Project Proposal and Feasibility Study

Team 11: Microphone Missionaries

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Executive Summary

Our project is to develop an audio device that will digitize an analog signal and store the digital information on a convenient media, for example in WAV or MP3 format on a USB flash drive. We are working with a mission organization called Epic Partners International, also known as One Story. Epic focuses on evangelism to illiterate people groups through Bible storytelling. Our device will be used for the professional quality audio recording of native peoples telling Bible stories in their native languages and is being designed per Epic's specifications. This device will replace the laptop computer and peripheral sound card that is currently being used by Epic for recording. These recordings will then be distributed via radio and other transmission means by Epic and other partner organizations. Our design approaches this problem from a Reformed Christian perspective and focuses on both the mechanical design of the case and interface and the electrical design of the circuitry. The projected production cost of our product is roughly $190 with a prototyping cost of roughly $300 for materials and components. Based on our research and requirements we have chosen to record the audio in WAV format on a USB flash drive and have named the product the Portable WAV Recorder. We are scheduled to begin building and testing in January and a completed, fully functional prototype by April.

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1. Project Overview

This project was initiated by the Senior Design Course which we are all taking as senior engineering concentration students. In this course students are required to take on a project as though they are an engineering team in industry and learn through the feasibility study and design processes. We chose this project based on our multidisciplinary team structure (two mechanical engineering concentration students, three electrical/computer engineering concentration students) and a desire to express our Christian beliefs in our vocation.

1.1 Epic Partners International

There are over 1 billion people in over 4400 people groups that have not been reached with the Christian Gospel. These people do not have access to the written scripture or any written text. Using traditional Bible translation methods it will take at least 150 years of translation work to make the Bible accessible for these people. Even if the Bible were translated, the people would not even be able to read it since many cannot read in their own languages. Epic Partners International was formed to find an alternate way to bring the gospel to these people. Epic Partners was launched through collaboration of five mission agencies: Campus Crusade for Christ (ccci.org), The International Mission Board of the Southern Baptist Convention (imb.org), Wycliffe International (wycliffe.net), Youth With a Mission (ywam.org), and Trans World Radio (twr.org). EPIC has a desire to reach people that have not been presented with the Gospel through bible stories conveyed by word of mouth. To do this they record Bible stories in the local languages and distribute the stories on small reusable audio players such as is shown in Figure 1. The people are then able to listen to the Bible stories as many times as they want and as often as they want. The Bible stories are also broadcast on the radio.

Figure 1: The MegaVoice Messenger Digital Audio Player [15]

1.2 The Microphone Missionaries

A member of Epic Partners, Rob Hughes, had been looking for a device that could be used to record quality audio in the mission field when he came across a senior design project at Calvin College. That project, done by the Precision Sound Input team in the 2004/2005 school year was close to Rob's ideal product. Rob needed somebody to make a device similar to that project; one that would record professional audio and store it on portable memory. He also needed that device to be portable and strong enough to survive in the mission field. The device Rob wants would replace the combination of a laptop and external sound card that is currently used in the field (Appendix A: Existing Equipment Setup). Our team has taken on the task of designing such a device. The team name that we have given ourselves is "The Microphone Missionaries". This team name is a reflection of what we are doing and the final use of our project. The five members of our team are:

Scott Heupel: an electrical/computer engineering concentration student from Singapore. He also has a mathematics minor and plans to join the work force upon graduation.

Josh Jarrard: an electrical/computer engineering concentration student from Middlebury, Indiana. He also has a computer science minor and plans to join the work force upon graduation.

Bryan Klingenberg: originally from London, Ontario, he is one of the three electrical/computer engineering concentration students on the team. He is also minoring in mathematics at Calvin and plans to attend graduate school after graduating from college.

Eric Lundy: a mechanical engineering concentration student from Holland, MI. He plans to join the work force upon graduation.

Mike Moselle: a mechanical engineering concentration student minoring in mathematics originally from Minneapolis, Minnesota. Michael grew up over seas and has much experience with third world cultures. He plans to attend graduate school for aerospace engineering after graduation.

1.3 Project Proposal and Feasibility Study

This document outlines the design that we propose is the best solution for this problem. It first gives a detailed outline of the various design requirements that constrain our design in section 2. Next, section 3 considers the possibilities and relative benefits of alternatives for each component and gives reasoning for the design decisions that were made. Finally, section 4 discusses the feasibility of this project based on current market forces, schedule and budget constraints.

2. Design Requirements

The requirements for this design come both from Rob Hughes' specifications and self-imposed requirements on general design practices and project scope.

2.1 Design Norms

A Reformed Christian approach to engineering design requires consideration of certain design norms, or standards against which the design can be judged to determine whether the design embodies the values of the Reformed Christian perspective. These design norms are cultural appropriateness, transparency, stewardship, integrity, justice, caring, and trust. The relevant norms for our design are

2.1.1 Cultural Appropriateness

Our product will be used in remote areas that may or may not have a distributed power grid and may also be used outside while a missionary is walking around. Therefore it must be battery powered. It shall use rechargeable or disposable batteries to maximize flexibility and convenience to the user. Foreign cultures may have problems with dealing with complex looking equipment that foreigners bring in. For this reason, the device will be designed as non-descript as possible to look simple and non-threatening.

2.1.2 Transparency

The education of the user is a cultural issue as well as an issue of transparency. The majority of the users will be high school graduates who have no knowledge of recording practices. The design must be simple and self-explanatory enough that this level of user can use it effectively with as little training as possible. Also, as any post-design work will most likely be done by Epic, a thorough explanation of the full scope of the design will need to be provided so that the product will continue to be useful.

2.1.3 Trust

The design requirements of the customer stressed durability and quality of operation because if our device fails in the field the missionary will be unable to record Bible stories until a replacement recorder is found. Our recorder must be designed for durability and predictable operation so that the end user can trust in the consistently correct operation of the product.

2.2 Overall System Requirements

The overall system requirements govern the general functionality and I/O of the device. The device will be called the Portable WAV Recorder will be replacing an external sound card/audio mixer and a laptop that is currently used; see Appendix A: Existing Equipment Setup. The problem with this setup is the difficulty associated with transporting it, the amount of setup work required, and the delicate equipment used. The device will accept microphones using either XLR jacks or 6.3mm mini plugs with a differential input (see Figure 2).

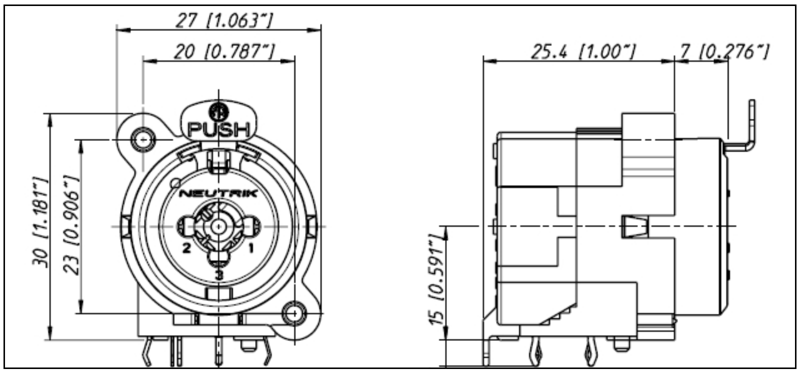

Figure 2: Combinational Jack [22]

An output port will be a 3.5mm stereo mini jack for headphone use. (see Figure 3: 3.5 mm mini jack)

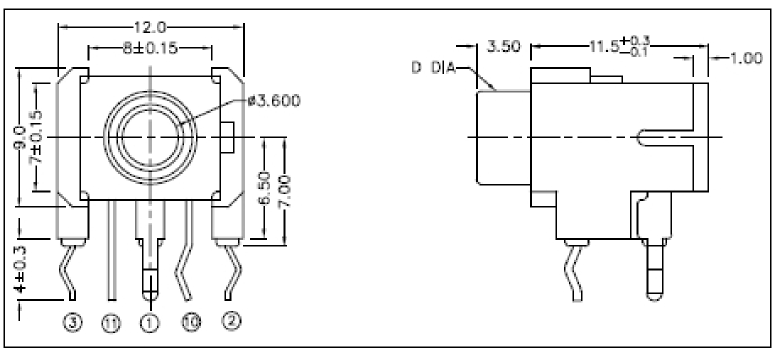

Figure 3: 3.5 mm mini jack [22]

The device will also have the capability to playback tracks, which requires an interactive control scheme that is user friendly and intuitive. The recorder will need rotary knobs to dynamically adjust the preamplifier gain levels. The operator will have some visual indication of the gain levels while recording and will have a clearly labeled control interface. The digitized data will be stored on a removable drive. Lastly, the device must be able to record audio for a minimum of ten hours per set of batteries.

2.3 Mechanical Requirements

Much of this project will rely on the mechanically robust design of the electronics packaging, making the mechanical requirements a very important piece of the scope of this project. If for any reason, the mechanical systems of the device fail, the protection of the electronics will be compromised. Due to the intended use and of this product and the conditions where it will be used, the mechanical requirements are vital for a sensible lifetime of the product. The size and weight have a substantial effect on the ease of use for the operator.

The recorder design will need to be extremely portable and tough. The size of the packaging will have to allow the user to hold and operate the device in their hands with ease. Making the device mobile directly influences the size and weight of the unit. Therefore, the overall size cannot be greater than about 4" x 6" x 2". The device cannot be heavy either, so the final weight, with batteries, cannot be greater than 3 lbs. The user will operate the device at a maximum of 10 hours per day, during this time period the operator should not encounter any fatigue from using the device including symptoms from repetitive use such as carpel tunnel syndrome. This will include ease of use and proper ergonomics to support extended operation. This device will be traveling international borders quite often so it is important to make it easily transportable and inconspicuous; the less attention brought to the unit, the easier it will be to carry across borders.

