Design and Layout of an Environmental Sensor Board for Oceanographic Instrumentation

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ABSTRACT

The design, layout and testing of an environmental sensor PCB used to monitor the conditions experienced by the internal circuitry of the Free Ocean CO_2 Enrichment (FOCE) experiment. This expansion board will replace existing circuitry within the electronics enclosure and fit the new form factor of the upgraded electronics backplane system effectively reducing the complexity required to monitor the internal conditions of FOCE.

INTRODUCTION

The FOCE experiment is a research project conducted at the Monterey Bay Aquarium Research Institute (MBARI) that aims to study the effects of increased ocean acidity on marine life. This project was proposed due to the expected increase in ocean acidity due to the current increasing trend of atmospheric CO_2. This system will be able to conduct in situ experiments on ocean life by injecting liquid CO_2 into sea water and exposing different ocean organisms to the resulting lower pH.

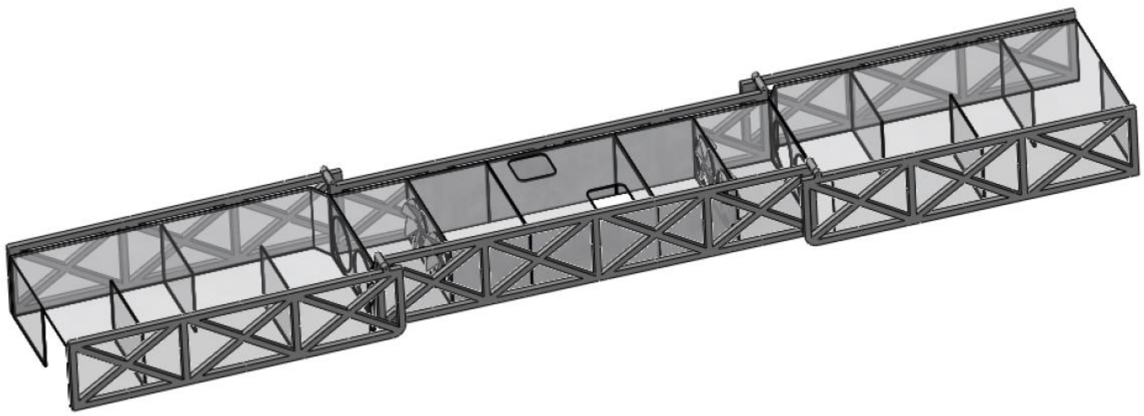

Image 1: FOCE Flume Design

The FOCE flume, depicted in Image 1, is where the liquid CO_2 is given time to mix with sea water and lower the pH evenly throughout the test chamber located in the center of the flume. This even mixture is necessary to ensure that the organisms being monitored do not experience sudden shocks of very low pH sea water. To move the water through the flume, four thrusters were placed on either side of the test chamber, two per side. This allows the scientists to adjust the current through the flume and maintain typical ocean conditions on the organism with the exception of the lower pH.

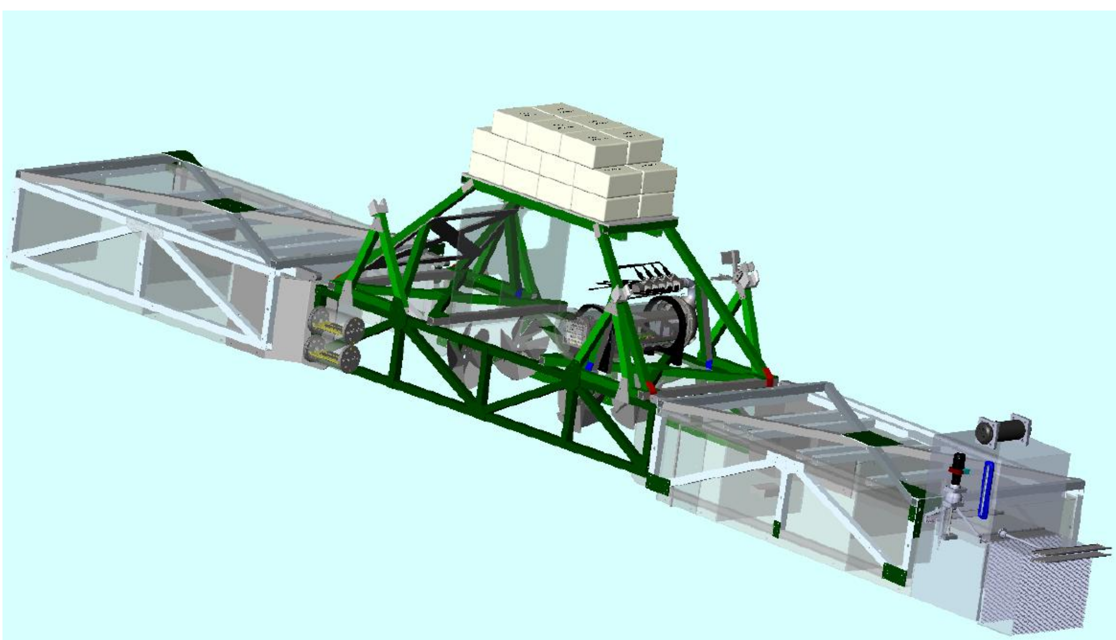

Image 2: FOCE Drawing

The liquid CO_2 is contained in the housing on the right of the FOCE flume in Image 2. Here, the CO_2 is released in varying amounts depending on how much sea water is circulated through the CO_2 expansion. This can be controlled from shore using the FOCE graphical user interface and the communications cable on the Monterey Accelerated Research System (MARS).

The FOCE frame also supports several science instruments used to monitor both the organisms within the test chamber as well as the conditions of the sea water inside and outside the FOCE flume. On FOCE there are three cameras, two conductivity, temperature and depth (CTD) sensors, 6 pH probes, a velocimeter and an Acoustic Doppler Current Profiler (ADCP).

Within the flume, four pH probes, one CTD, the velocimeter and the three cameras are setup. The pH probes, two on each side of the flume, monitor the pH of the sea water that flows through the flume before and after the test chamber. The velocimeter is used to measure the velocity of the sea water that the thrusters are producing and the CTD is used to monitor the conductivity, temperature and depth within the test chamber. Two of the cameras monitor each of the sets of thrusters to provide visual feedback of the status of the thrusters. The remaining camera is used to monitor any organisms that are within the test chamber.

Outside of the FOCE flume is the remaining CTD, pH probes and ADCP. These are used to measure the ambient conditions outside of the flume. These readings can then be compared to the measurements taken within the flume to determine what is happening in the flume.

UPGRADED/SHALLOW WATER VERSION

The FOCE Chassis environmental board will be used in the upgraded electronics system for the current deep water version of FOCE as well as the proposed Shallow Water Version. This chassis system will be controlled by a main CPU board and powered by a new power supply board as well as support eight daughter boards.

