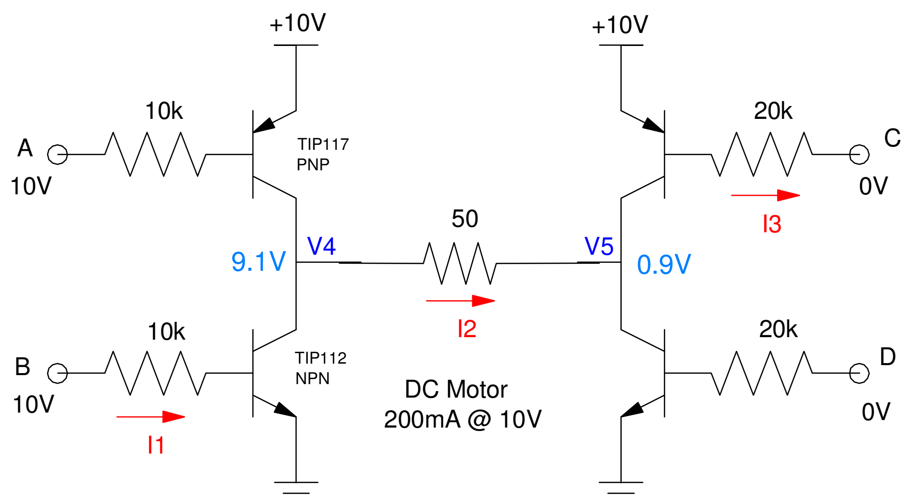
ECE 320 - Homework #5

H-Bridges, DC-to-DC Converters, Fourier Transform. Due Monday, October 7th

H-Bridges

1) Determine the voltages and currents for the following H-bridge. Assume TIP transistors

- | Vbe | = 1.4V
- β = 1000
- $V_{ce(sat)}$ = 0.9V



$$I_1 = \left(\frac{10-1.4}{10k}\right) = 860\mu A \qquad I_{2(max)} = \left(\frac{10-0.9-0.9}{50}\right) = 164mA \qquad I_3 = \left(\frac{10-1.4}{20k}\right) = 430\mu A$$

$$\beta I_1 = 860mA \qquad \beta I_3 = 430mA$$

$$I_2 = \min(860mA, 164mA, 430mA)$$

$$I_2 = 164mA$$

Both transistors are saturated

2) Design an H-Bridge cable of running a DC servo motor forward (+10V), reverse (-10V) and stop (0V). Assume the DC servo motor draws 200mA @ 10V.

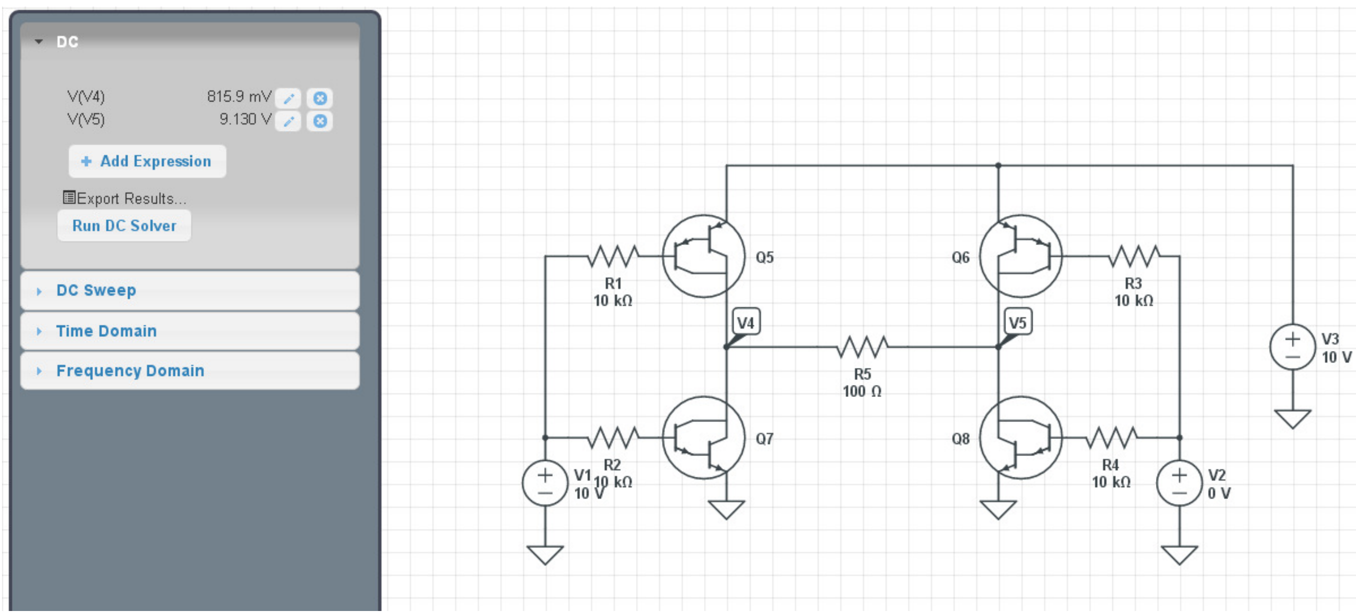
The above circuit works. No changes are needed.

