WORKREADY ELECTRONICS

lab activity

Class D Amplifiers Lab

Lab Summary: The purpose of this hands-on laboratory is to construct the class D amplifier circuit introduced in the Drill Down and Simulation. The lab describes small manageable block level discussions of the (a) Analog and Triangle Wave Input Generators, (b) Analog Comparator, (c) Power MOSFET Output, and (d) Low Pass Filter Output Modules. The circuit is affordable to build using readily available components.

Lab Goal: Construct a class D amplifier circuit, observe its operation, and perform measurements related to its operation.

Learning Objectives

1. Explain switching amplifier operation at the component level.
2. Determine the ratio of the analog input signal to the triangle wave input.
3. Describe the PWM pattern of a class D amplifier.
4. Determine the duty cycle of a circuit.
5. Compare the output of the simulation circuit when the input parameters are changed.

Grading Criteria: Your lab grade is determined by your performance in the lab, lab questions, and quality of your final written report.

Approximate Time Required: 3 hours

Equipment and Supplies

Part	Quantity	Description
Equipment:		
Protoboard (Breadboard)	1	Circuit assembly board
Signal generator	2	Sine wave and triangle wave outputs up to 100kHz; ±15 V_{pp}
Oscilloscope, 2 channel, probes	1	Digital storage capability helpful but not required
Hookup wire		Solid core recommended
Wire stripping tool		
Power supply	1 or 2	1 ±15 v DC output or 2 15V DC (Configured as ±15v output device)
Banana clip leads	3	
Components:		
Q_1 IRF 530N	1	N Channel E-MOSFET
Q_2 IRF 9530	1	P Channel E-MOSFET
U_1 LM311N	1	Comparator
R_3	4.7 kΩ	Resistor ¼ watt, 5% tolerance
R_L	600 Ω	Resistor ¼ watt, 5% tolerance
R_1, R_2	1 kΩ	Resistor ¼ watt, 5% tolerance
L_1	120 mH	Inductor
C_1	0.22µF	Capacitor

Lab Preparation

1. Read web based “Switching Amplifier Module”.
2. Print this entire procedure to use as a reference, schematic, and workbook while completing the lab.
3. Read the Introduction (below).
4. Review the Lab Procedures (below).

Introduction

In this lab, you will assemble, test, and operate the same class D amplifier that was used in the simulation activity. The circuit is constructed in a modular fashion based on the same four modules from the simulation. Measurements will be taken where appropriate to allow you to build and confirm circuit operation module by module as you move to more complex circuit connections. This increases the chances of the circuit working when fully assembled. The modular approach is one that successful technicians incorporate in both testing and assembly of new designs.

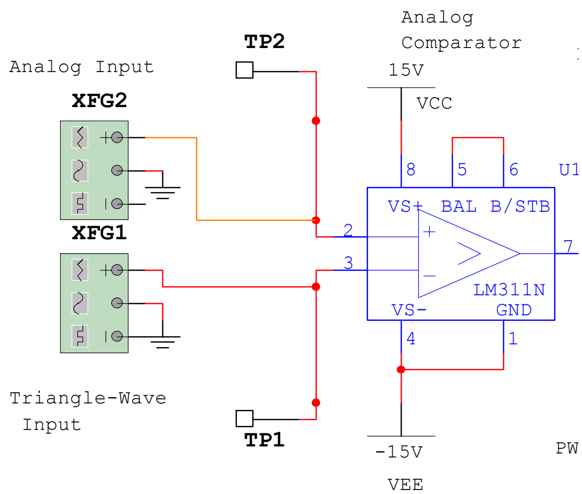
The four modules are (a) Analog and Triangle Wave Input Generators, (b) Analog Comparator, (c) Power MOSFET Output, and (d) Low Pass Filter Output Modules.

Lab Procedures

NOTE: The schematic, block diagram, protoboard layout, lab questions, and table are at end of this document. The circuit will be constructed on a protoboard module that uses wire jumpers to make connections between contacts. Strip both ends of the required jumper and connect to the indicated points. Keep wires neat and short to improve circuit operation and aid in troubleshooting when required.