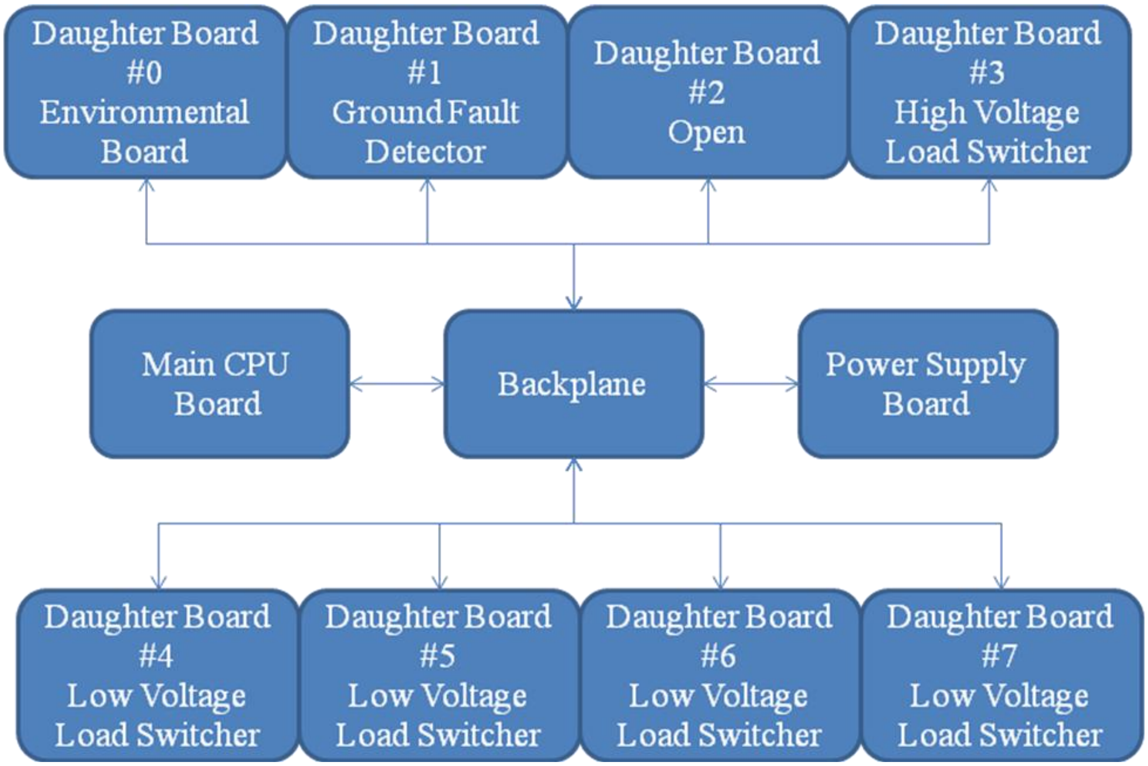

Image 3: FOCE Chassis Block Diagram

Image 3 shows the chassis system block diagram that the environmental board will become part of. This system will be used to reduce the number of individual PCBs that are contained within the FOCE electronics enclosure and simplify the wiring throughout the enclosure. The load switchers, alone, will remove four distribution boards as well as two boards from the PC/104 stack. By combining the functionality of these boards, several wire bundles can be removed as well as liberate a large area where the distribution boards were kept. The FOCE Chassis environmental board will be used to group all the environmental sensors within FOCE into one card. This, like the load switcher boards, will reduce the space used by the off-the-shelf boards and one-shot boards as well as the wiring complexity.

ENVIRONMENTAL BOARD

OVERALL FUNCTIONALITY/CAPABILITY

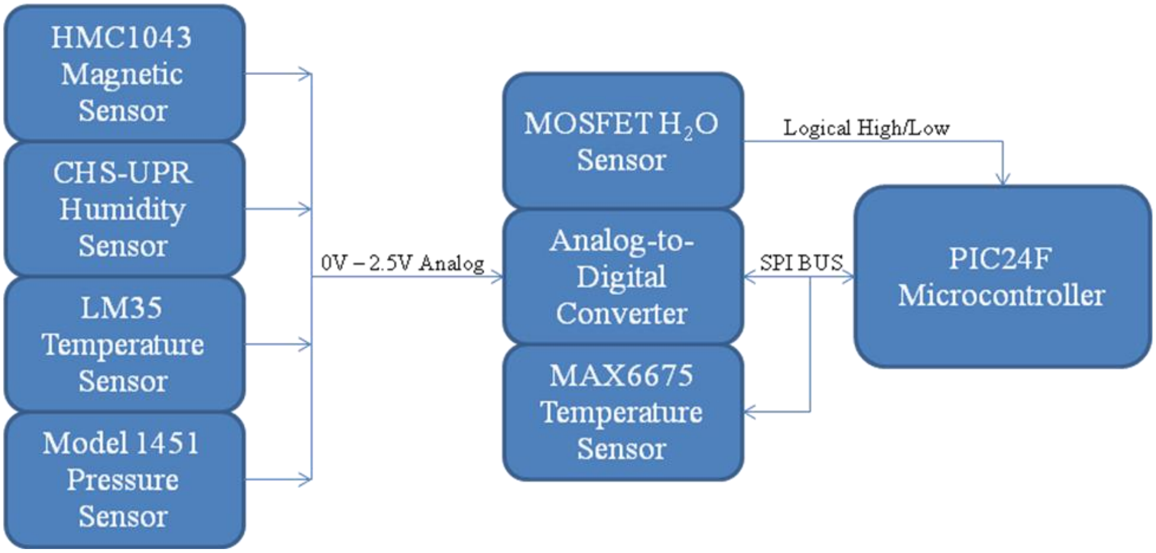

Image 4: FOCE Chassis Environmental Board Block Diagram

The FOCE Chassis environmental board was designed to fit in the new electronics stack that is planned for the Shallow Water Version of FOCE and as an upgrade to the electronics in the current FOCE system. It will consolidate several of the current environmental sensor boards that are currently within FOCE and reduce the number of wires necessary within the enclosure. However, this board was not designed solely for use with FOCE. It was envisioned to be a health monitoring system that could be included in any oceanographic instrumentation project.

This environmental board supports:

- 1 HMC1043 Three Axis Magnetic Sensor
  - Must measure ±1 Gauss and have offset correction for ±3 Gauss with an accuracy of ± 1°
- 1 onboard CHS-UPR Humidity Sensor
  - Must measure relative humidity up to 95% with an accuracy of ±3% RH

- 4 external CHS-UPS Humidity Sensors
    - Must measure relative humidity up to 95% with an accuracy of ±3% RH
- 1 onboard LM35 Temperature Sensor
    - Must measure temperature in Celsius between 2ºC and 100ºC with an accuracy of less than ±1ºC
- 8 external K-Type Thermocouples
    - Must measure temperature between 2ºC and 100ºC with an accuracy of less than ±1ºC
- 1 onboard Model 1451 Pressure Sensor
    - Must measure pressures up to 50 PSIA with an accuracy of less than ±1 PSIA
- 4 external H_2O Sensors
    - Must activate during the presence of water

Because several of these sensors output analog signals, 16-bit analog-to-digital converters (ADCs) are used to convert the data into a useable form that can be transmitted over a SPI bus to the microcontroller. Although these ADCs have unnecessarily high resolution, they were chosen because SPI drivers for these parts have already been created and they money saved by using a lower resolution ADC didn't outweigh the completed drivers.

IMPORTANCE OF INTERNAL ENVIRONMENTAL DATA

The main purpose behind including an environmental sensor board with the electronics of FOCE is to monitor the health of the electronics system. Although a system like the FOCE Chassis environmental sensor board is not necessary for the scientific functionality of FOCE, it does provide useful feedback about individual subsystems within the enclosure as well as the environmental stressors that the electronics must endure.

The FOCE Chassis environmental sensor board became an important addition to FOCE due to the electronics enclosure's history with leaks. When the enclosure was first fabricated, the connector insert holes were not beveled as per their design. This caused the O-rings to pinch and allow water to drip through. If the FOCE electronics system didn't have a humidity sensor within the enclosure, the only notification that there was something wrong with the enclosure would have been parts of the electronics system shutting down expectantly. However, there was a humidity sensor within the enclosure and FOCE was pulled up before too much damage was done to the electronics. This is the main purpose of the environmental board. It can provide real time information about a possible environmental cause to malfunctions within the electronics enclosure.

INDIVIDUAL CIRCUIT DESIGN

Board Select Digital Logic and Programming Circuitry

Each of the FOCE Chassis daughter boards will have the same board select digital logic and will contain circuitry similar to that in Appendix B1. By keeping all of the logic and key components the same on each board, programming and design can be simplified because the programming and design will be identical for each additional board.

This circuit takes a board address which is permanently assigned to each slot on the backplane and compares it to the board address that the main CPU board is requesting data from. If the addresses are the same, a signal will be sent and the microcontroller on the board will begin its scripted actions. This board address system works the same way as the SPI bus chip select but allows for additional functionality like turning on and off buffers that block the backplane SPI bus and activating interrupt signals on the backplane.

Each board will also use a standard programming jack and have a reset switch for a hardware reset. To assist with programming, the environmental board also contains a RS-232 transceiver that is mainly for debugging purposes. This circuit can be found in Appendix B5.

