

Homework 5: Theory of Operation and Hardware Design Narrative

Team Code Name: Beat Square

Group No. 01

Team Member Completing This Homework: Ben Pluckebaum

E-mail Address of Team Member: bpluckeb @ purdue.edu

NOTE: This is the second in a series of four “design component” homework assignments, each of which is to be completed by one team member. The body of the report should be 3-5 pages, **not** including this cover page, references, attachments or appendices.

Evaluation:

SEC	DESCRIPTION	MAX	SCORE
1.0	Introduction	5	
2.0	Theory of Operation	20	
3.0	Hardware Design Narrative	20	
4.0	Summary	5	
5.0	List of References	10	
App A	System Block Diagram	10	
App B	Schematic	30	
	TOTAL	100	

Comments:

Comments from the grader will be inserted here

1.0 Introduction

The BeatSquare is a simple approachable audio sequencer based off of popular flash applications like Muzy Music Grid and Tonematrix Audiotool. The BeatSquare will consist of an 8x8 LED pushbutton matrix. A TI Tiva TM4C123GH6PM microcontroller (referred to often in this document as Tiva or microcontroller) will be utilized to interface with the LED pushbutton matrix, reproduce data for multi-tone audio, interface with an SD card to load and save configurations, output user feedback and menus to a four line LCD display based on pushbutton and rotary pulse generator controls and further logic control. Major design considerations include how to interface with 192 LEDs, 64 push buttons, reproduce audio, and logic level translation for various integrated circuits.

Project Specific Success Criteria are as follows:

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

2.0 Theory of Operation

The BeatSquare has 4 major sections: the side panel, the user control section on top, the 8x8 interactive matrix, and the interior logic section.

The power for the BeatSquare will enter the device from the side panel. The BeatSquare will be powered by a 5 volt wall-wart power supply. The power supply will feature a barrel jack type connector which will help prevent power being inserted incorrectly. An SPST rocker switch will sit between the input of the 5 volt power supply and the rest of the PCB, physically connecting or disconnecting the power from the circuit when toggled. The side panel is also where the Molex 67913-0002 SD card connector will reside. The SD card will be connected with the microcontroller via four pin SPI at an estimated frequency of 200 kHz. The SD card standard uses a 3.3 voltage level so no translation will be needed when interfacing with the microcontroller as the microcontroller operates at 3.3 volt logic levels as well. The 200 kHz

speed was chosen as that frequency is within the standard operating range of 100 kHz to 400kHz [1] and is more than the minimum operating frequency which will enable faster data transfer.

The custom PCB will be located in the interior of the BeatSquare. The PCB will contain the “brains” of the operation, the TI Tiva TM4C123GH6PM (referred to hereafter as Tiva or microcontroller) microcontroller. A TPS73633 low-dropout (LDO) linear voltage regulator will be used in order to translate the 5 volt input of the power supply into the 3.3 voltage required for the Tiva microcontroller. A TI LM317M 5 volt regulator will be utilized for power regulation of the 5 volt components. In order to simplify design and maintain a precise clock for timing needs the precision internal oscillator (PIOSC) was chosen to provide the microcontroller’s clock. This means that there will be no crystal oscillator on the circuit board and the microcontroller will operate at 16 MHz. [2] A header for JTAG debugging will also reside in the interior of the device on the printed circuit board.

Another major section of the BeatSquare is the 8x8 LED Button matrix. The LED Button matrix consists of two major subsections; the tri-color LED subsection and the push button subsection. The push button subsection will be interface with the microcontroller via a 74HC165 parallel-in-serial-out IC coupled with a 74HC595 serial-in-parallel-out IC. Both registers will operate at a 3.3 volt level, on par with the microcontroller. The 165 can operate at a minimum frequency of 4MHz [3] and the 595 at 4.2 MHz [4] at 2 volts, so it is safe to say that they can run significantly faster at 3.3 volt levels. The button data input to the 165 register is debounced by a MAX6818 octal switch debounce circuit. This circuit can run at a supply voltage of 3.3 volts, but has a debounce delay period of 40 ms, meaning that debouncing operations can only be performed at a frequency of 25 kHz. While this is a limiting factor to the speed of this subsection, this is still an acceptable frequency for simply polling pushbuttons.

The LED matrix will interface with the microcontroller via SN74HC595 shift registers. The shift registers themselves will be chained together in order to limit the number of pins required on the microcontroller. These shift registers will operate at 5 volts, so level translation will take place between the Tiva and the shift registers. The anodes of each color will be interface with one shift register each and the cathodes of each column will be connected to one shift register see (Appendix B page 3). The LED matrix will be lit in a persistence of vision setup. One column of one color will be lit at a time, and a maximum of 8 LEDs will be illuminated. For a minimum estimated frequency it is assumed that each LED must flash at a

minimum of 24 times per second [5]. As there are 4 8 bit shift registers utilized in the matrix it will take approximately 33 shifts to illuminate one column – 32 to shift the data into the 595, and one more to output the data onto the bus. Therefore to temporarily illuminate all 8 columns and all 3 colors 792 shifts will be needed. In order to maintain 24 illuminations per second approximately 19,000 shifts will need to be performed per second, or less than 20 kHz. According to the datasheet of the SN74HC595 at 4.5 volts the maximum operating frequency of the shift registers is 21MHz. Thus, it can be seen that there is a wide range of acceptable frequencies to use for this component.

