E&M Laboratory 1106, Summer 2025

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https://www.physics.smu.edu/tneumann/110X_Summer2025/

Lab 7 — Time-varying RC circuits — Introduction Max. points: 41

Your preparation: Work through before coming to the lab

- Prepare for the lab by thoroughly reading and understanding the measurement and analysis procedures on this worksheet. Photos of the equipment and further introductory material are available on https://www.physics.smu.edu/tneumann/110X_Summer2025/schedule-em/.
- Collect all your questions and ask your instructor at the beginning of the lab.
- Work through the chapter on "Capacitors and RC Circuits" in Halliday, Resnick, and Walker [1]. Focus especially on these topics: Understand the concept of capacitance and capacitors. Understand charging and discharging of capacitors in RC circuits with DC voltage sources. Understand the definition and significance of the time constant ($\tau = RC$). Understand exponential charging and discharging curves.

Pre-lab: Upload to Canvas before coming to the lab

A reminder: Upload your answers as a text document (exported as PDF) to Canvas before the lab begins (Canvas uploads are no longer possible 30 minutes before the lab starts!).

Pre-lab 1 8 points

1. (1 point) Sketch a simple circuit diagram for an RC circuit connected to a DC voltage source through a switch, to demonstrate charging and discharging. Label Resistor (R), Capacitor (C), Voltage Source (V), and switch.
2. (1 point) (a) In Measurement 1 with a square wave input, sketch what you expect to see on the oscilloscope for the voltage across the capacitor if the time constant $\tau = RC$ is significantly shorter than the period of the square wave. Explain your sketch in terms of capacitor charging and discharging behavior.
3. (1 point) (b) Now, sketch what you expect to see for the voltage across the capacitor if the time constant $\tau = RC$ is approximately equal to half the period of the square wave. How will the waveform shape differ from case (a)? Explain.
4. (1 point) (c) Finally, sketch the expected capacitor voltage waveform if the time constant $\tau = RC$ is significantly *longer* than the period of the square wave. How does the waveform

change in this case compared to (b) and (c)? Explain.

5. (1 point) Imagine you want to double the frequency of the sine wave output from the function generator, while keeping the peak-to-peak amplitude the same. Which control(s) on the function generator would you adjust, and in what direction (increase/decrease)?
6. (1 point) Explain how you would connect an oscilloscope to measure the voltage across a specific component in a circuit. Should the oscilloscope be connected in series or parallel with the component?
7. (1 point) You are using the oscilloscope to display a waveform. You observe that the waveform is too small vertically and compressed horizontally on the screen. Describe which oscilloscope controls you would adjust to increase the vertical size of the waveform and to horizontally expand the waveform display so you can see more detail in time.
8. (1 point) In Measurement 2, you will qualitatively observe the *amplitude* of the capacitor voltage as you change the input frequency. Explain *why* we use an oscilloscope to observe this amplitude change, rather than just using a multimeter in AC voltage mode. What key information would be missed if you only used a multimeter?

Lab measurements and report: submission by end of class

A reminder: All measurements must be fully documented . The final report must be uploaded to Canvas *by the end of the class* exported as PDF with plots and tables from Excel or Capstone embedded as images. Canvas will stop accepting uploads 10 minutes after the class ends. If you have not fully completed your report, you must upload the documents as far as you have completed them for grading.

In this lab, you will be introduced to time-varying RC circuits and learn to use function generators and oscilloscopes to observe and analyze their behavior.

Measurement 1 *Measurement 1: Observing RC charging and discharging with a square wave* 9 points

In this measurement, you will build a simple RC circuit and drive it with a square wave from a function generator. You will use the oscilloscope to observe the charging and discharging behavior of the capacitor.

Equipment: Resistor ($10\,\mathrm{k\Omega}$), Capacitor ($0.1\,\mathrm{\mu F}$), Function Generator, Oscilloscope (preferably dual-channel), Connecting wires and breadboard (optional).

