Automotive Heads Up Display

Oregon State University

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Chapter 1

Introduction

The goal of this project is to create a Heads Up Display (HUD) that is simple to install and is easily transferable between vehicles. The motivation behind building this display is to allow the driver to obtain important metrics about the car without disrupting the driver's view and control. The metrics displayed include information such as speed, RPM, and engine temperature. To obtain information on the car, the HUD communicates with the OBD-II port [1] of the car as well as an optional GPS device to determine speed, in case the car does not have a compatible car computer. The HUD system is completely enclosed in a custom plastic enclosure to provide safety to the user, and a nice finished appearance. The system operates by reflecting the light from a matrix of bi-color LEDs onto the windshield. In full sun conditions this requires the application of a layer of film to the reflecting spot on the windshield. This film is static cling, so no permanent modifications are made to the vehicle. During either overcast days or night time, the film is not necessary. Which information is displayed is selectable via the menu system, as well as allowing for the selection of displaying speed in kilometers or miles per hour and showing temperature in Fahrenheit or Celsius. The final project allows the user to keep their eyes on the road at all times while still being informed of whichever car metric they have set the HUD to display.

Figure 1.1: The Finished Heads Up Display Project

Chapter 2

Texas Instrument Parts Used

2.1 TPS5430 Buck converter

This is the main power supply for the HUD. With the possible power draw of the light emitting diode (LED) matrix, which has a maximum of 1.4A, a highly efficient power supply was needed. There are a few other draws on the system, but nothing nearly as high as the matrix. The 3A capability of the TPS5430 left plenty of margin of safety for the project. This chip provided very constant voltage at any current level that was asked of it within the constrains of the project.

2.2 TPS77633

This is the power supply for the OBD-II translating chip and some minor auxiliary chips. It was important to have the low dropout because it was just pulling down from the 5V rail to provide a 3.3V rail for some of the project. This also left a nice safety margin in the design. This chip, while less efficient than the 5430, was easier to use with a smaller part count and less parasitics to worry about while prototyping.

2.3 LM339PWR

This chip was needed to convert the higher voltages present at the car interface down to a logic level that would not harm the chips that were used for inspecting the car protocols and displaying the relevant information on the LED matrix.

Chapter 3

Project Description

The project has two different main use cases. The first is when a user has a vehicle that is compliant with the OBD-II protocol. This is federally mandated for all 1996 and newer cars produced for the American market, so most cars on the road today will be able to use the HUD in this way [2]. The second is when the user can't use it in this way, but still wants to have a HUD in their car. Using it in this way means that the project needs an auxiliary power input from a cigarette lighter style power jack and the user also needs to then have a GPS unit that will output National Marine Electronics Association (NMEA) sentences [3, 4] in a RS-232 compliant way, with an RJ-45 connector wired as shown in figure 3.1. This project uses the Garmin 18x 5Hz, and its datasheet lists all specs of its communications protocol as well [5].

The main display is the Sure Electronics P7.62 32X16 RG Bicolor LED Dot Matrix Unit Board [6]. (fig. 3.2) This matrix has built in circuitry to handle all of the LEDs. The board logic can individually turn on or off any LED on the board, as well as choose which color each one is. It actually handles the bicolor LEDs as separate addressable LEDs, so to choose the color, the corresponding addresses in the array need to enabled or not, depending on the color choice. The board has four different controlling chips, with each having the control of one quadrant of the matrix. The board has a custom 4 wire interface, which is used to select which quadrant's chip is being addressed, and then sends the commands to that chip. It is possible to have anything from none to all four of the chips enabled at any one time, but any that are enabled will listen to that command, so care needs to be taken when sending commands [7].

In order to accomodate different ambient light levels, there is a photocell light detector, and the LED matrix is controlled through 15 different levels of light output. When it is bright outside then the LEDs should be at full output, in order to be seen, but in darkness the LEDs should be at minimum output, in order for the light to not distract the driver or be detrimental to night vision. The transition from one to the other is made smoothly, depending on the level of the ambient light. The automatic function can also be disabled and one light output be selected via the menu if that is desired.

The user's input is made through a main power switch, which completely disconnects power to the whole system, and a rotary push button knob to make selections. There is a menu system that is activated by pushing in on the rotary knob. From the menu the different operating conditions can be selected, such as Fahrenheit or Celsius, whether to have automatic light levels or select one level to stay at, as well as some debugging selections. When the user is not in the menu, different display items such as speed, RPM, or engine temperature can be selected just by rotating the encoder in one direction or another. The choices connect in a circular fashion, so that any item may be selected by continuously rotating in either direction. The end result is a very easy to use and intuitive selection process.

The HUD is able to connect to the different cars and autodetect the protocol being used. This makes it very easy for a user to simply plug in the cable and start getting data from the car. The HUD is powered directly from the OBD-II cable when connected, so it is the only thing that needs to be connected to the car for the device to work. If for any reason there is a desire to turn off the autodetection of the HUD then it is possible to specify which protocol to use under one of the menu selections.

For increased safety, the bottom of the case has an anti-slip pad to resist sliding on the dash.

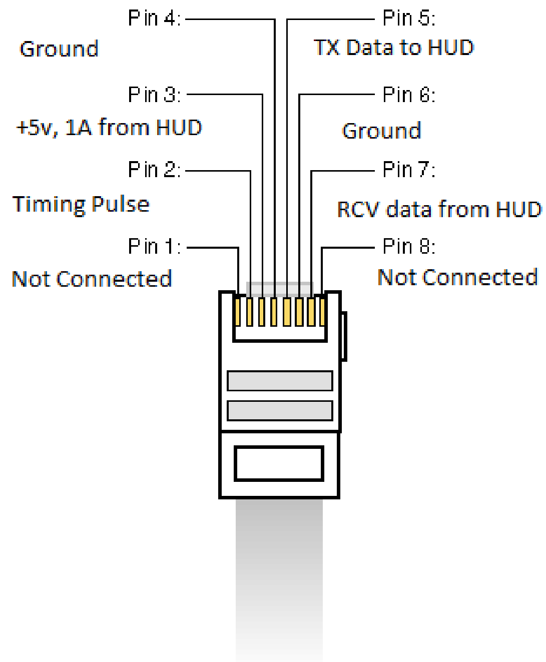


Figure 3.1: Pinout for Ethernet Connector for GPS

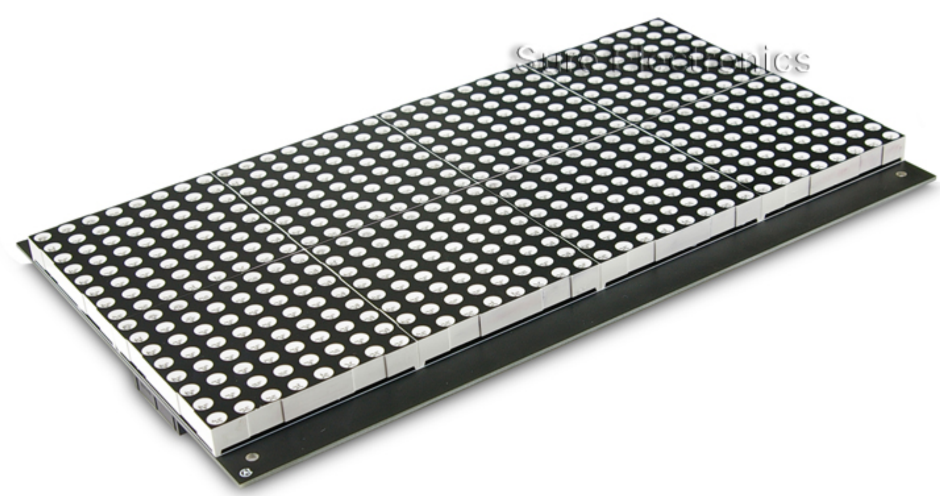


Figure 3.2: Sure Electronics 32x16 LED Matrix

Chapter 4

Hardware Design

The whole project centered on how the information was to be displayed on the windshield. Projectors, lasers and vacuum flourescent displays were considered early on.

- A projector was borrowed and tested on the windshield, but the focal range of the projector was not adequate to display anything on the windshield at such a short distance, so that was ruled out.
- A laser was considered, and looked like it would work very well, but there was too much of a worry about the safety hazards of a laser projection system on the dashboard of a car. Too many safety concerns existed with the possibility of the box slipping off the dash and having the laser shine in uncontrolled directions. This could harm both passengers in the car as well as people outside.
- A vacuum flourescent display was purchased for testing, but unfortunately under direct sunlight was not visible at all, much less reflecting off of a windshield.
- Finally it was decided to use the LED matrix, because it could be seen the best without installing extra equipment in a car to do the reflecting. The 32x16 matrix by Sure Electronics was chosen because of its ease of use and known good operation. With the bicolor LEDs it is possible to choose green, red, or orange (from the green+red combination). This provided some flexibility to the user in what color is displayed, depending on personal choice or which showed up best on the windshield.