CHS-UPR Humidity Sensor Circuit

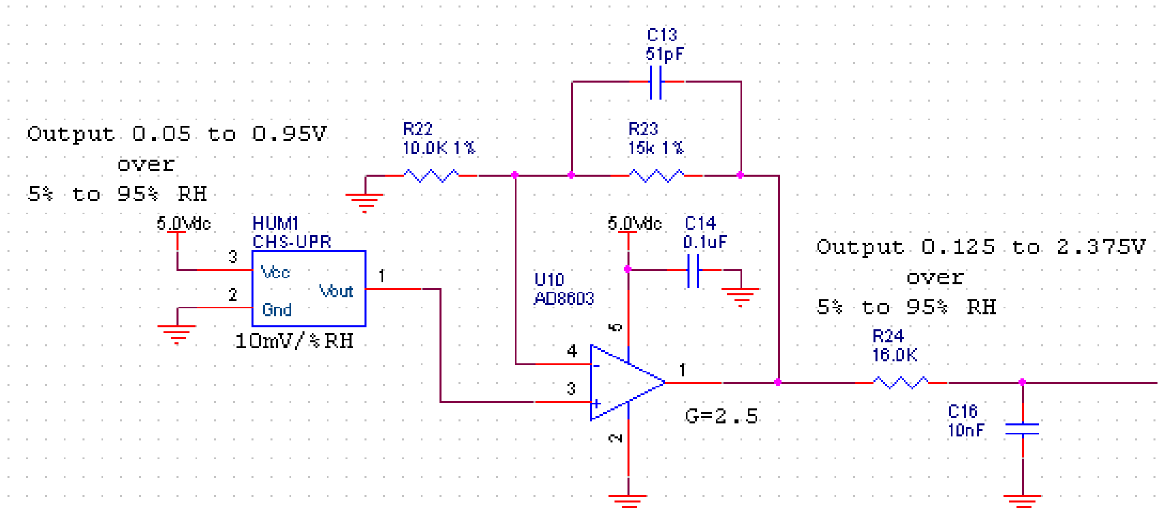

Image 5: Onboard CHS-UPR Humidity Sensor Circuit Design

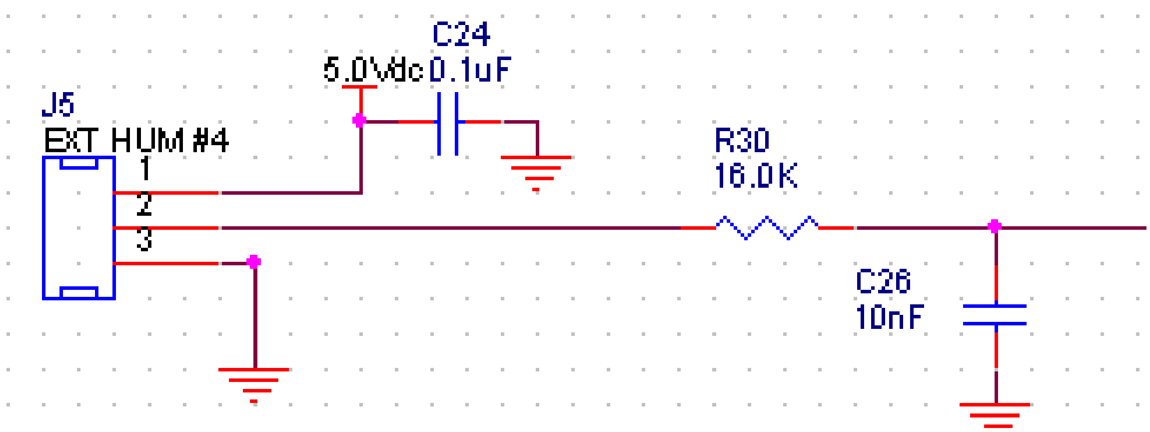

Image 6: External CHS-UPS Humidity Sensor Circuit Design

In the current version of the FOCE electronics, the CHS-UPS humidity sensor is used. This sensor is attached to a small PCB that has amplification identical to that in Image 5, and a connector cable leads to an ADC to make the data available for the microcontroller. This circuit is still used by the FOCE Chassis environmental board, however, the onboard humidity sensor cannot be the same CHS-UPS because the physical dimensions of this part will not fit the constraints of the board (6 inches x 3.5 inches x 0.75 inches). In order to preserve the circuit design of the CHS-UPS, the CHS-UPR was chosen. This part has identical properties to the CHS-UPS, however, the package is short and round opposed to the CHS-UPS's tall and narrow package.

By using identical sensors, the amplification and conversion equations for both the onboard and external humidity sensors remain the same. This also reduces the number of different parts that need to be ordered.

Specifications of the CHS-UPS/R Humidity Sensor Circuit:

- Range: 5% – 95% RH
- Output: 25mV per %RH
- Maximum Accuracy with 16-bit ADC: ±3%RH (Limited by part)

Model 1451 Pressure Sensor Circuit

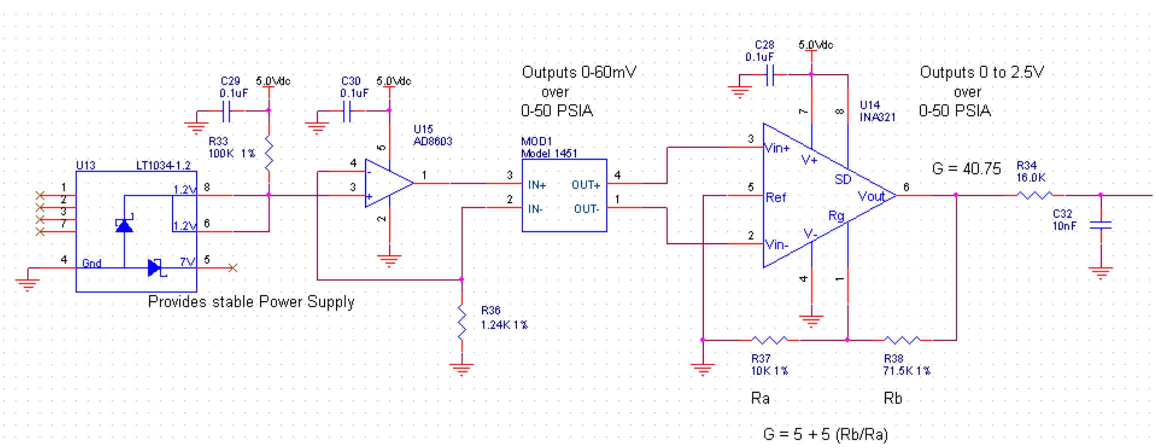

Image 7: Model 1451 Pressure Sensor Circuit Design

The Model 1451 pressure sensor was selected mainly because it meets the minimum specifications required of the sensor and it has been used successfully by MBARI in previous instrumentation projects. To operate this sensor, a stable power supply that provides constant current was required.

The design in Image 7 was based on an application note created for the Model 1451 and a previous PCB created by Chad Kecy. By combining the LT1034-1.2 and the AD8603, a constant current was applied to the inputs of the sensor. The sensor then produces a differential signal which requires amplification to take advantage of the full range of the ADC.

Specifications of the Model 1451 Pressure Sensor Circuit:

- Range: 0 PSIA – 50 PSIA
- Output: 49mV per PSIA
- Maximum Accuracy with 16-bit ADC: 125 mPSIA (Limited by Part)

LM35 Temperature Sensor Circuit

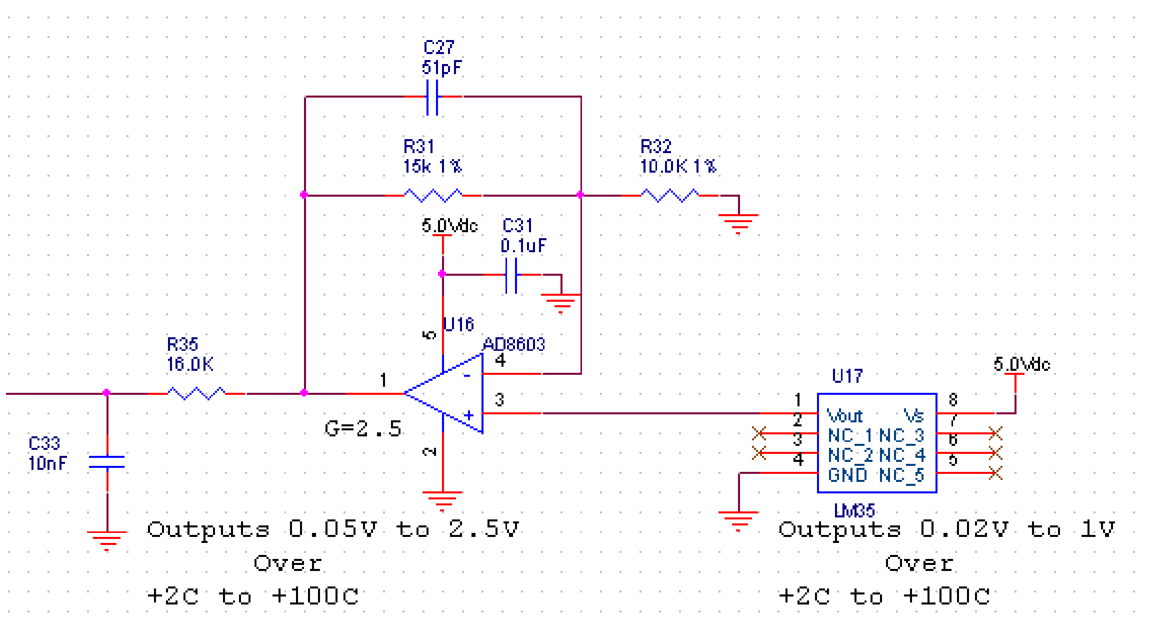

Image 8: LM35 Temperature Sensor Circuit Design

While planning the design of the FOCE Chassis environmental board, an onboard temperature sensor was included along with the eight external temperature sensors. The LM35 was chosen to serve as the onboard temperature sensor because it communicates over an analog output which can be easily amplified and fed into one of the 16-bit ADCs. This amplification, like that of the CHS-UPR requires a gain of 2.5 to increase the output range of 0V-1V to 0V-2.5V. Because of this, the same circuit and parts can be used.