3) Check your design for problem #2 in PartSim (or similar program)

PartSim wasn't working, so I used CircuitLab.

CircuitLab actually has Darlington pairs (!), so I used these with 10k resistors for all base resistors. As expected, the transistors were saturated

	V4	V5
Calculated	9.1 V	0.9 V
Simulated	9.130 V	0.8159 V

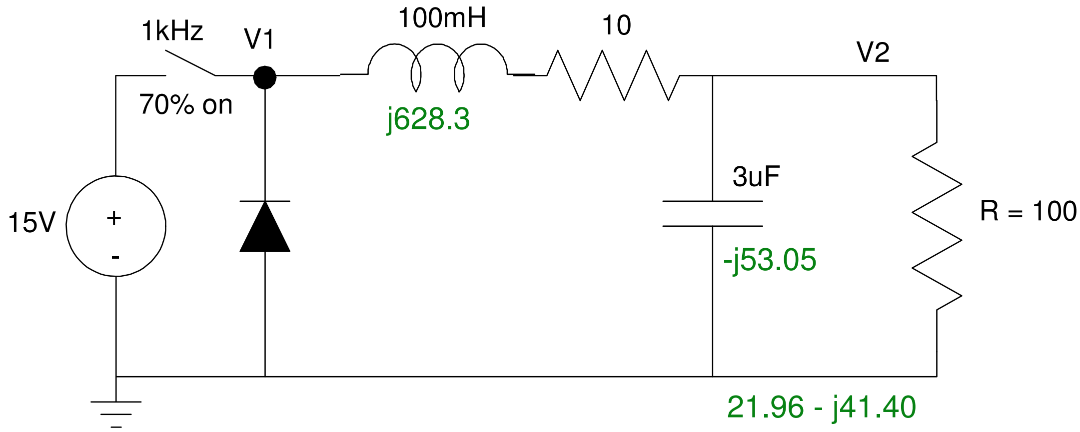


4) Lab: Build your circuit in lab and verify it works for all three states (forward, reverse, stop).

- note: Check Vce. If it's 0.9V, the transistor is saturated (on)

DC to DC (Buck) Converters

5) For the following DC to DC converter, determine the voltage at V1 and V2 (both DC and AC).



DC:

$$V_1 = 0.7 \cdot (15V) + 0.3 \cdot (-0.7V)$$

$$V_1 = 10.29V$$

$$V_2 = \left(\frac{100}{100+10}\right) V_1$$

$$V_2 = 9.35V$$

AC:

$$V_1 = 15.7V_{pp}$$

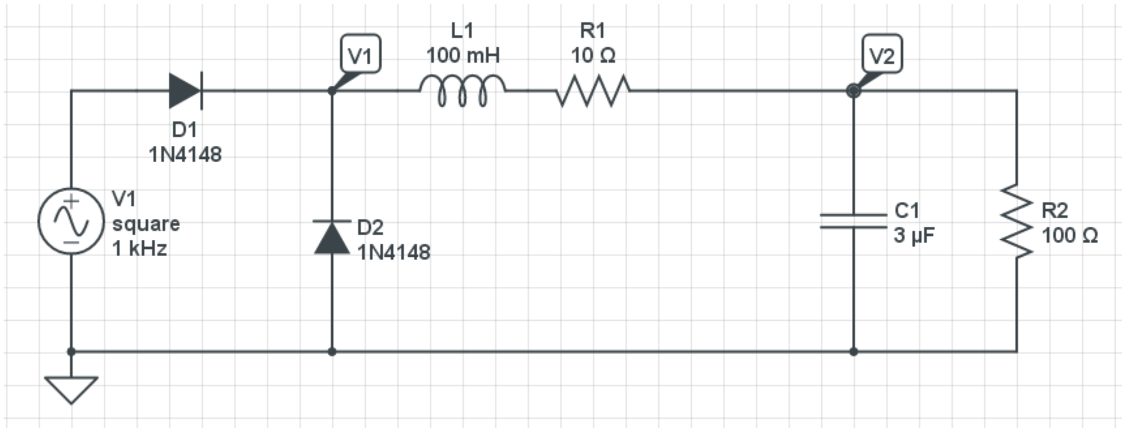
$$V_2 = \left(\frac{21.96 - j41.40}{(21.96 - j41.40) + (10 + j628.3)}\right) 15.7V_{pp}$$

$$V_2 = 1.25V_{pp}$$

6) Check your analysis in PartSim (or similar program)

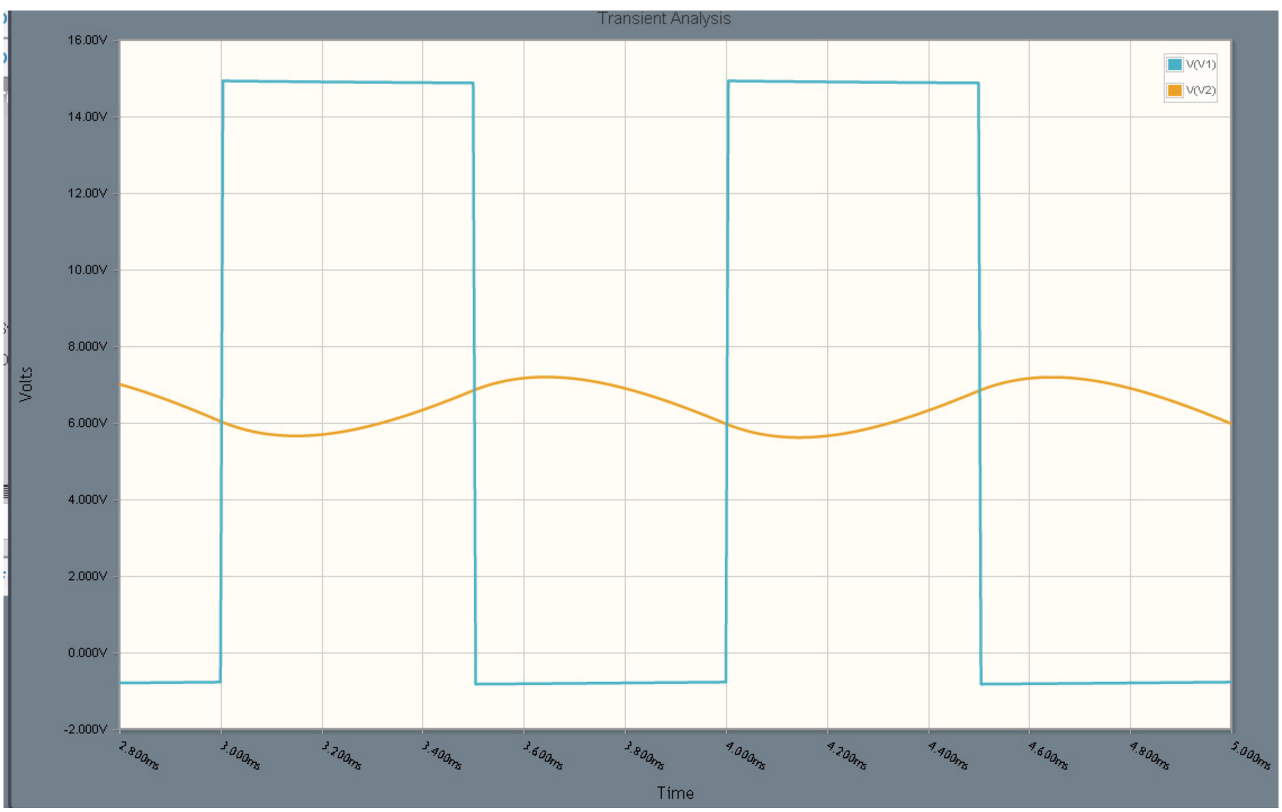
A square wave generator and a diode model the input (15V) and switch

