Homework 3: Design Constraint Analysis and Component Selection Rationale

Team Code Name: BeatSquare **Group No. 01**

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Evaluation:

SEC	DESCRIPTION	MAX	SCORE
1.0	Introduction (including updated PSSC)	10	
2.0	Design Constraint Analysis	-	
2.1	Computational Requirements	10	
2.2	Interface Requirements	5	
2.3	On-Chip Peripheral Requirements	10	
2.4	Off-Chip Peripheral Requirements	5	
2.5	Power Constraints	5	
2.6	Packaging Constraints	5	
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3.0	Component Selection Rationale	20	
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5.0	List of References	10	
App A	Parts List Spreadsheet	5	
App B	Updated Block Diagram	5	
	TOTAL	100	

Comments:

1.0 Introduction

The BeatSquare is a music creation device. The overall design consists of an eight by eight square matrix of push buttons with RGB LEDs embedded within. When the user presses a button the led will light. Each column represents one beat in 4/4 time. Multi tone audio is then produced based off of the user's previous selections. The device will also include a four line LCD display to allow the user to save and load previous configurations. The user will also be able to save a melody to an SD card in the MIDI format. The LED matrix will be lit with a persistence of vision technique. This will be done by illuminating the selected cells of one column at a time. When this is done at a high speed it appears to the user that all of the selected cells are illuminated.

Updated Project Specific Success Criteria:

1. The ability to poll an array of pushbuttons to manipulate the musical configuration and display a visual pattern using LEDs.
2. The ability to adjust the beats per minute.
3. The ability to output multi-tone audio.
4. The ability to save audio output as a MIDI file on an SD card.
5. The ability to save and load musical configurations to and from the flash memory of a microcontroller.

2.0 Design Constraint Analysis

Major design constraints include computational requirements, interface requirements, on and off chip peripherals, power, packaging, and cost. The major requirements that must be considered computation wise include maintaining persistence of vision, scanning the button matrix, and producing the multitone audio. The device must interface with various integrated circuits including shift registers, decoders, an amplifier, and so on. Many of the on chip peripherals will be used to interface with these integrated circuits. Protocols include SPI, analog to digital conversions, timing interrupts, and pulse width modulation. Power consideration must remain moderate as this design is meant to be a consumer level product. The device as a whole must also be moderately robust to account for the enthusiasm of younger users.

2.1 Computation Requirements

One of the main computational requirements is the displaying the pattern on the 8x8 grid of RGB LEDs. In order to maintain persistence of vision, each LED must be flashed at a minimum frequency of about 40 Hz. Given that the chosen microcontroller operates at an average of 80 MHz, and that a typical 8-bit shift register operates at an estimated 25 MHz, this is more than enough to satisfy the minimum frequency needed for persistence of vision and it's highly likely that the microcontroller will have plenty of time to perform other tasks aside from controlling the LED matrix.

Another computational requirement is polling the pushbutton matrix for inputs. The proposed design calls for scanning the columns sequentially and the rows in parallel, thus producing 8 bytes of data indicating pushed buttons in the specified column and row. Switch debouncing will be required, and may be done in software. Considering that a typical 8-bit shift register operates at an estimated 25 MHz, the microcontroller will have plenty of time to read the button matrix, debounce the inputs if necessary, and then continue on with other work.

The micro controller must also output reconstructed audio. This will include pulling tone sample data from lookup tables in flash memory, synthesizing the appropriate multi-tone audio, and setting the required outputs accordingly. In a test done in Matlab, the estimated number of samples needed is around 500 floating point values. At 4 bytes each and 8 different tones to output, the total storage required for these tones will be around 16 KB. The reason for having so many data points is so that a desired complex tone may be output. A simple sine wave is much easier to construct compared to a piano tone that includes many harmonics which create the richer sound. This sound output operation must occur at set intervals in order to maintain auditory fidelity.

The last main computational requirement is interfacing with an SD card. The micro will communicate with the card via SPI protocol to output a configured melody in MIDI format. The construction of the MIDI file will be done by the microcontroller before being transmitted to the card.

2.2 Interface Requirements

The microchip will need to perform a variety of functions for this design. First, the chip needs to utilize at least four SPI interfaces: one for the LEDs matrix, one for the button matrix, one for the LCD, and one for the SD interface. The LED and button matrices will likely require two additional SPI interfaces, however, bringing the total pins required for these interfaces to 24 pins. Next, to drive the speakers for audio output, a single analog pin will be utilized. Third, two rotary encoders and four pushbuttons will comprise the user interface for volume control, speed adjustment, interfacing with the LCD menu. Each of the encoders will require two pins to decode, and each pushbutton will need one pin, for a total of 8 pins. All together, the estimated pin requirement is about 33 pins.

