DC to DC Converters

ECE 320 Electronics I

Jake Glower - Lecture #15

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

DC to DC Converters

Objectives:

- Convert a DC voltage to some other voltage.
- 13.2V is the power to a car. 5V DC is the power for a USB port.
- Going the other way, 5VDC is a common voltage for digital logic. The serial port on a PC needs +/-12V, however.

DC to DC Converter Capable of 0mA

Use voltage division

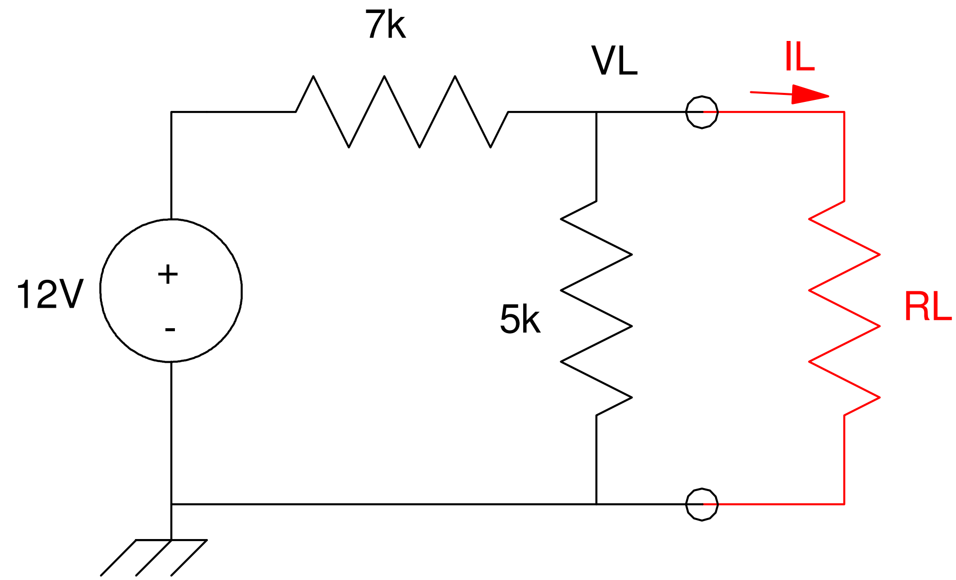
$$V_L = \left(\frac{5k}{5k+7k}\right)12V = 5.00V$$

Works unless you use it: Draw 100mA

$$R_L = \frac{5V}{100mA} = 50\Omega$$

the voltage drops

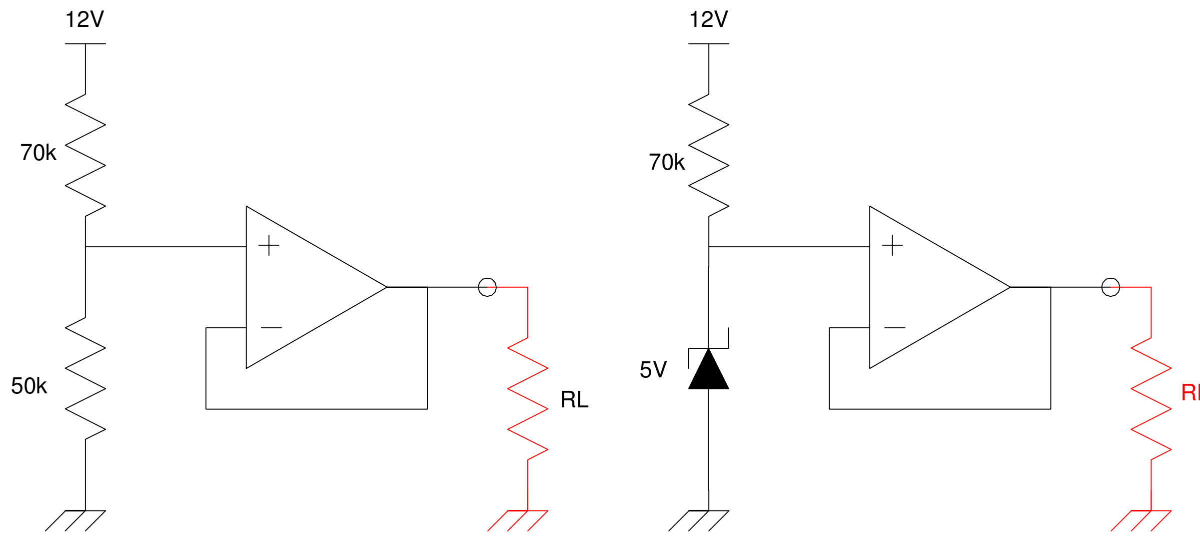
$$V_L = \left(\frac{5k||50}{5k||50+7k}\right)12V = 0.08V$$



DC to DC Converter Capable of 20mA: (take 2)

Add an op-amp buffer

- OK up to 20mA
- (depends upon op-amp)



Efficiency = 41.67%

$$P_{out} = 20mA \cdot 5V = 100mW$$

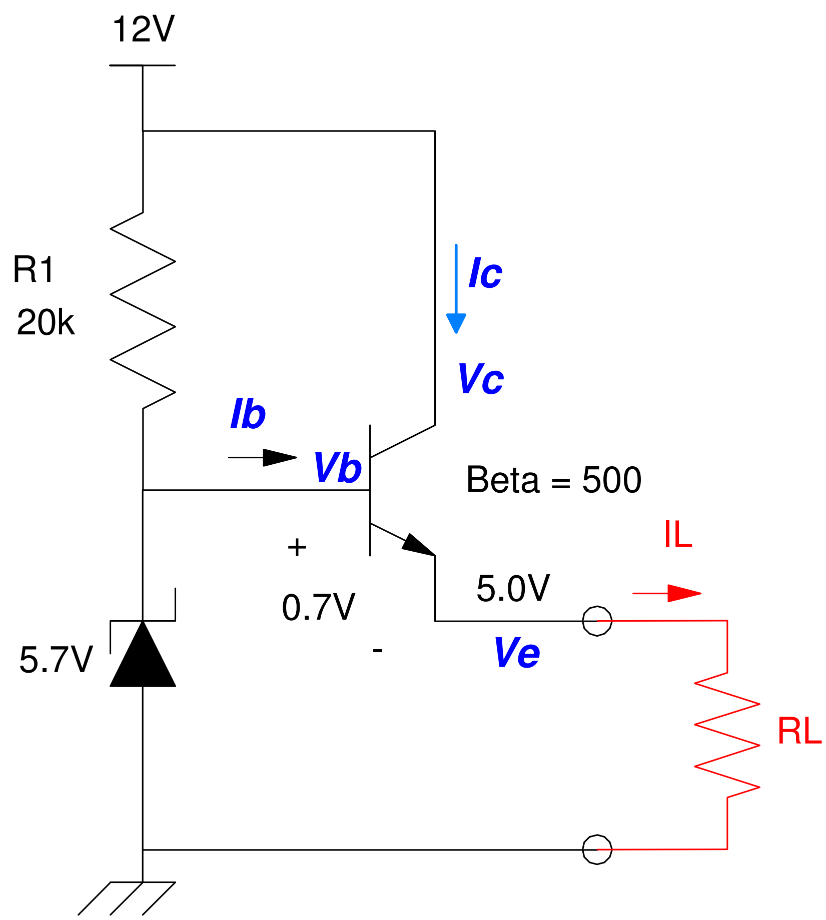
$$P_{in} = 20mA \cdot 12V = 240mW$$

$$\eta = \frac{P_{out}}{P_{in}} = 0.4167$$

DC to DC Converter Capable of 3A: (7805 Voltage Regulator)

