A Timed Reaction

Laboratory Outline

In this module, you will learn one method to create a timed reaction to an impulsive voltage from, say, the momentary press of a button or vibration sensor.

Often we desire a circuit to respond to a sensor for a short period of time and then to "reset" and wait for the next event before responding again. Examples might include detection of knocks on a door by a vibration sensor or detection of claps by a microphone. A timed reaction can be accomplished by taking advantage of the time constant of an "RC" (resistor plus capacitor) circuit.

An RC circuit pairs a capacitor to be charged and/or discharged with a current-limiting resistor. Large-valued capacitors require a longer charging/discharging time due to higher charge capacity (hold more Q) and large-valued resistors restrict the current also increasing the charging/discharging time. It is not surprising that the time constant (a value related to the expected charge and discharge times) is directly proportional to the choice of both the capacitance, C, and the resistance, R.

$$\tau = RC$$

See also: https://en.wikipedia.org/wiki/RC_time_constant

Prerequisites

- Practical experience placing an IC on a breadboard and reading a datasheet.
- Comfort using a Schmitt-trigger invertor as well as an nMOS transistor.

Parts Needed

- The 40106 Schmitt-trigger inverter
- A fixed-voltage supply (battery)
- A $330\ \Omega$, $1\ k\Omega$, and a $100\ k\Omega$ resistor
- A $100\ \mu F$ and a $10\ \mu F$ capacitor
- nMOS (FQP30N06L; just about any substitution is okay)
- LED (any color)
- Button
- Piezo vibration sensor (optional)

Notes:

At Home

Let's start our design by investigating the RC portion of a circuit. Build the circuit in Figure 1.

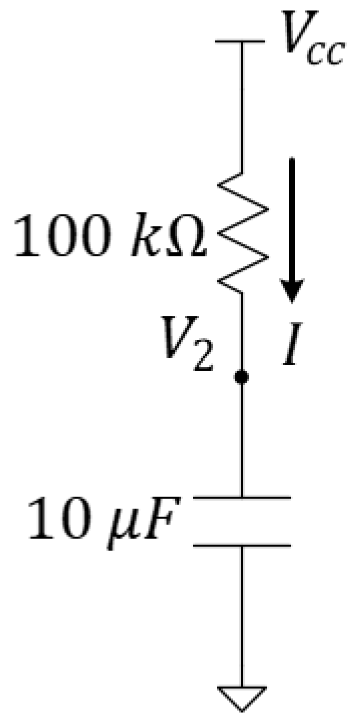

***Figure 1**: An "RC" circuit for investigating time constants.*

Although the charging of the capacitor cannot be visually seen, we can anticipate from the time constant, $\tau \approx (100k)(10\mu) = (0.1M)(10\mu) = (0.1)(10) = 1\ s$ that the capacitor will charge in about 1 second. Let's verify this (very roughly), by expanding the circuit to include a Schmitt-Trigger invertor and an LED with current-limiting resistor so that the (mostly-charged) capacitor will turn off the LED. See Figure 2.

