Improving Energy-Efficient and Offering Quality Audio for Mobile Devices

IPRO 344_Spring 2008_Final Report

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Introduction

In Spring semester 2008, IPRO 344 is a team focusing on improving energy‐efficient and offering quality audio for mobile. Our objectives in this semester are:

1. Study commercially available class D amplifier, with a focus on providing an improved audio amplifier and microphone combination for McDonald's Drive Thru system.
2. Study and comparison of commercially beneficial conventional class AB/B amplifiers with similar specifications and constraints.
3. Build a Class D amplifier and its supporting devices using readily available circuits/subsystems.
4. Examine McDonald's current audio environment and apply the obtained knowledge to help provide a global business solution to their drive through ordering systems.

Background

IPRO 344 was founded by Dr. Wong for the Fall 2007 semester with a stated long term purpose of studying and improving technologies for use in low-power mobile audio applications. IPRO 344 had been outlined as the first in a multi-semester project, with each subsequent semester building on the work of the previous semesters and a final objective of providing a diverse and complete toolkit for low-power mobile audio applications.

The current trends in social-electronic integration are indicative of a level of “Ambient Computing”. That is, providing users with electronic services independent of their physical location or condition. Examples of this new form of integration can be seen in everything from cell-phones, portable music players, portable gaming devices, laptops, personal digital assistants (PDAs), and most recently smart-phones. For this entire generation of

new devices, one of the most critical design factors to emerge is that of power efficiency. Users are demanding smaller and lighter devices, more features and more powerful processing power, and longer battery times. Unfortunately, improvements in the power density of consumer level batteries are significantly lacking behind user demands, bringing about the increasingly urgent need for exceptionally energy-efficient technologies upon which the next generation of devices can be built.

Final signal amplification for mobile audio devices can reasonably be in the range of several watts, and can make up significant portions of a devices power budget. Furthermore, traditional amplifiers are limited by a tradeoff between low efficiencies and audio distortion. Lower efficiencies further increase power consumption, and require additional hardware to dissipate waste heat, while higher distortion levels are considered unacceptable by many users.

Amplifiers are classified into letter grades based on what parts of the original waveform are amplified. In most audio applications, Class B and Class AB amplifiers are used. However, as an alternative amplifier design, Class D amplifiers are beginning to emerge as an ideal solution to the tradeoffs of traditional amplifiers. Traditional amplifiers have output devices that conduct even when “off.” This dissipates power, which means there is zero percent efficiency during this time. This lowers the maximum efficiency of these amplifiers.

Class D amplifiers operate on analog principles. They represent the maximum theoretical efficiency of any audio amplifier, with a minimum of audio distortion. Their high efficiency is achieved because they require less power from the power supply, and this requires a smaller heat sink. Also, Class D amplifiers have high power levels and small design. They have two output states “on” and “off” instead of one. In the “on” state, current flows through the device when no drain to source voltage is present. This means that the power dissipation is theoretically zero. In the “off” state, current through the device is zero. Figure 2.1 shows the efficiency for Class AB and Class D amplifier.

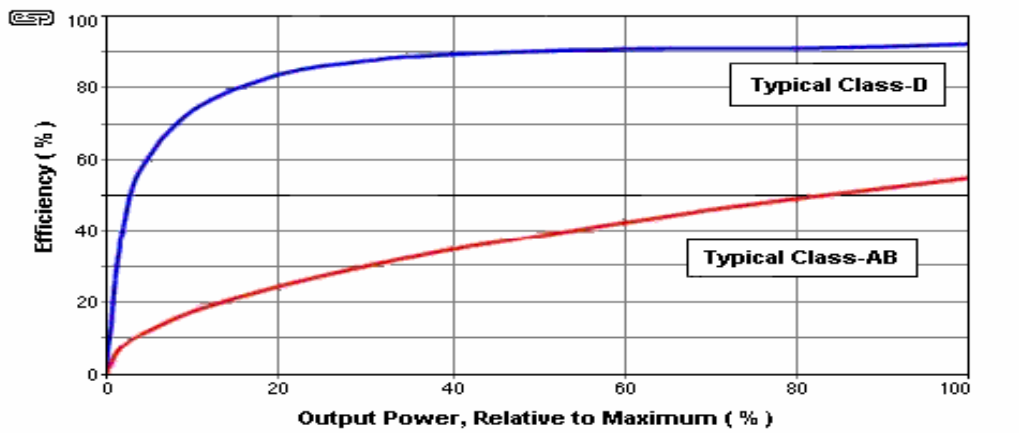


Figure 1. Efficiency Comparison for Class AB and Class D Amplifier

Historically, the usage of Class D amplifiers has been limited by their complexity compared to other amplifier types, and their sensitivity to electromagnetic noise. However, modern improvements and design methods are making Class D amplifiers a more attractive alternative.

Both the benefits and complexity of Class D amplifiers stem from their unique design. Traditional amplifiers function by selecting portions of the input waveform and amplifying them with transistors or vacuum tubes before outputting the new waveform. Class D amplifiers, however, function by re-encoding the entire input waveform into a new signal type, which is then amplified, and finally decoded by means of a passive filter. Most Class D implementations utilize a high frequency pulse-width modulation for their encoding, which allows for higher efficiency in amplification (as the transistor/vacuum tube is only ever completely “on” or completely “off”) and still impose a minimum of audio distortion.

Special Cooperation - The McDonalds Project

McDonalds needs improvement in their driving-thru system. Our team could contribute the technology on audio system improvement. McDonald's concerns with its drive through system may stem from a number of sources. To begin with the equipment may be dated and has not been upgraded for some time. From a customer's perspective, the issues that need to be addressed are:

1. Order Accuracy:

It reduces the efficiency of a busy Drive Through by 40% if an order needs to be retaken. Hence, clarity on both ends of the system is necessary. Some factors are important to ensure this:

- Sound Quality / Noise Reduction
- Sound Amplification
- Speaker and Microphone

2. Drive-Thru Experience:

According to surveys, one bad experience at a drive-thru can bring negative influence to the customer's purchase at McDonalds thus resulting in reduction in profits. The requirements range from a well organized menu, to the order taker's pleasantness and verification of the order correctly, readiness of the order and so on. In out project, over this semester and the next couple we will try to focus on:

- Efficient Speech Recognition: Either improve the current McDonald's system by changing amplifiers, preamplifiers, microphone positioning and the choice of microphone on both ends of the drive through so that the order taker can recognize various accents with more clarity and the customer can understand the order taker.
- Order Record and Processing: Our team might look into the possibility of the order being recorded and processed quicker using speech recognition.

This semester our focus will be twofold. Primarily, we will revisit our previous goals of attaining higher efficiency using various techniques such as Dynamic Power and heat

sinks. Also, we will be trying to increase sound quality for our prospective sponsor, McDonald's, by using noise reduction techniques. To be effective in this endeavor, we will also make a field trip to understand the setup and constraints of their current drive-thru system.

Purpose

Those kinds of information which makes clear the differences between class D and the other amplifiers are required to be added for better understanding on our current pursuing audio system. Thus our team members are focused on study about these different amplifiers for the first step.
The next step we were working on was the devices we have to purchase to go on to next phase. Preferred Pre-Amplifier and Post Amplification Filtering were chosen based on our research.

