# MP3 Player System Design

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San Luis Obispo

2011

## Contents

## Acknowledgements

I'd like to thank my advisor, Dr. Tina Smilkstein, for answering all my dumb questions and putting up with my lack of punctuality for our meetings.

I'd also like to thank my friends for throwing me ideas regarding this project and helping out where ever possible.

And of course, I'd like to thank my family for providing me emotional and financial support for getting through college and this tough engineering program.

## Introduction

Portable music players have existed for decades, with the first truly portable consumer device released by Sony in 1979. Known as the "Walkman", this cassette player for the first time allowed people to easily carry hours of music on their persons. Since then, technology in this field abruptly moved away from analog storage mediums to strictly digital ones. The CD player was the next revolution, as it was the first foray into mainstream digital music mediums. With the trend of shrinking the sizes of consumer electronics, and the growing popularity of sharing music online, the CD player was given up for flash-based music players. Dubbed the MP3 player, these devices allowed users far more convenience in customizing which music they wanted to load onto their players. Since flash memory was (and to some degree, still is) fairly expensive in terms of capacity per monetary cost, a shift to mechanical hard-disk drive based players began.

Unfortunately, the current market trend for portable music players is shrinking physical size, shrinking monetary cost, expanding capacity, and having svelte user interfaces, but with no respect for high-fidelity sound. The purpose of this project is to create the base hardware for a music player that sacrifices just about all else for the ultimate musical experience; possibly taping into a niche market of audiophiles who do not require tons of gigabytes of storage, or need fancy user interfaces.

## Requirements

Since this is the design of an MP3 player system, the requirements are fairly straight forward. All components must be as low power as possible, with digital hardware running in low-power, or sleep states, whenever feasible. Because the purpose of this project is to create a device that puts sound quality above all else, the analog circuitry must be well designed. Only the core components of the music player are to be designed; the design of secondary parts such as battery powered subsystems and user interfaces are beyond the scope of this project.

## Primary Component Descriptions

*Main Microcontroller (Atmel ATMEGA32A):*

The microcontroller chosen for this project was the Atmel ATMEGA32A, due to already being familiar with the chip and its capabilities. With 32kB of flash program memory, SPI, $I^2C$, UART, three timers and 33 GPIOs, this microcontroller was a very good starting place because of its rich peripheral set. Also, since it can run up to 16MHz, it is plenty fast for shifting data around. It is also ideally suited for a portable application because of fairly low active power consumption (<1mA) many sleep modes that further reduce current draw to below 1µA. The block diagram

