EE462L – H-Bridge Audio Amplifier Lab

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Spring, 2015

Lab Overview

This lab is a further extension of the previous work on building and testing a H-Bridge circuit. In this lab an audio source is used as th

e PWM control signal and the amplification level is changed by adjusting the DC voltage of the H-Bridge [1]. A block diagram is shown in Fig. 1.

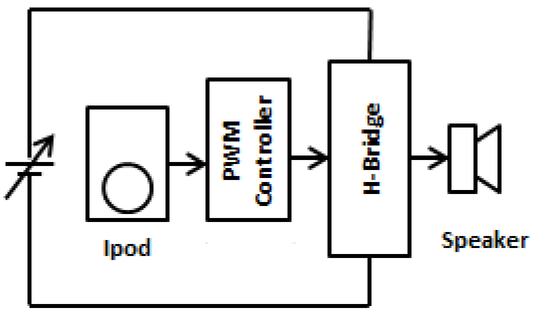


Figure 1. Block diagram of H-Bridge circuit based audio amplifier.

Modulation Index Measurements

In a H-Bridge amplifier it is important to set the modulation index m_a close to 1. If m_a is much less than 1 then the fundamental component in the H-Bridge output, which is the main signal of interest, will be weak. If m_a is much bigger than 1 the output signal will be clipped and distorted. This section describes various methods to check the modulation index m_a.

In the first method, the PWM controller circuit is first adjusted to set the carrier signal Vtri to be around 137 kHz (using a 1.5nF C_F capacitor) and to ensure the triangular wave is symmetric. Then a 4V, 100 Hz sinusoidal control signal Vcont is applied from a signal generator. The two signals are observed simultaneously on an oscilloscope and the amplitude of the Vcont wave is adjusted to make it visually equal to the amplitude of Vtri. Fig. 3 shows the resulting waveforms. The heights of the two waveforms are about the same. The scope readouts are 8.40V and 8.32V for Vtri and Vcont, respectively. This implies a modulation index of 0.99. Additionally, the frequency ratio m_f from the scope readouts is 140.4kHz/99.97Hz or 1404.42.

In the second approach, the PWM signal VA-VB was observed on the oscilloscope. Results are as shown in Fig. 3. It is seen that there is a "gap" in the middle which indicates some amount of overmodulation.

In the third approach, the same VA-VB waveform is examined, but a filtered view is used. Results are as shown in Fig. 4. There is a small amount of clipping at the tops of the wave, indicating a small amount of overmodulation.

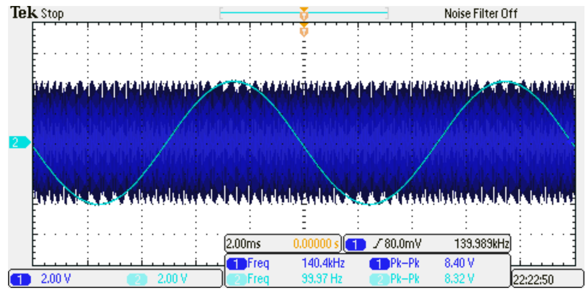


Figure. 2 Measured Vcont and Vtri signals showing a modulation index very close to 1.

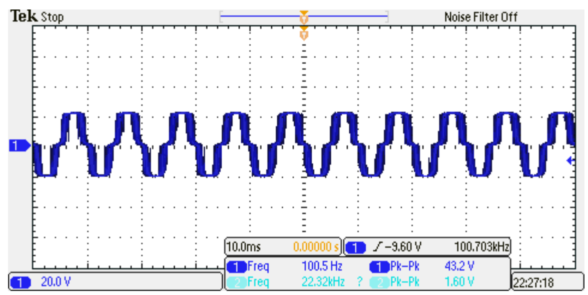


Figure. 3 Measured PWM signal VA-VB, unfiltered.

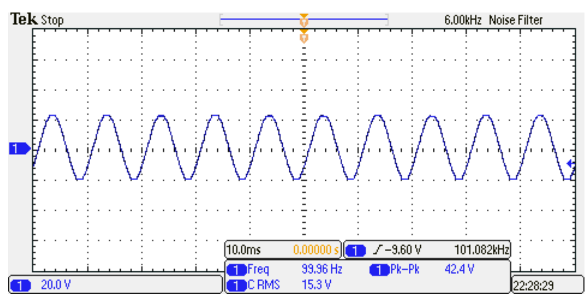


Figure 4. Measured PWM signal VA-VB, filtered.

Based on the above results it appears that the second method of using unfiltered (VA-VB) is the best method to achieve a modulation index of 1. A suitable procedure would be to keep increasing the amplitude of Vcont from a small value till as "gap" just appears in the unfiltered view and then pull back a bit to close the gap. Fig. 5 shows such a waveform of (VA – VB) which is at the edge of $m_a = 1$..