2.4 Operating Conditions

The aspect of this design that sets it apart from most other electronic systems are the operating conditions. The final product will operate in some of the world's harshest conditions, and will have to withstand the majority of the abuse from the environment. The areas that this device will be used in are almost all very hot and humid. These mission fields (most often in Africa and South America near the equator) can regularly see temperatures well over 100˚F with humidity levels up of up to 100%. The device will therefore have to be able to operate in these conditions. So the requirement shall be that the device will function normally at temperatures up to 150˚F and at 100% humidity levels. The places in which this device will be used are quite often dusty or wet as well. The device will need to be water resistant or even water proof if possible. It will also have to be able to keep any foreign material from the environment out so that there is no interference with the operation of any moving parts or internal devices. Finally, since the device will be portable it will have to be a robust design that will survive rough handling and drops. It is a requirement that the device will survive a 5 foot drop onto concrete.

2.5 Audio Requirements

The main objective of this project is to capture audio and store it digitally, while retaining the maximum quality of audio. In order to capture high quality audio, the signal must enter the device through a differential microphone. A differential microphone uses two inputs to feed a differential amplifier, which rejects differences in the signals and amplifies the remaining signal. The application of such technology is helpful in this project because it reduces noise being fed into the amplifier. The signal must be filtered to remove unwanted frequencies. This refined signal must be digitally sampled with at no less than 16 bit precision and at a sampling rate of twice the input bandwidth in order to meet the Nyquist Sampling rate[5]. The device must have user operated gain control in order to limit the signal amplitude in the event of clipping. To assist in gain control, a feedback device that indicates gain levels being applied to the audio signal must be visible and easily interpreted. Digitized audio must be stored on a mass media device for further processing.

2.6 Memory Interface

This device shall store recorded audio data to an industry standard removable memory device which can later be attached to a personal computer from which the audio files can be downloaded. Our device shall be able to write, read, and delete files on the memory device. The memory interface will also need to have enough bandwidth to stream the sampled audio data to the memory device. With a sample resolution of 16 bits per channel and a possible sampling frequency of up to 48 kHz in future production models, a transfer rate of 192 kbps is required.

2.7 Power Requirements

From a power management standpoint the device must be able to run for ten hours on a single set of AA or AAA batteries. The battery compartment must be onboard the device and be accessible in order to change batteries.

2.8 User Interface

The device must have controls for starting and stopping recording and knobs for manual level adjustments on each channel. It must have the ability to play back tracks that have already been recorded, and must be able to skip through tracks that are stored in memory. The device will accept two microphone inputs and record both simultaneously for stereo sound through either XLR or 6.3mm jacks. It must have an ON/OFF switch, a volume control for the playback output, and a level indicator.

3. Design Research and Decisions

The design requirements for this project can be met through a number of different solutions. The design chosen for this project must meet or exceed all of the given requirements. The overall design of this device can then be broken down into to main categories, the mechanical and electrical aspects. The electrical aspects deal with the audio input, processing, and storage. The mechanical aspects deal with the case and the user interface. The basic electrical system that we have developed can be seen in the following block diagram.

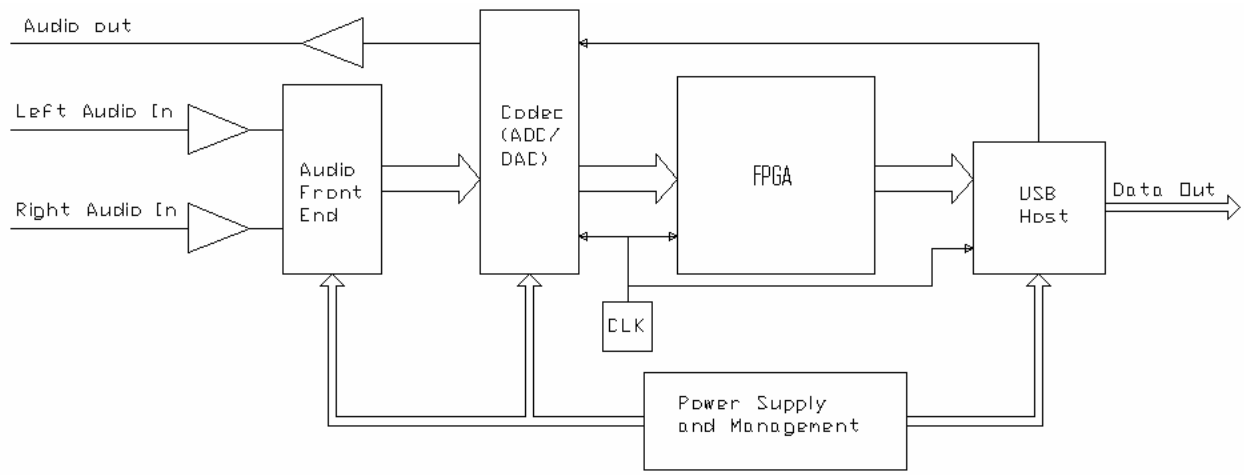

Figure 4: Electrical Block Diagram

3.1 Electrical System

3.1.1 Audio Input

3.1.1.1 Determining Frequency Range

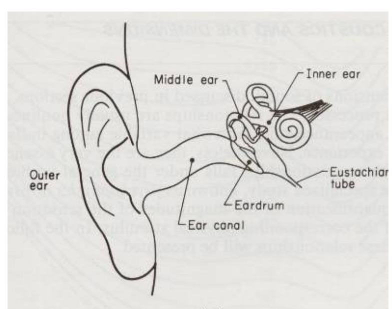

Figure 5: The Human Ear

The audio spectrum ranges from 20 Hz to 20 kHz[5], however, the human ear is not equally sensitive to such frequencies. According to audio research, the ear is most sensitive to frequencies at and around 2.6 kHz[5]. The outer ear is a physical amplifier (see figure 5[5]) and performs best at said frequencies. As a result of the physical characteristics of the human ear, frequency sensitivity declines the further away from 2.6 kHz a signal gets. By the time a signal is 200 Hz or 15kHz, it has lost approximately 20 dB of its original signal strength[5]. For this reason, signals that reach the upper limits of the audio spectrum, 20 kHz, are virtually undetectable. A study performed in 1931 established that a sufficient music bandwidth ranges from 40 Hz to 15 kHz[5]. A later study found that lower frequencies, even those less than 20 Hz, contribute to a more lifelike sound quality. It has been suggested for best results that a system might even include frequencies approaching 0 Hz[5]. On the other hand our team was advised by a member of Calvin Technical Services, a department that deals in depth with technical audio processing, that the low frequency cutoff necessary for descent audio quality is around 80 Hz[39]. The motivation for an 80 Hz low frequency cutoff is the reduction of the loud "P-popping" noise often present when a speaker uses words starting in "P". The use of a higher low-end frequency cuts out a large majority of the popping noise according to our consultant from Technical Services[39]. By using the higher frequency, we are serving our employers well by continuing to provide an excellent bandwidth as well as resolving a known recording problem. Based on our research and advice, we have decided that our device will capture frequencies ranging from 80 Hz to 15 kHz. The low pass filter used to cutoff the higher frequencies will be designed in such a way that the transition between pass and reject will begin just after 15 kHz and will be at the maximum rejection before 18 kHz.

3.1.1.2 Determining Gain

The human ear acts as a microphone by detecting variations in air pressure through vibration of hairs and nerve endings found in the inner ear[5]. For this reason sound is measured by making a comparison between two pressure levels, typically a pressure of interest and a reference pressure. The reference pressure corresponds to the smallest pressure level variation detectable by the average human and is around 20 micropascals[28]. The ratio is called a decibel (dB), and is calculated using the equation shown in Figure 6[28].

$$L_p = 20 \log_{10}\left(\frac{p_1}{p_0}\right)$$

Figure 6: The dB equation

Audio decibels are differentiated from other forms of decibel calculations by denoting them with dB SPL (sound pressure level). The purpose of the audio front end is to receive the audio, filter it and increase its signal strength. To get a better understanding of reasonable gain levels for such a project we consulted Technical Services. Our contact there suggested we apply no more than 45 to 50 dB SPL to our signal[39]. Two major factors governed the reasoning for this amount of gain. First, the digitized signal will eventually be brought back to America for further processing on a PC, at which time further gain can be applied. Secondly, audio devices have natural gain limits. For example, some microphones work by detecting variations in capacitance between two plates that are vibrated due to noise. Under intense pressure variations, the two plates can contact each other and cause a physical form of clipping and result in poor audio capture. In order to minimize the possibility of clipping our signal we have opted to decrease the maximum gain level and leave further processing to a computer. Our device will have channel gain of no more than 50 db SPL. By designing our device in such a way we are serving our employers by decreasing the chance of ruining audio recordings and giving them extended freedom on the signal processing end.

3.1.1.3 Preamplifier Design

The frequency and gain specifications generated in the previous sections closely dictate our preamplifier design. We are looking for an amplifier that will limit our input signal from 80 Hz to 15 kHz and will provide no more than 50 dB SPL. When the initial problem of building a preamplifier was addressed our first response was to research and build from scratch our own preamplifier tailored to the specifications we set. This was the original intent until the three electrical engineers on our team met with a group from the Audio Engineering Society (western MI chapter) and discussed our project. The head of the Technical Services department at Calvin College was in attendance and was able to offer us an alternative to reinventing the wheel. His suggestion was to use the preamplifier that Andy Wallner's designed and built for a similar project done one year ago. He suggested this to us for two reasons: First, he expressed the need to keep things simple and not redesign parts whenever possible. Secondly, he worked with Andy throughout the development of the preamp and was confident that Andy's design would help us meet our goals. His design uses differential inputs that in common mode rejection will reject 112 dB of signal variations. His design also meets both the frequency and gain specifications we desire. After this advice, our team contacted Andy about using his preamplifier in our project. He was delighted that we use his design in our project and therefore we have decided to use his preamplifier design as our audio front end.