The main power draw on the project was the LED matrix, so the power requirements were primarily drawn from that. It can draw 1.4A at 5V [7], so a switching power supply was chosen as the best option for that. The TPS5430 was a good choice, although it was problematic in prototyping due to long wires and their inductance. The first capacitors that were chosen for the final product were also a problem, because their equivalent series resistance (ESR) was too high and the power supply wouldn't function. Once that was taken care of the 5V rail was rock solid no matter how many amps were being drawn in the rest of the circuit, within design limitations.

The microcontroller chosen was the Atmel Atmega328p. A MSP430F5510 was considered due to this TI challenge, but ruled out due to the pre-existing hardware library for the Atmega to support the display that could be used as a base for how to drive the matrix. The MSP430 line has some good candidates, but the faster development time trumped attempting to learn a new line of microcontrollers. A PIC microcontroller was also considered, due to the low cost, and even a Parallax Propeller, because of the 8 cores that all run in parallel and have a lot of processing power. The Propeller was a very strong contender when the video projection system was being considered. In the endthe decideing factor was greater previous familiarity with the Atmel line as well as having pre-existing code to start from with the Atmega library. The code was actually written for the Arduino platform, but was essentially the same due to the Atmega328p being the same processor used on that board. This library had to be modified for the purpose of easy display of multi-digit numbers as well as creating new fonts for the inverted display that is needed with the reflection from the windshield. With the need for storage of many strings of characters for the display, parsing of many

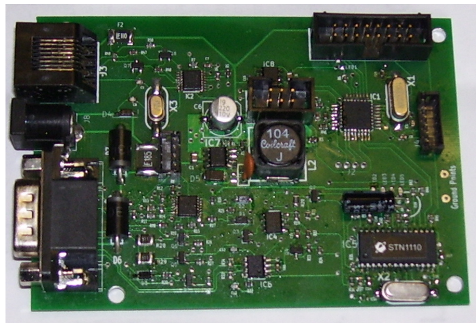


Figure 4.1: Printed Circuit Board Revision 2

different inputs, and the space to store bitmaps of all of the fonts, most of the 32kB of the Atmega chip was needed.

Instead of starting from scratch to decode all of the possible different protocols supported by OBD-II, it was chosen to use a commercially available translating chip. There are multiple options, but the cheapest one found was the Scantools STN1110 [8]. This chip is compatible with the de-facto standard ELM327 [9], but runs at a higher speed and has extra options not available with the ELM327. The extra options were not used in this project, however. This chip needs its own crystal and runs at 3.3V only. There are also multiple lines that can be connected to run LEDs for diagnostic purposes. Each of these was connected to a surface mount LED, which will blink when data is being transferred.

The STN1110 cannot deal with the high voltages coming from the car, so a level converting chip was needed to do the interfacin from the car to the STN1110, and different transistors and small voltage regulators were used to send the proper voltage levels back to the car. For the most part this supporting circuitry was selected via the reference schematic supplied by Scantools with the chips [10]. The TI LM339PWR was chosen as the level converting chip, as its open drain comparator outputs took care of all the level shifting so that the Scantools chip always saw a maximum of 3.3V. There was also a CAN bus chip used to convert the various CAN protocols to a version that the STN1110 could understand. Like most of the support chips, this was selected from following the reference design.

The Atmega328p only has one hardware UART on the chip, and rather than provide one in software, it was decided to use the I^2C hardware on the microcontroller, and use a bridge chip to convert the RS-232 to I^2C. The chip selected was the NXP Semiconductors SC16IS740 [11]. It just needs to be configured with which address to use and the speed of the UART compared to its crystal and it will simply transfer data from one side to the other whenever asked to do so on the I^2C side. This chip also runs on 3.3V. The GPS uses the RS-232 protocol, so the level needed to be shifted down and inverted with some MOSFETS in order for it to be understood by the bridge chip.

The TPS77633 was chosen to provide the 3.3V power that is needed by the OBD-II chip and the I^2C bridge chip. With its low part count and low dropout it was ideal for the application. It provided an easy solution for power for the 3.3V parts.

The OBD-II cable selected was just what was cheapest. After reviewing different options, it was found that all cables with OBD-II on one end and DB-9 on the other were wired identically. Since all cables that were found followed the same format, price was the only deciding factor in this choice.

In order to get everything to fit and work properly right away, it was decided to make a custom printed circuit board (PCB) for the HUD. This board contained all the parts on one easy to use board and reduced the number of wires inside the box to the minimum. This allowed for the enclosure to only be 2"x4"x6". The enclosure for this project was designed in Solidworks and printed on a 3D fused deposition plastic printer. A production model would be injection molded for decreased cost. The design files for the PCB and enclosure can be seen in the appendix.

Chapter 5

Testing and Results / Conclusions

There were some problems with the prototypes. The issue that took the most debugging time was the ESR of two different capacitors. In both cases it was thought that the capacitors had an adequately low ESR, but was then later discovered that it was the source of the problem. Both the boost capacitor for the TPS5430 and an auxiliary capacitor for the STN1110 were the ones that were issues. In both cases replacing the capacitor with a better one took care of the problem.

Other than that there were also issues with a misunderstanding of the GPS datasheet. It seemed to say that the output was limited between ground and the positive Vdd input to it, but in reality it was limited to ±Vdd. The datasheet also seemed to say that the GPS used UART compatible protocol, when in fact it was the inverse RS-232 protocol. Both of these problems were worked around with some inverting MOSFET circuits to handle the voltage difference as well as the inversion.

There was also an error in the design of the board that changed one of the footprints from a 14 pin to a 16 pin, which created a whole host of problems. It was on the comparator chip, so that most of the protocols would not work without it. It was worked around in a fashion with jumper wires, but this was not a robust solution. Redesigning the board to fix that and add some spots for the alternative capacitors led to a board that functioned much better.

After all of this there were still some issues, that were then tracked down to a software issue. In order for the Scantools to realize that a request is finished, a carriage return needs to be sent to the chip. The code was defaulting to sending this as well as a newline, but it was later learned that as soon as the chip saw the newline it ignored everything and waited again. Once the newline was removed from the code everything started working properly.

The HUD now works properly on every vehicle that has been available for testing, which includes differnet American models as well as imports. It has proven very robust and works well. As can be seen in figure 5.1 it doesn't even need to use tinting to get a good reflection at night.

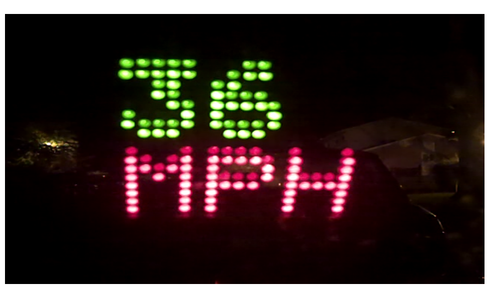


Figure 5.1: Reflection on the Windshield

Chapter 6

Future Work / Recommendations

The major thing that needs improvement with this design is the display on the windshield. While this one does work, assuming either partial overcast or darkness, it does not work well in full sunlight without the tinting film. Some kind of brighter display that could work in full sun would be a great improvement to the project.

Also having the option of having more colors and a finer pitch display would be good. The matrix has a LED diameter of 3mm, so each dot is somewhat big, which doesn't allow for very fine resolution of the display. If full color output was a possibility then there would be a lot more flexibility with both what, as well as how it was shown. The downside to having higher resolution and more color would be that more memory would be required. Likely it would not fit in the 32kB of the Atmega328p so a larger Atmega, a different line of processors, or a supplementary memory chip would be required.

Copies of all work, including code and source files for the design, are available on our design page, along with pictures and video of it in operation [12].

Acknowledgements

We would like to thank Garmin for sponsoring the project and providing us with the GPS to use with it. Especially helpful was John Batch, our mentor at Garmin. Thank you for all of your time and input.

We would like to thank Texas Instruments for providing the chips and support to us, and providing this contest for us to enter. The chips helped us along the way, the well made datasheets were an invaluable source of information, and the contest was a nice incentive to get it all done in an improved format.

We would like to thank Scantools for providing us with their STN1110 chip when asked, and volunteering a development board along with it that was immensely helpful. We didn't even know it existed, but they sent it along without being asked, just because they knew the value of it. It saved us many hours of running back and forth to cars for testing, and was a stable, known quantity when chasing down bugs.

We would like to thank our instructor, Don Heer, and our teaching assistants Arne Bostrom and Samuel House for all of their time and dedication. It was a tough year, but we learned a lot from all of it.

Last, but definitely not least, we would like to thank our families for supporting us during our school years. Without your sacrifice we would not have been able to do any of this.

References

[1] Obd-ii on board diagnostic system. http://www.obdii.com/.

[2] Obd-ii mandated. http://www.obdii.com/background.html.

[3] National marine electronics association. http://www.nmea.org/.

[4] Dale DePriest. Nmea sentence data. http://www.gpsinformation.org/dale/nmea.htm.

[5] Garmin gps 18x 5hz. http://www8.garmin.com/manuals/GPS18x_TechnicalSpecifications.pdf.