(Alternatively: Resistor $33\,\Omega$, Capacitor $100\,\mathrm{\mu F}$ for a similar time constant.)

Measurement procedure:

1. Circuit building:
   (1) Construct a series RC circuit by connecting the resistor and capacitor in series.
   (2) Connect the function generator output to the series RC circuit to act as the input voltage source.

2. Function generator setup:
   (1) Set the function generator to output a square wave.
   (2) Set the frequency to a low value, e.g., 1 Hz.
   (3) Set the amplitude to 5 V peak-to-peak.
3. Oscilloscope connection and setup:
   (1) Connect channel 1 of the oscilloscope to measure the voltage across the capacitor. Connect the probe tips across the capacitor terminals (parallel connection).
   (2) Connect channel 2 of the oscilloscope to measure the input voltage from the function generator. Connect the channel 2 probe tips across the output of the function generator.
   (3) Turn on the function generator and the oscilloscope.
   (4) Adjust the Volts/division and Time/division knobs on the oscilloscope to display the waveform clearly. Aim to see at least one full charging and discharging cycle on the screen.
   (5) Adjust the trigger settings on the oscilloscope (start with "Auto" trigger mode) to get a stable waveform display. You may need to experiment with trigger level and source if "Auto" trigger is not stable.
4. Waveform observation and recording:
   (1) Observe the waveform(s) on the oscilloscope screen.
   (2) (2 points) Record oscilloscope settings: Note down the Time/division and Volts/division settings used for each channel on the oscilloscope. Include these recorded settings in your report.
   (3) (5 points) Save oscilloscope screenshot: Save a screenshot of the oscilloscope display showing the square wave input (measured on channel 2) and the charging/discharging waveform across the capacitor (channel 1). Ensure the screenshot clearly shows the waveforms and the oscilloscope settings (Time/div, Volts/div). The screenshot should be done using the oscilloscope, and not through a photo using your smartphone. Include this screenshot in your lab report PDF.
   (4) (2 points) Estimate experimental time constant: From the oscilloscope display of the charging curve, estimate the experimental time constant τ_{exp}. Measure and report the time it takes for the capacitor voltage to rise to approximately 63% of its maximum (or fall to 37% during discharge). Record your estimated τ_{exp} and describe your estimation method in your report.

Measurement 2 *Measurement 2: Exploring sine wave response (qualitative frequency dependence)* 11 points

In this measurement, you will investigate how the voltage across the capacitor changes when the frequency of a sine wave input is varied, using the same RC circuit.

Equipment: Resistor ($10\,\mathrm{k\Omega}$), Capacitor ($0.1\,\mathrm{\mu F}$), Function generator, Oscilloscope (preferably dual-channel), Connecting wires and breadboard (optional).

Measurement procedure:

1. Function generator setup:
   (1) Change the function generator waveform from square wave to sine wave.
   (2) Keep the amplitude constant at $5\,\mathrm{V}$ peak-to-peak.
2. (4 points) Vary frequency and observe capacitor voltage:
   (1) Start with a low frequency: Set the function generator frequency to $100\,\mathrm{Hz}$.
   (2) Increase frequency in steps: Gradually increase the frequency of the sine wave input in steps. Suggested frequencies: $500\,\mathrm{Hz}$, $1\,\mathrm{kHz}$, $5\,\mathrm{kHz}$, $10\,\mathrm{kHz}$. For each frequency:
      (i) Observe the waveform of the capacitor voltage on the oscilloscope.
      (ii) Qualitatively observe and describe how the amplitude of the capacitor voltage waveform changes.
3. Screenshot and Amplitude Recording:
   (1) (3 points) Screenshots for frequency response: Choose *one* frequency from the lower range and *one* frequency from the higher range that clearly demonstrate the change in capacitor voltage amplitude you observed. For these two frequencies, save oscilloscope screenshots showing the sine wave input (measured on Channel 2) and the capacitor voltage (Channel 1). Include these two screenshots in your lab report PDF, clearly labeling the frequency for each.
   (2) (2 points) Record oscilloscope settings: For each of the two screenshots you saved, record the Time/division and Volts/division settings. Include these settings with the corresponding screenshots in your report.
   (3) (2 points) Amplitude measurement table: For a few selected frequencies (e.g., $100\,\mathrm{Hz}$, $1\,\mathrm{kHz}$, $10\,\mathrm{kHz}$), use the oscilloscope to measure and record the peak-to-peak voltage of the capacitor waveform. Create a table in your report listing these measured voltage values and the corresponding frequencies.