Specifications of the LM35 Temperature Sensor Circuit

- Range: 0°C – 100°C
- Output: 25mV per °C
- Maximum Accuracy with 16-bit ADC: ±¼°C (Limited by part)

MAX6675 Thermocouple-to-Digital Converter Circuit

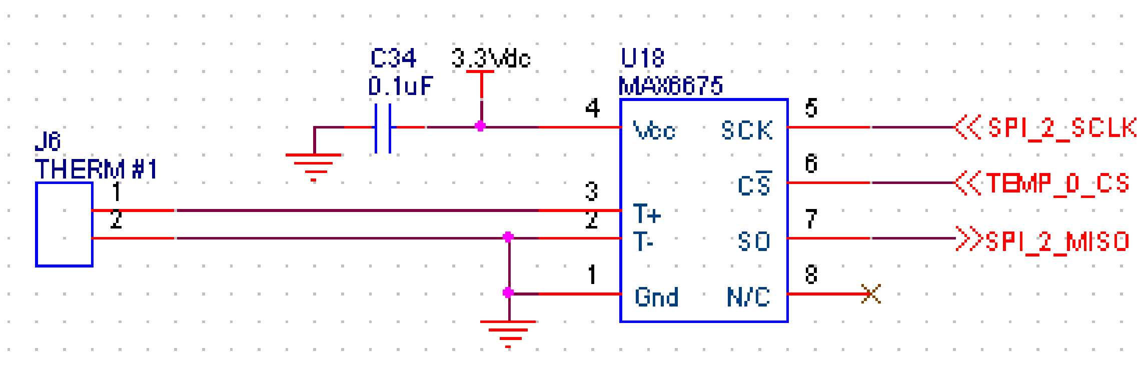

Image 9: MAX6675 Thermocouple-to-Digital Converter Circuit Design

Thermocouples were selected to act as the external temperature sensors during the minimum specification selection due to their current use in the FOCE electronics. However, additional support circuitry is required to convert their output into a usable signal and include cold-junction compensation which is necessary for this application.

To accomplish this, the MAX6675 was chosen because it provides cold-junction compensation as well as converts the temperature into a 12-bit digital signal ready for a SPI bus. The cold-junction compensation on this chip works by comparing the ambient temperature at the chip with the reading from the thermocouple, resulting in a more accurate tracking of the temperature at the thermocouple junction.

Specifications of the MAX6675 Thermocouple-to-Digital Converter Circuit

- Range: 0°C – 100°C
- Output: 12-bit digital signal over SPI
- Maximum Accuracy: ±¼°C (Limited by part)

H_2O Sensor Circuit

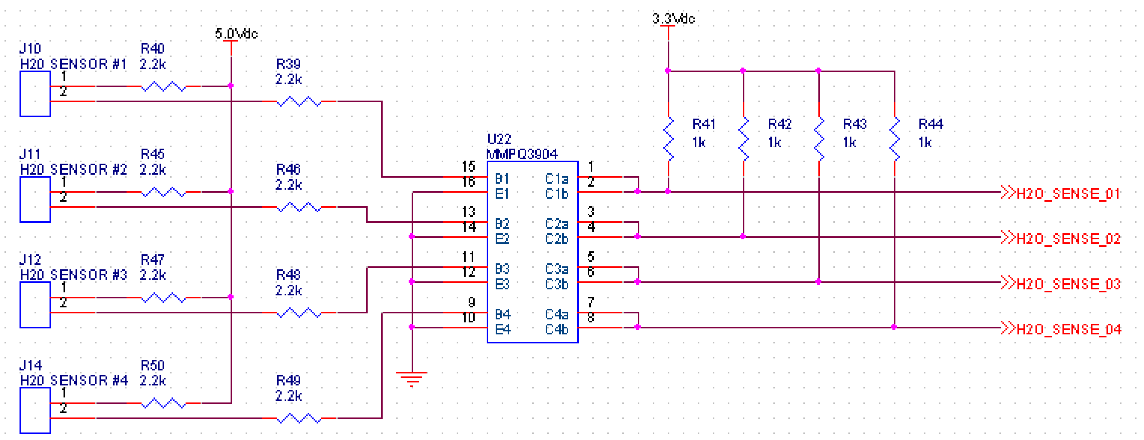

Image 10: H_2O Sensor Circuit Design

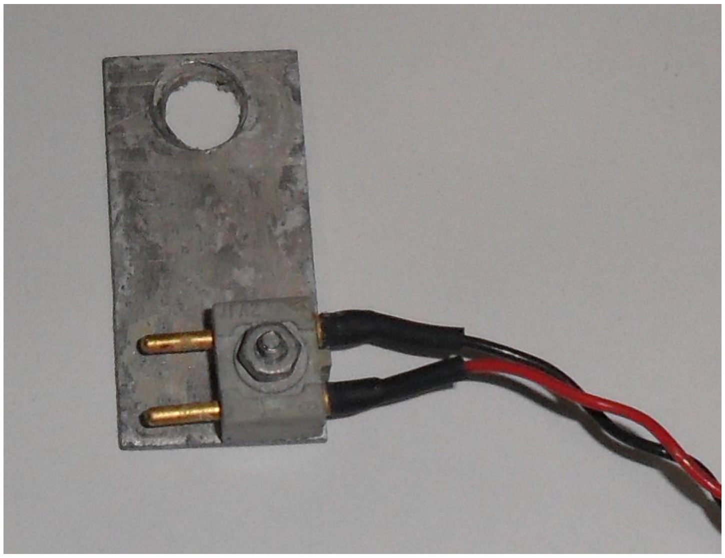

Image 11: H_2O Sensor Probe

The design for this circuit is based around a quad package bipolar junction transistor (BJT) integrated circuit. The four connectors on the left of Image 10 attach to probes, Image 11, that are placed at key locations throughout the FOCE electronics enclosure. This circuit works because of sea water's conductivity. Whenever it is present at the location of the probes, electricity is conducted between the two probe leads. This, in turn, activates the BJT that the probe is connected to, creating a logical low to one of the microcontroller's digital I/O pins. This signal can then be used to notify the scientists and engineers that there is a leak in the enclosure.

Specifications of the H_2O Sensor Circuit

- Range: N/A
- Output: 0VDC or 3.3VDC
- Maximum Accuracy: N/A

HMC1043 Magnetic Sensor Circuit

The motivation behind including a direction sensor on a health monitoring system board was that the scientists working on FOCE wanted an accurate reading of the orientation of the FOCE flume. To accomplish this, the HMC1043 three axis magnetic sensor in Appendix B4 was selected.

The HMC1043 three axis magnetic sensor works by using three bridge style circuits each composed of four magnetoresistive resistors. These bridge circuits work when voltage and a magnetic field are applied to the bridge causing the resistance of the resistors to change. This results in a voltage appearing between the center-tap points. This analog signal can then be amplified and measured using an ADC.

Unfortunately, the HMC1043 produces an analog signal that is centered on 0V and can become either negative or positive. To ensure that the full range of this signal is read through the ADC, an offset of 1.24V was applied to the amplified output. This makes the output analog signal range from about 0V to 2.5V which is within the range of the ADC. With this analog voltage range and a 16-bit ADC, the resolution of the HMC1043 becomes 38µV per count. This means that this circuit can achieve an absolute maximum resolution of 31µGauss which is more than sufficient to take advantage of the sensitivity of the HMC1043 which can measure up to 120µGauss.

The HMC1043 also hosts offset straps which allow a user to correct for any static magnetic fields that may be present and unwanted. To operate these straps, a 10mA current must be applied to the straps for every Gauss that is corrected. This also applies to negative Gauss which means that a bipolar programmable current source is required to fully operate these offset straps. To accomplish this, two LT3092 current sources were chosen due to their maximum current output and the way they are programmed. To program these current sources, the MCP42100 digital potentiometer was chosen to vary the output current from 0A to 30mA to correct for up to ±3 Gauss.

To create the bipolar functionality of this bipolar current source, four SI4511DY MOSFETs were used as a solid state switch. This part is a dual package N and P type MOSFET which allows a digital signal from the microcontroller to switch the direction of current flow effectively making two programmable bipolar current sources.

The HMC1043 also features a SET/RESET strap which allows a user to reset the magnetoresistive bridges to the factory default state. This is necessary due to the natural hysteresis that the part experiences in a constant magnetic field. To operate this strap, a current pulse must be sent to the strap that pulses negative and then positive. This induces a magnetic field that realigns the poles in the bridge resistors. To accomplish this, another SI4511DY MOSFET IC was chosen to provide a short burst of negative and positive current.

