AC to DC Converters

ECE 320 Electronics I (Digital Electronics)

Jake Glower - Lecture #8

AC to DC Converters

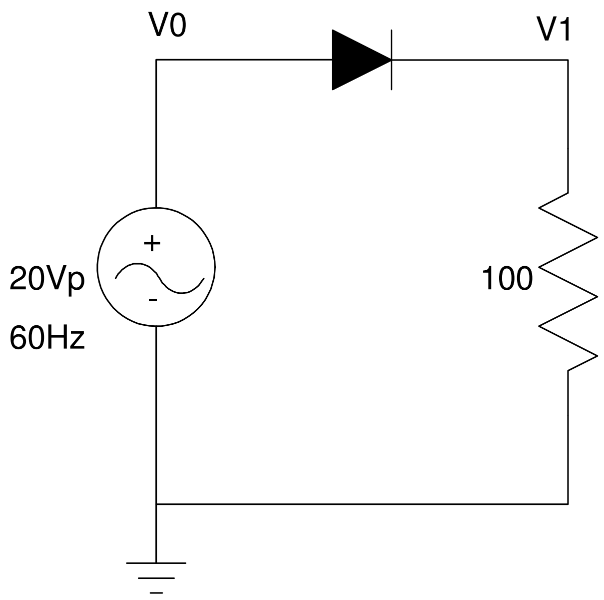
- Convert 60Hz AC to a DC signal.
- AC travels more efficiently over power grids than DC (transformers don't work at DC).
- DC works better for microcontrollers. (They don't like being turned on and off 60 times a second.)

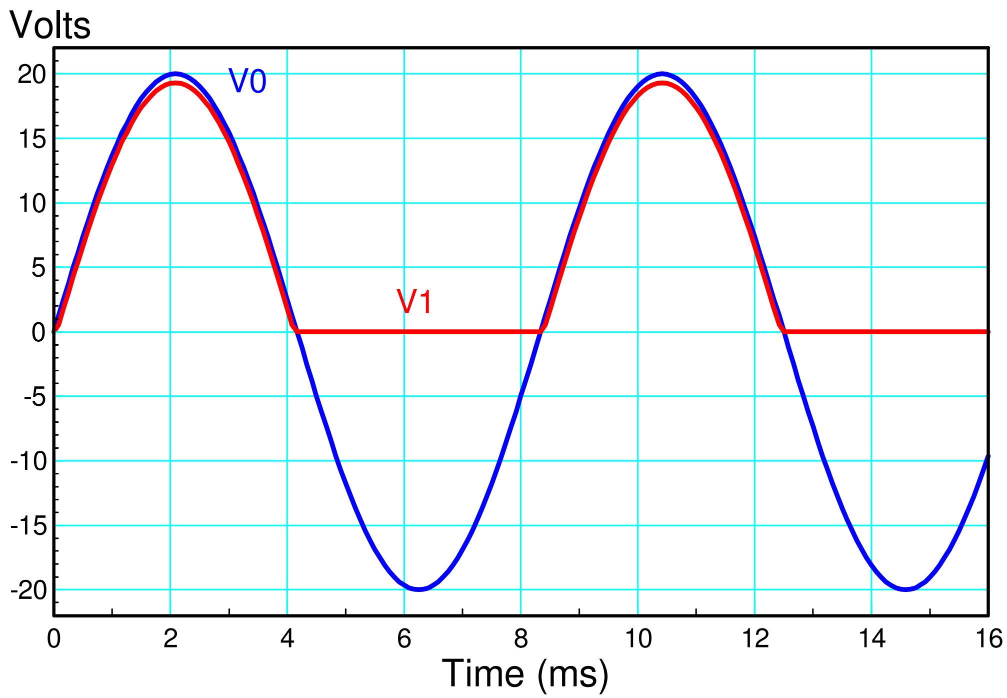
The heart of an AC to DC converter is a rectifier

- 1/2 Wave Rectifier
- Full-Wave Rectifier

Half-Wave Rectifiers:

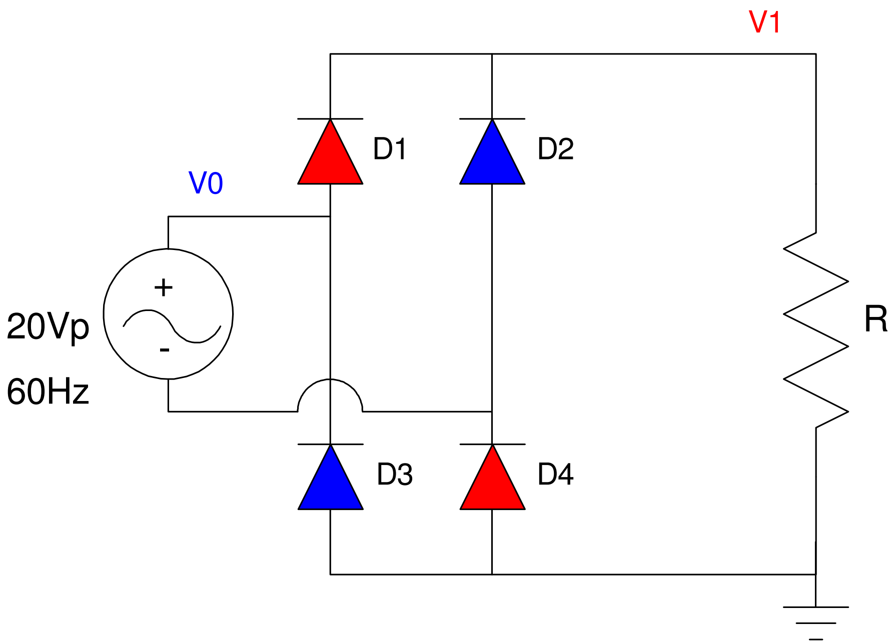
- It's simple: it only uses a single diode,
- You only lose 0.7V through the diode,
- The source (V0) and the load can share a common ground, and
- The frequency of the ripple at V1 is 60Hz