Analysis 1 *Analysis of Time-Varying RC Circuit Measurements* 13 points

In this analysis, you will analyze your observations from Measurements 1 and 2 to understand the time-domain and frequency-domain behavior of the RC circuit.

1. Measurement 1: Charging/Discharging with square wave:
   (1) (1 point) Waveform Shape: Describe the shape of the charging and discharging waveform you observed across the capacitor in Measurement 1 (from your oscilloscope screenshot). Does it resemble the expected exponential charging and discharging curves?
   (2) (1 point) Calculate the theoretical time constant $\tau_{theory} = RC$ for your RC circuit using the nominal values of the resistor and capacitor. Show your calculation, including units.

(3) (1 point) Compare your estimated experimental time constant τ_{exp} with the calculated theoretical time constant τ_{theory}. Calculate the percentage difference between them. Discuss possible reasons for any differences you observe.

(4) (1 point) Oscilloscope Settings: Report the Time/division and Volts/division settings you used for the oscilloscope screenshot in Measurement 1. Explain why these settings were appropriate for observing the charging and discharging waveforms.

2. Measurement 2: Sine wave frequency response:

   (1) (1 point) Qualitative frequency dependence: Describe your qualitative observations from Measurement 2 regarding how the amplitude of the capacitor voltage changed as you increased the frequency of the sine wave input. Summarize your observations across the range of frequencies tested.

   (2) (1 point) Low-Pass filter behavior: Based on your observations, does this RC circuit behave as a low-pass filter or a high-pass filter (or neither) for the voltage signal applied to the capacitor? Explain your reasoning. (Hint: Think about which frequencies are "passed" more effectively to the capacitor in terms of voltage amplitude).

   (3) (1 point) Screenshot comparison: Refer to the two oscilloscope screenshots you saved for Measurement 2 (for a lower and a higher frequency). Compare the amplitude of the capacitor voltage waveform in these two screenshots. Does this visual comparison support your qualitative description of the frequency dependence?

   (4) (2 points) Amplitude vs. Frequency table: If you measured and recorded the peak-to-peak capacitor voltage for different frequencies, present the table of frequency vs. measured voltage. Describe the trend in the measured voltages as frequency increases, based on the table.

   (5) (1 point) Oscilloscope settings for frequency response: Report the Time/division and Volts/division settings you used for the oscilloscope screenshots in Measurement 2. Were these settings appropriate for visualizing the waveforms at different frequencies?

3. (3 points) Reflection on Instrument Usage:

   (1) Briefly describe your experience using the function generator and oscilloscope in this lab.

   (2) What were the main functions you used on the function generator and oscilloscope?

   (3) What were the biggest challenges (if any) you encountered in using these instruments for the first time?

   (4) In what ways did using the oscilloscope help you understand the behavior of the RC circuit compared to just using a multimeter?

Learning outcomes

- Learn basic operation of function generators and oscilloscopes for circuit analysis.
- Generate square and sine wave signals using a function generator.

- Visualize and qualitatively measure time-varying voltages using an oscilloscope.
- Observe RC circuit charging/discharging with square wave input and relate to the time constant.
- Investigate the qualitative frequency response of an RC circuit to sine wave inputs (low-pass filter behavior).

References

[1] D. Halliday, R. Resnick, and J. Walker. *Fundamentals of Physics*. Fundamentals of Physics. John Wiley & Sons.