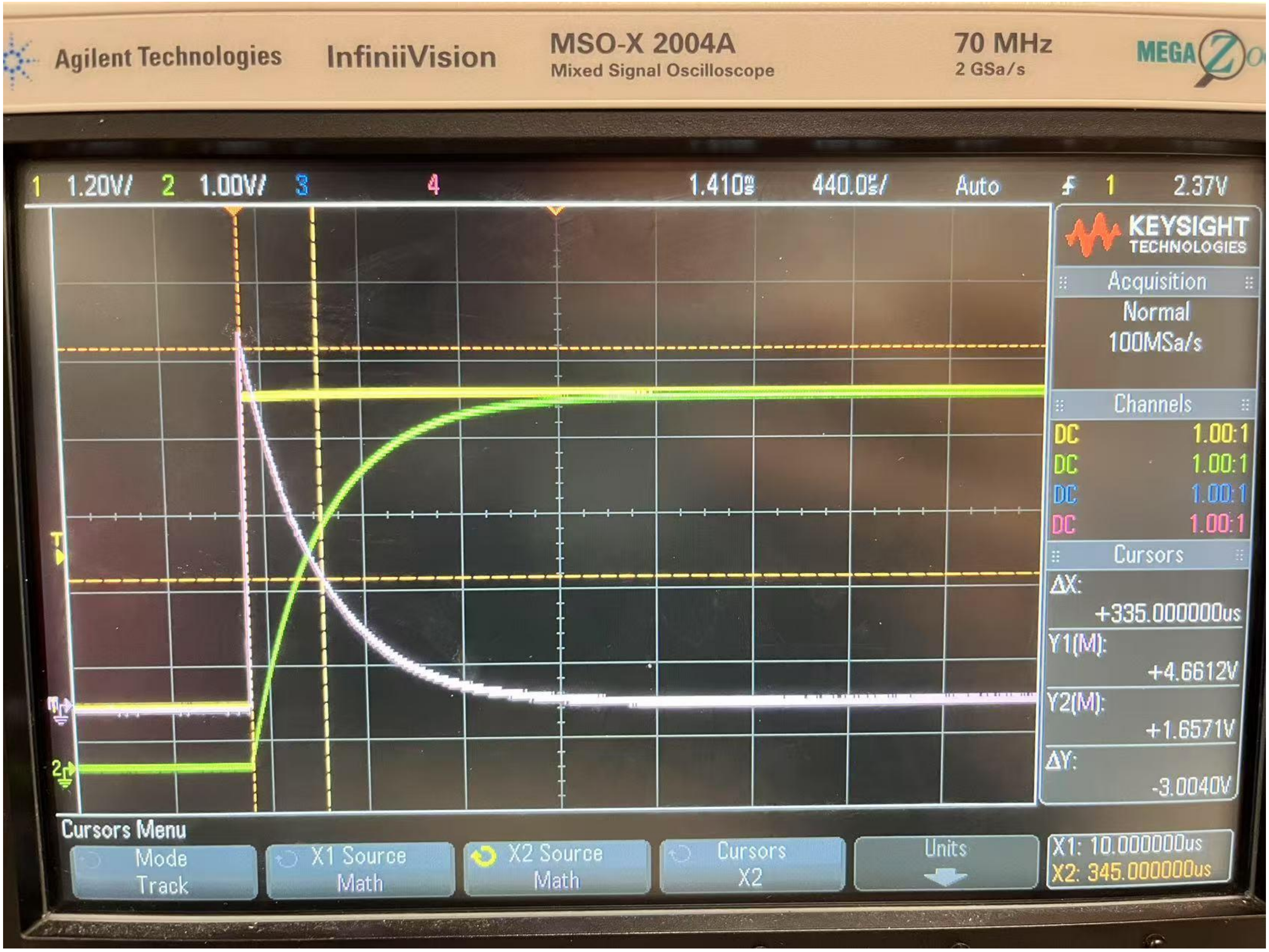
b) The current is the voltage across the resistor divided by the resistance. What is R ____3.25k Ω.

c) Calculate peak I_{CHARGE} ___1.514 mA_______ and peak $I_{DISCHARGE}$ __-1.492 mA_________.

5. One more measurement. Use the R1 current curve to determine the time constant. The current is initially a negative spike and finally settles to 0.

