Lab# 4 – Linear power supply

Objectives:

- Prototype and troubleshoot an over current protection for a linear regulator power supply
- Prototype and troubleshoot a hysteresis op-amp circuit

Material: Simulated on Mindi

To hand in to Team Assignment

1- This document with the answers and measures. Copy-paste screenshots when required.
2- You provide comments to all screenshots
3- Upload the wxsch project file for part2

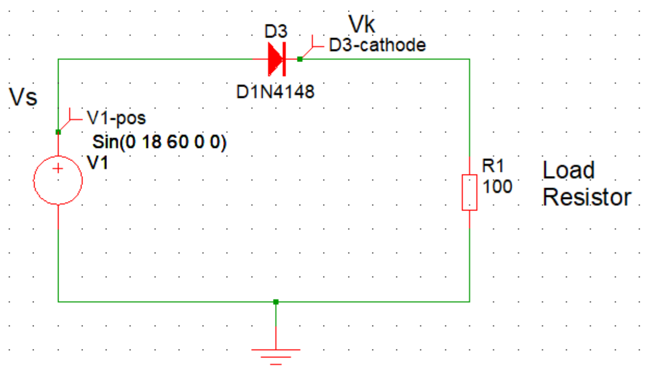
Lab preparation: Fill in the calculate column for all tables

Lab work

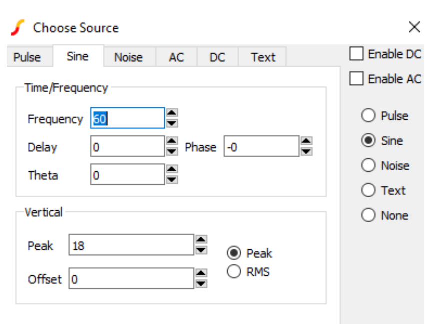
Part 1: Linear power supply

- Set the simulator analysis to:
  - Transient
  - Stop time to 150mS

- Wire following half wave rectifier.



Vs must be set as follows: 60Hz and 18V peak



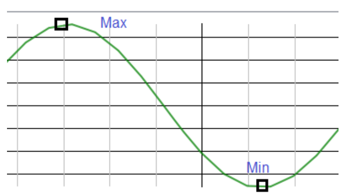
- Take a screenshot of $\mathbf{V_S}$ and $\mathbf{V_K}$. DON'T stack on top of one another.
- Fill up the following measure table in *steady state mode:

Table 1a Ripple voltage and average voltage

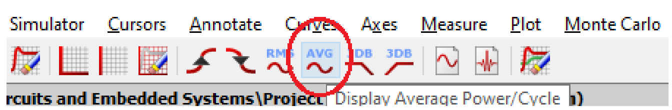
	$\mathbf{V_S}$	$\mathbf{V_K}$
$\mathbf{V_{PP}}$	35.34V	16.53V
$\mathbf{V_{DC}}$	-12.61mV	5.30V

*steady state mode: when the waveform stabilizes after about 2 to 3 cycles.

Hints: to measure Vpp, you must move the cursor on the max value and then on the min value. The peak to peak value is the difference between the min and max values.

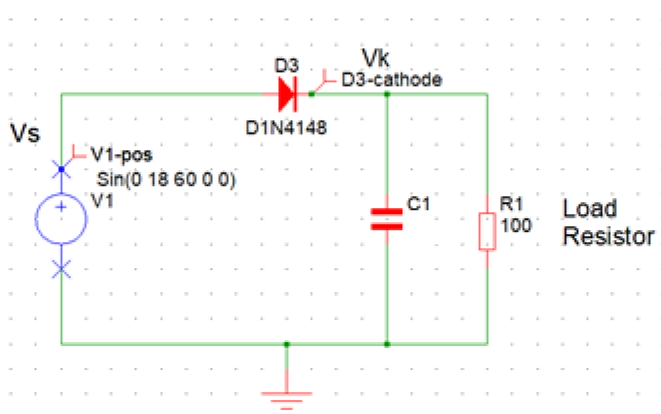


To measure V_{DC} value, click on AVG:



Add a filter capacitor to the circuit. Increase its value until is $\mathbf{V_{PP}}$ 1V or less.
Give its value:

2'000uF



- Take another screenshot of $\mathbf{V_S}$ and $\mathbf{V_K}$. DON'T stack on top of one another.

