MIDDLE EAST TECHNICAL UNIVERSITY

ELECTRICAL-ELECTRONICS ENGINEERING DEPARTMENT

EE400

SUMMER PRACTICE REPORT

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1514918

THE COMPANY:YENEL LTD

BEGINNING DATE:03.07.2006

ENDING DATE:28.07.2006

INDEX:

1. INTRODUCTION

I have performed my second Summer Practice in YENEL LTD (Yenilikçi ve Buluşçu Elektronik Sistemler Sanayi ve Ticaret Limited Şirketi) which is a new and young electronics company that make design, research-development and manufacturing in modern electronic systems for other companies and the users. My practice lasted totally four weeks starting from 03.07.2006 and ending in 28.07.2006. I had a project about the design, assembly and testing of a PWM amplifier that can be used for different purposes such as motor control. During my summer practice, my supervisor was Barış Bakla who has a B.Sc degree in Electrical-Electronics Engineering and two M.S degrees in Electrical-Electronics Engineering and Industrial Engineering.

During my summer practice I gained lots of experiences with the help of the staff and my project. I learned lots of things about PWM amplifiers. This report includes everything that has been done and observed during the summer practice. It'll be mentioned all detailed explanations, descriptions, experiences about my project. The report starts with the description of the company. The main part includes every detailed information about what has been done and observed about the project week by week. At the end there is a conclusion part about my experiences and findings from the summer practice, a reference part which includes the sources that I used and an appendice part that includes various datasheets examined during the summer practice.

2. DESCRIPTION OF THE COMPANY

2.1 COMPANY NAME

YENEL Yenilikçi ve Buluşçu Elektronik Sistemler Sanayi ve Ticaret Limited Şirketi

2.2 COMPANY LOCATION

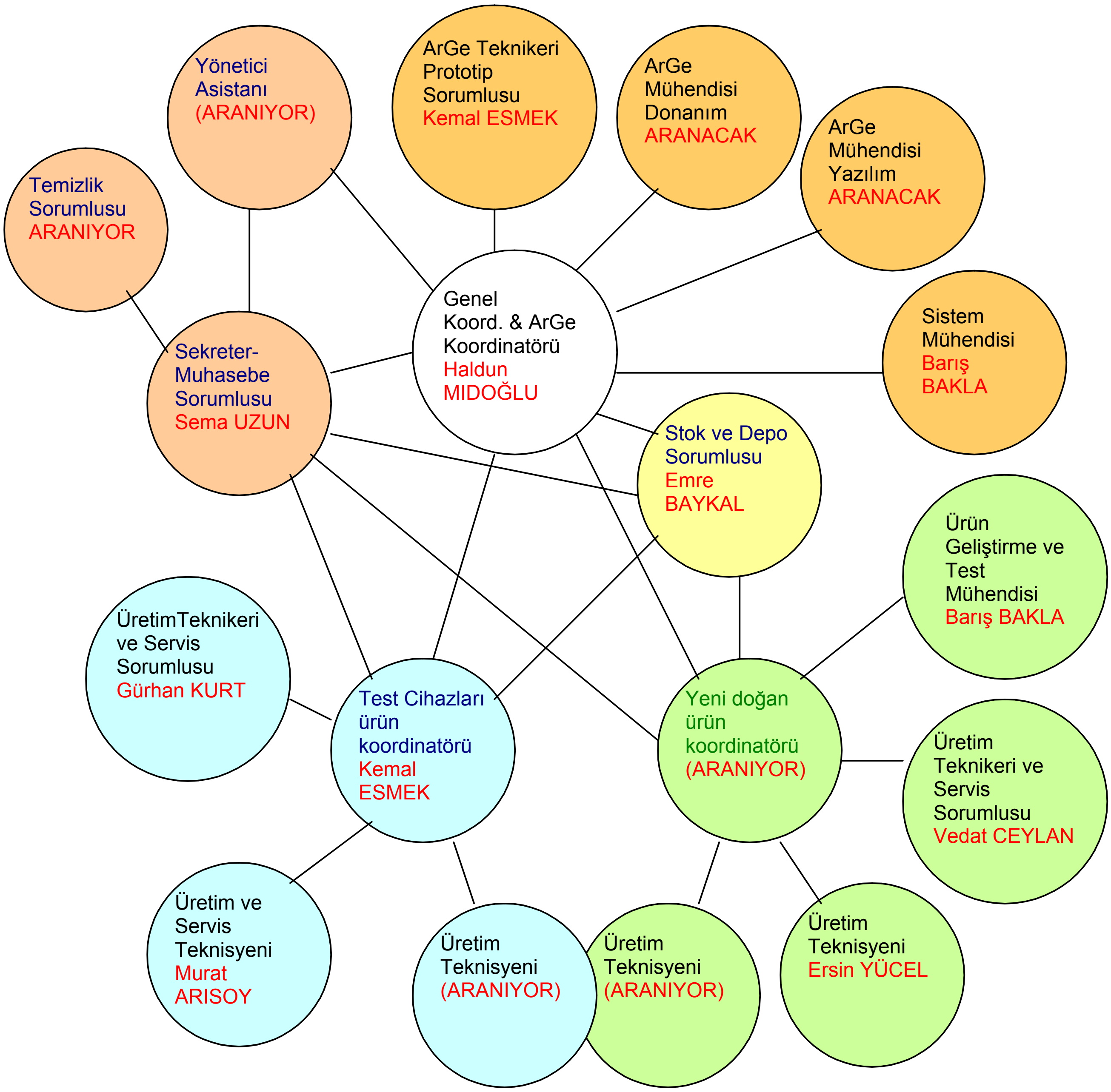
ODTÜ İkizleri Ar-Ge Binası A-Blok Kat:1 No:9 ODTÜ-TEKNOKENT 06531 ANKARA

2.3 HISTORY OF THE COMPANY

YENEL LTD Yenilikçi ve Buluşçu Elektronik Sistemler Sanayi ve Ticaret Limited Şirketi was founded by Haldun Mıdoğlu in ODTU technopolis in July 2001 as an electronics company. The company aims to produce its own product after lots of research and development. The company has done several facilities related with industrial and medical electronics and software engineering. Nevertheless, YENEL works as a distributor of the ADDI-DATA and AXIOM. Although, it's a new company, it can be seen the experiences of the employers. The company also gives lots of importance to research and development. In that way, they are thinking to grow easier.

2.4 ORGANIZATION

YENEL is a young company which is growing day by day. In the following years company aims to become more organized. It's searched the labor force for the different areas in the company. In that way company aims to grow with the cooperation of the employers. The Founder and the General Manager of the company is Haldun Mıdoğlu. He gave more importance to the research and development. So the company wanna be organized in such a way that employing research and development engineers for hardware and software.The organization table below shows the organization of the company.



The general organization diagram

2.5 NUMBER OF PEOPLE EMPLOYED

The total number of people in the company is 9. There are 6 technicians, 2 engineers in the company. But with this growing potential of the company these numbers seem to increase.

2.6 THE FIELDS OF THE BUSINESS

YENEL designs, manufactures and develops modern electronic systems for other companies and the users. It has several projects with METU Electrical-Electronics Engineering Department. It does research and development for the specific purposes. The fields that are related to the business area of the company are listed in three main parts. These are Medical Electronics, Industrial Electronics and Software Engineering.

In Medical Electronics, the products that are produced are like below.

➔Incubator Control Module
➔Phototherapy Equipments
➔Homecare Equipments
➔Electrical Safety Analyzers

In Software Development the applications are like that.

➔Database Applications
➔Internet Applications
➔Palm Applications
➔Special Purpose Test Software

In Industrial Electronics, the products are like below.

➔Electrical Safety Test Equipments
➔Performance Test Systems
➔Motor Test Equipments
➔Electronics Control Cards
➔Intelligent Power Supplies

2.6.1 INCUBATOR CONTROL MODULE

Incubator is the most famous product of YENEL. It is the product developed for prematüre babies who are born earlier. For supplying them the conditions of the mother abdomen for their healthy and safety.

The view of the incubator

The incubator has lots of properties on it. It can measure the temperature of the cabin and the baby skin. According to the values of the temperature it can be controlled, stabilized and the desired value of the temperature for baby skin can be obtained. Beside, it can measure the weight of the baby. The humidity of the environment can be measured and controlled. According to the values it can be supplied fresh air to the environment to provide the desired conditions. And there is an automatic protecting system for the unexpected values of the temperature, humidity. At that time there is an alarm to warn you about the unexpected conditions. Also it has a display panel which shows all of the instant values of temperature, humidity. It can also control the oxygen of the environment which is developed recent times by the company. It will thought to add new properties to the control module of the incubator according to the demand.

This project of YENEL is also supported by TUBITAK for research and development. YENEL also work for the development of the incubator control module. It has been thought to communicate on the internet with the control module. It has been planning to make the online control of the module and following the datas of the babies on the web.

3. FIRST WEEK:

I started my Summer Practise in YENEL LTD on the 3th of July in ODTÜ technopolis in Ankara. First day I met the staff in the company and was given our job to do. My job was to assemble APEX SA60 EVAL11 kit to the prototype board and try to run it to obtain the powerful signal at the output. First of all to specify the design parameters I need to have the theoritical substructure. So I started to search about the PWM amplifiers, Class-D amplifiers, to gain some experience. Let me inform you about this topic.

3.1 PWM (PULSE WIDTH MODULATION) AMPLIFIERS:

3.1.1 WHY PWM ?

As you know when power levels increase, the task of designing variable drives increases dramatically. A project can become unmanageable when calculation of internal power dissipation reveals the extent of cooling hardware required. Example a 20A output stage often requires multiple 20A semiconductors mounted on massive heatsinks and usually employs noisy fans or liquid cooling in some cases.

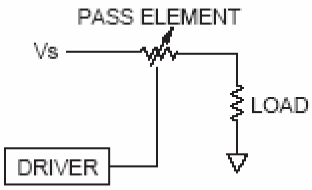


FIGURE 1. LINEAR POWER DELIVERY

Figure 1 illustrates the linear approach to delivering power to the load. When maximum output is commanded, the driver reduces resistance of the pass element to a minimum. At this output level losses in the linear circuit are relatively low. When zero output is commanded the pass element resistance approaches infinity and losses approach zero. The disadvantage of the linear circuit appears at the midrange output levels and is often at its worst when 50% output is delivered. At this level, resistance of the pass element is equal to the load resistance which means heat generated in the amplifier is equal to the power delivered to the load! We have just found the linear circuit to have a maximum efficiency of 50% when driving resistive loads to midrange power levels.

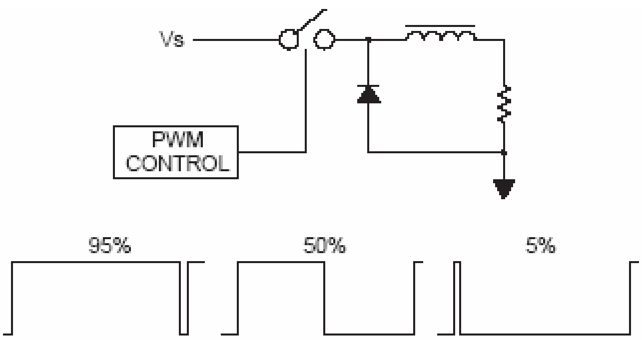


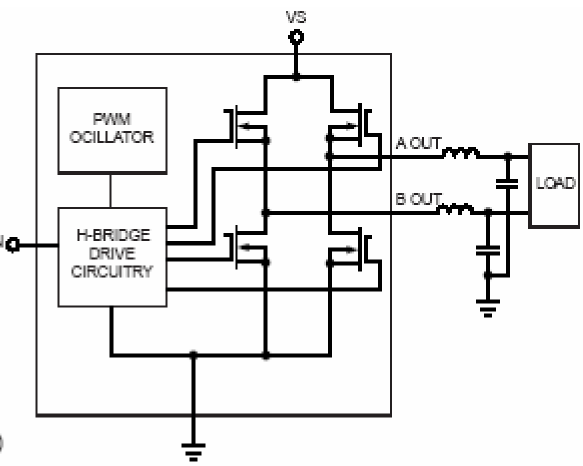
FIGURE 2. PWM POWER DELIVERY

Figure 2 illustrates the most basic PWM operation. The PWM control block converts an analog input level into a variable duty cycle switch drive signal.