Above the 8x8 matrix is the user control area. This section consists of two Panasonic EVE-JBBF2020B rotary pulse generators, four tactile push buttons, and a GDM2004D four line LCD screen. The rotary pulse generators and push buttons are passive devices so they will interface with the microcontroller at 3.3 volts [6]. The LCD Screen will be interfaced via a 3 volt to 5 volt level translator then a SN74HC595 shift register. The LCD datasheet lists the internal controller as a S6A0069. [7] The S6A0069 list a maximum frequency of 270 kHz thus the 8 bit shift register will be run at a maximum of 2.16 MHz.

The last major subsection of the BeatSquare is the audio reproduction hardware. The function of this section is to convert digital data output by the microcontroller into analog signals playable by speakers. This is accomplished by utilizing a TI 8571 Digital to Analog (DAC) device. The DAC can operate at 3.3 volts so no level translation is needed. [8] The output of the DAC will be amplified using a pair of non-inverting amplifiers constructed via an LM 324 chip containing multiple operational amplifier circuits. [9] The amplifier outputs will each be fed into a 1 uF capacitor, which will be used to filter out the DC bias component of the signal and produce a purely analog signal. This in turn will be fed to a pair of DS-HIBM36S12-8A speakers.

3.0 Hardware Design Narrative

The data sheet for the Tiva, provided by the manufacturer, details where to place bypass capacitors and recommended values for those capacitors. In accordance with that data sheet there will be a total of 3.4 uF (see Appendix B page 2) in bypass capacitance located as close as possible to pin 56 and 25 (page 1367 of Tiva datasheet [1]) this provides instantaneous power for the on-chip low dropout regulator. Furthermore as described by the datasheet there will be a total

of 1.01 microfarads of bypass capacitance between the single analog and multiple digital supply voltage pins (2, 11, 26, 42, and 54 respectively) and ground. For further pinout information, refer to Appendix A, Table 1.

The GDM2004D LCD features configurable backlight brightness and contrast. Pulse-width modulation will be used to achieve adjustments of these values. In Appendix B page 5, the Interface page, the signals LCD_CON and LCD_LED correspond to the contrast and brightness inputs respectively. PWM is a common way to dim an LED, but more prototyping will need to be done in order to ensure that PWM will work as a contrast adjustment control as well.

The rotary encoders will be interfaced with the QEI subsystem of the microcontroller. As seen in page 2 of Appendix B and page 7 of Appendix B, the ports utilized will be pins 14, 15, 10, and 53. These pins were chosen as they are the only pins that support the QEI module while leaving other modules (such as SPI) open for use. The QEI subsystem is likely a bit more detailed than is needed for the planned use of interaction with menus displayed on the LCD but using the QEI subsystem should allow for ease of software configuration and design as well as more possible features.

The I2C subsystem of the microcontroller will be used to interface with the DAC. Furthermore, should it be decided to expand the project, more audio-related peripherals may be put on the same two lines and interfaced via I2C. I2C also allows for a reduction in pins needed when compared to parallel input. This reduction is quite high for devices like this DAC, because driving a similar device in parallel would require 16 pins instead of two. The DAC will operate at 3.3 volts so no logic level translation is needed.

One of the major subsystems of the microcontroller that will be utilized is the SPI modules. The SPI subsystem will be used to interface with the 8x8 LED button matrix, to send data to the LCD, and to interact with the SD card. As stated previously the 8x8 LED matrix will be interfaced with via SN74HC595 shift registers. These shift register contain two stages which allow data to be shifted in to the register while the previous data remains on the output pins. This will result in a more even illumination as there will not be momentary flickering while data propagates down the shift registers. The shift registers were chosen to be chained together in order to reduce the required number of pins, to help simplify the circuit and overall design, and because preliminary calculations show that there will be more than enough time to shift all bits out. Furthermore a test circuit was made in order to prove that the shift registers could source and

sink sufficient power. Similarly, parallel in serial out chips allow for fewer required pins on the microcontroller and shift registers are used to interface with the LCD for similar reasons. SPI is also a common, well documented way to interface with an SD card.