[6] Sure electronics bicolor display. http://www.sure-electronics.com/goods.php?id=1095.

[7] Sure electronics bicolor display datasheet. http://www.sure-electronics.net/download/down.php?name=DE-DP14112_Ver1.1_EN.pdf.

[8] Scantools stn1110. http://www.scantool.net/scan-tools/ics/stn1110.html.

[9] Elm327 obd-ii chip. http://www.elmelectronics.com/obdic.html.

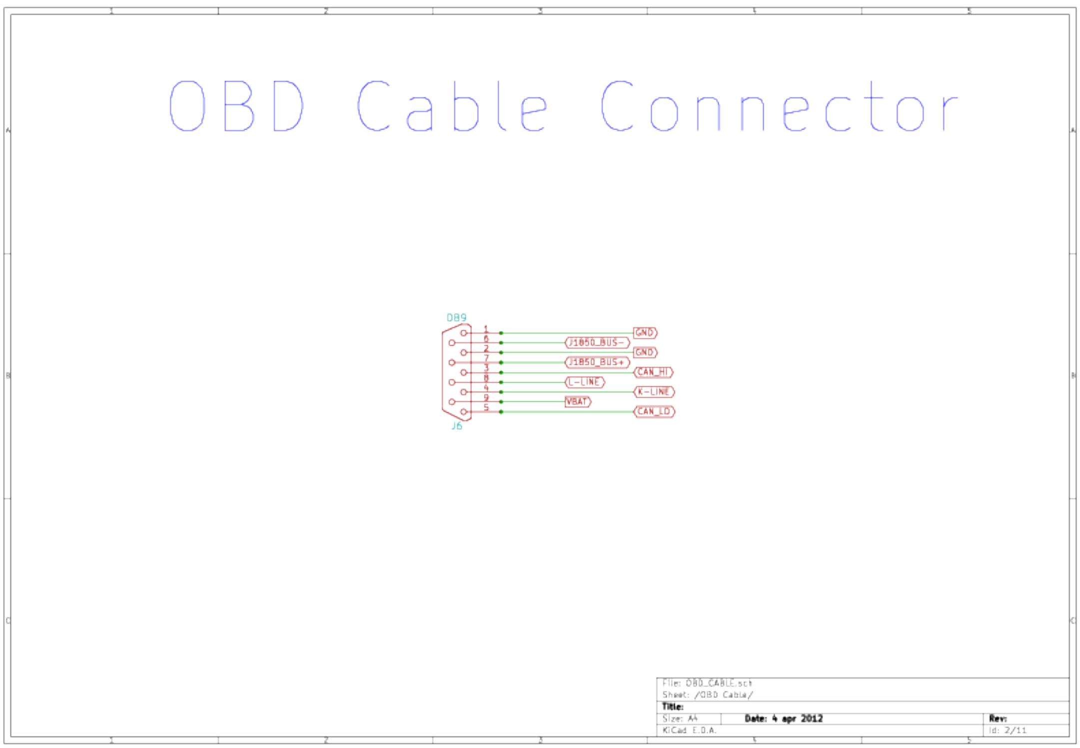
[10] Stn1110 datasheet. http://www.scantool.net/scantool/downloads/97/stn1110-ds.pdf.

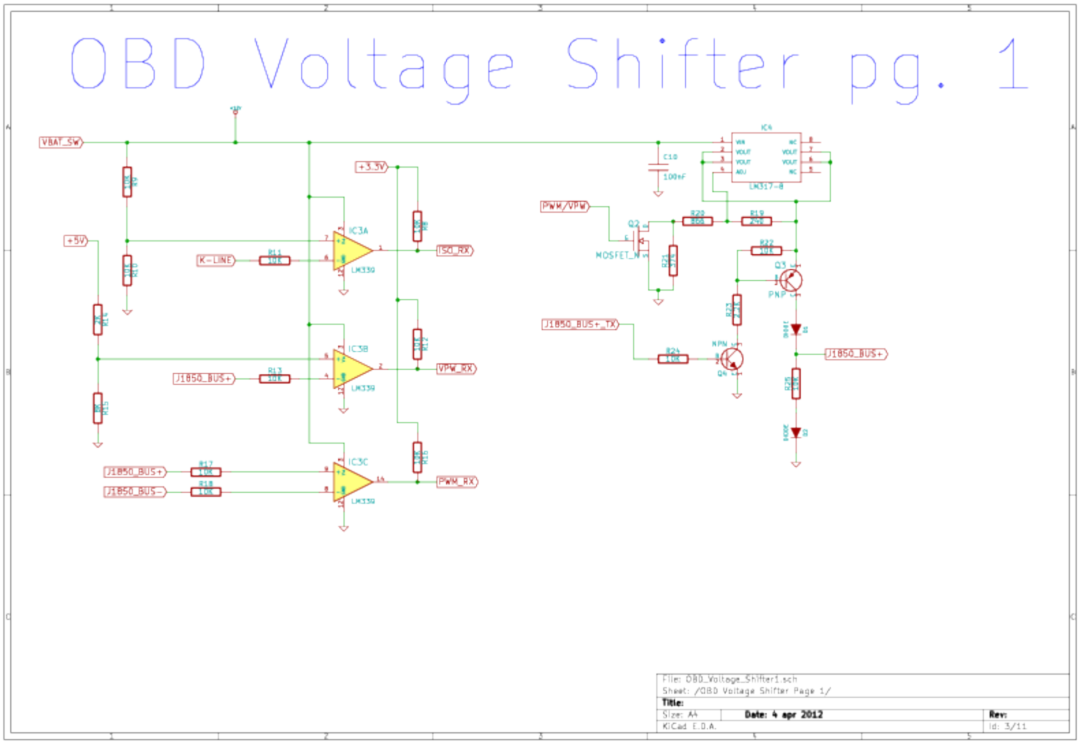
[11] Nxp semiconductors sc16is740. http://www.nxp.com/documents/data_sheet/SC16IS740_750_760.pdf.

[12] Tsung-Han Chiang, Erik Lane, and Curtis Zahr. Oregon state university "beaversource" homepage for heads up display project. http://beaversource.oregonstate.edu/projects/44x201112, 2012.

Appendix A

Schematics





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J1850_BUS-
+3.3V
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IC3B
IC3C
LM339
ISO_RX
VPW_RX
PWM_RX
PWM/VPW
MOSFET_N
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C10
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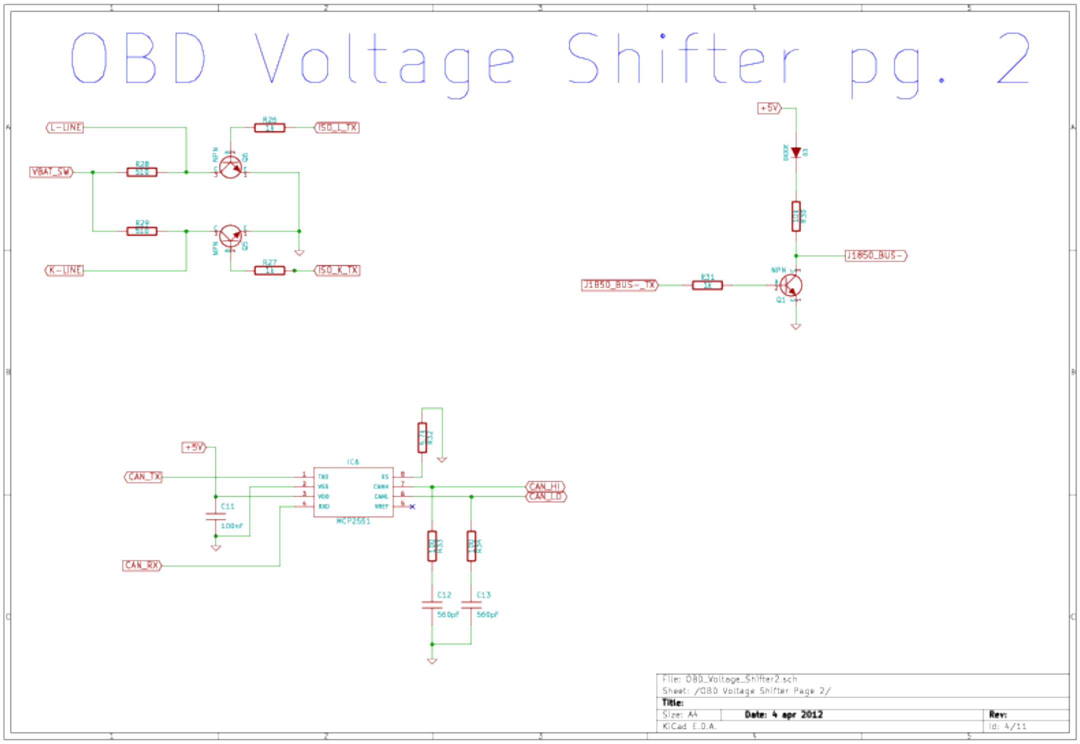