- The scope image you used previously should allow you to do this nicely.
- Use the negative peak value of current for V_{INIT} or I_{INIT} as it really is. INIT ___-1.492 mA_________.
- V_{FINAL} or I_{FINAL} is about 0V or 0mA.
- What is the 63% voltage on the current curve for finding the time constant? __-3.055V___________.
- Capture the scope image with the cursors shown for this measurement.

$\tau_{DischargeCurrentRC}$= ___335 mu S_________________________.



6. Change R1 to 10.0K. The following steps are similar to steps 2 - 3.

- Setup the Wave Gen source to put out a 5V$_{PP}$ square wave with 2.5V offset at a frequency low enough that lets the voltages across the capacitor reach the initial or final values. A frequency in Hz where the period is about 20 or 30 times τ in time is a good start. This low frequency will be used to determine the initial and final voltages across the D.U.T. (Device Under Test). You can tell if the frequency you choose is low enough by looking at the voltage across the capacitor and seeing if it approaches a constant voltage, 5V or 0V, before it changes to the other voltage, 0V or 5V respectively. (Note that the frequency will have to be lower than the frequency used in previous steps, because of the larger value of τ)
- Trigger on WaveGen again.
- Set the time base (Horizontal Control) to an appropriate uS/ or mS/ (time per division) which allows you to see both the charging and discharging of the capacitor on one screen and also shows the initial and final voltages. This will show about 2 cycles of the square wave.
- Measure the initial and final voltages, V_{INIT} __20mV_____, V_{FINAL} _4.92V______ across the capacitor.

7. Use the cursors to measure the time constant τ_{Charge}.

- Change the Time Base to cover the initial to final event to easily measure τ.
- Use X and Y cursors again.
- Use the 0.63 value of the voltage across the capacitor again.

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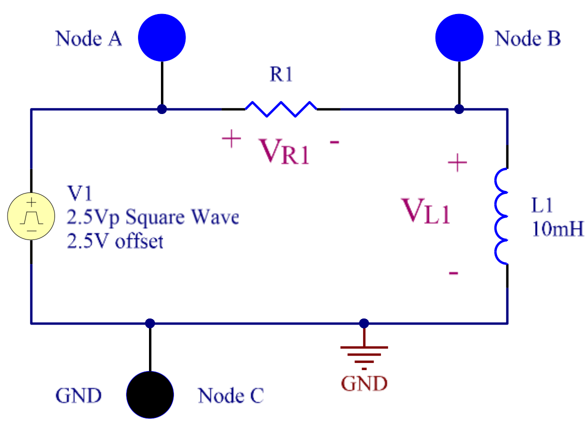
- Capture the resulting display for your report.

$\tau_{Charge10KC}$ = ___________990 mu S_________________.

Part 2 Measuring the transient response of an RL network.

8. Measure the charging of an inductor to determine $\tau_{ChargeRL}$: Build the circuit shown in figure 8. R1 is 510 for a 10mH inductor. However before you build this circuit measure the resistance of the indictor. R_L = ___26.522______ Ω and the resistance of R1 = ____0.510 k_________ Ω



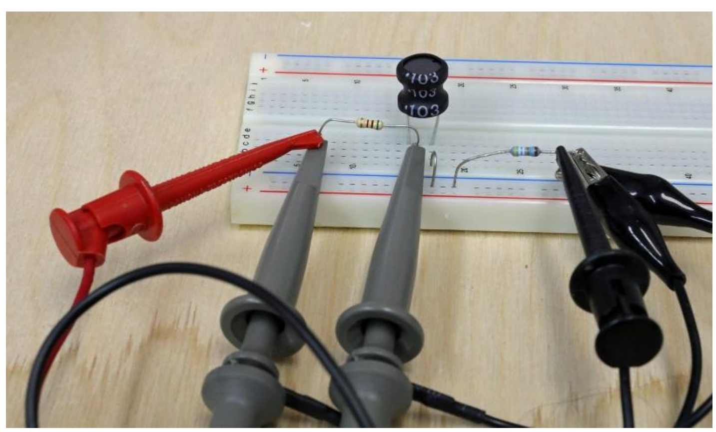


Figure 8: LC circuit with breadboard example.