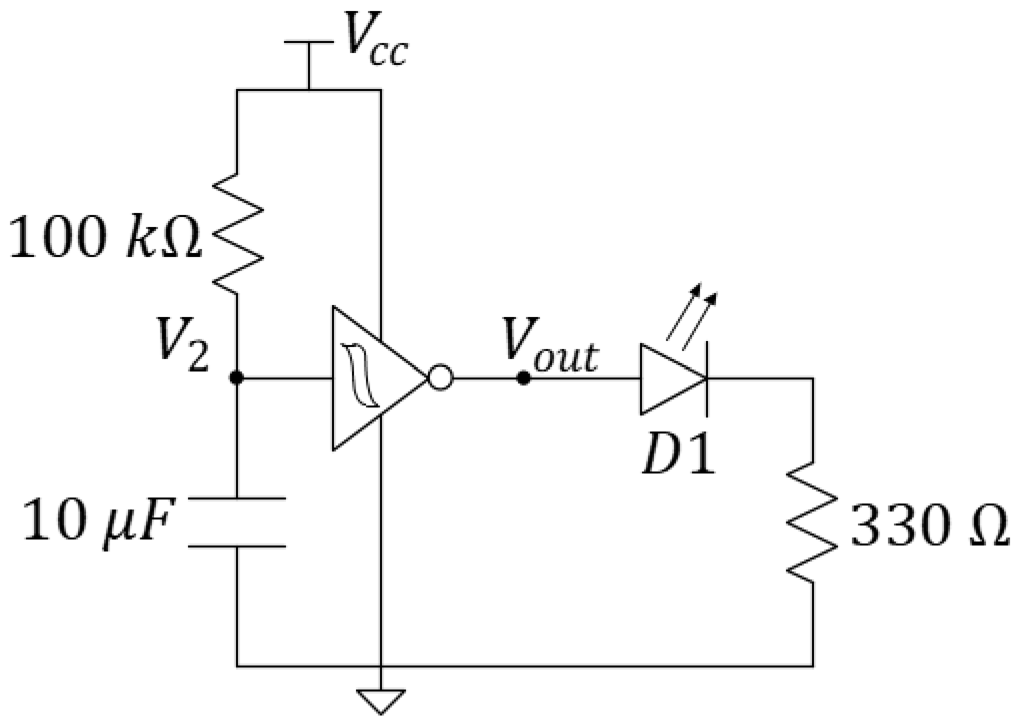

Figure 2: Addition of a "buffering" Schmitt-trigger and an LED for visual observation of the capacitor's voltage.

Remove the capacitor of Figure 2 and plug both of its leads into the ground node for a couple seconds to make sure it is discharged. Now re-insert the capacitor as shown in Figure 2 and observe how long the LED stays lit. If using an "electrolytic" capacitor, one side will be marked with as negative. Be sure to place the negative lead to the negative side of the battery. Repeat as necessary until you are satisfied of your observation.

Answer Question 1.

To verify the time constant, replace the capacitor with a $100\ \mu F$ value. Repeat the observation.

Answer Question 2.

Replace the $100\ \mu F$ cap with the $10\ \mu F$ cap to reduce the reaction time back to the shorter $\approx 1\ s$ time constant for debugging purposes (we don't want to wait $\approx 10\ s$ for each trial!).

Notes:

Notes:

To leverage this circuit as a timed-response to a sensor, we can further expand the circuit. We can use a MOSFET to suddenly drain the capacitor when the gate of the nMOS device is triggered on, placing the transistor in active (or, very likely, ohmic mode). After an *impulsive* voltage at the gate goes away, the nMOS returns to cutoff and the capacitor is allowed to charge again until the LED turns off. Build the circuit of Figure 3.