Use a zener diode to set the voltage

Use a transistor to increase the current



Advantage:

- Easy to use: 3-wire device
- Works over a wide range (6V .. 36V)

Disadvantage:

- Low efficiency

$$\eta \approx \frac{P_{out}}{P_{in}} = \frac{5V \cdot I}{12V \cdot I} = \frac{5}{12}$$

$$\eta = 41.67\%$$

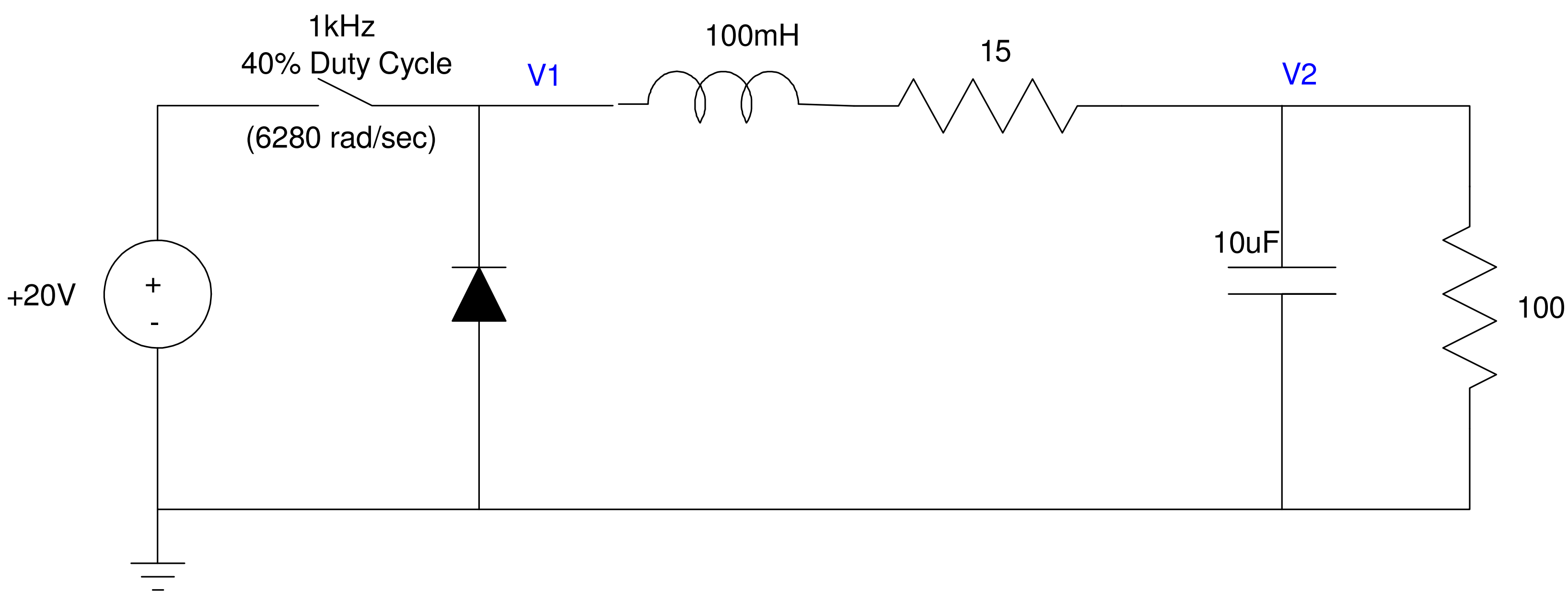
Buck Converters:

A way to get higher efficiency is to use a Buck converter:

Switch Closed: $V_2 \to 20V$

Switch Open: $V_2 \to 0V$

- The duty cycle sets the DC voltage
- C & L reduce the ripple

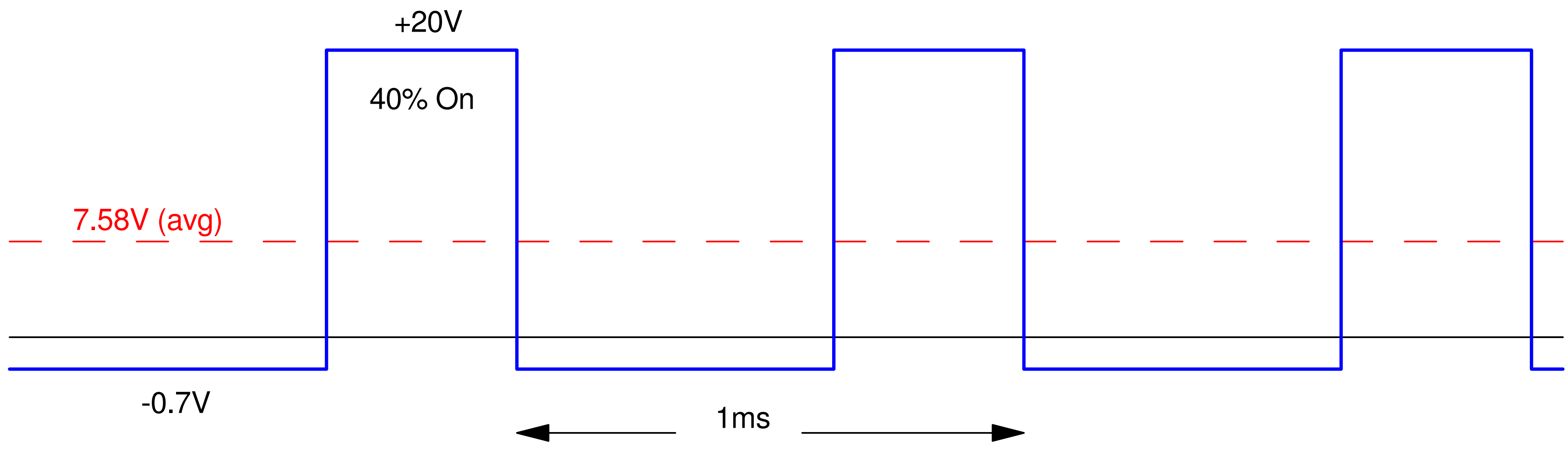


Buck Converter Analysis:

Assume the switch closes at 1kHz with a duty cycle of 40%

What happens is

- When the switch is closed, V1 = +20V
- When the switch is open, the inductor maintains current flow - sourced by the diode. This diode results in V1 = -0.7V.