As higher outputs are commanded, the switch is held ON longer portions of the period. Normally, the switch is ON and OFF once during each cycle of the switching frequency. The duty cycle of the PWM signal is specified according to the task of the load. As you see in this case, losses are simply a factor of the ON resistance of the switch plus the inductor resistance. As less output is commanded the duty cycle or percent of ON time is reduced. Also losses include heat generated in the flyback diode. At most practical supply voltages this diode loss is still small because the diode conducts only a very small portion of the time and this voltage drop is a small fraction of the supply voltage.

With the PWM circuit, the direct (unfiltered) amplifier output is either near the supply voltage or near zero. Typical efficiency of filtered PWM circuits range from 80 to 95%.Consider a circuit delivering a peak power of 1KW. A 90% efficient PWM circuit generates 100W of waste heat when running full output and around 50W delivering half power. The theoretically perfect linear circuit will generate 500W of waste heat while delivering 500W. As you see the linear approaches require five times the heatsink rating of the PWM approach. So discrete linear approach will have more than five times the heatsink size and weight of the PWM. The advantage of the PWM amplifier is obvious. It has 80 to 95% high efficiency ratings, lower internal power loss, smaller heatsinks and reduced overall physical size. Usually for the switch task H-Bridge amplifiers are used.

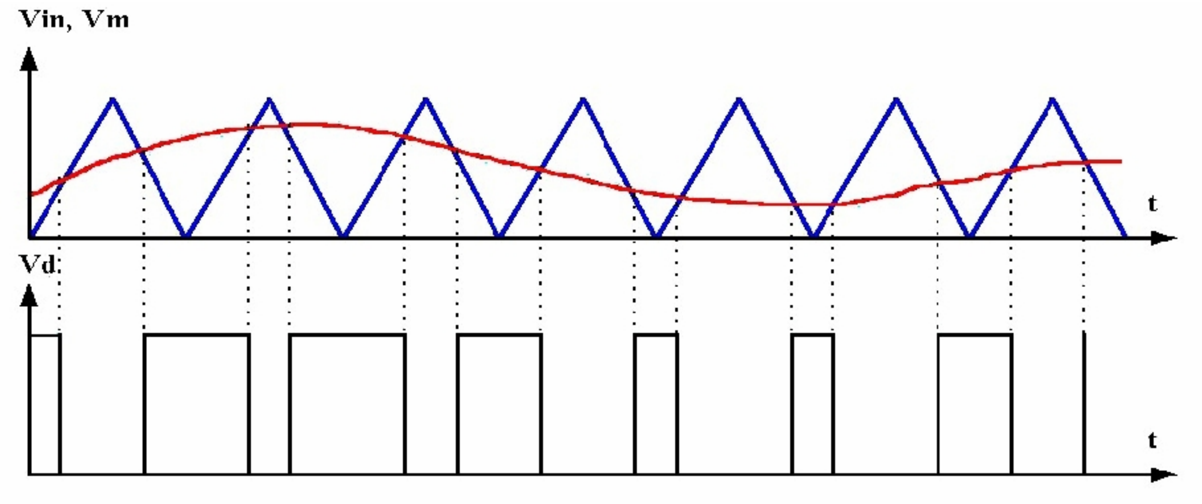
3.1.2 HOW IT WORKS ?



(a)

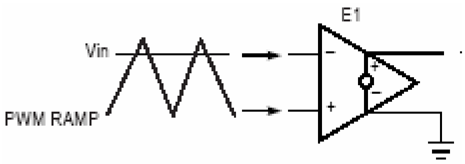
Even though a PWM amplifier offers analog signals in and analog signals out, its circuit functionality is entirely different from a linear amplifier's. A PWM amplifier modulates a pulse train in the time domain and uses LC filtering to extract the analog-signal output.Let me explain the parts of the circuitry.

H-Bridge drive circuitry is used to drive the H-Bridge transistors according the usage. It's designed according to the different usage areas by the designer. But as I said its main task is to drive the H-bridge according to the PWM signal. Its input PWM signal is produced with a simple logic.



➔The red signal is Vin and the blue signal is the modulation signal Vm.

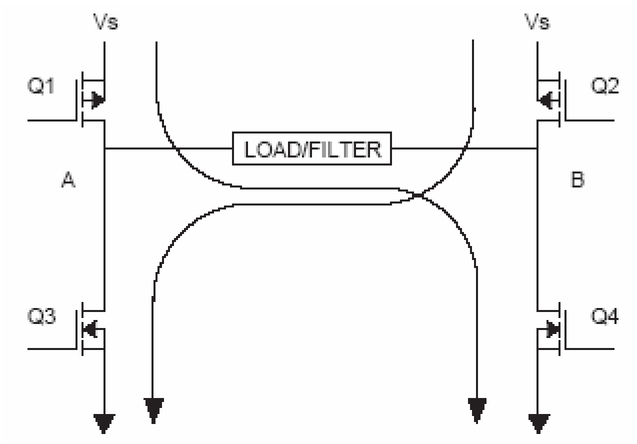
As I said class-d amplifier uses Pulse Wide Modulation PWM. This means that the original signal Vin at the input is modulated with another signal Vm which has a much higher fixed frequency. The waveform which is used as carrier wave or modulation signal is normally a sawtooth signal. It is produced by the ramp generator. The principle is actually quite simple to understand if you look at the figure below.



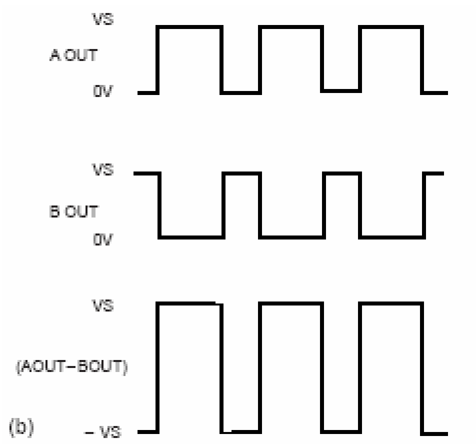
By the help of a comparator we can obtain a pulse train PWM signal. The duty cycle of the PWM signal can be set by changing the frequency of the triangle wave. As you see the frequency of the triangle wave is bigger than the frequency of the input signal. It is generally chosen 10 times larger than the frequency of the input to make the modulation and demodulation beter. So we can filter it easily. I'll mention about the filtering too. Now let me mention about the H-Bridge in detail.

3.1.3 H-BRIDGE

As I said for the switch task generally we use H-Bridge amplifiers. It is also known as Class-D amplifiers. It has very simple logic to understand.



This is H-Bridge amplifier. The H-bridge switches work in pairs to reverse polarity of the drive even though only one polarity supply is used. According to the driver circuit and the PWM signal before the H-Bridge the Q1-Q4 and Q2-Q3 amplifiers are ON at the same time. And the current directions are like in the figure above. When Q1-Q4 are ON, Q2-Q3 are OFF and vice versa. Notice how the levels of the A-B waveform are different even though shape is identical to the A waveform. Q1 and Q4 conduct during one portion of each cycle and Q2 and Q3 are on during the remainder of the cycle. According to these we can obtain these waveforms.



As you see at the output we put the Vs supply voltage to the waveform. So we will have a powerful signal after filtering the waveform.

3.1.4 FILTERING

Pulse width modulation (PWM) amplifiers require low pass filtering of the output to demodulate the PWM carrier. Some applications also utilize the filter as a way to achieve an impedance transformation which draws less power supply current than is delivered to the load. These filters can be as simple as a single inductor, to multiple LC nodes depending on the application. In some applications the load will have enough inductance to act as its own filter.

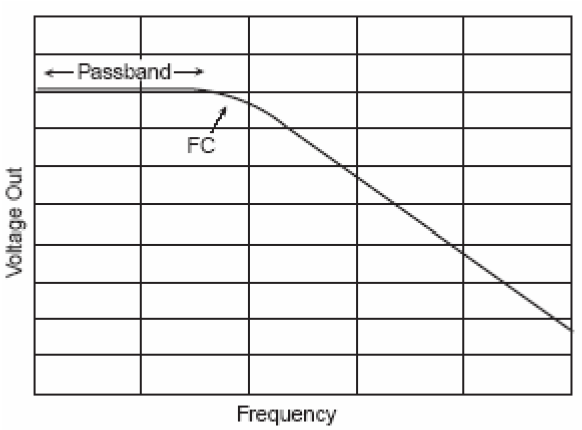
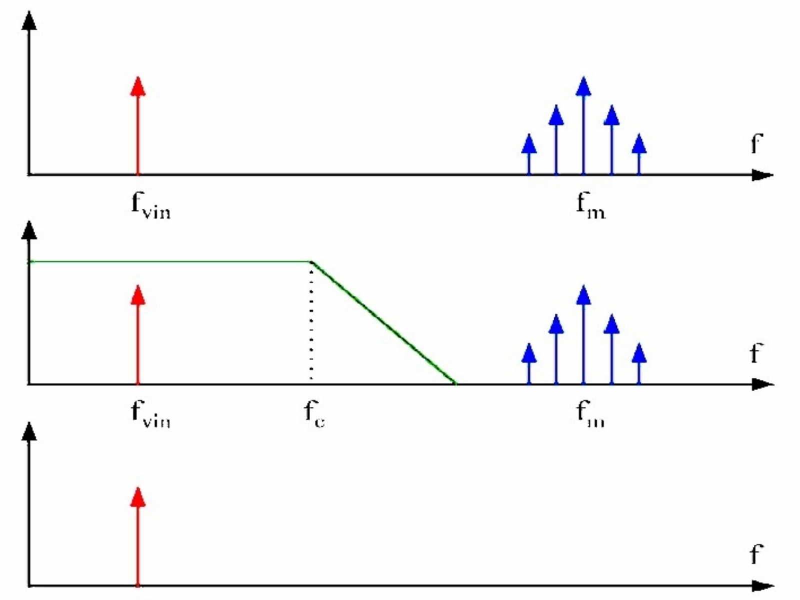


FIGURE 1. LOW PASS FILTER RESPONSE

PWM filters are normally a low pass configuration. These exhibit low attenuation to the frequency spectrum from 0 Hertz to the frequency of cutoff (FC). This low attenuation region is called the passband. Beyond the FC, attenuation increases at a rate determined by the filter type and the number of poles (order). Figure 1 indicates the general response of the low pass filter. Many different types of low pass filters exist. Common filters include Butterworth, Chebyshev, and Bessel. The Butterworth filter has a flat response in the passband and good roll off beyond the cutoff frequency. Component variations do not greatly affect the performance. It is considered a good general filter that is often used and therefore will only be considered here.