Methodology

IPRO 344 will be conducted as a continuous research project, with team members focused on learning about Class D amplifiers: their potential application in the field of low-power audio devices, as well as potential improvements in the field of low power audio amplification. Also, field research will be conducted to understand McDonald's drive-thru system. Exact tests and testing procedures will be researched and developed throughout the course of this IPRO. High levels of student-faculty interaction will ensure work continues in a positive direction at all times, while individual, recurring, and peripheral tasks will be handled by assigned sub-teams. Sub-team assignment was voluntary, with team members being allowed positions in multiple sub-teams. Additionally, all team members are encouraged

"cross sub-team boundaries" whenever possible to provide assistance, input, and assist in overall integration.

1. Team Tasks

In the beginning of the semester, we divided our all members in 8 subteams and for the mid-term presentation, we built a new presentation team which has Govind Wakhlu, Nastasja Terry and Chang Song. Also, the presentation team will in charge of the final presentation.

Team leader: Govind Wakhlu

Subteams	Tasks in project plan	Results in final report
Research Team Gil-su Choi, Michael Mikulka, Hwansung Cho, Govind Wakhlu	The Research team consists of all members of the IPRO 344 team, and is charged with the task of continual research in relevant fields of study as directly by faculty. This field involves researching commercially available Class D amplifiers. It is compared with Class A, B, and AB amplifiers. Team members may be required to regularly report findings to the entire IPRO.	The research team successfully created the components for the whole microphone input amplification system with helping to the implementation team. Since goal of IPRO 344 has modified to construct considerably reliable Drive-Thru audio system, which is definitely one of their potential applications in the field of low-power audio devices, a Pre-Amplifier and Post Amplification Filtering systems were needed to have better quality of sound. By the effort of each team member of the research team, the research team could have selected components of various pipelines. Based on tested results by ourselves, the system has quite good quality in terms of efficiency and sound.

Webpage Team Jarrod Godfrey, Donald Spears, Yujin Park, Cheng Sun	The Webpage team is charged with the responsibility of designing, deploying, and maintaining a public webpage displaying information relevant to IPRO 344 and the field of Low-Power Audio devices.	The web team built a website of IPRO 344 (www.ece.iit.edu/~ipro344). This web is a large, HTML based static web which has more than 7 pages and is installed on the official server of the ECE Department. Instead of making minor changes with the previous 2007 fall team's web, we developed a far more attractive web using JAVA script and CSS style. In order to introduce our group members, we took pictures for each one, and used Adobe Photoshop CS3 to edit the pictures.
Documentation Team Yu Zhang, Noh Hyup Kwak , Nastasja Terry, Donald Spears	The Documentation team is responsible for creating, maintaining, and posing all IPRO and IPRO related documents through official channels.	The documentation team produces the project plan, and according to the IPRO office's information, we revise project plan with adding new faculty: Dr. Riley and Dr. Bauer who are advisory faculty for the team on speech quality evaluation and usability assessment, which are relevant to the application of audio systems to speech communication and client interactions in a retail facility. Additionally, for Fall semester IPRO 344, we add the content about McDonald's Drive-Thru system. The documentation team also creates the midterm report which records every step in IPRO 344. And we provide our paperwork to poster team so that poster team can get the proper information they need to create poster for IPRO day.

Purchasing Team Michael Mikulka, Nastasja Terry	The Purchasing team is responsible for reviewing, proposing, and acting on all team purchase requests, as well as maintaining documentation on all purchases and any necessary budget reports.	It was the duty of the purchasing team throughout the semester to see to it that IPRO 344 had the items we needed in order to accomplish our objectives. While this presented many challenges, both in financial terms, since money was required up front before reimbursement could be acquired from IIT, and in discovering places where it was possible to purchase the needed equipment, we were able to overcome those problems. It was also the responsibility of the purchasing team to see that purchases were appropriately recorded. This proved challenging, as missing documentation and a propensity of team members to not scan their information both impeded progress.
Implementation Team Chang Song, Jarrod Godfrey, Hwansung Cho, Govind Wakhlu, Gil-su Choi, Noh Hyup Kwak, Michael Mikulka	The Implementation team is responsible for assembly, operation, and maintenance all equipment studied as part of this IPRO, including Evaluation boards, commercially purchased amplifiers, amplifier components, audio sources and loudspeakers.	The Implementation team has focused on building the actual audio device with the Class-D Amplifier and also focused on testing the performance. We focused on three divisions: the pre-amplifier, the filter and the implementation on boxes, and conducted thorough research in order to determine the feasibility of these devices with the Class-D amplifier bring satisfactory results by successfully attaining the anticipated test measurements. The Implementation team has also gained successful results after having them implemented with the Class-D amplifier and feeding the audio system with voice input instead of generated wave signals.

Tools and Media Team Cheng Sun, Yu Zhang, Donald Spears	**Description:** The Tools and Media Team is responsible for the assembly, operation, and maintenance of instrumentation used throughout the IPRO as well as the preparation of acquired data for presentation.	The tools and media team creates the PPT for the midterm presentation which records every step in the progress of IPRO 344. And we provide our pictures to poster team so that poster team can get the proper information they need to create poster for IPRO day. And, the tools and media team also provides the materials and photos to the presentation team for the final presentation.
Poster Team Yujin Park, Yu Zhang, Govind Wakhlu, Hwansung Cho	The Poster team is responsible for creating a professional summary-poster to be used during team presentations and during IPRO day	Create and print poster for IPRO 344 on IPRO day, prepare brochures and print abstract for IPRO day.
Logistics & Attributes Team Nastasja Terry , Govind Wakhlu	The intention of the Logistics & Attributes team is to put the team's activity in sync with the programs of the IPRO office (IPRO Calendar of Events). Members of the Logistics & Attributes team are to advocate for their IPRO as well as keep track of programs team members have attended.	Remind subteams and team members to complete the research and the works in time.

We are glad to have Dr. Riley and Dr. Bauer who are advisory faculty for the team on speech quality evaluation and usability assessment, which are relevant to the application of audio systems to speech communication and client interactions in a retail facility. Dr. Bauer has given IPRO 344 team several speeches about the physics of speech, which include how we recognize the sound, why we sometimes misunderstand the sound and how to analyze the sound wave. These series of speeches provide us a clear clue to how to achieve the

McDonald's Drive-thru system and show the whole team how to combine the audio system and sound recognizing system together.

2. Implementation Procedure

Taking into account that we would be using the Class-D Amplifier, the implementation team reviewed the data from previous IPRO, analyzed datasheets and made thorough research to decide which equipments would be the best to perform our task. In the nascent stage, the team first started off with experiencing the performance of the Class-D amplifier by setting up with the necessary equipments: power supply, speakers and a DVD player.

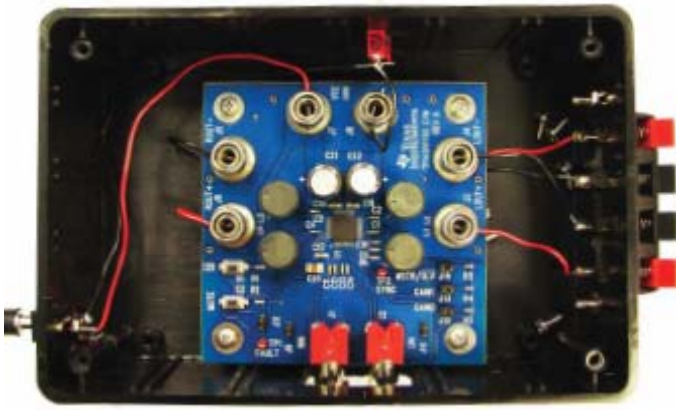


Figure 2. Class D amplifier

While being aware of the benefits of the Class-D Amplifier, the team realized that in order to use this amplifier to its full capacity there were few more parts that would need to be built to satisfy our goal of constructing energy efficient, quality sound audio device. Also, with McDonalds interest later on in our project, the sound quality in communication between people became an important issue and thus in the end the team have decided to build pre-amplifiers and filter devices which would each play its significant role in improving the sound quality.