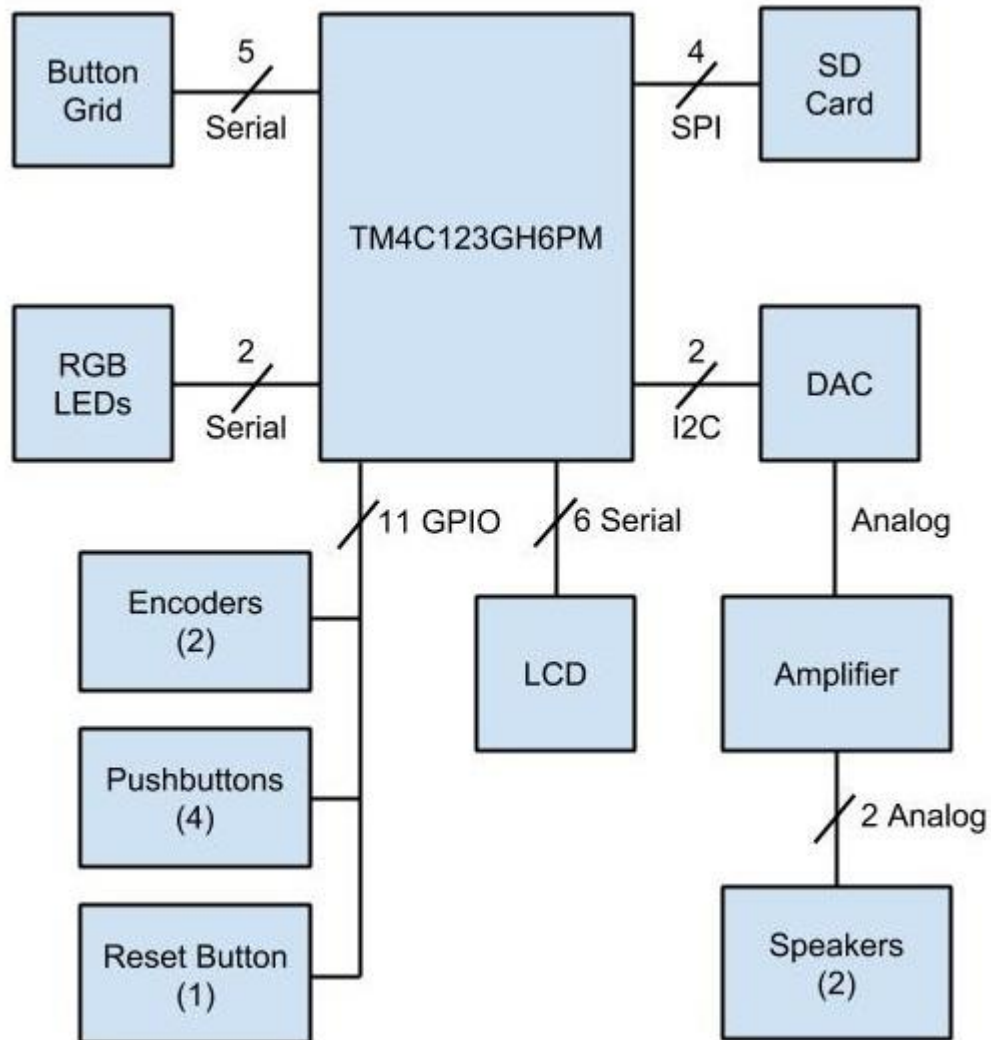
4.0 Summary

As seen in previous section major design concerns include driving a large amount of LEDs, interfacing with many push buttons, reproducing audio, and logic level translation for various integrated circuits. Design considerations, including utilizing shift registers and PISO chips, were made in order to reduce the number of microcontroller pins needed to interface with components. Various microcontroller subsystems used to interface with sections of the product include QEI, I2C, GPIO, and most importantly SPI. Furthermore, it was seen that the shift register chips are capable of running at high enough speeds to support the desired POV application for the LED matrix.

5.0 List of References

- [1] How to Use MMC/SDC, Electronic Lives Mfg., [Online]. Available: http://elm-chan.org/docs/mmc/mmc_e.html (Accessed: 21 February 2014).
- [2] Tiva TM4C123GH6PM Data Sheet, Texas Instruments, [Online]. Available: <http://www.ti.com/lit/ds/symlink/tm4c123gh6pm.pdf> (Accessed: 21 February 2014).
- [3] 74HC165 Data Sheet, NXP Semiconductors, [Online]. Available: http://www.nxp.com/documents/data_sheet/74HC_HCT165.pdf (Accessed: 21 February 2014).
- [4] SN74HC595 Data Sheet, Texas Instruments, [Online]. Available: <http://www.ti.com/lit/ds/symlink/sn74hc595.pdf> (Accessed: 21 February 2014).
- [5] Scanning and Persistence of Vision, Radios-TV.co.uk, [Online]. Available: <http://www.radios-tv.co.uk/?q=node/21> (Accessed: 21 February 2014).
- [6] 12 mm Square GS Encoders with Push-on Switch, Panasonic, [Online]. Available: <http://industrial.panasonic.com/www-data/pdf/ATC0000/ATC0000CE21.pdf> (Accessed: 21 February 2014).
- [7] GDM2004D, SparkFun Electronics Inc., [Online]. Available: <http://industrial.panasonic.com/www-data/pdf/ATC0000/ATC0000CE21.pdf> (Accessed: 21 February 2014).
- [8] DAC8571, Texas Instruments, [Online]. Available: <http://www.ti.com/lit/ds/symlink/dac8571.pdf> (Accessed: 21 February 2014).
- [9] Low Power Quad Operational Amplifiers, Texas Instruments, [Online]. Available: <http://www.ti.com/lit/ds/symlink/lm124-n.pdf> (Accessed: 21 February 2014).