Finding V2:

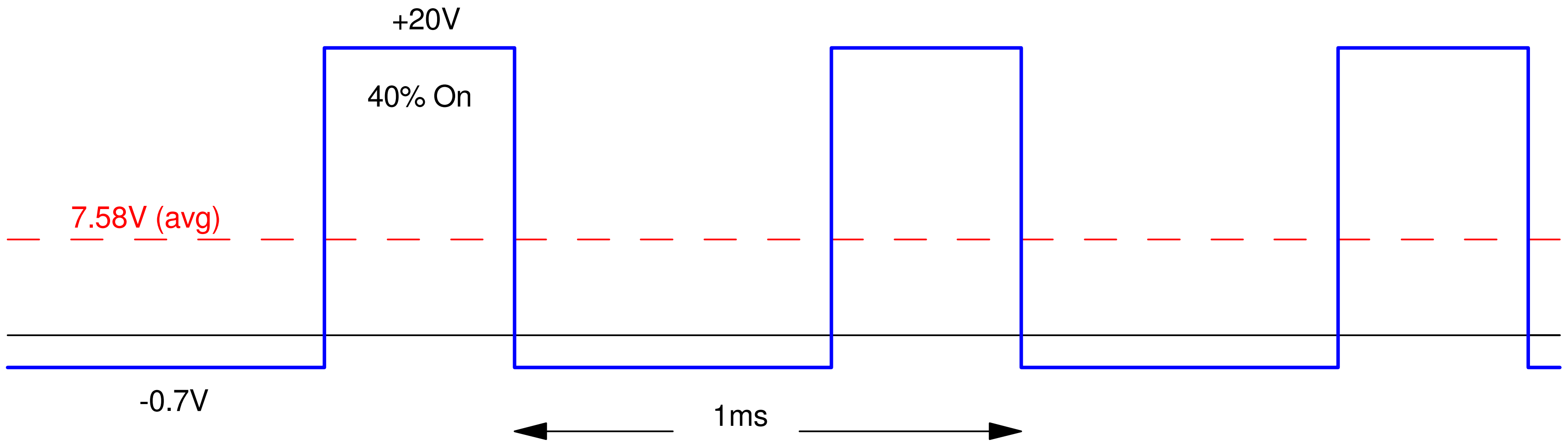
Very hard problem: V1 isn't a sine wave

- To solve exactly we need to use Fourier Transforms (coming soon...)

Change the problem: Assume instead that V1 has just two terms

- DC: V1 = 7.58V
- AC: V1 = 20.7Vpp @ 1kHz

Same DC value, same frequency, same ripple. Almost the same signal

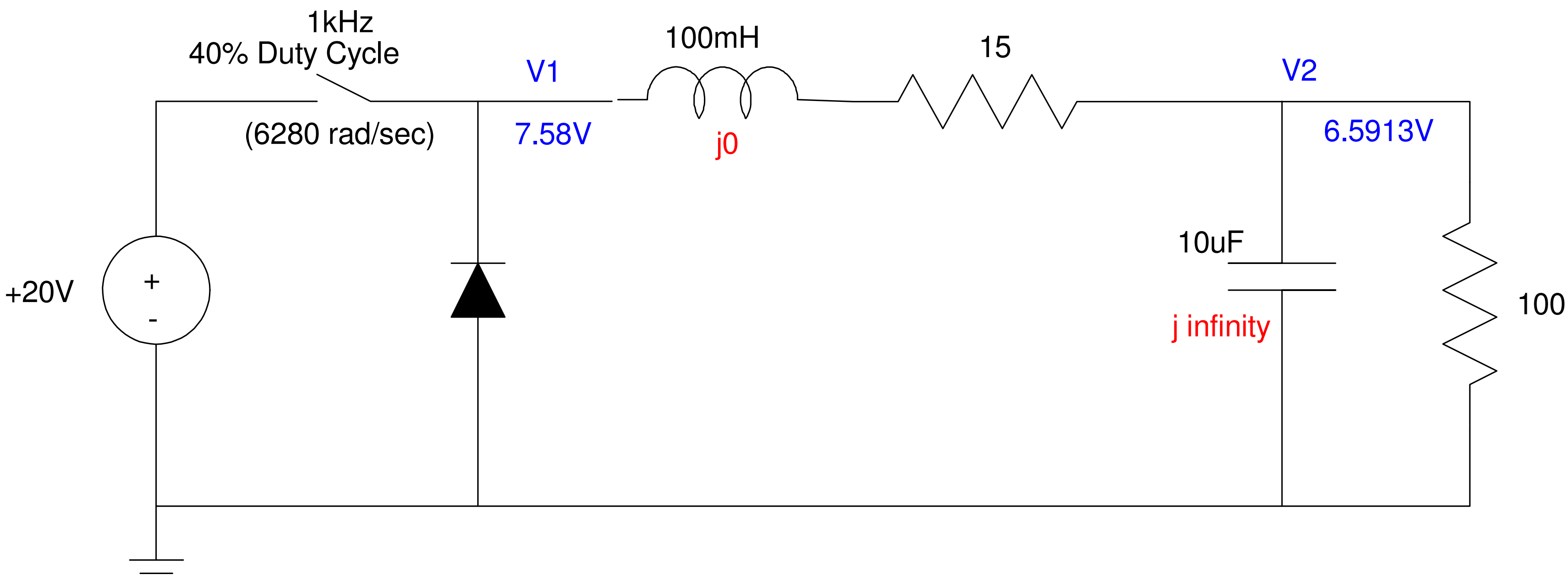


V2: DC Analysis:

Inductors and capacitors don't matter at DC. By voltage division

$$V_2 = \left(\frac{100}{100+15}\right) 7.58V$$

$$V_2 = 6.5913V$$

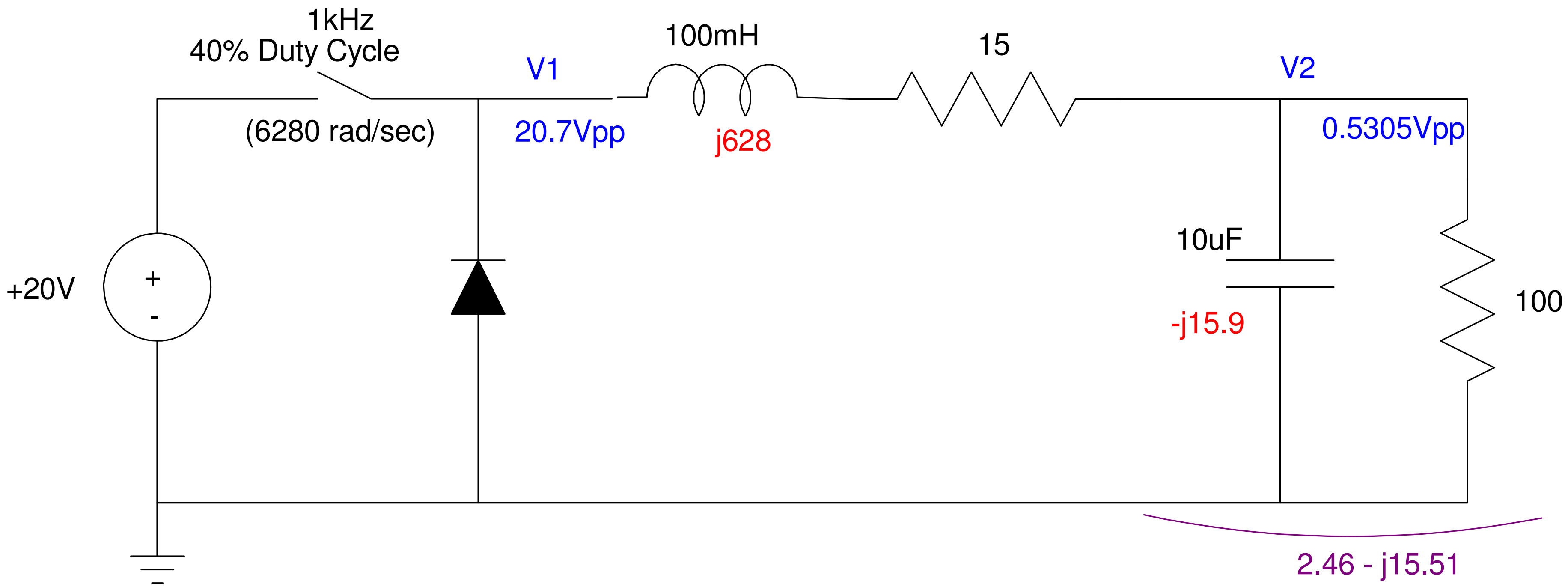


V2: AC Analysis:

V1 = 20.7Vpp @ 1kHz

$$V_2 = \left(\frac{(2.46 - j15.51)}{(2.46 - j15.51) + (15 + j628)} \right) 20.7V_{pp} = 0.5305V_{pp}$$

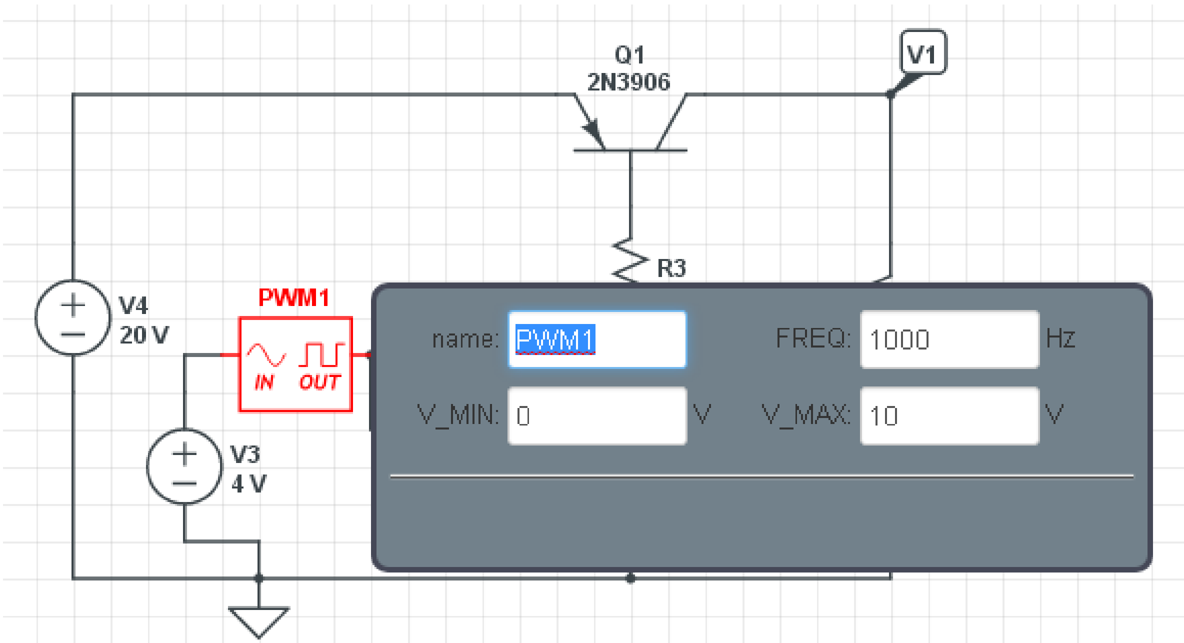
V2 = 6.5913V (DC) + 0.5305Vpp @ 1kHz (AC)



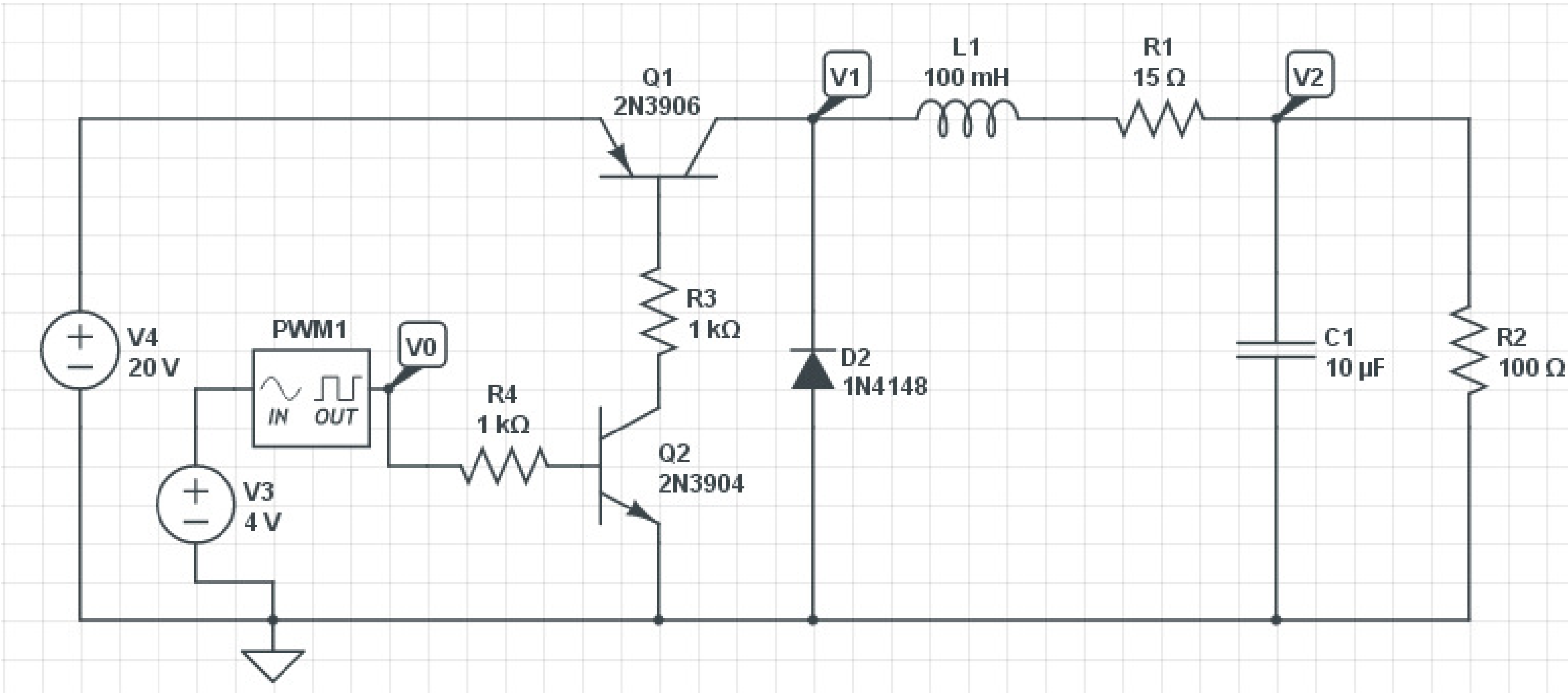
CircuitLab Verification

Add a switch in CircuitLab

- PNP transistor connected to power
- How you actually build a switch in lab
- Use a PWM to generate 40% duty cycle @ 1kHz (a microcontroller)