3.1.1.4 Analog to Digital Conversion

The output of the audio preamp needs to be converted to a digital signal using an analog to digital (A/D) converter so that it can be processed. There are many A/D converters available on the market from major manufacturers like Texas Instruments, Analog Devices, and Wolfson Microelectronics. These companies all offer low power, differential input, audio rated A/D converters. We looked at two devices from Texas Instruments; the PCM1804 [9] and PCM4201 [9]. The Analog devices AD1871[10] is another converter we looked at. Finally, we also looked at the Wolfson WM8786[13]. The relevant properties for each of these can be found in Table 1: A/D options.

Table 1: A/D options

Device	# of channels	Power (mW)	Max Sampling Frequency (kHz)	Signal to Noise (dB)	Resolution (bits)	Price
PCM1804	2	225	192	112	24	5.20
PCM4201	1	40	108	112	24	3.50
AD1871	2	150	96	105	24	5.63
WM8786	2	180	192	111	24	6.36

All of these devices meet the audio quality design requirements. The PCM4201 does not have two channels, however it has really low power consumption so we could use two of these, however, this doubles the cost. These options can be placed into a decision matrix, shown in Figure 7.

Analog to Digital Conversion

	Cost	Power	SNR	Max Sampling Freq.	Total
Weights	40	40	10	10	
PCM1804	8	1	10	10	**560**
PCM4201	3	10	10	6	**680**
AD1871	7	5	9	5	**620**
WM8786	4	5	10	10	**560**

Figure 7: A/D converter decision matrix

From this decision matrix the device that scores the best is the Texas Instruments PCM4201. This device is a single channel differential input A/D converter. The power consumption is exceptionally low and the performance is more than adequate for our application.

3.1.2 Audio Processing

For this project we considered three audio processing options. The first audio processing solution is the most ambitious, in that it requires the most amount of work. It is to customize an existing audio compression algorithm so that it will run on a digital signal processor(DSP). To do this, an existing compression algorithm, like Ogg Vorbis, LAME, or MP3, would need to be obtained and ported to run on a DSP. The DSP would have to run the algorithm in real time so that the audio is compressed while it is being recorded and before it is stored to the storage medium. This requires data buffers that will keep the data flowing in and out of the processor. Porting of the mp3 algorithm to a Texas Instruments DSP has been done and is available commercially, but it costs several thousand dollars. The Mp3 encoding algorithm is not freely available, Vorbis however, is an open source algorithm, which means it is free. The problem is that it has not been ported to a DSP [23][24][1][2][3][4][14][16][17][18].

Another solution that would ease the implementation of the required data buffers that the DSP would need, is a single board computer. A single board computer is an entire computer, on a small circuit board, that has similar capabilities to a personal computer. The single board computer (SBC) would not be faster than the DSP, however it would allow for a simpler implementation. The SBC would have integrated USB hosts already and would have an available compact flash hard drive. Having these available would be an advantage for the design since a memory controller host would not have to be developed. The compact flash hard drive would also provide another option for a memory controller that would not have to be designed. With an SBC it would have to record the data to memory and process it after writing it to a disk. The compression algorithm used for this could be any open source algorithm like vorbis since it is readily available for the PC [19][20][21].

The final design option is a simplified version. This design possibility has no audio compression and would record raw audio data into a WAV file. When audio is compressed with mp3 or Vorbis some of the audio data is lost because these compression algorithms make guesses at the audio data when compressing. The output of the A/D converter is in pulse code modulated (PCM) audio format, which is the same format in which WAV files are written [9]. There is no audio processing required then and the PCM data simply needs to be written into a WAV file. This option would require that a field programmable gate array (FPGA) be used to control the file creation and header information. The WAV option requires no proprietary software and minimal hardware, the only drawback is the file size. WAV files are much larger than mp3 files though, typically around 10-15MB per minute of audio [25].

Table 2: Audio Processing Decision Matrix

Audio Processing

Weights	20	20	30	20	15	15	30	
	Hardware Cost	Algorithm Cost	Power	Complexity	Size	File Size	Audio Quality	**Total**
DSP	1	0	5	9	5	10	5	**725**
SBC	3	1	2	5	2	10	5	**570**
WAV	9	10	10	1	9	1	10	**1150**

The above decision matrix was developed to aid in the decision of which process to use. The categories and their weights highlight the important aspects of each approach. Power is one of the most important categories because this device needs to be portable. The audio quality is important as well since our requirements are for professional quality audio. The cost is important because we need to be able to afford to complete the project. The complexity is important for a similar reason; the approach needs to be feasible for our team to develop. The best candidate for our project is to use the WAV approach; it outscores both the digital signal processor and single board computer approach.

While we were researching and making our design decisions we met with a group of audio engineers and recording specialists for advice on our project. Their advice was that if one is recording audio in the field for future processing, which we are doing, the audio should never be compressed; it should be stored in a raw format. They told us that recording at a lower quality without compression, is better than recording a higher quality but compressing the audio. They also pointed us to a device that already does what we plan to do; it is called the Marantz PMD660 Portable Solid State Recorder [27]. This device retails for over $500. The design we settled on will not have any audio compression and will record into WAV files without the need for any processing and will still meet all of our requirements. The block diagram for our initial electrical design can be seen in Appendix D.

3.1.3 Data Storage

There are many options for storing data in the Portable WAV Recorder. These options are limited by the required data transfer rate. If the data were to be stored internally it could be written to EEPROM, Flash, or a micro hard drive. If the data is stored external to the circuit CompactFlash, USB Flash drives, or Firewire Flash drives are an option. The criteria and goals for the data storage solution are minimization of cost, physical size, and weight with maximization of durability, industry compatibility, future expandability, ease of implementation, and storage capacity. The most important of these are durability and future expandability because of the emphasis of the requirements on dependability and quality construction. Next most important is capacity and compatibility for ease of use and a simple user interface. Cost, although important, is the next priority. Based on the constraints and the impact of other design decisions, physical size, weight, and implementation ease form the lowest set of importance.

Memory										
Weights		20	30	10	10	40	30	40	10	
Internal		Cost	Capacity	Physical Size	Weight	Durability	Compatibility	Expandability	Implementation Ease	**Total**
	Onboard Flash	3	2	5	3	4	5	0	2	**530**
	MicroHD	2	5	1	1	1	5	1	1	**450**
	EEPROM	3	2	5	3	4	5	0	2	**530**
External										
	Firewire Flash	3	3	3	3	3	2	3	4	**550**
	Compact Flash	4	4	4	3	4	3	5	3	**750**
	USB Flash	5	3	3	3	3	5	5	4	**760**

Figure 8: Decision Matrix for Data Storage Selection

Any kind of internal storage limits future expandability. Cost is also increased and implementation ease decreased because some method of transferring data from the internal storage to a computer must be included. This results in good compatibility, however, assuming that the data transfer method invoked would have compatibility equal to USB Flash storage, which, based on personal experience has the best compatibility. Storing on a hard drive provides great capacity, but hard drives are known to not be very durable. A hard drive also takes up a lot of space and adds a lot of weight relative to the other alternatives. A USB Flash drive is a better solution than CompactFlash because in personal experience USB ports are much more likely to be native to a computer than CompactFlash card readers. Thus, in most cases a card reader would need to be purchased and transported with the computer if CompactFlash were used. In the same way USB Flash drive are more prevalent and thus less expensive than Firewire Flash drives [30]. Pricegrabber.com quotes a 1 GB Firewire Flash drive as costing over $100, while a similar sized USB drive is quoted as costing just over $50 [40]. Figure 8 shows the results for this weighted decision.

For these reasons we chose to use a USB Flash drive for our memory interface. It is the de facto industry standard for PC peripherals connection and is the protocol that EPIC currently uses to connect the external sound card to the laptop.

3.1.4 Power

Power management of battery powered devices is an important issue to address. In order to meet our goals of 10 hour battery life we will need to select components that use minimal amounts of power. The first component to consider is the analog-to-digital converter (ADC). Four different ADCs were compared to determine which component would perform the best within our budget, operational needs, and power consumption. Figure 7 shows a comparison of each ADC. The PCM4201 was chosen for its ability to accomplish the digitization necessary and minimize power. Due to the fact that the PCM4201 is a single input ADC, our device will use two of them and combine for a total of 80 mW of power. The control for our device will be an Altera Field Programmable Gate Array (FPGA). Using the Stratix II FPGA family, power consumption appears to be 3mW for every 1 MHz of clock speed[29]. Using these numbers we estimate that our FPGA will not use more than 10mW of power. The last major component is the USB device. The USB standard requires that USB devices connect to a host in low power mode (100mA)[30]. Additional current, up to 500mA, can be requested by the slave upon which the host must provide more current. In the worst case our device will draw 500mA at 5V[30]. The total power consumption by our devices major components is shown below.

$$Major\_component\_Power\_Consumption \equiv Power\_ADC + Power\_FPGA + Power\_USB$$

$$Major\_component\_Power\_Consumption := .08 \cdot W + .01 \cdot W + 2.5W$$

$$Major\_component\_Power\_Consumption = 2.59\, W$$

Figure 9: Major Power Consumption Calculation

To meet the power needs of our device we compared two common battery types: AA and AAA. AA batteries are capable of supplying 1800 to 2600 mAh of power, while AAA can supply 900 to 1150 mAh, each at 1.5V[31],[32]. Other batteries sizes such as C and D, which offer increased power outputs, were not considered for analysis because our contact at OneStory expressed the need for field agents to be able to obtain new batteries in remote areas. Type AA and AAA batteries are the most common battery types and therefore meet our clients need for accessibility. The calculations in the following figure show the number of batteries necessary to supply worst-case-scenario power to our critical components. From the calculations below we have decided to use eight AA batteries to power our system.