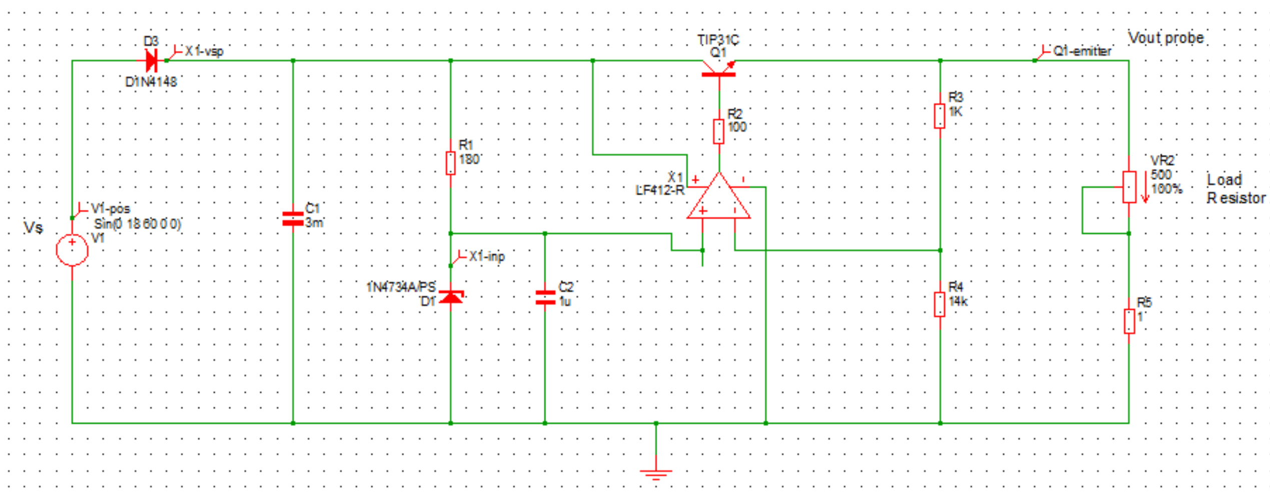
- Fill up the following measure table in steady state mode:

Table 1b Ripple voltage and average voltage at the load

	V_{LOAD}
V_{PP}	1V
V_{DC}	14.69V

- Now, replace the load resistor by a voltage regulator – use the previous lab circuit:

  1. Inside Mindi, open the previous lab project
  2. Copy the whole circuit
  3. **Paste it in your current project**



- For now, the load must be set at 100 Ohms. Fill up the following table.