Specifications of the HMC1043 Magnetic Sensor Circuit

- Range of Magnitude: ±1 Gauss
- Range of Direction: 0° – 360° on xyz planes
- Range of Offset correction: ±3 Gauss at 10mA per Gauss
- Output Center: 1.24V at 0 Gauss
- Output: ±1.2V per Gauss
- Maximum Accuracy with 16-bit ADC: 120µGauss (Limited by Part)

POWER BUDGET

Voltage Rail:	**3.3VDC**	**Total Power**	**1.056W**
Part	**Quantity**	**Part Current (A)**	**Total Current (A)**
PIC24	1	2.50E-01	2.50E-01
SN74LVC1G08	1	1.00E-05	1.00E-05
SN74HC42	1	8.00E-05	8.00E-05
SN74LVC125A	2	8.00E-05	1.60E-04
SN74LVC00A	1	5.00E-04	5.00E-04
CD74HC85	1	4.40E-04	4.40E-04

SN74CB3Q3251	1	4.00E-03	4.00E-03
SN74HC245	1	8.00E-05	8.00E-05
10k Ohm Pull Up Resistor	6	3.30E-04	1.98E-03
10k Ohm Pull Down Resistor	5	3.30E-04	1.65E-03
ADS8344	1	1.85E-03	1.85E-03
MAX6675	8	1.50E-03	1.20E-02
1k Ohm Pull Up Resistor	4	3.30E-03	1.32E-02
MCP42100	1	5.00E-04	5.00E-04
100k Ohm Pull Down Resistor	1	3.30E-05	3.30E-05
HMC1043	1	3.00E-02	3.00E-02
32.4k Ohm Current Limit Resistor	1	1.02E-04	1.02E-04
LMV324	1	4.10E-04	4.10E-04
ADS8341	1	2.00E-03	2.00E-03
MAX3226E	1	1.00E-03	1.00E-03

Table 2: Power Budget at 3.3VDC

Voltage Rail:	**5VDC**	**Total Power**	**367mW**
Part	**Quantity**	**Part Current (A)**	**Total Current (A)**
CHS-UPR	5	6.00E-04	3.00E-03
AD8603	7	5.00E-05	3.50E-04
MAX6066	2	1.25E-04	2.50E-04
LM35	1	1.31E-04	1.31E-04
LT1034-1.2	1	3.00E-05	3.00E-05
INA321	1	4.00E-05	4.00E-05
2.2k Ohm Current Limit Resistor	4	2.27E-03	9.09E-03

LT3092	2	3.00E-02	6.00E-02
200 Ohm Current Limit Resistor	1	5.00E-04	5.00E-04

Table 2: Power Budget at 5VDC

The information provided in Tables 1 and 2 offer a worst case scenario of how much power will be consumed by the environmental board. The total power calculations of 1.056W at 3.3VDC and 367mW at 5VDC are created assuming that every component on the board is consuming the most power possible and are always on. This is necessary when calculating the power supply requirements because if the power supply cannot provide enough power to the board, components may not always work.

This total power calculation is not, however, the amount of power that the PCB is likely to consume. Depending on how the microcontroller is programmed, certain components may draw less power because they are not turned on all the time and by decreasing the clock speed of the microcontroller, the PIC24 will draw less current. For a more detailed prediction of the average power consumption over time, knowledge of the programming and duty cycle of the components is necessary.

DESIGN REVIEW

During the design review for the FOCE Chassis environmental board, several observations and suggestions were made concerning the circuit design of the board. These suggestions and observations were based mainly around the parts selection, however, one pointed out that the microcontroller may require high voltage programming. If the microcontroller did require high voltage programming, a protection diode would be required to block the high voltage from leaking back into the 3.3V power supply. If this were to occur, several of the circuit components on the chassis would be damaged. This design, however, was taken from a previous testing board designed by Chad Kecy and the PIC24 chosen for the environmental board can be programmed at a voltage that will not damage the board.

The other two main suggestions were to investigate using a delta-sigma ADC and to check the input offset and drift over temperature characteristics of the output amplifier on the HMC1043. The delta-sigma ADC was debated but programming code for the current ADCs has already been made and using a delta-sigma ADC would not provide any valuable additions to the circuit. The input offset and drift characteristics of the amplifiers was also investigated and determined to be well within acceptable margins.

CIRCUIT LAYOUT USING ALLEGRO

The layout for this PCB was relatively simple compared to most of the boards that MBARI produces. There were only four major constraints that needed to be considered during layout. The first was that the DIN connector that attaches the environmental board to the backplane needed to be centered on the top layer of the board against the left side (see J19 in Appendix C1). The second was that the test output connector needed to be placed on the top layer of the board against the top edge near the center (see J20 in Appendix C1). The third constraint was that the support components for all the external sensors needed to be as close to the connectors as possible. This was necessary to reduce the amount of noise that is introduced to the signals. The final constraint was that any and all bypass capacitors must be placed physically close to their respective components. This was achieved by placing most of them on the bottom layer of the board directly underneath their respective components.

SUBMITTING FOR FABRICATION

The final step in the layout process of this PCB was the submission for fabrication. A quote was requested from Circuits West for ten copies of the board with a three day lead. Once the quote was returned and approved, Jose Rosal placed the order with Circuits West.

PARTS ORDERING

In order to populate the FOCE Chassis environmental board, enough parts to populate four boards were ordered by Chad Kecy. This was to ensure that there were sufficient parts to make multiple identical boards in case of failure on one of them. This also ensures that if an individual component fails, there are replacements that a defective part can be swapped with.

POPULATION AND TESTING

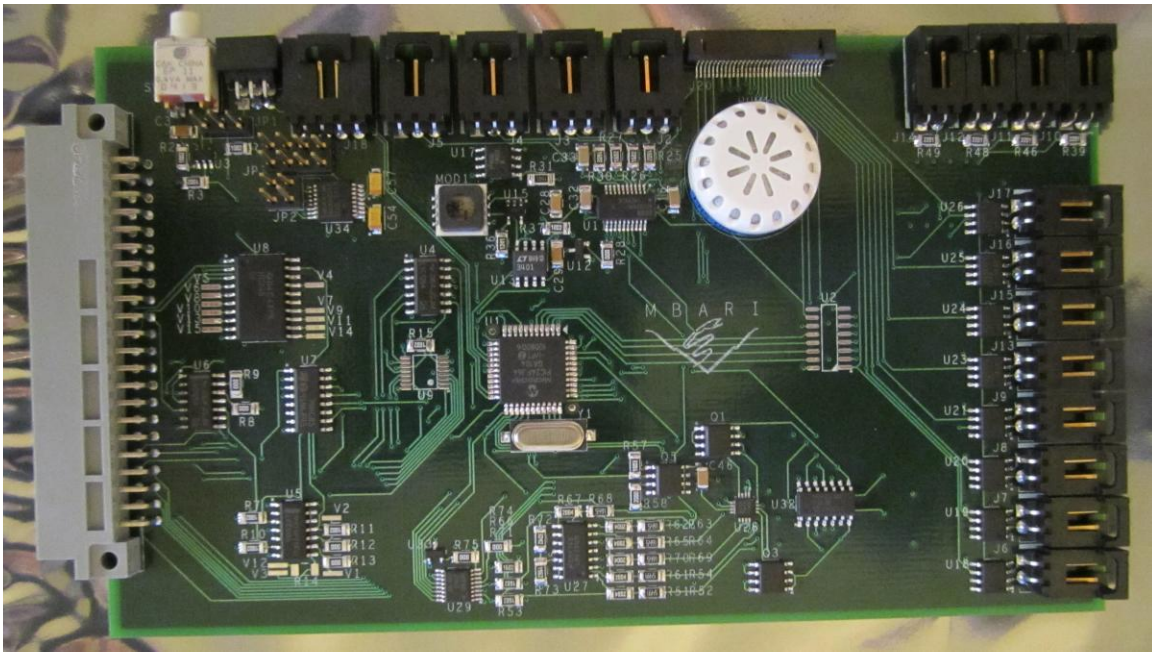

Image 12: FOCE Chassis Environmental Board

The population for the FOCE Chassis environmental board was completed supervision and aid of Jose Rosal. Unfortunately, the testing will not be completed in time of the internship; however, preliminary testing has shown promising results on the analog circuits. For a complete test of the environmental board, software for the microcontroller will be needed to test the digital addressing.

