DRD3 Summer School - SPICE simulations

by Dan Weatherill

1 Simple RC Filter

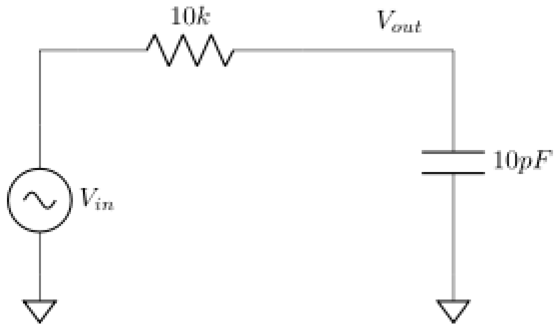

Figure 1. RC Filter Circuit

1. What do we expect this circuit to do (i.e. what is the behaviour of V_{out} as we change the frequency or amplitude of V_{in}?

2. What is the corner frequency (the point at which the transmitted power is half, equivalently the transmitted power reduces by 3dB) of this circuit? If the power goes down by half, how much does the voltage go down? What is the phase of V_{out} with respect to V_{in} at the corner frequency?

3. Draw the circuit into a Kicad schematic (use the SPICE library for the voltage source). Set the amplitude of V_{in} to 1V. For an AC sweep type simulation on this circuit, why does the value of V_{in} not matter physically? Why, therefore, is it useful to set $|V_{\text{in}}| = 1\,V$? Plot the transfer function (magnitude and phase)

4. Change the type of the V_{in} source to be a pulse, of a suitable length to see 3 time constants of the circuit (the time constant is RC) and with a rapid rise time. What do we expect to see?

5. Build the circuit on the breadboard. Use the sine wave generator to validate your expectations around the frequency response, and switch to a square wave generator to observe the time domain behaviour.

6. Run an FFT on the time domain response (input square wave) using the scope. What do we expect to see happen to the harmonic content of the signal?

2 Op amp integrator

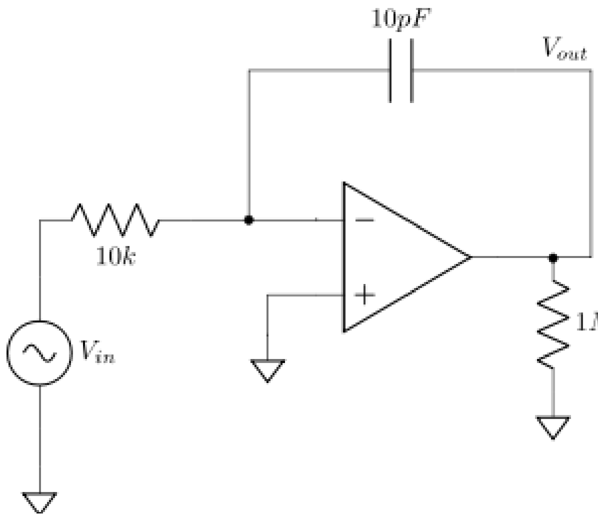

Figure 2. op-amp integrator schematic

1. Work out the transfer function of this circuit algebraically (you can leave out the 1M load resistor), either using complex impedance or with calculus, assuming a perfect op-amp.

2. Draw the circuit into a new KiCAD schematic, using the TL081 model for the op-amp (you may have to remap the pins of this SPICE model). Use the SPICE library "op amp" symbol rather than the TL081 symbol built into KiCAD. Don't forget the op amp also needs power supplies (not shown in the schematic above!)

3. Run an AC sweep simulation with a sinusoidal input and plot the transfer function (gain and phase). How does the simulated transfer function differ from the "ideal" op amp behaviour? Why is the "ideal" behaviour actually a bad thing in real life (from a stability point of view)? Save a graphic of this plot to refer to later.

4. Change the op-amp model to the TLE2071 (you may have to remap the pins again). Re-run your AC sweep simulation. How does the transfer function differ from the TLE081? What main property of the op amp is different that is affecting this result?

5. Change the input voltage to a square/pulse signal and increase its size to be much larger (e.g. +− 10V). Have the new pulse source also have an AC magnitude of 10V. Run the AC sweep simulation again, and also run a transient simulation with the new pulse. What behaviour does the transient simulation reveal that is not modelled accurately by the AC sweep?

6. Run the FFT analysis on your transient simulation. Can you see the effects of the effect from question 5 in this FFT? (Try changing the amplitude of the input voltage pulse and re-running the simulation to see the difference)

7. Build the circuit on your breadboard using the TLE2071 op-amp (you will not need the 10M load resistor on the breadboard). Experiment with putting in several different types of functions from the signal generator, and verify that the integrator works as expected.