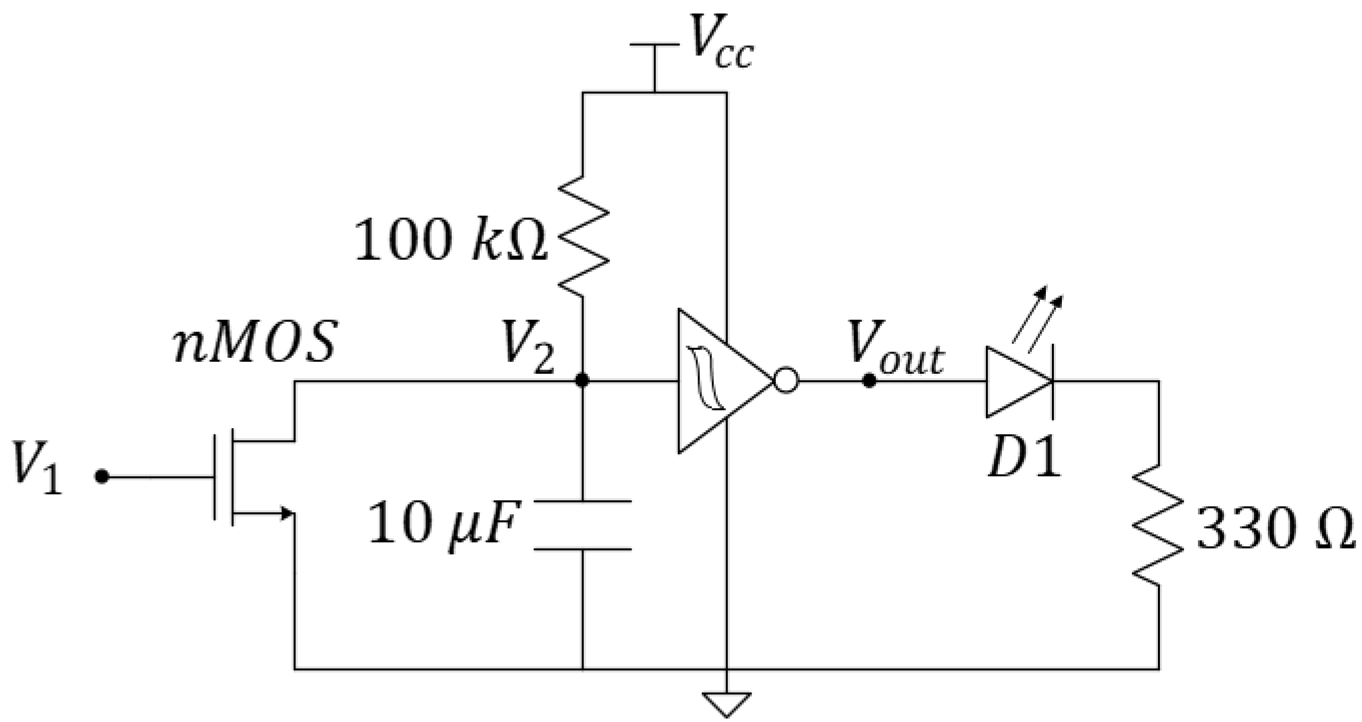

***Figure 3**: Addition of an nMOS transistor to quickly drain the capacitor's charge.*

To trigger the nMOS transistor to drain the capacitor, add a button and a pull-down resistor (1 $k\Omega$ would work well). See Figure 4. The pull-down resistor keeps the transistor in cutoff until the button is pressed. When the button is pressed, the transistor turns on draining the capacitor. Release of the button pulls the gate back to ground and the transistor returns to cutoff allowing the capacitor to recharge according to its time constant.

Build the circuit of Figure 4.

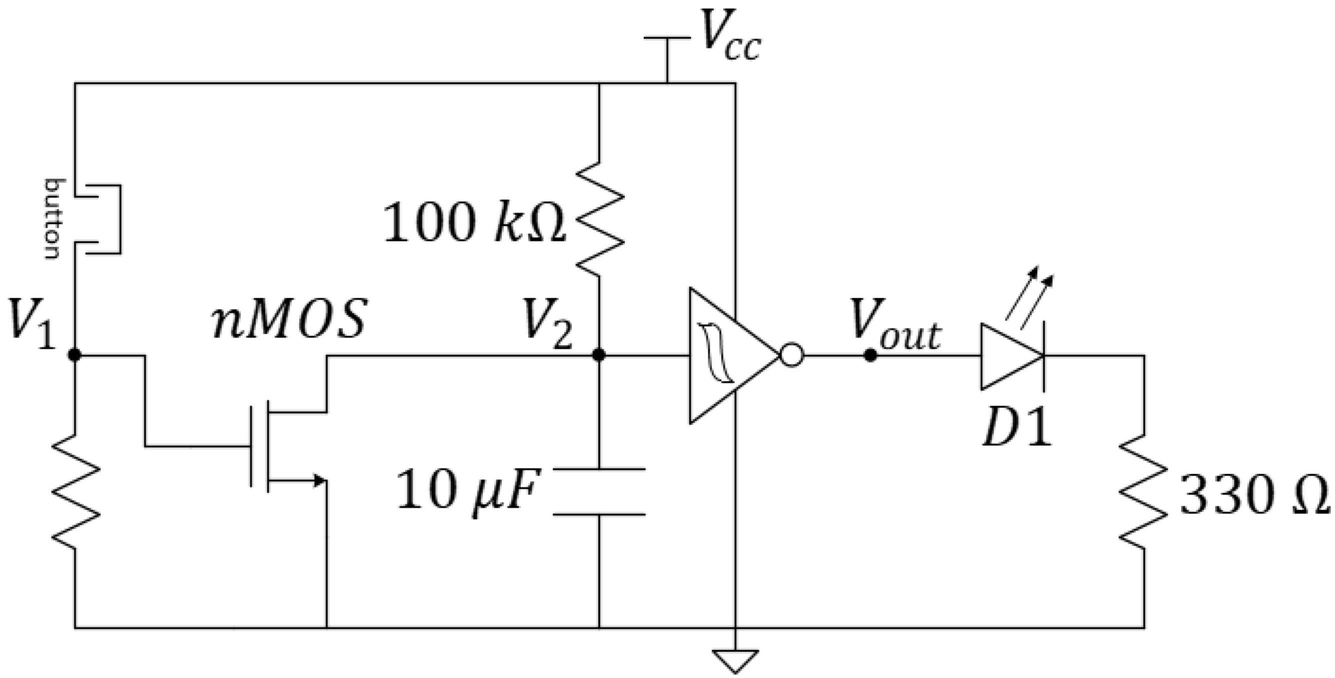

***Figure 4**: Addition of a button to trigger the discharge of the capacitor.*

Answer Question 3.