Current sourcing will be very important for our implementation of the RGB LED matrix. Each column of the matrix contains eight LEDs; if all of these need to be illuminated at once, the worst case required current will be 160 mA. As the microcontroller can only source 25 mA, additional current from the power supply will be required to power the LEDs.

The SD protocol calls for a 3.3 voltage level at the card's pins. For this reason, the microcontroller needs to interface with a level translator to appropriately adjust the voltage.

2.3 On-Chip Peripheral Requirements

There are several on-chip peripherals that the project requires. It will use 4 channels of 4-bit SPI outputs from the microcontroller. One for the pushbutton matrix, one for the LED matrix, one for the LCD screen, and one for the SD card interface. It will also require an on-chip floating point unit to handle the analog values of the multiple tones. Since this project heavily relies on timing for flashing the lights, polling the pushbuttons, and playing audio, it will need 3 channels of at least 16-bit timers. Multiple real-time interrupt channels will also be required in order to handle any asynchronous routines driven by the menu interface.

2.4 Off-Chip Peripheral Requirements

To interface with the LED grid, the microcontroller will require shift registers connected to the rows and columns of the array. The microcontroller will use these devices to "strobe" the LEDs, one color at a time, one column at a time, in a very short time span. The design will need to include parts that can handle the necessary speed requirements and either transmit the required current or interface with transistors that can provide additional power to the LED array.

Shift registers will also be needed to interface the controller with the button array. In a similar fashion to the LED array, the shift registers will allow the controller to "scan" the array of buttons, one column at a time, for button presses. This will also need to be done swiftly, so the register will have to handle the speed of the signals coming in to perform its function.

To provide enough power to drive the speakers, an amplifier will be required to boost the audio signal prior to output. The amplifier will need to provide a signal that is within the power and frequency requirements of the speakers.

Another peripheral used by the device is a level shifter, for interfacing with the SD card. The SD protocol calls for a 3.3 V interface voltage, but the microcontroller provides 5V. Thus a level shifting chip will be required to interface with the SD card.

2.5 Power Constraints

Since the project will require a decent amount of power to run the LED matrix, the proposed power source will solely consist of A.C. power from a wall outlet, which should be sufficient to run the entire device. A voltage regulator will likely be integrated with the A.C. transformer. If this is included, the heat of the voltage regulator will need to be considered and measures should be taken to dissipate this heat, such as a heat sink. Any other elements should not be giving off an excessive amount of heat so long as the packaging provides sufficient space.

Current for driving the LED matrix is an important part of this project and requires some consideration. To drive the LED matrix, a "persistence of vision" technique will be used. This involves illuminating a single column of a single color of LEDs at once – that is, providing enough current to drive 8 LEDs in parallel. The typical forward operating current for a single LED color is 20 mA, so driving a single column of a single color will require up to 160 mA of current at a given time. However, because persistence of vision requires flashing the LEDs on and off at a rapid rate, current consumption may be much lower due to the current's continuously transient state. [1]

2.6 Packaging Constraints

The device's packaging will be a relatively simple box of plastic or wood. The design needs to be large enough to accommodate the 8x8 grid, the user interface components, and the interior PCB, yet small enough to be relatively portable. It should be able to be held with two hands, and should also be easy to store. The casing should allow access to interfaces such as USB and Ethernet. Finally, the packaging should be fairly resistant to bumps and knocks by clumsy or younger users.

2.7 Cost Constraints

The cost constraints of the project are defined by competition with similar products on the market. Online, there exist several products such as the Monome [2] for $500 and the Launchpad Mini for $150. [3] The $300 budget allocated for this project should be sufficient to cover the cost of all electronic components required, and is competitive with other similar products already on the market.

3.0 Component Selection Rationale

The major component of the project is the 8x8 LED and pushbutton matrices. By using several parts from SparkFun, it is possible to construct an 8x8 pushbutton/LED matrix by utilizing a four 4x4 PCB breakout boards [4] and attaching the corresponding components, including pushbuttons [5] and RGB LEDs. [6] By comparison, it would also be possible to purchase four pre-assembled RGB Omni boards [7] and 16 sets of keypads [8] from Livid Instruments for a comparable price. However, due to a lack of documentation on the RGB Omni boards and keypads, it was determined to utilize the parts from SparkFun and Marlin P. Jones for this component.

In choosing an LCD interface, it was determined that four lines would be adequate for a menu style of interface. Two similar products from SparkFun were investigated – one that has a basic 11-pin parallel interface [9] and one that has a built-in serial interface. [10] The LCD with the built-in serial interface was preferred due to the simplicity it offered to the design. With this display, no external shift register or other deserializing device would be necessary to conserve pins.