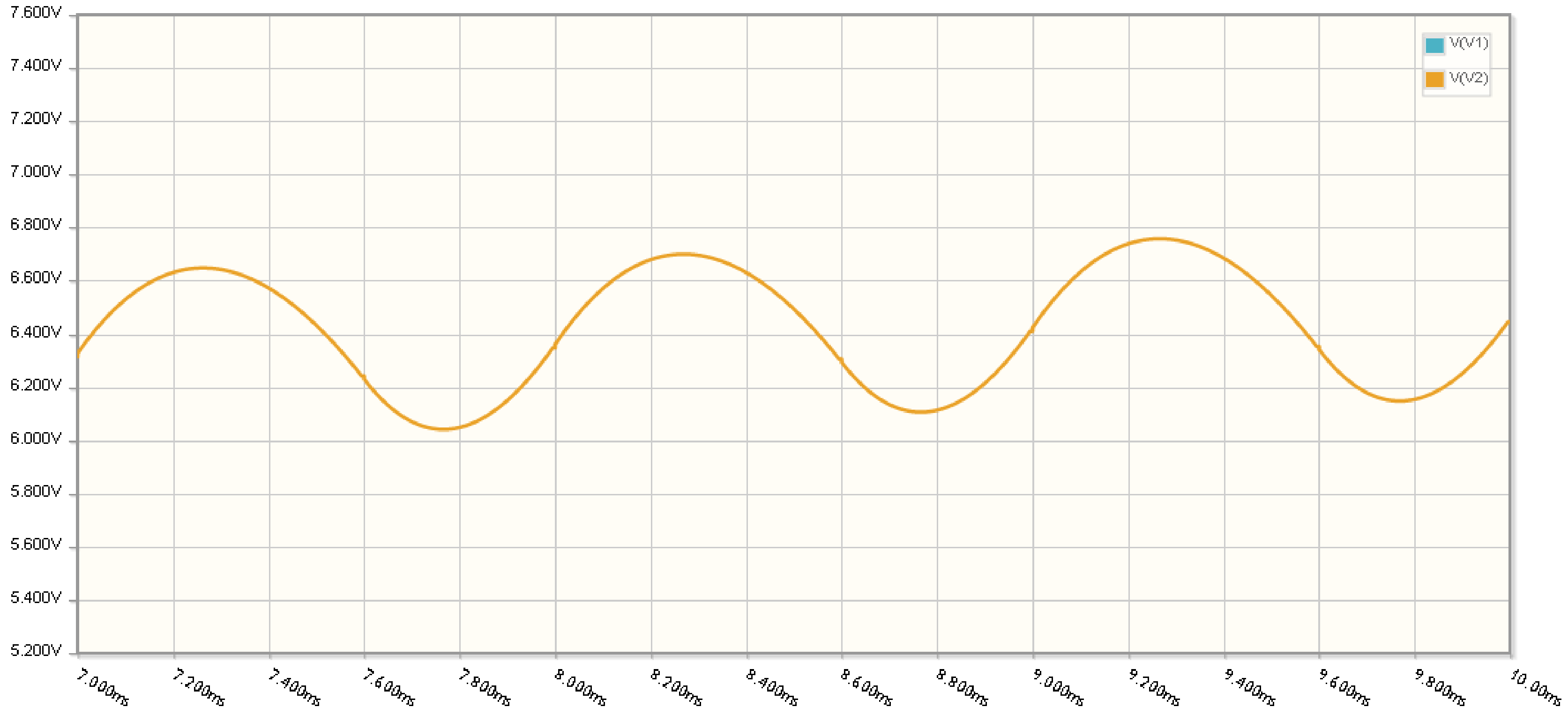
Add the rest of the circuit



Buck converter: Q1 acts as a switch. L1 and C1 serve as filters to reduce the AC ripple at V2.

Simulation Results (V2)

	V2(DC)	V2(AC)
Calculated	6.5913 V	530.5 mVpp
Simulated	6.404 V	592 mVpp



Buck Converters and Efficiency

The big advantage of a Buck converter is its efficiency.

- A 7806 voltage regulator is 30.5% efficient (6V / 20V).

When the switch is closed (40% of the time here), the efficiency is 84.7%.

- Current = 65.9mA (on average)
- Power to the 100 Ohm load = 434.5mW
- Power to the 15 Ohm resistor (part of the inductor) = 65.2mW
- Power to the 0.2V drop across Q1 = 13.2mW

$$\eta = \frac{\text{power to load}}{\text{total power}} = \frac{434.5mW}{434.5mW + 65.2mW + 13.2mW} = 0.8473$$

When the switch is open (60% of the time), the efficiency is 79.6%

The net efficiency is 81.6%

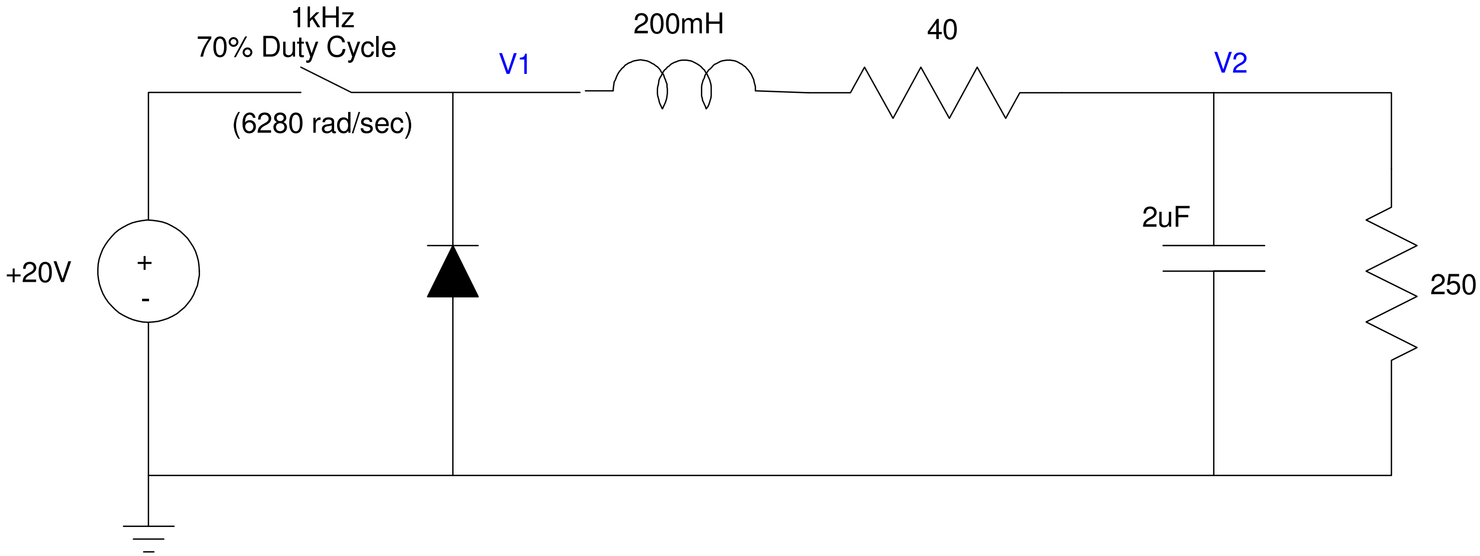
$$\eta = 0.4 \cdot (84.7\%) + 0.6 \cdot (79.6\%)$$