The DC level is off since I don't know how to change the duty cycle from 50%.



The resulting waveform is:

	max	min	average (DC)	difference (AC)
V1	14.91 V	-0.7998 V	7.055 V	15.70 Vpp
V2 (simulated)	7.187 V	5.614 V	6.400 V	1.573 Vpp
V2 (calculated)	*	*	9.35 V	1.25 Vpp



7) Design a Buck converter to convert +15VDC to +5VDC, capable of driving 100mA

Use the above circuit.

If the DC value of V2 is 5.00V, then V1 is

$$V_2 = 5.00V = \left(\frac{100}{100+10}\right) V_1$$

$$V_1 = 5.50V$$

The duty cycle is then

$$\text{Duty Cycle} = \left(\frac{5.50+0.7}{15+0.7}\right) = 39.49\%$$

The load changes to

$$R_{load} = \left(\frac{5V}{100mA}\right) = 50\Omega$$

(not asked for): If the ripple at the load is 100mVpp, then

$$\left(\frac{Z_{load}}{Z_{load}+(10+j628.3)}\right) \cdot 15.7V_{pp} = 0.1V_{pp}$$

Assuming Zload << 628 Ohms (take the magnitude of the answers - we want real numbers)

$$\left(\frac{Z_{load}}{10+j628.3}\right) \cdot 15.7V_{pp} = 0.1V_{pp}$$

$$Z_{load} = 4.00\Omega$$

$$\frac{1}{j\omega C} \approx 4\Omega$$

$$C = 39.7\mu F$$

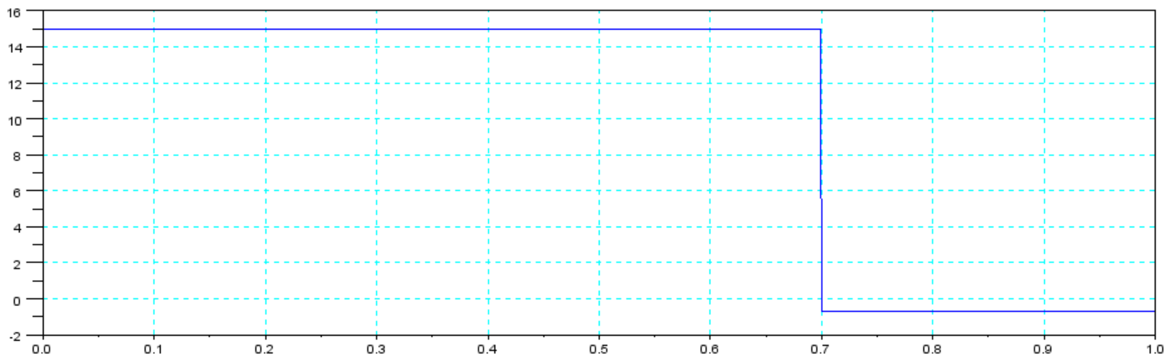
Fourier Transform

8) Find the first 5-terms of the Fourier Series for V1 in problem #5

$$V_1 = \begin{cases} +15V & 70\% \text{ of the time} \\ -0.7V & 30\% \text{ of the time} \end{cases}$$

Time is arbitrary for Fourier transforms. Let the period be 1 second

```
t = [0:0.001:1]';
V1 = 15*(t < 0.7) - 0.7*(t > 0.7);
plot(t,V1);
```