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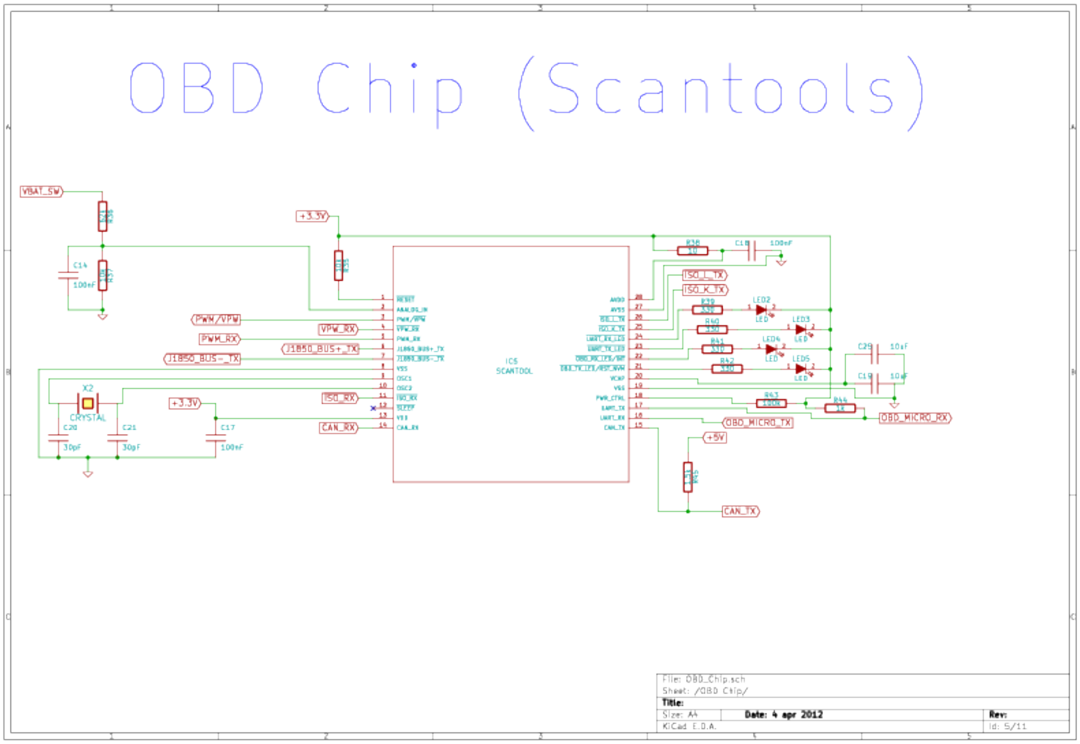
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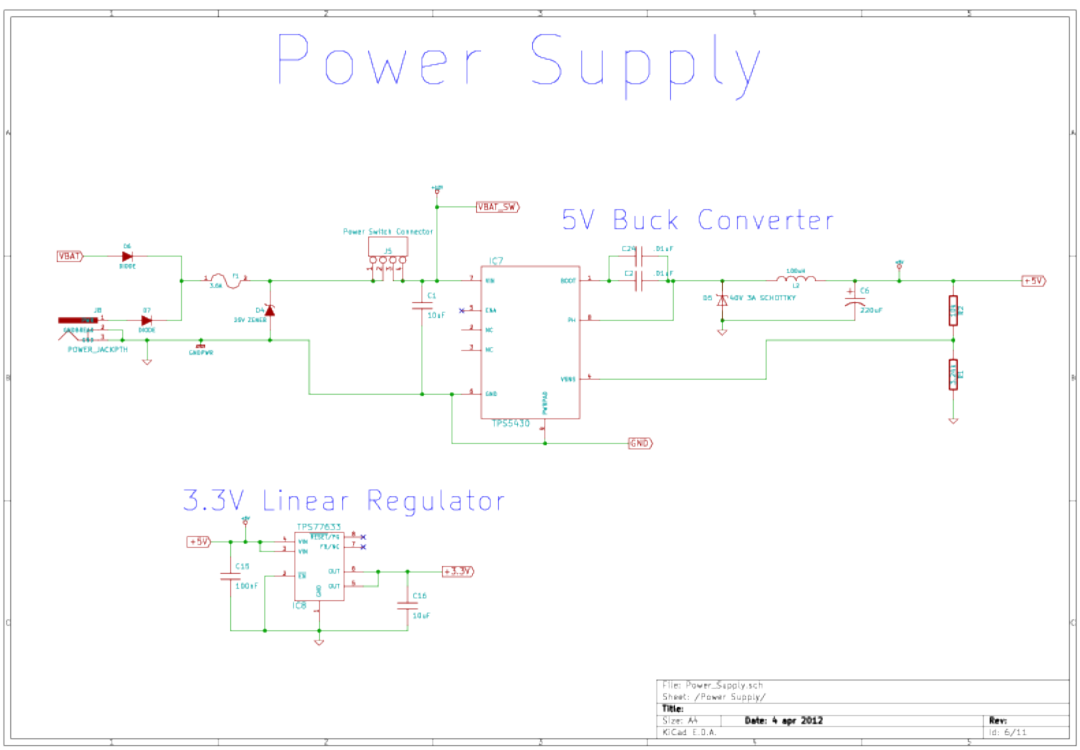
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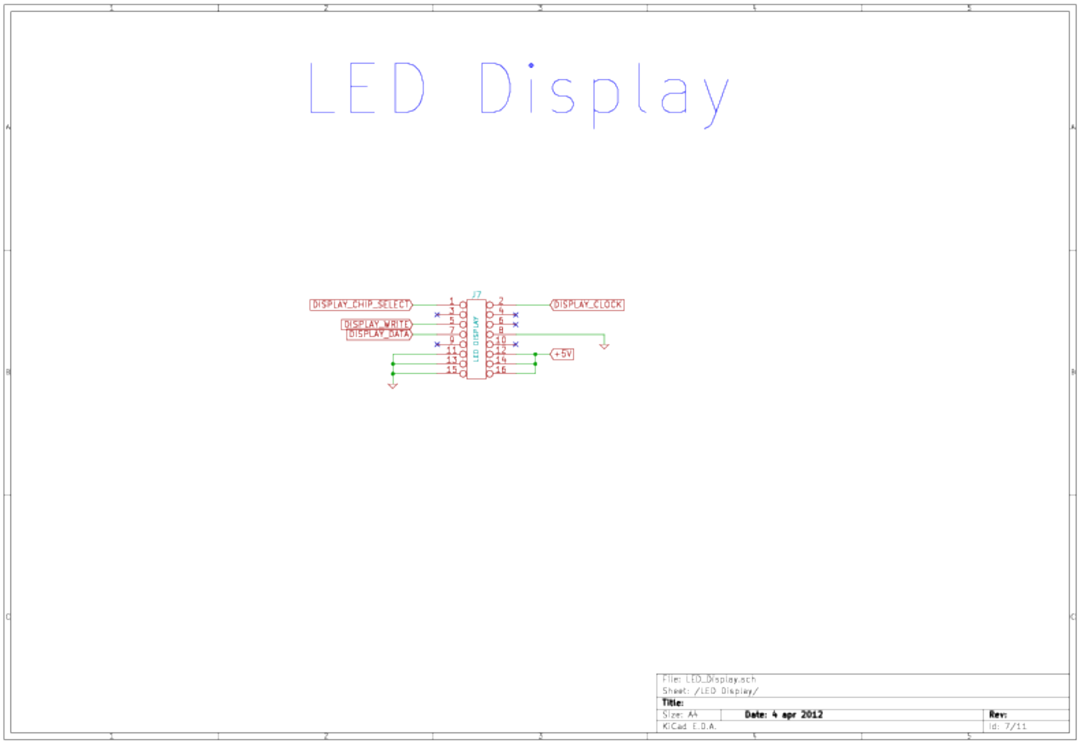
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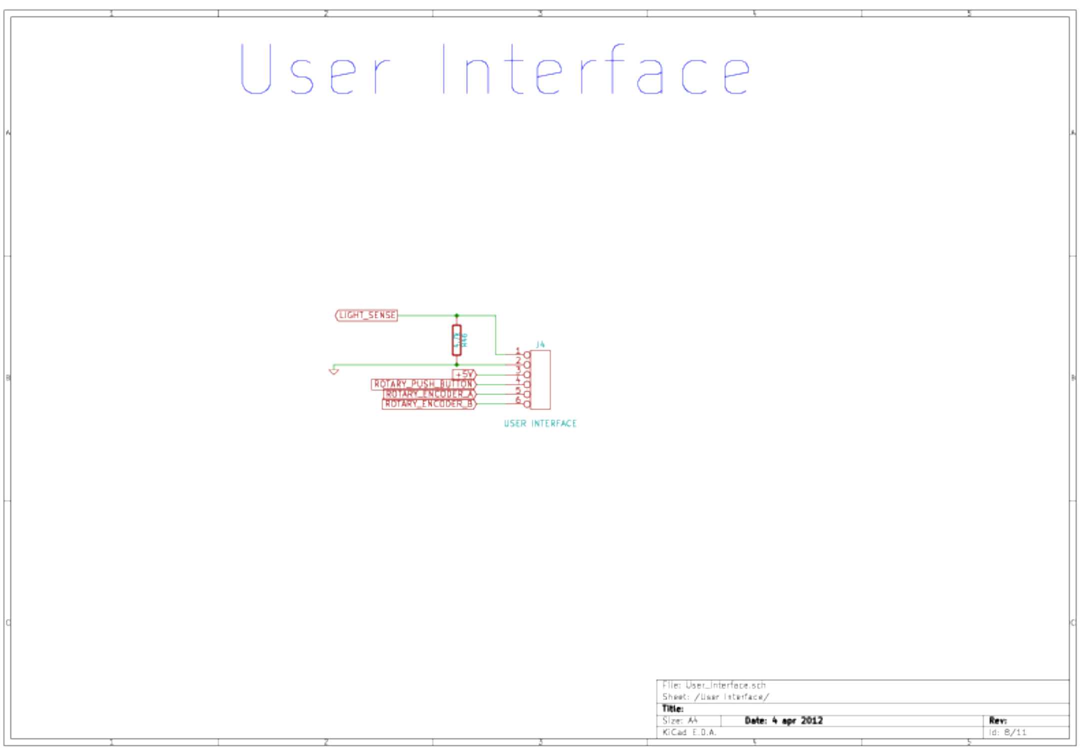
