ECE 320 - Homework #6

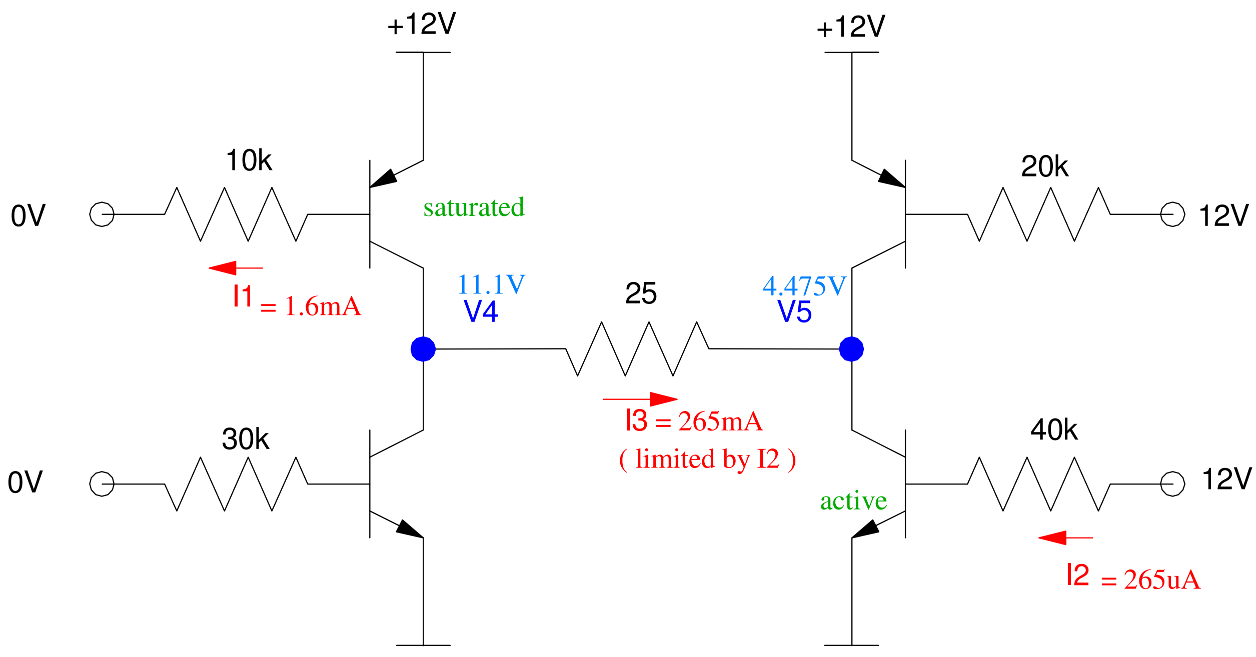
H Bridge, DC to DC Converters, Fourier Transform.   Due Wednesday, February 20, 2019

H-Bridge

Assume a TIP112 and TIP117 transistor for the following H-bridge (Darlington pairs)

- $\beta = 1000$
- $V_{be} = 1.4V$
- $\min(|V_{ce}|) = 0.9V$

1) Determine the voltages V1 and V2 for the following H-bridge



$$I_1 = \left(\frac{12-1.4}{10k}\right) = 1.6mA \qquad \beta I_1 = 1.6A$$

$$I_2 = \left(\frac{12-1.4}{40k}\right) = 265\mu A \qquad \beta I_2 = 265mA$$

Assuming both transistors are satuated...

$$I_3 = \left(\frac{12-0.9-0.9}{25}\right) = 408mA$$

The actual current, I3, is the smallest of these

$$I_3 = \min\left(\ 1.6A\ ,\ 408mA\ ,\ 265mA\ \right) = 265mA$$

meaning that transistor 1 is saturated, transistor 2 is active

$$V_4 = 12 - 0.9V = 11.1V$$

$$V_3 = V_2 - 25\Omega \cdot 265mA = 4.475V$$

2) Modify this circuit to meet the following requirements

- Input: A,B,C,D. 0/12V binary signals, capable of 20mA
- Output: 50 Ohm resistor
- Relationship: By varying A,B,C,D, the voltage across the 50 Ohm resistor can be set to +12V, -12V, and 0V (+/-1V)