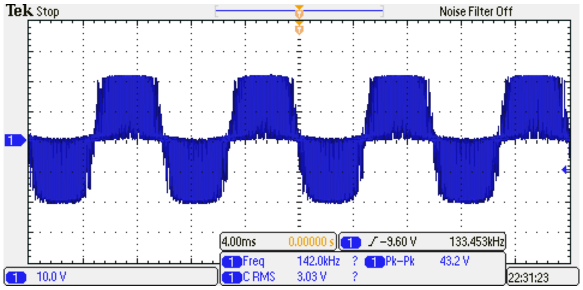


Figure 5. Unfiltered VA-VB output at the edge of over-modulation..

H-Bridge Output and Efficiency Measurements

Next, a nominal 10 ohm power resistor is connected to the H-Bridge output. The exact value of this resistor, as measured on a multimeter, is 10.5 ohms. The AC supply to the DBR powering the H-Bridge is adjusted to about 28V. The modulation index is adjusted to 1 and a 100Hz sine wave with 4V amplitude is used as Vcont. Fig. 6 shows the resulting output signal. The lower sine wave is the 100 Hz Vcont signal. Its rms is 2.67V compared to a theoretically expected value of $4/\sqrt{2} = 2.83$V. The upper waveform is the filtered H-Bridge output. Its frequency is practically the same as the frequency of Vcont, i.e. 100Hz, and its rms voltage is 9.03V. Careful observation shows a slight distortion around the zero crossing points. This is due to the dead time introduced by the gate drive circuit in order to prevent the possibility of shoot through where both high side and low side mosfets of the H-Bridge are conducting at the same time.

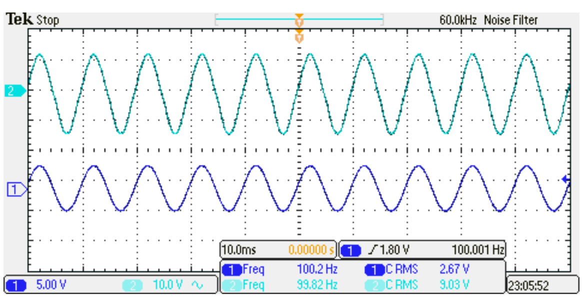


Figure 6. Measured waveforms of Vcont and H-Bridge output.

Using a multimeter, the dc voltage at the H-Bridge output is measured. It is found to be 23 mV which is negligibly small.

In order to estimate the efficiency of the H-Bridge amplifier, the input DC voltage and current are measured. These are found to be 34.61V and 1.36A, respectively. Thus, the input power is 47.07W. On the output side, the ac voltage is measured to be 19.49V. Since the load resistor is 10.5 ohms, the output power is 36.18W. This implies an efficiency of 76.9%. This is comparable to the efficiencies measured in the dc-dc converter experiments.

H-Bridge THD Measurements

Next, the THD of the H-Bridge amplifier is estimated from the FFTs of the output waveform for control signal frequencies of 100 Hz, 1 kHz, and 5 kHz. Fig. 7 shows the FFT of the H-Bridge output with a control signal frequency of 100 Hz. The fundamental output is 20dB while the third harmonic is at -7.2dB. Ignoring the contributions of higher harmonics the resulting THD is 4.37%.

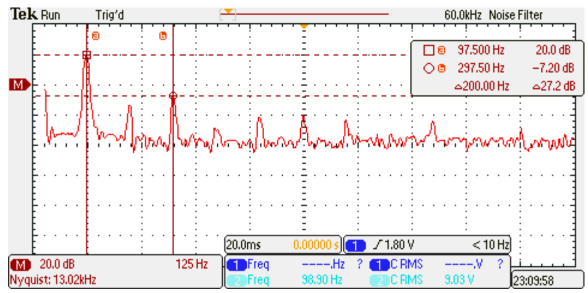


Figure 7. FFT of H-Bridge output with 100Hz control signal..

Fig. 8 shows the FFT of the H-Bridge output with a control signal frequency of 1 kHz. The fundamental output is 16.8dB while the third harmonic is at -3.2dB. Again, ignoring the contributions of higher harmonics the resulting THD is 10%.

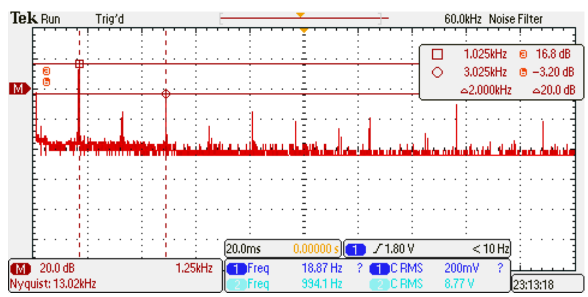


Figure 8. FFT of H-Bridge output with 1kHz control signal..

Fig. 9 shows the FFT of the H-Bridge output with a control signal frequency of 5 kHz. The fundamental output is 20dB while the second harmonic is at 3.2dB and the third harmonic is at -6dB. Again, ignoring the contributions of higher harmonics the resulting THD is 14.5%.