$$\eta = 81.6\%$$

Handout

Determine V1 and V2

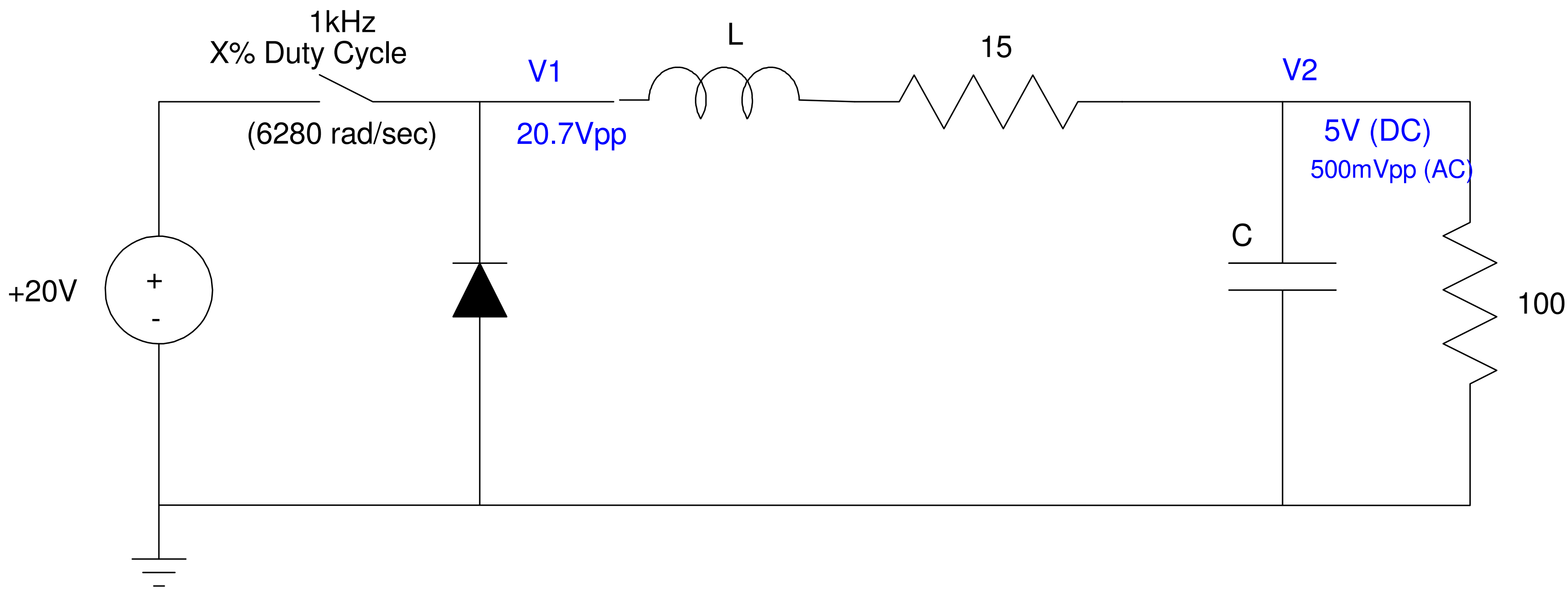
- DC and AC



Buck Converter Design

Design a Buck converter to convert

- +20VDC to +5VDC,
- With a ripple of 500mVpp,
- A switching frequency of 1kHz, and
- A 100 Ohm load (50mA).



Step 1: DC Analysis

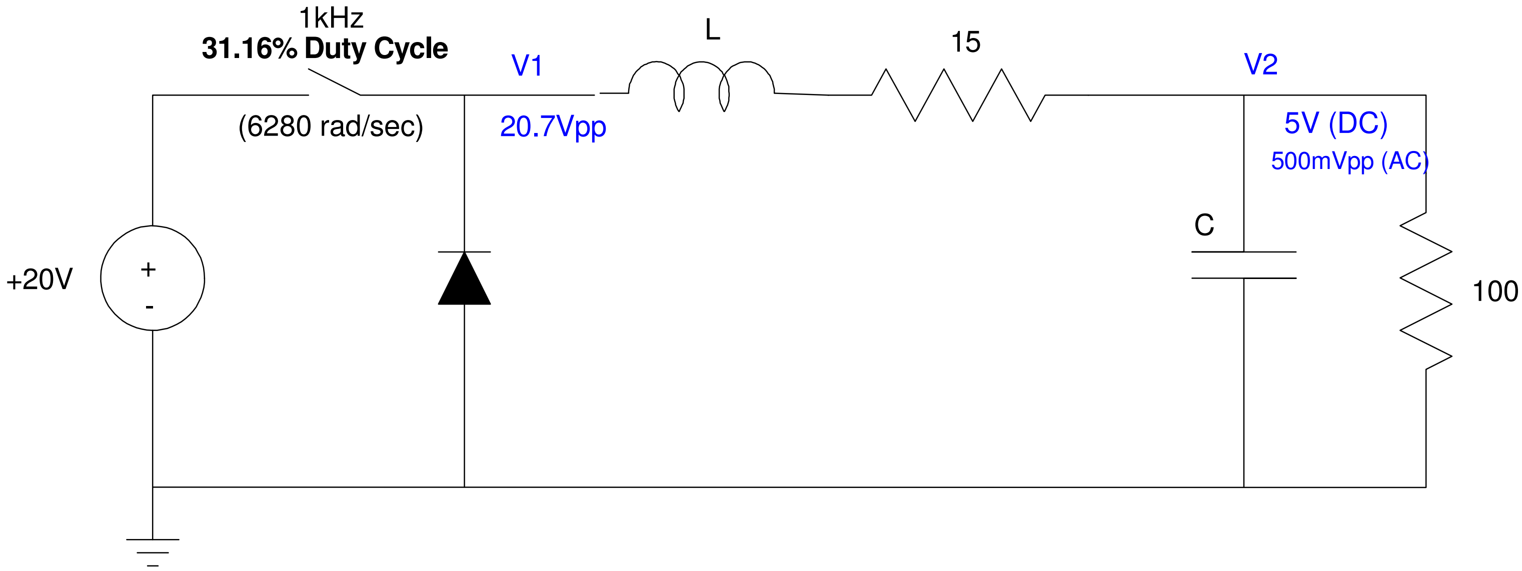
$$V_2 = 5.00V = \left(\frac{100}{100+15}\right) V_1 \quad \Rightarrow \quad V_1 = 5.75V$$

The duty cycle is then

$$5.75V = \alpha \cdot 20V + (1 - \alpha) \cdot (-0.7V)$$

$$\alpha = \left(\frac{5.75+0.7}{20+0.7}\right) = 0.3116$$

The duty cycle should be 31.16%.