The current you're trying to drive through a 50 Ohm resistor is

$$I_3 = \left(\frac{12V-0.9V-0.9V}{50\Omega}\right) = 204mA$$

To saturate each transistor, you need

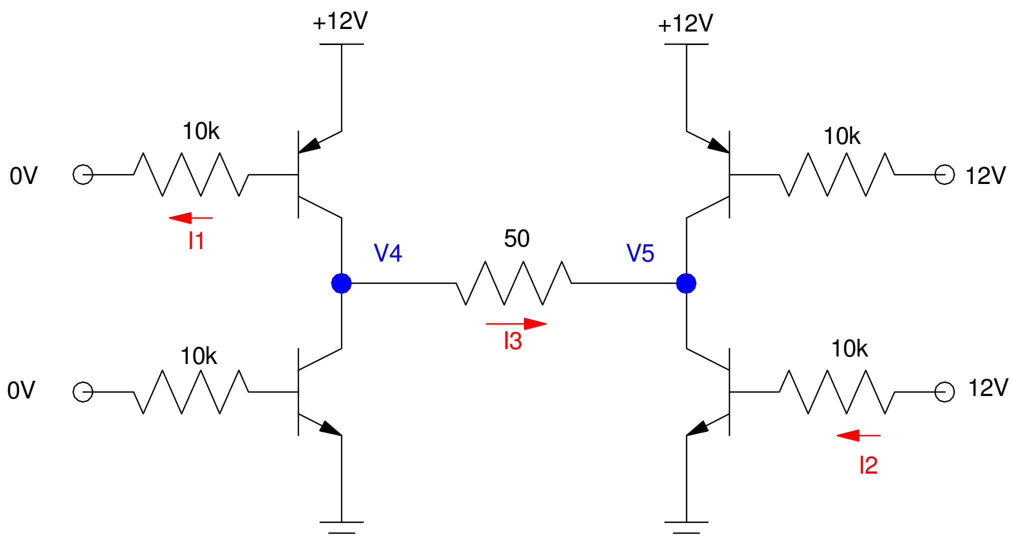
$$\beta I_b > I_c$$

$$I_b > \frac{204mA}{1000} = 204\mu A$$

Let Ib = 1mA. Then

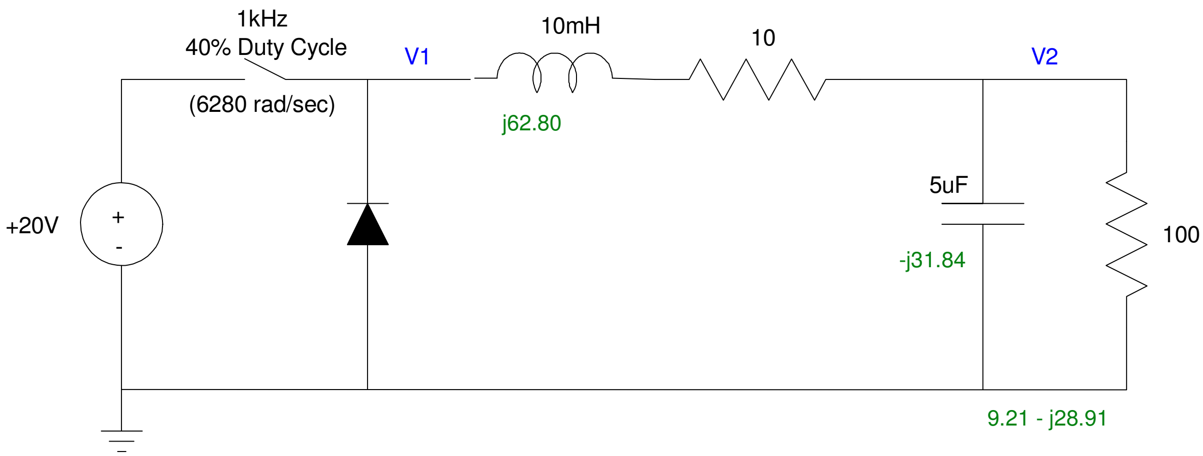
$$R_b = \left(\frac{12V-1.4V}{1mA}\right) = 10.6k$$

Let Rb = 10k



DC to DC Converters (Buck converter)

