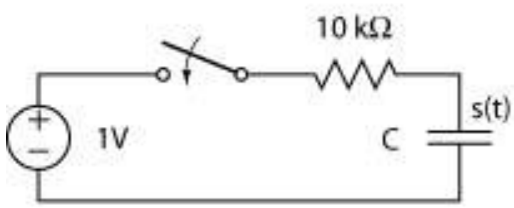
ECE 35 **Project 4 RC Circuits**

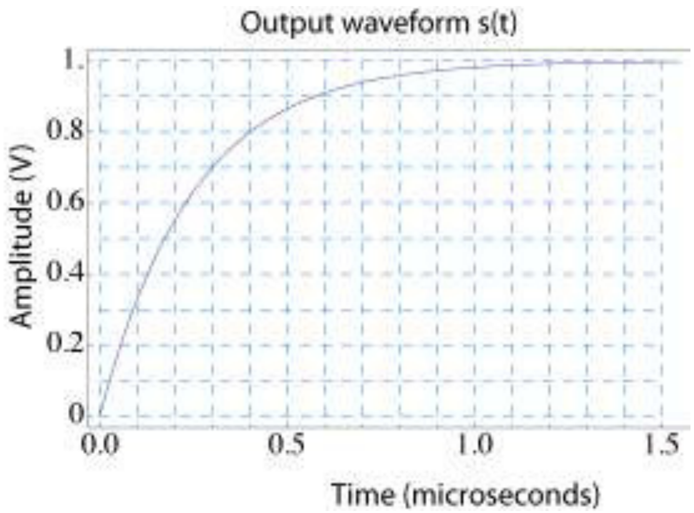
The objective of this lab is to measure the time characteristics of RC circuits and demonstrate how RC circuits can affect the transmission of digital information.

Prelab:

NOTE: Your prelab will be checked before lab begins for completeness.

1) The switch is closed in the circuit below at t = 0, and the output waveform s(t) is observed across the capacitor. Determine the value of the capacitor C, assuming it was initially uncharged. Do this by plotting ten values of the function ln(1-s(t)) spaced every 0.1 μs and fitting a straight line to the data points. The value of C can be determined from the slope of this line. Explain in detail how you found that value. Hint: What is the time constant?
You can use other methods to arrive at the answer if you understand the process. Be ready to explain it to your TA.





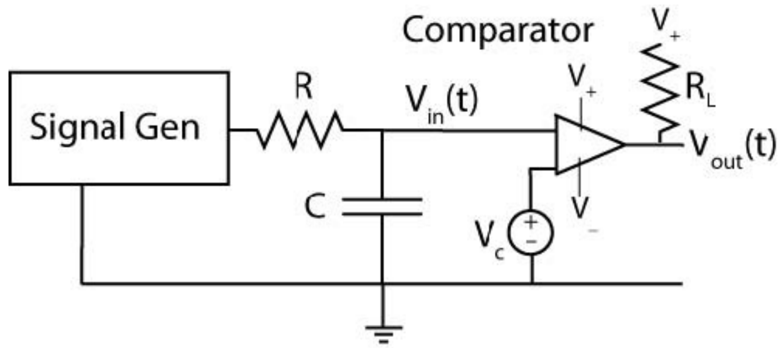
2) Design an experiment to measure the capacitance C replacing the DC voltage source and the switch in the circuit above with a function generator. Sketch the setup and discuss what measurements are required to determine the capacitance and specifically how to set up the frequency and waveform of the function generator if the capacitance is not known. Note that you will use this procedure in lab. Hint: What should the input look like in comparison to the output?

Experiment 1 – Measuring the capacitance from the RC time constant.

The tutor will give you a capacitor with an unknown value. Use the sketch of the experimental set up done before lab and the same procedure as used to determine C for prelab. Determine the value of the unknown capacitor, and have the TA sign the signature sheet after showing them your calculated value. They will then measure the value independently to determine how close you came to the real value.

Effect of RC circuits on digital signals:

In this part of the lab, we will qualitatively demonstrate the effect that an RC circuit has on a digital waveform. Our simplified digital communication system is the following:



The diagram above can be seen as having three parts:

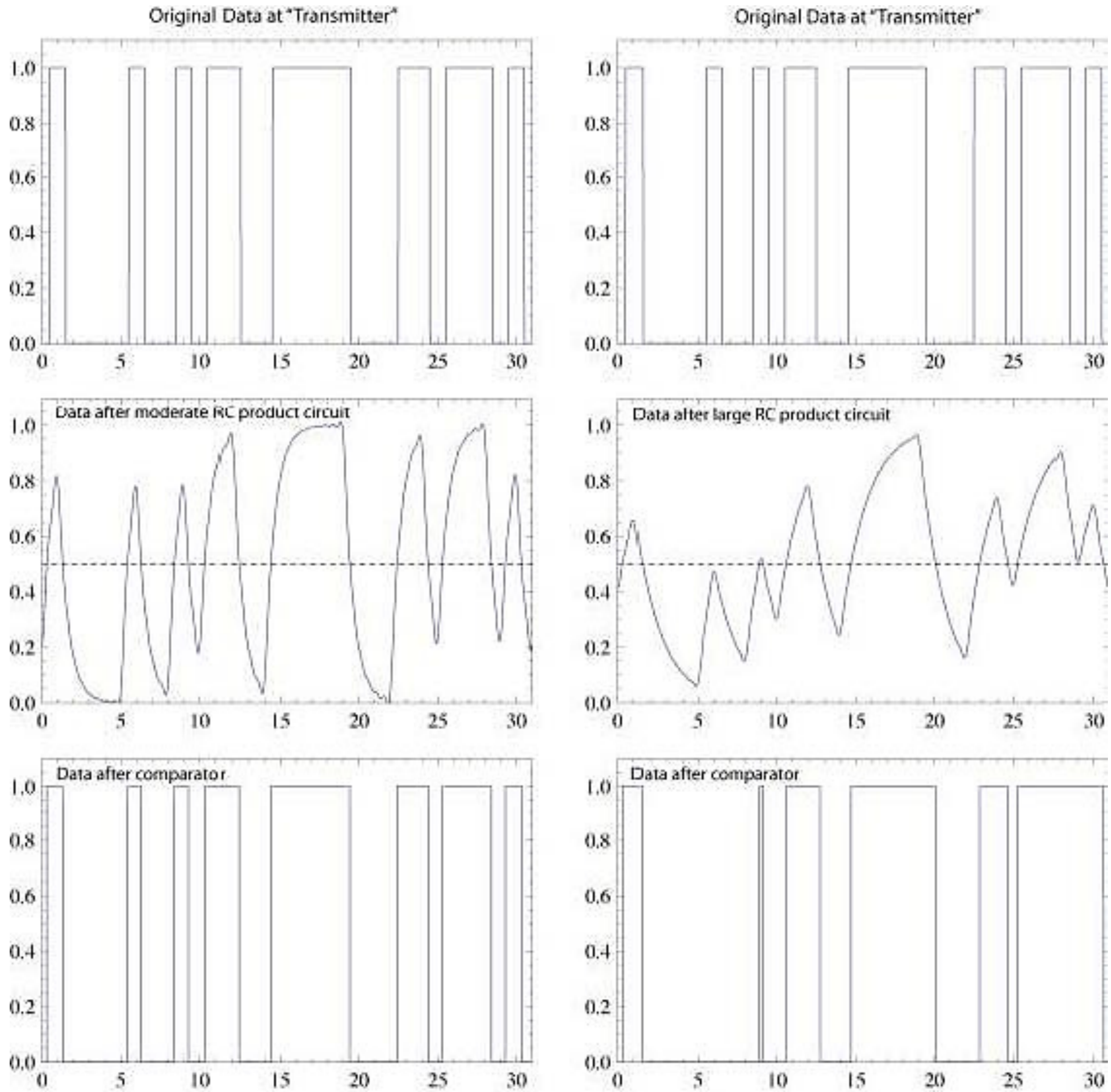
1. The signal generator, set on square wave, will act as our digital data source.
2. The RC circuit acts as a "lowpass" filter and represents the effect of a communication "channel" which **distorts** the waveform.
3. The comparator acts as our receiver that attempts to reconstruct the original digital waveform from the distorted waveform.
   a. If Vin(t) > Vc , then Vout(t) = V_+ .
   b. If Vin(t) < Vc , then Vout(t) = V_ .

   You can think of Vc as a threshold voltage, in which input voltages above it will lead to a digital "high" at the output, while voltages below it will go to a digital "low". **We will vary Vc and observe what effect this has on the output.**

The effect of the RC circuit on a digital waveform is shown via a simulation on the next page. The top sets of panels are ideal digital waveforms before transmission. The middle set of panels are the distorted waveforms caused by the averaging effect of the RC circuit with the right panel being more distorted than the left panel owing more averaging caused by a larger RC time constant. The bottom set of curves is the recovered waveforms by the comparator.

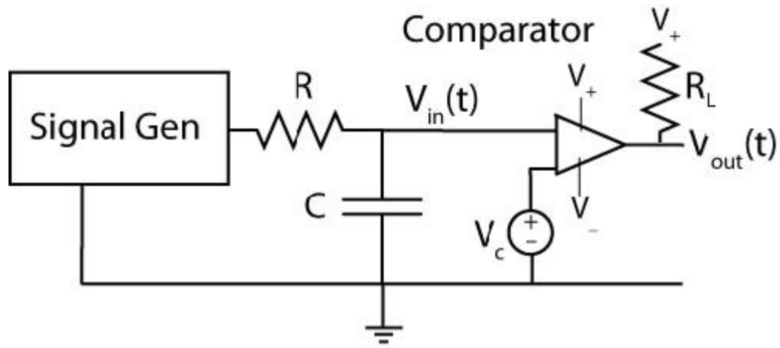
For the moderate distortion shown on the left set of panels, the comparator does a good job of recovering the original waveform with the width of the recovered pulses being nearly the same as the original data. **However, when the RC time constant is large, the waveform is significantly distorted** (right panels). The simple comparator then "misses" the second high signal sent at t = 6 and outputs a "zero," causing the transmission error.