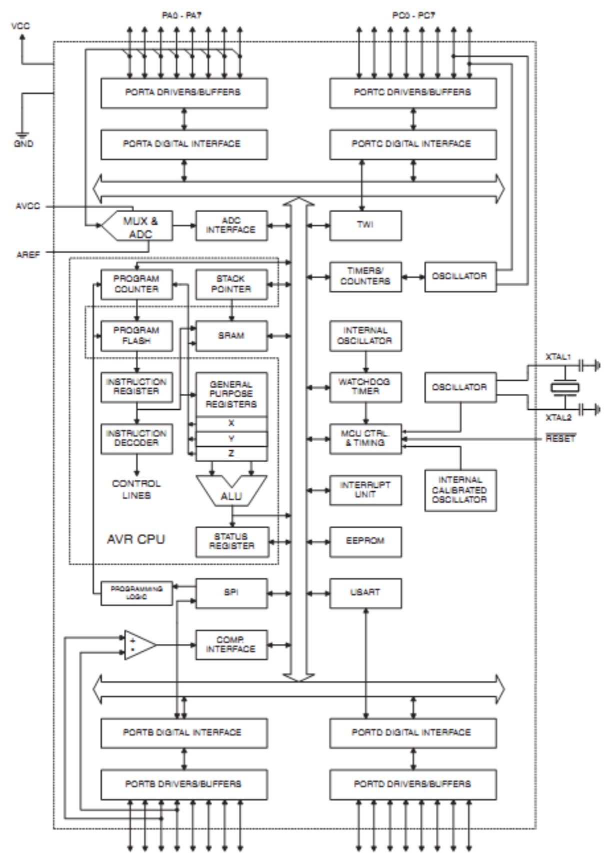


**Figure 1: Block Diagram of ATMEGA32A Microcontroller**

*Stereo Audio DAC (Wolfson WM8740):*

This high-end audio DAC chip was chosen because it is found in some of the most expensive commercial CD players, and is well regarded in the audiophile community. Although this is no longer the highest performing DAC chip in the Wolfson inventory, its successors (WM8741 and WM8742) are twice as expensive and on paper only have slightly higher specifications. Conveniently, these three chips are 100% pin compatible drop-in replacements of each other, so if the WM8740 is ever discontinued, the newer chips can be used instead.

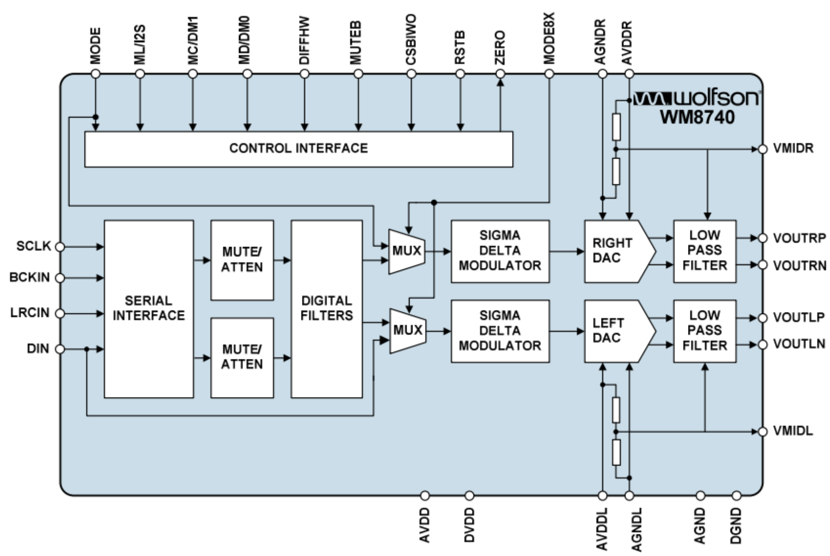


**Figure 2: Block Diagram of WM8740 Stereo DAC**

*Audio Decoder Chip (VLSI VS1053):*

The VLSI VS1053 is a decoder chip that can decode many different types of audio formats (MP3, OGG, FLAC, WMA and AAC), has a variety of possible outputs and has low power consumption. Because the chip is actually a DSP microcontroller, one could expand functionality by using it, along with the ATMEGA32A, to perform additional functions in the music player.  Since this part has a built-in amplified analog output and can output $I^2S$, it has the added benefit of flexibility: if the designer wants to save on power and/or complexity, the analog output can be used, which requires no additional parts.  But because the purpose of this design is to create the highest fidelity sound possible, the $I^2S$ output is used to send the audio data to the WM8740.

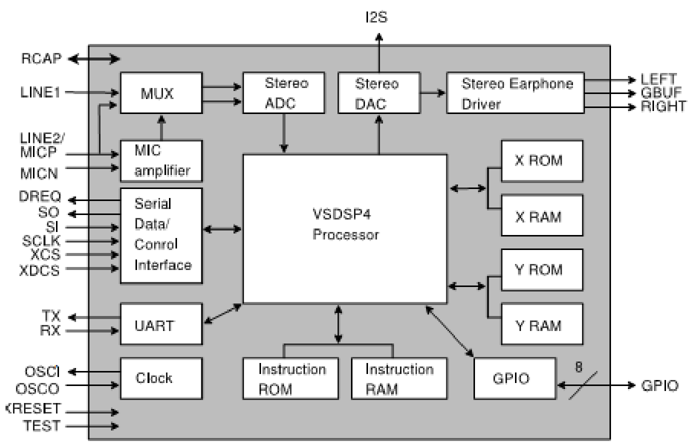


**Figure 3: Block Diagram of VS1053 Decoder Chip**

*Real-Time Operating System (FreeRTOS):*

Although not a physical part, this real-time embedded operating system is still a vital component in this project.  The slightly added complexities of using an RTOS was more than offset by the fast context switching and low latency afforded by the preemptive scheduler, and the availability of built-in objects (mutex semaphores, queues…etc) made it very easy to share data and protect global resources.