3) For the following Buck converter, determine the votlages at V1 and V2 (DC and AC)



DC:

$$V_1 = 0.4 \cdot 20V + 0.6 \cdot (-0.7V) = 7.58V$$

$$V_2 = \left(\frac{100}{100+10}\right) V_1 = 6.89V$$

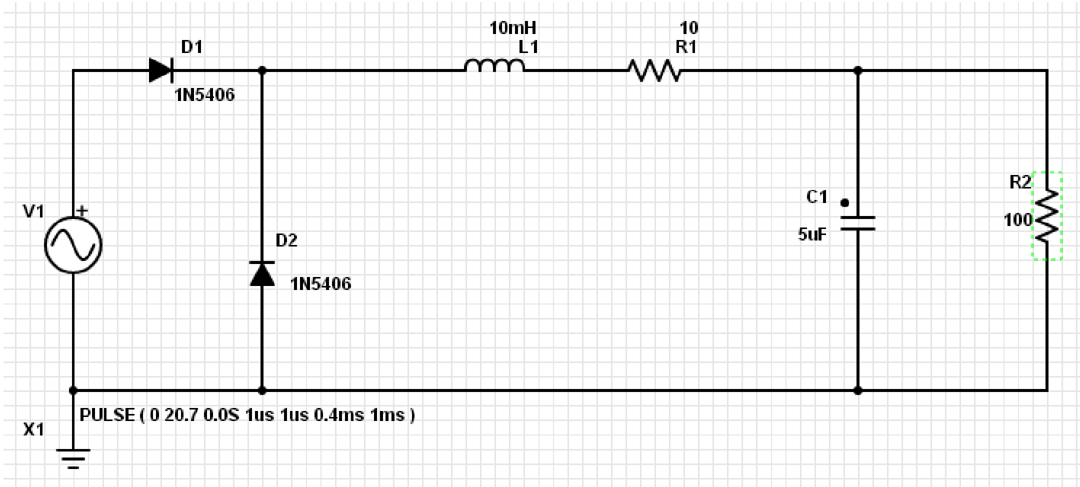
AC

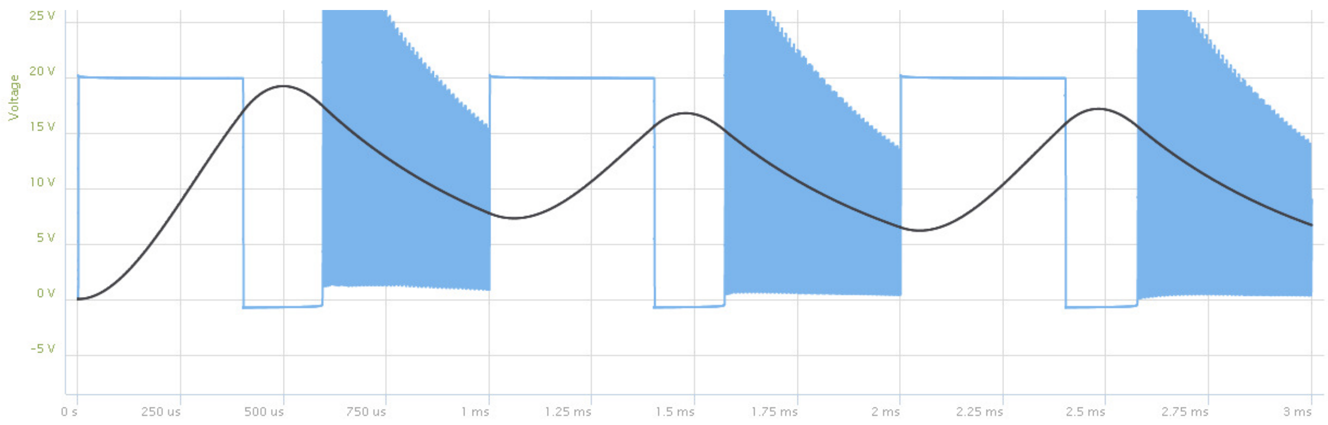
$$V_1 = 20.7V_{pp}$$

$$V_2 = \left(\frac{9.21 - j28.91}{(9.21 - j28.91) + (10 + j68.20)}\right) \cdot 20.7V_{pp}$$

$$V_2 = 16.12V_{pp}$$

4) Simulated your design for problem #3 in PartSim (or similar program) to verify the DC and AC voltages at V2