Known values

$$Major\_component\_Power\_Consumption \equiv Power\_ADC + Power\_FPGA + Power\_USB$$

$$Major\_component\_Power\_Consumption\_Watts := .08 + .01 + 2.5$$

$$Major\_component\_Power\_Consumption\_Watts = 2.59$$

$$AA\_and\_AAA\_Voltage := 1.5$$

$$AA_{amp\_hours} := 2.2$$

$$AAA_{amp\_hours} := 1.025$$

$$Major\_component\_Power\_Consumption\_Watts = 2.59$$

$$Desired\_Run\_Time\_Hours := 10$$

Power supplied by each battery

$$AA_{power\_supply} := AA\_and\_AAA\_Voltage \cdot AA_{amp\_hours}$$

$$AA_{power\_supply} = 3.3\ \ W$$

$$AAA_{power\_supply} := AA\_and\_AAA\_Voltage \cdot AAA_{amp\_hours}$$

$$AAA_{power\_supply} = 1.537\, W$$

Figure 10: Power Consumption calculations

Total power consumed in 10 hours

$$Power\_consumption := Desired\_Run\_Time\_Hours \cdot Major\_component\_Power\_Consumption\_Watts$$

$$Power\_consumption = 25.9 \ W$$

Number of AA batteries

$$AAs\_required := \frac{Power\_consumption}{AA_{power\_supply}}$$

$$AAs\_required = 7.848$$

$$AAs\_required = 8 \ batteries$$

Number of AAA batteries

$$AAAs\_required := \frac{Power\_consumption}{AAA_{power\_supply}}$$

$$AAAs\_required = 16.846$$

$$AAAs\_required = 17 \ batteries$$

Figure 11: Power consumption calculations continued

3.2 Mechanical System

3.2.1 Case Material

For case material selection, there were two possible options: plastic injection molding or metal encasing. Between the two material considerations of metal and molded plastic, a molded plastic was chosen because it is much cheaper and plastic is much more resilient to shock resistance; if the Portable WAV Recorder encounters a drop, the case must absorb the shock so the electronics are not damaged. Metals were not considered because they will contribute unwanted weight as seen in Table 3: Specific Gravities.

Table 3: Specific Gravities [33]

Material	Specific Gravity
ABS	1.04 – 1.07
Polycarbonate	1.25
Aluminum	2.7
Stainless Steel	7.7
Iron Carbonate	3.9+

Another negative characteristic of metals is that they are subject to corrosion; an undesired effect. For polymers, the team researched common electronics packaging materials and found that ABS was most commonly used in industry. Polycarbonate was considered due to its durability properties (see Table 3: Material Strength Properties). Acetal was not considered because under injection molding conditions, it suffers outgassing problems (the removal of gas during setting, causing structural defects). LCP (Liquid Crystal Polymer) possessed the necessary strength qualities but failed in cost comparison

[37]. Acrylic met most material requirements, however at very cold temperatures it becomes brittle and endangers the electronics during shipment. Acrylic also has a higher water absorption percentage than the other materials, so for these reasons, it was not chosen. Thus, the only viable options for case materials were ABS or polycarbonate. [38]

Table 4: Material Strength Properties [33]

ABS		
Elastic Modulus (MPa)	1794 - 2208	tensile
Tensile Strength (MPa)	28 - 42	at break
	30 - 44	at yield
Processing Temperature (ºC)	238 - 272	injection molding
Molding Pressure (MPa)	56 - 173	
PC		
Elastic Modulus (MPa)	2381	tensile
	2415	compressive
Tensile Strength (MPa)	52 - 58	at yield
	53 - 59	at break
Processing Temperature (ºC)	247 - 294	injection molding
Molding Pressure (MPa)	104 - 138	
Acrylic		
Elastic Modulus (MPa)	2208 - 2415	tensile
Tensile Strength (MPa)	56 - 63	at break
Melting Temperature (ºC)	140	T_g, amorphous
Processing Temperature (ºC)	233 - 266	injection molding
	222 - 249	extrusion
Molding Pressure (MPa)	35 - 138	

The decision matrix shows the comparisons between ABS and polycarbonate for four categories; cost, durability, feasibility and usefulness (see Table 5: Mechanical Decision Matrix).

Table 5: Mechanical Decision Matrix

Material:					
Weights	30	40	20	10	
	Cost	Durability	Feasibility	Usefulness	**Total**
ABS	9	8	10	10	**890**
Polycarbonate	5	10	7	10	**790**

ABS was chosen over polycarbonate because ABS excelled both cost and feasibility. Although durability was the most important category for decision and polycarbonate has higher durability, the cost and feasibility of ABS outweighed the desired property of polycarbonate. The fact that ABS is used more than polycarbonate in the electronics packaging industry indicates its feasibility for such applications

[36]. At this time polycarbonate is in high demand due to its popularity, so lead times for this material are long, making this a difficult and expensive material to use. If the cost issue was not relevant, an ABS polycarbonate alloy would be seriously considered.

Aside from these considerations, an analysis was done on the deflection of the two materials assuming the case was produced at the given specifications. The loading model assumed an automobile with a weight of 2000 lbs. The maximum load applied to the device assumed the weight of one fourth of a 2000lb car. Though the data concluded that polycarbonate was a slightly stronger material for the maximum load situation, polycarbonate has been twice the cost of ABS in terms of raw material and the tradeoff of cost to strength was not valuable (see Table 6)

Table 6: Material Strain Analysis

	Abs	Polycarbonate		L	0.1016	m
E (Mpa)	2000	2300		T	0.0047625	m
Thermal (um/m-°C)	90	70.2		I (m^4)	9.14571E-10	m^4
Load	227.2727273	kg				
Initial Stress (car)	50	psi				
	344732.4876	Pa				
	Delta Base	Delta Thermal	Delta Total (m)	Delta Total (in)		
Abs	0.002714812	0.00027432	0.002989	**0.117682369**		
PC	0.002360706	0.00021397	0.002575	**0.10136519**		

3.2.2 User Interface

To make the user interface simple as required by design specifications, the control system will consist of simply labeled buttons, dials and some kind of gain indication. There were two options for button selection; push buttons or capacitive buttons. Because capacitive buttons lack moving parts and because they can be sealed off from the environment, they proved more desirable characteristics that push buttons (see Table 7).

Table 7 : Button Decision Matrix

Weights	30	40	20	10	
	Cost	Durability	Feasibility	Usefulness	**Total**
Push Buttons	10	6	9	8	**800**
Capacitive	8	9	8	9	**850**

For variable control of the gain inputs, dials will be used in conjunction with the gain indication system (see Figure 14: Current Design). There are no alternatives for the button layout because the intent of the design is to have a very small learning curve. If the buttons worked in some sort of combination it would become difficult for the user to learn how to operate. Adding extra buttons is very cheap and ensures ease of use.

The contacts will be made from a high copper alloy that is extremely resistant to corrosion, but maintains high electrical conductivity (see Figure 13). The Galvanic Series shows the most active on the right and least on the left. A copper alloy (e.g. Copper Nickel) is ideal because it is readily available and very resistant to corrosion.

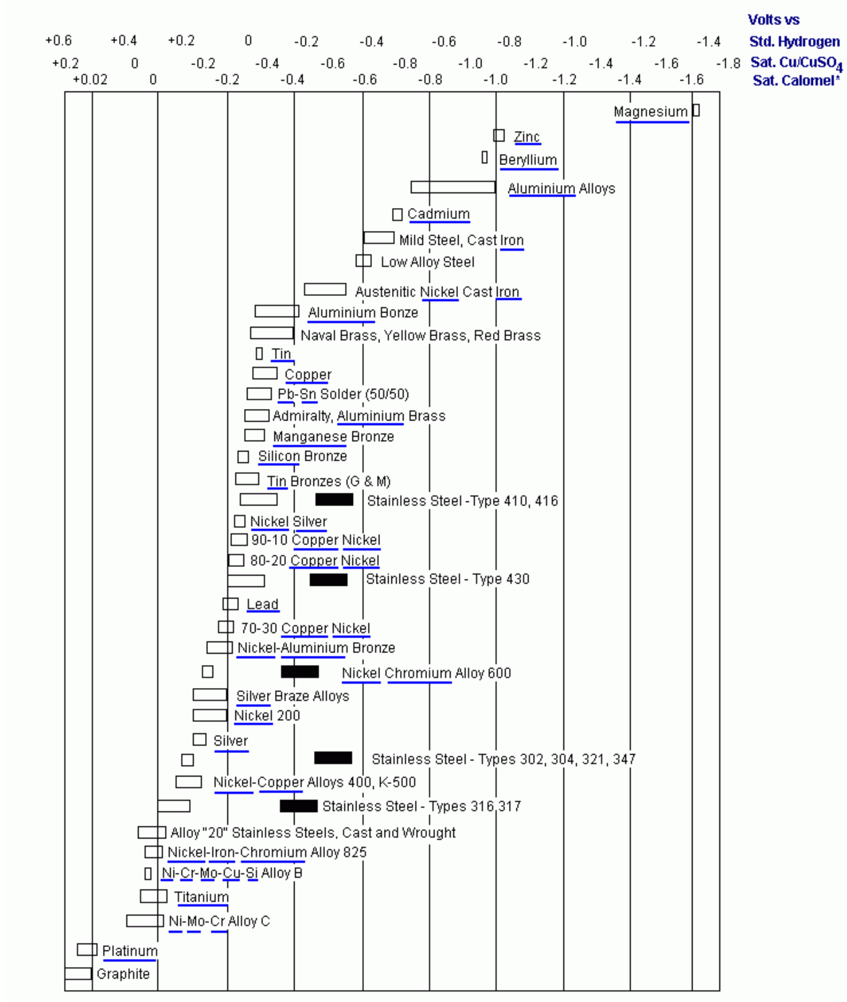

Figure 12: Galvanic Series [41]

Since the microphone inputs will be facing the person being recorded most of the time, the design will include the microphone jacks out of the "top" of the device to avoid wire tangles (See Figure 13: Demonstration of use). The top will be the side facing away from the person when it is being held. All of the buttons will be on the "front" face for easy access, and will be limited to a power button, play, record, stop, forward and reverse. These buttons are implemented this way to ensure ease of use. If the play button was pushed twice to go forward, the user may not catch on to this. None of these buttons work in combination, thus minimizing any potential confusion. There will be three dials, two for the left and right microphone levels and one dial for the output volume. The dials will be labeled in English to decipher between the two. This is possible because the Epic employees that will use it can all speak English. The power switch will be a rocker switch and will be on the face near the combo jacks. A rocker switch was chosen because it is very simple to operate and its "I" "O" labeling is universally known. There will be four red and one green indicator LED's for each input. Each red will indicate clipping while the green led will indicate clear recording. If a power plug for internal charging the rechargeable AA batteries, upon request from Epic, it will be placed near the battery location.