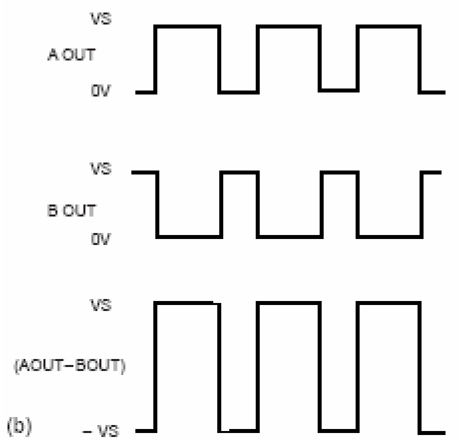
As we can understand from the modulation of the signal, the signal has a fundamental frequency equal to that of the modulation frequency fm (the frequency of the modulation signal Vm) but will also contain the input signal and a band of frequency components around the modulation frequency. So to obtain the original signal with the same frequency, but more powerful we can apply our low pass fitler to the system.

A Low Pass-filter with bandwidth fc has to reject the switching frequency fm and components around fm, passing the amplified input signal at the output.



As we can see, at the output after filtering we obtain the signal the same frequency but more powerful with the original signal. So we can drive the loads, which need more power, with a small signal by the help of the PWM amplifiers. Let me give some examples about some typical applications of the PWM amplifiers.

3.1.5 A TYPICAL APPLICATION



Assume that Vin is the analog input of the PWM amplifier. AOUT is a pulse train, and BOUT is its inverse. The PWM oscillator determines the frequency of the pulse train. As Vin changes from its minimum to its maximum value, the duty cycle of AOUT changes from 0 to 100%, and the duty cycle of BOUT changes from 100 to 0%. The difference voltage of AOUT–BOUT has the same pulse train as AOUT but with double the amplitude of 2xVs p-p (Figure b). If you connect a dc brush-type motor across AOUT and BOUT, you can control the motor speed with Vin. When you set Vin in the middle of its range, for 50% duty cycle at AOUT and BOUT, the motor stands still. With Vin at its maximum, the motor turns at maximum rpm; with Vin at its minimum, the motor reverses direction of rotation and turns at maximum rpm again. You can directly connect AOUT and BOUT to a motor because the winding inductance of the motor turns the pulsed voltage into a rippled dc current whose magnitude controls the motor speed and whose polarity controls the clockwise or counterclockwise direction of the motor. As you can see, you control the speed and position of the motor by means of the PWM amplifiers.

3.2 THE RESULT OF THE FIRST WEEK

➔At the end of the week of my Summer Practise in Yenel LTD, I get used to the company and the staff. Everybody helped me a lot to become familiar. I also worked with the technical staff of the company to learn the technical side and to make the assembling of my prototype board alone. So I assembled lots of board. I soldered them. I learned the technical equipment. I used them. Besides, as I mentioned above I searched about the PWM technology to prepare a background for my project. So I can say that it was good starting for me.

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4. SECOND WEEK:

At the beginning of the second week, to gain some experience about the practical aplication of the PWM amplifiers, I examined the High Power Digital Audio Amplifier HIP4080A, which is a good example of PWM application. I examined how it works, how the values of the components are chosen etc. Let me mention about this.

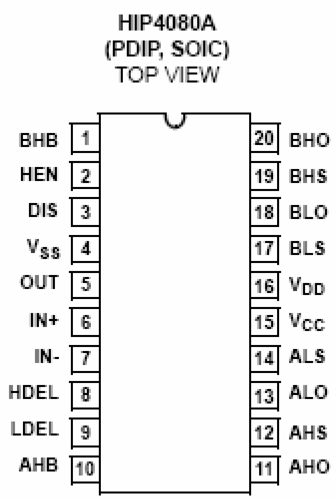
4.1 HIP4080A

The HIP4080A is a high frequency, 80V/2.5A peak Full Bridge N-Channel FET driver IC, available in 20 lead plastic SOIC and DIP packages. The HIP4080A includes an input comparator, used to facilitate PWM modes of operation. Its HEN (high enable) lead can force current to freewheel in the bottom two external power MOSFETs, maintaining the upper power MOSFETs off. Since it can switch at frequencies up to 1MHz, the HIP4080A is well suited for driving Voice Coil Motors, switching power amplifiers and power supplies. Short propagation delays of approximately 55ns maximize control loop crossover frequencies and dead-times which can be adjusted to near zero to minimize distortion, resulting in precise control of the driven load.

4.1.1 FEATURES

- Drives N-Channel FET Full Bridge Including High Side Chop Capability
- Bootstrap Supply Max Voltage to 95VDC
- Drives 1000pF Load at 1MHz in Free Air at +50°C with Rise and Fall Times of Typically 10ns
- User-Programmable Dead Time
- Charge-Pump and Bootstrap Maintain Upper Bias Supplies
- DIS (Disable) Pin Pulls Gates Low
- Input Logic Thresholds Compatible with 5V to 15V Logic Levels
- Very Low Power Consumption
- Undervoltage Protection
- Pb-Free Available as an Option (SOIC)

4.1.2 PINOUT

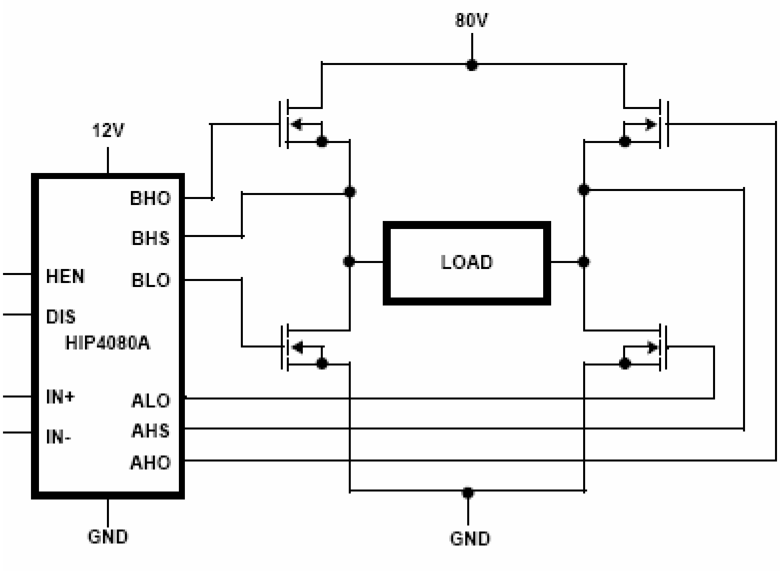


4.1.3 PINOUT DESCRIPTION

PIN NUMBER	SYMBOL	DESCRIPTION
1	BHB	B High-side Bootstrap supply. External bootstrap diode and capacitor are required. Connect cathode of bootstrap diode and positive side of bootstrap capacitor to this pin. Internal charge pump supplies 30μA out of this pin to maintain bootstrap supply. Internal circuitry clamps the bootstrap supply to approximately 12.8V.
2	HEN	High-side Enable input. Logic level input that when low overrides IN+/IN- (Pins 6 and 7) to put AHO and BHO drivers (Pins 11 and 20) in low output state. When HEN is high AHO and BHO are controlled by IN+/IN- inputs. The pin can be driven by signal levels of 0V to 15V (no greater than V_{DD}).
3	DIS	DISable input. Logic level input that when taken high sets all four outputs low. DIS high overrides all other inputs. When DIS is taken low the outputs are controlled by the other inputs. The pin can be driven by signal levels of 0V to 15V (no greater than V_{DD}).
4	V_{SS}	Chip negative supply, generally will be ground.
5	OUT	OUTput of the input control comparator. This output can be used for feedback and hysteresis.
6	IN+	Noninverting input of control comparator. If IN+ is greater than IN- (Pin 7) then ALO and BHO are low level outputs and BLO and AHO are high level outputs. If IN+ is less than IN- then ALO and BHO are high level outputs and BLO and AHO are low level outputs. DIS (Pin 3) high level will override IN+/IN- control for all outputs. HEN (Pin 2) low level will override IN+/IN- control of AHO and BHO. When switching in four quadrant mode, dead time in a half bridge leg is controlled by HDEL and LDEL (Pins 8 and 9).
7	IN-	Inverting input of control comparator. See IN+ (Pin 6) description.
8	HDEL	High-side turn-on DELay. Connect resistor from this pin to V_{SS} to set timing current that defines the turn-on delay of both high-side drivers. The low-side drivers turn-off with no adjustable delay, so the HDEL resistor guarantees no shoot-through by delaying the turn-on of the high-side drivers. HDEL reference voltage is approximately 5.1V.
9	LDEL	Low-side turn-on DELay. Connect resistor from this pin to V_{SS} to set timing current that defines the turn-on delay of both low-side drivers. The high-side drivers turn-off with no adjustable delay, so the LDEL resistor guarantees no shoot-through by delaying the turn-on of the low-side drivers. LDEL reference voltage is approximately 5.1V.
10	AHB	A High-side Bootstrap supply. External bootstrap diode and capacitor are required. Connect cathode of bootstrap diode and positive side of bootstrap capacitor to this pin. Internal charge pump supplies 30μA out of this pin to maintain bootstrap supply. Internal circuitry clamps the bootstrap supply to approximately 12.8V.
11	AHO	A High-side Output. Connect to gate of A High-side power MOSFET.
12	AHS	A High-side Source connection. Connect to source of A High-side power MOSFET. Connect negative side of bootstrap capacitor to this pin.
13	ALO	A Low-side Output. Connect to gate of A Low-side power MOSFET.
14	ALS	A Low-side Source connection. Connect to source of A Low-side power MOSFET.
15	V_{CC}	Positive supply to gate drivers. Must be same potential as V_{DD} (Pin 16). Connect to anodes of two bootstrap diodes.
16	V_{DD}	Positive supply to lower gate drivers. Must be same potential as V_{CC} (Pin 15). De-couple this pin to V_{SS} (Pin 4).
17	BLS	B Low-side Source connection. Connect to source of B Low-side power MOSFET.
18	BLO	B Low-side Output. Connect to gate of B Low-side power MOSFET.
19	BHS	B High-side Source connection. Connect to source of B High-side power MOSFET. Connect negative side of bootstrap capacitor to this pin.
20	BHO	B High-side Output. Connect to gate of B High-side power MOSFET.

4.1.4 APPLICATIONS

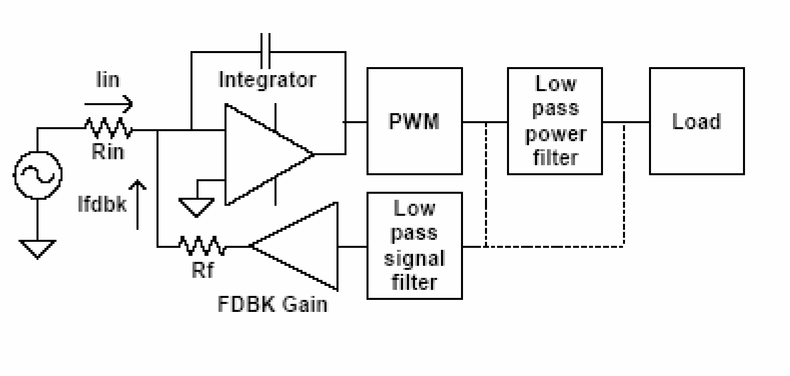
- Medium/Large Voice Coil Motors
- Full Bridge Power Supplies
- Switching Power Amplifiers
- High Performance Motor Controls
- Noise Cancellation Systems
- Battery Powered Vehicles
- Peripherals
- U.P.S.



➔The HIP4080A can be used to drive the H-Bridge like in the figure above. The load in the circuitry that I examined, was like in the H-Bridge above. But it has a control feedback loop too. Actually the feedback loop was the most important thing for me in the circuitry. Because the most difficult part in my project will be about the design of the feedback loop. So I gave more attention the feedback loop in this circuitry. Before talking about this in detail let me mention why closing the loop is important.