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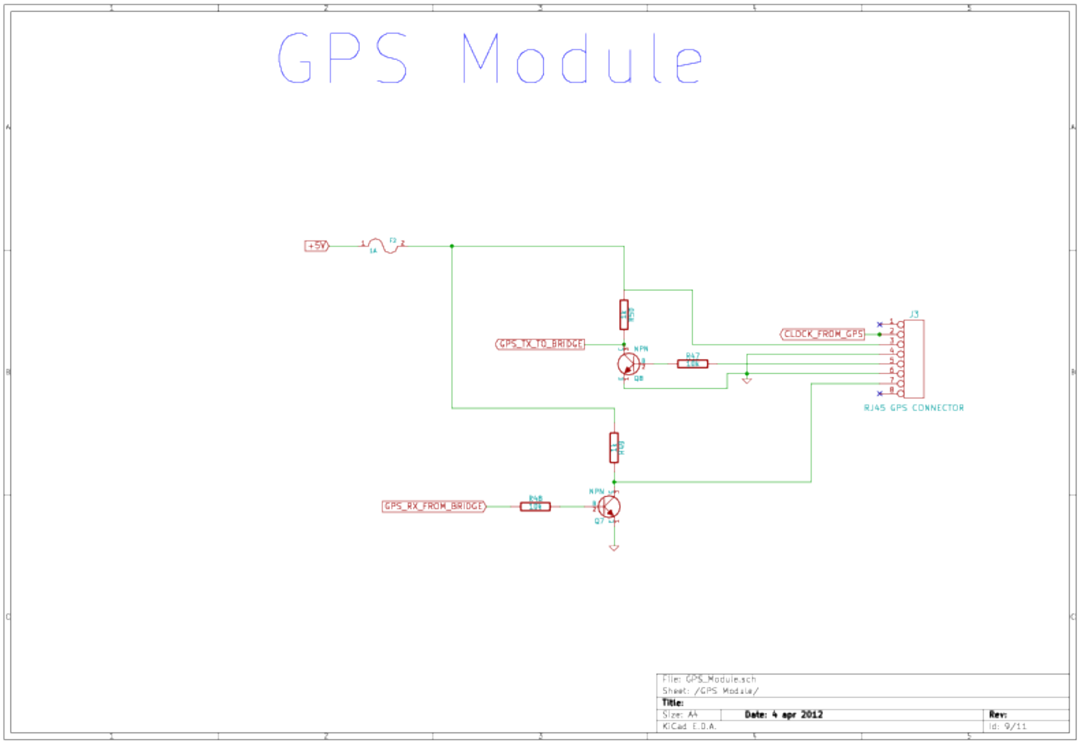
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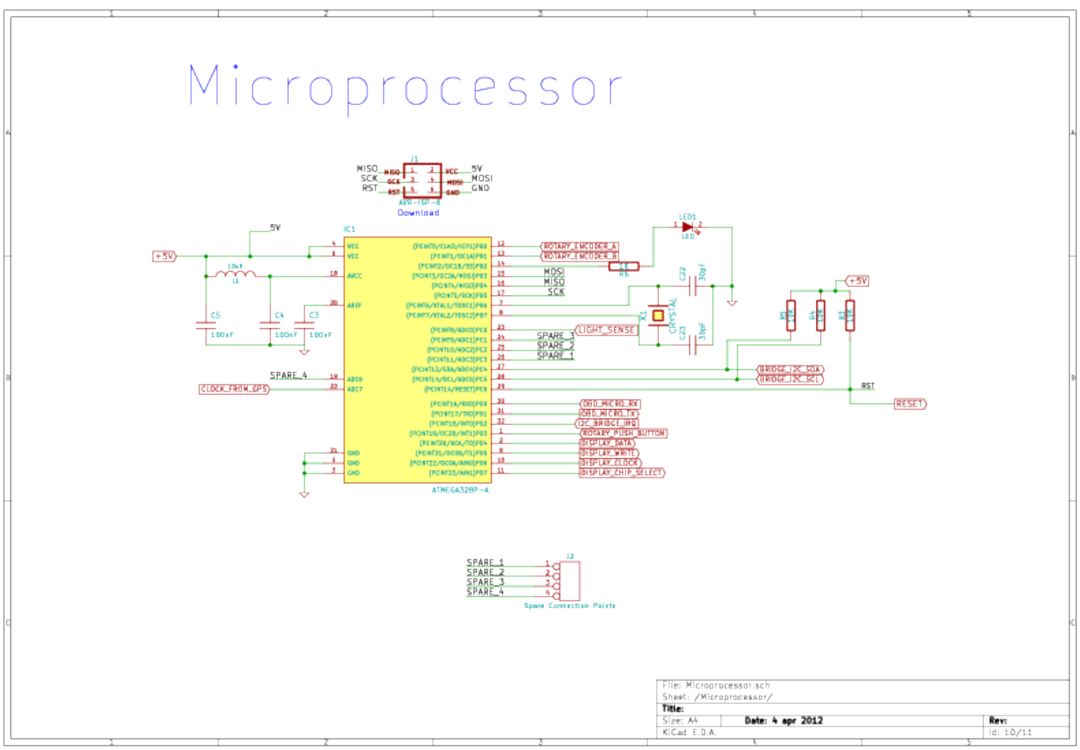
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ROTARY_ENCODER_B
LIGHT_SENSE
SPARE_1
SPARE_2
SPARE_3
SPARE_4
CLOCK_FROM_GPS
BRIDGE_I2C_SDA
BRIDGE_I2C_SCL
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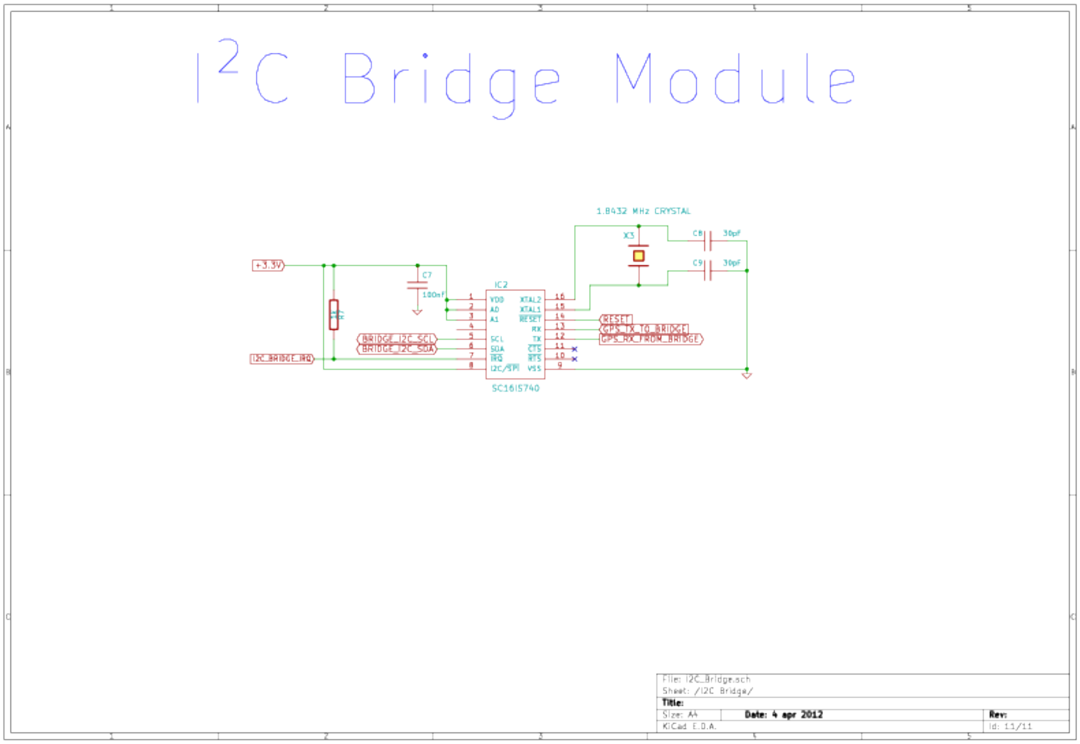