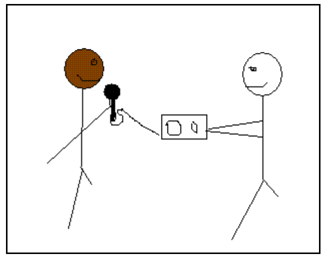

Figure 13: Demonstration of use

3.2.3 Case Design

The case design was chosen to be simple. This was to make sure the final product is culturally appropriate. The options for case design were one compartment containing all components of the design, or multiple compartments for accessibility. Within the case a two compartment design was chosen (see Table 8: Compartment Decision Matrix). This allows the electronics to be separate from the batteries and the USB storage device. The two compartments are necessary because the user will be accessing the USB compartment frequently to change USB devices, and this exposure to the elements may harm the electronics. An alternative to this would be to have the USB mount externally and have the batteries internal. The second compartment (USB/battery) will be sealed with a latch and a rubber gasket. An alternative to the latch and gasket method would be to have the compartment door slide on via molded tracks. The fact that the compartments are water resistant includes other positive effects, such as dirt and dust protection, due to the fact that water molecules are more penetrating than larger dirt particles.

Table 8: Compartment Decision Matrix

Weights	30	40	20	10	
	Cost	Durability	Feasibility	Usefulness	**Total**
One	10	6	10	5	**790**
Two	8	9	9	6	**840**
Three	6	9	8	7	**770**

The current mounting method for the circuit board is to attach it to the case via screws that tap into molded posts. In the event the current mounting method fails because of high impact, a new system that implements higher shock absorption to the circuit board via rubber mounting surface will be considered. If battery power is insufficient for the current design, case modification will be made as needed to house more batteries. There no design alternatives considered for the “impact bolsters” as they are not a design necessity, but a redundancy system for strength and impact protection.

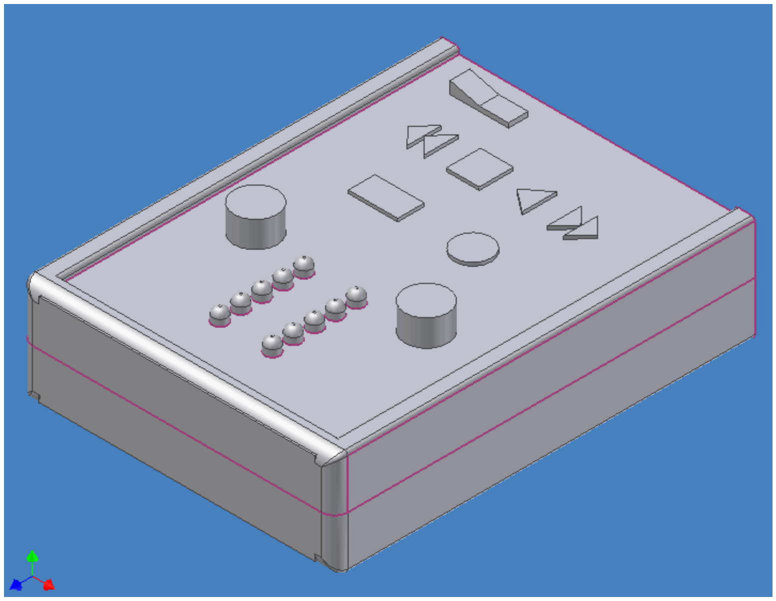

Figure 14: Current Design

The jacks that will be implemented in the final design will be XLR/ .25” [22] combo jacks and were recommended by our contact at One Story. By implementing these two jacks as combination jacks, the overall surface that the jacks take up on the case is minimized. Minimizing the surface area occupied by the jacks on the front reduces clutter and makes it easier to connect cords. Having the combination jack also assures compatibility with both types of microphone inputs.

4. Feasibility

4.1 Design Feasibility

The design that we have chosen is feasible for several reasons. Although there are sound recorders that will record premium quality audio to wav file format on the market, most include additional features that are extraneous to Epic's purposes.

Table 9: Competing device features and prices

Device	Features	Price (from froogle.com)
Marantz PMD660 [27]	Portable, XLR input, records in WAV on compact flash.	$499.99
Sound Devices 722 [26]	XLR input, records mp3 onto internal hard drive or compact flash, LCD screen.	$2375.00

Because of the additional features, these recorders are considerably more expensive than the projected cost for our device, which is less than $200, as seen in the cost analysis section. Our device will have fewer features and options, but will be significantly less expensive to design, build, and produce. These goals are in the interest of our customer, Epic Partners. The portable WAV recorder will also be appealing to consumers interested in recording audio. It offers high quality recording in a portable device that would allow consumers to record their own audio. The combination jacks allow the consumer who does not have XLR microphones to still be able to utilize this product. In the future this device may also be refined to meet new design goals for products such as high quality secondary microphones, remote microphones on film sets; or even simple voice recorders. Industry giants such as Apple and Creative Labs have made mp3 players a household term and a multi-million dollar industry. With some refinement our device could be transformed into a combination recorder-player to take advantage of popular portable audio industry.

4.2 Project Management

Initially, it was difficult for us as a group to get organized as we began the fall semester. However, we began to form categories of specialized work for each member. Scott has been in charge of doing most the research of the audio front end, power management and PCB layout. Bryan has been in charge of the areas of audio conversion and processing, and control structure. Josh is in control of the USB host and other software considerations. Mike and Eric have worked cooperatively on case research and design, button selection and layout considerations.

To keep ourselves working hard on our project we have been selecting group leaders every two weeks. This one person is then the leader for the next two weeks. The current group leader is responsible for all deliverables making their due dates, delegating work to other members and our weekly status reports. This system has worked out well since we all get the experience of being leaders and delegating tasks. In case of conflict in our team the team leader is responsible to make sure that it gets resolve, usually through group discussion. If we have technical disagreements we will analyze the data sheets and try to make an unbiased decision. Another tool that we have used to resolve conflict is having both conflicting parties researching the others parties choice and finding reasons for and against that choice. This helps to eliminate biased opinions when one party has only researched their own option. If a team member is late on a task the team leader is responsible to either complete the task or delegate it again. There is also no chance for us to complain about leadership since we are all leaders.

Every Friday status reports are sent to our advisor, Professor VanderLeest, giving him updates on what we have done for the week as a group and what we have done individually. Also, work to be done the following week is included as well as hours logged that week and total for the semester. These status reports have been helpful for us to keep track of where we are on our project and what needs to be done.

4.2.1 Schedule

Our project schedule is set for the entire project with hours set aside for research, design and testing. Included in our schedule is a team work session that we have every Monday afternoon. We have scheduled in the time needed to research, design, build and test each of the main aspects. These main aspects are: preamp, A/D conversion, USB host, control, power, PCB layout, user interface, case, and documentation. The bulk of the research should be completed and the design should be started by the end of the first semester. The full project schedule can be seen in Appendix D: Project Schedule. In this schedule some of the major milestones are deciding on design decisions for each aspect of the product, choosing components for these designs, and building the design. The most important milestones are the completion of research, design, and building of the preamp, data conversion, and USB host stages. Important mechanical milestones are in deciding on case design, case materials, and finalizing the design so that it is ready to be produced.

4.4 Cost Analysis

Table 10: Prototype Cost Analysis

Item	Unit Cost	Quantity	Incurred Cost
Case	$1,795.00	1	$0.00
XLR Jacks	$2.33	2	$4.66
USB Jack	$5.00	1	$5.00
Gasket	$75.00	1	$75.00
Latch	$7.00	1	$7.00
Buttons/Knobs	$15.00	1	$15.00
FPGA	$20.00	1	$0.00
USB Chip	$9.00	1	$0.00
USB Evalboard	$200.00	1	$200.00
USB Jumpdrive	$35.00	1	$35.00
A/D Converter	$3.50	2	$0.00
PCB	$300.00	1	$0.00
Batteries	$30.00	1	$30.00
Misc. Electrical Components	$75.00	1	$75.00
Grant from Epic Partners	-$250.00	1	-$250.00
Totals:	$2,321.83		$196.66

The prototype cost analysis for the Portable WAV Recorder is used by our team to ensure that we can stay within our budget for senior design. The Total cost for the components of our project is very high, this is mainly due to the case prototype. This prototype will be a rapid prototyped case, not a production case and so that is why the cost is so high. The company that will be doing the rapid prototyping has offered to do this for free for our team since it is for a non-profit organization. The FPGA we will be using in our prototype will be borrowed from the engineering labs for the duration of the project; this eliminates the cost of buying one. The largest single cost that we do have to pay for then, is the USB development kit at $200. Another donation we have received is for our printed circuit board (PCB). PCBexpress.com has given us $350 worth of credit to use for PCBs. We have also received a grant from Epic Partners/OneStory of $250.