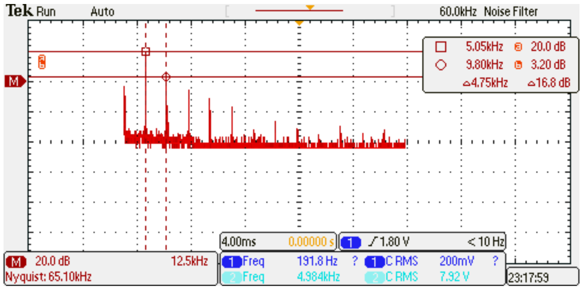


Figure 9. FFT of H-Bridge output with 5 kHz control signal..

Attempts to improve the THD at higher frequencies by lowering fTri (frequenct of the triangular signal) were not very successful. This is probably because it reduces the separation between the harmonics of the control signal and fTri.

Audio Amplifier Measurements

This section describes measurements done with an actual music source feeding into the Vcont port of the H-Bridge amp, as hown in Fig. 1. By adjusting the volume control of the audio source and the gain potentiometer of the controller circuit, the modulation index m_a is first set to about 1. Fig. 10 shows the resulting comparison of the audio signal and Vtri. The amplitudes of both can be seen to be about the same.

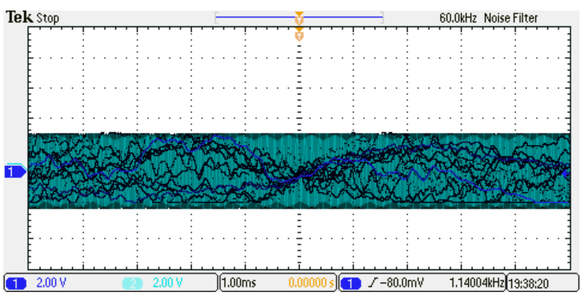
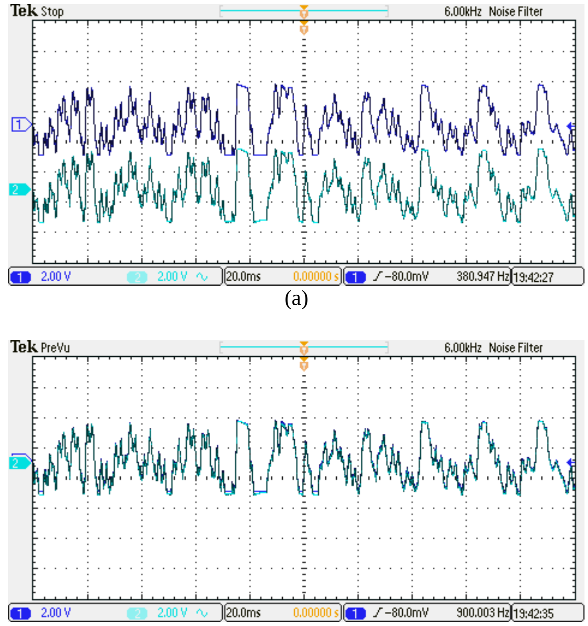


Figure 10. Time domain waveforms of the audio signal and carrier signal (Vtri), showing a modulation index very close to 1.

Lastly, with the H-Bridge powered up, the input and output signals were measured simultaneously on the oscilloscope. Fig. 11 shows the comparison. It is seen that the input and output signals are very similar with a few areas of clipping visible in this passage. The noise filter threshold had to be set at 6 kHz to capture a clean signal although it was recommended to keep this threshold above 20 kHz to allow the entire audible spectrum to pass.



(a)

(b)

Figure 11. Time domain waveforms of the input audio signal and H-Bridge output signal. In (a) the plots are separated, in (b) they are overlayed to show similarity. Probe 1 = input, probe 2 = output.

Answers to Questions

a) Higher order harmonics in H-Bridge output signal are screened out by the oscilloscope's input filter. When the H-Bridge output is connected to a speaker, the speaker itself acts like a filter since its frequency response is typically limited to the human audible range.

b) For the audio lab, in order to remove any dc content in the H-Bridge output before feeding it to the speakers, a bank of capacitors of 495 μF is connected in series between the H-Bridge and the speakers. The capacitance is large enough for its impedance to be low compared to the speaker impedance over the range of audible frequencies.

c) The resonant frequency is the value of f for which the reactances of the capacitor and inductor cancel each other out. Therefore $2\pi fL = 1/(2\pi fC)$, which leads to $f = 1/\{2\pi\sqrt{(LC)}\}$. Plugging in L = 100μH and C = 10mF gives the resonant frequency to be 5.033kHz.

Conclusions

This lab shows that the H-Bridge we have built and tested previously can function as a decent audio amplifier for those non-audiophiles. The input audio signal and output audio signal after amplification are very similar, however the amplified signal is not an exact replica of the input signal and if the input voltage to the H-bridge is raised too high, the amplified audio signal can become distorted and clip at its peaks.

	Rounok	Jonathan
Circuit Build	N/A	N/A
Circuit Test	50%	50%
Lab Report	60%	40%

References

[1] M. Flynn, "_Lab_Week_13_EE462L_H_Bridge_Audio_Amp.pdf", The University of Texas at Austin, Austin, TX, EE 462L: Power Electronics Laboratory course, Spring 2015. [Online]. Available: https://utexas.instructure.com/courses/1129504