The work of the Implementation Team mainly focuses on three divisions: the pre-amplifier, the filter and the implementation on boxes. The pre-amplifier and filter was built as the following schematic shown below:

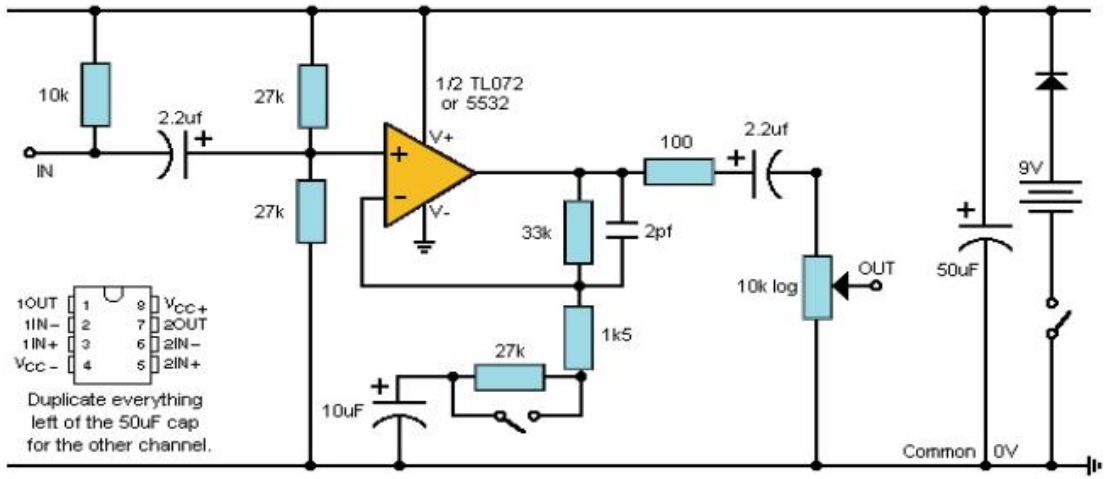


Figure 3. Pre-amplifier

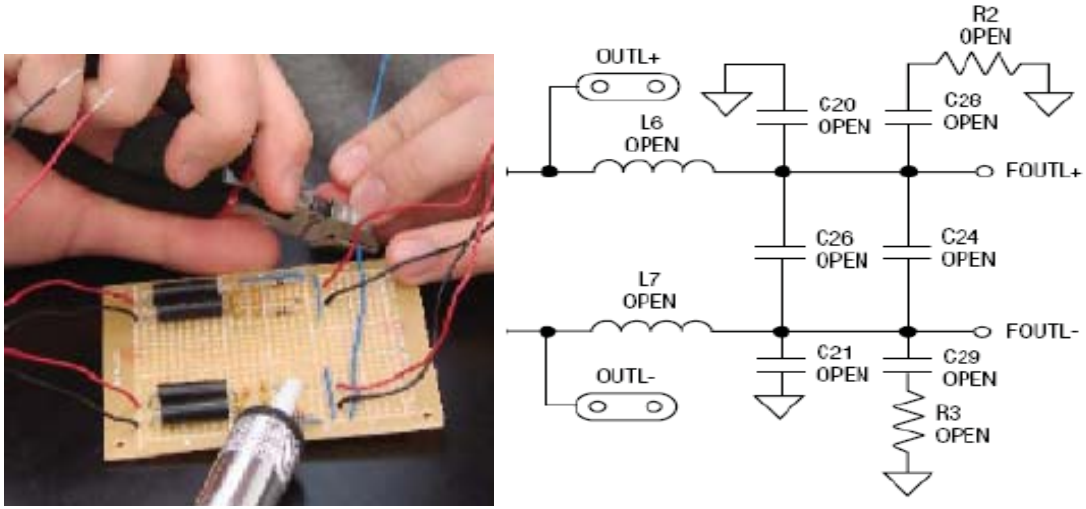
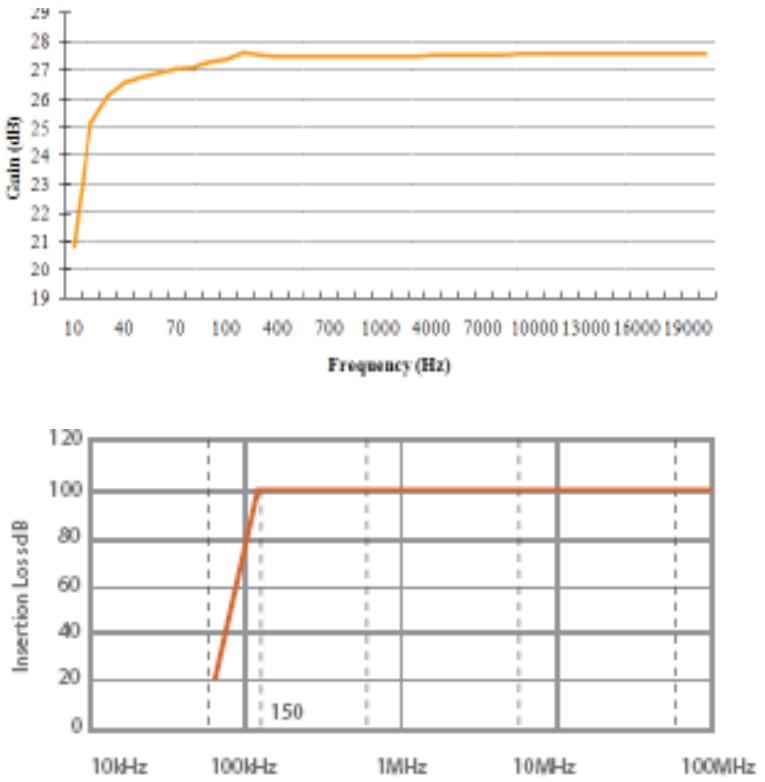


Figure 4. Filter: actual built model and schematic

Using many resources from the laboratory and also with assistance from our advisors, the Implementation team was able to focus in putting as much effort to building these devices. The Implementation team has analyzed datasheets, conducted thorough research in order to determine the feasibility of these devices with the Class-D amplifier. After weeks of working through trial-and-error, the Implementation team was able to bring satisfactory results by successfully attaining the anticipated test measurements.



Graph 1. Test Results from the Pre-Amplifier and the Filter

Implementation team has also gained successful results after having them implemented with the Class-D amplifier and feeding the audio system with voice input instead of generated wave signals.

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Assignments

1. Research and the Results:
The research team and the implementation team are in charge of our hardcore part.

The research team successfully created the components for the whole microphone input amplification system with helping to the implementation team. Since goal of IPRO 344 has modified to construct considerably reliable Drive-Thru audio system, which is definitely one of their potential applications in the field of low-power audio devices, a Pre-Amplifier and Post Amplification Filtering systems were needed to have better quality of sound. By the effort of each team member of the research team, the research team could have selected components of various pipelines. Based on tested results by ourselves, the system has quite good quality in terms of efficiency and sound.