The production cost analysis can be seen below in Table 11. This cost analysis was based on the production of 5000 Portable WAV Recorders. This number was chosen since our contact at OneStory has told us that he could see a demand of around 4500 devices in the mission field. We hope that we could market at least 500 more devices to reach 5000. Again, the greatest cost comes from the case; the injection molding equipment is very expensive, but it is a one time cost. The engineering work is another large cost, this is found by taking the estimated number of engineering hours our team will be putting into the development of this device and multiplying by a cost rate of $100/hr. When all of these costs are compiled the total cost per produced unit works out to about $186.

Table 11: Production cost analysis

Item	Projected Cost	Quantity	Total
Injection Mold	$100,000.00	1	$100,000.00
Case	$5.00	5000	$25,000.00
Prototype	$196.66	1	$196.66
XLR Jacks	$2.00	10000	$20,000.00
USB Jack	$1.00	5000	$5,000.00
Gasket	$1.00	5000	$5,000.00
Latch	$3.00	5000	$15,000.00
Buttons/Knobs	$5.00	5000	$25,000.00
A/D Converter	$4.00	10000	$40,000.00
USB Chip	$9.00	5000	$45,000.00
USB Jumpdrive	$10.00	5000	$50,000.00
Preamp Components	$10.00	5000	$50,000.00
FPGA	$10.00	5000	$50,000.00
PCB	$30.00	5000	$150,000.00
Misc. Electrical Components	$10.00	5000	$50,000.00
Engineering Work	$100.00	1003	$100,300.00
Board Population	$10.00	5000	$50,000.00
Board Testing	$5.00	5000	$25,000.00
Mechanical Assembly	$5.00	5000	$25,000.00
Overhead	$10.00	5000	$50,000.00
Packaging	$5.00	5000	$25,000.00
Shipping	$5.00	5000	$25,000.00
		Total:	$930,496.66
		Total Per	$186.10

5. References

5.1 Research Sources

[1] Paul, Klein M. "Compression Techniques Encode Audio Signals for Digital Processing." *EDN* (1994): 97-98.

[2] Enerstam, Joakim; Peman, Jan. 1998. Hardware Implementation of MPEG Audio Real-Time Encoder. Master's thesis, Lulea University of Technology.

[3] Toshiyuki, Ishino, Hasegawa Satoshi, Iwedare Masahiro, and Kitabatake Osamu. "A Real-Time MPEG/Audio Layer 3 Codec." *IEEE* (1993): 54-55.

[4] Seonjoo, Kim, Li Yi, Kim Heesu, and Choi Hanmook. "Real Time MPEG1 Audio Encoder and Decoder Implemented on a 16-bit Fixed Point DSP." (n.d.): 900-04.

[5] Benson, Blair. "." Audio Engineering Handbook. Ed. Daniel Gonneau, and Beatrice Eckes. New York: McGraw-Hill, 1988. 1.34 & 4.8.

[6] http://www.epicpartners.org/ep/ (9 December 2005).

[7] http://epic.ccci.org/epc/default.htm (9 December 2005).

[8] http://www.pcbexpress.com/ (9 December 2005).

[9] http://www.focus.ti.com/docs/prod/folders/print/pcm1804.html (9 December 2005).

[10] http://www.analog.com/en/prod/0%2C2877%2CAD1871%2C00.html (9 December 2005).

[11] http://www.cypress.com/portal/server.pt?space=CommunityPage&control=SetCommunity&CommunityID=209&PageID=259&fid=10&rpn=CY7C67300 (9 December 2005).

[12] http://www.selecteng.com/ (9 December 2005).

[13] http://www.wolfsonmicro.com/products/digital_audio/adcs/WM8786/http://www.wolfsonmicro.com/ (9 December 2005).

[14] http://xiph.org/vorbis/ (9 December 2005).

[15] http://www.megavoice.com/home/ (9 December 2005).

[16] http://en.wikipedia.org/wiki/Vorbis (9 December 2005).

[17] http://www.go-dsp.com/fet/c5000/index.html (9 December 2005).

[18] http://www.lvr.com/usb.htm#HostsForEmbeddedSystems (9 December 2005).

[19] http://www.linuxdevices.com/articles/AT2614444132.html (9 December 2005).

[20] http://lame.sourceforge.net/ (9 December 2005).

[21] http://www.embeddedarm.com/epc/prod_SBC.htmhttp://www.embeddedarm.com/ (9 December 2005).

[22] http://www.neutrik.com/ (9 December 2005).

[23] http://lists.xiph.org/pipermail/vorbis-dev/2003-September/016541.html (9 December 2005).

[24] http://www.prodys.net/english/products/dsp/audio/MP1&2-LIII-ACOD.htm (9 December 2005).

[25] http://www.mp3-converter.com/faq/wav.htm (9 December 2005).

[26] http://www.sounddevices.com/products/722.htm (9 December 2005).

[27] http://www.d-mpro.com/users/folder.asp?FolderID=3629&CatID=19&SubCatID=180 (9 December 2005).

[28] http://en.wikipedia.org/wiki/Sound_pressure_level (9 December 2005).

[29] http://www.altera.com/literature/wp/wp_s2v4_pwr_acc.pdf (9 December 2005).

[30] http://en.wikipedia.org/wiki/Usb (9 December 2005).

[31] http://en.wikipedia.org/wiki/AAA_battery (9 December 2005).

[32] http://en.wikipedia.org/wiki/AA_battery (9 December 2005).

[33] Shackelford, James F. *CRC Practical Handbook of Materials Selection*. Boca Raton, Fla.: CRC Press, Inc, 1995: 578-579.

[34] Van Vlack, Lawrence H. *A Textbook of Materials Technology*. , Canada: Addison-Wesley Publishing Company, 1973: 175-180

[35] Chen, Xu. *Moisture Absorption and Diffusion Characterization of Molding Compound*. 4th ed. Vol. 12. Tianjin, China: American Society of Mechanical Engineers, 2005.

[36] http://www.hammondmfg.com/1553.htm (9 December 2005).

[37] http://www.ticona.com/index/products/liquid_crystal.htm (9 December 2005).

[38] http://www.actech-inc.com/engmrgt.htm (9 December 2005).

[39] Eric Wildschut of Technical Services

[40] http://www.pricegrabber.com/search_attrib.php?form_keyword=firewire+flash&topcat_id=&page_id=152&lo_p=0&hi_p=0

[41] www.corrosionsource.com/handbook/galv_series.htm (9 December 2005).

5.2 Professional Contributors

Rob Hughes – OneStory/EPIC contact
PCBexpress.com – Providing PCB fabrication service
Greg Griffes – Advice on project design
Andy Wallner – Precision Sound Input team member
Eric Wildschut – Calvin College Technical Services
Carl Hordyk – Calvin College Technical Services Manager
Ross Gates – Select Manufacturing Services Incorporated
West Michigan section of Audio Engineering Society – Advice on project design

Appendix A: Existing Equipment Setup

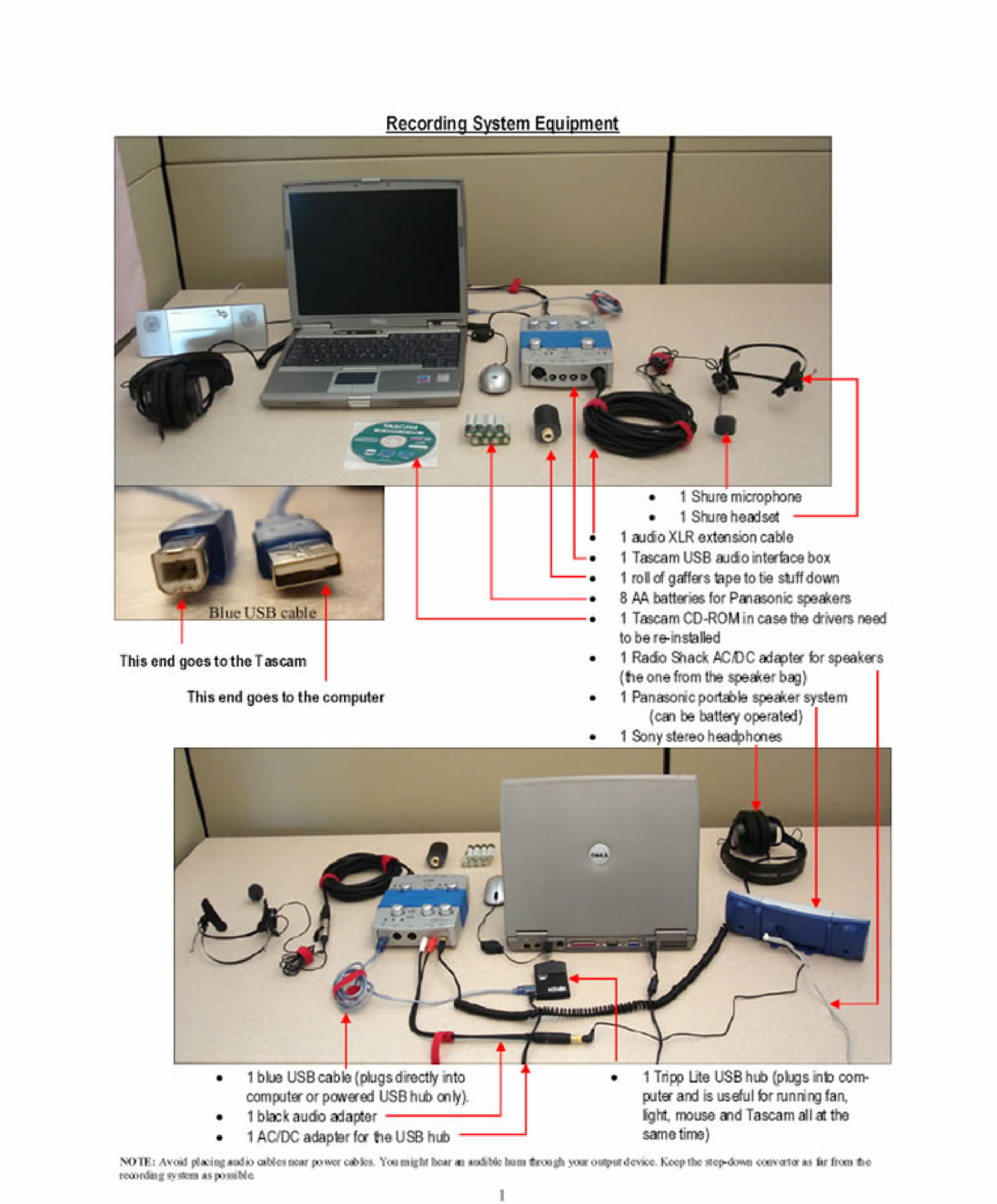

Figure 15: Epic's current setup

Appendix B: Design Requirements

Mechanical Requirements:

1. The product shall be a portable device, easily held with one hand.
2. The weight shall be less than 3 lbs.
3. The dimensions shall be less than 4” x 6” x 2”.