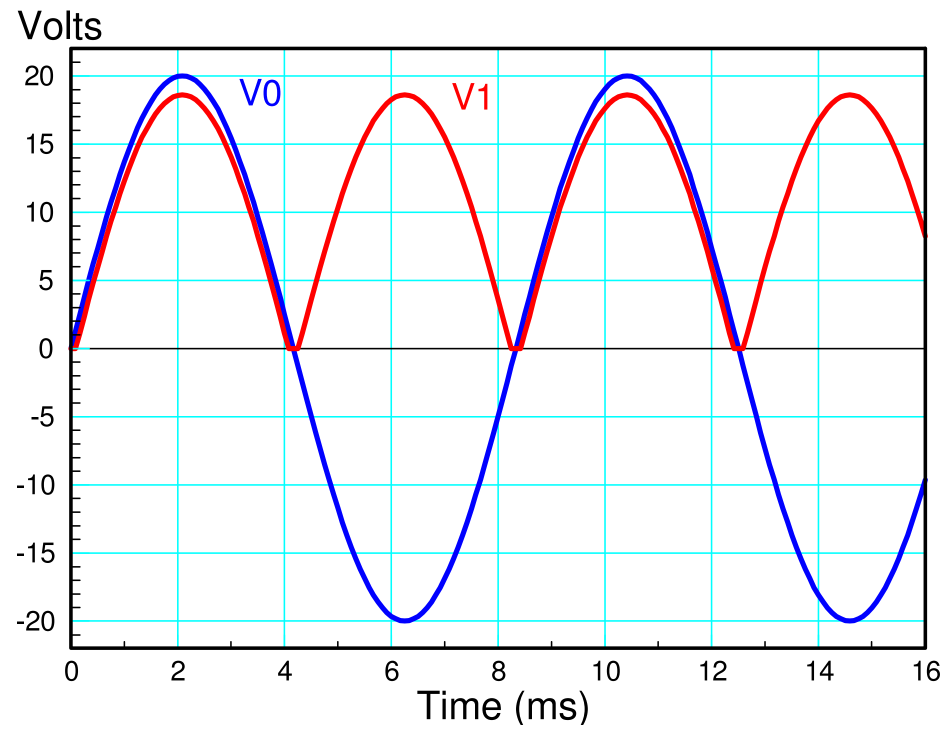




Full-Wave Rectifier

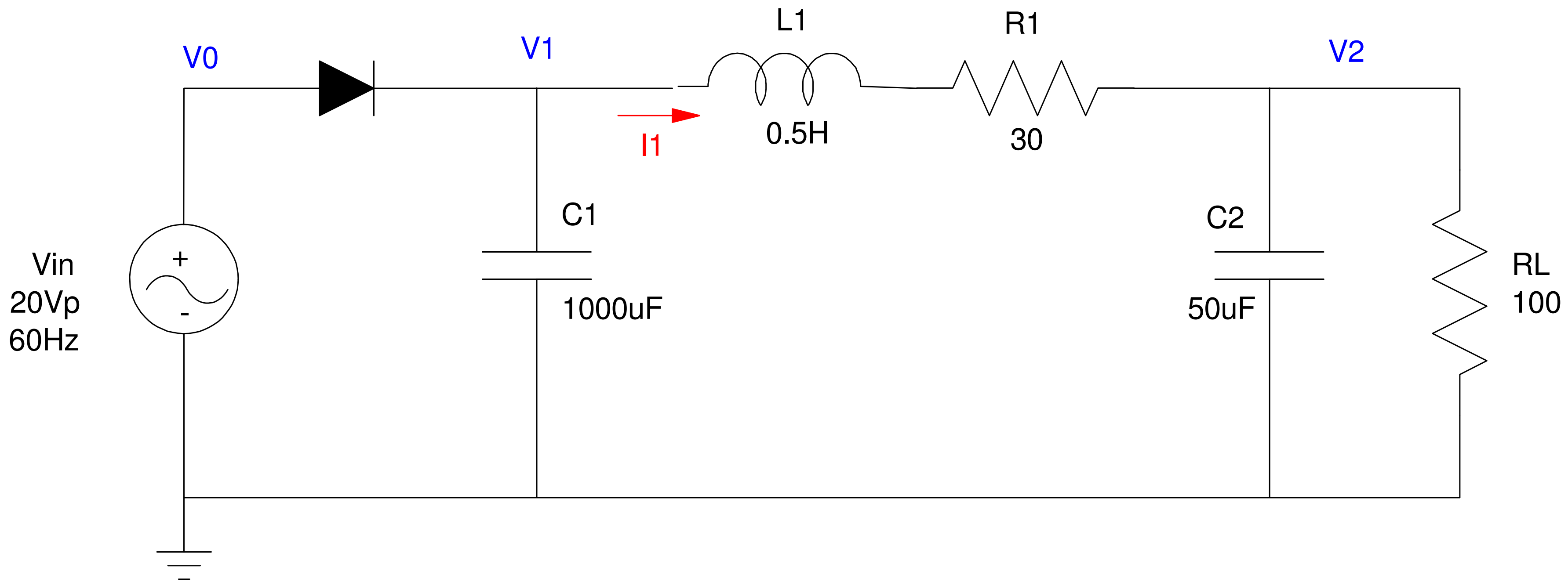
- A little more complex using four diodes
- You lose 1.4V from the source: any path passes through two diodes,
- The source and load cannot share a common ground
- The frequency of the ripple is 120Hz (twice the input frequency)





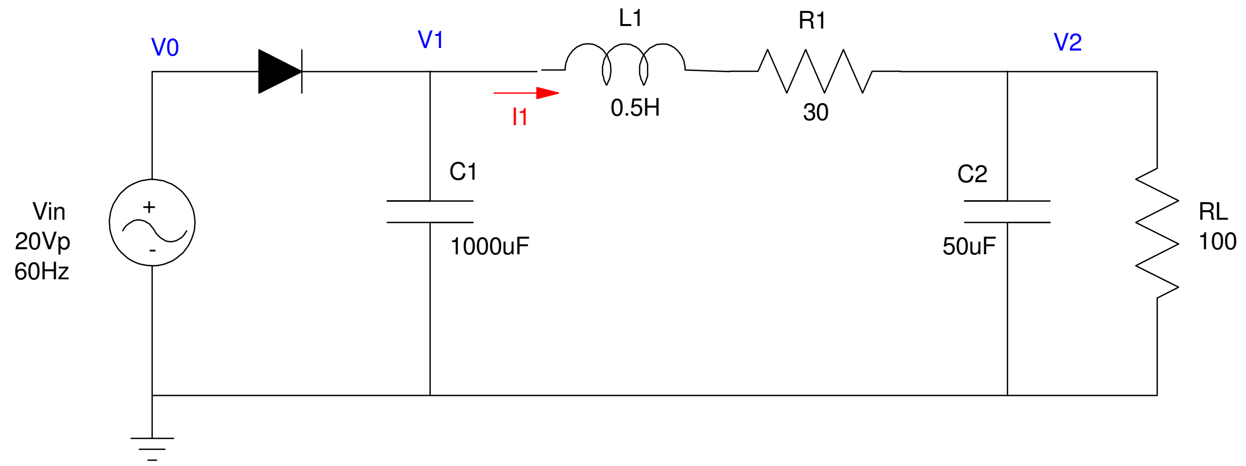
AC to DC Converters: Analysis

- Diode = 1/2 Wave Rectifier
- C1 is a battery: Stores energy for when the diode is off
- L1 and C2 are filters: they reduce the ripple at 60Hz



Step 1: DC Analysis.