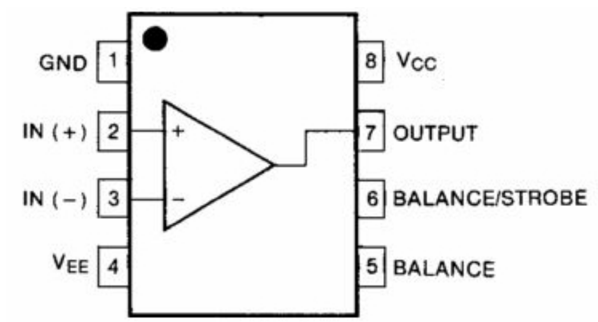
In addition, the width of the recovered pulses does not always match the width of the original data producing duty cycle distortion (Duty Cycle in a square wave means the % of time the wave stays High over the entire period). We will investigate the effects of RC circuits on digital waveforms in this next part of the lab.



Note that these images should not correspond to your results. Rather, they illustrate what your circuit is accomplishing. You should understand what these waveforms are demonstrating before continuing with the lab. It is very important to understand what effect Vc has on the output before continuing.

Experiment 2 – Digital Signal Reconstruction after RC circuit





LM311 comparator Pinout diagram

When you construct your comparator, V_+ = 5V (pin 8), V_= Ground (pin 4), and R_L ~ 51 kΩ connect one end to pin 7 and the other to 5V. Vc will be from the other power port, where we can adjust its value, connect it to pin 3 with 2.5V. Ground pin 1. Pin 5 and 6 can be left floating.

NOTE: For the easiest understanding of this section, read the entire section first.

1. Using a 1μF capacitor, determine the value of R that will produce an RC value of approximately 10^{-4} second. These will be your R and C values for your RC circuit. The capacitor may have a black strip on it, that side of the pin goes to ground. Connect the output of your RC circuit to pin 2 of LM 311 chip.
2. Set the function generator to a 100 Hz, 0-5 V square wave. Use a cable to connect the function generator to the scope. It should default to 50% duty cycle (meaning 50% of the time the wave stays at 5V, the other 50% at 0V). When you verify your square wave on the oscilloscope, we will save the square wave on the scope display for comparison. To do so, position your waveform such that it only takes the top 1/3 of your display as you will need the bottom space to eventually display 2 more wave forms in the next steps. Select "Save/Recall" and change the "Action" menu to "Save Waveform." Save it to either "Ref A" or "Ref B." Make sure that the reference you used is on by pressing "Ref", and it will display it on your O-scope. Move your original wave down and you'll see it's copied in white.

3. Connect the function generator to the input of your RC circuit. Connect channel 1 of the O-scope to the output of your RC circuit (Vin). **For frequency of 100 Hz, you'll notice that the output is a square wave, can you explain why? If it is not a square wave, double-check your R-value calculations in part 1. There should now be two traces on the scope.

4. We will now adjust the threshold voltage (Vc) to 3 different values. We will adjust it to 25%, 50%, and 75% of the RC output signal. The general equation we'll use is:

$$Vc = V_{Low} + [(\text{percentage we want}) \times (V_{High} - V_{Low})]$$

   *V_{High} and V_{Low} are the highest and lowest voltages of the signal on channel 1. Use the cursor, set type to amplitude, to measure your voltages.

   What are the three threshold values you calculated for Vc? Set your Vc value to what you calculated for 50%. Connect channel 2 to the output of the comparator (Pin 7). There should be three traces on your O-scope display. How sensitive is the shape of your comparator output trace to minor adjustments of the threshold value? Does this value with what you would expect? Now adjust your threshold Vc to 25% and 75%. Make hardcopies at each of these threshold values and explain clearly the comparator output waveform's behavior (Vout).

5. Repeat step 4 with a frequency of 10 kHz. How does this affect the output of your RC circuit? Are the recovered waveforms still the same as the original? Why? Explain the differences when compared to 100 Hz frequency. Show your results to the TA.

You should have 6 printouts total, each with 3 waveforms on them, the saved 100 Hz or 10 kHz reference, the output of the RC circuit, and the output of the comparator. Why are your square wave results different relative to the data waveforms used in the simulation above (on the previous page)?

Discuss in your lab report:

- Explain the methods you chose to solve for the unknown capacitor
- Explain the difference between the OP-Amp in this lab to the Op-Amp in the last lab
- For the Comparator circuit, explain the role of each part of the circuit. ie, the function generator, RC circuit, and Op-Amp comparator
- How does the frequency of the function generator effect the signal $V_{in}(t)$? Relate this to the time constant of the RC circuit
- Determine and show in your print-outs where the different V_c values are. Does the V_{out} agree with your observations?
- What can be done to the RC circuit, such that a 10kHz signal will not be distorted?