CONCLUSION

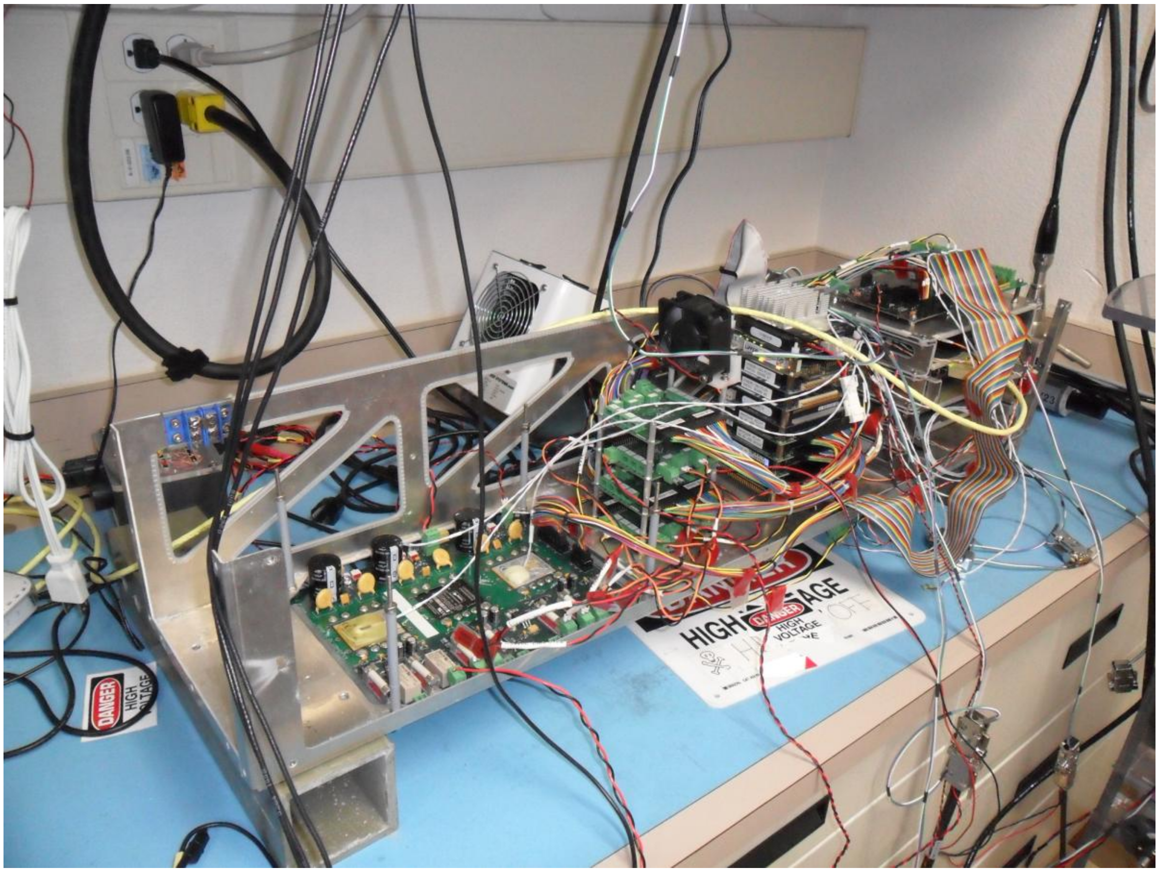

Image 13: FOCEtest1

Currently the FOCE Chassis environmental board is one of four boards ready to become part of the chassis system. The main CPU board, power supply board and backplane have already been designed by Chad Kecy and assembled by the electronics technicians. And, like the environmental sensor board, these chassis boards have undergone the same design process. Each board began with a minimum specifications discussion, the circuit design followed by a design review and finally the layout and population.

Now, all of the boards will be tested individually for functionality. This testing will begin by testing all of the analog circuitry, digital logic circuitry, basic PIC code on the microprocessor, and the incorporation of the SPI drivers. Once all of this is completed, the environmental sensor board along with the others will begin integration testing.

Once all of the testing and integration of the FOCE Chassis has been completed with the inclusion of the remaining seven daughter boards, a redesign of the electronics within FOCE will begin. However, FOCE is currently attached to MARS and upgrades to the electronics would require the apparatus to be brought to shore. Because of this, integration and testing of the FOCE Chassis system will likely take place on FOCEtest1 seen in Image 13.

ACKNOWLEDGEMENTS

David and Lucille Packard Foundation.

C. Kecy, J. Rosal, A. Sherman, E. Mellinger, M. Risi, G. Matsumoto, L. Kuhnz, J. Connor, MBARI 2010 Interns

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Appendix A1

FOCE Chassis Environmental Board Revised: Monday, August 02, 2010
10020577 Revision: A

Bill Of Materials A Page1

Reference	Value	Quantity	Manufacturer	Manuf PN	Supplier	Supplier PN	Package	Description	PCB Footprint
C1,C2,C3,C7,C8,C9,C10,C11,C12,C14,C15,C18,C19,C21,C22,C24,C28,C29,C30,C31,C34,C35,C36,C37,C38,C39,C40,C41,C42,C44,C49,C51,C52,C53	0.1uF	34	Panasonic-ECG	ECJ-3VB1E104K	Digikey	PCC1883CT-ND	1206	X7R 10% 25V 0.1uF	CAPC3216X150N_1206
C4	10uF	1	AVX Corp	TAJB106K016RNJ	Digikey	478-1673-1-ND	3528-21	10uF 16V 10%	CAPMP3528X210N
C5,C6	20pF	2	Yageo	CC1206JRNP09BN200	Digikey	311-1153-1-ND	1206	CC Cer 5% COG 20pF 50V	CAPC3216X150N_1206
C13,C27	51pF	2	Yageo	CC1206JRNP09BN510	Digikey	311-1219-1-ND	1206	COG 5% 50V 50pF	CAPC3216X150N_1206
C16,C17,C20,C23,C26,C32,C33	10nF	7	Panasonic ECG	ECJ-3FB2J103K	Digikey	PCC2292CT-ND	1206	10nF 50V 5% COG	CAPC3216X150N_1206
C25,C50	1uF	2	Panasonic-ECG	ECJ-3YB1E105K	Digikey	PCC1893CT-ND	1206		CAPC3216X150N_1206
C43	10nF	1	AVX Corp	12105A103JAT2A	Digikey	478-1601-1-ND	1210	10nF 50V 5% COG	CAPC3216X150N_1206
C45	4.7uF	1	Kemet	C1206C475J8NACTU	Digikey	399-5773-2-ND	1206		CAPC3216X150N_1206
C46	0.47uF	1	Kemet	C1206C474J5NACTU	Digikey	399-5771-1-ND	1206		CAPC3216X150N_1206
C47,C48	10nF	2	AVX Corp	12105A103JAT2A	Digikey	478-1601-1-ND	1206	10nF 50V 5% COG	CAPC3216X150N_1206
C54,C55,C56,C57	0.1 uF	4	AVX Corp	TAJA104K035RNJ	Digikey	478-2368-1-ND	3216-18	Tant 10% 35V 0.1uF	CAPMP3216X180N
C58	33uF	1	AVX Corp	TPSD336M020R0200	Digikey	478-4111-1-ND	7343-31		CAPMP7343X430N
C59,C60,C61,C62,C63	33uF	5	AVX Corp	TCJB336M010R0070	Digikey	478-4713-1-ND	3528-21		CAPMP3528X210N
HUM1	CHS-UPR	1	TDK Corp	CHS-UPR	Digikey	445-2579-ND	Thru-Hole	Humidity Sensor	SENS_CHS-UPR
JP1	PIC RESET	1	Tyco Electronics	87224-3	Digikey	A26545-ND		3-Pos 0.1" Sing Row Male Hdr	HDR1X3
JP2	UART1 SD	1	Tyco Electronics	1-87215-1	Digikey	A26566-ND	Thru-Hole	2-Pos Vert Male Header	HDR2X2
JP3	UART2 232 SWAP	1	Tyco Electronics	87215-1	Digikey	A26570-ND	Thru-Hole	2-Row 8-Pos Header	HDR2X4
J1	PROGRAM	1	Molex	87833-0620	Digikey	WM18859-ND	Thru-Hole RA	RJ11 6p6c	MOLEX_87833-0620
J2,J3,J4,J5	CONN SOCKET 3	4	Molex	70553-0002	Digikey	WM4901-ND	Thru-Hole	3-Pin Vert Header	MOLEX_70553-0002
J6	THERM #1	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J7	THERM #2	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J8	THERM #3	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J9	THERM #4	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J10	H20 SENSOR #1	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J11	H20 SENSOR #2	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J12	H20 SENSOR #3	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001