3 Charge Sensitive Amplifier

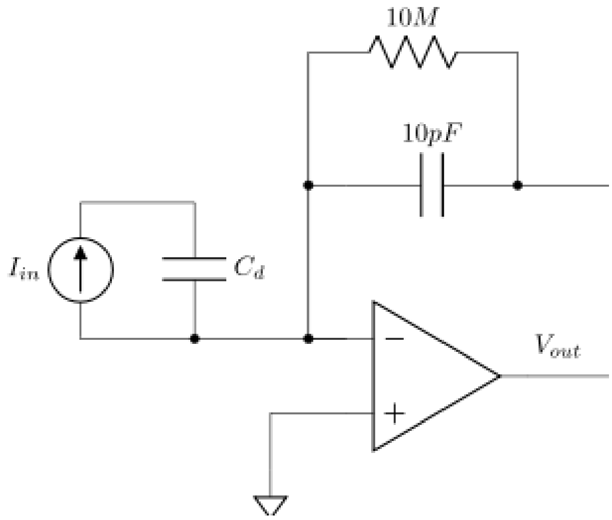

Figure 3. Schematic of Charge Sensitive Amplifier

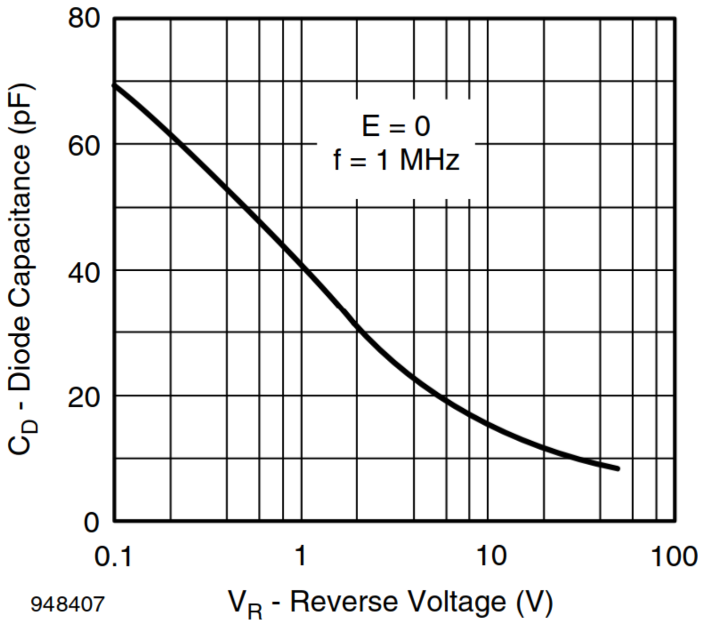

Figure 4. Bias voltage vs capacitance of the BPW34 photodiode

1. Draw the CSA circuit into a new KiCAD schematic (or modify your previous op-amp integrator). Use the TLE2071 op amp model.

2. Do a calculation to estimate how much current a minimum ionizing particle will deposit into the BPW34 photodiode (discuss & ask questions!) and over what timescale. Hints: estimate the thickness of the diode imagining it's fully depleted and approximates a perfect parallel plate capacitor. Its area is 1mm^2 and the relative permittivity of silicon is $\varepsilon_r \approx 11.7$. Imagine the induced current all comes from electrons (forget holes for now), and that the primary particle always gets absorbed exactly at the centre of the detector. Note from Schokley-Ramo theorem that the time to collect the charge is exactly equal to the time for

an electron to transit to the edge of the photodiode from the centre. The mobility of silicon at room temperature is roughly $\mu \approx 1350\,\text{cm}^2\,\text{V}^{-1}\text{s}^{-1}$. Set up your I_{in} source as a pulse current source to roughly simulate this

3. Run an AC simulation and plot the transfer function with the value of C_d set to 70 pF. Add a slider to change the value of C_d . Experiment with values of C_d between 70pF and 10pF and see how it affects the transfer function.

4. Run a transient simulation with the current pulse and observe the shape of the output voltage pulse from the circuit.

5. Modify your input current source to be a DC source. Estimate the amount of current you expect from the room lighting through the diode (assume diode area is 1mm^2, room lighting has an incident flux of 0.05W cm^{-2}, and that the spectral sensitivity of the BPW34 photodiode is 0.6 A W^{-1} averaged over the spectrum of the room lights. Run a DC operating point analysis with this current source and observe the output DC voltage level

6. Run a DC sweep analysis on your input current source between 10% and 100% of room lighting conditions. Plot the input current vs the output voltage. At what point does the output become non-linear? Why does this happen?

7. Modify your breadboard op-amp integrator circuit to incorporate the BPW34 photodiode with a 15V reverse bias (Use the LCR meter and check with demonstrators before turning on the circuit to make sure the diode is placed the right way round!)

8. Use your CSA to observe the PWM frequency of the LED room lights.

9. Use your CSA and the TV remote to decode how to turn on Disney+ on the lab television.

10. Carefully add black tape and potassium salt to the top of your photodiode. Set up your scope with a reasonable trigger level and wait until the end of the lab session to see if we can see a beta particle (or cosmic ray muon).

4 Analytic Simulation of CSA (while waiting for betas / muons)

You will be provided with a python script that runs a SLiCAP simulation of the charge sensitive amplifier. Use it to display the transfer function of the more complete photodiode model included.

With direction from demonstrators, change the model to be more simple (take limit as shunt resistance goes to infinity, set contact resistance to zero).

Substitute in the symbolic first-order response of a fully compensated op-amp:

$$A_v(\omega) = \frac{A_0}{1 + j\frac{\omega}{\omega_c}}$$

Taking the magnitude of the resulting gain expression, consider the effects of detector capacitance and op amp gain bandwidth product on the ability to detect cosmic rays with this circuit. Consider also the effect on stability of the phase expression.

5 (Optional, if time) Use XSPICE / B-source element to simulate comparator

In discussion with demonstrator, add an ideal comparator using a behavioural voltage source. Also add an ideal comparator using the built in XSPICE comparator element. Plot the comparator output as well as the analog output of your CSA.