EE462L, Power Electronics, H-Bridge as Audio Amplifier
Version April 1, 2014

The purpose of this experiment is to use your H-bridge inverter as an audio amplifier and analyze its performance. Step A of the experiment can be performed at any lab bench. Step B requires you to use the music test station with four 8Ω speakers in series. Sign up for a 30-minute time slot for the music test station, and please be considerate of others who are waiting to use it.

A. Inverter Performance with Vcont from a Benchtop Waveform Generator (perform this step at any lab bench)

1. **Make sure that your scope is plugged in through a "ground buster." Otherwise, using the scope and benchtop waveform generator at the same time will create a short circuit through the scope probes.**
2. No DBR power to the inverter yet.
3. Turn on the benchtop waveform generator. Adjust the settings for **100Hz** sinusoidal output and 4V peak. Note – the benchtop waveform generator will display 4Vpp. **It is important that you have no DC offset in the waveform.**
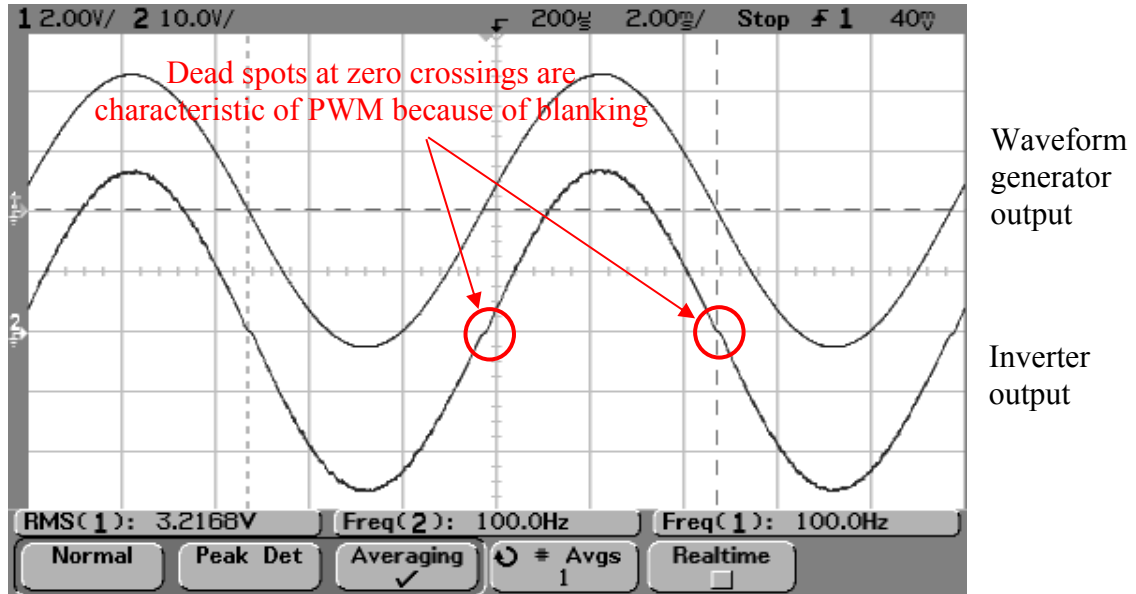

4. Energize your PWM Control Circuit. Connect Vcont from the benchtop waveform generator.
5. Confirm that your triangle wave is symmetric and in the 120kHz range.
6. With $m_a = 1.0$, view (VA – VB) output to ensure proper tune-up and operation. You may want to use a viewing filter.
7. Reduce m_a to zero.
8. Connect a 10Ω power resistor to your inverter output, and connect a DC ammeter between a (variac + transformer + DBR) and your inverter Vdc input.
9. Slowly raise the DC voltage to about 10V. If the ammeter still reads zero, go ahead and raise Vdc to the maximum.
10. **Read carefully to avoid a short circuit!** Connect scope probe #1 and its ground clip to view the inverter output voltage. Then, connect scope probe #2 to the $+V_{cont}$ signal, **but do not connect the #2 ground clip anywhere or you will likely short circuit the −12Vdc power supply**. Use an inverter output filter or scope "averaging over one cycle" to denoise the scope trace. The V_{cont} signal that you view is actually $V_{cont} + 12V$.
11. Adjust m_a to approximately 1.0 (i.e., the "fuzzy" flat spot at the maximum and minimum of the sine wave disappears).