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A1
SCL
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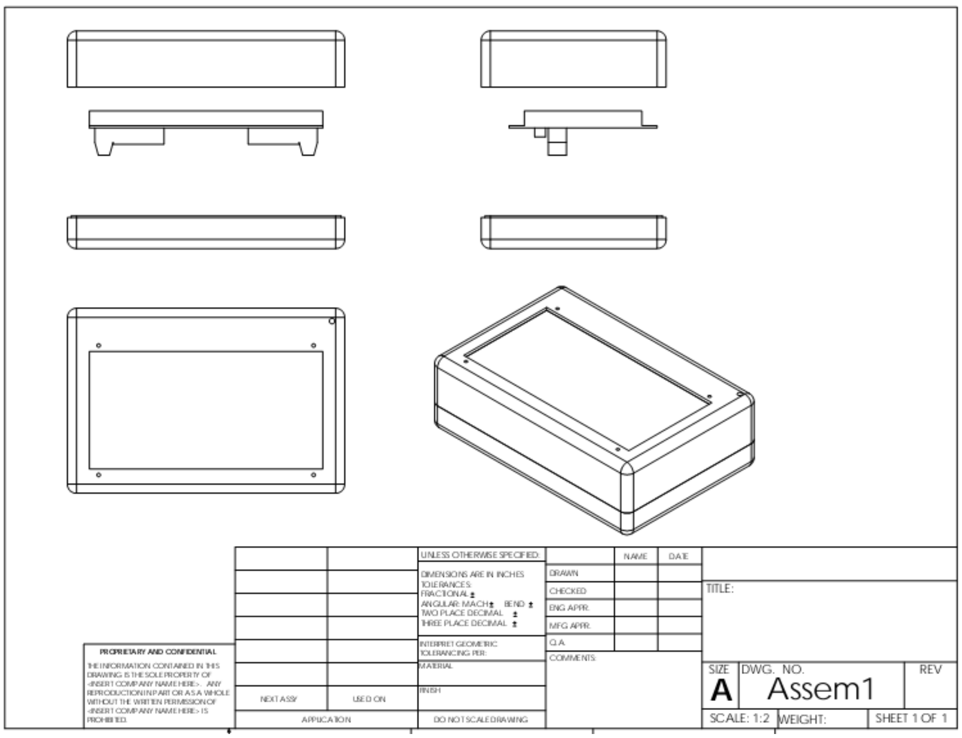
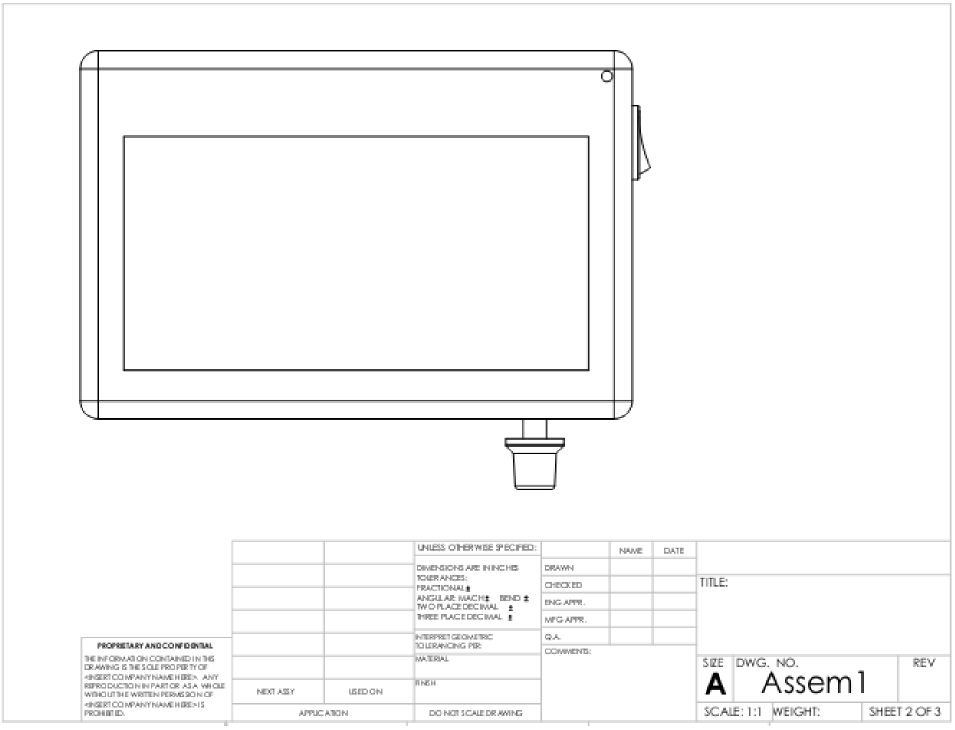
Appendix B