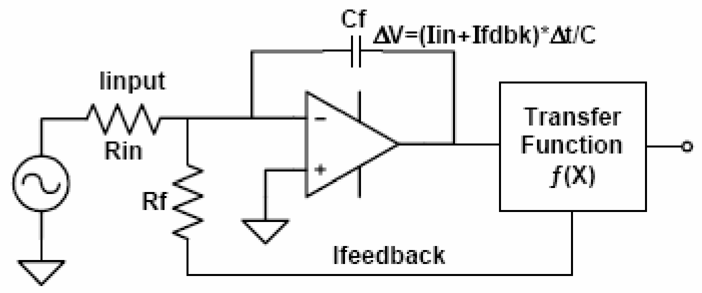
4.2 CLOSING THE LOOP

To reduce the variations in output voltage due to the load,supply and the temperature closing the loop is very important. In closed loop applications, an integrating error amplifier is used to eliminate the difference between command signals and feedback signals. Its output voltage will go to the exact voltage required by the PWM block to generate the proper duty cycle corresponding to the desired output. The first job of the error amplifier is responding to input signal changes, but it also compensates other variables inside the feedback loop. Variations in supply voltage will require an adjustment of the input to maintain a output stability.



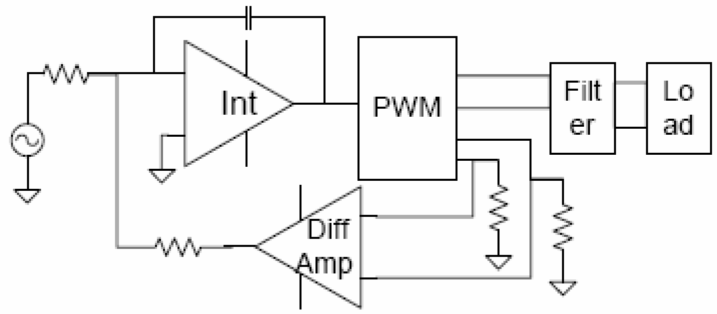
The figure above is very general look at closing a PWM amplifier locally. The PWM output is filtered and delivered to the load as a power analog signal (occasionally a load may do its own filtering). A feedback circuit usually contains a low pass filter and often an amplifier. The integrator now drives the PWM input where ever required to force input and feedback currents to be equal and opposite. Controlling with the integrator is also called PI (Proportional Integral) control. Briefly the integrator takes the integral of the difference I_{IN} and I_{FDBK} currents. Let me explain the integrator in detail.

4.3 INTEGRATOR IN A SYSTEM



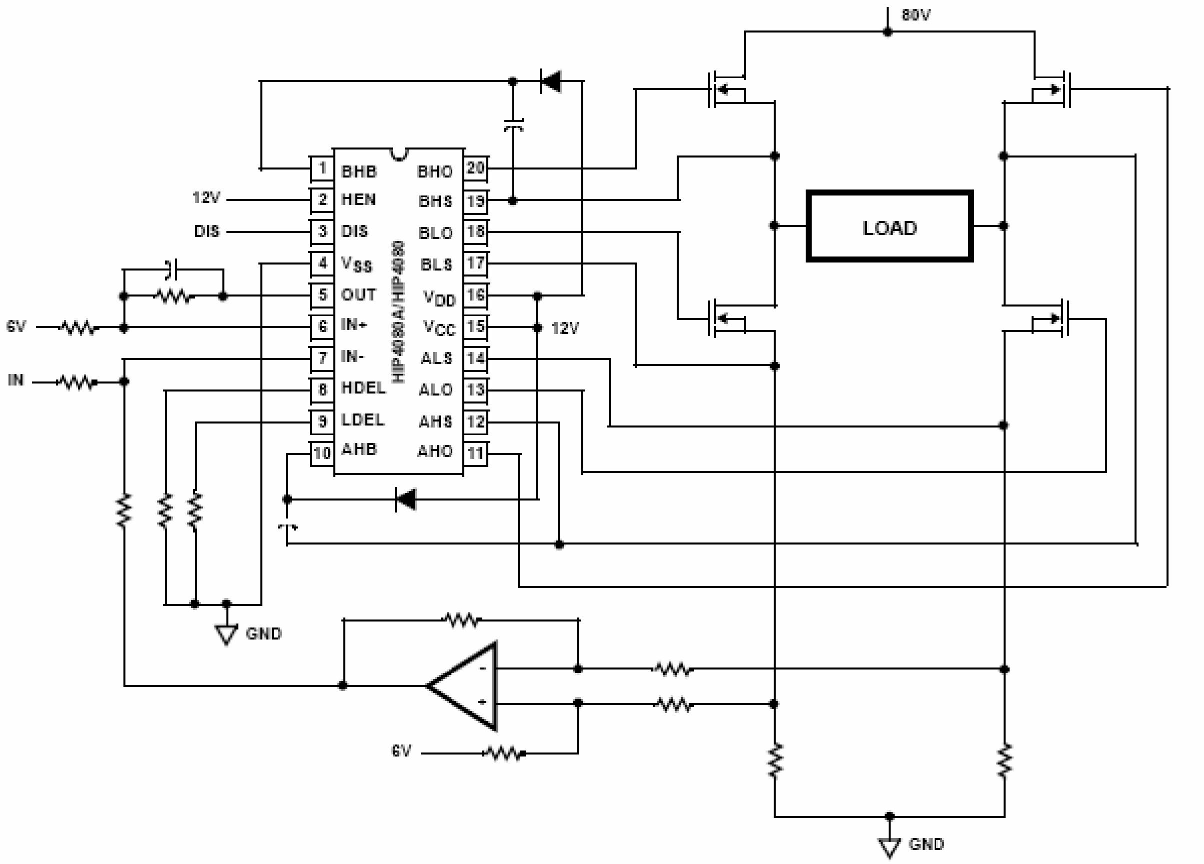
If we assume the ideal opamp operation, there is no current in the opamp input pins. Looking at the summing junction with three connections, current in any given path must equal the sum of the other two paths. Therefore, capacitor current will be the algebraic sum of the input and feedback currents. If I_{IN} and I_{FDBK} are equal and opposite, the output does not move. So integrator acts like a summing junction of the I_{IN} and I_{FDBK} currents. It integrates the difference of them until the system is brought to the desired conditions. We can make voltage control too beside the current control.

4.4 VOLTAGE AND CURRENT CONTROL



Control by sensing voltage is a little different from the current control. In voltage control, we sense the voltage at the output and give it to the input of the differential amplifier. Then by means of the feedback loop we can compare it with the input voltage.

In current control it is different in a way of sensing. That time we sense the current at the output by means of the low value sense resistors. Then with a differential amplifier again, we will obtain a bipolar voltage corresponding to the bipolar current in the output. So again we control the PWM by simple opamp rules. Let me return to the circuitry that I examined with HIP4080A.



➔ The typical application that I examined with the HIP4080A is like above schematically. In addition, it has some circuitry for overcurrent and short circuit protection. But they weren't so important for me in that level. As I said, the design of the feedback loop was very critical for me. From the application notes I learned lots of things about the fundamentals of its working. Before transfering my experiences about this audio amplifier let me explain the HIP4080A evaluation board.

4.5 HIP4080A EVALUATION BOARD FEATURES

- 150W at 86% Efficiency
- Reduced Heat Sinking Eval Board Uses Std TO-220 Heatsinks for 150W
- Light Weight
- Smaller Size
- Lower Systems Cost
- 14V DC to 18V DC(Input to On-Board 12V Regulator)
- 10V to 50V DC for Output Rail Voltage

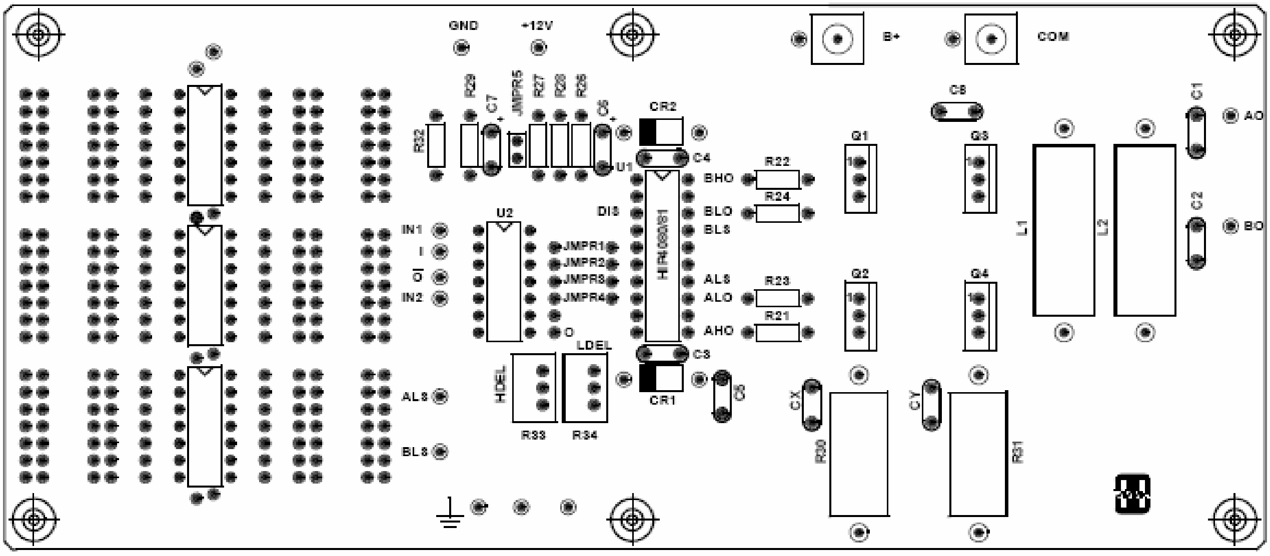


FIGURE 33. HIP4080A EVALUATION BOARD SILKSCREEN

➔The figure above is the evaluation board silkscreen where all the components are assembled. Now let me explain about its specifications and fundemantals.

4.6 PWM FREQUENCY ADJUSTMENT

The PWM frequency adjustment has been made at Haris and is set for 240kHz. However, you can change the frequency of the triangle wave so the PWM by turning the potentiometer. But it's not recommended reducing the frequency below 150kHz. Because operating the triangle wave frequency too near the feedback loop crossover frequency will cause instability.

4.7 OVERCURRENT AND SHORT CIRCUIT PROTECTION

Audio amplifiers provide a voltage gain to amplify a signal from a preamplifier output. If the output is shorted, the amplifier will try to provide sufficient current to establish a voltage at the output which is equal to the input signal multiplied by the gain of the amplifier. Short circuit protection will help reduce down time and expensive repairs.

Beside, current limit protection will reduce the output voltage applied across the load and can help to protect the amplifier and its load from overheating. The amplifier can also be protected from those who could connect too many speakers across the output or connect a speaker with too low impedance.Short circuit and overcurrent limitations can be made again by adjusting the potentiometers to the desired value in this circuitry.

4.8 POWER SUPPLY BYPASS

Most of us are familiar with the good design practice of including a supply bypass capacitor at every IC in a low level logic design. If this is not done, the high switching rates cause problems on the power bus. As the most common fault in switching circuit design, inadequate bypass causes ripple and spikes on the supply line which make circuits inoperative and can even destroy components. We should use at least 10µF per ampere of load current to bypass the lower frequencies. Some applications appear to require many times this amount of capacitance. The high frequency bypass is absolutely critical! Think of frequencies in the 1 to 10Mhz range. Remember that many capacitors appear inductive in this range. We should use ceramic capacitors for the high frequencies. We connect these capacitors directly between the supply and ground pins of the amplifier. Briefly, the function of bypass capacitors is to satisfy AC current demands of the amplifier and pick up the noise to prevent the system.