*SD Card/FAT File System:*

The SD card, which is a flash-based storage medium, is where the data for the music files are stored. Conveniently, SD cards by default use SPI as the communications protocol, so the interface with the microcontroller is relatively straight forward. Unfortunately, reading and writing from the FAT file system is extremely non-trivial.

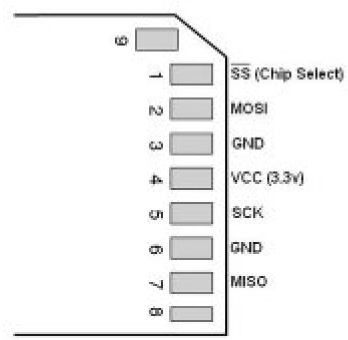


**Figure 4: Pin-out of SD Card**

## Technical Design

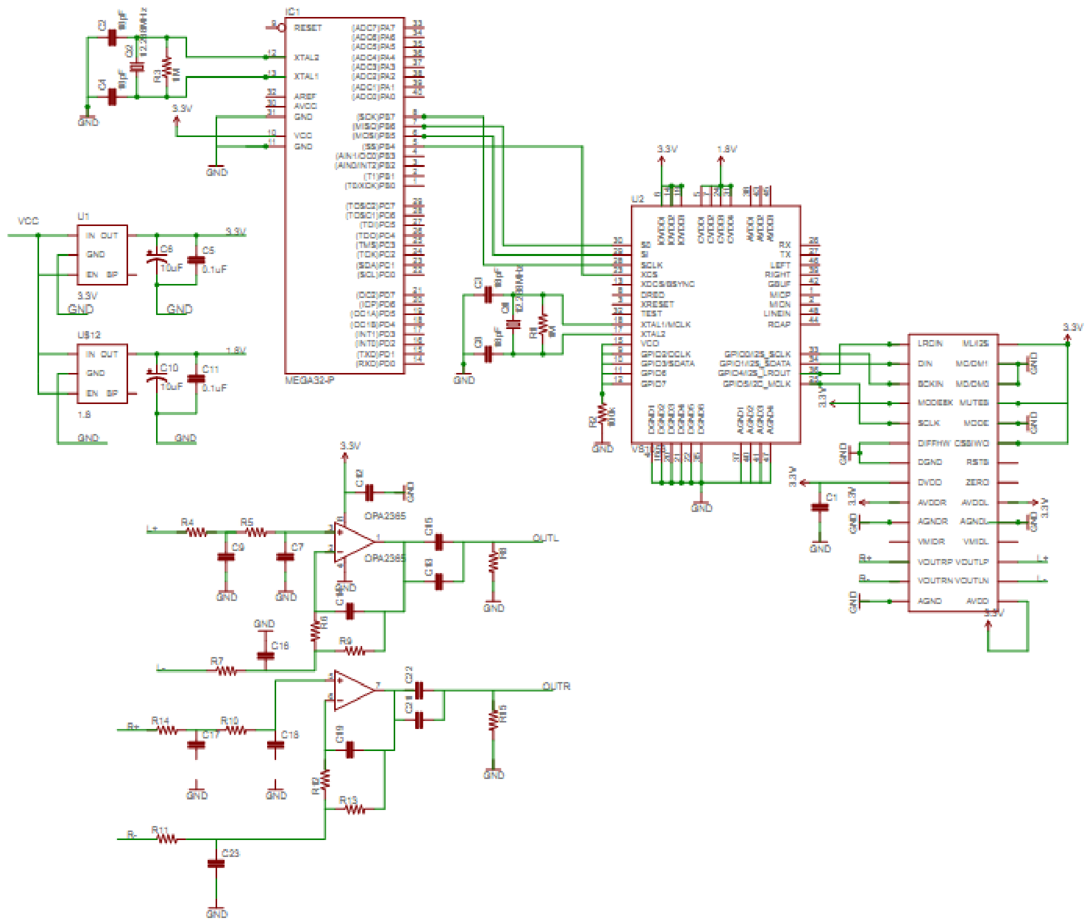

**Figure 5: Schematic of Main Components of the System**

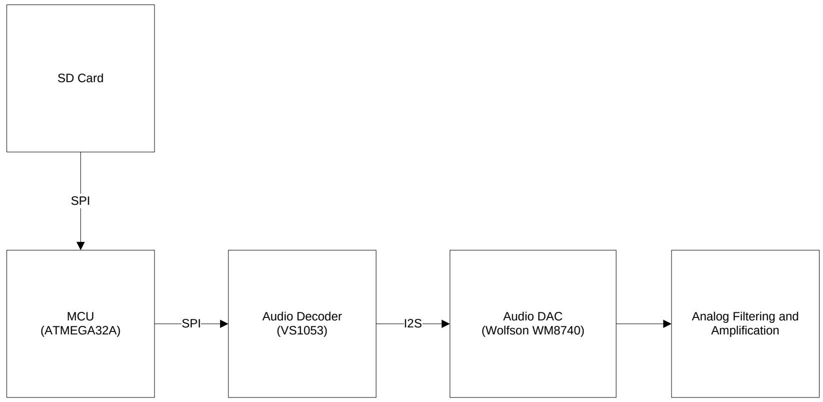


**Figure 6: Hardware Block Diagram**

The schematic and hardware block diagram are seen in Figure 5 and Figure 6, respectively. The design is fairly simple: the ATMEGA32A handles most of the digital legwork and facilitates pulling data from the SD card, by reading its file system, then sends that data, which is in the form of a compressed music file, to the decoder chip. From there, the decoder chip decodes the music file into a raw bit-stream, which is then sent to the DAC chip for digital filtering and analog conversion. The majority of the schematic consists of recommended implementations as stated in the components' datasheets.

| | **Designation** | **Value** | **Vendor** | **P/N** | **Price** |
|---|---|---|---|---|---|
| **Resistors** | R1 | 1M | Mouser | 270-1.0M-RC | 0.15 |
| | R2 | 100k | Mouser | 270-100K-RC | 0.15 |
| | R3 | 1M | Mouser | 270-1.0M-RC | 0.15 |
| | R4 | 4.75k | Mouser | 270-4.7K-RC | 0.15 |
| | R5 | 2k | Mouser | 270-2K-RC | 0.15 |
| | R6 | 2k | Mouser | 270-2K-RC | 0.15 |
| | R7 | 4.75k | Mouser | 270-4.7K-RC | 0.15 |
| | R8 | 47k | Mouser | 270-47K-RC | 0.15 |
| | R9 | 3.3k | Mouser | 270-3.3K-RC | 0.15 |