Consider Figure 5 where the nMOS transistor has been replaced with a functional model.

Answer Questions 4 and 5.

Notes:

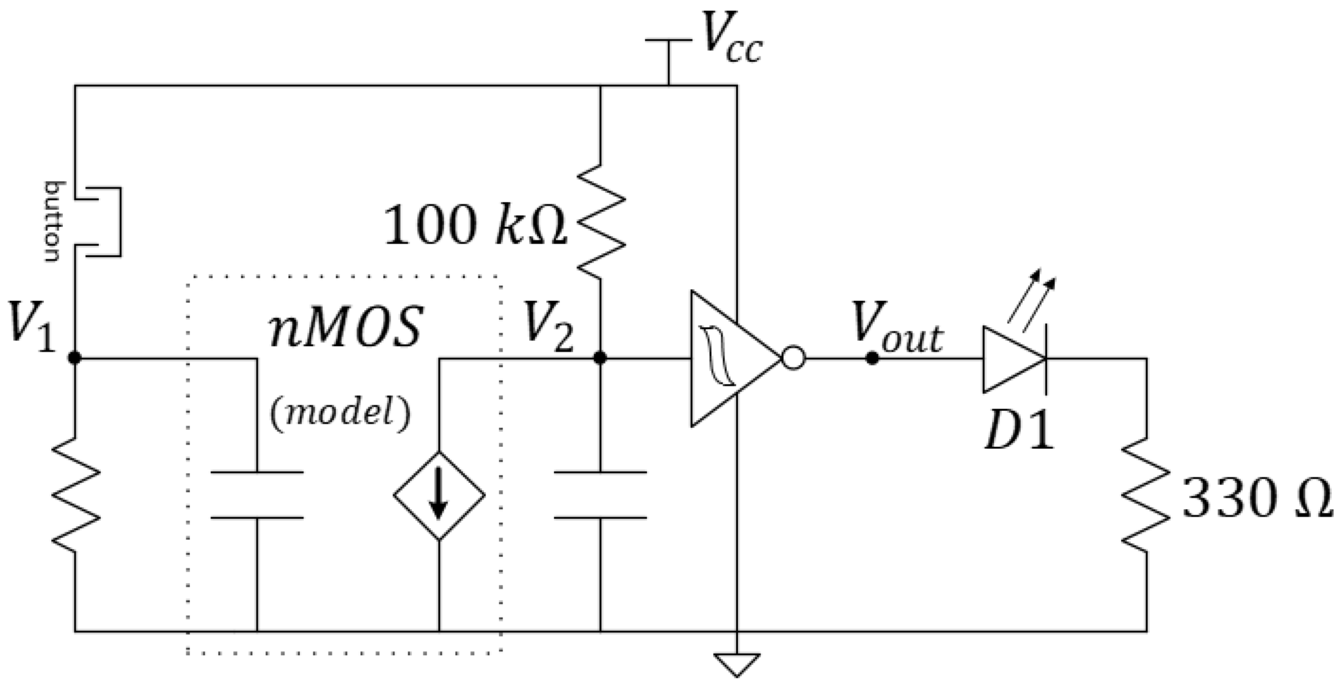

***Figure 5**: Modelling the nMOS for clarity of operation.*

Second Application (optional)

Now that we have been able to trigger a timed response with a button, we can consider other sensors to use as a trigger for this timed response. In Figure 6, we have removed the button circuit and replaced it with a piezo vibration sensor (which might be available through your TA). A piezo vibration sensor contains a crystal with metal contacts that, when mechanically vibrated, generates a time-varying voltage. In this case, that voltage reaches a high-enough value to turn on the transistor and drain the capacitor. Usually, the gate voltage returns the transistor to the cutoff state. Sometimes, you might find that the gate does not fully discharge (or can actually remain in a negatively-charged state!). For this reason, a button has been added for a manual reset option. You may also consider replacing the button with a large ($100\ k\Omega - 1\mathrm{M}\Omega$) resistor to facilitate draining the capacitor of the nMOS gate if this event were to occur.