4.9 ZOBEL FILTER

A zobel filter (LC) is used to pick up the undesired frequency components from the PWM signal. It is also used to make the chosen speaker look like a pure resistive load. The HIP4080AEVAL2 Demo Board is designed to operate with 4Ω loads, since the zobel fitler design is designed for a 4Ω load.

4.10 COMPONENT CHOICE

As you know, a good audio amplifier will require operational amplifiers with high gain-bandwidth product. The CA5470 amplifier used in the HIP4080AEVAL2 Demo Board has 15mV maximum offset voltage which can be almost 0,5V at the load. So chosing opamp with a lower ofset voltage is beter for the operation of the circuit.

4.11 OTHER SPECIFICATIONS

The HIP4080AEVAL2 Demo Board requires an external DC source of power to operate the mosfet bridge, and a seperate low voltage DC power source to supply the ICs, bias circuits and the HIP4080A. The low voltage supply is 14V to 18V and the high voltage is up to 40V maximum. To obtain 12V and 6V, which is needed for the board, it has two regulators LM2931 and LM78L06. And it has been used RC snubbers very close to the mosfets to minimize the voltage transients and to protect the mosfets and the HIP4080A driver IC. And also to minimize the power supply ripples, the signal and the power ground connections were seperated. The input frequency range is between 20Hz-20kHz. The gain of the HIP4080AEVAL2 is 10 at 20kHz. So at the output it can be seen 150Wrms power at 86% efficiency.

4.12 THE RESULT OF THE SECOND WEEK

➔At the end of this week, I gain lots of experience about the practical working of PWM amplifiers. I tested the HIP4080AEVAL2 audio amplifier. I observed the waveforms in different nodes by means of the scope. I observed the triangle wave. With these observations I gain a good impression about the waveforms in the circuit. I learned the working fundamentals of the HIP4080AEVAL2 very good. I think it will be a good experience for the problems in my project. I'll solve them easily. Now I know what should be desired at the output. I took this design as a base for my project. Well then I'm ready to focus on my project.

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5. THIRD WEEK:

At the beginning of this week, I’m ready for my project. I can say that first two week I gain the substructrure that is necessary for my project. Let me remind my project description.

5.1 PROJECT DESCRIPTION

The project that I have to carry out was about the the design of the feedback loop to obtain the desired PWM signal before filter. The aim was creating the necessary PWM signal according to the load. After filtering this PWM signal, we’ll obtain a powerful signal that has the same frequency with the input. To realize this we used a demo kit. Briefly, after the design of the feedback loop, APEX SA60 EVAL11 kit will be assembled to the prototype board and the working of the circuitry will be observed. After the completion of the project, it will be used as driver circuit for a different kinds of load and it has a suitable base for other developments on it.

➔I started my project at the beginnig of the week. Before explaining the details of the design procedure that I made, let me inform you about APEX SA60 chip.

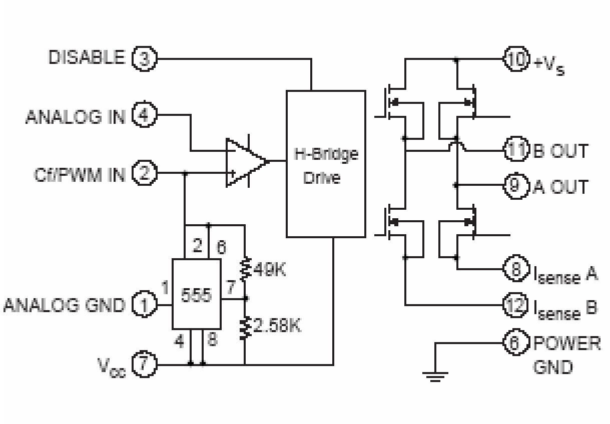
5.2 APEX SA60

The SA60 is a pulse width modulation amplifier that can supply 10A continuous current to the load. The full bridge amplifier can be operated over a wide range of supply voltages. All of the drive/control circuitry for the lowside and highside switches are internal to the hybrid. The PWM circuitry is internal as well, leaving the user to only provide an analog signal for the motor speed/direction, or audio signal for switchmode audio amplification. The internal PWM frequency can be programmed by an external integrator capacitor.

5.2.1 FEATURES

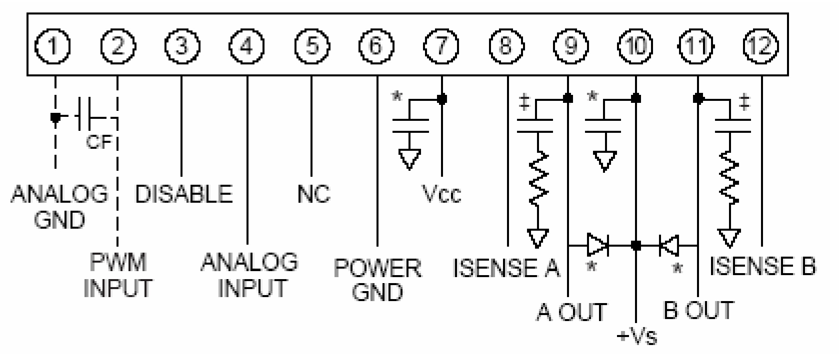
- Low Cost Complete H-Bridge
- Self-Contained Smart Lowside/Highside Drive Circuitry
- Wide Supply Range: Up To 80V
- 10A Continuous Output
- Isolated Case Allows Direct Heatsinking
- Four Quadrant Operation, Torque Control Capability
- Internal/Programmable PWM Frequency Generation
  Applications
- Brush Type Motor Control
- Class D Switchmode Amplifier
- Reactive Loads
- Magnetic Coils (MRI)
- Active Magnetic Bearing
- Vibration Cancelling

5.2.2 BLOCK DIAGRAM



➔As you see APEX SA60 chip includes H-Bridge, H-Bridge drive, 555 timer astable circuit, and the comparator all together. 555 astable timer circuit produces a triangle wave. This triangle wave is compared with the input signal by the comparator to produce the PWM signal. According to this PWM signal H-Bridge drive circuit drives the H-Bridge transistors. So APEX SA60 chip carry out the important steps in producing the PWM signal all inside.

5.2.3 EXTERNAL CONNECTIONS



5.2.4 PIN DESCRIPTION

Vcc is the low voltage supply for powering internal logic and drivers for the lowside and highside mosfets. The supplies for the highside drivers are derived from this voltage.

Vs is the higher voltage H-bridge supply. The mosfets obtain the output current from this supply pin. The voltage on this pin is limited to +80V by the drive IC. The mosfets are rated at 100 volts.

Isense A and B: These are tied to power gnd directly or through sense resistors.

Analog Gnd is the reference for the internal PWM oscillator. Connect this pin to pin 6. Connect low side of Vcc supply and any other supply used to generate analog input signals to Analog Gnd.

Analog Input is an analog input for controlling the PWM pulse width of the bridge. A voltage higher than Vcc/2 will produce greater than 50% duty cycle pulses out of B OUT. A voltage lower than Vcc/2 will produce greater than 50% duty cycle pulses out of A OUT.

Disable is the connection for disabling all 4 output switches. Disable high overrides all other inputs. When taken low, everything functions normally. An internal pullup to Vcc will keep Disable high if pin left open.

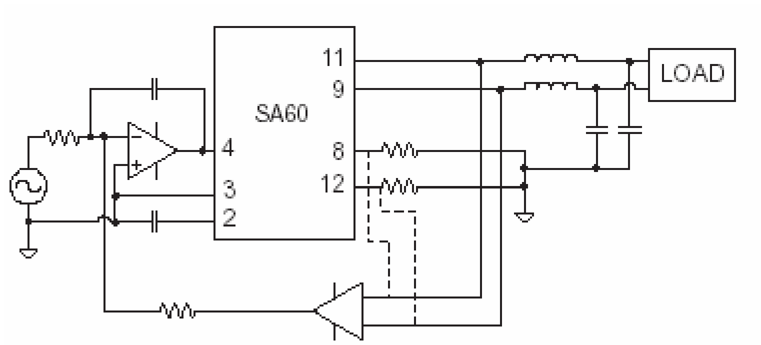
PWM Input is the TTL compatible digital input for controlling the PWM pulse width of the bridge. A duty cycle greater than 50% will produce greater than 50% duty cycle pulses out of the A out. A duty cycle less than 50% will produce greater than 50% duty cycle from the B out. For analog inputs, the integration capacitor for the internal clock must be connected between this pin and analog ground. The internal switching frequency is programmable up to 125 kHz by selection of the integration capacitor. The formula is:

$$C_F\,(pF) = \left(\frac{1.44 \times 10^7}{Fsw}\right) - 50$$

5.2.5 APPLICATIONS

- Brush Type Motor Control
- Class D Switchmode Amplifier
- Reactive Loads
- Magnetic Coils (MRI)
- Active Magnetic Bearing
- Vibration Cancelling

5.2.6 TYPICAL APPLICATION



A wide variety of loads can be driven in either the voltage mode or the current mode. The most common applications use three external blocks: a low pass filter converting pulse width data to an analog output, a difference amplifier to monitor voltage or current and an error amplifier. Filter inductors must be suitable for square waves at the switching frequency. A difference amplifier with gain of less than one translates the differential output voltage to a single feedback voltage. Dashed line connections and a higher gain difference amplifier would be used for current control. The error amplifier integrates the difference between the input and feedback voltages to close the loop.

➔Actually, my main task in this project was relevant to the application above. I tried to design the feedback loop like the application above. I used the voltage mode control during my design. The specifications for APEX SA60 was important for me. Before explaining my design let me show you the specifications taken from the datasheet of APEX SA60.

SA60

ABSOLUTE MAXIMUM RATINGS
SPECIFICATIONS

ABSOLUTE MAXIMUM RATINGS

SUPPLY VOLTAGE, $+V_S$	80V[4]
OUTPUT CURRENT, peak	15A
LOGIC SUPPLY VOLTAGE, Vcc	16V
POWER DISSIPATION, internal	156W[1]
TEMPERATURE, pin solder - 10s max.	260°C
TEMPERATURE, junction[3]	150°C
TEMPERATURE RANGE, storage	–40 to +85°C
OPERATING TEMPERATURE RANGE, case	–25 to +85°C

SPECIFICATIONS

PARAMETER	TEST CONDITIONS[2]	MIN	TYP	MAX	UNITS
INPUT					
ANALOG INPUT VOLTAGES	Vcc = 12V				
A, B OUT = 50% Duty Cycle			1/2VCC		Vdc
A OUT = 100% Duty Cycle High			1/3VCC		Vdc
B OUT = 100% Duty Cycle High			2/3VCC		Vdc
PWM INPUT					
PWM PULSE LOW VOLTAGE		0		0.8	Vdc
PWM PULSE HIGH VOLTAGE		2.7		5.0	Vdc
PWM FREQUENCY			45	250	KHz
DISABLE ON		2.7		Vcc	Vdc
DISABLE OFF		0		0.8	Vdc
OUTPUT					
Vds (ON) VOLTAGE, each MOSFET	Ids = 10A		1.7	2.5	Vdc
TOTAL Ron, both MOSFETs				.45	Ω
EFFICIENCY, 10A OUTPUT	$+V_S$ = 80V		91		%
CURRENT, continuous		10			A
CURRENT, peak	t = 100 msec	15			A
SWITCHING FREQUENCY	Cf = 270 pf		45		KHz
DEAD TIME			90		nS
POWER SUPPLY					
$+V_S$ VOLTAGE[4]	$+V_S$ Current = Load Current			80	Vdc
Vcc VOLTAGE		9.5	12	15	Vdc
Vcc CURRENT	Vcc = 12Vdc		28	36	mA
$+V_S$ CURRENT	Switching, no load, V_S = 50V		5		mA
THERMAL[3]					
RESISTANCE, junction to case	Full temp range, for each transistor			1.6	°C/W
RESISTANCE, junction to air	Full temperature range		30		°C/W
TEMPERATURE RANGE, case		–25		+85	°C