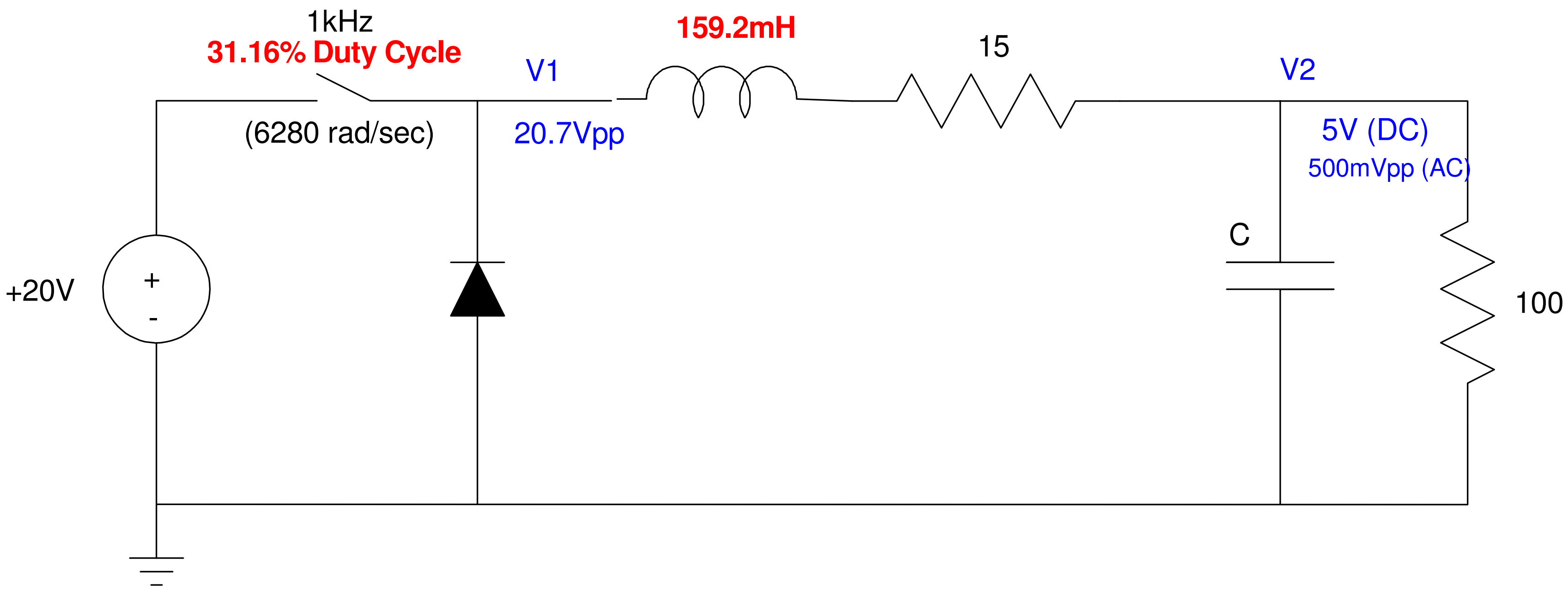
Step 2: AC Analysis

Pick L to reduce the ripple 10x (somewhat arbitrary)

$$|j\omega L| = 10\,R$$

$$L = \left(\frac{10R}{\omega}\right) = 159.2mH$$

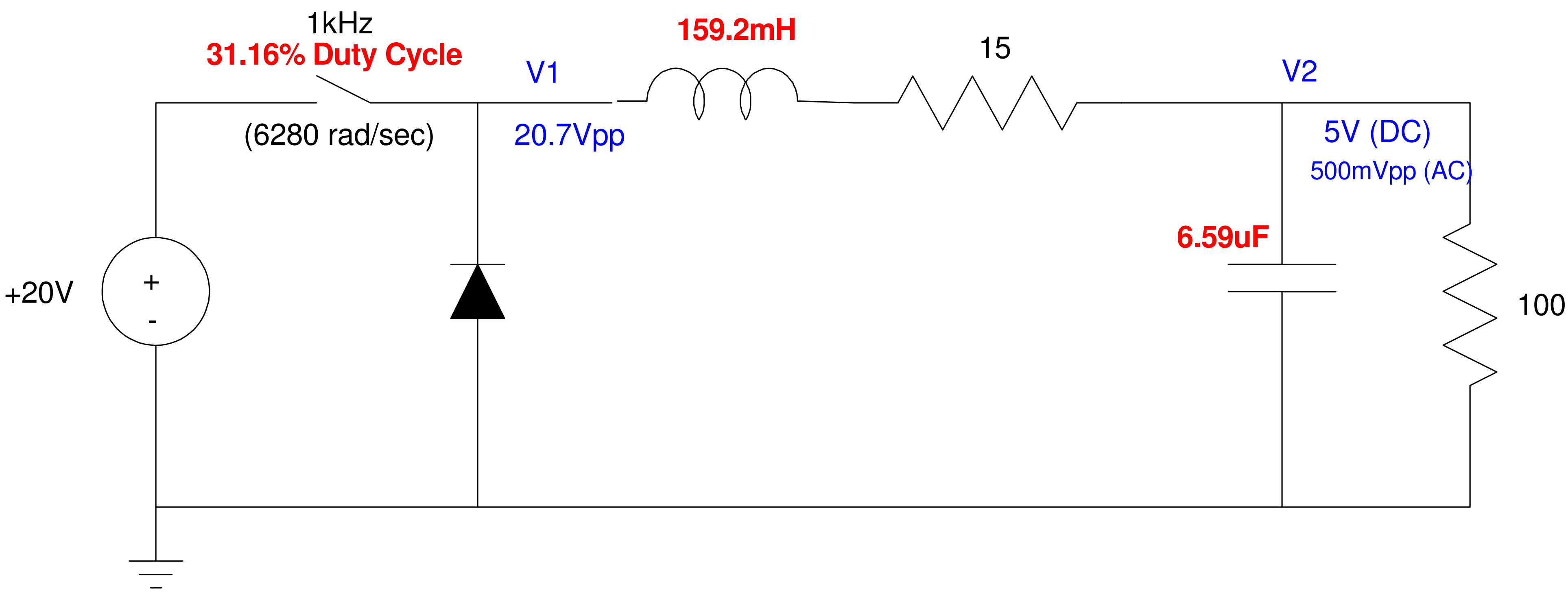
This should reduce the ripple at V2 to 2.07Vpp.