Notes:

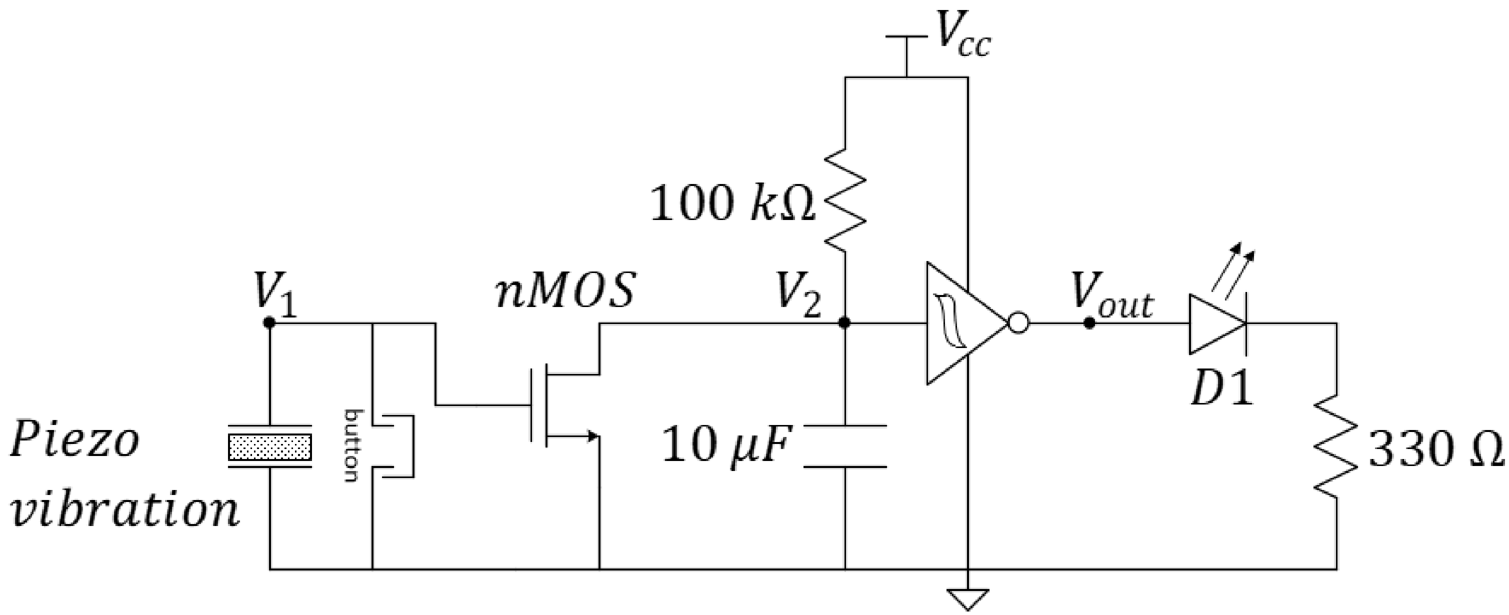

***Figure 6**: Using a piezo vibration sensor to trigger the timing circuit. The button is used as a reset only as needed.*

Drawing Conclusions

Answer Question 6.

Learning Objectives

- To build and modify a timed-response circuit useful for many projects.
- To gain deeper understanding of potential uses of the nMOS transistor.

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Notes:

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Notes:

Module 930: Timed Reaction

Question 1: How long does it take to charge the $10\ \mu F$ capacitor to the point the LED turns off?

Question 2: How long does it take to charge the $100\ \mu F$ capacitor to the point the LED turns off? Compare with Question 1 and explain using the formula for time constant, τ.

Question 3: Discuss the operation of the circuit when pressing the button with both the $10\ \mu F$ and the $100\ \mu F$ capacitors.

Question 4: Using the model of Figure 5, explain using basic circuit laws (Kirchhoff's Voltage Law, Kirchhoff's Current Law, and/or Ohm's Law) why the gate capacitor of the nMOS transistor will drain to ground.

Notes:

Question 5: Claim: after the nMOS gate's capacitor has drained of its charge, the nMOS transistor does not affect the charging rate of the $10\ \mu F$ capacitor. Use Figure 5 to explain why using circuit theory facts and assumptions about the model of the nMOS transistor and the Schmitt trigger.

Question 6: Brainstorm and name one or more other projects where a timed-response might be used.