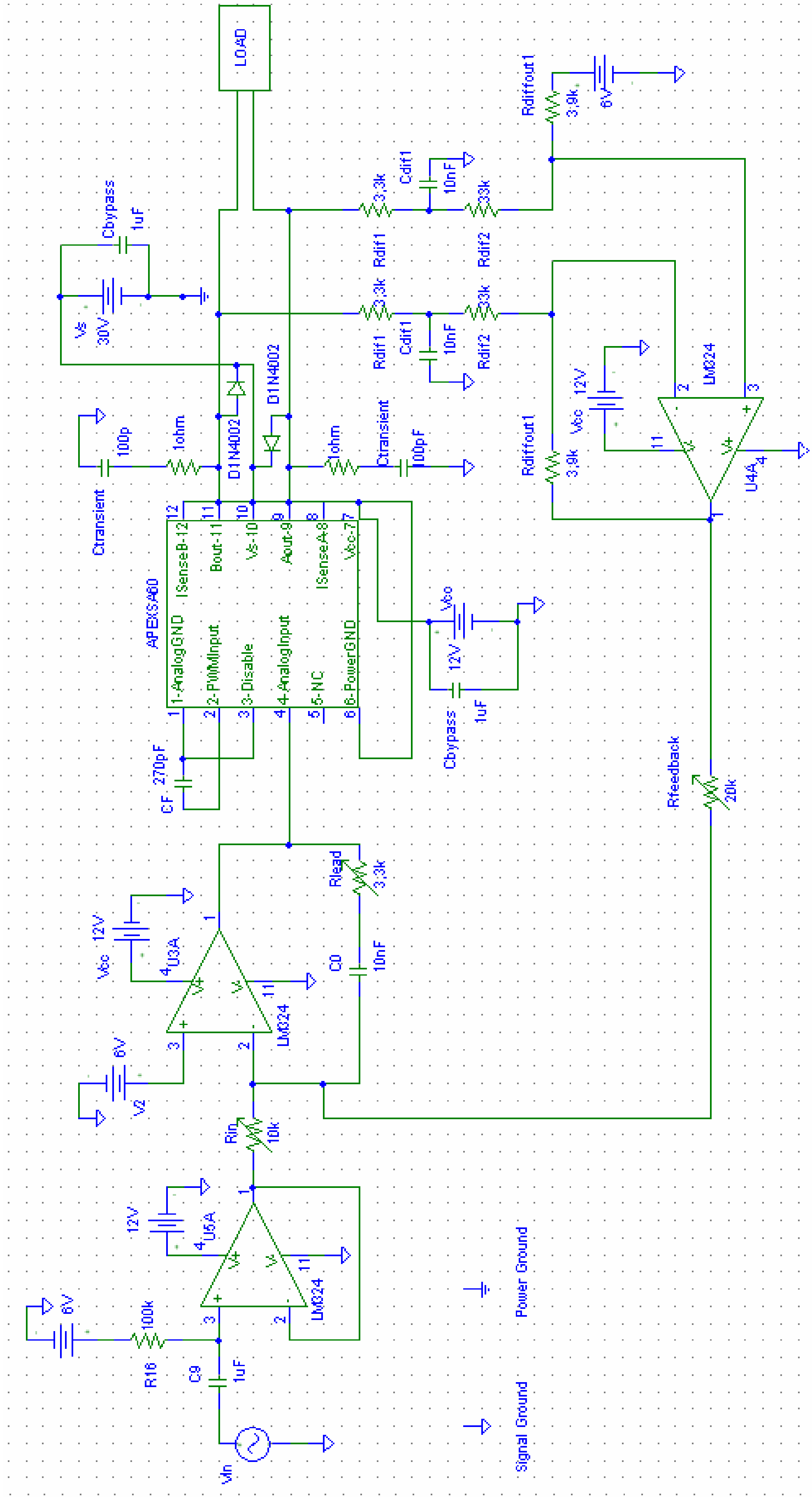
NOTES:
1. Each of the two active output transistors can dissipate 78W.
2. Unless otherwise noted: T_C = 25°C, Vcc = 12Vdc.
3. Long term operation at the maximum junction temperature will result in reduced product life. Derate internal power dissipation to achieve high MTTF. For guidance, refer to the heatsink data sheet.
4. Derate to 70V below T_C = +25°C.

CAUTION The SA60 is constructed from MOSFET transistors. ESD handling procedures must be observed.

The exposed substrate contains beryllia (BeO). Do not crush, machine, or subject to temperatures in excess of 850°C to avoid generating toxic fumes.

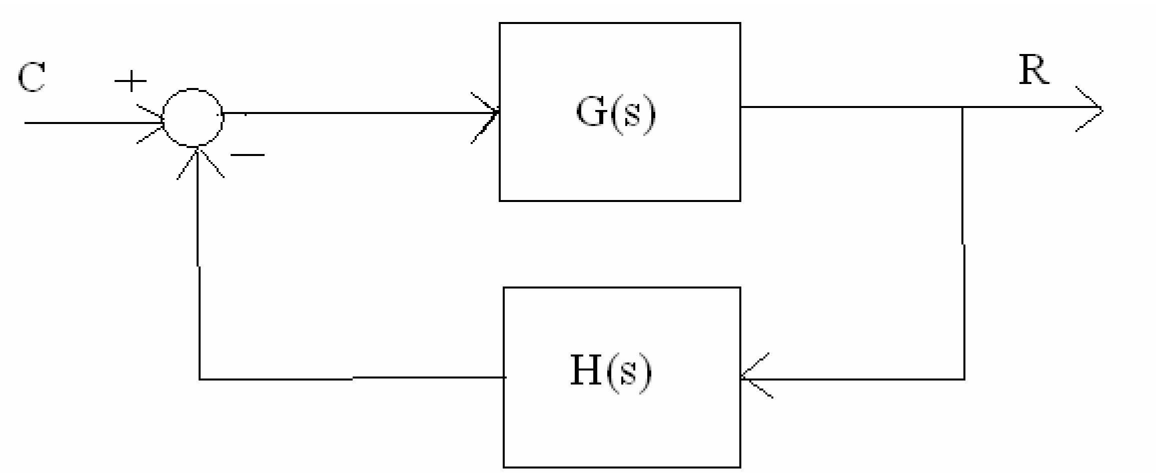
➔After explaining the SA60 chip let me now mention about the details of my design. From the circuit schematic I try to explain the tricky points that are used in the design process of the project. Below is the circuit schematic of my design.

5.3 CIRCUIT SCHEMATIC OF THE PROJECT

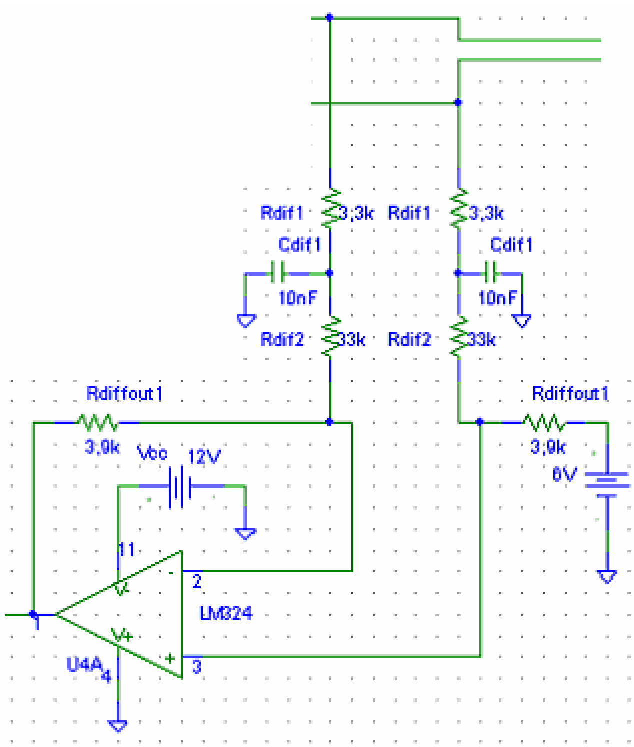


5.4 DETAILS OF THE DESIGN

Let think the whole design as a block diagram representation. I have two transfer function G(s) and H(s) in the block diagram. While starting my design I specified the values of the transfer functions so the gain of the design .



➔I chose G(s)=10 and so H(s)=1/10 and start to my design according to these specifications. Let me now focus on the parts of the design seperately.



➔I used there a differential amplifier. As you know the gain of this amplifier equals to Rdiffout1/(Rdif1+Rdif2). So I chose the values of Rdiffout1, Rdif1 and Rdif2 arbitrarily to make the H(s)=1/10. And I chose Rdif2=10Rdif1 according to my experience on HIP4080A. So in my design H(s)=3,9k/(3,3k+33k)=0,107≈0,1

➔And also due to the working principles of the differential amplifier I paid attention in the choice of the resistors Rdiffout1, Rdif1 and Rdif2. As you know the symmetry is too important in the working of the differential amplifier. So I chose Rdiffout1, Rdif1 and Rdif2 as 1% sensitivity which is more sensitive according to the normal resistors.

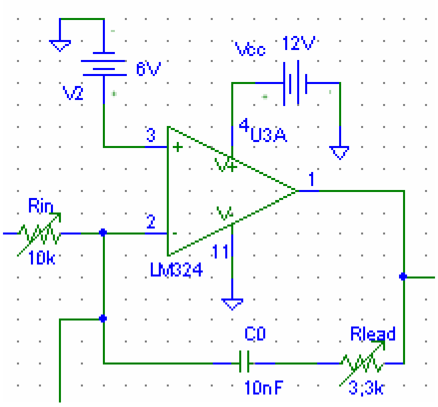
➔ I specified the PWM frequency of the Project as 45kHz. So I calculated the value of the Cf capacitor according to the formula given in the datasheet.

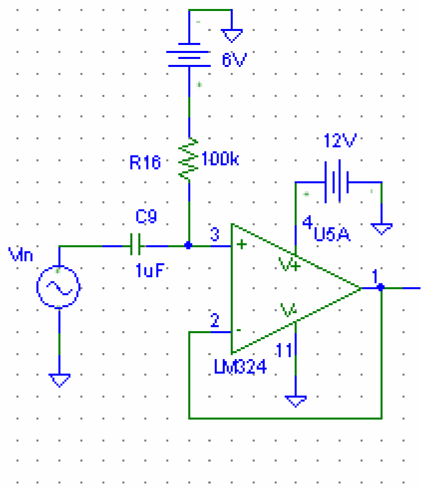
$$C_F\,(pF) = \left(\frac{1.44 \times 10^7}{Fsw}\right) - 50$$

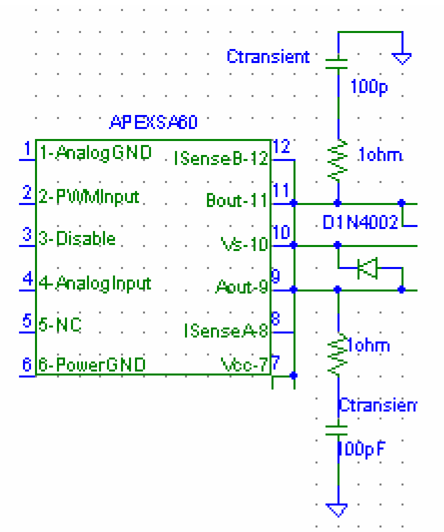
Fsw=45kHz and we found Cf=270pF

➔ I chose the value of the Co and Rlead in the integrator Co=Cdif1=10nF and Rlead=Rdif1=3,3k according to the HIP4080A. I used a potentiometer for Rfeedback(20k) and Rin(10k) resistors. Because we dont have a formula to specify the values of these resistors. All we know from the HIP4080A is the increasing of the gain as Rin increases. But Rin doesnt affect the stability of the system. Rfeedback affects the stability of the system. So I used potentiometer instead of these resistors. Thus, I can adjust them to the desired value for the system to be stable.