CAD Drawings

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TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
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FINISH
NEXT ASSY
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APPLICATION
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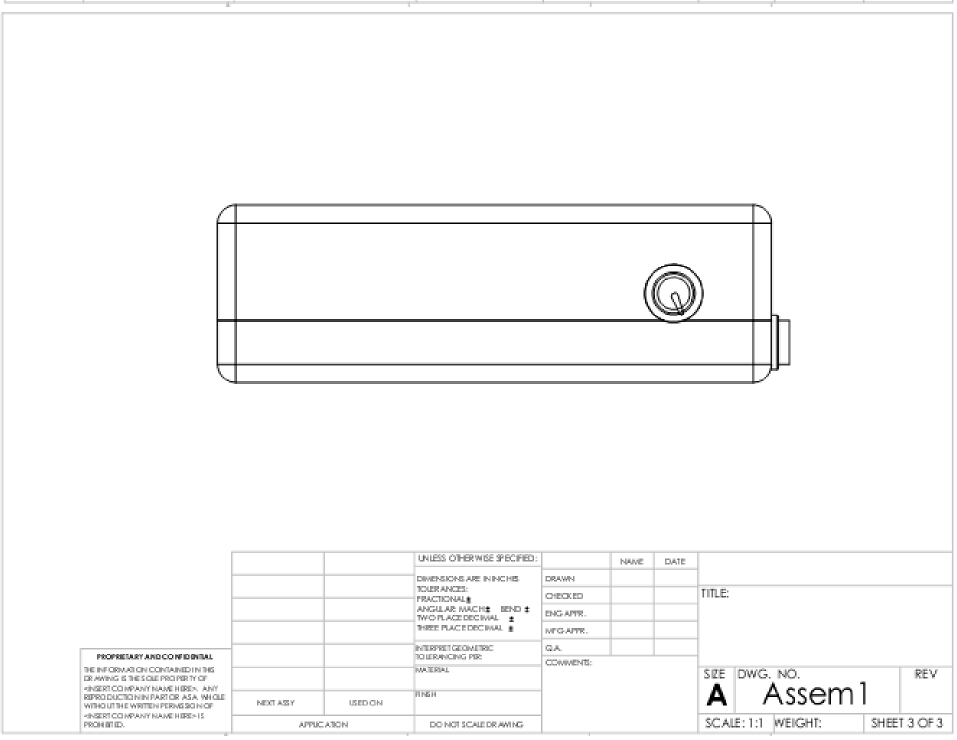
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DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
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SIZE
DWG. NO.
REV
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Assem1
SCALE: 1:1
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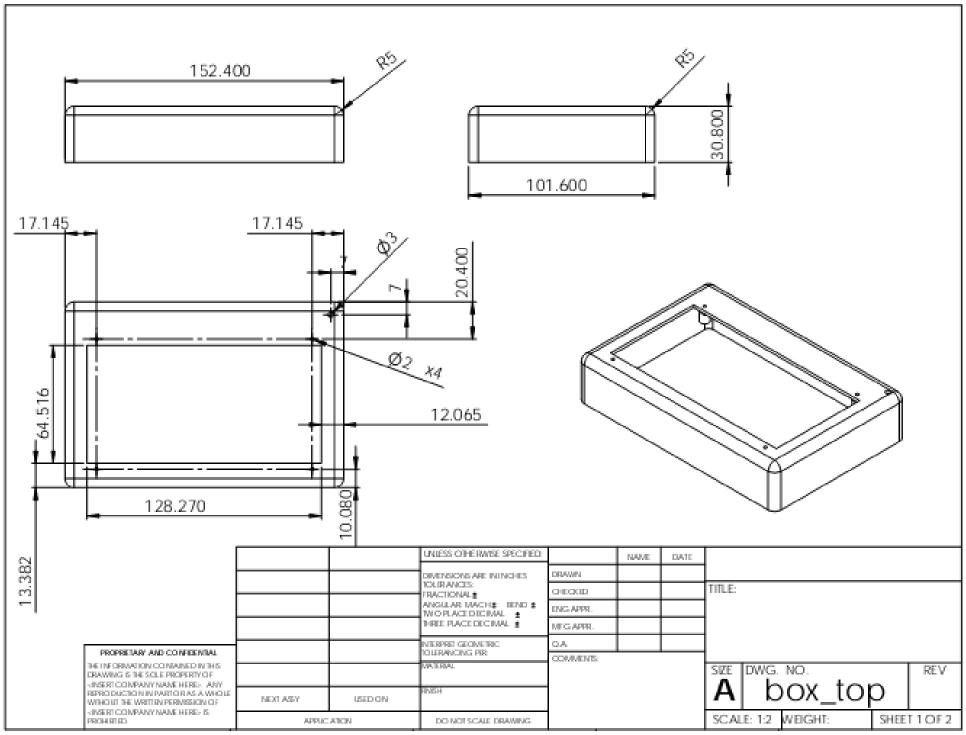
SHEET 3 OF 3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R5
R5
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7
7
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Ø2 x4
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128.270
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UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
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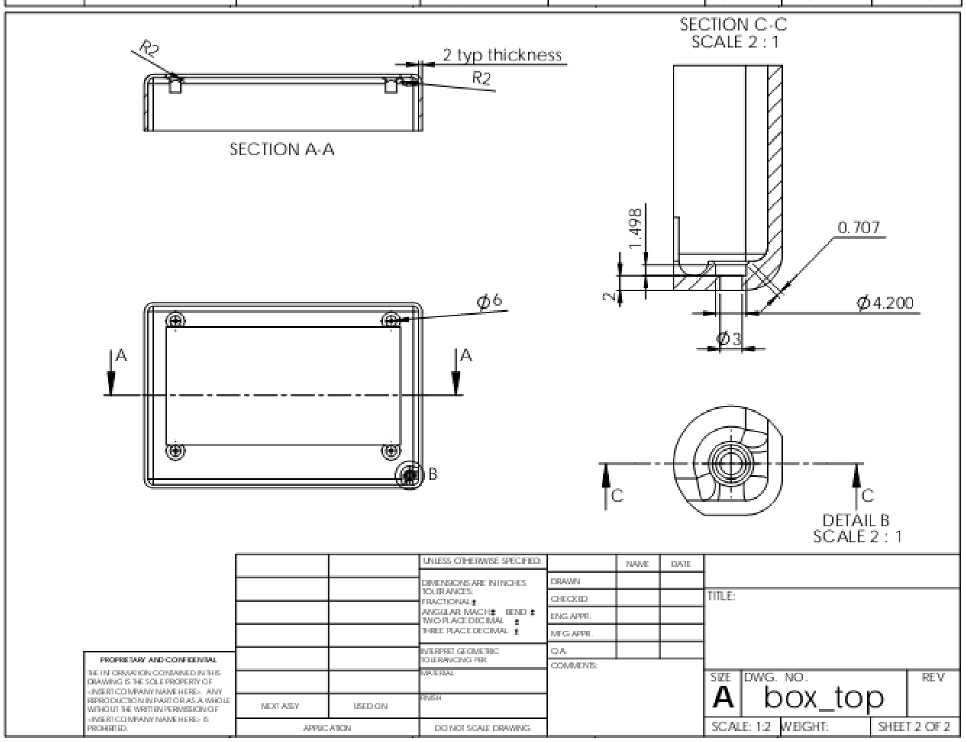
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
DWG. NO.
REV
A
box_top
SCALE: 1:2
WEIGHT:
SHEET 1 OF 2


R2
2 typ thickness
R2
SECTION A-A
SECTION C-C
SCALE 2 : 1
1.498
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2
Ø4.200
Ø3
Ø6
A
A
B
C
C
DETAIL B
SCALE 2 : 1
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
DWG. NO.
REV
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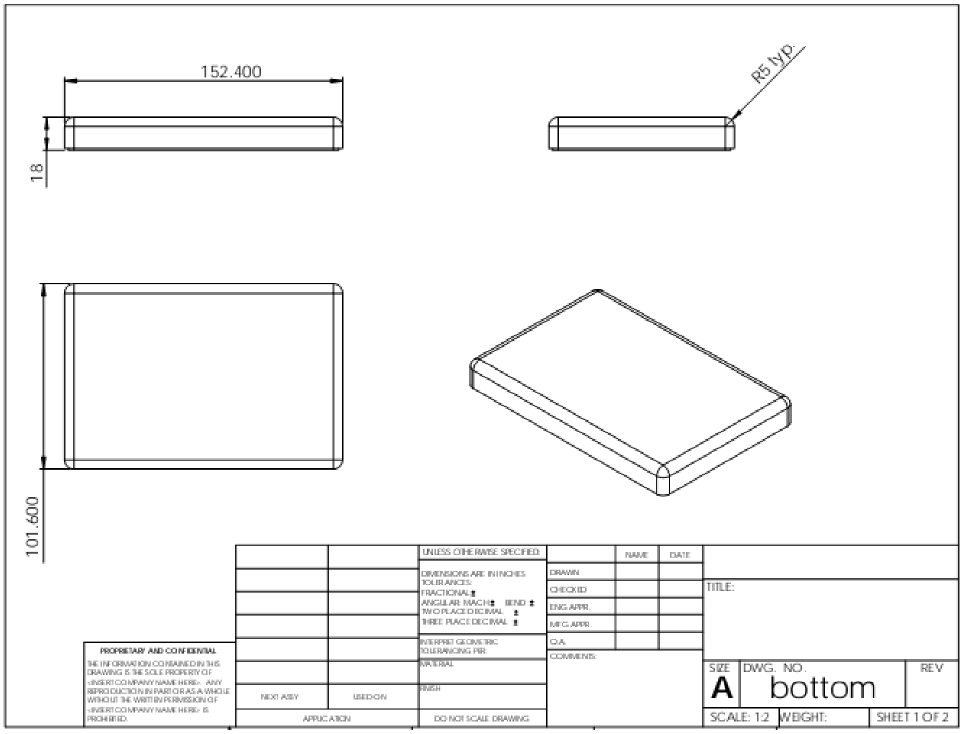
box_top
SCALE: 1:2
WEIGHT:
SHEET 2 OF 2


152.400
18
R5 typ.
101.600
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
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TOLERANCES:
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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
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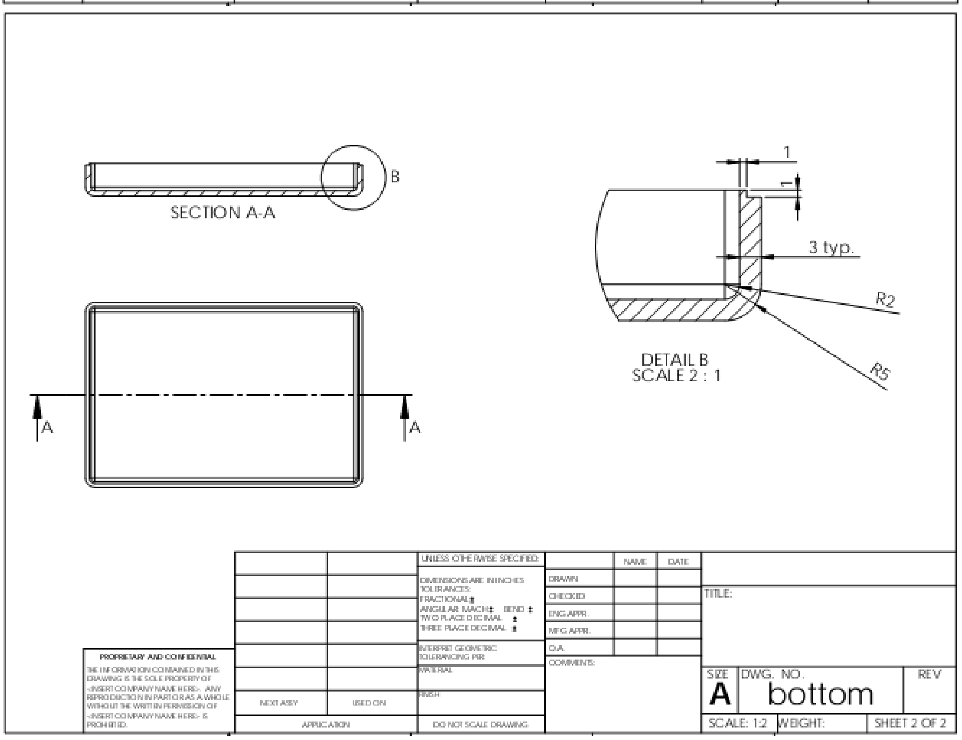
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
TITLE:
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
DWG. NO.
REV
A
bottom
SCALE: 1:2
WEIGHT:
SHEET 1 OF 2