- C1 will charge up to 19.3V
- $I_1 \approx \frac{19.3V}{30\Omega + 100\Omega} = 148.5mA$



Step 2: AC Analysis for V1.

$$I = C\frac{dV}{dt}$$

$$148.5mA = 1000\mu F \frac{dV}{1/60s}$$

$$dV = 2.4744Vpp$$

$$V_1(DC) = 19.3V - \frac{1}{2}(2.4744V_{pp})$$

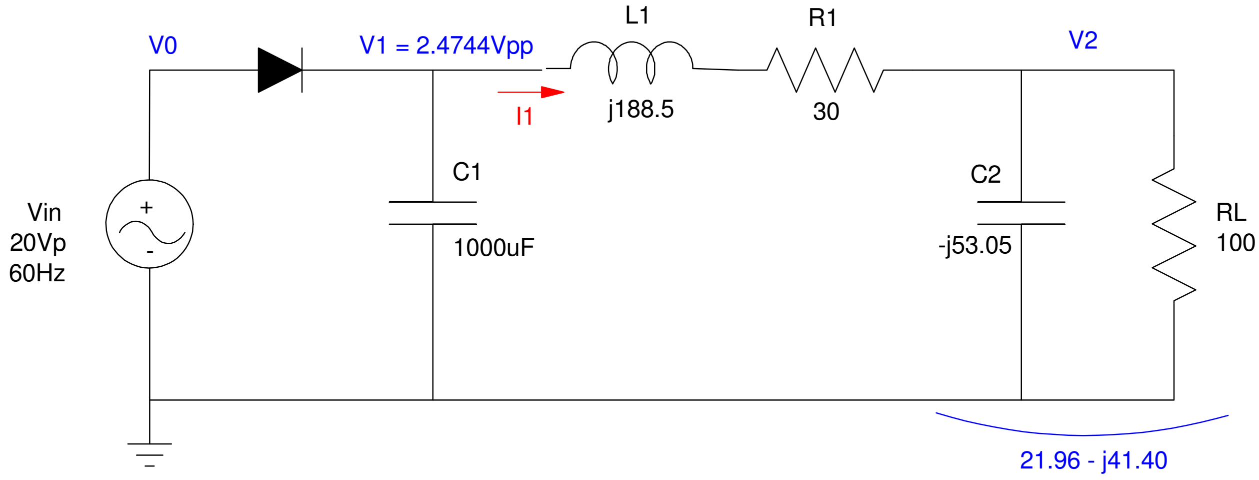
$$V_1(DC) = 18.06V$$

$$V_1(AC) = 2.4744V_{pp}$$

Step 3: DC Analysis for V2

$$V_2 = \left(\frac{R_L}{R_L+R_1}\right)V_1 = \left(\frac{100}{100+30}\right)18.06V$$

$$V_2 = 13.8945V$$



Step 4: AC analysis for V2

$$V_1 = 2.4744 + j0$$

$$\omega = 377 \frac{rad}{sec}$$

$$L \rightarrow j\omega L = j188.5\Omega$$

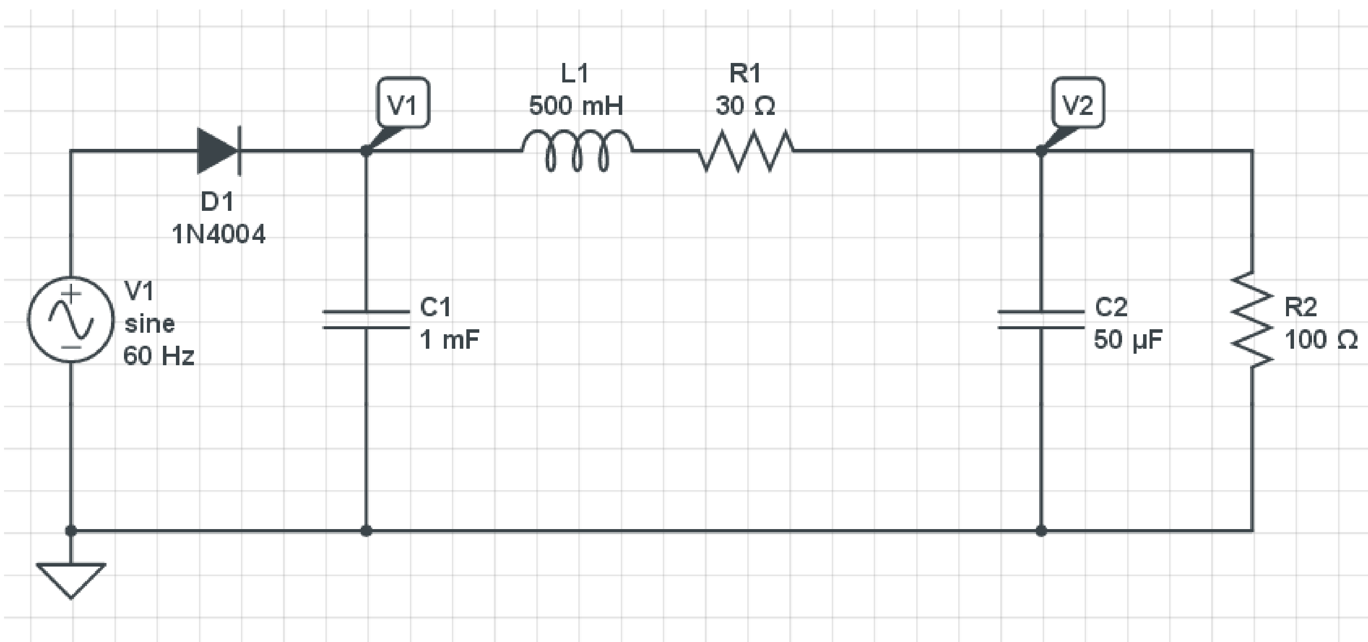
$$C_2 \rightarrow \frac{1}{j\omega C} = -j53.05\Omega$$

$$V_2 = \left(\frac{21.96-j41.40}{(21.96-j41.40)+(30+j188.5)}\right)(2.4744V_{pp})$$