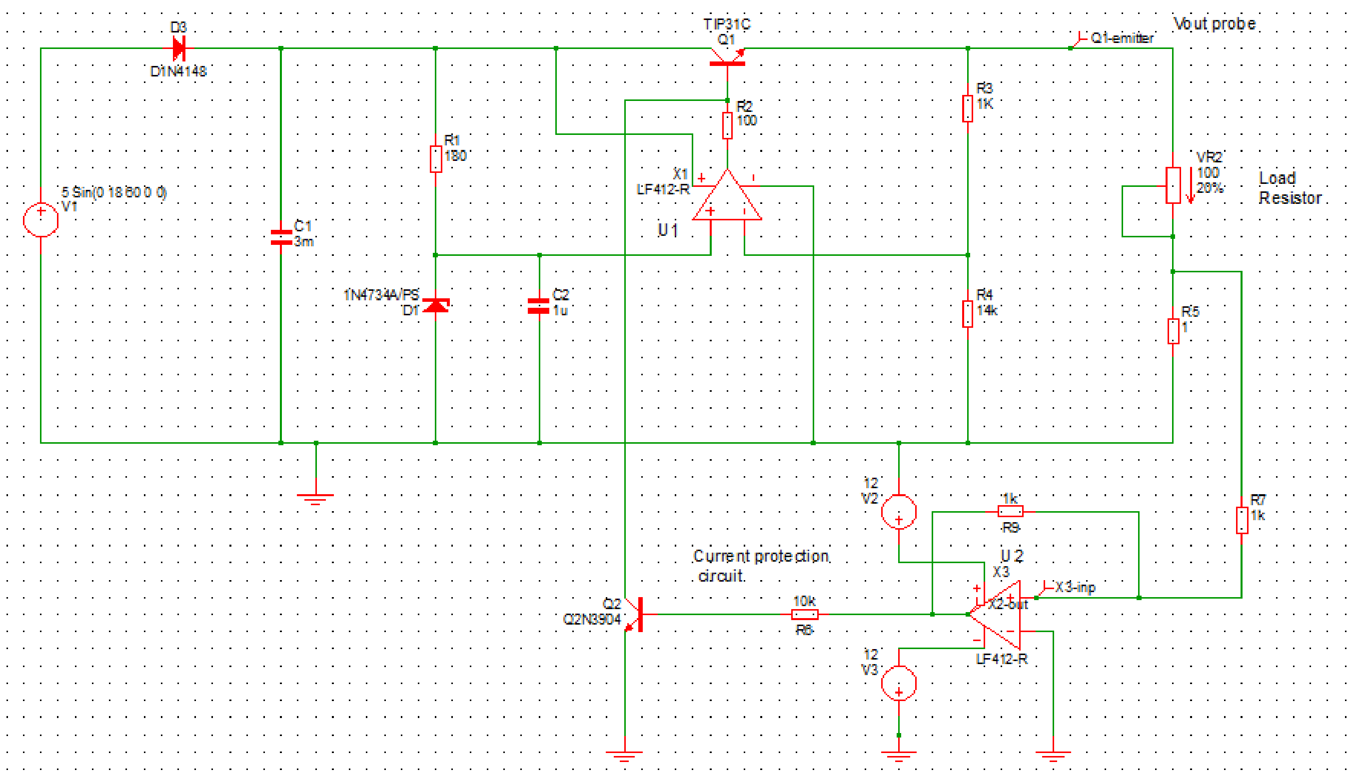
Table 2 Ripple voltage and average voltage

	V_S	V_{C1}	V_{OUT}	V_{ZENER}
V_{PP}	35.76V	500mV	0V	0V
V_{DC}	76.46mV	14.53V	5.92V	5.54V

Part 2: Set up the current protection circuit

In this part, the system is improved to prevent overcurrent at the load. A circuit is added to limit the current.

Add and wire the following current protection power supply. At first set **R_{LOAD}** at 100 Ω



Calculate R9 for a current limit of 200mA. The measuring resistor's value is 1 Ohm.

Assume a voltage drop of about 1.7 V for the LF412-R Op-Amp:
+V_{out} max = Vcc – 1.7V

$$V_{UTP} = \frac{R7}{R9} * (12V - 1.7V) = 200mV * 1\Omega$$

$$200mV * 1\Omega = \frac{1k\Omega}{R9} * 10.3V$$

$$200mV = \frac{10.3k\Omega}{R9}$$

$$R9 = 51.5k\Omega$$

When the overcurrent happens, a hysteresis comparator must latch and turn on a transistor to shut down the main current.

What should be the load resistance that triggers the current limit?

The observed load resistance that triggers the current limit is around 25Ω. The calculated load resistance that triggers the current limit can be shown below:

*Note: Current limit is abbreviated to C.L. below.

$$R_{C.L.} = \frac{V_{OUT}}{I_{C.L.}} = \frac{6V}{200mA} = 30\Omega$$

In other words, any load with a resistance of 30Ω or below will trigger the hysteresis comparator and shut-down the circuit.

- Test the current limit circuit by loading with different values:

Table 3 Circuit with different loads

R_{LOAD} (Ω)	70	35	25
Overloaded (Yes – No)	No.	No.	Yes.

Part 3: Snapshot measures with/without overcurrent

- Fill in the following table for **R_{LOAD}** = 60 Ohms.