1. Verify oscilloscope calibration.
   a. Turn oscilloscope on.
   b. Connect both Channel A and Channel B to the oscilloscope calibration test point.
   c. Verify that both channels are reading the proper levels of voltage and time by comparing your readings with those printed on the face of the calibration test point.
   d. If the readings are not in calibration, ask your instructor for assistance.
   e. If at any point in this lab, you fail to see waveforms on the oscilloscope graticule, reconnect the suspect channel or probe to the oscilloscope calibration test point on the oscilloscope, and reconfirm functionality before continuing.

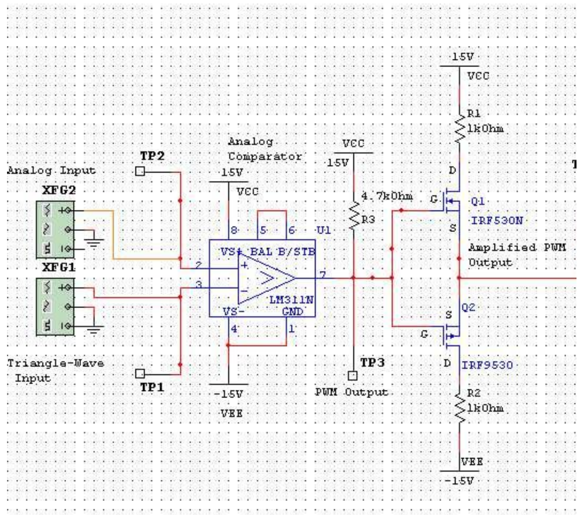
Analog and Triangle-Wave Input Generators Module



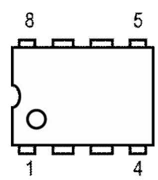
NOTE: In a typical class D amplifier, there is a specific circuit that generates the required triangle wave that forms part of the pulse width modulating circuit. In this lab, both the analog input signal and triangle wave signal are generated using bench top signal generators.

2. Connect the analog input signal generator (XFG2) to oscilloscope channel 1.
3. Adjust the signal generator to output a sine wave of 5 V_{pp} at a frequency of 1 kHz. Record your measurements in Table 1.
4. Connect signal generator 2, (XFG1) to oscilloscope channel 2.
5. Adjust the signal generator to produce a triangle wave output of 10 V_{pp} at a frequency of 10 kHz. Record your measurements in Table 1.
6. Answer questions 1 and 2 at the end of this procedure.
7. Count the number of triangle wave cycles (Channel B) on the oscilloscope graticule that occur for one cycle of the sine wave input (Channel B).
   a. You may have to adjust your oscilloscope triggering to slow the waveforms down to do this.
   b. If you have a digital scope, store the waveforms and then analyze them.
8. Record your answer in the Table 1.

Analog Comparator Module



9. Place an LM311N comparator chip at the left edge of the protoboard. Pin 1 should sit on the bottom edge of the board as you hold it in your hands and look down on it. Pin 1 has a small circle printed or notched into the component. Refer to the figure below for the pinout.



Front View

10. Insert one end of a jumper wire into a hole that connects to pin IC1-2 of the comparator chip.

11. Connect the other end of the wire to the sine wave generator (XFG2) output test clip lead.

12. Insert one end of a second wire into a hole that connects to IC1-3 of the comparator chip.

13. Connect the other end of the wire to the triangle wave signal generator (XFG1) output test clip lead.

CAUTION: Verify the DC supply is turned off for safety purposes.

14. Prepare your DC supplies.
    a. Configure one for +15 volt output and the other for -15 volt output.
    b. Verify the voltages with a digital multimeter.
    c. Turn the power off when setup is complete.

15. Make the following connections to LM311N:
    a. +15 V to pin 8 of the LM311N. Pin 8 is the comparator's positive power supply input.
    b. Pins 1, 4 both connect to -15 volt. Pin 1 is the comparator's negative power supply input. Pin 4 shorts to Pin 1.

c. Pins 5,6 are connected together using a jumper wire.

d. Connect one side of resistor R_3 (4700 ohms) to pin 7 of the LM311N and the other side to the +15 volt supply as shown in the schematic.