The Implementation team has focused on building the actual audio device with the Class-D Amplifier and also focused on testing the performance. We focused on three divisions: the pre-amplifier, the filter and the implementation on boxes, and conducted thorough research in order to determine the feasibility of these devices with the Class-D amplifier bring satisfactory results by successfully attaining the anticipated test measurements.

2. Website
The web team and the tools and media team are in charge of the website building.

The web team built a website of IPRO 344 (www.ece.iit.edu/~ipro344). This web is a large, HTML based static web which has more than 7 pages and is installed on the official server of the ECE Department. Instead of making minor changes with the previous 2007 fall team's web, we developed a far more attractive web using JAVA script and CSS style. In order to introduce our group members, we took pictures for each one, and used Adobe Photoshop CS3 to edit the pictures.

3. Paperwork
The documentation team produces the project plan, and according to the IPRO office's information, we revise project plan with adding new faculty: Dr. Riley and Dr. Bauer who are advisory faculty for the team on speech quality evaluation and usability assessment, which are relevant to the application of audio systems to speech communication and client interactions in a retail facility. Additionally, for Fall semester IPRO 344, we add the content about McDonald's Drive-Thru system.

4. Supplementary
The purchasing team makes the budget through professional website and assigns the task of buying the accessories to every member in IPRO 344.

The following is a complete list of items purchased this semester by the members of IPRO 344 under the direction of the purchasing subteam. Prices are listed precisely where possible, but several cases of missing documentation and a few cases in which shipping fees were not accounted for in the scanned receipts creates some measure of error in the results.

ITEM	COST	VENDOR
Binding Posts (7)	$34.88	Radio Shack
Computer Tool Kit	$54.49	Radio Shack
Electrical Switches (3)	$9.80	Radio Shack
Headset w/Microphone	$27.24	Radio Shack
Case Components and Related Hardware	$55.48	Radio Shack

ITEM	COST	VENDOR
Further Case Components	$16.31	Radio Shack
Screws, Connectors, Other Misc. Hardware	$89.11	Radio Shack
HDMI to DVI cable	$59.80	Radio Shack
MAX9776 Amplifier Evaluation Kit	$55.00	Maxim
MAX9714 Amplifier Evaluation Kit	$55.00	Maxim
iPod Shuffle	$52.55	Apple
Breadboards (2)	$28.56	Digi-Key
Filter Components	$31.34	Digi-Key
Additional Filter Components	$26.36	Mouser
TPA1517 Amplifier Evaluation Kit	$55.07	Texas Instruments
Potentiometers (2)	$55.16	Newark
Power Supply	$208.00	Astrodyne
Saw/Drill Kit	$19.00	Unrecorded

The total expenditures of IPRO 344 this semester were approximately $933.15.

5. Poster and Presentation
The poster team and the presentation team contribute their efforts on our professional and beautiful posters and slides.

Obstacles

As the hardcore of IPRO 344, the research team could not get substantial information about McDonald's Drive-Thru system in totality and desirable microphone from Shure Inc., neither. Instead our team purchased a cheaper one at the Radioshack,
which is good enough for testing though.

Another problem the research and implementation team dealt with was completing the tasks for the teams on time because of the unanticipated problem in getting desirable experimental results from the whole audio amplification system. The output signal was not enough clear to tabulate the result even though we had Post Amplification Filtering circuit. Thus with help from the laboratory facilitator Ivan Martinov, we tried to spend more time to solve this problems and focus on improving the actual sound quality at the output speaker.

Besides that, however, the learning has been immense and future semesters will be assisted by our research efforts.

Results

1. Class D amplifier
The Amplifiers are classified into letter grades based on how the original waveform is amplified. Class A amplifiers' output devices are conducting for the entire period of the

cycle, which means there is always bias current flowing in the output devices even when they do not really need it. This brought inefficiency, but gives linearity into the device. The output devices of Class B amplifiers only conduct for half the sinusoidal cycle. Thus no input signals, no current flows in the output. However, this has some issue with linearity at some point. Class AB amplifier is a combination of the Class A and B types, and one of the most common types of power amplifier. Non-linearity of Class B and the efficiencies of a Class A design has improved. Efficiency for Class AB amplifiers is about 50 % and up to 75% at its maximum. In Class D amplifier, the switches are either fully on or fully off, theoretically making power dissipation zero in the "off" state. Efficiencies more than 90% – as shown in Figure 1- are possible. With a PWM carrier signal which drives the output devices, the audio signal will be modulated, and a low pass filter will remove the high frequency PWM carrier frequency in the last stage. Due to its high efficiency, Class D amplifier reduces heatsink requirements dramatically. Therefore they do not need heavy heatsinks such as big aluminium extrusions to keep the electronics relatively cool. The loading on the power transformer is also reduced, allowing the use of a smaller transformer for the same power output. Thus Class D amplifiers are lighter and smaller than an equivalent Class AB amplifier. Historically, the usage of Class D amplifiers has been limited by their complexity compared to other amplifier types, and their sensitivity to Electromagnetic noise. However, thanks to recent improvements and design methods with faster switches, Class D amplifiers are regarded as a more attractive alternative of audio amplifiers.

“Shoot through” is a problem which can decrease the efficiency of class D amplifiers. This problem happens when one device is being turned off and another is being turned on. Both devices are on during this transition, and a large pulse current can flow through the two. To solve this problem, the gates of the MOSFETs can be driven by the asymmetrical square waves. This would enable one device to be turned off before the other device is turned on. The “shoot through” problem can be solved through using two comparators, one for each MOSFET, instead of one.

Historically, the usage of class D amplifiers has been limited by their complexity compared to other amplifier types, high Total Harmonic Distortion (THD), audible noise, and sensitivity to Electromagnetic noise. However, modern improvements and design methods are making class D amplifiers a more attractive alternative.

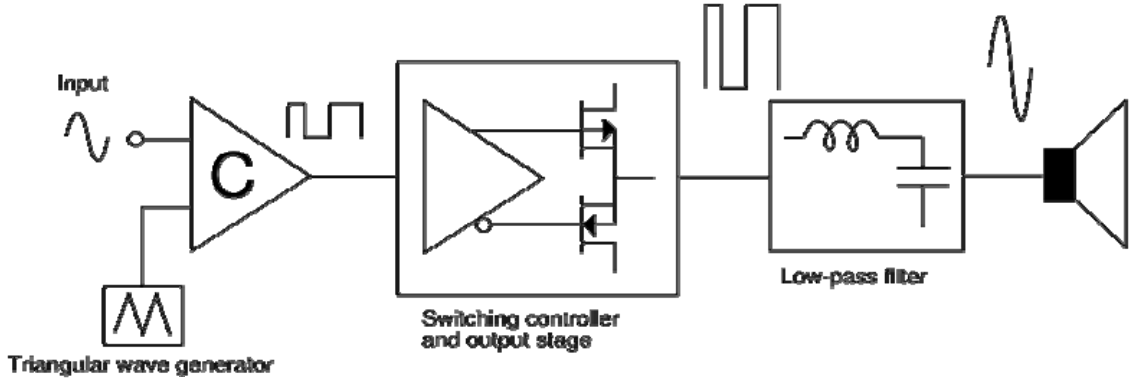


Figure 5. Functional Block Diagram of a class-D Amplifier.