Operating Conditions:

1. The device shall be able to operate in humidity levels of up to 100%.
2. The device shall be water resistant.
3. The device shall be able to operate from freezing up to 130F.
4. The device shall be able to survive temperatures down to -40F.
5. The device shall be able to withstand dirt and dust infiltration.
6. The device shall be able to survive a drop on concrete from 5’.

Overall System Requirements:

1. The device will accept two differential XLR microphone inputs.
2. The device will accept two mono 3.5mm microphone input.
3. The device will have a 3.5mm headphone jack.
4. The device will allow playback of tracks recorded on a mass storage device.
5. The controls shall be as simple as possible.
6. The level adjustment shall be made using rotary dial knobs.
7. The device will have a data transfer interface plug inside a compartment.
8. The device shall be able to record on batteries for at least 10 hours.

Audio Requirements:

1. The audio quality shall be 16 bit samples at 22kHz.
2. The differential audio input amplitude shall be limited above 45 dB.
3. The audio shall be stored in a easily manipulated file format.

Memory Interface:

1. The memory device shall be stored in a protected compartment inside the case.
2. The memory device shall be removable.
3. Our device shall be able to create and delete files on the memory device.

Power Requirements:

1. The Batteries shall last for at least 10 hours of recording.
2. The device shall not support phantom power.

User Interface:

1. The interface shall be as simple as possible to allow for amateur use.
2. The levels adjustment shall be prominent and easily adjusted.
3. There shall be record, stop, play, change track, ON/OFF, and delete track keys.

Appendix C: Initial Case Design

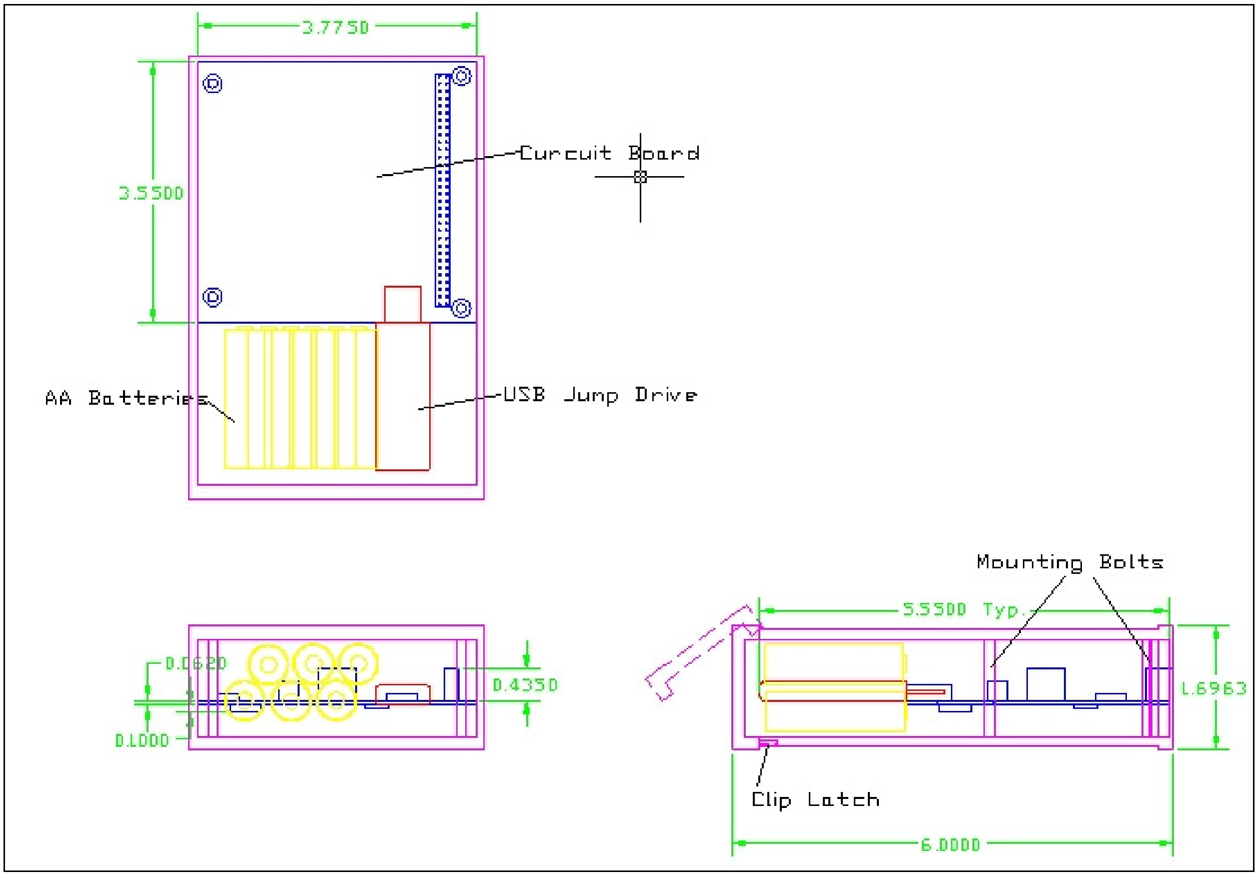

Figure 16: Engineering Drawing

Appendix D: Project Schedule

ID	Task Name	Duration	Start	Finish	Predec	% Work Complete
1	**Electronics**	**163 days?**	**Wed 9/21/05**	**Fri 5/5/06**		**0%**
2	**Preamp**	**163 days?**	**Wed 9/21/05**	**Fri 5/5/06**		**0%**
3	Research	51 days?	Wed 9/21/05	Wed 11/30/05		95%
4	Design	56 days	Thu 12/1/05	Thu 2/16/06	3	90%
5	Build	14 days	Fri 2/17/06	Wed 3/8/06	4	0%
6	Test	42 days	Thu 3/9/06	Fri 5/5/06	5	0%
7	**A/D conversion**	**163 days?**	**Wed 9/21/05**	**Fri 5/5/06**		**0%**
8	Research	51 days?	Wed 9/21/05	Wed 11/30/05		95%
9	Design	56 days	Thu 12/1/05	Thu 2/16/06	8	50%
10	Build	14 days	Fri 2/17/06	Wed 3/8/06	9	5%
11	Test	42 days	Thu 3/9/06	Fri 5/5/06	10	0%
12	**USB Host**	**163 days?**	**Wed 9/21/05**	**Fri 5/5/06**		**0%**
13	Research	51 days?	Wed 9/21/05	Wed 11/30/05		95%
14	Design	56 days	Thu 12/1/05	Thu 2/16/06	13	10%
15	Build	14 days	Fri 2/17/06	Wed 3/8/06	14	0%
16	Test	42 days	Thu 3/9/06	Fri 5/5/06	15	0%
17	**Controls**	**135 days?**	**Wed 9/21/05**	**Tue 3/28/06**		**0%**
18	Research	51 days?	Wed 9/21/05	Wed 11/30/05		40%
19	Design	21 days	Mon 1/2/06	Mon 1/30/06	18	5%
20	Build	14 days	Fri 2/17/06	Wed 3/8/06	19	0%
21	Test	14 days	Thu 3/9/06	Tue 3/28/06	20	0%
22	**Power**	**73 days?**	**Mon 11/14/05**	**Wed 2/22/06**		**0%**
23	Research	13 days?	Mon 11/14/05	Wed 11/30/05		50%
24	Design	7 days	Thu 12/1/05	Fri 12/9/05	23	10%
25	Build	14 days	Wed 2/1/06	Mon 2/20/06	24	0%
26	Test	2 days	Tue 2/21/06	Wed 2/22/06	25	0%
27	**PCB Layout**	**105 days?**	**Mon 11/21/05**	**Fri 4/14/06**		**0%**
28	Research	12 days?	Mon 11/21/05	Tue 12/6/05		10%
29	Design	14 days	Wed 2/8/06	Mon 2/27/06	28	0%

5 Aug
M T

Project: T11_Schedule
Date: Fri 12/9/05

Task	Project Summary
Split	External Tasks
Progress	External Milestone
Milestone	Deadline
Summary	