16. Connect oscilloscope probe Channel B to TP1 using a jumper wire as a test point.
17. Connect oscilloscope probe Channel A to TP2 using a jumper wire as a test point.
18. Configure the oscilloscope time base as close to 200µs/div as possible.
19. Set the oscilloscope vertical sensitivity knob (v/div) at 10v/div for both channels.
20. Apply power to the circuit. Monitor for excessive heat or smoke from the comparator. Gently place your finger on the top of the chip. If it feels hot, disconnect and check your wiring.
21. If you have connected your oscilloscope properly, waveforms should fill the screen from both channels.
22. Use a digital multimeter and verify the power supply voltages:
    a. IC 1 pin 8 = 15 volt Actual measurement: __________
    b. IC 1 pin 4,1 = -15 volt Actual measurement: __________

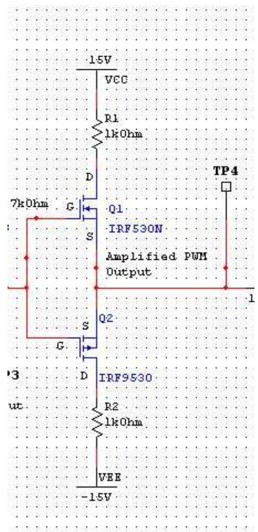
NOTE: If your design appears somewhat noisy, you may need to use bypass power supply capacitors (0.1µF). These are shown in the completed design board at the end of this procedure.

CAUTION: Do not move on if you cannot properly verify voltages at any stage in this lab indicating your circuit may not be performing as required.

23. Align channel A and B of the oscilloscope at the top of the oscilloscope grid.
24. Move Channel B oscilloscope probe to TP3 (PWM output of the comparator)
25. If you have properly constructed your circuit, you should see the analog input sine wave and the PWM waveform on channel B. This completes the assembly of the first two modules of the amplifier.
26. Answer questions 3 and 4 at this time.
27. If your measurements were correct, the comparator output swings close to ±15 volt. The positive rising and falling edge of the PWM signal turns ON/OFF MOSFET Q_1 while the negative falling and rising edge turns ON/OFF MOSFET Q_2.
28. Set the time-base setting to 500µs or greater to view more waveform cycles of the analog input sine wave.
29. Notice the pattern between the analog input and the duty cycle or waveshape of the PWM signal. In particular, observe the “pulse widths” from the comparator output and how they relate to the analog input. The analog input in this circuit is a sine wave but could be music, voice, or other data that requires amplification.

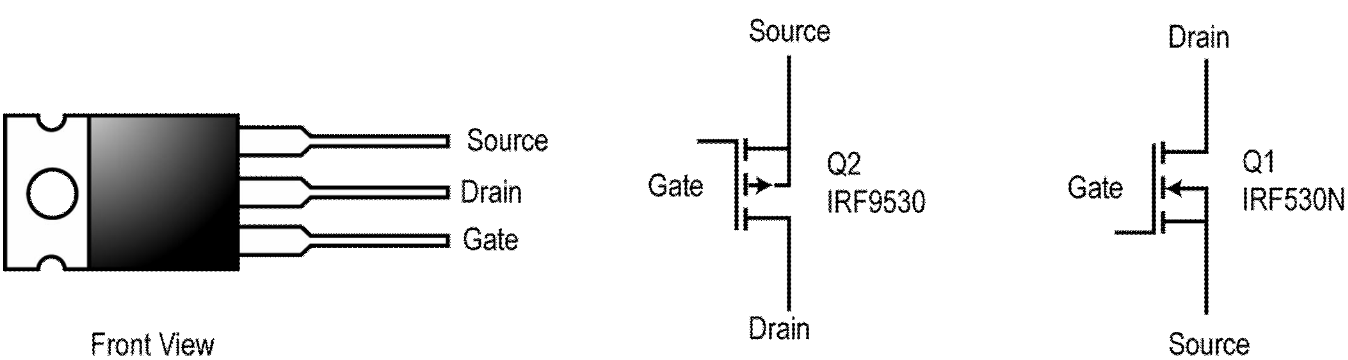
30. Review the oscilloscope output. In some cases, you may have to freeze the scope or store the data if the oscilloscope has storage capability. This will make viewing easier.
31. Answer questions 5 and 6 at this time.
32. Turn the DC power and the signal generators off as you assemble the next stage on your circuit.