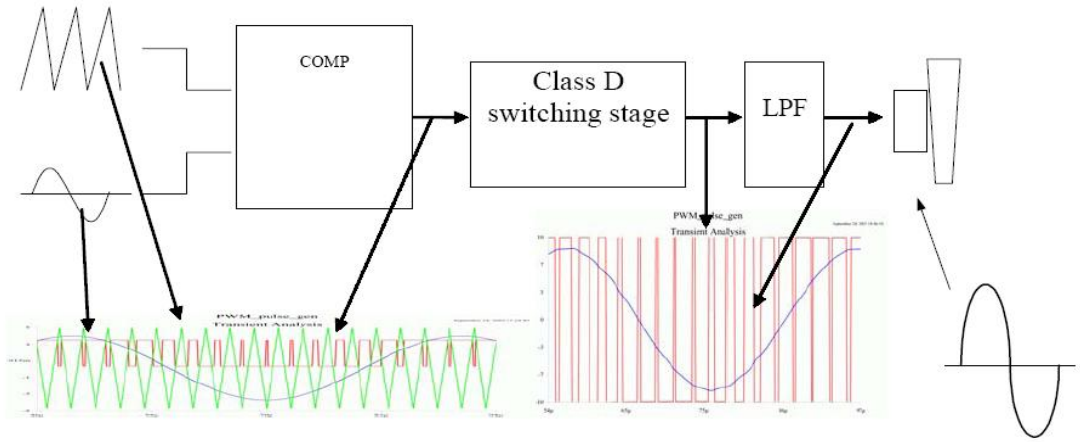


Figure 6. Class D amplifier waveforms

2. The evaluation boards

MAX9776 (CLASS D)

This amplifier exhibits constant gain of about 43 dB from 100 Hz to 20 KHz. Below 100 Hz, there is a drop in the gain. The efficiency varies between 70 % and 80 % for frequencies from about 100 Hz to 20 KHz; the lowest efficiency is at the lowest frequency of 10 Hz. The highest efficiency is 80.2 % observed at 6 KHz. This was based on a 10 ohm load.

When the frequency is kept constant and the gain is varied, maximum efficiency is observed when the gain is set to maximum (31 volume setting). For gain settings above 24 volume setting, efficiency is observed to be above 70% efficiency, and below 21 volume setting the efficiency drops bellow 50%. This was based on an 8 ohm load.

MAX9714 (CLASS D)

This amplifier was not evaluated because when a sinusoidal input is applied, there was no amplified sinusoidal output because the output filter was missing. The datasheet specifies recommended inductance and capacitance for the output filter, but due to time constraints which occurred because of delay in purchasing there was not sufficient time to order the parts and perform the surface mount soldering. However when the amplifier is connected to a speaker, the sinusoidal wave is heard without any noticeable distortion because the speaker has some inductance associated with which helps accomplish the some filtering.

TI TPA 1517 (CLASS AB)

This amplifier exhibits a constant gain of about 20 dB for frequencies from 100 Hz to 20 KHz. For frequencies bellow 100 Hz the gain drops off. The efficiency varies between 50 and 60 Hz for the same frequency range of 100 Hz to 20 KHz, with a peak efficiency of 59.8 % observed over the range of 7 KHz to 12 KHz. The lowest efficiency was observed at 20 Hz and was 16.7 %.

When the frequency is kept constant and the gain is varied, maximum efficiency of 37 % is observed when the gain is about 9.45 dB. Both observations were based on an 8 ohm load.

TI TPA310D2 (CLASS D)

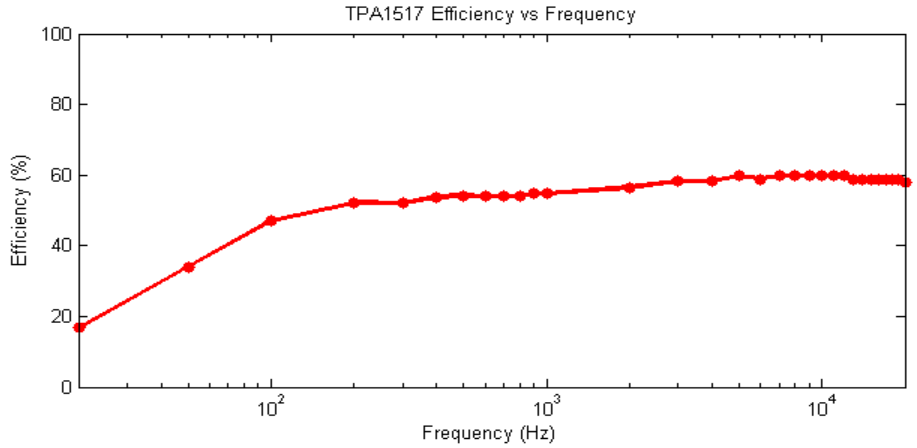
When this amplifier was set at 90% of it's rated power, it exhibited an average gain of around 35 dB for the audio spectrum. At this setting, the efficiency was very high; with an average around 80%. The peak efficiency was 81.4%, which occurred at 700 Hz. The lowest efficiency measured was 73.41%, which occurred at the maximum frequency of 20 kHz, which is not really a concern because most artists don't create sounds at that high of a frequency.

A problem with this amplifier was evident when we looked at the efficiency for varying gains. There was a drastic change in efficiency from 42% to 80% on the range of gains of 20 dB to 26 dB. Yet, this may not really be as big of a problem as we think because even

though it has a low efficiency at low gains; it isn't using much power anyways at that level of gain. Thus, the problem of low efficiency is minimized by the intrinsic fact that less power is used at low gains anyway.

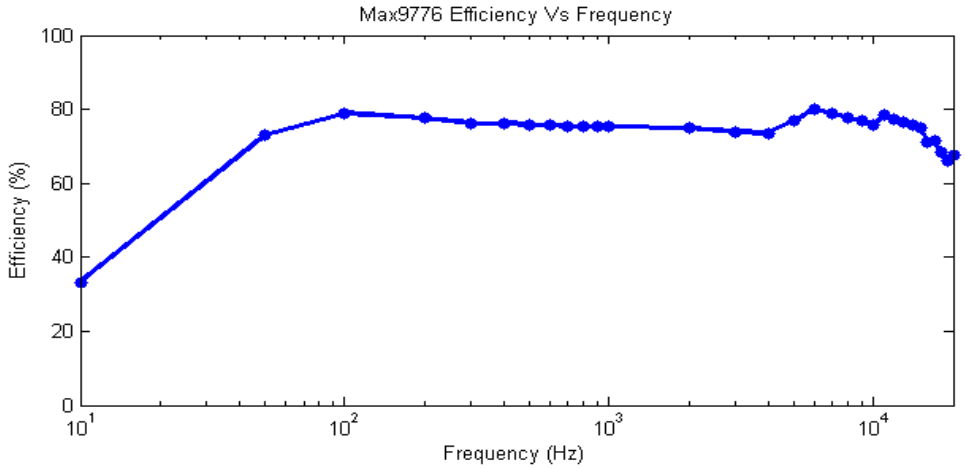
From the gathered data in the lab, it is observed that the CLASS D amplifier exhibits much better overall efficiency than the CLASS AB amplifier. This is in fact because of the switching technique the CLASS D amplifier uses. Of all the data gathered, the most important correlation was that which related the efficiency to the frequency at 90% of the amplifiers' rated output power. The following graphs illustrate this relationship:

Class AB:



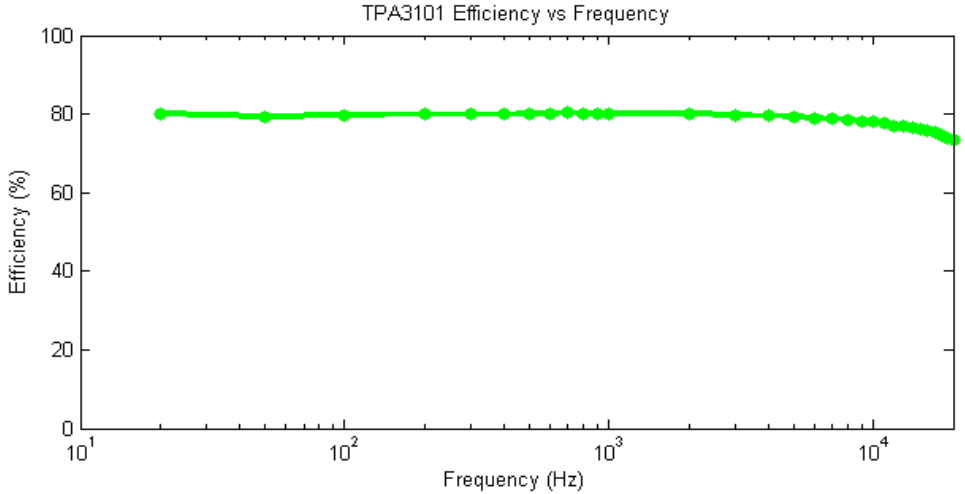
Graph 2. Class AB amplifier efficiency vs. frequency

Class D.



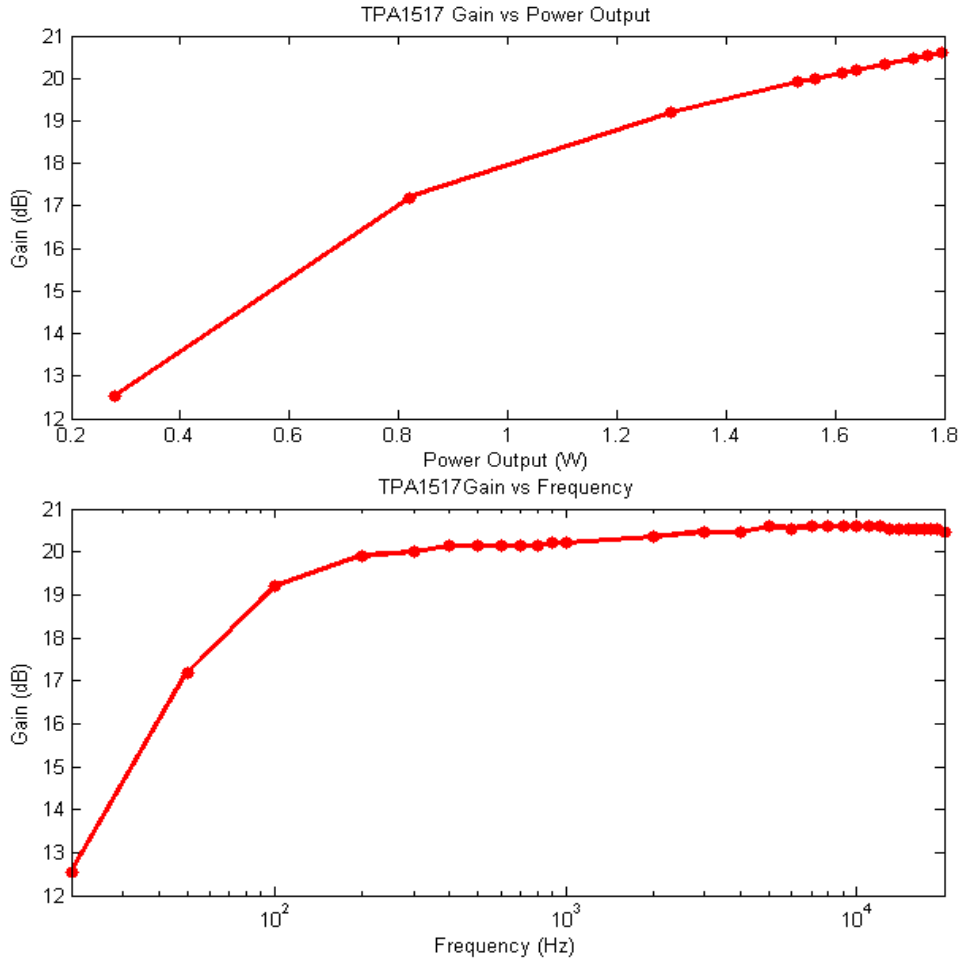
Graph 3. Class D amplifier efficiency vs. frequency(Max9776)

Class D.



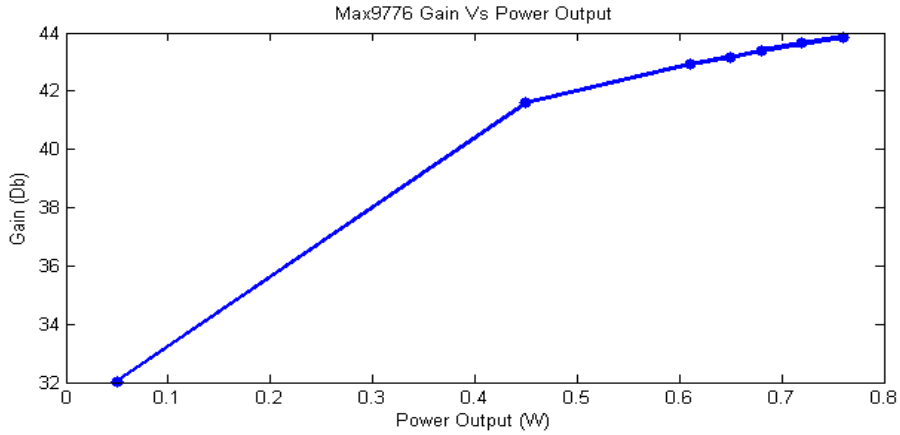
Graph 4. Class D amplifier efficiency vs. frequency(TPA3101)