IMPORTANT: Use standard IEEE format for references, and CITE ALL REFERENCES listed in the body of your report. Provide “live” links to all data sheets utilized.

Appendix A: System Block Diagram**Figure 1. System Block Diagram**

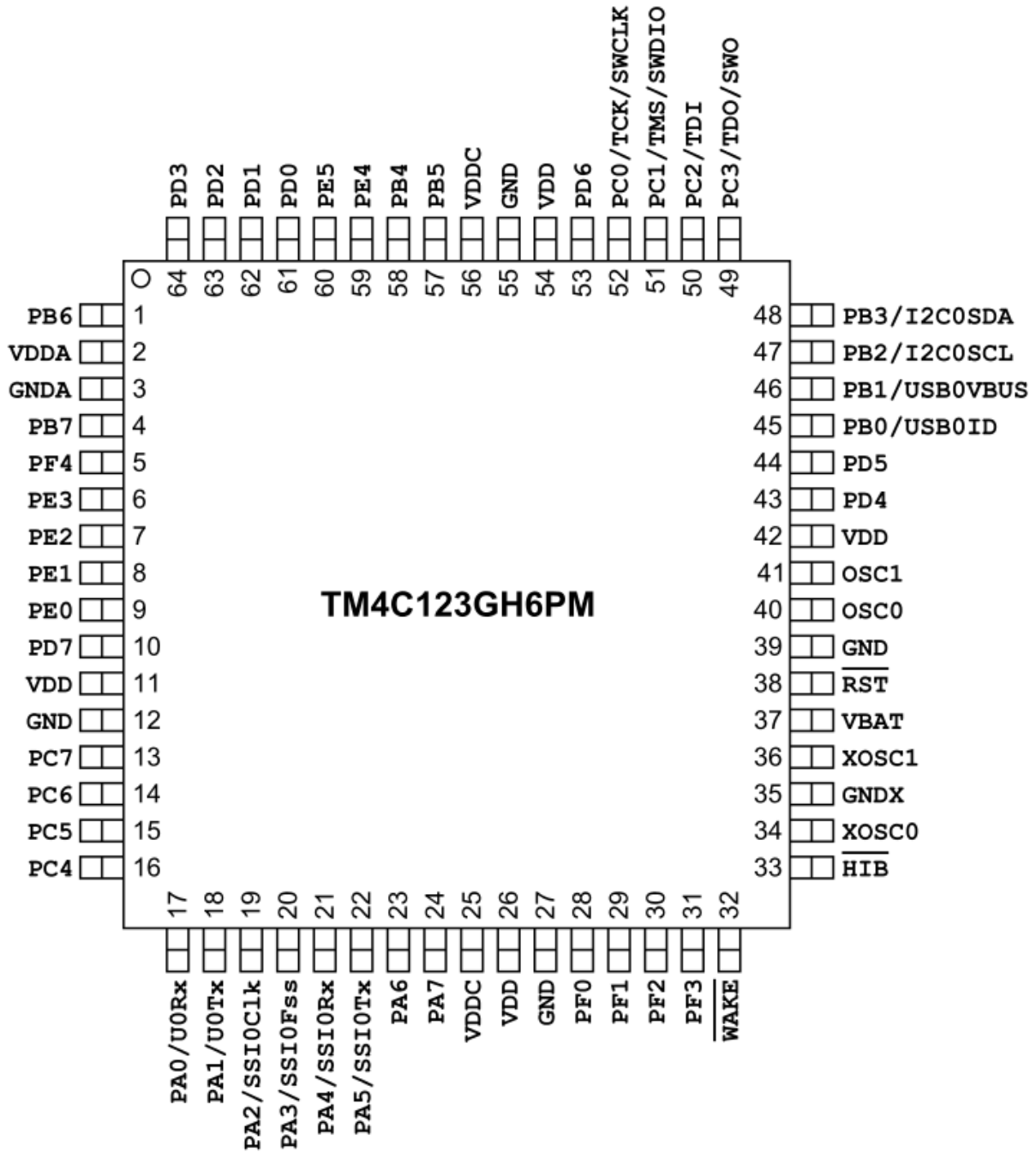
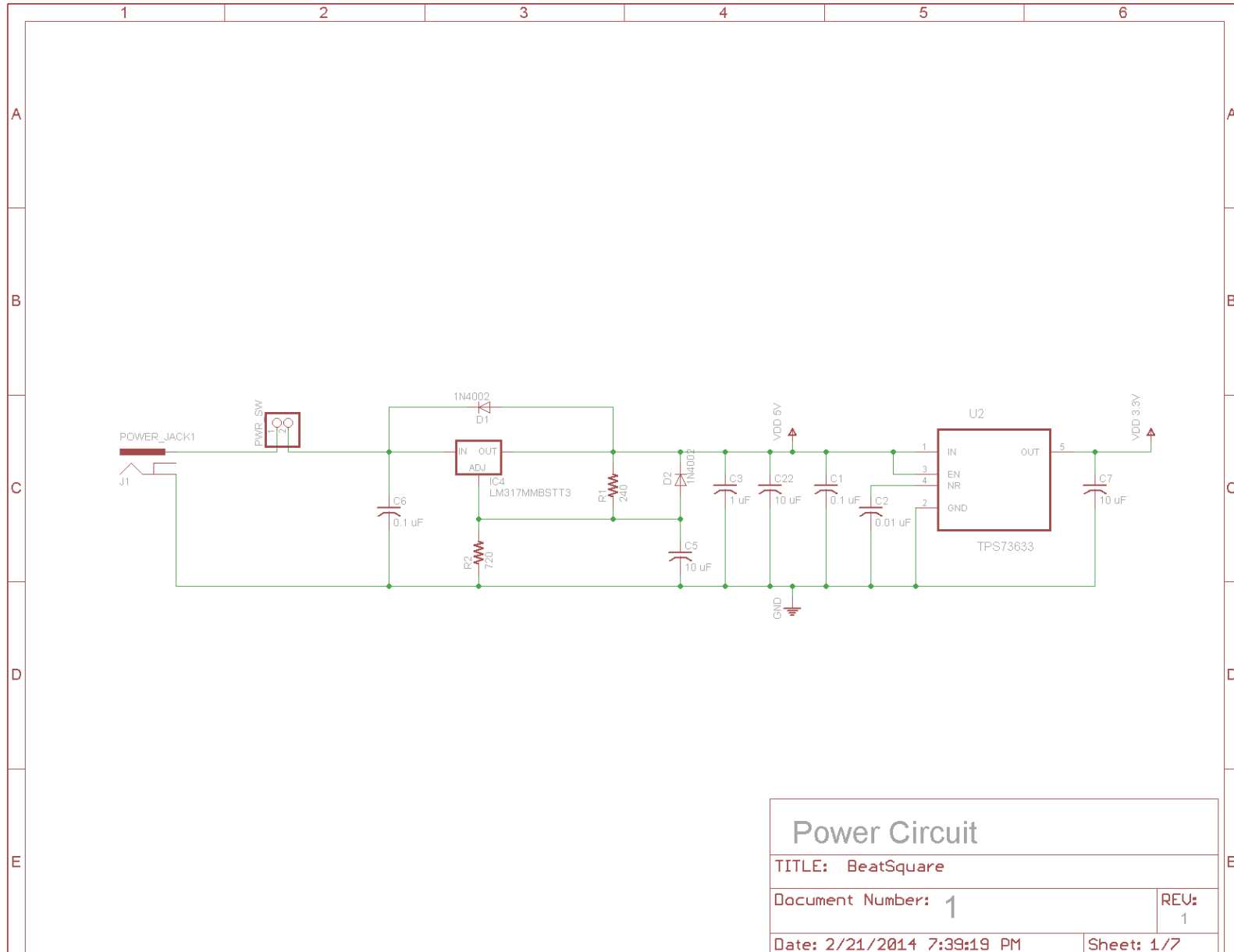