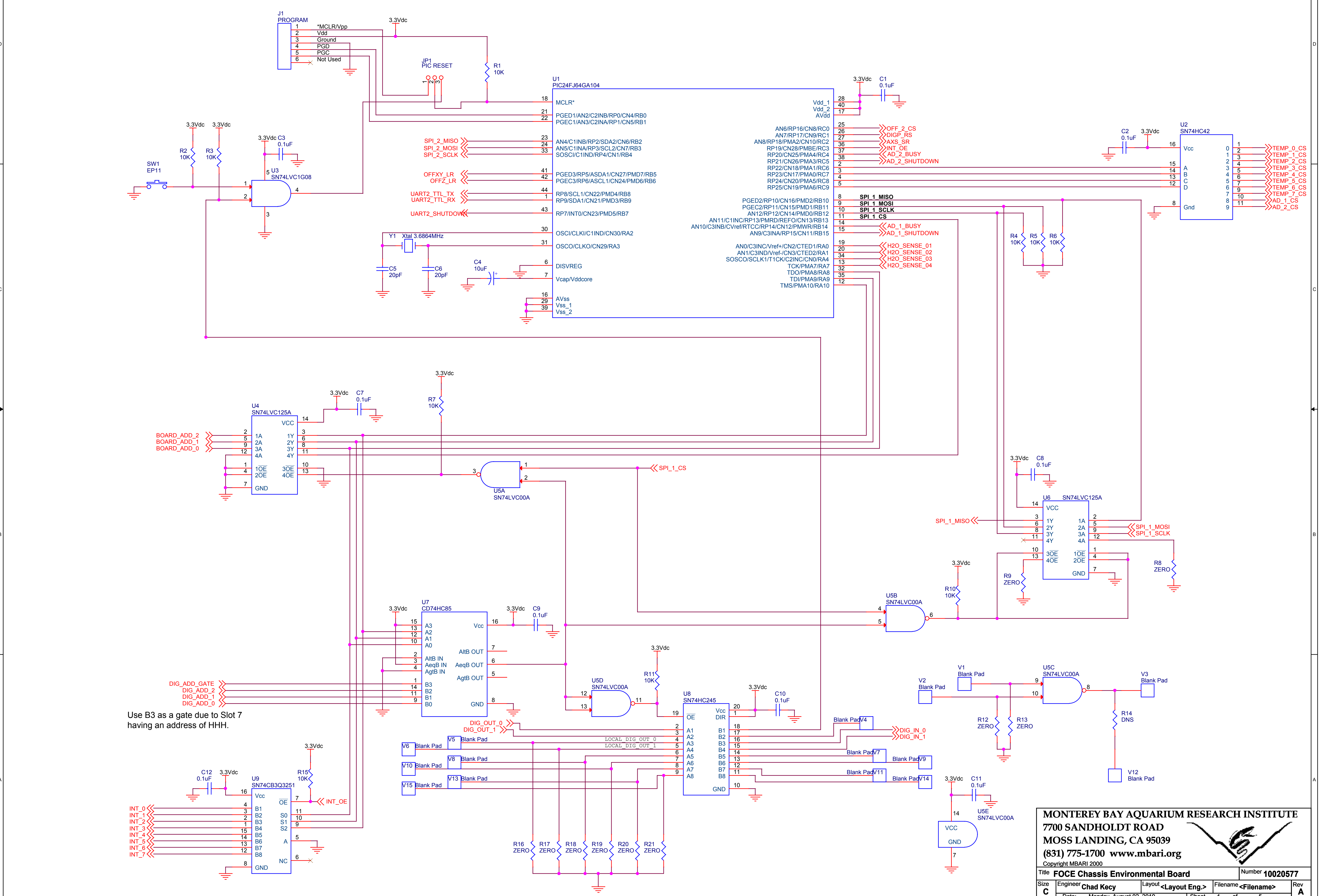
Appendix A2

J13	THERM #5	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J14	H20 SENSOR #4	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J15	THERM #6	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J16	THERM #7	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J17	THERM #8	1	Molex	70553-0001	Digikey	WM4900-ND			MOLEX_70553-0001
J18	DEBUG	1	Molex/Waldom	70553-0003	Digikey	WM4902-ND	Thru-Hole	4-Pin Vert Male Header	MOLEX_70553-0003
J19	DIN 44_AB-H	1	Hirose	PCN10C-44S-2.54DSA(72)	Digikey	H11194-ND		Straight Thru Female	HIROSE_PCN10-44S-254DS
J20	FI-W31P-HFE	1	JAE Electronics	FI-W31P-HFE	Digikey	670-1722-ND	Thru-Hole	31-Pin RA Male Header	JAE_FI-W31P-HFE
MOD1	Model 1451	1	Measurement Specialties	1451-050A-W	Digikey	MSP6810-ND	SM	SMD Pressure Sensor 0-50PSI Absolute	SENS_1451-050A-W
P1,P2,P3,P4	PLUG 3	4	Molex	50-57-9403	Digikey	WM2901-ND	Free Hanging	3-Pin Vert Header	dummy
P5,P6,P7,P8,P12,P14,P15,P16	PLUG 2	8	Molex	50-57-9402	Digikey	WM2900-ND	Free Hanging	2-Pin Female Plug	dummy
P9,P10,P11,P13	PLUG 2	4	Molex	51004-0200	Digikey	WM18951-ND	Free Hanging	2-Pin Female Plug	dummy
Q1,Q2,Q3,Q4,Q5	Si4511DY	5	Vishay	SI4511DY-T1-E3	Digikey	SI4511DY-T1-E3CT-ND	8-SOIC		SOIC127P600X175-8N_SOIC8
R1,R2,R3,R4,R5,R6,R7,R10,R11,R15,R59,R60	10K	12	Panasonic-ECG	ERJ-8ENF1002V	Digikey	P10.0KFCT-ND	1206	ERJ 0.25W 10K 1%	RESC3216X60N_1206
R8,R9,R12,R13,R16,R17,R18,R19,R20,R21	ZERO	10	Panasonic-ECG	ERJ-8GEY0R00V	Digikey	P0.0ECT-ND	1206	ERJ 0.25W 10K 1%	RESC3216X60N_1206
R14	DNS	1	Panasonic-ECG	ERJ-8ENF1002V	Digikey	P10.0KFCT-ND	1206	ERJ 0.25W 10K 1%	RESC3216X60N_1206
R22,R32	10.0K 1%	2	Panasonic-ECG	ERJ-8ENF1002V	Digikey	P10.0KFCT-ND	1206	0.25W 1% ERJ Series	RESC3216X60N_1206
R23,R31	15k 1%	2	Panasonic-ECG	ERJ-8ENF1502V	Digikey	P15.0KFTR-ND	1206	0.25W 1% ERJ Series	RESC3216X60N_1206
R24,R25,R26,R27,R30,R34,R35,R53,R66,R71	16.0K	10	Panasonic-ECG	ERJ-8ENF1602V	Digikey	P16.0KFCT-ND	1206	ERJ 0.25W 16.0K 1%	RESC3216X60N_1206
R28,R29,R74,R75	ZERO	4	Panasonic ECG	ERJ-8GEY0R00V	Digikey	P0.0ECT-ND	1206		RESC3216X60N_1206
R33,R57	100K 1%	2	Panasonic-ECG	ERJ-8ENF1003V	Digikey	P100KFCT-ND	1206	1% 100ppm 0.25W	RESC3216X60N_1206
R36	1.24K 1%	1	Panasonic-ECG	ERJ-8ENF1241V	Digikey	P1.24KFCT-ND	1206	1% 100ppm 0.25W	RESC3216X60N_1206
R37	10K 1%	1	Panasonic-ECG	ERJ-8ENF1002V	Digikey	P10.0KFCT-ND	1206	0.25W 1% ERJ Series	RESC3216X60N_1206
R38	71.5K 1%	1	Panasonic-ECG	ERJ-8ENF7152V	Digikey	P71.5KFCT-ND	1206	0.25W 1% ERJ Series	RESC3216X60N_1206
R39,R40,R45,R46,R47,R48,R49,R50	2.2k	8	Panasonic-ECG	ERJ-8GEYJ222V	Digikey	P2.2KECT-ND	1206	5% 200ppm 0.25W	RESC3216X60N_1206
R41,R42,R43,R44	1k	4	Panasonic-ECG	ERJ-8GEYJ102V	Digikey	P1.0KECT-ND	1206	5% 200ppm 0.25W	RESC3216X60N_1206
R51,R61,R62,R65,R67,R70	2M 1%	6	Panasonic-ECG	ERJ-8ENF2004V	Digikey	P2.00MFCT-ND	1206	ERJ 0.25W 16.0K 1%	RESC3216X60N_1206
R52,R54,R63,R64,R68,R69	5.49k 1%	6	Yageo	RC1206FR-075K49L	Digikey	311-5.49KFRCT-ND	1206	ERJ 0.25W 16.0K 1%	RESC3216X60N_1206
R55,R56	30.0 1%	2	Panasonic-ECG	ERJ-8ENF30R0V	Digikey	P30.0FCT-ND	1206	ERJ 0.25W 16.0K 1%	RESC3216X60N_1206
R58	200	1	Panasonic-ECG	ERJ-8ENF2000V	Digikey	P200FTR-ND	1206		RESC3216X60N_1206
R72	32.4k 1%	1	Panasonic ECG	ERJ-8ENF3242V	Digikey	P32.4KFCT-ND	1206		RESC3216X60N_1206
R73	19.6k 1%	1	Panasonic-ECG	ERJ-8ENF1962V	Digikey	P19.6KFCT-ND	1206	ERJ 0.25W 10K 1%	RESC3216X60N_1206
SW1	EP11	1	C&K Components	EP11FPD1APE	Digikey	CKN9129-ND	Through Hole	SPST-NO Off-Mom	SW_EP11FPD1APE
U1	PIC24FJ64GA104	1	MicroChip	PIC24FJ64GA104-I/PT	Digikey	PIC24FJ64GA104-I/PT-ND			QFP80P1200X1200X120-44M_TQFP44
U2	SN74HC42	1	TI	SN74HC42D	Mouser	595-SN74HC42D			SOIC127P600X175-16N_SOIC16
U3	SN74LVC1G08	1	Texas Instruments	SN74LVC1G08DBVR	Digikey	296-11601-1-ND	SOT23-5	Single Gate 2-in AND Gate	SOT95P280X145-5N_DBV
U4	SN74LVC125A	1	TI	SN74LVC125ADR	Digikey	296-8453-1-ND			SOIC127P600X175-14N_SOIC14
U5	SN74LVC00A	1	TI	SN74LVC00AD					