➔ The supply voltage for the opamp and APEXSA60 is 12V in my design. I wanted the signal around 6V. So we connect some nodes to 6V supply. Example in the integrator below I compared the input signal with 6V. I specified Vs voltage, which is put on to the signal to obtain a powerful signal, as 30V.







➔I used a buffer above after the input before the integrator to protect the negative affect of the suppressions in the input to the integrator. Also I used a 1µF capacitor to block the DC components of the input values.

➔ I used an RC network above in the right with 1ohm resistor and 100pF capacitor to take the transient suppressions. The assemble of this RC network will be very near to the APEXSA60 to assure proper operation under various loads.

➔ I seperated the signal and power ground to protect the stability of the system to the various negative changes. I connected all Vs power supply and load related ground connections to the power ground, and all Vcc power supply and input related connections to the signal ground. Also I made the adequate bypass of the power supplies for the proper operation.

5.5 THE RESULT OF THE THIRD WEEK

➔At the end of this week, I specified all my design parameters about my project. I paid more attention in the component choice. I chose them proper for the system to be stable. So I knew that I can face with the stability problems. So I was too careful in the component choice. Example I chose the power diodes at the output as DUF4002 which is more faster than a normal diode. So I tried to think every detail which can affect the system in a bad manner. Now, Im ready for the assembling part of the components to the kit and to observe the working of my design.

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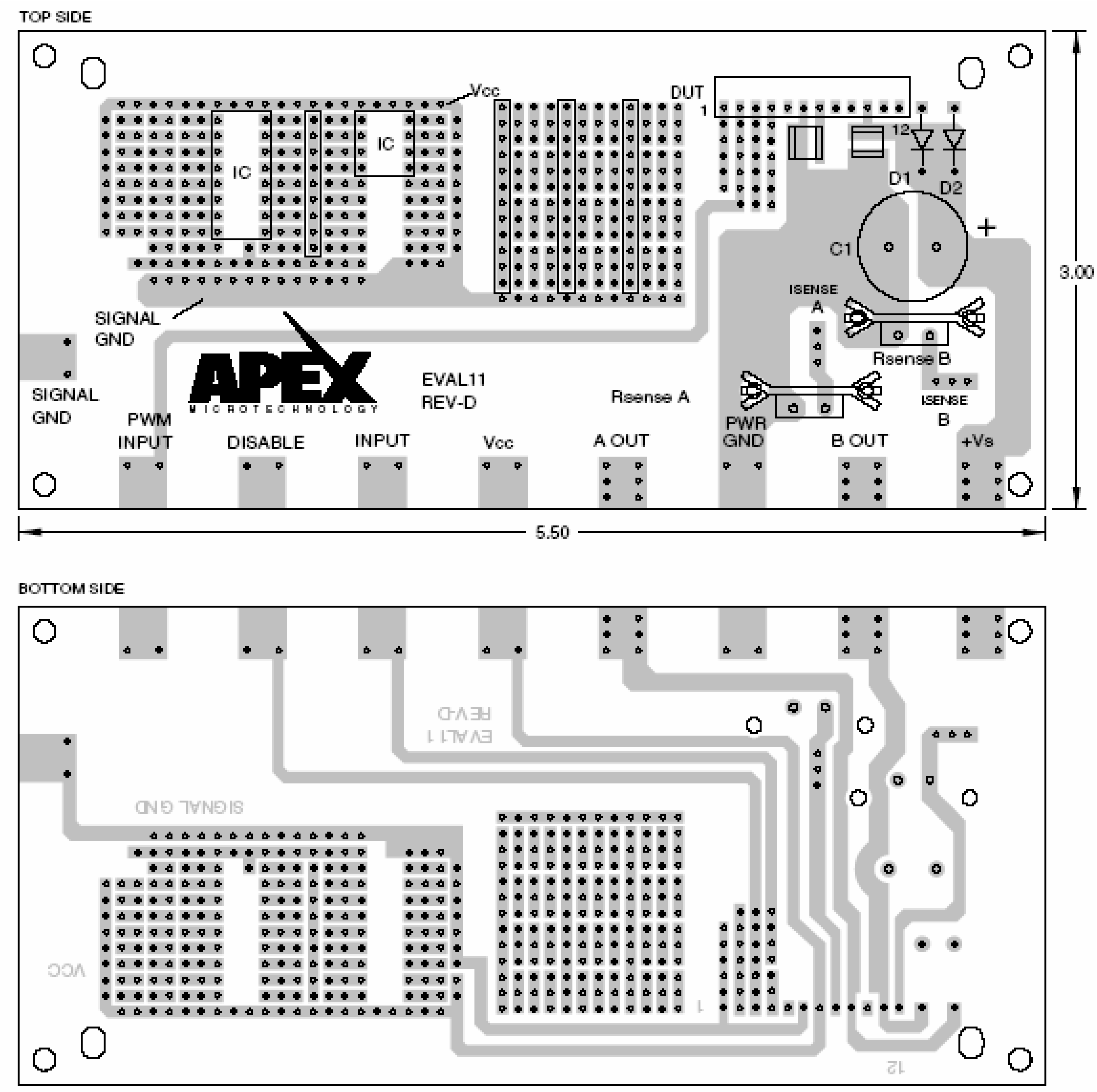
6. FOURTH WEEK:

At the beginning of the week, I started to assemble my design to the prototypeboard. All the components and equipments that are desired, are taken from the YENEL LTD. The evaluation kit was like that.

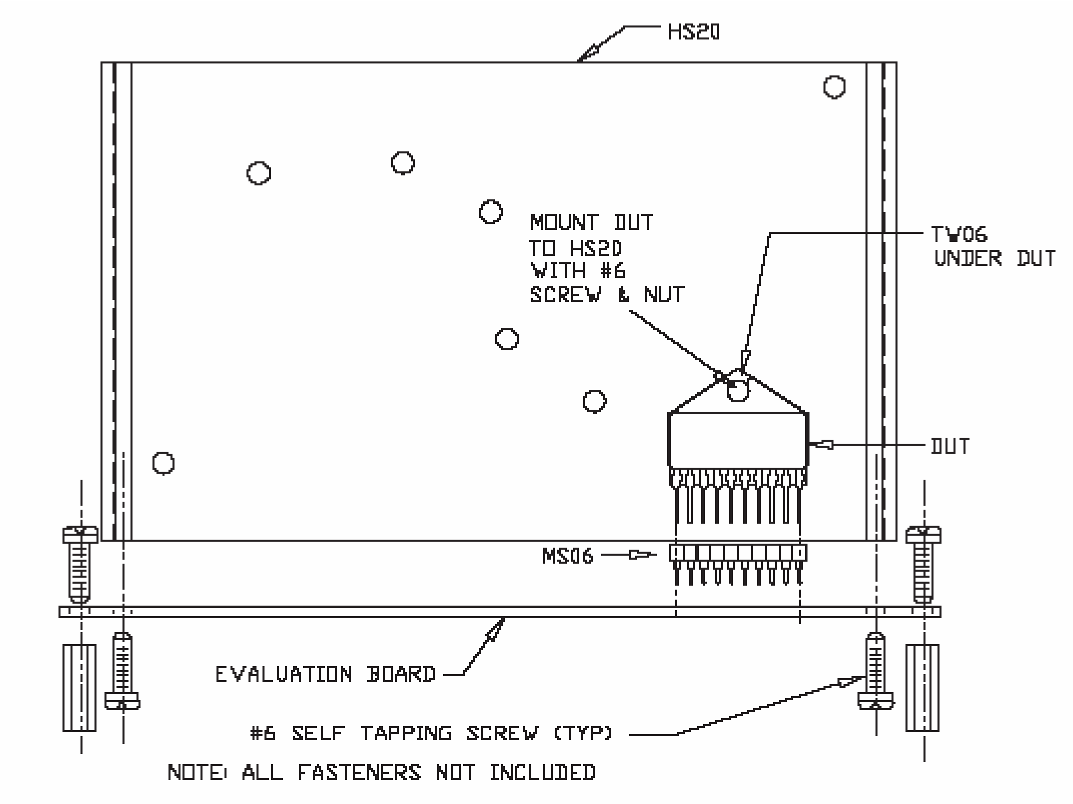


➔Since I used voltage mode control of the output I shorted two load current sensing pins, IsenseA and I senseB to the power ground. Naturally I didn't use Rsense resistors too. The parts that are included in te evaluation kit was like that.

6.1 PARTS LIST

Part #	Description	Quantity
HS20	Heatsink	1
EVAL11	PC Board	1
MS06	Mating Socket	1
OX7R105KWN	1µF Ceramic Capacitor	2
CSR07	.1 Ω 1% Resistor	2
TWO6	Thermal Washer	1 package
HS22	Heatsink	2

➔ We had a heatsink big in size. Also it showed us the bigness of the heat that will be appeared at the output. The assembly of the heat sink was showed in the datasheet like below.

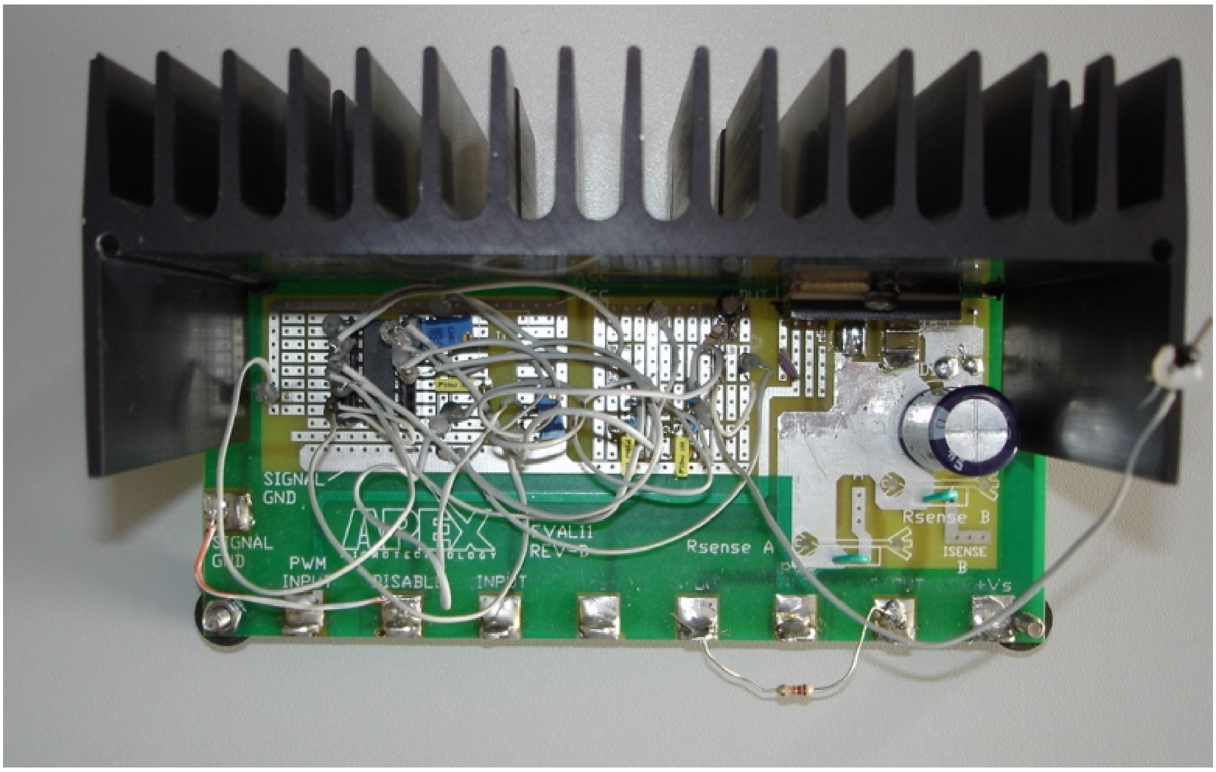


➔ I used a thermal washer TW06 between APEXSA60 chip and the heatsink to reduce the negative affect of the thermal resistor formed between APEXSA60 chip and the heatsink due to the contact of each other.