	V1		V2	
	DC	AC	DC	AC
Calculated	7.58 V	20.7 Vpp	6.89 V	14.36 Vpp
Simulated	?	20.67 Vpp	11.67 V	10.96 Vpp

5) Modify this circuit so that the votlage at V2 is

- 5V (DC)
- 250mVpp (AC)

DC:

$$V_2 = 5V$$

$$V_1 = \left(\frac{100+10}{100}\right) V_2 = 5.50V$$

$$5.50V = \alpha \cdot 20V + (1-\alpha)$$

$$\alpha = \left(\frac{5.50+0.7}{20+0.7}\right) = 0.2995$$

Duty Cycle = 29.95%

AC:

Pick L to reduce the ripple by 10x (ripple becomes 2.07 Vpp)

$$|j\omega L| = 10 \cdot R_{load} = 1000\Omega$$

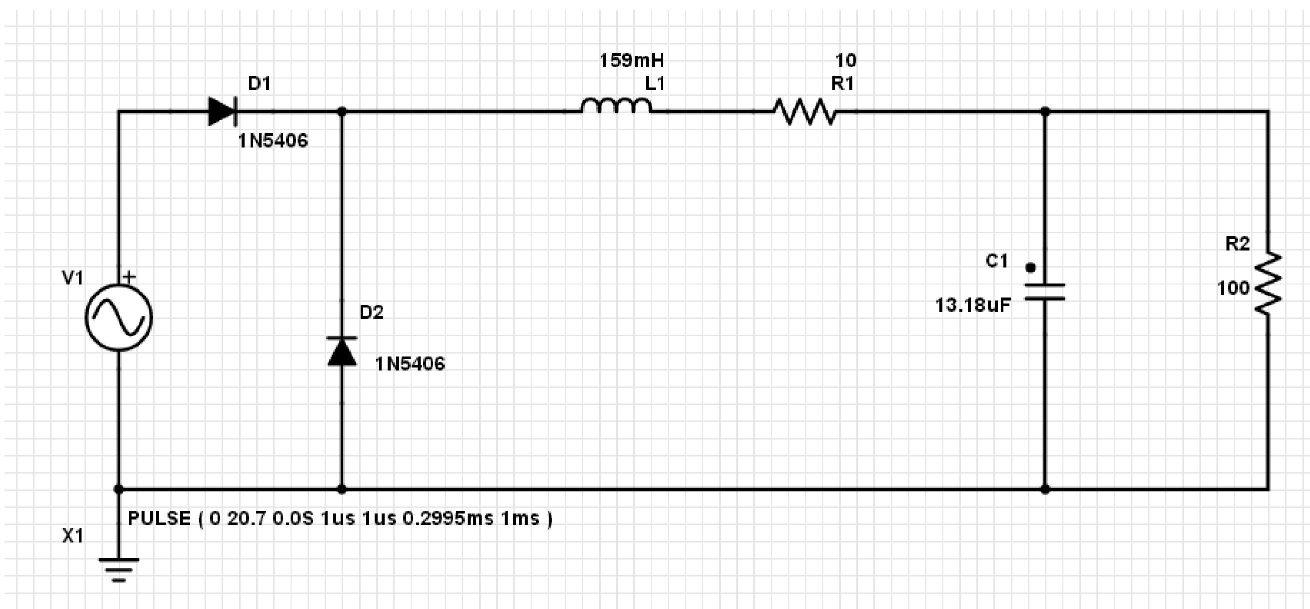
$$L = 159mH$$

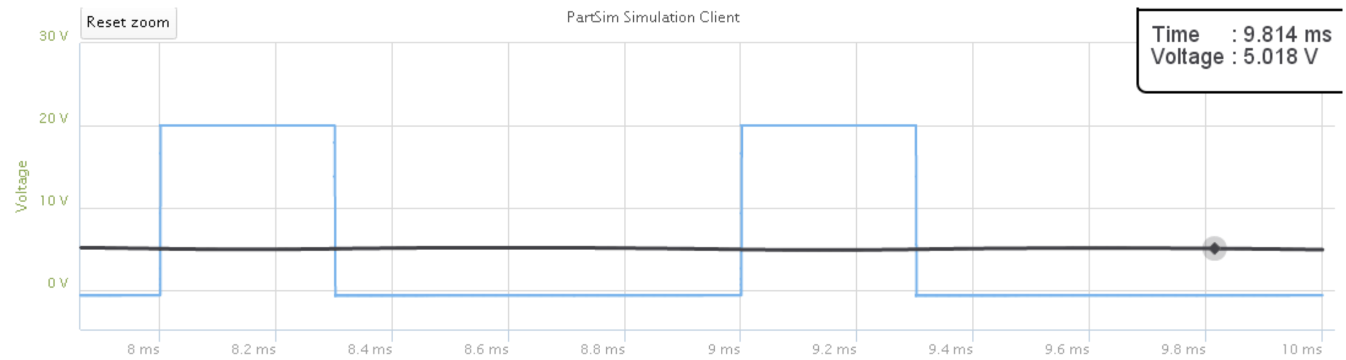
Pick C to reduce the ripple down to 250mVpp

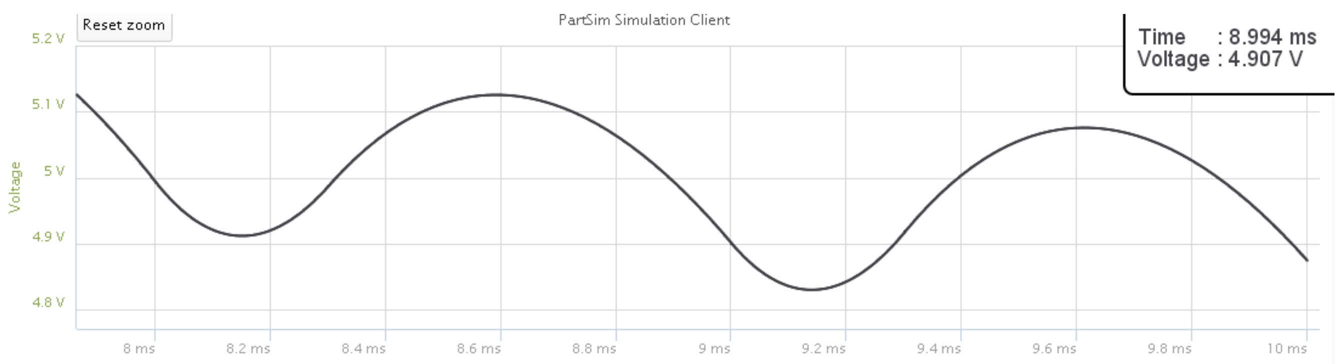
$$\left|\frac{1}{j\omega C}\right| = \left(\frac{250mV_{pp}}{2.07V_{pp}}\right) \cdot 100\Omega = 12.08\Omega$$

$$C = 13.18\mu F$$