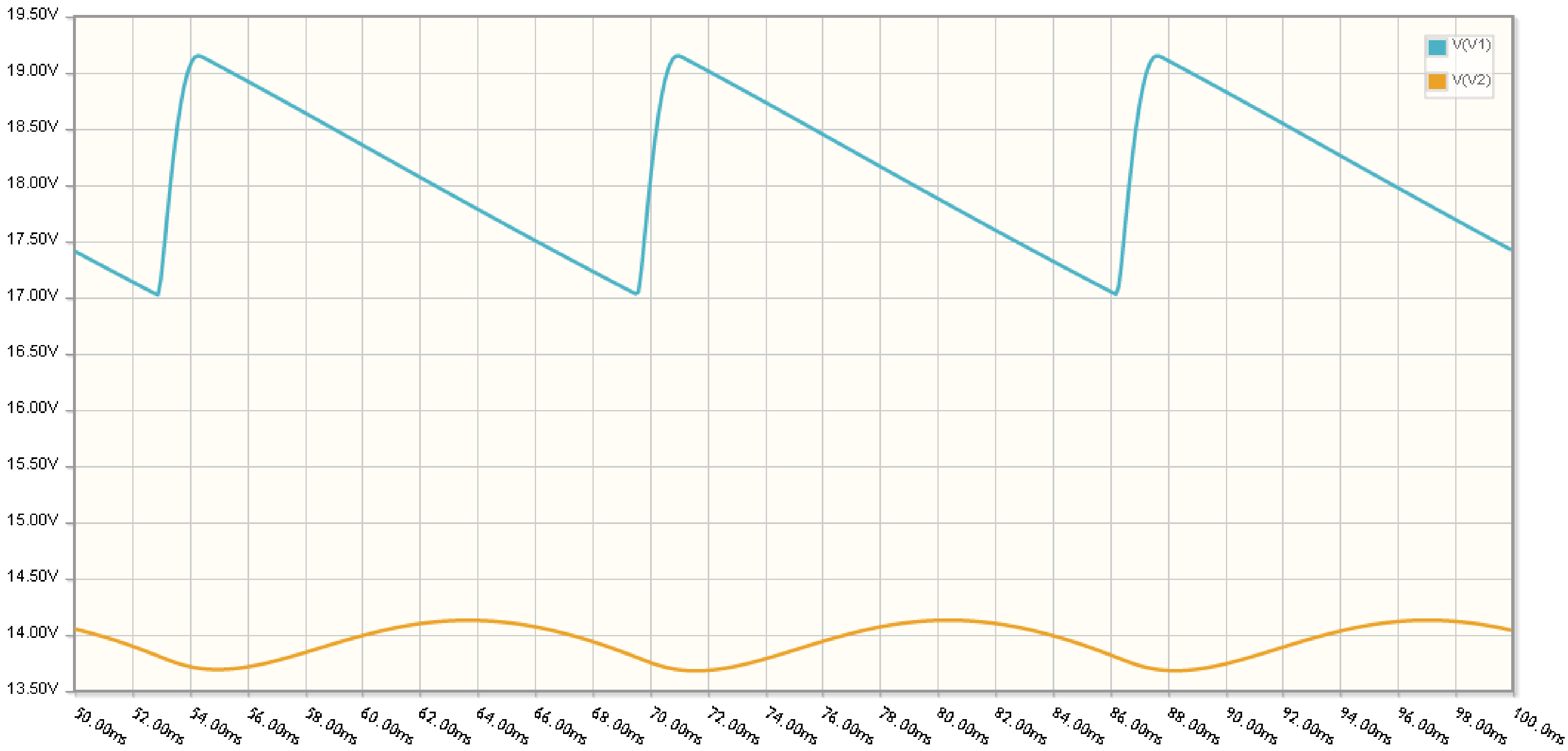
$$|V_2| = 0.7433V_{pp}$$

Checking in CircuitLab, the results are

	V1		V2	
	DC	AC	DC	AC
Calculation	18.08V	2.4744 Vpp	13.8945V	0.7433 Vpp
CircuitLab	18.08V	2.110 Vpp	13.90 V	0.450 Vpp



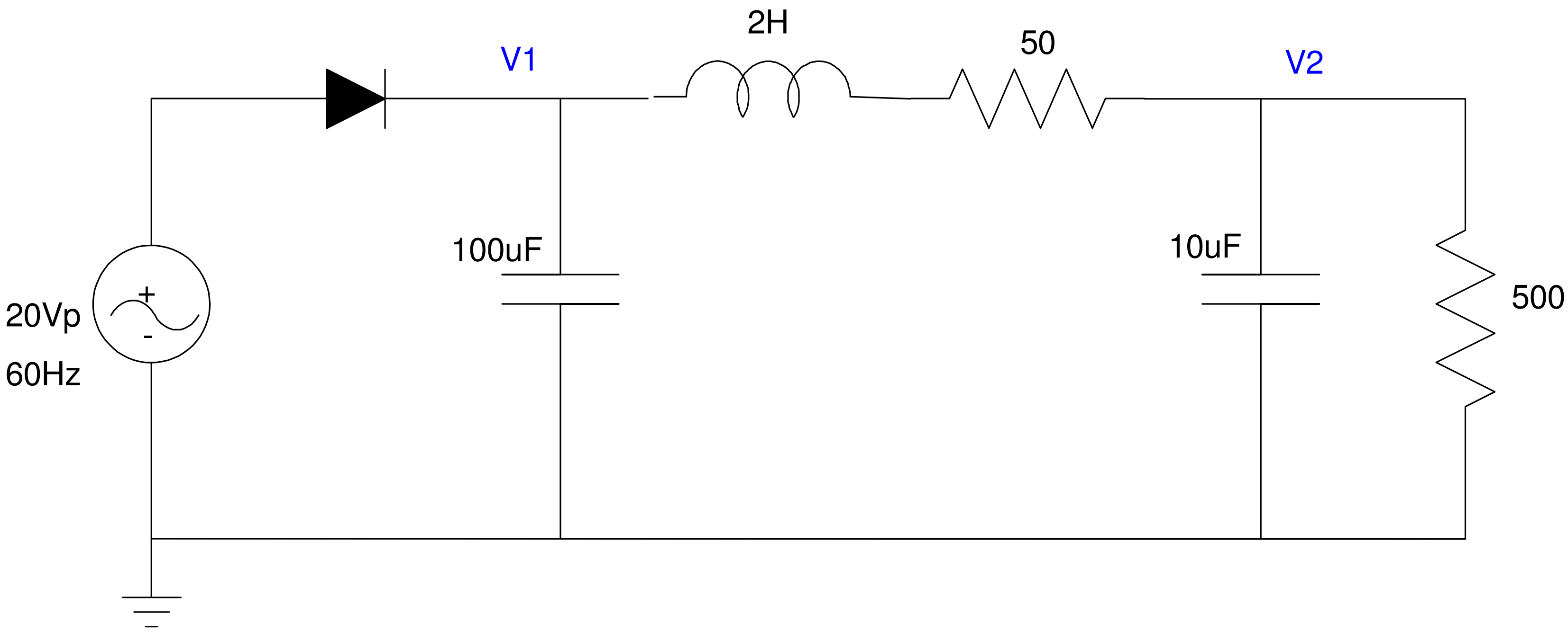
CircuitLab circuit for an AC to DC converter