12.   Confirm that the H-bridge inverter is working properly and producing a replica of the **100Hz** sinusoidal V_{cont}. Measure the DC voltage at the inverter output. It should be less than 0.1V.
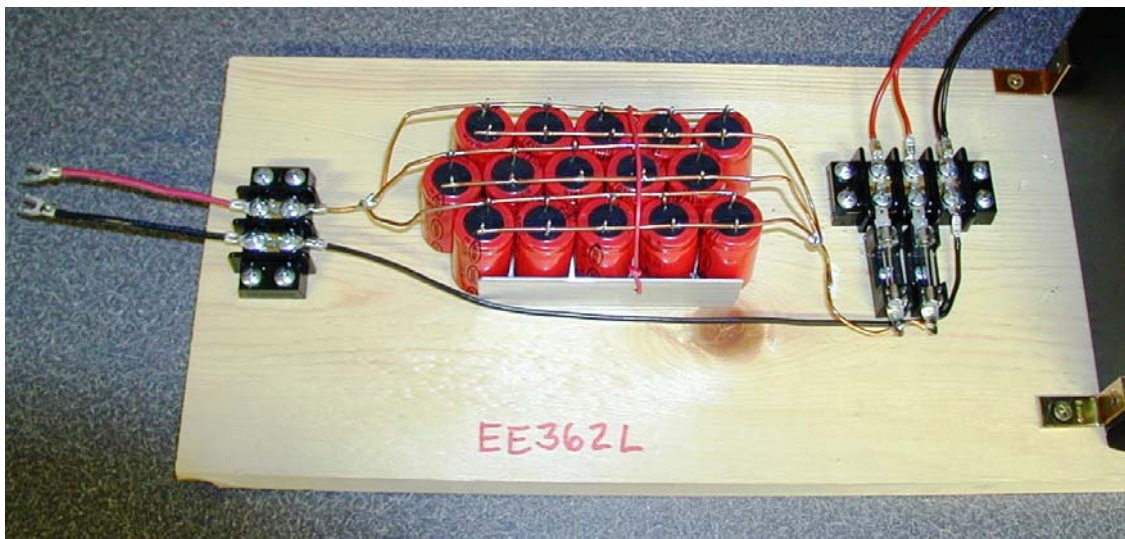

100Hz Test

13.   Disconnect scope probe #1.
14.   Take the FFT of the inverter output voltage, focusing on the 0 to 5kHz range. Observe the significant peaks, and take note of their frequencies and magnitudes. Compute the THD of the voltage, using the equation shown in the appendix.
15.   Repeat Steps 11 through 14 using 1kHz, and then 5kHz Vcont from the waveform generator. **Observe the FFT over the 0 to 10kHz range**.
16.   Experiment with higher triangle wave frequencies, for example 150kHz or 200kHz, to see if the THD at 1kHz and 5kHz can be lowered. Make sure that your triangle wave is still clean.

B. Inverter Performance with Vcont from a Laptop or IPOD
(sign up for a 30-minute time slot and perform this portion at the Music Test Station)

Four 8Ω speakers in series present 32Ω to the inverter

495µF in series with speakers to block the flow of DC current

18. The Music Station has a 0-15Vdc power supply and series ammeter. Start with this power supply because it will limit the inverter output to about 2W. Afterwards, you may want to switch over to a DBR so that you can raise Vdc to 35-40V. **But 40V will be loud!**

19. Connect a laptop or IPOD as your Vcont, using a stereo jack to red/white phono adapter. Your PWM Inverter Control Circuit will sum both channels for a mono Vcont. Use your own music, or EE462L's CD at the music station, which contains

   Track 1. The Hollies, "Long Cool Woman in a Black Dress"
   Track 2. Eagles, "Peaceful Easy Feeling"
   Track 3. America, "Sister Golden Hair"
   Track 4. Electric Light Orchestra, "Don't Bring Me Down"
   Track 5. Charlie Dore, "Pilot of the Airways"
   Track 6. The Beach Boys, "Help Me, Rhonda"
   Track 7. The Moody Blues, "Your Wildest Dreams"
   Track 8. Ronnie Milsap, "Any Day Now"
   Track 9. Fleetwood Mac, "You Make Loving Fun"
   Track 10. Steppenwolf, "Magic Carpet Ride"
   Track 11. Roger Miller, "Chug-A-Lug"

20. Before connecting the 0-15Vdc power supply to your inverter, first start the music signal and observe (VA – VB) from your PWM Inverter Control Circuit. You will likely need to raise your laptop or IPOD to full volume, and then boost the gain more with the volume control on our circuit. Raise the music signal level until very little clipping is seen on (VA – VB) while your song plays.

21. Use Vdc as your "volume control" and enjoy the music!

Comments
- Your inverter, which is used mostly for motor drives and power-to-grid purposes, is also known as a Class D amplifier. It is very efficient, but the music quality is not as good as conventional linear amplifiers (which, by the way, have only 50% max efficiency).
- A rule of thumb is that Class D amplifiers are OK for frequencies up to f_{tri} / 30. In your case, f_{tri} is about 120kHz, so your amplifier is generally OK through 4kHz.
- Class D amplifiers are best suited for powerful bass applications. As you have seen in previous experiments, your inverter can produce 100W from a 40Vdc supply without difficulty.

Appendix. Total Harmonic Distortion (THD)

The THD (in percent) of a waveform is defined as the rms value of the harmonics divided by the rms value of the fundamental, or

$$THD(\%) = \left[\frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots}}{V_1} \right] \bullet 100\% \,,$$

where V_1 is the fundamental frequency component, V_2 is the second harmonic, etc. If the harmonics are given in per unit of the fundamental, a more convenient form of the expression is

$$THD(\%) = \left[\sqrt{\left(\frac{V_2}{V_1}\right)^2 + \left(\frac{V_3}{V_1}\right)^2 + \left(\frac{V_4}{V_1}\right)^2 + \cdots} \right] \bullet 100\% \,.$$

When one harmonic, e.g. harmonic k, is much greater than the others, it dominates the sum of squares, and the expression becomes

$$THD(\%) \approx \left[\frac{V_k}{V_1} \right] \bullet 100\% \,.$$