Power MOSFET Stage:



NOTE: MOSFETs are static sensitive devices and proper care should be taken when handling them.

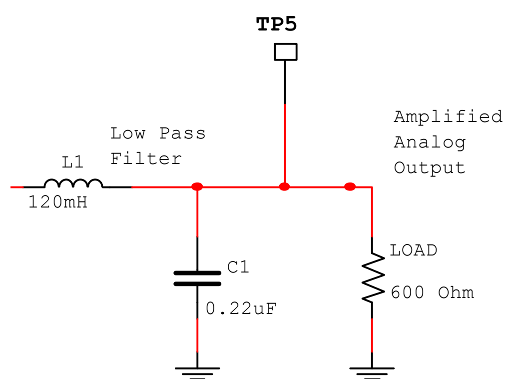
33. Review the component pinout for MOSFETs Q_1 and Q_2 as shown below.



34. Insert the two MOSFET devices into the protoboard area to the right of the comparator.
35. Add a wire that connects the gates of both FETs together and then run a separate wire from Pin 7 of IC 1 to the gate of either MOSFET.
36. Add a jumper wire between the source of Q_1 and the source of Q_2. This test point is TP4 in the schematic.

37. Connect resistor R_1, to the drain of Q_1 MOSFET and the other end of R_1 to +15 volt.
38. Connect resistor R_2, to the drain of Q2 MOSFET and the other end of R_2 to -15 volt.
39. Connect Channel A oscilloscope probe to TP2 (Analog Input).
40. Connect Channel B oscilloscope probe to TP4 (Amplified PWM Output).
41. Turn on the ±15 volt supplies and power to both signal generators 1 and 2.
42. If you have successfully connected all your wires and parts, you should see the analog input sine wave on Channel A and a PWM output from the MOSFETS on Channel 2. The PWM signal should resemble what you saw at the output of the comparator at TP3, but it will be somewhat noisy and distorted from the MOSFET switching action.
43. Set the sensitivity (volts/div and sec/div) of each oscilloscope channel so you can view 1-2 complete cycles of the sine wave on Channel A and the full amplitude of both channels.
44. Trigger your oscilloscope to synchronize the waveforms or store them if you have a digital oscilloscope to make viewing easier.
45. Observe how the analog input signal peaks as the PWM output of the MOSFET circuit reaches it largest ON time pulse widths at maximum analog input voltages and how narrow the pulses become as the analog input transitions to its negative voltage maximum. This pulse width ON time drives the filter stage of the amplifier where the original analog signal is recovered.
46. Answer question 7 at this time.
47. Turn the power and signal generators off as you assemble the low pass filter stage

Low Pass Filter Module



48. Connect the appropriate wires for L_1 (120mh), C_1 (0.22µf) and R_L(600Ω) to form the filter circuit. It is recommended you locate these parts to the right of the MOSFET pair to keep signal flow from left to right. The low pass filter module recovers the analog input signal while filtering the high frequency PWM carrier. In many class D audio amplifiers the frequency of the PWM runs at 250 kHz or higher which is beyond the human level of hearing. The filter in this circuit is responsible for removal of the 10 kHz triangle wave frequency while passing the analog tone (1 kHz).