Transient simulation for the AC to DC converter

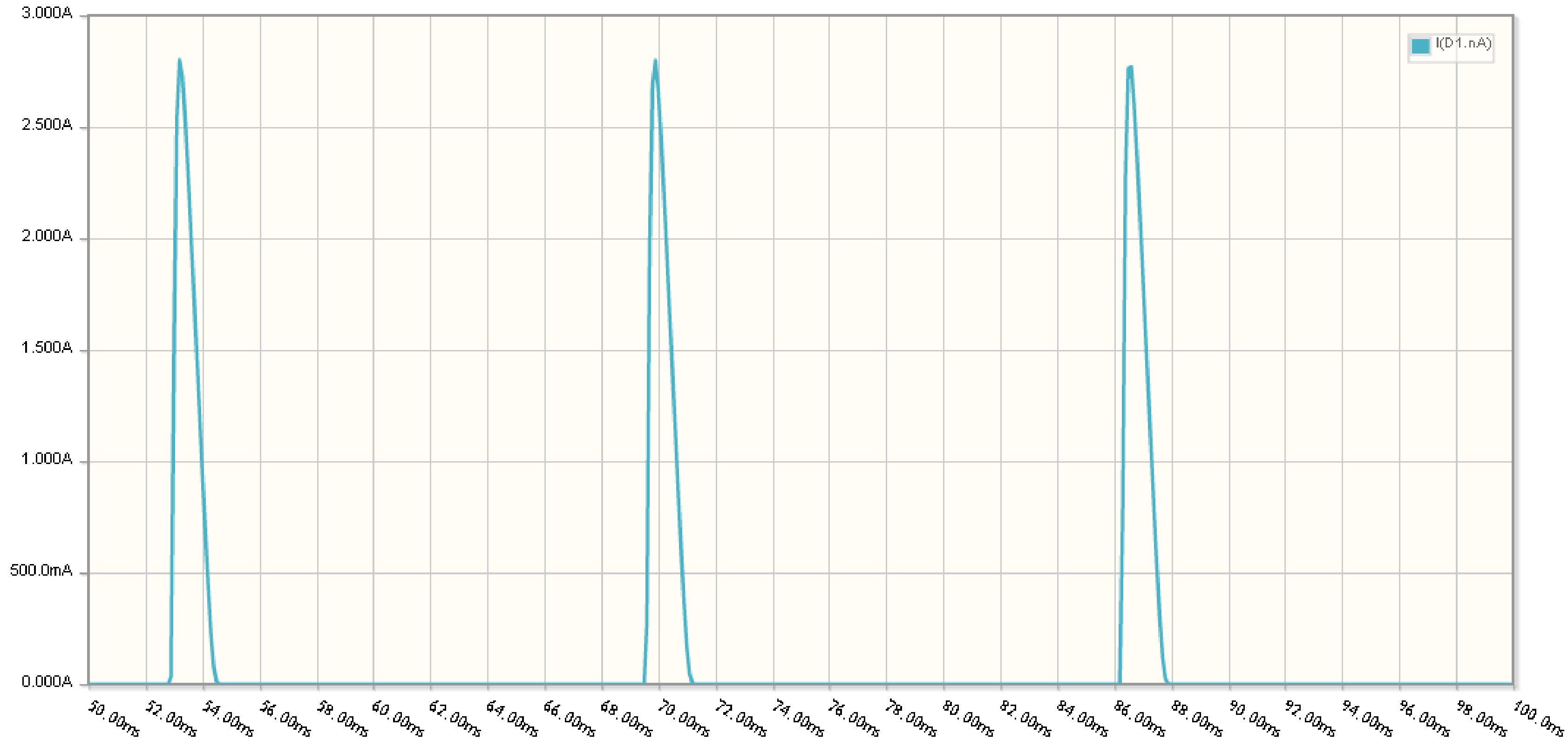
Handout

Determine the DC and AC voltages at V1 and V2. Assume ideal silicon diodes



Problem: Current Spikes

- Your AC power supply needs to be able to deliver up to 3A peak.
- Spikes create losses in transformers
- Spikes can burn out neutral lines



Challenge:

Design an AC to DC converter which

- Draws clean 60Hz sinusoidal current from the source
- Provides clean DC current to the load
- Using only electronics
- With > 90% efficiency

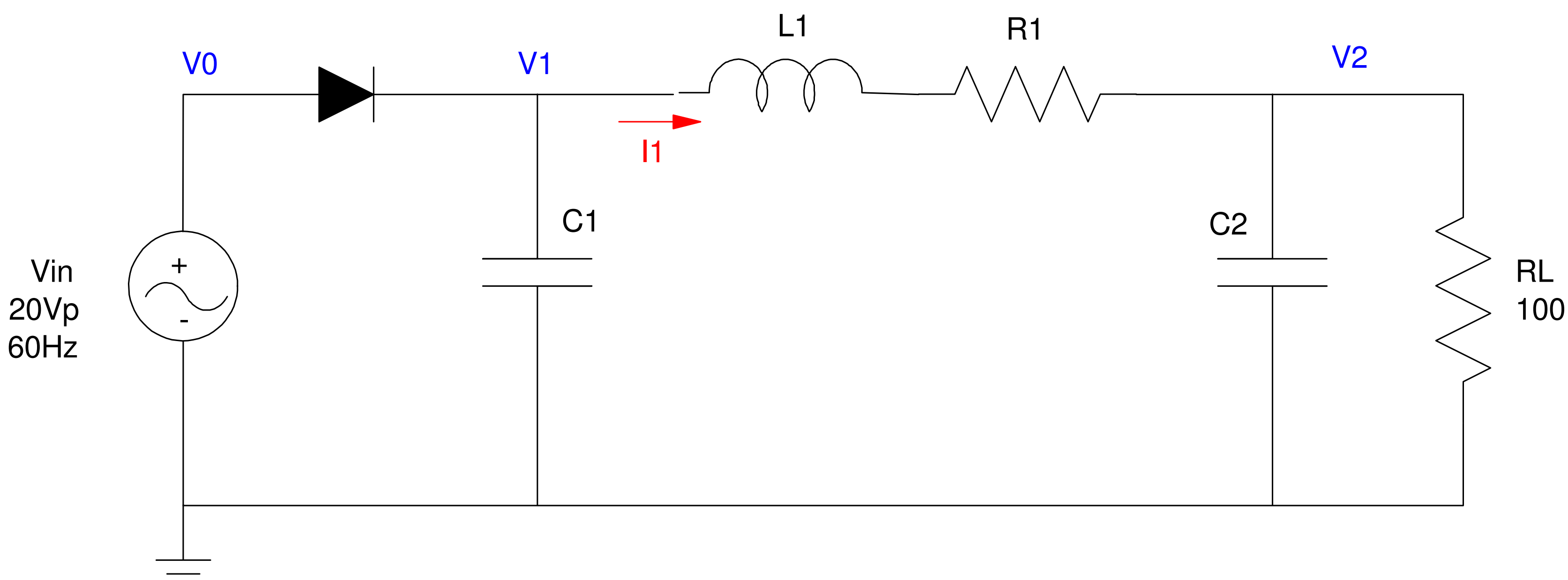
Whoever does this will be worth billions.