Figure 2. Tiva Pin Diagram (available in data sheet)

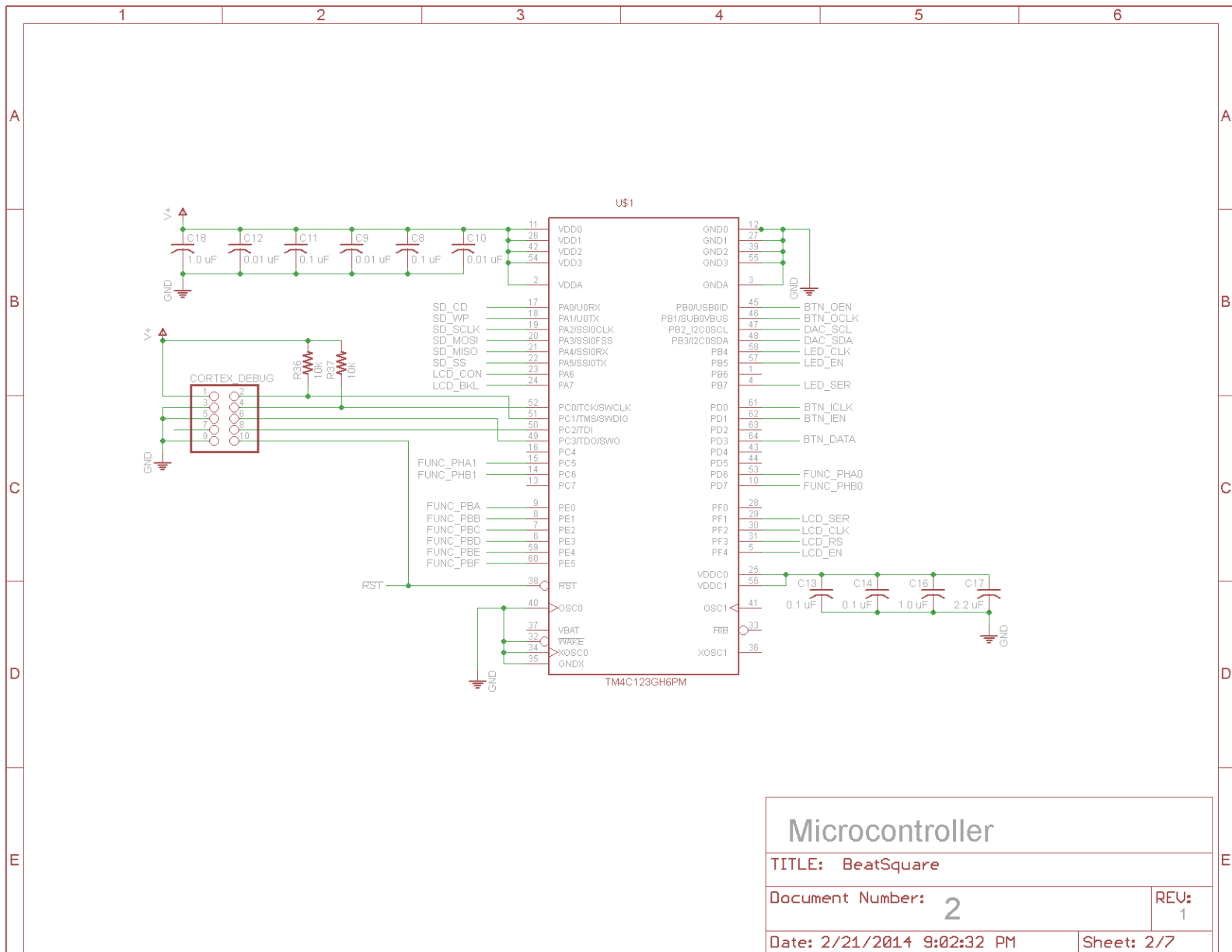
Project Function	Pin Function	Pin Name	Pin Number
<i>LED Matrix</i>			
Serial In	SSI2Tx	PB7	4
Clock	SSI2Clk	PB4	58
Enable		PB5	57
<i>Button Matrix</i>			
Column Shift		PB0	45
Column Clock		PB1	46
Row Data	SSI3Tx	PD3	64
Row Clock	SSI3Clk	PD0	61
Row Enable	SSI3Fss	PD1	62
<i>LCD</i>			
Serial Out	SSI1Tx	PF1	29
Clock	SSI1Clk	PF2	30
Register Select	SSI1Fss	PF3	31
Enable		PF4	5
Contrast	M1PWM2	PA6	23
Brightness	M1PWM3	PA7	24
<i>Digital-Analog Converter</i>			
Clock	I2C0SCL	PB2	47
Data	I2C0SDA	PB3	48
<i>Function Controls</i>			
Pushbutton A		PE0	9
Pushbutton B		PE1	8
Pushbutton C		PE2	7
Pushbutton D		PE3	6
Reset Button		RST	38
<i>Rotary Encoders</i>			
RPG0 Phase A	PhA0	PD6	53
RPG0 Phase B	PhB0	PD7	10
RPG1 Phase A	PhA1	PC5	15
RPG1 Phase B	PhB1	PC6	14
RPG0 Switch		PE4	5
RPG1 Switch		PE5	4
<i>SD Card</i>			
Clock	SSI0Clk	PA2	19
Data Out	SSI0Tx	PA5	22
Data In	SSI0Rx	PA4	21
Card Select	SSI0Fss	PA3	20
Card Detect		PA0	17
Write Protect		PA1	18
<i>Debug Interface</i>			
TCK	TCK	PC0	52
TMS	TMS	PC1	51
TDI	TDI	PC2	50
TDO	TDO	PC3	49