B
SECTION A-A
A
A
1
1
3 typ.
R2
R5
DETAIL B
SCALE 2 : 1
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
TITLE:
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
DWG. NO.
REV
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bottom
SCALE: 1:2
WEIGHT:
SHEET 2 OF 2

Appendix C

Bill of Materials

Ref.	Value	Part Number	Price @ 1000	Source
C1	10uF	81-GRM21BR61E106KA3L	\$0.128	Mouser.com
C2	.01uF	581-06033A100K	\$0.052	Mouser.com
C3	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C4	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C5	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C6	220uF	598-AVE227M10X16T-F	\$0.068	Mouser.com
C7	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C8	30pF	80-C0603C300J5G	\$0.009	Mouser.com
C9	30pF	80-C0603C300J5G	\$0.009	Mouser.com
C10	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C11	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C12	560pF	81-GRM185C1E561JA01D	\$0.018	Mouser.com
C13	560pF	81-GRM185C1E561JA01D	\$0.018	Mouser.com
C14	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C15	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C16	10uF	81-GRM21BR61E106KA3L	\$0.128	Mouser.com
C17	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C18	100nF	77-VJ0603V104ZXAPBC	\$0.028	Mouser.com
C19	10uF	80-C0603C103K3R	\$0.006	Mouser.com
C20	30pF	80-C0603C300J5G	\$0.009	Mouser.com
C21	30pF	80-C0603C300J5G	\$0.009	Mouser.com
C22	30pF	80-C0603C300J5G	\$0.009	Mouser.com
C23	30pF	80-C0603C300J5G	\$0.009	Mouser.com
D1	DIODE	78-1N4148W-VGS18	\$0.042	Mouser.com
D2	DIODE	78-1N4148W-VGS18	\$0.042	Mouser.com
D3	DIODE	78-1N4148W-VGS18	\$0.042	Mouser.com
D4	25V ZENER	863-MMSZ4710T1G	\$0.102	Mouser.com
D5	40V 3A Schottky	625-BD340A-E3/61T	\$0.150	Mouser.com
D6	DIODE	625-SRP300B-E3	\$0.151	Mouser.com
D7	DIODE	625-SRP300B-E3	\$0.151	Mouser.com
F1	3.6A	576-2920L185	\$0.300	Mouser.com
F2	1A	576-1812L110PRT	\$0.186	Mouser.com
IC1	ATMEGA328P-A	556-ATMEGA328P-AU	\$2.770	Mouser.com
IC2	SC16IS740	771-SC16IS740IPWQ900	\$1.400	Mouser.com

Ref.	Value	Part Number	Price @ 1000	Source
IC3	LM339	595-LM339PWR	$0.109	Mouser.com
IC4	LM317-8	863-LM317LDG	$0.136	Mouser.com
IC5	SCANTOOL	STN1110	$7.990	Scantools.net
IC6	MCP2551	579-MCP2551-I/SN	$0.780	Mouser.com
IC7	TPS5430	595-TPS5430DDA	$2.990	Mouser.com
IC8	TPS77633	595-TPS77633D	$1.210	Mouser.com
J1	AVR-ISP-6	517-30306-6002HB	$0.290	Mouser.com
J2	Spare Cnct Pts			
J3	RJ45 GPS Cnct	571-5555167-1	$0.552	Mouser.com
J3	RJ45 GPS Cnct	678-300268	$0.290	Mouser.com
J4	User Interface	798-DF3A-6P-2DS10	$0.108	Mouser.com
J4	User Interface	798-DF3-6S-2C	$0.055	Mouser.com
J5	Pwr Switch Cnct.	798-DF3-4S-2C16	$0.035	Mouser.com
J5	Pwr Switch Cnct.	798-DF3A-4P-2DS10	$0.075	Mouser.com
J6	DB9	152-3309	$0.920	Mouser.com
J7	LED Display	517-30316-5002	$0.660	Mouser.com
J7	Disp. Ribbon Cable	517-3603/16	$0.450	Mouser.com
J7	LED Display	538-54597-1600	$0.140	Mouser.com
J8	Power Jack	806-KLDX-0202-A	$0.311	Mouser.com
L1	10uH	810-MLF1608E100M	$0.049	Mouser.com
L2	100uH	810-VLCF528T101MR332	$0.644	Mouser.com
LED1	LED	859-LTST-C190GKT	$0.043	Mouser.com
LED2	LED	859-LTST-C190GKT	$0.043	Mouser.com
LED3	LED	859-LTST-C190GKT	$0.043	Mouser.com
LED4	LED	859-LTST-C190GKT	$0.043	Mouser.com
LED5	LED	859-LTST-C190GKT	$0.043	Mouser.com
Q1	NPN	512-MMBT3646	$0.022	Mouser.com
Q2	MOSFET_N	771-2N7002BK215	$0.034	Mouser.com
Q3	PNP	512-MMBT3640	$0.204	Mouser.com
Q4	NPN	512-MMBT3646	$0.022	Mouser.com
Q5	NPN	512-MMBT3906	$0.014	Mouser.com
Q6	NPN	512-MMBT3906	$0.014	Mouser.com
Q7	NPN	512-MMBT3646	$0.022	Mouser.com
Q8	NPN	512-MMBT3646	$0.022	Mouser.com
R1	3.24k	71-TNPW06033K24BEEN	$0.414	Mouser.com
R2	10k	301-10K-RC	$0.003	Mouser.com
R3	10K	301-10K-RC	$0.003	Mouser.com
R4	10K	301-10K-RC	$0.003	Mouser.com
R5	10K	301-10K-RC	$0.003	Mouser.com
R6	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R7	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R8	10K	301-10K-RC	$0.003	Mouser.com
R9	10K	301-10K-RC	$0.003	Mouser.com
R10	10K	301-10K-RC	$0.003	Mouser.com
R11	10K	301-10K-RC	$0.003	Mouser.com
R12	10K	301-10K-RC	$0.003	Mouser.com
R13	10K	301-10K-RC	$0.003	Mouser.com
R14	2K	660-RK73B1JTTD202J	$0.017	Mouser.com
R15	8K	302-8.06K-RC	$0.015	Mouser.com

Ref.	Value	Part Number	Price @ 1000	Source
R16	10K	301-10K-RC	$0.003	Mouser.com
R17	10K	301-10K-RC	$0.003	Mouser.com
R18	10K	301-10K-RC	$0.003	Mouser.com
R19	240	652-CR0603-JW-241ELF	$0.010	Mouser.com
R20	866	71-CRCW0805-866-E3	$0.018	Mouser.com
R21	374	71-CRCW0603-374-E3	$0.015	Mouser.com
R22	10K	301-10K-RC	$0.003	Mouser.com
R23	2.2K	652-CR0603-JW-222ELF	$0.010	Mouser.com
R24	10K	301-10K-RC	$0.003	Mouser.com
R25	10K	301-10K-RC	$0.003	Mouser.com
R26	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R27	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R28	510	660-RK73B2ETTE511J	$0.070	Mouser.com
R29	510	660-RK73B2ETTE511J	$0.070	Mouser.com
R30	10k	301-10K-RC	$0.003	Mouser.com
R31	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R32	4.7k	71-CRCW0603J-4.7K-E3	$0.015	Mouser.com
R33	100	652-CR0603-JW-101GLF	$0.010	Mouser.com
R34	100	652-CR0603-JW-101GLF	$0.010	Mouser.com
R35	10k	301-10K-RC	$0.003	Mouser.com
R36	62k	71-CRCW0603-62K-E3	$0.015	Mouser.com
R37	10k	301-10K-RC	$0.003	Mouser.com
R38	10	667-ERJ-3GEYJ100V	$0.002	Mouser.com
R39	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R40	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R41	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R42	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R43	100k	667-ERJ-3GEYJ104V	$0.002	Mouser.com
R44	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R45	1.5k	667-ERJ-3GEYJ152V	$0.002	Mouser.com
R46	4.7k	667-ERJ-3EKF2202V	$0.003	Mouser.com
R47	10k	301-10K-RC	$0.003	Mouser.com
R48	10k	301-10K-RC	$0.003	Mouser.com
R49	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
R50	1k	667-ERJ-3GEYJ102V	$0.001	Mouser.com
X1	16 MHz Xtal	815-ABLS-16.0M-T	$0.148	Mouser.com
X2	16 MHz Xtal	815-ABLS-16.0M-T	$0.148	Mouser.com
X3	14.7456 MHz Xtal	815-ABLS-14.7456M-T	$0.154	Mouser.com
	Rotary Encoder	652-PEC11-4220F-S24	$0.770	Mouser.com
	Power Switch	629-AA211B31	$0.490	Mouser.com
	LED Display	DE-DP14112	$23.900	SureElectronics.net
	Case Moulds		$7.000	estimate
	Case Plastic		$2.000	estimate
		Total	$59.834	