49. Connect Channel A to TP2 (Analog Input)
50. Connect Channel B to TP5 (Amplified Analog Output).
51. Turn power on to the DC supplies and signal generators. If you have constructed the circuit and connected the test equipment correctly, you should see two sine waves on Channel A and Channel B. Adjust the oscilloscope timebase of both channels to view 1-2 cycles of each signal at the same time.
52. Adjust the amplitude of both channels so both signals fit in the window as large as possible without clipping.
53. Answer questions 8 and 9 at this time.
54. Reduce the triangle wave frequency of the signal generator to various values between 1 kHz and 10 kHz and observe the frequency response of the amplifier output at TP5 (Channel B).
55. Answer question 10 at this time.
56. Increase the triangle wave frequency on the signal generator to various values between 10 kHz and 50 kHz and observe the frequency response of the amplifier.
57. Answer question 11 at this time.
58. Temporarily disconnect the wire at pin 2 of the IC1 by removing the connection to the signal generator, and grounding the input of IC1 pin 2. You are now essentially inputting a 0 volt signal with the triangle wave sampling signal. This forces the class D amplifier to produce a 50% duty cycle PWM output at both the analog comparator TP3 and at the MOSFET output TP4 which when filtered produces a 0 volt output at TP5.
59. Connect Channel A to TP3 and then TP4 to verify the PWM outputs of these devices is indeed producing a 50% duty cycle signal.
60. Measure the ON time and OFF time of TP3 and answer questions 12 and 13.

Table 1. Amplifier Input Configuration:

Parameter	Analog Input (XFG2)	Triangle Wave Input (XFG1)
	Measurement (Channel A)	Measurement (Channel B)
Output Function: (sine wave/triangle/ square)		
Frequency:		
Voltage Out (V_{pp}):		
Triangle Wave Cycles		

1. Examine Table 1. The two signal generators have been configured to produce frequencies that differ by a factor of 10X between the analog input signal and the triangle wave input signal that controls the PWM output function of the circuit comparator stage. The 10X or greater sampling frequency and how it controls the operation of the PWM comparator are at the heart of class D amplifier operation.

   From the data recorded in Table 1, calculate the exact frequency ratio of the triangle wave to analog input.

2. Is the predefined triangle wave to analog input ratio adequate? Why/Why not?

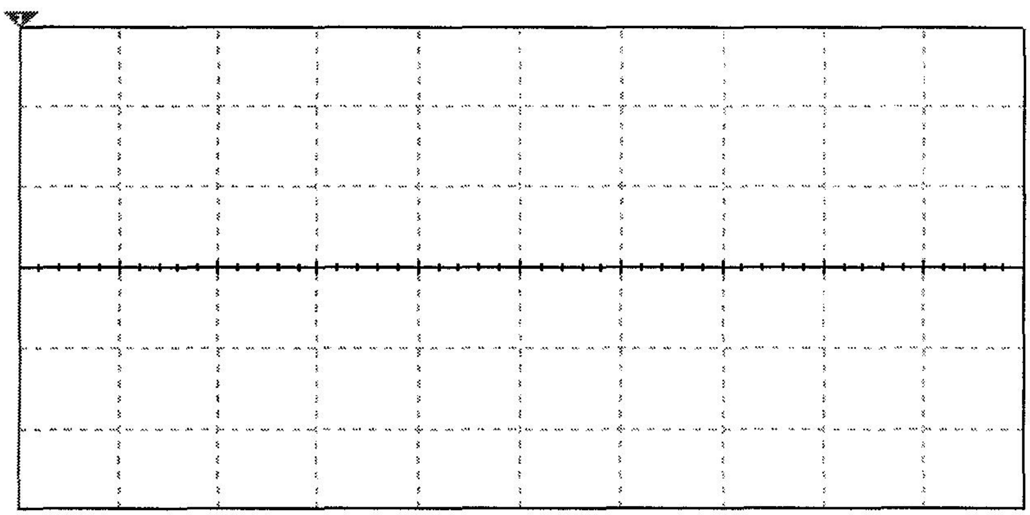
3. What is the V_{pp} voltage swing of the PWM signal you observe?

4. Describe in sentence format, what you have accomplished so far in assembling the first two stages of your class D amplifier. Be sure to include something about the setup of critical signals required to drive the circuit.

5. Using complete sentences describe what you observe.

6. If the triangle wave were set to a higher frequency, say 20 kHz (double) or higher how do you think the PWM signal would look?

7. Draw a picture of TP2 vs. TP4 as seen on your oscilloscope screen in the space below.



8. What is the oscilloscope displaying? Refer to your class D amplifier schematic and the block diagram as required.

9. Compare the original sine wave to the class D amplified signal. Explain any significant differences between the two with respect to phase or amplitude shape.