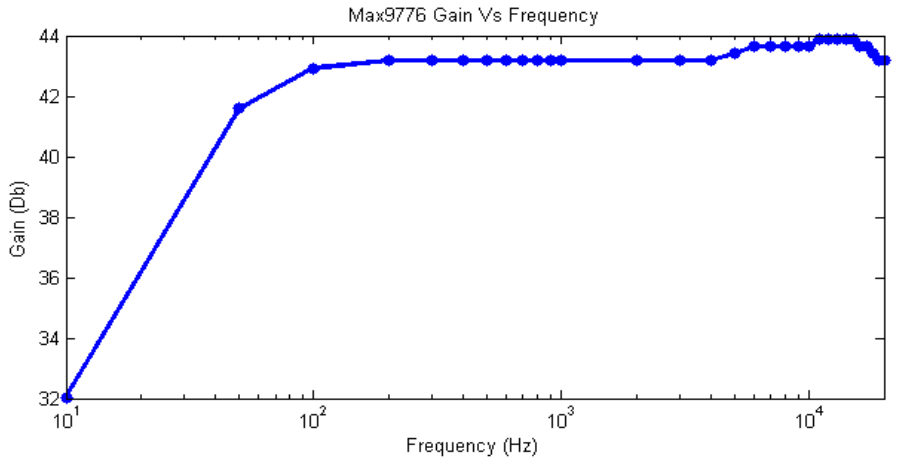
Class AB

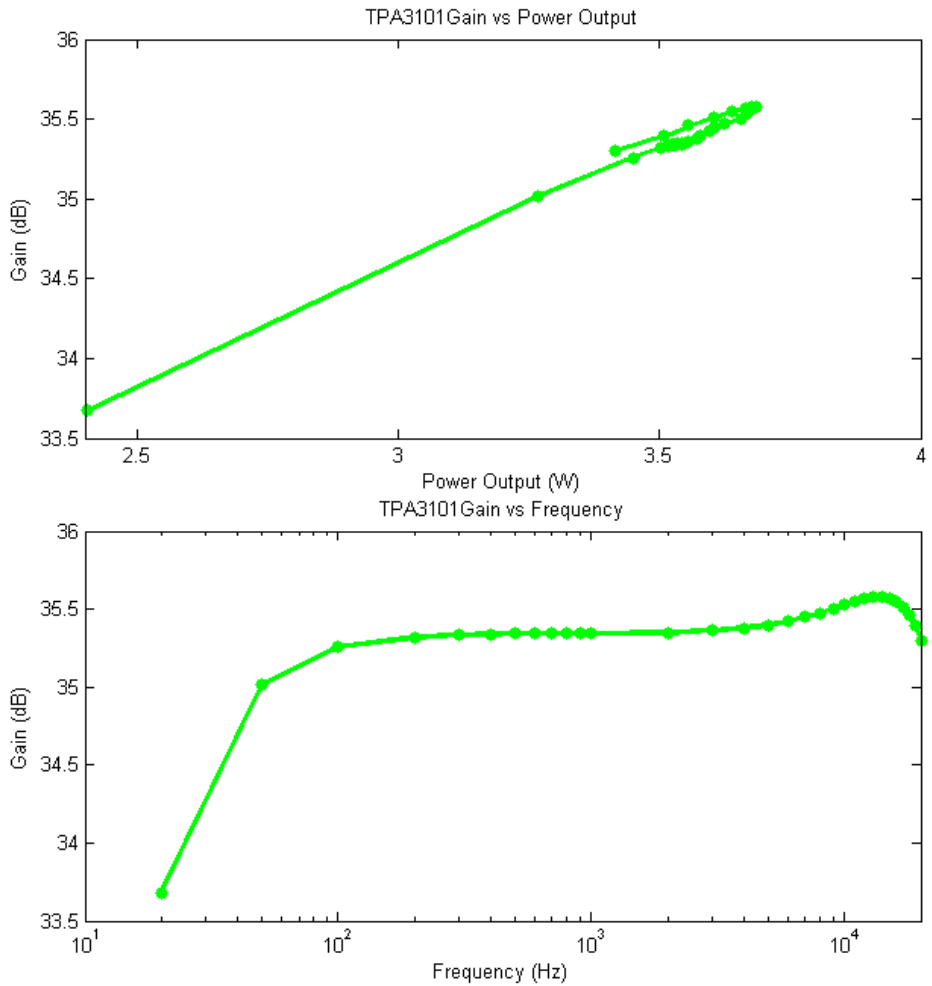


Graph 5. Class AB amplifier: relation between gain, power putput and frequency

Class D.


Max9776 Gain Vs Power Output
Gain (Db)
Power Output (W)
44
42
40
38
36
34
32
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


Max9776 Gain Vs Frequency
Gain (Db)
Frequency (Hz)
44
42
40
38
36
34
32
10^1
10^2
10^3
10^4



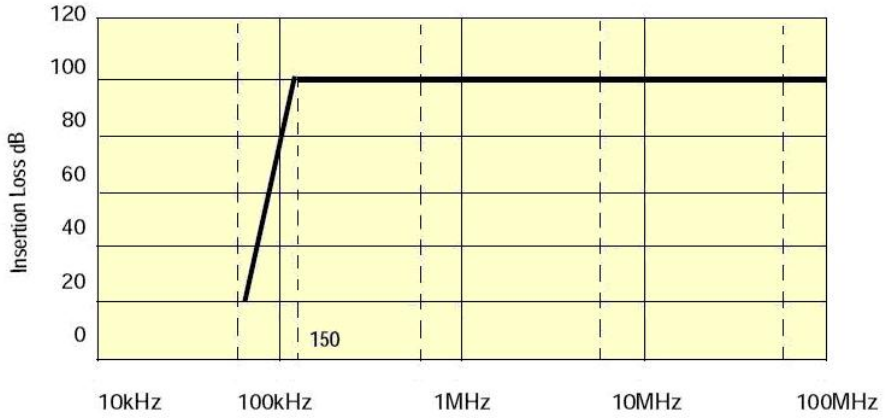
Graph 6. Class D amplifier: relation between gain, power output and frequency

3. The filter

The performance of low pass filter is often characterized in terms of an insertion loss curve. Insertion loss can be described as the ratio of voltage across the load with and without the filter.

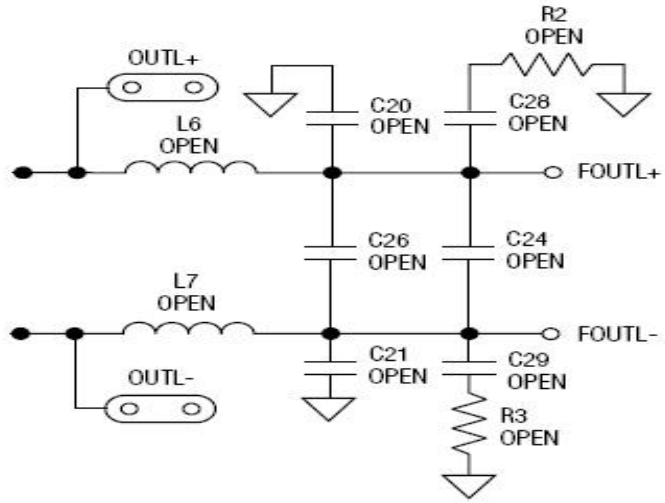
$$\text{Insertion Loss (dB)} = 20 \log_{10}(V_1 / V_2)$$

Where V_1 the signal voltage without the filter is present and V_2 is the voltage after the filter has been put into the circuit.



Graph 7. Typical filter performance

EMI filters and RFI filters describe unwanted signals (noise) that EMI filters and RFI filters are intended to eliminate. For this application, filtering was achieved by discrete devices such as capacitors, resistors and inductors. The filter implemented on the circuit board is shown below.