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What is the theoretical τ for this RL circuit? _________1.96 * (10^-5)____ S

- Setup the Wave Gen Source to put out a $5V_{PP}$ square wave with 2.5V offset at a frequency low enough that lets the voltages across the inductor reach the initial or final values. A frequency in Hz where the period is about 20 or 30 times τ in time is a good start. This frequency will be used to determine the initial and final voltages across or current through the D.U.T. (Device Under Test). You can tell if the frequency you choose is correct by looking at the voltage across the inductor and seeing if it approaches a constant voltage, before it changes to the other voltage. (Note that the frequency will have to be much higher than the frequency used for the capacitor because of the lower value of τ)
- Trigger on WaveGen again.
- Set the time base (Horizontal Control) to an appropriate uS/ or mS/ (time per division) which allows you to see both the charging and discharging of the capacitor on one screen and also shows the initial and final voltages. This will show about 2 cycles of the square wave.

Oscilloscope inputs.

- Connect the CH1 to Node A and the alligator clip to GND.
- Connect the CH2 to Node B and the alligator clip to GND.
- Turn on the MATH channel and set it to CH1-CH2.

I got a scope image that looked like figure 9.

First of all what is CH1 measuring?
CH1 is measuring the voltage across the signal generator.
What is CH2 measuring?
CH2 is measuring the voltage across the capacitor.

What is MATH measuring?
Difference of voltage between CH1 and CH2, which is the voltage across resistor.

What is the source V1 min and max voltages based on the Wave gen settings?

Min ___0_____ V, Max ____5____ V.

