## ECE 320 - Homework \#6

H-Bridge, DC to DC Converters, Fourier Transforms. Due Wednesday, February 23rd

## H-Bridges:

The following circuit is $1 / 2$ of an H -bridge. (the mirror image (minus the 2.5 V supply) is repeated to the right for a full H -bridge). Also note: the $50 \mathrm{Ohm} \& 2.5 \mathrm{~V}$ source is the Thevenin equivalent of two 100 Ohm resistors (shown to the right). The circuit to the right is easier to build and is equivalent to the part shown in purple.

1) Determine the voltages and currents for the following $1 / 2 \mathrm{H}$-bridge for

- $\mathrm{V} 1=0 \mathrm{~V}, \mathrm{~V} 2=0 \mathrm{~V}$
- $\mathrm{V} 1=5 \mathrm{~V}, \mathrm{~V} 2=5 \mathrm{~V}$
- $\mathrm{V} 1=5 \mathrm{~V}, \mathrm{~V} 2=0 \mathrm{~V}$

Assume 3904/3906 transistors

- | Vbe I = 0.7 V
- current gain = 100
- $\mathrm{V}_{\text {ce(sat) }}=0.2 \mathrm{~V}$


2) Check your results (votlages and currents) in CircuitLab

3) Lab: Build this circuit and measure the voltages and currents. (note: it's OK to compute the currents from the measured votlages).

|  |  | Calculated | Simulated | Measured |
| :---: | :---: | :---: | :---: | :---: |
| $\mathrm{V} 1=5 \mathrm{~V}$ <br> $\mathrm{~V} 2=5 \mathrm{~V}$ | V 3 | 0.20 V | 86.89 mV | 0.09 V |
|  | 12 | -46.0 mA | -48.26 mA | -48 mA |
| $\mathrm{V} 1=0 \mathrm{~V}$ <br> $\mathrm{~V} 2=0 \mathrm{~V}$ | V 3 | 4.80 V | 4.884 V | 4.96 V |
|  | 12 | +46.0 mA | +46.87 mA | +49 mA |
| $\mathrm{V} 1=5 \mathrm{~V}$ <br> $\mathrm{~V} 2=0 \mathrm{~V}$ | V 3 | 2.50 V | 2.500 V | 2.46 V |
|  | 12 | 0.0 mA | 0.0 mA | -1 mA |



## DC to DC Converters

4) Determine the voltages (both DC and AC) for V1 and V2.


DC Voltage

$$
\begin{aligned}
& V_{1}(D C)=0.55 \cdot 20 \mathrm{~V}+0.45 \cdot(-0.7 \mathrm{~V}) \\
& V_{1}(D C)=10.685 \mathrm{~V} \\
& V_{2}(D C)=\left(\frac{75}{75+10}\right) \cdot 10.685 \mathrm{~V} \\
& V_{2}(D C)=9.428 \mathrm{~V}
\end{aligned}
$$

AC Voltage

$$
\begin{aligned}
& V_{1}(A C)=20.7 V_{p p} \\
& V_{2}(A C)=\left(\frac{(8.346-j 23.586)}{(8.346-j 23.586)+(10+j 314)}\right) \cdot 20.7 V_{p p} \\
& V_{2}(A C)=1.780 V_{p p}
\end{aligned}
$$

(note: take the magnitude of V2(AC). Phase doesn't matter)
5) Simulate the circuit in CircuitLab and determine V2 (DC and AC)

- $\max (\mathrm{V} 2)=10.38 \mathrm{~V}$
- $\min (\mathrm{V} 2)=8.206 \mathrm{~V}$
- $\mathrm{V} 2(\mathrm{DC})=(\max +\min ) / 2=9.293 \mathrm{~V}$
- $\mathrm{V} 2(\mathrm{AC})=(\max -\min )=2.174 \mathrm{Vpp}$

|  | V1 |  | V2 |  |
| :---: | :---: | :---: | :---: | :---: |
|  | DC | AC | DC | AC |
| calculated | 10.658 V | 20.7 Vpp | 9.428 V | 1.780 Vpp |
| simulated | - | - | 9.293 V | 2.174 Vpp |



6) Change the duty cycle and $C$ so that

- The DC voltage at $\mathrm{V} 2=5.00 \mathrm{~V}$
- The ripple at V 2 is 1 Vpp

$$
\begin{aligned}
& V_{2}=\left(\frac{75}{75+10}\right) V_{1} \\
& V_{1}=\left(\frac{85}{75}\right) V_{2}=5.667 \mathrm{~V}
\end{aligned}
$$

Duty cycle

$$
\alpha=\left(\frac{5.667 V+0.7 V}{19.8 V+0.7 V}\right)=31.1 \%
$$

note: I'm using 19.8 V in the denominator to account for the 0.2 V drop across the PNP transistor when saturated