AC to DC Converters: Design.

Input: 60Hz, 20Vp sine wave capable of 500mA (i.e. a wall transformer)

Output:

- 100 Ohm resistor
- V1 = 1Vpp
- V2 = 100mVpp



Step 1: Pick your favorite rectifier: half wave of full wave.

- Full-wave requires smaller L1 and C2 since the frequency at V1 is 120Hz
- Half-wave can use a common ground for everything (V1 = 60Hz).

Step 2: Pick L1. Either set L1 = 0 (in which case C2 isn't needed) or pick L1 so that it's impedance is more than RL at 60Hz.

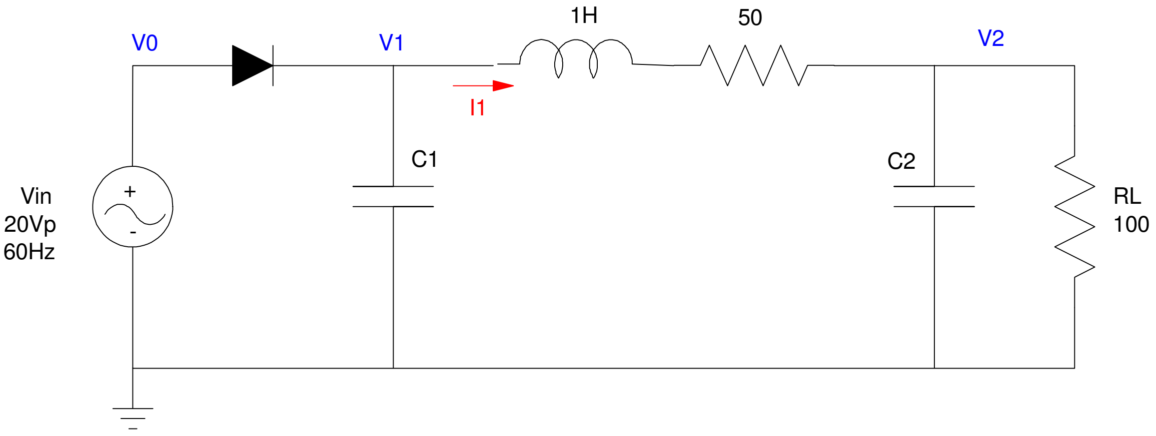
- Assume L1 reduces the ripple at V2 by 3x. This means

$$|j\omega L_1| \approx 3 \cdot R_L$$

$$L_1 \approx 795.7mH$$

C-24X inductor from Digikey:

- L1 = 1H
- R1 = 50 Ohms (from the data sheets)