10. In light of your adjustments in sample frequency, what happens to the output of the sine wave as the triangle wave frequency is reduced below 10 kHz? Why does this happen?

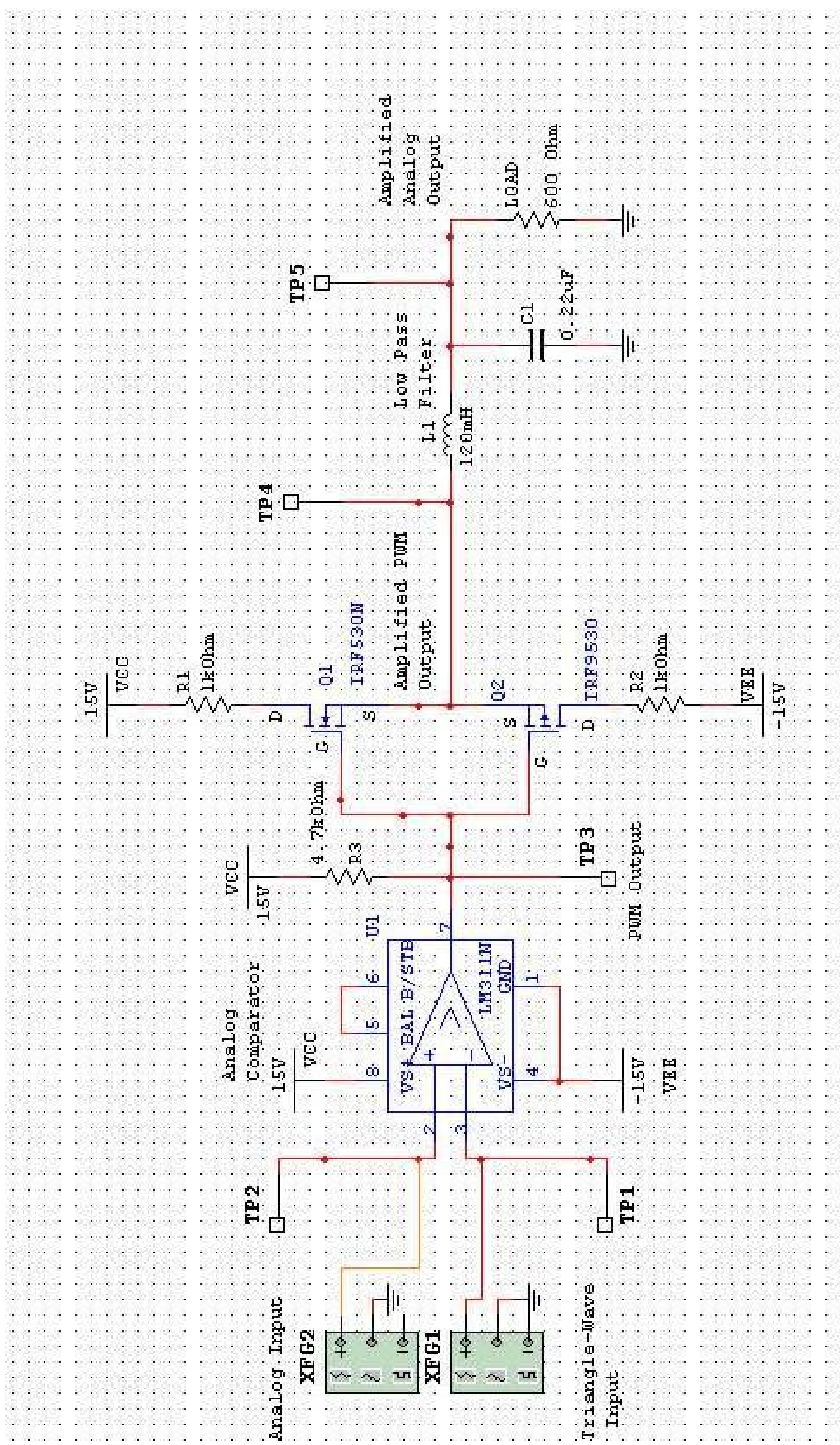
11. In light of your adjustments in sample frequency, what happens to the output of the sine wave as the triangle wave frequency is increased? Why does this happen?