| | | | | | |
|---|---|---|---|---|---|
| | R10 | 2k | Mouser | 270-2K-RC | 0.15 |
| | R11 | 4.75k | Mouser | 270-4.7K-RC | 0.15 |
| | R12 | 2k | Mouser | 270-2K-RC | 0.15 |
| | R13 | 3.3k | Mouser | 270-3.3K-RC | 0.15 |
| | R14 | 4.75k | Mouser | 270-4.7K-RC | 0.15 |
| | R15 | 47k | Mouser | 270-47K-RC | 0.15 |
| **Capacitors** | C1 | 1u | Mouser | 810-FK24X7R1E105K | 0.35 |
| | C2 | 18p | Mouser | 80-C315C103K5R | 0.57 |
| | C3 | 18p | Mouser | 80-C315C103K5R | 0.57 |
| | C4 | 18p | Mouser | 80-C315C103K5R | 0.57 |
| | C5 | 0.1u | Mouser | 80-C320C104K5R | 0.32 |
| | C6 | 10u | Mouser | 80-T350E106K025AT | 1.42 |
| | C7 | 220p | Mouser | 505-FKP2220/100/2.5 | 0.38 |
| | C9 | 100p | Mouser | 505-FKP2100/100/2.5 | 0.38 |
| | C10 | 10u | Mouser | 80-T350E106K025AT | 1.42 |
| | C11 | 0.1u | Mouser | 80-C320C104K5R | 0.32 |
| | C12 | 0.1u | Mouser | 80-C320C104K5R | 0.32 |
| | C13 | 1u | Mouser | 810-FK24X7R1E105K | 0.35 |
| | C14 | 220p | Mouser | 505-FKP2220/100/2.5 | 0.38 |
| | C15 | 22u | Mouser | 647-UKW1H220MDD | 0.16 |
| | C16 | 100p | Mouser | 505-FKP2100/100/2.5 | 0.33 |
| | C17 | 100p | Mouser | 505-FKP2100/100/2.5 | 0.33 |
| | C18 | 220p | Mouser | 505-FKP2220/100/2.5 | 0.38 |
| | C19 | 220p | Mouser | 505-FKP2220/100/2.5 | 0.38 |
| | C21 | 1u | Mouser | 810-FK24X7R1E105K | 0.35 |

| | | | | | |
|---|---|---|---|---|---|
| | C22 | 22u | Mouser | 647-UKW1H220MDD | 0.16 |
| | C23 | 100p | Mouser | 505-FKP2100/100/2.5 | 0.33 |
| **Integrated Circuits** | U1 | REG101-33 | Mouser | REG101UA-3.3 | 3.56 |
| | U2 | REG101-18 | Mouser | REG101UA-3.3 | 3.56 |
| | U3 | WM8740 | Mouser | 238-WM8740SEDS | 5.70 |
| | U4 | VS1053 | Sparkfun | COM-08892 | 19.95 |
| | U5 | OPA2365 | Mouser | 595-OPA2365AID | 2.88 |
| | IC1 | ATMEGA32A | Mouser | 556-ATMEGA32A-PU | 5.36 |
| | | | | Total | 53.03 |

**Table I: Bill of Materials**

As seen in Table I, the base cost per unit is $53.03, not including shipping charges or development hardware.

## Test Plans and Results

*Initialize decoder chip and run in a diagnostic mode:*

The point of this test was to ensure that that the VS1053 chip actually worked. The VS1053 has a few diagnostic modes, and the one that verifies that the analog and digital hardware actually works sends sinusoidal test tones to the analog outputs.

Status: PASS

Results:

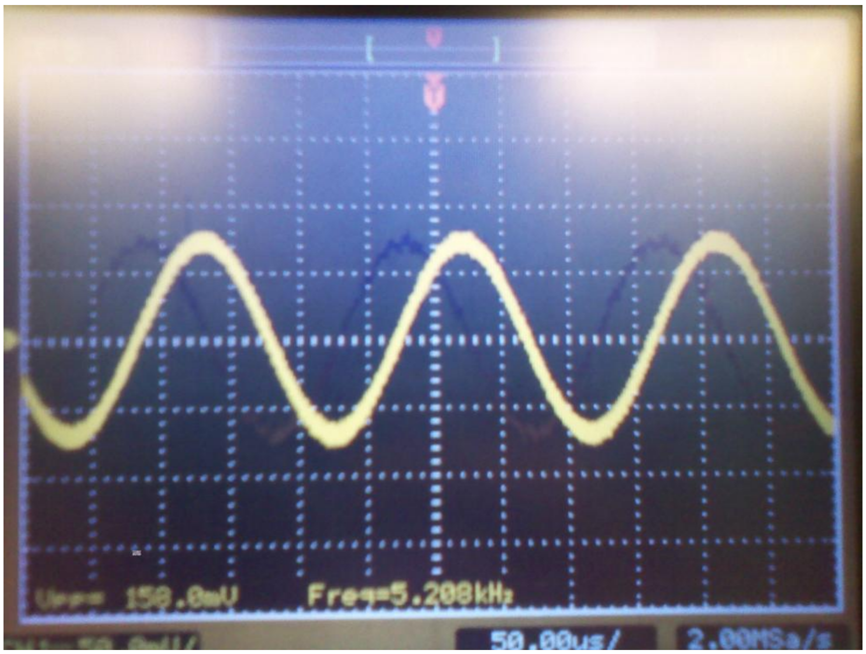


**Figure 7: Oscilloscope Screen-Capture of Test Tone**

As seen in Figure 7, the decoder chip was able to respond to this "Hello World" of sorts. The output was somewhat noisy, which could have been attributed to the questionable oscilloscope probe, or it could have been the fact that the analog output hardware on the decoder chip is not very good.

*Initialize FAT File System on SD Card:*

The point of this test was to ensure that the ATMEGA32A was able to open and close files on the file system when told to do so.  LEDs were used to determine if SPI transactions with the SD card were successful.

Status: Questionable (PASS?)

Results: The LEDs indicated that the microcontroller was able to initialize the SD card and grab files from it.  However, results from this test are still somewhat inconclusive since this test cannot prove that the microcontroller can read the contents of the opened files.

*Transfer MP3 Data from SD Card to Decoder Chip:*

The point of this test was to determine whether or not files could be opened, and if data could be transferred to the decoder chip.

Status: FAIL

Results: No sound was heard from the analog outputs of the decoder chip.

## Conclusions and Recommendations

Although the project seemed relatively simple in the hardware realm, the software was quite tricky. Lack of documentation turned out to be the real obstacle in this project.

For example, while the VLSI VS1053 is technically an SPI compliant device, it contained some strange aspects that were definitely uncommon for an SPI device. Communicating with various registers on the chip depended on pulling the chip-select pin either high or low, which was somewhat unclear in the timing diagrams. Also, various pins had to be pulled up high or low, depending on desired initial configuration, and the datasheet did not make entirely clear which initial configuration was correct.

## Analysis of Senior Project Design

**Project Title:** MP3 Player System Design

**Student's Name:** Eric Wu

**Advisor's Name:** Dr. Tina Smilkstein

**Summary of Functional Requirements:**

The function of this project is to develop a high-end portable music player that supports many different formats (namely MP3s). Music files are read from flash-based storage (SD Card), decoded through a decoder chip and played through a high-end audio DAC.

**Primary Constraints:**

The main challenge faced was poor documentation for various pieces of hardware, which made it far more time consuming and difficult to implement.

**Economics:**

The cost of components for the basic design is $53.03, not counting shipping or handling charges. This also does not include the cost of an SD card, which should be supplied by the user/customer. Although not required, access to oscilloscopes and logic analyzers is extremely helpful, but because this test equipment is extremely expensive, it should not be factored into the final cost. Development time took substantially longer than anticipated.

**If Manufactured on a Commercial Basis:**

The niche market for this product would probably not result in a large number of devices sold yearly, so the markup per unit should be high due to low economies of scale.

**Environmental:**

There are not really any direct environmental impacts associated with the use of a music player, however, the manufacture would probably have somewhat of an environmental impact since silicon and other components cannot be manufactured cleanly.

**Manufacturability:**

There are not really any issues with manufacturing.  Hand assembly would be difficult and time consuming, but a pick-and-place would make populating the board quick and easy.

**Sustainability:**

The only part of this product that could be considered disposable would be the battery, which would need replacing every few hundred hours of operation due to the degradation of rechargeable lithium batteries, so in that regard it is fairly sustainable. Also, the hardware itself would not need to be upgraded (unless parts became obsolete) and the software itself can easily be updated, further making the device more sustainable.

**Ethical:**

Since some of the supported music file types are proprietary, special care must be taken to ensure that the required royalties are paid if this were to be put into production.

**Health and Safety:**

The manufacture and use of the device is no more unsafe than any other portable music player already on the market.

**Social and Political:**

There are no social or political concerns.

**Development:**

Extensive use of oscilloscopes and logic analyzers were required for the development of the product.  Also, learning the Atmel microcontroller development environment was very important.

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