Assume a voltage drop of about 1.7 V for the LF412-R Op-Amp:
$+V_{out}$ max = Vcc – 1.7V

Table 4 Over current not triggered

Variable	Measured Value	Calculated value
I_L (mA) Load current	97.68mA	$I_L = \frac{V_{OUT}}{R_L} = \frac{6V}{60\Omega} = 100mA$
Voltage across 1Ω resistor (mV)	97.49mV	$V_{R_5} = \frac{R_5}{R_L + R_5} * V_{OUT} = \frac{1\Omega}{60\Omega + 1\Omega} * 6V = 98.3mV$
Vin+ X3	-102.84mV	$-V_{OUT(MAX)} = -V_{CC} + 1.7V = -12V + 1.7V = -10.3V$ $V_{in+(X3)} = (V_{R_5} + (-V_{OUT(MAX)} - V_{R_5})) * \frac{R_7}{R_7 + R_9} = (98.3mV + (-10.3V - 98.3mV)) * \frac{1k\Omega}{1k\Omega + 51.5k\Omega} = -99.76mV$
Vin- X3	0V	$0V\ (GND)$
Vout X3	-10.35V	$V_{OUT(X3)} = 1.7V - V_{cc} = 1.7V - 12V = -10.3V$
Vb Q2	-10.35V	$V_{b(Q2)} = V_{OUT(X3)} = -10.3V$
$V^+ - V^-$ X1	5.569V-5.561V = 8mV	$V_{+(X1)} = V_{Zener} = 5.6V$ $V_{-(X1)} = \sim V_{+(X1)} = \sim 5.6V$ $V_{diff} = V_{+(X1)} - V_{-(X1)} = 5.6V - \sim 5.6V = \sim 0V$

- Fill in the following table for **R_{LOAD}** = 20 Ohms

Table 5 Over current triggered

Variable	Measured Value	Calculated value
I_L (mA) Load current	0A	$I_L = \frac{V_{OUT}}{R_L} = \frac{0V}{60\Omega} = 0A$
Voltage across 1Ω resistor (mV)	0V	$V_{R_5} = \frac{R_5}{R_L + R_5} * V_{OUT} = \frac{1\Omega}{60\Omega + 1\Omega} * 0V = 0V$
Vin+ X3	213.18mV	$+V_{OUT(MAX)} = +V_{CC} - 1.7V = +12V - 1.7V = 10.3V$ $V_{in+(X3)} = (V_{R_5} + (+V_{OUT(MAX)} - V_{R_5})) * \frac{R_7}{R_7 + R_9} = (0V + (10.3V - 0V)) * \frac{1k\Omega}{1k\Omega + 51.5k\Omega} = 196.19mV$
Vin- X3	0V	$0V\ (GND)$
Vout X3	11.17V	$V_{OUT(X3)} = V_{cc} - 1.7V = 12V - 1.7V = 10.3V$
Vb Q2	721.55mV	$V_{b(Q2)} = 0.7V\ (forward\ biased)$
V^+ - V^- X1	5.645V – 0V = 5.645V	$V_{+(X1)} = V_{Zener} = 5.6V$ $V_{-(X1)} = 0V$ $V_{diff} = V_{+(X1)} - V_{-(X1)} = 5.6V - 0V = 5.6V$

You must give a demo before leaving the classroom.

After lab questions

Comment table 2 at the end of part1. Did you achieve the intended goal?

In the end, the goal was achieved. The linear power supply was able to convert the AC signal and output a regulated DC voltage (at around 6V with no ripple). It was able to maintain that same output throughout various loads. Furthermore, the power supply was able to protect itself when a load became too excessive (thanks to the additional hysteresis circuit).

Why use a hysteresis comparator in this lab? Why not use a normal comparator?

The use of a hysteresis comparator will be a better option to use over a normal comparator because the hysteresis comparator is immune to noise and has a greater upper and lower threshold so noise will not affect the circuit behaviour. With a normal comparator, it is easily affected by noise and circuit behaviour will be erratic and unpredictable because of unwanted noise.