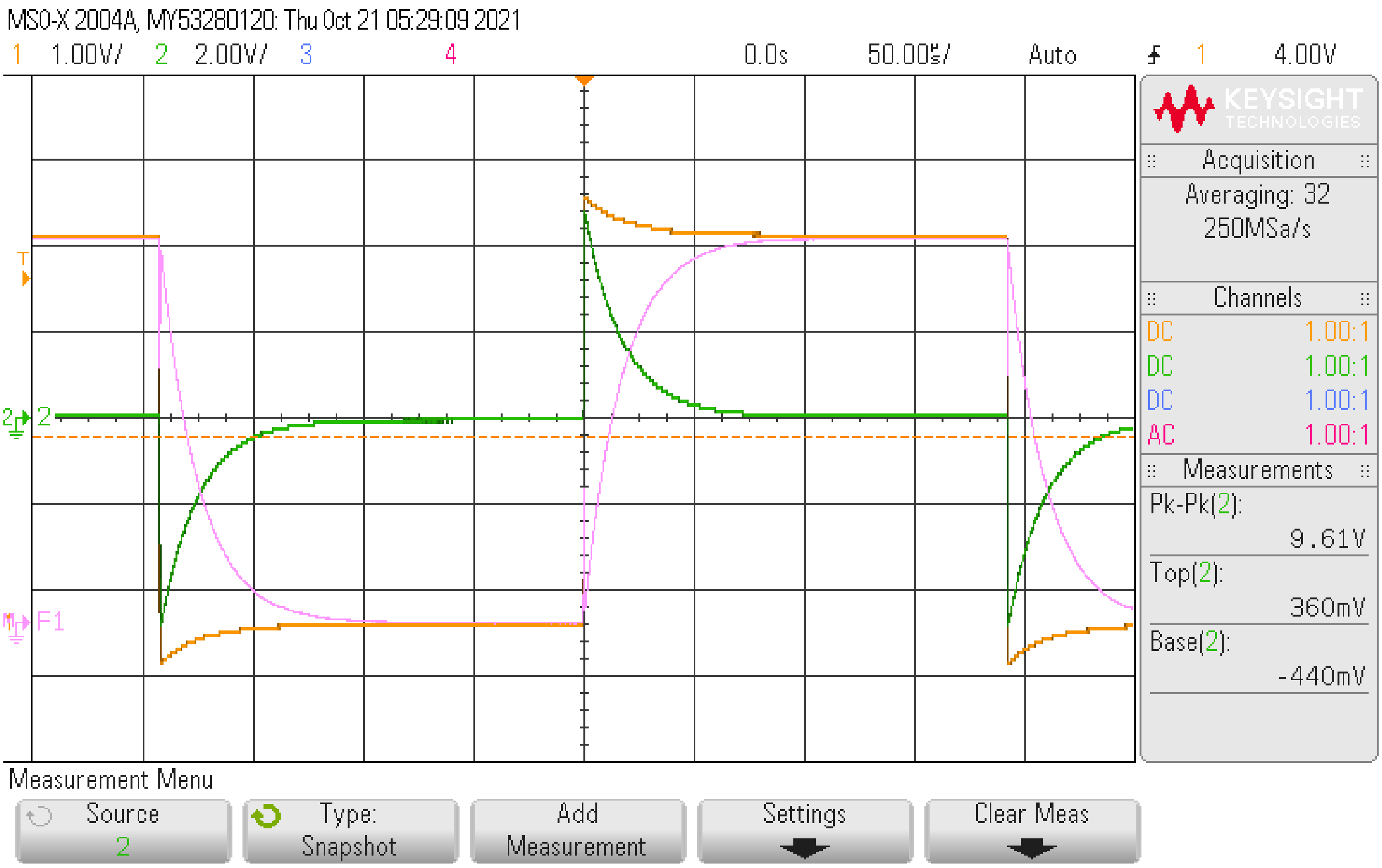

Figure 9: RL time constant measurement traces.

Notice a few things about these traces.

- First the square wave source is no longer square. It peaks up at the change of direction.
- There is a spike in the voltage across the inductor (CH2)
- The curves are complimentary to the capacitor curves. The V_C curve looks like the I_L and the I_C looks like the V_L.

When we looked at the RC circuit we used the directly measured V_C to find the time constant. We will do the same thing for finding the RL time constant. We will use V_L. So you should do a similar thing to what you did to find the RC time constant using the current trace. One problem is the Measurement of Base and Top don't give us anything useful for the time constant determination. You will have to measure $V_{INITIAL}$ and V_{FINAL} manually.

Measure the initial and final voltages for charging the inductor, CH2, across the inductor. This is not trivial as the inductor voltage never goes to 0 and starts out as a peak value. Don't use the negative half of the curve for this. That is for the discharging.

- Use the Cursors to measure CH2, the initial (top of the peak) and final (not quite 0V for charging) voltages across the inductor. V_{INIT} __4.87 V_____, V_{FINAL} ___10.97 mV____ across the inductor. Make sure you are convinced the waveform is done rising or falling.

As with the RC circuit there are 2 ways to measure the time constant $\tau_{ChargeRL}$. Using the voltage across the inductor or the voltage across the R (current through) the resistor.