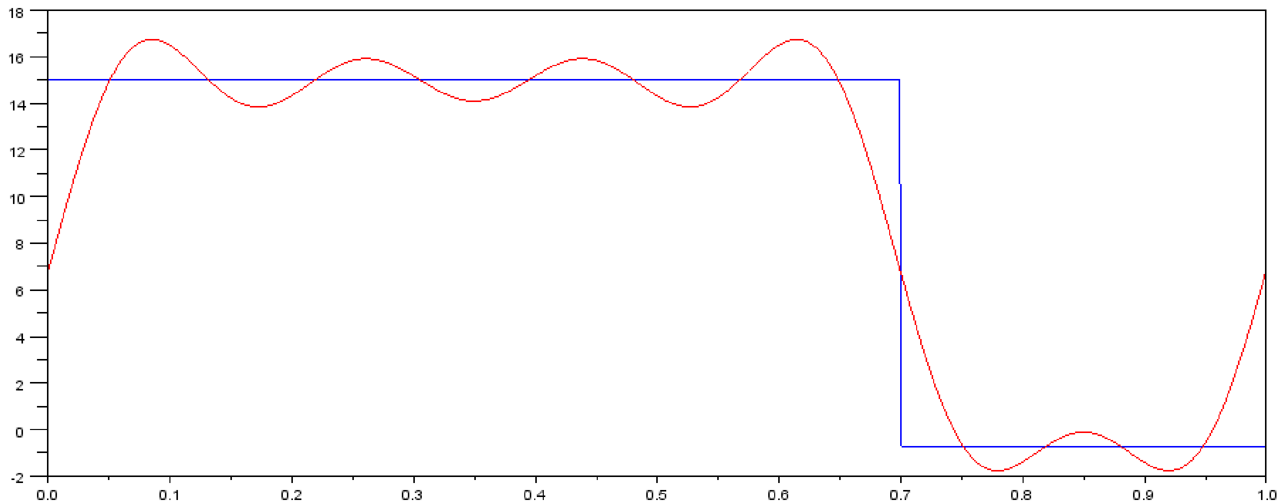


Change the period to 2 pi. Compute the Fourier terms

```
DC = mean(V1)

    10.279021

C1 = 2*mean(V1 .* exp(-j*2*pi*t))

  - 4.7289757 - 6.5501268i

C2 = 2*mean(V1 .* exp(-j*4*pi*t))

    1.4942062 - 4.5064556i

C3 = 2*mean(V1 .* exp(-j*6*pi*t))

    0.9797352 - 0.3085974i

C4 = 2*mean(V1 .* exp(-j*8*pi*t))

  - 1.1775295 - 0.8772997i

C5 = 2*mean(V1 .* exp(-j*10*pi*t))

    0.0299700 - 1.9968248i
```

Check: build up V1 from its Fourier terms and it ought to match....

```
Vf = 0*t + DC;

Vf = Vf + real(C1)*cos(2*pi*t) - imag(C1)*sin(2*pi*t);
Vf = Vf + real(C2)*cos(4*pi*t) - imag(C2)*sin(4*pi*t);
Vf = Vf + real(C3)*cos(3*2*pi*t) - imag(C3)*sin(3*2*pi*t);
Vf = Vf + real(C4)*cos(4*2*pi*t) - imag(C4)*sin(4*2*pi*t);
Vf = Vf + real(C5)*cos(5*2*pi*t) - imag(C5)*sin(5*2*pi*t);

plot(t,V1,'b',t,Vf,'r');
```



As you add more and more terms, it gets closer and closer.