Explain the values of Vb Q2 in table 4 and table 5

In table 4, the value of Vb is -10.35V because the hysteresis circuit is not triggered and therefore Q2 is not forward-biased (shutoff value is open). When the hysteresis circuit is triggered, the value of Vb is around 0.7V because the base-emitter junction is forward-biased (shutoff value is closed) and a sufficient base current is applied to Q2.

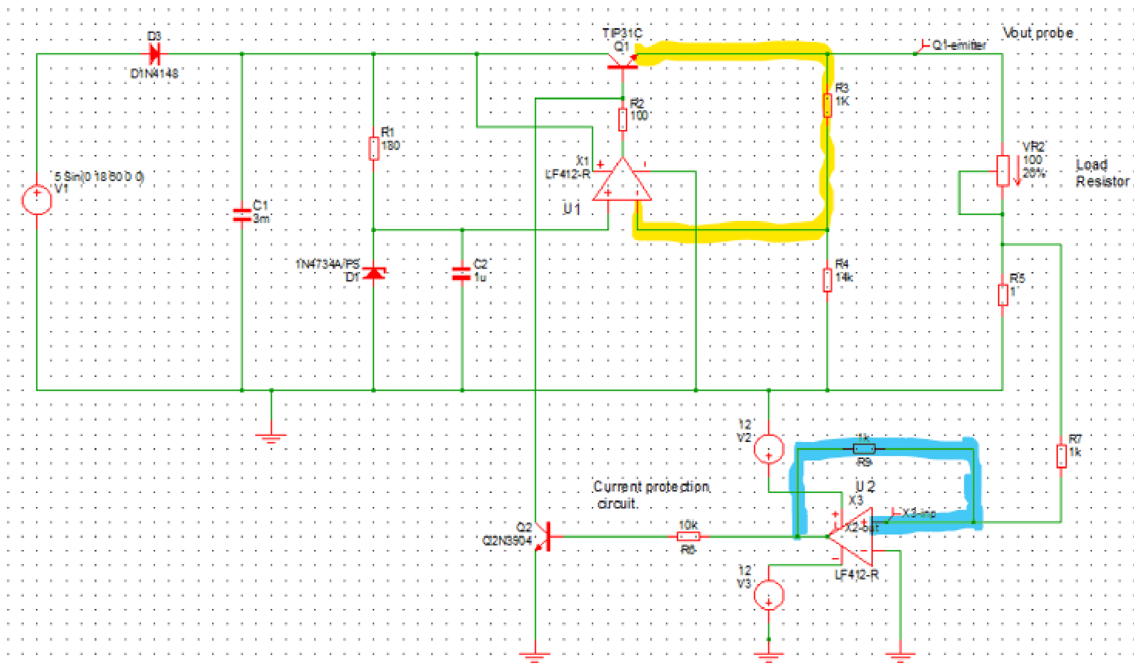
For the hysteresis comparator, find V_{LTP} and V_{UTP}.

$$+V_{OUT(max)} = 12V - 1.7V = +10.3V$$
$$-V_{OUT(max)} = -12V + 1.7V = -10.3V$$
$$V_{UTP} = \frac{R_7}{R_7 + R_9} * \left(+V_{OUT(MAX)}\right) = \frac{1k\Omega}{1k\Omega + 51.5k\Omega} * (+10.3V) = 196.19mV$$
$$V_{LTP} = \frac{R_7}{R_7 + R_9} * \left(-V_{OUT(MAX)}\right) = \frac{1k\Omega}{1k\Omega + 51.5k\Omega} * (-10.3V) = -196.19mV$$

What is the use of Q2? Be specific.

The use of Q2 is part of the non-inverting hysteresis circuit and behaves like a shut-off valve when the hysteresis circuit gets triggered by the current limit (measured through R5 – low ohms resistor). When triggered, the circuit will apply a positive voltage to Q2 and sufficient base current (base-emitter junction = 0.7V) and Q2 will in turn make Q1 no longer output a voltage.

Identify all feedbacks in the circuit. You must use a high liner to identify them. Also, say whether it is a positive or a negative feedback.



Yellow: negative feedback going into X1 and Blue: positive feedback going into X3.