To bring the ripple down to 1 Vpp
$6 u F$ results in 2.174 Vpp ripple

$$
C=\left(\frac{2.174 V_{p p}}{1 V_{p p}}\right) 6 \mu F=13.04 \mu F
$$

7) Check your results for problem \#6 in CircuitLab

- $\max (\mathrm{V} 2)=5.435 \mathrm{v}$
- $\min (\mathrm{V} 2)=4.558 \mathrm{~V}$
- $\mathrm{V} 2(\mathrm{DC})=4.997 \mathrm{~V}$
- $\mathrm{V} 2(\mathrm{AC})=0.877 \mathrm{Vpp}$



## Fourier Transforms

8) Going back to problem \#4, determine the Fourier Transform for V1 out to the 3rd harmonic (3kHz)
```
>> t = [0:0.0001:1]';
>> V1 = 19.8 * (t<0.55) - 0.7*(t >= 0.55);
>>
>> X0 = mean(V1)
X0 = 10.5739
>> X1 = 2*mean(V1 .* exp(-j*2*pi*t))
X1 = -2.0124 -12.7307i
>> x2 = 2*mean(V1 .* exp(-j*4*pi*t))
X2 = 1.9178 - 0.6218i
>> X3 = 2*mean(V1 .* exp(-j*6*pi*t))
X3 = -1.7564 - 3.4549i
\[
\begin{aligned}
& \begin{array}{l}
V_{1}(t) \approx \\
\\
\\
\\
+2.01 \cos \left(\omega_{0} t\right)+12.73 \sin \left(\omega_{0} t\right) \\
\\
\\
-1.75 \cos \left(2 \omega_{0} t\right)+0.62 \sin \left(2 \omega_{0} t\right) \\
\omega_{0}=6280 \frac{\mathrm{rad}}{\mathrm{sec}}
\end{array}
\end{aligned}
\]
```


9) Using the Fourier Transform approximation for V1, determine V2 out to the 3rd harmonic (3kHz)
>> $\quad \mathrm{DC}$
>> $\mathrm{X0}=$ mean(V1);
$\gg G 0=75 / 85 ;$
$\gg Y 0=G 0 * X 0$;
$\mathrm{YO}=\quad 9.3299$
>> \% 1st harmonic

```
>> X1 = 2*mean(V1 .* exp(-j*2*pi*t));
```

$\gg \mathrm{w}=6280$;
$\gg L=j * W * 0.05 ;$
$\gg C=1 /(j * W * 6 e-6) ;$
$\gg R 2=1 /(1 / 75+1 / C) ;$
$\gg \mathrm{L}=0.05$;
>> C = 6e-6;
>> R2 $=1 /\left(1 / 75+j{ }^{*}{ }^{*} \mathrm{C}\right)$;
>> R1 = $10+j^{*} W^{\star} L$;
$\gg Y 1=(R 2 /(R 1+R 2)) * X 1$
$\mathrm{Y} 1=-0.2703+1.0747 \mathrm{i}$
>> Y1pp $=2 * a b s(Y 1)$
$\mathrm{Y} 1 \mathrm{pp}=2.2163$
>> \% 2nd harmonic
>> $\mathrm{X} 2=2 * \operatorname{mean}\left(\mathrm{~V} 1 .{ }^{*} \exp (-j * 4 * \mathrm{pi*t})\right)$;
$\gg \mathrm{w}=6280$ * 2;
$\gg R 2=1 /\left(1 / 75+j{ }^{*}{ }^{*} \mathrm{C}\right)$;
$\gg R 1=10+j * w^{*} L ;$
$\gg Y 2=(R 2 /(R 1+R 2)) * X 2$
$\mathrm{Y} 2=-0.0425+0.0051 \mathrm{i}$
>> \% 3rd harmonic
>> X3 = 2*mean(V1 .* exp(-j*6*pi*t));
>> w = 6280 * 3;
$\gg R 2=1 /\left(1 / 75+j{ }^{*}{ }^{*} \mathrm{C}\right)$;
$\gg R 1=10+j * W * L ;$
$\gg Y 3=(R 2 /(R 1+R 2)) * X 3$
$Y 3=0.0122+0.0344 i$

$$
\begin{array}{cc}
V_{2}(t) \approx & 9.3299 \\
& -0.270 \cos \left(\omega_{0} t\right)-1.075 \sin \left(\omega_{0} t\right) \\
-0.043 \cos \left(2 \omega_{0} t\right)-0.005 \sin \left(2 \omega_{0} t\right) \\
+0.012 \cos \left(3 \omega_{0} t\right)-0.034 \sin \left(3 \omega_{0} t\right)
\end{array}
$$

Note:

- In CircuitLab, V2(AC) $=2.174 \mathrm{Vpp}$, which closely matches the 1st-harmonic Y1pp.
- The harmonics past the 1 st harmonic are almost zero. Ignoring them doesn't change the results that much.