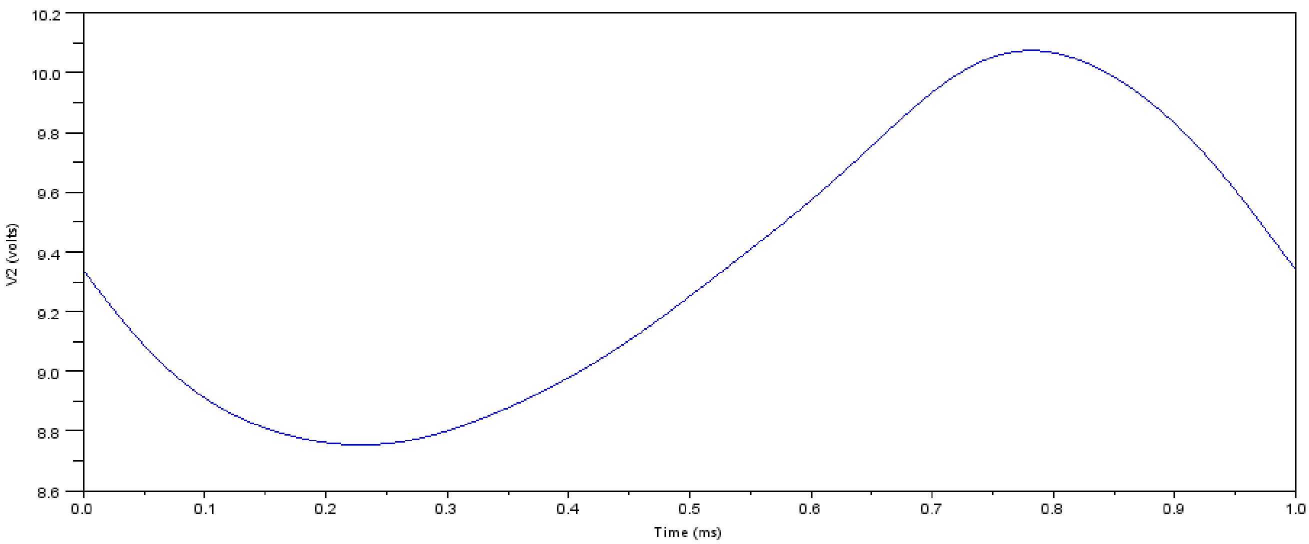
9) Determine V2 for problem #5 for the Fourier series approximation of V1 from problem #8

Fourier Term	w	V1	V2 Volts	V2 Watts
DC	0	10.279021	9.34	87.32 W
1	6283 rad/sec	-4.728 - 6.550i	0.0535 + 0.6419i	0.212 W
2	12,566 rad/sec	1.494 - 4.506i	-0.055 + 0.0819i	0.00488 W
3	18,849 rad/sec	0.979 - 0.308i	-0.0095 + 0.0011i	0.000045 W
4	25,132 rad/sec	-1.177 - 0.877i	0.0055 + 0.0054i	0.000029 W
5	31,415 rad/sec	0.029 - 1.996i	-0.0008 + 0.0066i	0.000022 W

Note that 99.9% of the energy is in the DC term and 1st harmonic for V2. Ignoring all other terms isn't 100% correct, but it's really close.

Matlab Code:

```
n = 0;
w = n*1000*2*pi;
ZL = inv(j*w*C + 1/100);
D0 = ZL / (ZL + 10 + j*w*L) * DC

n = 1;
w = n*1000*2*pi;
ZL = inv(j*w*C + 1/100);
D1 = ZL / (ZL + 10 + j*w*L) * C1

n = 2;
w = n*1000*2*pi;
ZL = inv(j*w*C + 1/100);
D2 = ZL / (ZL + 10 + j*w*L) * C2

n = 3;
w = n*1000*2*pi;
ZL = inv(j*w*C + 1/100);
D3 = ZL / (ZL + 10 + j*w*L) * C3

n = 4;
w = n*1000*2*pi;
ZL = inv(j*w*C + 1/100);
D4 = ZL / (ZL + 10 + j*w*L) * C4

n = 5;
w = n*1000*2*pi;
ZL = inv(j*w*C + 1/100);
D5 = ZL / (ZL + 10 + j*w*L) * C5

V2 = 0*t + D0;
V2 = V2 + real(D1)*cos(1*2*pi*t) - imag(D1)*sin(1*2*pi*t);
V2 = V2 + real(D2)*cos(2*2*pi*t) - imag(D2)*sin(2*2*pi*t);
V2 = V2 + real(D3)*cos(3*2*pi*t) - imag(D3)*sin(3*2*pi*t);
V2 = V2 + real(D4)*cos(4*2*pi*t) - imag(D4)*sin(4*2*pi*t);
V2 = V2 + real(D5)*cos(5*2*pi*t) - imag(D5)*sin(5*2*pi*t);

plot(t,V2)
```


10.2
10.0
9.8
9.6
9.4
9.2
9.0
8.8
8.6
V2 (volts)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Time (ms)