Checking in PartSim (not required)







	V1		V2	
	DC	AC	DC	AC
Calculated	5.50 V	20.7 Vpp	5.00 V	250mVpp
Simulated	?	20.67 Vpp	4.95 V	246mVpp

Fourier Transform:

6) Find the Fourier transform for V1 (problem #3) out to the 5th harmonic. (a 40% duty cycle square wave at 1kHz)

$$V_1(t) = \begin{cases} 20V & 0 < t < 400\mu s \\ -0.7V & 400\mu s < t < 1ms \end{cases}$$

In Matlab (actually SciLab)

```
t = [0:0.0001:1]';
x = 20*(t < 0.4) - 0.7*(t >= 0.4);

t = t * 2*pi;

c0 = mean(x);
c1 = 2*mean(x .* exp(-j*t) );
c2 = 2*mean(x .* exp(-j*2*t) );
c3 = 2*mean(x .* exp(-j*3*t) );
c4 = 2*mean(x .* exp(-j*4*t) );
c5 = 2*mean(x .* exp(-j*5*t) );
[c0;c1;c2;c3;c4;c5]

N      c(N)
0    7.5791721
1    3.8761426 -11.917231i
2   -3.1316587  -2.2781891i
3    2.0899225  -1.5155117i
4   -0.9645298  -2.9808269i
5   -0.0001400  -3.540D-16i
```