12. Measure the number of divisions or subdivisions that the waveform stays ON and OFF, and multiply this value by the sec/div setting of the oscilloscope to get the horizontal time figure of your wave. You may have to properly trigger your oscilloscope to stabilize and view the waveforms while making this measurement. If you are using a digital oscilloscope, simply store the waveforms before viewing.

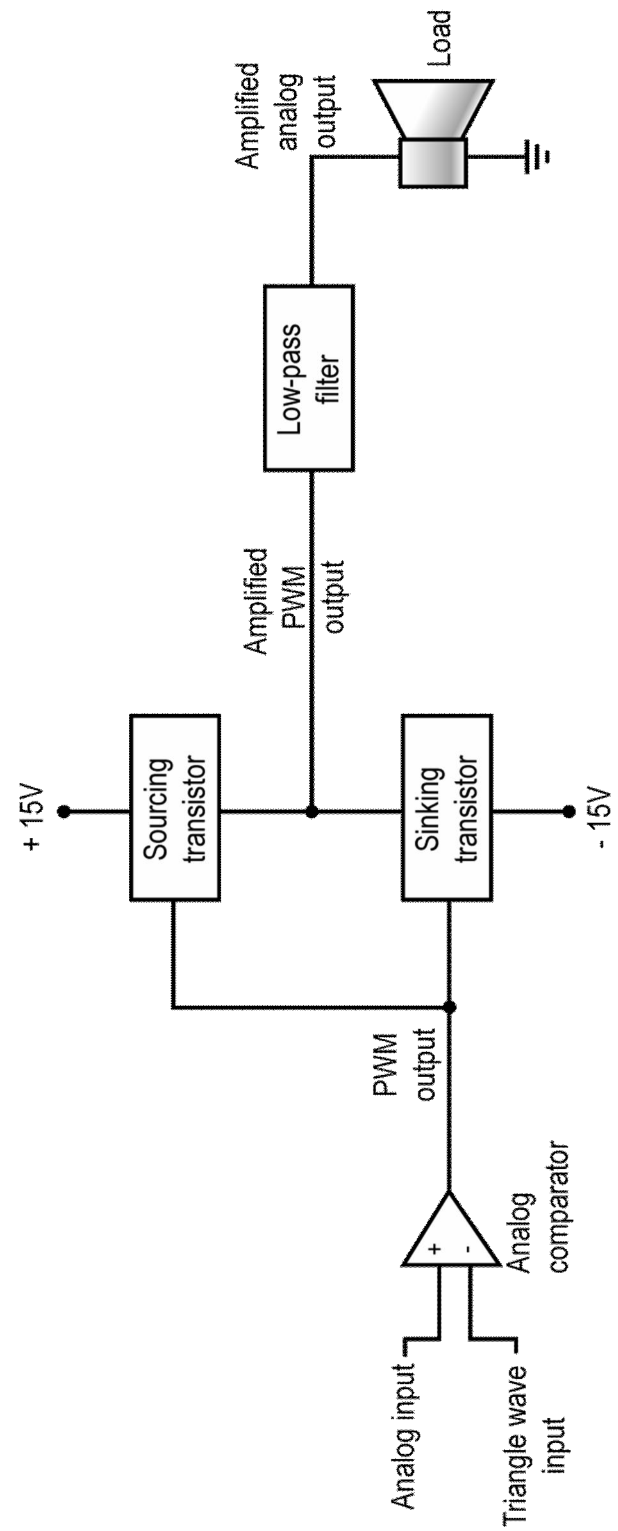
ON time: __________ OFF time: ___________

13. Measure the output of the amplifier at TP5 using Channel B of the oscilloscope. What do you see on Channel B of the scope? Does this make sense to you, why or why not?

Class D Amplifier Schematic



Class D Amplifier Block Diagram



Protoboard Layout