Step 3: Determine C1: V1pp = 1.00Vpp

The current, I1, is

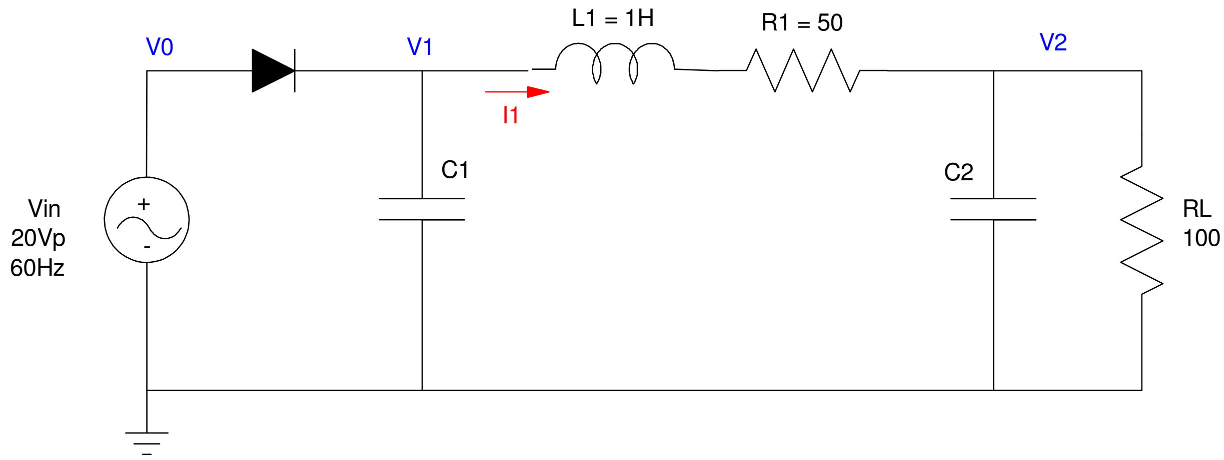
$$\max(V_1) = 19.3V$$

$$V_1(AC) = 1V_{pp}$$

$$V_1(DC) = 19.3V - \tfrac{1}{2} \cdot 1V_{pp}$$

$$V_1(DC) = 18.8V$$

$$I_1 \approx \frac{18.8V}{150\Omega} = 125.3mA$$



This produces a ripple of

$$I_1 = C_1 \frac{dV_1}{dt}$$

$$125.3mA = C_1 \frac{1V_{pp}}{1/60s}$$

$$C_1 = 2089\mu F$$

Step 4: Determine C2 for V2 = 100mVpp

Assume C2 = 0

$$V_2 = \left(\frac{100}{100+(50+j377)}\right) 1V_{pp}$$

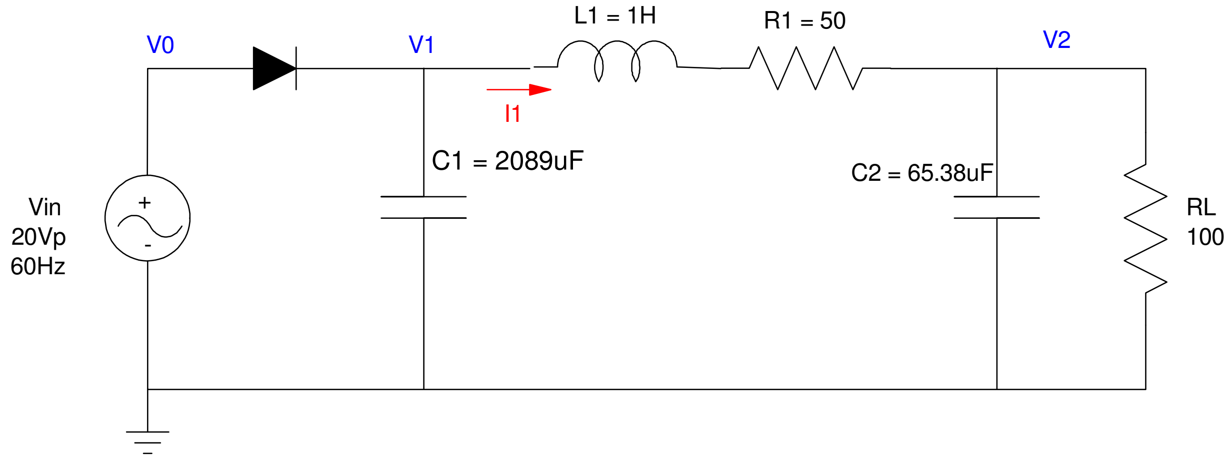
$$V_2 = 246.5mV_{pp}$$

Add C2 to reduce the ripple 2.465 times

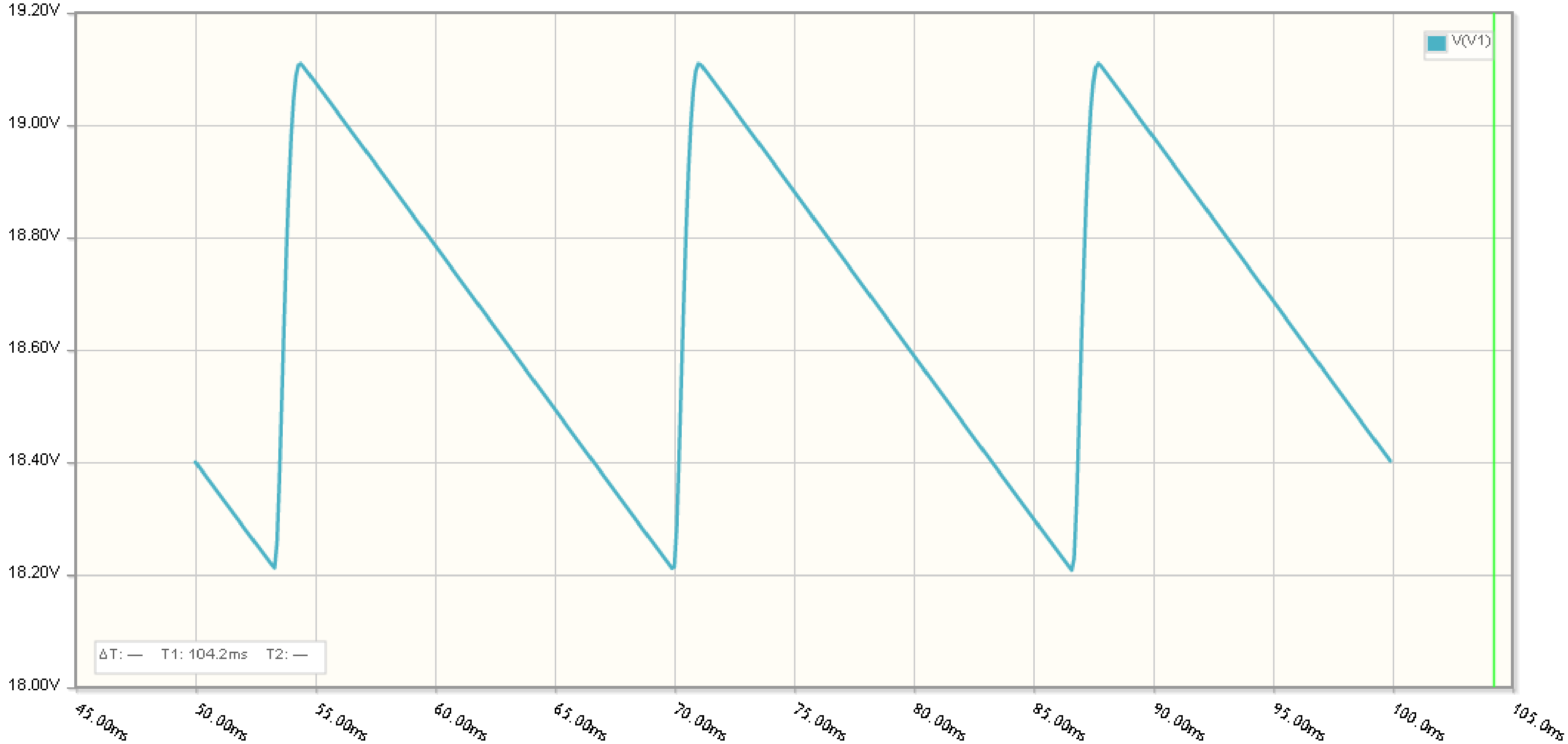
$$Z_c = \left(\frac{100mV_{pp}}{246.5mV_{pp}}\right) \cdot 100\Omega$$