Graph 8. Schematic of a filter

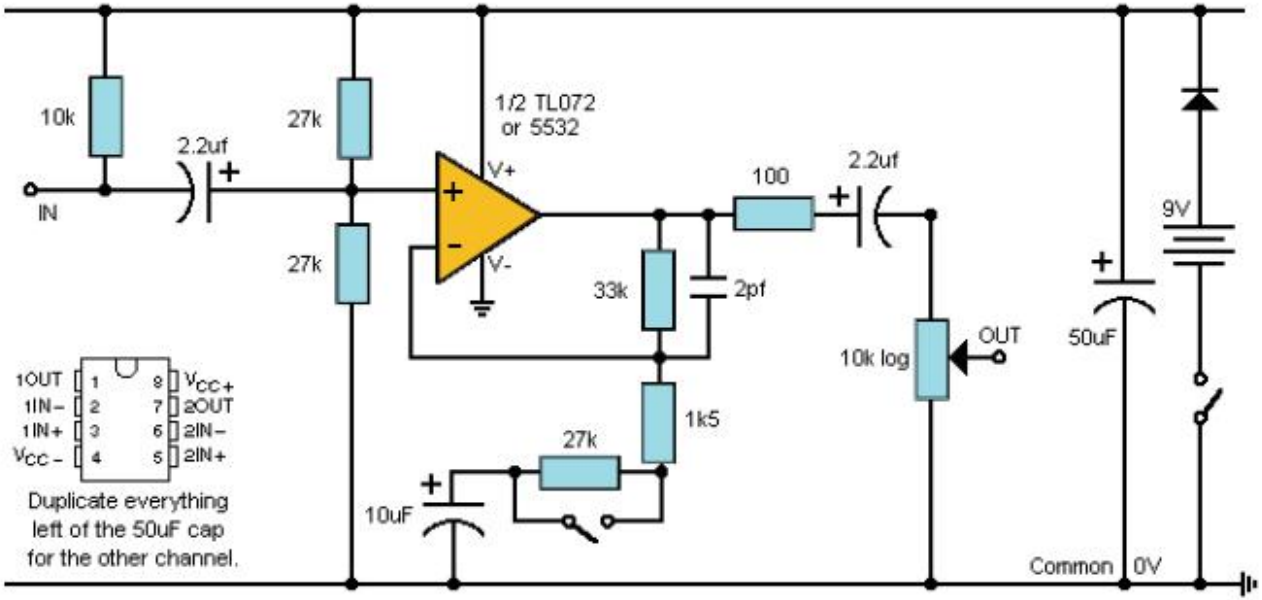
EMI filters have three main functions, the first is of course to filter EMI/RFI, the second is to protect inputs and outputs against ESD and the third one is to transmit data from inputs to outputs. The most important specifications for EMI filters and RFI filters include rated voltage, rated current, and insertion loss. The rated voltage is the voltage for which the EMI / RFI filter was designed. The rated current is the current for which the EMI / RFI filter was designed. Insertion loss is a statement of the filter's attenuation characteristics, exercising in decibels (dB) the ratio of noise that would get through without the filter, to that which gets through with the filter installed. Another important specification to consider when searching for EMI filters and RFI filters is the operating temperature; the temperature range the filter was designed to operate correctly.

The method for filtering and suppression of ESD are described below:

Suppressing Noise at the Source
·Filter all I/O signals leaving the noisy environment
·Locate I/O driver circuits close to the connector
·Use the longest rise/fall times possible for all digital signals
Reducing Noise at the Receiver
·Filter all I/O signals entering the unit
·Locate the I/O filters as close as possible to the connector
Minimizing Noise Coupling
·Use multilayer PCBs to minimize power and ground inductance
·Keep clock circuits away from the I.O connector
·Ground planes should be used whenever possible
·Minimize the loop area for all high speed signals
·Provide for adequate power decoupling
ESD Protection
·Locate the suppression devices as close to the I/O connector as possible
·Minimize the PCB trace length to the suppression device
·Minimize the PCB trace length for the ground return for the suppression device

4. Pre–Amplifier

A preamplifier, preceding another amplifier to prepare an electronic signal for further amplification or processing, needs to be constructed before the input stage of class D amplifier. This circuit is to amplify a low-level signal to desired level.



Graph 9. Schematic of One Channel - Single Rail Version

The leftmost 10k resistor supplies plug-in-power to the electret, forming part of the FET amplifier in the electret capsule. This could be anything from 2k to 10k, the higher the better the stereo separation (another mic derives bias from the same rail). Apparently higher values also lower distortion, and the best bias power circuits involve actually breaking a trace on the electret capsule to allow the use of both a drain & source resistor.

The leftmost 2.2uF cap blocks the bias voltage from the input. In conjunction with the following 27k resistor it forms a high pass filter, but cutoff is essentially near DC.

The input impedance is set by the two 27k resistors and the 10k resistor. The +ve rail is also connected to ground as far as the AC signal is concerned because of the power supply cap. So there are two 27k resistors in parallel, making 13.5k, in parallel with the 10k, making about 6k or so for the input impedance. But for the proper dual supply, the upper 27k resistor is not necessary, as the input doesn't have to be biased mid rail anymore.

The feedback loop has two resistors 27k & 1k5 from the inverting input to ground. When they are both in circuit, the gain is a bit under 2 ((33/28.5)+1). The 27k resistor can be bypassed with a switch, then only the 1k5 sets the gain, to 23 ((33/1.5)+1).

The 10uF cap in the bottom half of the feedback loop reduces DC gain to ~1. The value isn't very important. If any DC input offset were amplified it would create a larger output offset, pushing the output toward one of the rails and reducing headroom. (At a gain of 23 with the expected input levels it probably doesn't matter.)

The optional 2pF cap in relation to the 33k resistor sets the high frequency roll-off. The cutoff frequency is in the 100's of kHz. It has to go further than 20kHz to keep the phase shift at audio frequencies small, and also because output starts falling long before cutoff. The op-amps cannot maintain enough gain at these frequencies anyway and their output will already be falling, but the cap makes the circuit more stable, though it will probably work without it. There will probably be 2pF of capacitance just from the PCB traces, and op-amps tend to be fairly well compensated these days so it's really not needed.

The 100ohm resistors are there partly to limit current to protect the op-amp if the output is shorted, but the op-amps have internal protection anyway. They mainly allow the op-amp to drive capacitive loads (long/cheap cables) without oscillation.

The 2.2uF cap on the output blocks DC and the value is not specially important. It forms a highpass filter with the 10k pot, the cutoff is virtually at DC.

5. Microphone

After carefully consideration, we prefer Shure WL185 Microphone (Figure below), because it is good for general purpose sound reinforcement applications requiring good rejection of ambient noise. Also it has pretty good frequency response and relatively economical price. We highly recommend using of windscreen whose pickup angle is 130 degrees. Much more research will be done after visiting the Shure Radio Company.
Our Selection of equipments is:

- Shure WL185 Microphone
- Breadboards
- Pre-Amplification Filter
- Harmonic Distortion Unit

Figure 7. Shure WL185 Microphone

Future Work and Recommendations

IPRO344 team this semester suggests the following recommendations for future work:
• Design, build, and further analysis of class D amplifier
• Use analysis tools to study quality of audio signal and get desirable result from the output load
• Focus on the microphone and loudspeaker sections in greater detail to obtain better sound quality
• Develop strong ties with McDonalds and companies like Shure Inc. that can provide us with equipment for our academic purposes.

Reference

1. Leach, Marshall W. Introduction to Electroacoustics and Audio Amplifier Design. Kendall/Hunt, 2001.

2. Moreno, Sergio. “Class D Audio Amplifiers - Theory and Design.” June 2005. 31 Aug. 2007. <http://sound.westhost.com/articles/pwm.htm>.

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