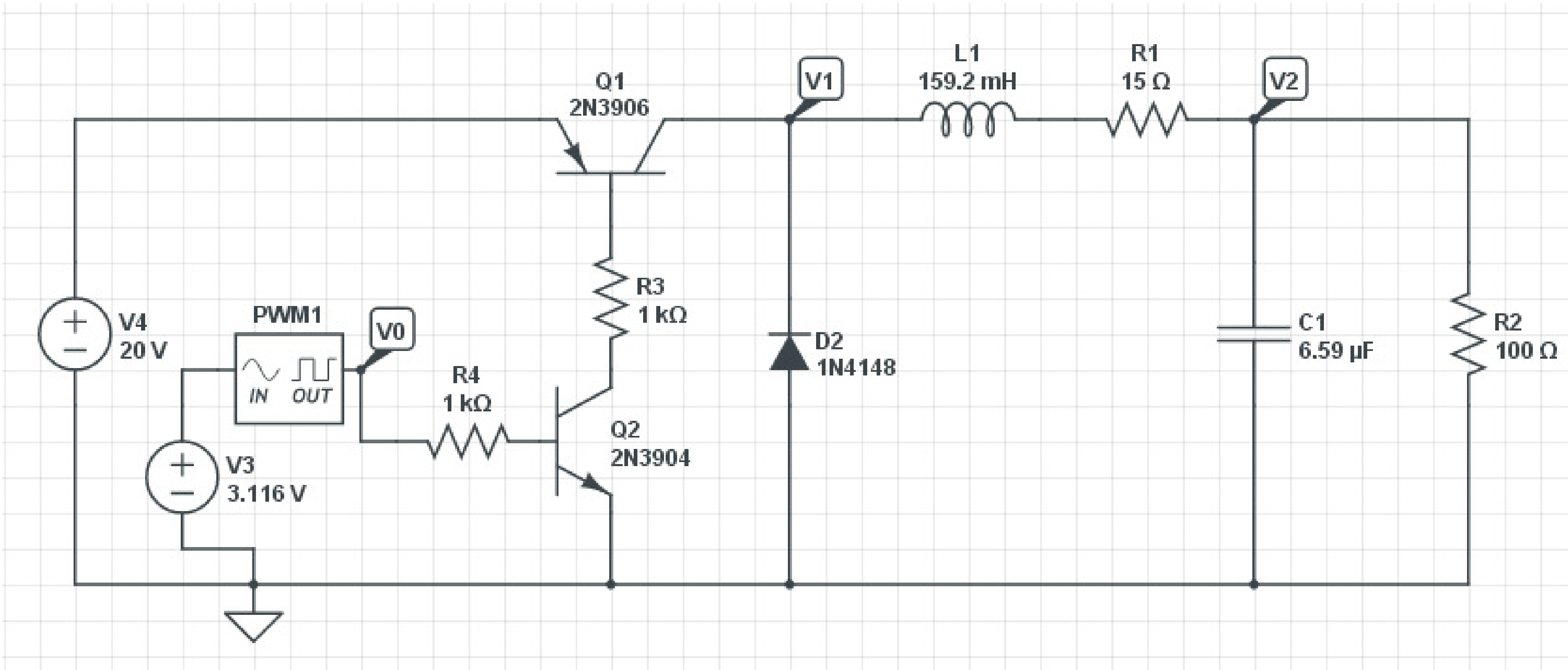
Add C.

- C reduces the ripple from 2.07Vpp to 0.5Vpp, a reduction of 4.14x.
- To do this, pick C so that its impedance is 4.14x smaller than R

$$\left|\frac{1}{j\omega C}\right| = \frac{1}{4.14}\cdot R \qquad \frac{1}{\omega C} = 24.15\Omega \qquad C = 6.59\mu F\backslash$$

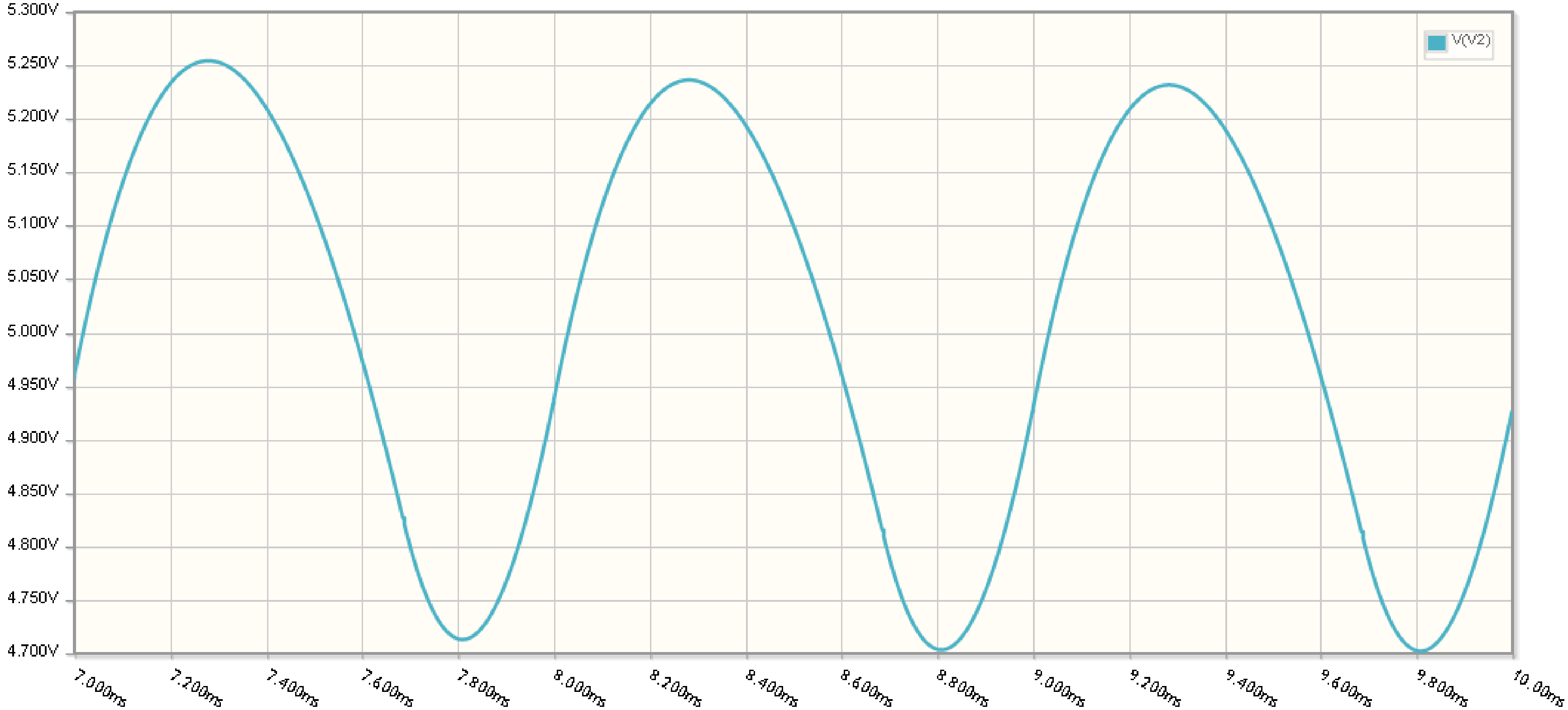


Checking in CircuitLab



Schematic for CircuitLab implementation of a Buck Converter

	V2(DC)	V2(AC)	
Calculated	5.00 V	500.0 mVpp	
Simulated	4.97 V	532 mVpp (6% high)	497 mVpp (C = 7.01uF)



Summary

Converting AC voltages is easy

- Use a transformer

Converting DC voltages is possible, but harder

If you need less than 50mA

- Use a voltage divider and an op-amp

If 40% efficiency is OK

- Use a 7805 regulator

If higher efficiency is needed

- Use a buck (step down) or boost (step up) converter