Page 1

ID		Task Name	Duration	Start	Finish	Predec	% Work Complete	5 M	Aug T
30		Build	14 days	Mon 3/6/06	Thu 3/23/06	29	0%		
31		Test	16 days	Fri 3/24/06	Fri 4/14/06	30	0%		
32									
33		**Housing**	**153 days**	**Wed 9/21/05**	**Fri 4/21/06**		**0%**		
34		**Jacks**	**14 days**	**Fri 12/9/05**	**Wed 12/28/05**		**0%**		
35		Research	7 days	Fri 12/9/05	Mon 12/19/05		95%		
36		Acquire and Implement	7 days	Tue 12/20/05	Wed 12/28/05	35	0%		
37		**Control Interface**	**91 days**	**Fri 12/16/05**	**Fri 4/21/06**		**0%**		
38		Research	1 day	Fri 12/16/05	Fri 12/16/05		80%		
39		Design	21 days	Mon 12/19/05	Mon 1/16/06	38	50%		
40		Build	14 days	Tue 4/4/06	Fri 4/21/06	39	0%		
41		**Case**	**153 days**	**Wed 9/21/05**	**Fri 4/21/06**		**0%**		
42		Research	63 days	Wed 9/21/05	Fri 12/16/05		80%		
43		Design	75 days	Mon 12/19/05	Fri 3/31/06	42	50%		
44		Build	7 days	Thu 4/13/06	Fri 4/21/06	43	0%		
45		**Production**	**28 days**	**Mon 3/13/06**	**Wed 4/19/06**		**0%**		
46		Find Production Vendor	21 days	Mon 3/13/06	Mon 4/10/06		10%		
47		Purchase Assembly	7 days	Tue 4/11/06	Wed 4/19/06	46	0%		
48									
49		**Documentation**	**169 days**	**Mon 9/26/05**	**Thu 5/18/06**		**0%**		
50		Project Objectives	3 days	Mon 9/26/05	Wed 9/28/05		100%		
51		Preliminary eval of Feasibility	14 days	Tue 10/11/05	Fri 10/28/05		100%		
52		Preliminary budget	3 days	Thu 10/27/05	Mon 10/31/05		100%		
53		Refined Task Specs	3 days	Wed 11/2/05	Fri 11/4/05		100%		
54		Prelminiry Project Schedule	2 days	Fri 11/4/05	Mon 11/7/05		100%		
55		Project Brief	2 days	Thu 11/10/05	Fri 11/11/05		100%		
56		PPFS Draft	14 days	Wed 11/9/05	Mon 11/28/05		100%		
57		PPFS	14 days	Tue 11/22/05	Fri 12/9/05		100%		
58		Final Report	14 days	Mon 5/1/06	Thu 5/18/06		20%		

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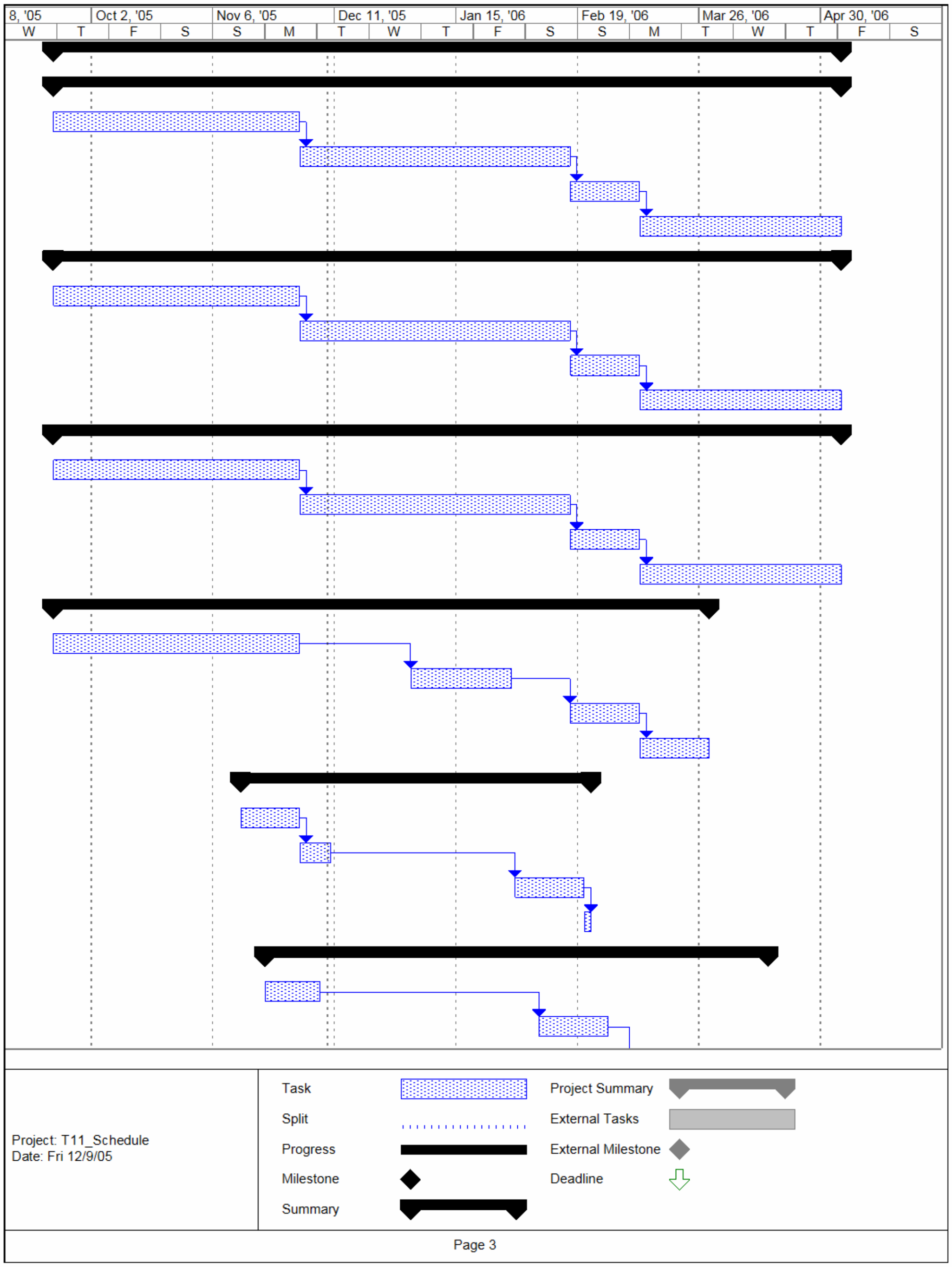
8, '05
Oct 2, '05
Nov 6, '05
Dec 11, '05
Jan 15, '06
Feb 19, '06
Mar 26, '06
Apr 30, '06
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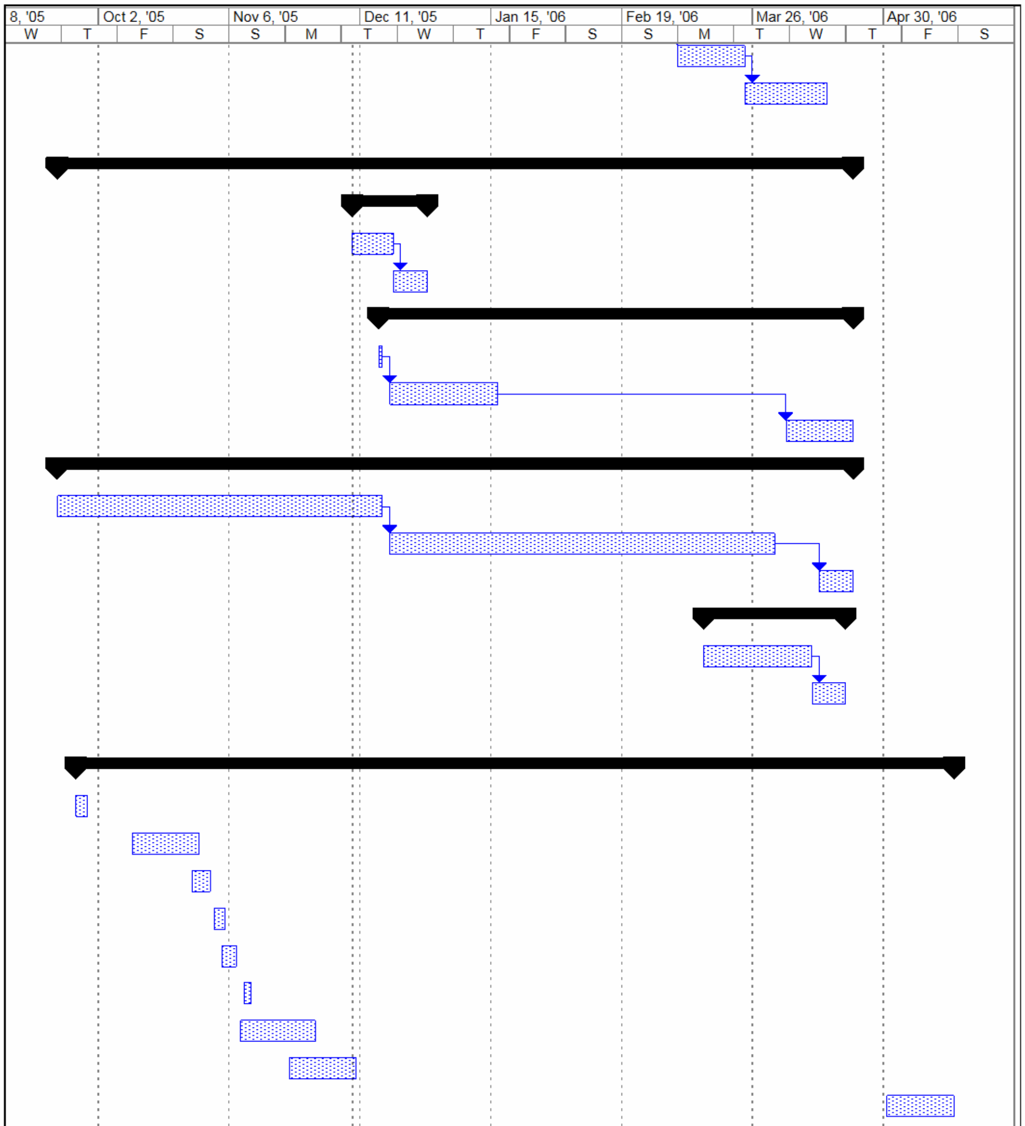

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