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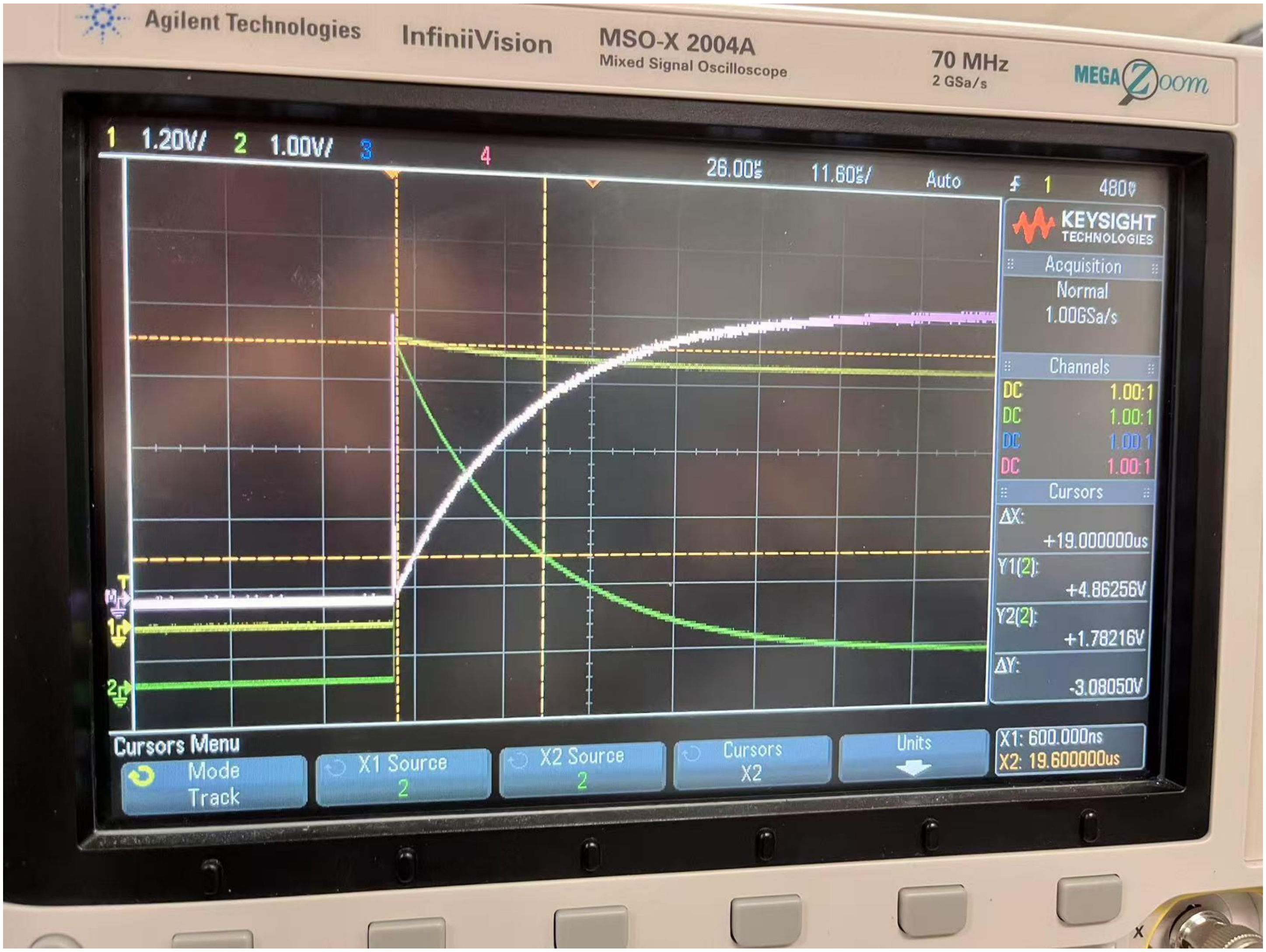
Which RL voltage looks more the voltage across the capacitor from the previous steps? V_R __4.89 V___ or V_L __4.18 V_____

You will use the voltage across the inductor to determine τ.

Use the cursors to measure the time constant $\tau_{ChargeRL}$.

- Change the Horizontal Time Base to cover most of the rising event on the screen.
- Set one y cursor to the initial voltage across the inductor.
- Set the other y cursor to the voltage which is $(1 - e^{-1})$~0.63 the way to V_{FINAL}. This is 63% from V_{INIT} to V_{FINAL} = V_{INIT} + 0.63(V_{FINAL}-V_{INIT}) _____1.802__________V. Note V_{FINAL}-V_{INIT} is a negative number.
- Capture the resulting display for your report.

$\tau_{ChargeRL}$ = ___________18.8 mu S_______________.



The CH1 and CH2 curves show that there is small voltage across the resistor and the inductor just as charging changes to discharging.

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9. Why is there voltage across the inductor?
   Inductor is actually many coils of wire, there's a small resistance so there's a small voltage across the inductor due to current divider law.
10. How much current is flowing through the inductor just before the charging curve changes to discharge? $V_{FINAL} / R_L = I_{Lcharge}$ __9.92__________ mA.

11. How much current is flowing through R1 at the end of charging?
    $V_{R1MAX} / R1 = I_{R1charge}$ ______9.90_______ mA

12. Is $I_{Lcharge} = I_{R1charge}$? ____yes, almost _____________ They should be identical.

13. Assuming the WaveGen is set to 5V calculate the amount of resistance that gives this current.
    $5 / I_{R1charge} = R_{Lcharge}$ = _________506.07__________ Ω

14. Is this close to the measured values R_L + R1? ____yes, almost___________ It should be.

15. If $R_{Lcharge}$ is the resistance used in the time constant what value of inductance would give you the measured time constant τ. Remember the inductance should be within 10% or 20% of 10mH.
    L_{ACTUAL} = ________10.1________mH

16. Use LTSpice (or any program) to draw the Voltage source, V1, measured R1 and RL and L_{ACTUAL} you just determined and include it here.