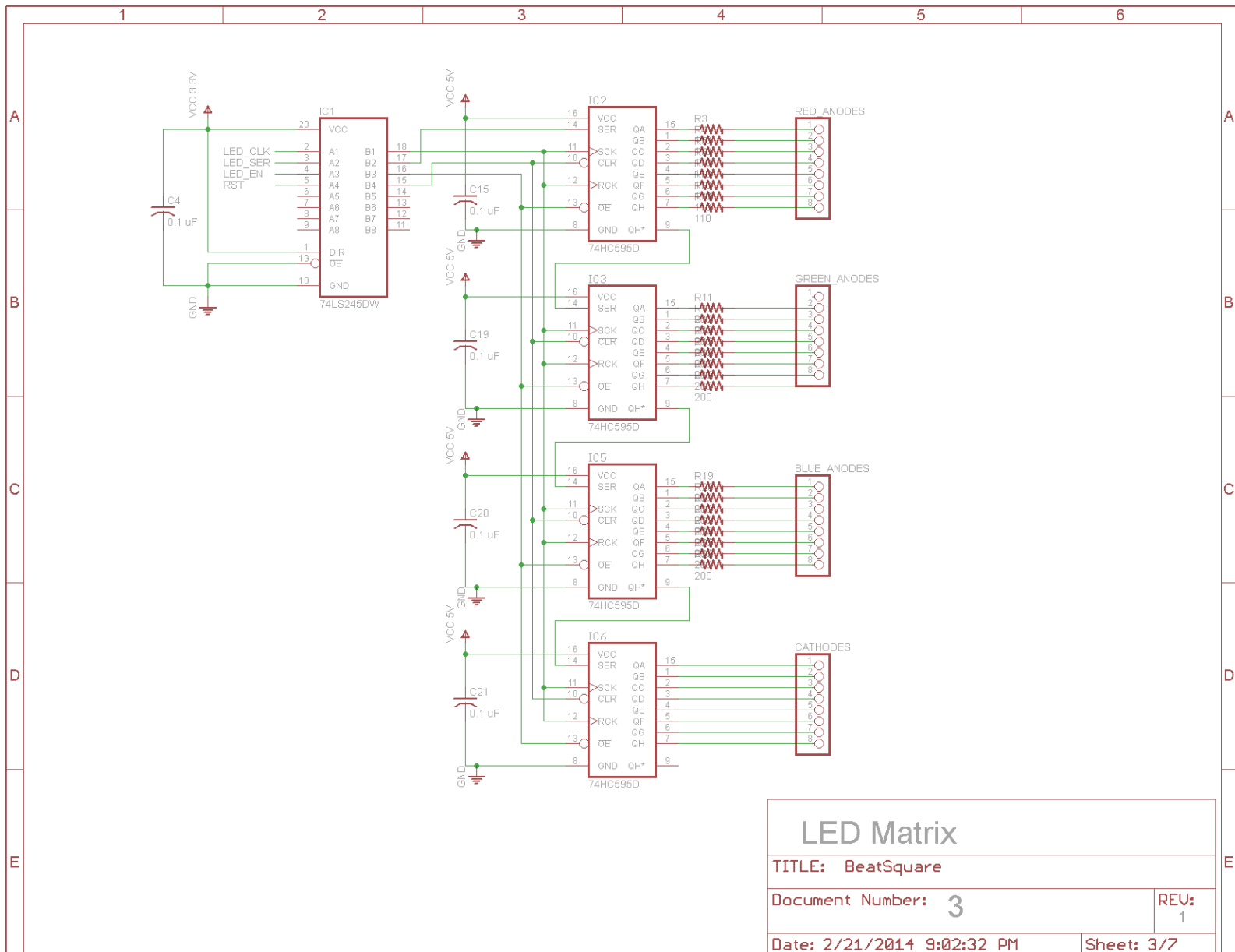
Table 1. Microcontroller Pinout Table

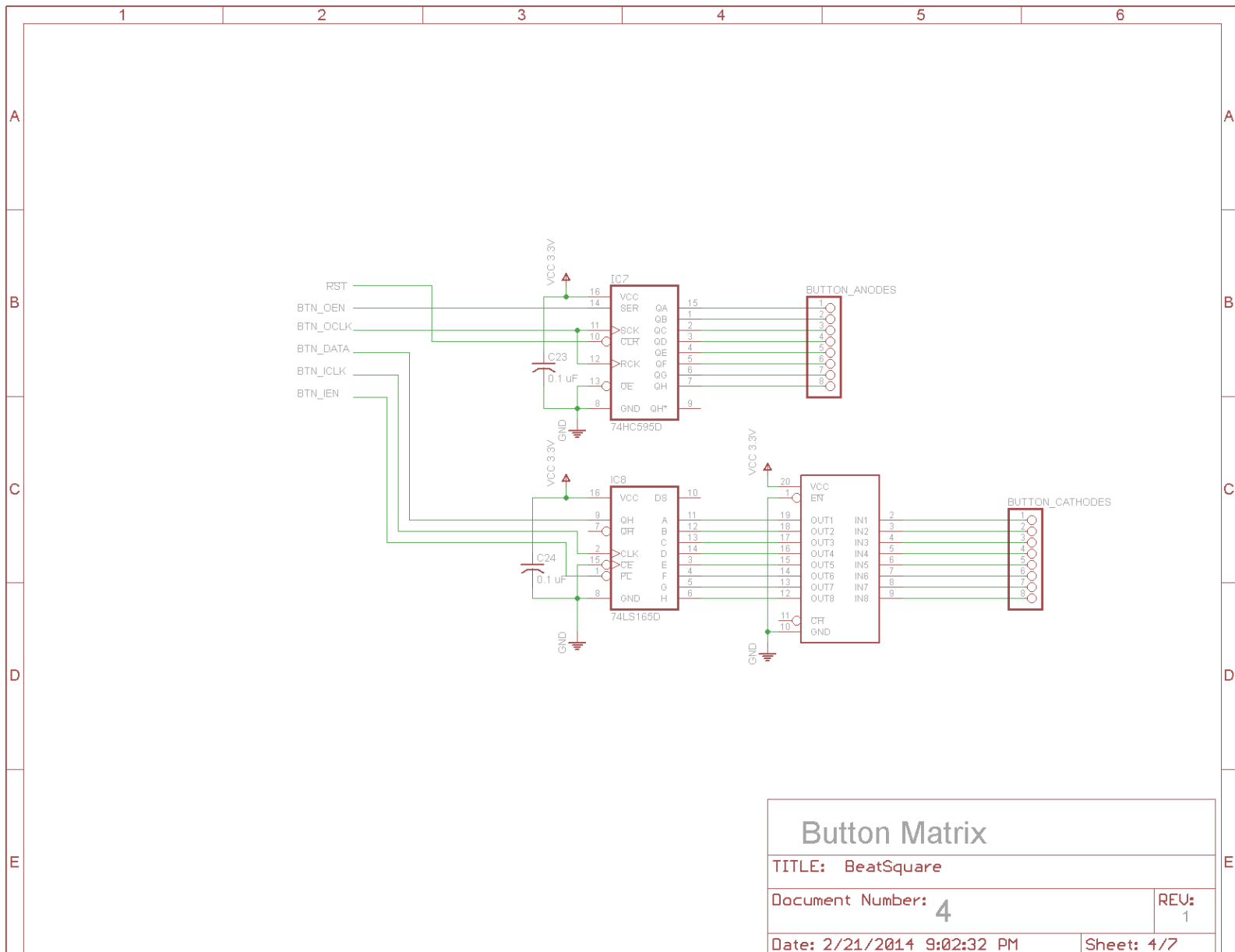
Appendix B: Schematic

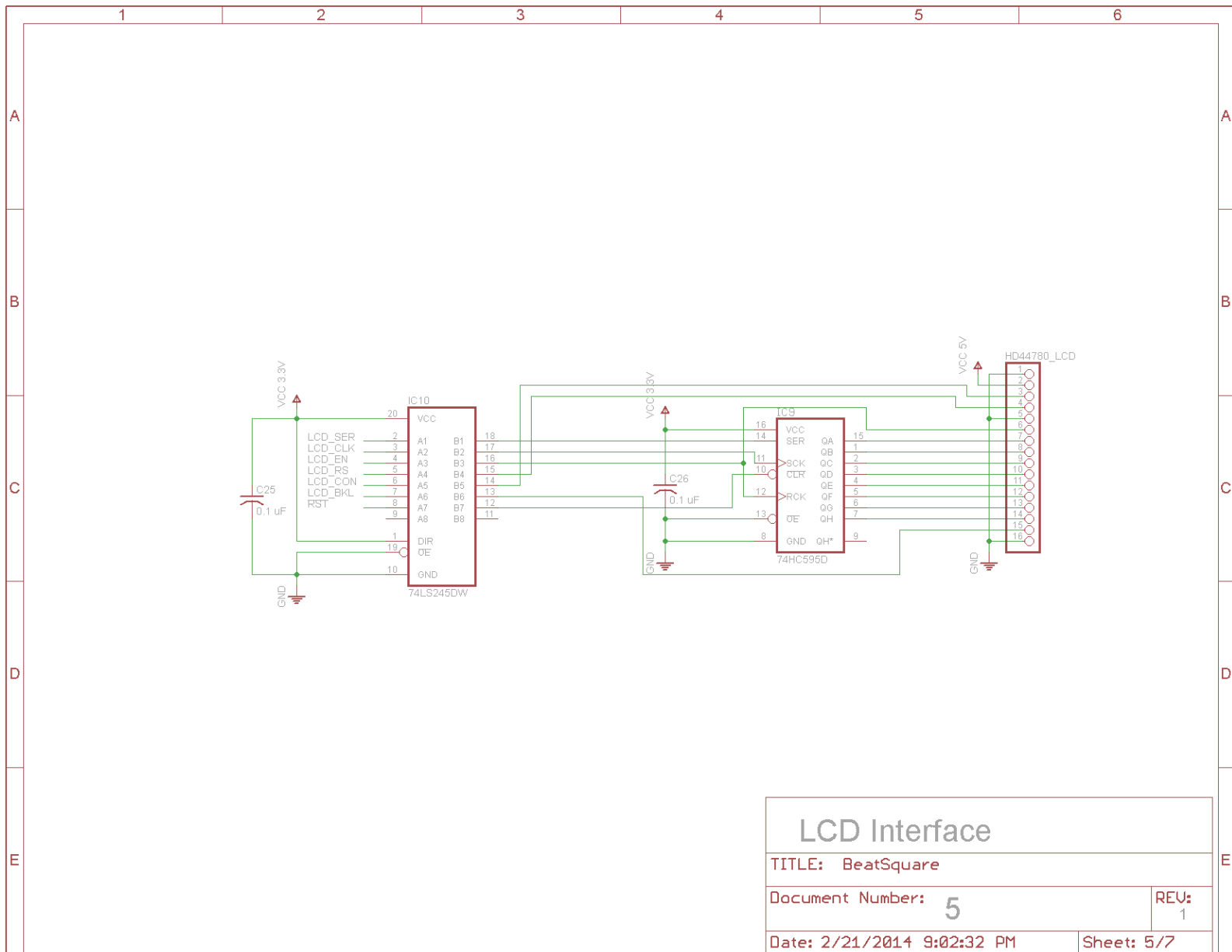


<h3>Power Circuit</h3>	
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LCD Interface	
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