➔ I used an electrolit capacitor for C1 for bypass purposes. I chose it 2200µF and 50V. In fact it is chosen for the voltage required by the application generally. I used an opamp chip KF347, which include 4 opamps inside, for the opamps in the design. Also the 1 µF assembly ceramic capacitors OX7R105KWN were used. The difference of the assembly capacitors from a normal capacitor is that they dont have any leg. And I used UF4007 for D1 and D2 diodes which is more faster than a normal diode.

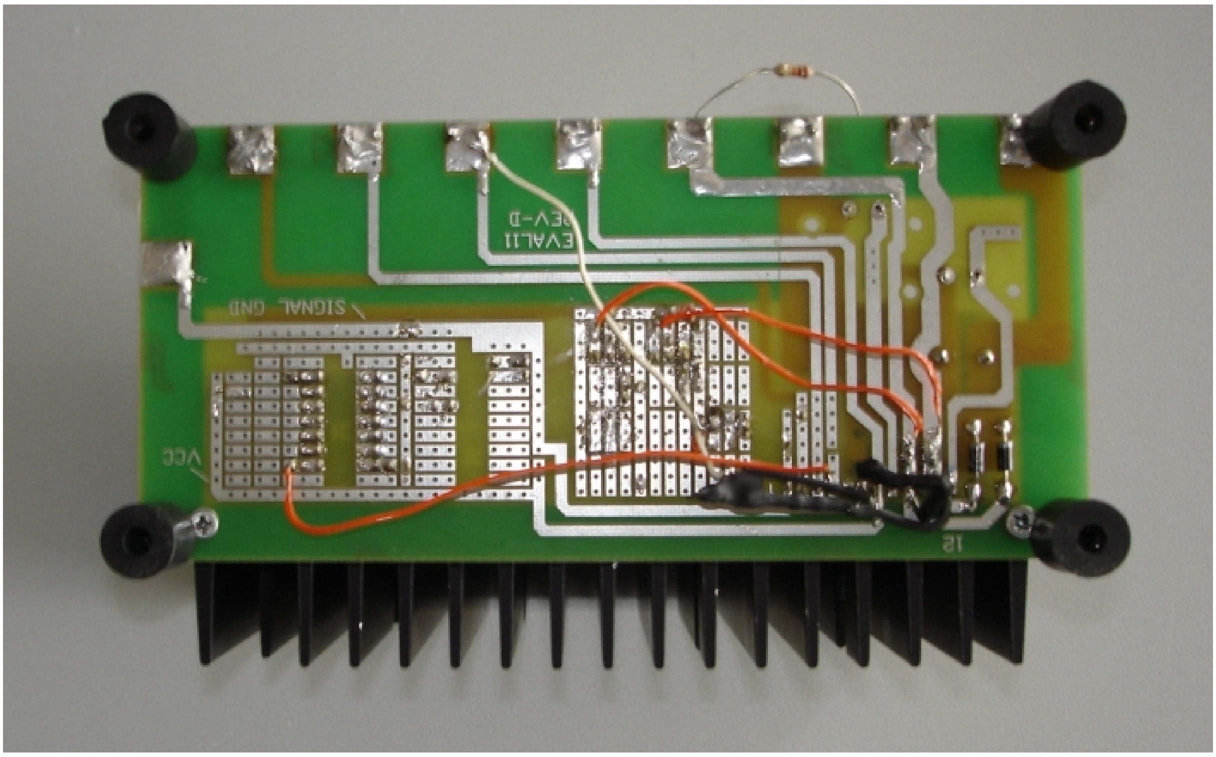
➔After I assembled all the components to the evaluation board, I soldered them. Now it can be ready for testing. Let me show you the photos of my project.

6.2 PHOTOS OF THE PROJECT

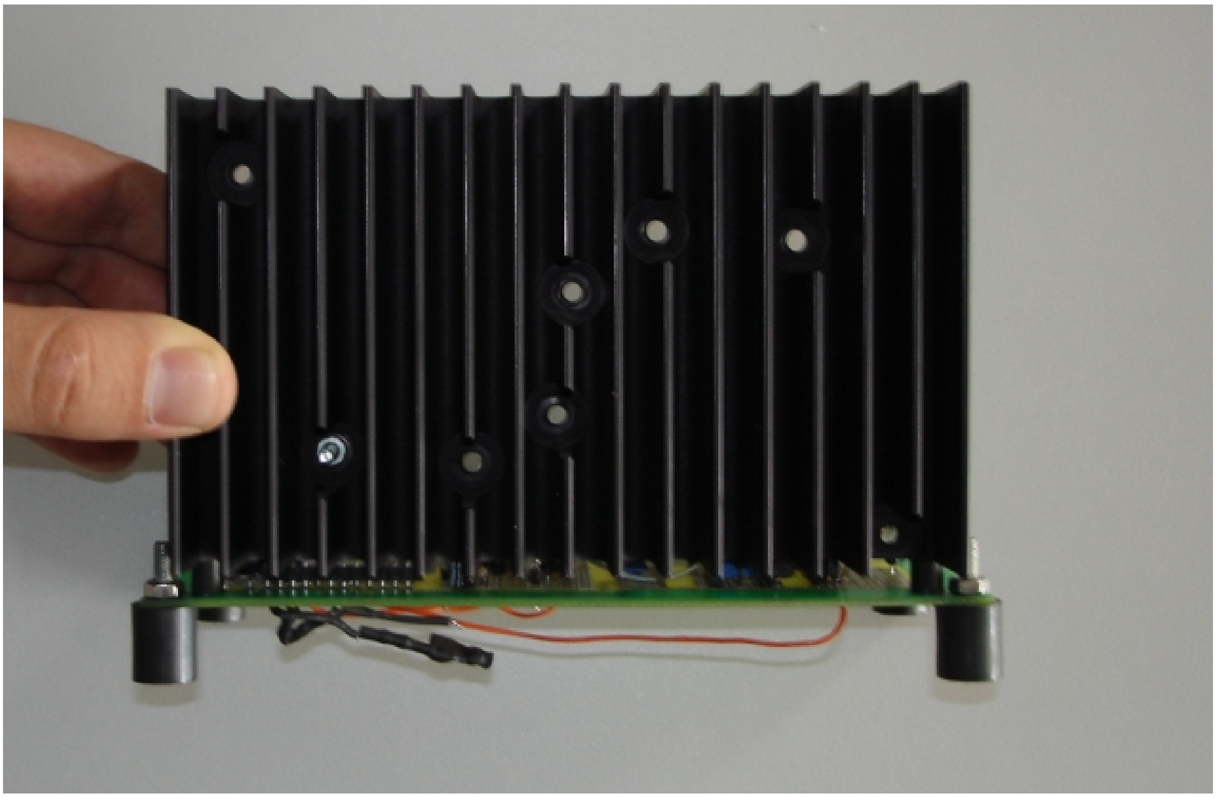


The top view of the evaluation board

The front view of the evaluation board



The bottom view of the evaluation board



The back view of the evaluation board

➔As you see we have a big heatsink. After the assembly of the components, I'm ready for the testing of the design. First of all after giving the input around 1V p-p I controlled the signals in some nodes that I wanted to see. Example I controlled the triangle wave. So in this way the solving of the problems was getting easier for us. I didn't have too much problem. I solved the problems in this way easily. I had some contact problems too due to the disappearing of the contactness of some nodes. I controlled the contactness with the short circuit test of the multimeter. At the end I can succeed in working the project. I saw the PWM signal that I wanted in the scope. I made my testings with and without load.

6.3 THE RESULT OF THE FOURTH WEEK

➔At the end of this week, I completed my project successfully. The week was completed with the assembling and testing of the design. I solved the problems that I faced during the testing in a systematic way. Actually, I didn't have so much problems. For the system to be stable I adjusted at the beginning of the testing Rfeedback resistor to 20k which is the biggest value. I changed it a little during testing for the stability. So in this way I resulted my summer practice successfully.

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7. CONCLUSION

I completed my Summer Practice in YENEL LTD in ODTU technopolis in Ankara. It was a good experience for me to work on ODTU technopolis in YENEL LTD. At the beginning of the first week I met with the staff. Everybody helped me a lot, especially my supervisor Barış Bakla, to get used to the company. I learned about the fields that YENEL works in. These field are medical, industrial electronics and software development. Beside, it has been given lots of importance to the research and development side.

My project was about the PWM amplifiers. I started to made lots of search to prepare a background for my project. I learned lots of things about the working principles of the PWM amplifiers. I examined a specific PWM application of an audio amplifier to gain experience in the application side beside the theoritical information. Day by day I got used to the company. There is a very good relationship between the staff. This relationship creates a good working environment for the staff and me. As I provided the sufficient background for my project, I focused on it. And I succeed in working my project. The most important thing for me as an engineer candidate that I gained during my summer practice is, the different point of views to the problems that I faced in my project. I solved them in a systematic way. It was easier to solve them in that way. I wanna thank so much to Haldun Mıdoğlu, the General Manager and Founder of the company, for his help during my summer practice. Although he is a very busy person, he answered all my questions with the same patience. He helped me a lot to gain different point of views to the problems. Generally, it was a different experience to present as a member of YENEL LTD during four weeks. I completed my summer practice with good impressions and experiences.

8. REFERENCES

- Harris Semicoductor, Application Notes For HIP4080A, March 1996
- The internet sites that are used
  - http://www.apexmicrotech.com
  - http://www.beyondlogic.org
  - http://www.microchip.com
  - http://www.semi.harris.com
  - http://www.mstracey.btinternet.co.uk
  - http://www.yenel.com.tr

9. APPENDICES

9.1 DATASHEETS

- PWM Basics, Application Notes 30, AN30U REV. D JUNE 2002

- Filters and Power Dissipation For PWMs, Application Notes 39, AN39U REV. A FEBRUARY 2001

- Stability and Biasing For PWM Amplifiers, Application Notes 41, AN41U REV. A JUNE 2001

- General Operating Conditions, Application Notes 1, AN1U REV. C DECEMBER 2000

- PWM Low-Pass Filtering, Application Notes 32, AN32U REV. D FEBRUARY 2001

- Spice Model and PWM Amplifier Applications, Application Notes 33, AN33U REV. A JULY 1999

- H-Bridge Motor Driver/Amplifiers SA60, SA60U REV. G JUNE 2002

- Evaluation Kit For SA60 Pin-Out, EK06U REV. B JULY 2003

- Loop Stability With Reactive Loads, Application Notes 38, AN38U REV. B AUGUST 2001