Microcontrollers investigated for this project included members of the Texas Instruments Tiva C Series of controllers. Of these, the choices were narrowed down to two candidates: the TM4C123GH6PM and the TM4C1233H6PM. Each unit has 32 KB of SRAM and 256 KB of flash, which is more than enough memory to store the various tones required for the music grid. Both units support floating point values that will be needed to store and play back analog audio. And both units run at an average clock speed of 80 MHz. [11] However, the TM4C123GH6PM supports 16 PWM modules and 2 QEI modules that will prove more useful in interfacing with the proposed design, [12] e.g. audio output and interface with rotary encoder controls.

4.0 Summary

Key design constraints for the BeatSquare include the need to light up to 64 LEDs simultaneously. Persistence of vision was chosen to accomplish this goal as it is straightforward and reduces the total power required. Similarly 64 buttons must be polled for user interaction. The preliminary design for button interaction is also a progressive scan implementation. User interaction is provided not only by the illumined buttons but also via a four line LCD display. The LCD display will allow for a greater range of user feedback. The user interacts with the display via rotary pulse generators and push buttons. Configurations may be saved to internal flash or externally to a MIDI file on an SD card. This format was chosen because of its wide spread use and availability in electronic music. Multi tone audio will be implemented via an analog out pin. The reasoning behind this is to maintain a high rate of output sampling and maintain simplicity.

5.0 List of References

[1] Matt Stabile (2008), *Controlling a Dot Matrix LED Display with a Microcontroller,* [Online]. Available: http://www.create.ucsb.edu/200C/2008_Students/MAT-200C_2008_Files/matt_stabile/MAT200CStabile.pdf (Accessed: 7 February 2014).

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[4] Button Pad 4x4 – Breakout PCB, *SparkFun*, [Online]. Available: https://www.sparkfun.com/products/8033 (Accessed: 6 February 2014).

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[7] RGB Omni, *Livid Shop*, [Online]. Available: http://shop.lividinstruments.com/rgb-omni/ (Accessed: 6 February 2014).

[8] 4x1 Omni Keypads, *Livid Shop*, [Online]. Available: http://shop.lividinstruments.com/4x1-omni-keypads/ (Accessed: 6 February 2014).

[9] Basic 20x4 Character LCD – Black on Green 5V, *SparkFun*, [Online]. Available: https://www.sparkfun.com/products/256 (Accessed: 6 February 2014).

[10] Serial Enabled 20x4 LCD – Black on Green 5V, *SparkFun*, [Online]. Available: https://www.sparkfun.com/products/9568 (Accessed: 6 February 2014).

[11] TM4C1233H6PM, *Texas Instruments*, [Online]. Available: http://www.ti.com/product/tm4c1233h6pm (Accessed: 6 February 2014).

[12] TM4C123GH6PM, *Texas Instruments*, [Online]. Available: http://www.ti.com/product/tm4c123gh6pm (Accessed: 6 February 2014).

Appendix A: Parts List Spreadsheet

Vendor	*Manufacturer*	*Part No.*	*Description*	*Unit Cost*	*Qty*	*Total Cost*
Texas Instruments	Texas Instruments	TM4C123GH6PM	Tiva C Series TM4C123GH6PM	11.43	1	$12.99
SparkFun Electronics	SparkFun Electronics	LCD-09568	Serial Enabled 20x4 LCD - Black on Green 5V	29.95	1	$29.95
SparkFun Electronics	SparkFun Electronics	COM-08033	Button Pad 4x4 – Breakout PCB	9.95	4	$39.80
SparkFun Electronics	SparkFun Electronics	COM-07835	Button Pad 4x4 - LED Compatible	9.95	4	$39.80
SparkFun Electronics	SparkFun Electronics	COM-08746	Button Pad 2x2 Top Bezel	3.95	8	$31.60
SparkFun Electronics	SparkFun Electronics	COM-08747	Button Pad 2x2 Bottom Bezel	3.95	8	$31.60
Marlin P. Jones	Foryard Optoelectronics	18605-OP	5mm Red Green Blue Full Color LED, 4 Lead Common Cathode	0.65	64	$41.60
Marlin P. Jones	Unknown	Unknown	1N4148 Logic Diode	0.06	64	$3.84
Parts Express	Tectonic Elements, Ltd.	HIBM36S12-8/A	HiWave BMR12 Compact 2" Full-Range Square Speaker 12W 8 Ohm	6.00	2	$18.00
				TOTAL		**$232.18**

Appendix B: Updated Block Diagram