$$Z_c = 40.57\Omega = \left|\frac{1}{j\omega C_2}\right|$$

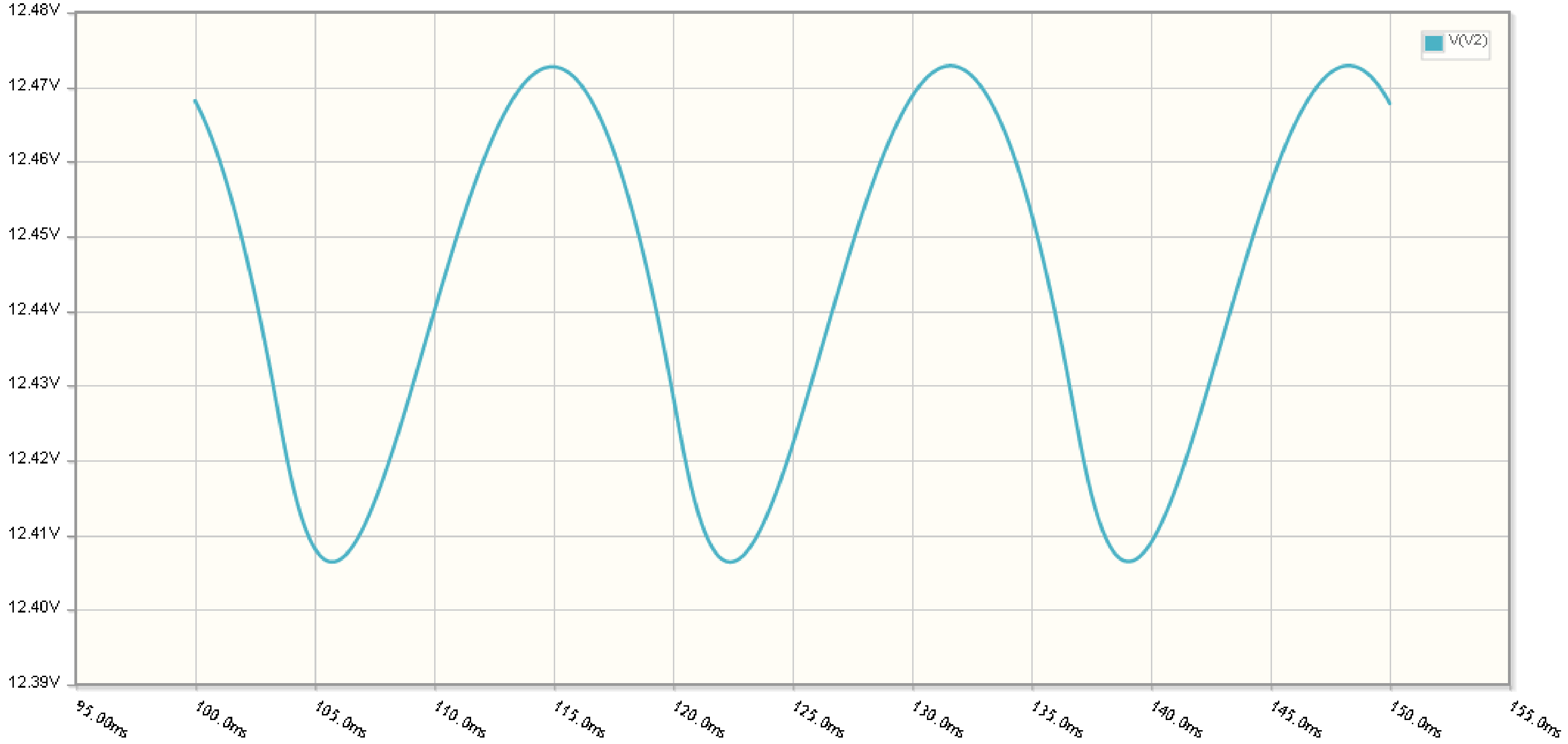
$$C_2 = 65.38\mu F$$



Checking in CircuitLab



V1(t): Ripple = 900mVpp (vs. 1Vpp target)

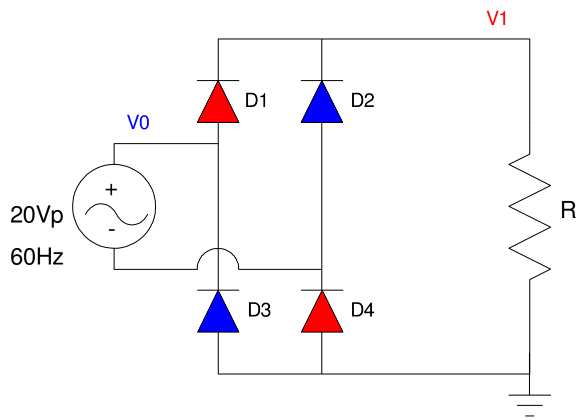


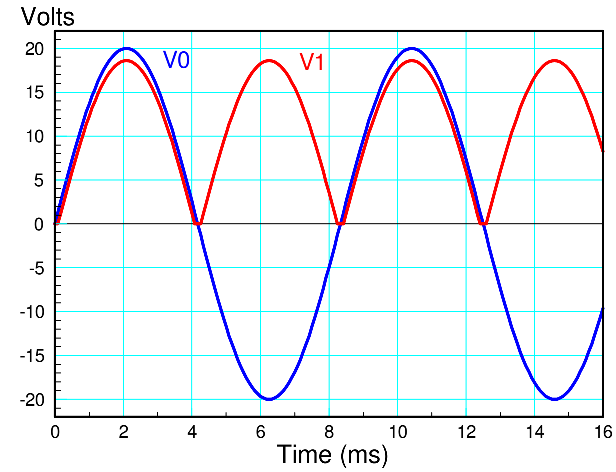
V2(t): Ripple = 60.0mVpp (vs. 100mVpp target)

Full-Wave vs. 1/2 Wave Rectifier

Full Wave

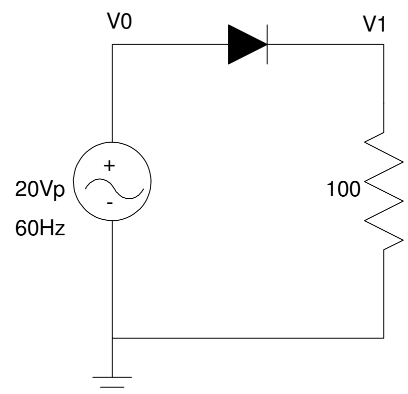
- Four diodes
- Requires a floating ground
- Fundamental frequency = 120Hz
- Means L & C are twice as effective

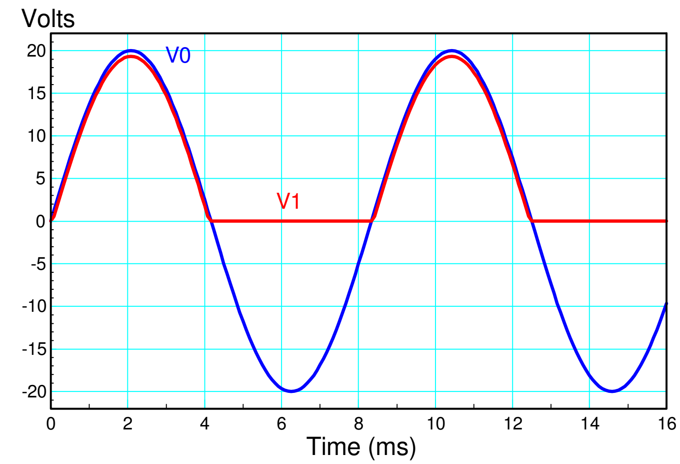




Half-Wave

- One diode
- Power supply and load ground can be the same
- Fundamental frequency = 60Hz





Summary

An AC to DC converter allows you to drive home appliances with AC power

- Most power is transmitted at 60Hz
- Most devices required DC to operate

Analysis is in two parts

- DC analysis: The average (DC) voltage driving the load
- AC analysis: The ripple in the DC voltage

AC analysis is hard

- The input is not a sine wave
- Approximating it with a sine wave gets you close
  - Same frequency
  - Same peak-to-peak voltage
  - Almost the same signal