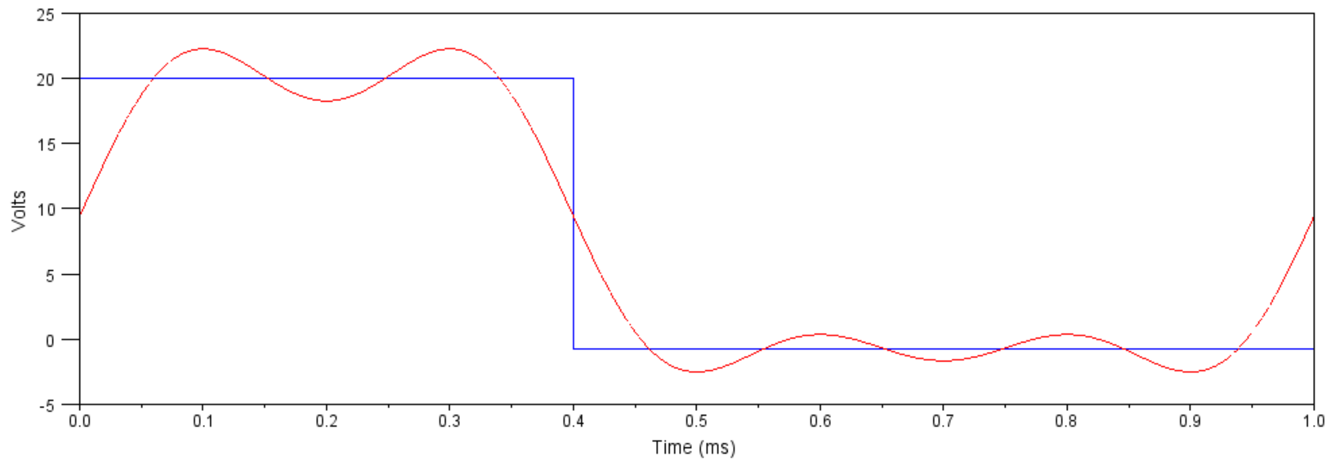
This means

$$\begin{aligned} x(t) = \; & 7.579 + 3.876\cos(6280t) + 11.917\sin(6280t) \\ & -3.131\cos(2 \cdot 6280t) + 2.278\sin(2 \cdot 6280t) \\ & +2.089\cos(3 \cdot 6280t) + 1.155\sin(3 \cdot 6280t) \\ & -0.964\cos(4 \cdot 6280t) + 2.980\sin(4 \cdot 6280t) \\ & +0.000\cos(5 \cdot 6280t) + 0.000\sin(5 \cdot 6280t) \end{aligned}$$

Plotting this in MatLab

```
xf = c0;
xf = xf + real(c1)*cos(t) - imag(c1)*sin(t);
xf = xf + real(c2)*cos(2*t) - imag(c2)*sin(2*t);
xf = xf + real(c3)*cos(3*t) - imag(c3)*sin(3*t);
xf = xf + real(c4)*cos(4*t) - imag(c4)*sin(4*t);
xf = xf + real(c5)*cos(5*t) - imag(c5)*sin(5*t);

t0 = t/(2*pi);
plot(t0,x,t0,yf);
xlabel('Time (ms)');
ylabel('Volts');
```



x(t) (blue) and its Fourier approximation taken out to the 5th harmonic (red)

7) Using the results from problem #6, find V2(t) in terms of its Fourier Trasnform out to the 5th harmonic.

Sample Calculations:

$$n = 3$$

$$\omega = n \cdot 6280 = 18,840 \ \frac{\text{rad}}{\text{sec}}$$

$$V_1 = 2.0899 \text{ -j}1.5155$$

$$L \rightarrow j\omega L = j188.4\Omega$$

$$C \rightarrow \frac{1}{j\omega C} = -j10.61\Omega$$

$$100\Omega \ || \ -j10.61\Omega = 1.114 - j10.497\Omega$$

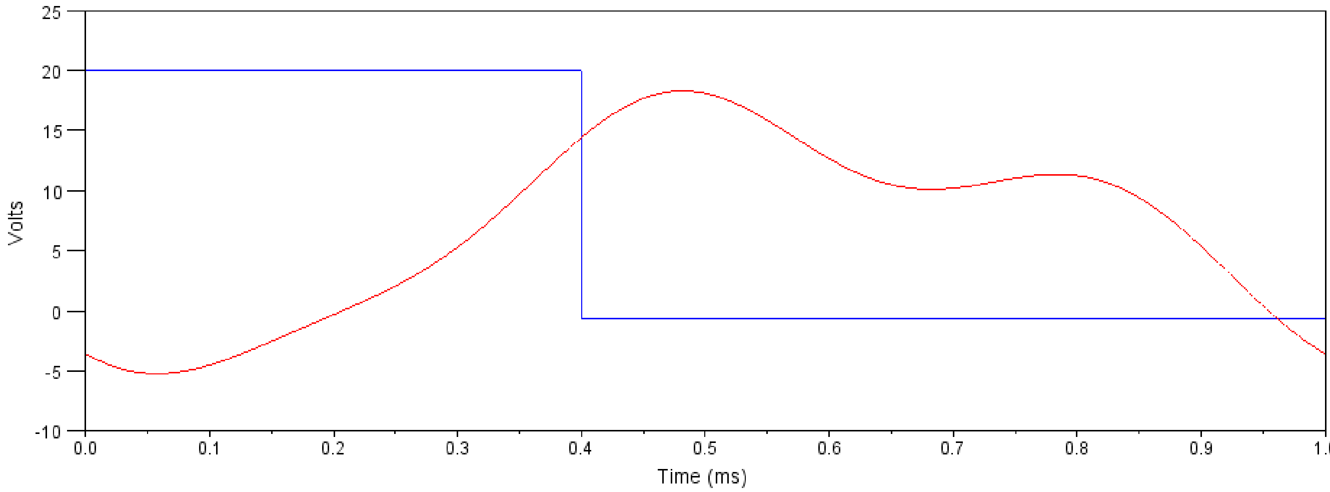
$$V_2 = \left(\frac{(1.114 - j10.497\Omega)}{(1.114 - j10.497\Omega) + (10 + j188.4)} \right) \cdot (2.0899 - j1.5155)$$

$$V_2 = 0.1370 + j0.0678$$

Repeating for all five terms

n	V1	gain	V2
0	7.58	0.9090909	6.8901564
1	3.876 -j11.917	-0.5292 - j0.5715	4.762 - j8.523
2	-3.131 -j2.278	-0.137 -j0.038	0.342 + j0.430
3	2.089 -j1.515	-0.058 - j0.010	-0.137 + j0.068
4	-0.964 -j2.980	-0.032 - j0.004	0.019 + j0.100
5	0.000 -j0.000	-0.021 -j 0.002	0

Plotting V2(t) in Matlab




```
R = 100;
C = 5e-6;
L = 0.01;
R1 = 10;

y0 = (100 / 110) * x0;

n = 1;
w = 6280*n;
Zc = inv(1/R + j*w*C);

g1 = Zc / (Zc + 10 + j*w*L);
y1 = g1 * x1;

n = 1;
w = 6280*n;
Zc = inv(1/R + j*w*C);

g2 = Zc / (Zc + 10 + j*w*L);
y2 = g2 * x2;

n = 3;
w = 6280*n;
Zc = inv(1/R + j*w*C);

g3 = Zc / (Zc + 10 + j*w*L);
y3 = g1 * x3;

n = 4;
w = 6280*n;
Zc = inv(1/R + j*w*C);

g4 = Zc / (Zc + 10 + j*w*L);
y4 = g4 * x4;


n = 5;
w = 6280*n;
Zc = inv(1/R + j*w*C);

g5 = Zc / (Zc + 10 + j*w*L);
y5 = g5 * x5;

y = y0;
y = y + real(y1)*cos(t) - imag(y1)*sin(t);
y = y + real(y2)*cos(2*t) - imag(y2)*sin(2*t);
y = y + real(y3)*cos(3*t) - imag(y3)*sin(3*t);
y = y + real(y4)*cos(4*t) - imag(y4)*sin(4*t);
y = y + real(y5)*cos(5*t) - imag(y5)*sin(5*t);


plot(t0,x,t0,y)
```