Appendix A3

	Digikey	296-1694-5-ND							
			SOIC127P600X175-14N_SOIC14						
U5	SN74LVC00A	1	TI	SN74LVC00AD	Digikey	296-1694-5-ND			
			SOIC127P600X175-14N_SOIC14						
U5	SN74LVC00A	1	TI	SN74LVC00AD	Digikey	296-1694-5-ND			SOIC127P600X175-14N_SOIC14
U6	SN74LVC125A	1	TI	SN74LVC125ADR	Digikey	296-8453-1-ND			
			SOIC127P600X175-14N_SOIC14						
U7	CD74HC85	1	TI	CD74HC85M96	Digikey	296-9242-1-ND			SOIC127P600X175-16N_SOIC16
U8	SN74HC245	1	TI	SN74HC245DWR	Digikey	296-1197-1-ND			SOIC127P1033X265-20N_SOIC20
U9	SN74CB3Q3251	1	TI	SN74CB3Q3251PWR	TI	SN74CB3Q3251PWR			SOP65P640X120-16N_TSOP16
U10,U15,U16	AD8603	3	Analog Devices	AD8603AUJZ-REEL7	Digikey	AD8603AUJZREEL7CT-ND		Single Op Amp	SOT95P280X100-5N
U11	ADS8344	1	Analog Devices	ADS8344EB-ND	Digikey	ADS8344EB-ND			SOP64P600X175-20N_QSOP20
U12,U33	MAX6066	2	Maxim	MAX6066AEUR+T	Digikey	MAX6066AEUR+TCT-ND			SOT95P237X112-3N_132
U13	LT1034-1.2	1	Linear Tech	LT1034CS8-1.2#PBF	Digikey	LT1034CS8-1.2#PBF-ND	8-SOIC	1.225V Ref	SOIC127P600X175-8N_SOIC8
U14	INA321	1	Texas Instruments	INA321EA/250	Digikey	INA321EACT-ND	8-MSOP	Sing Instr Amp	SOP65P490X110-8N_MSOP8
U17	LM35	1	National Semi	LM35DMX/NOPB	Digikey	LM35DMXCT-ND			SOIC127P600X175-8N_SOIC8
U18,U19,U20,U21,U23,U24,U25,U26	MAX6675	8	Maxim	MAX6675ISA+	Digikey	MAX6675ISA+ND	8-SOIC	Thermocouple Conditioner	SOIC127P600X175-8N_SOIC8
U22	MMPQ3904	1	Fairchild	MMPQ3904	Digikey	MMPQ3904FSCT-ND	16-SOIC	Quad NPN	SOIC127P600X175-16N_SOIC16
U27	LMV324	1	National Semi	LMV324MX/NOPB	Digikey	LMV324MXCT-ND			SOIC127P600X175-14N_SOIC14
U28	HMC1043	1	Honeywell	HMC1043-TR	Digikey	342-1054-1-ND			SENS_HMC1043
U29	ADS8341	1	Analog Devices	ADS8341E	Digikey	ADS8341E-ND			SOP63P602X175-16N_QSOP16
U30,U31	LT3092	2	Linear Technology	LT3092EST#PBF	Digikey	LT3092EST#PBF-ND			SOT230P700X180-4N
U32	MCP42100	1	MicroChip	MCP42100-I/SL	Digikey	MCP42100-I/SL-ND			SOIC127P600X175-14N_SOIC14
U34	MAX3226E	1	Maxim IC	MAX3226EEAE+	Digikey	MAX3226EEAE+-ND	16-SSOP	RS 232 Xcvr	SOP65P778X199-16N_SSOP16
V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,V12,V13,V14,V15	Blank Pad	15							MISC_SM-TP
Y1	Xtal 3.6864MHz	1	ECS Inc.	ECS-36-20-5PXDU-TR	Digikey	XC1523CT-ND	SMD	Quartz Xtal Fund. 30ppm	XTAL1140X470X430N_ECS-CSM-7

Appendix B1



U1 PIC24FJ64GA104
U2 SN74HC42
U3 SN74LVC1G08
U4 SN74LVC125A
U5A SN74LVC00A
U6 SN74LVC125A
U7 CD74HC85
U8 SN74HC245
U9 SN74CB3Q3251
J1 PROGRAM
JP1 PIC RESET
SW1 EP11
Y1 Xtal 3.6864MHz
Use B3 as a gate due to Slot 7 having an address of HHH.
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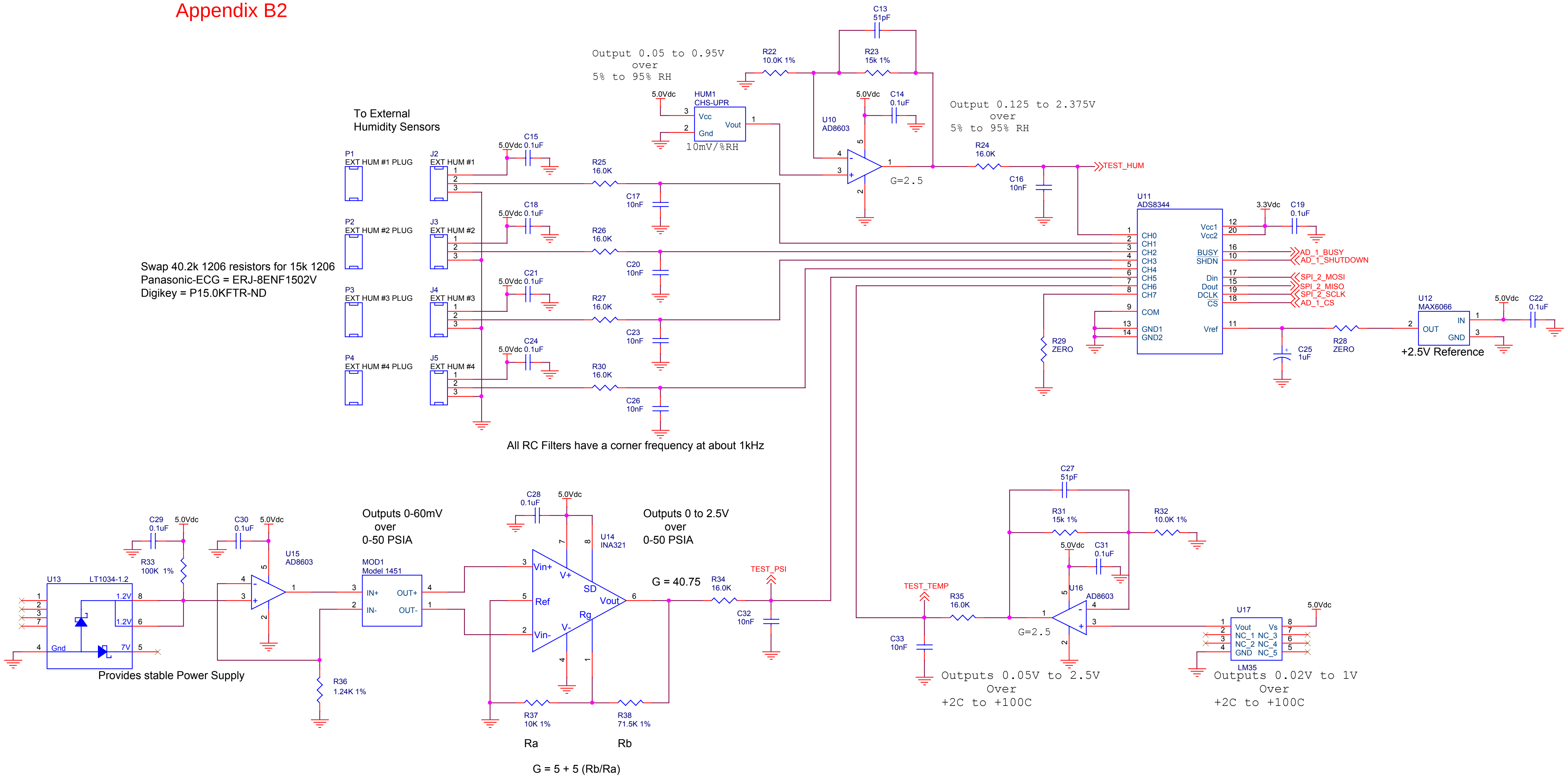
Title FOCE Chassis Environmental Board
Number 10020577
Size C
Engineer Chad Kecy
Layout <Layout Eng.>
Filename <Filename>
Rev A
Date: Monday, August 02, 2010
Sheet 1 of 5

Appendix B2



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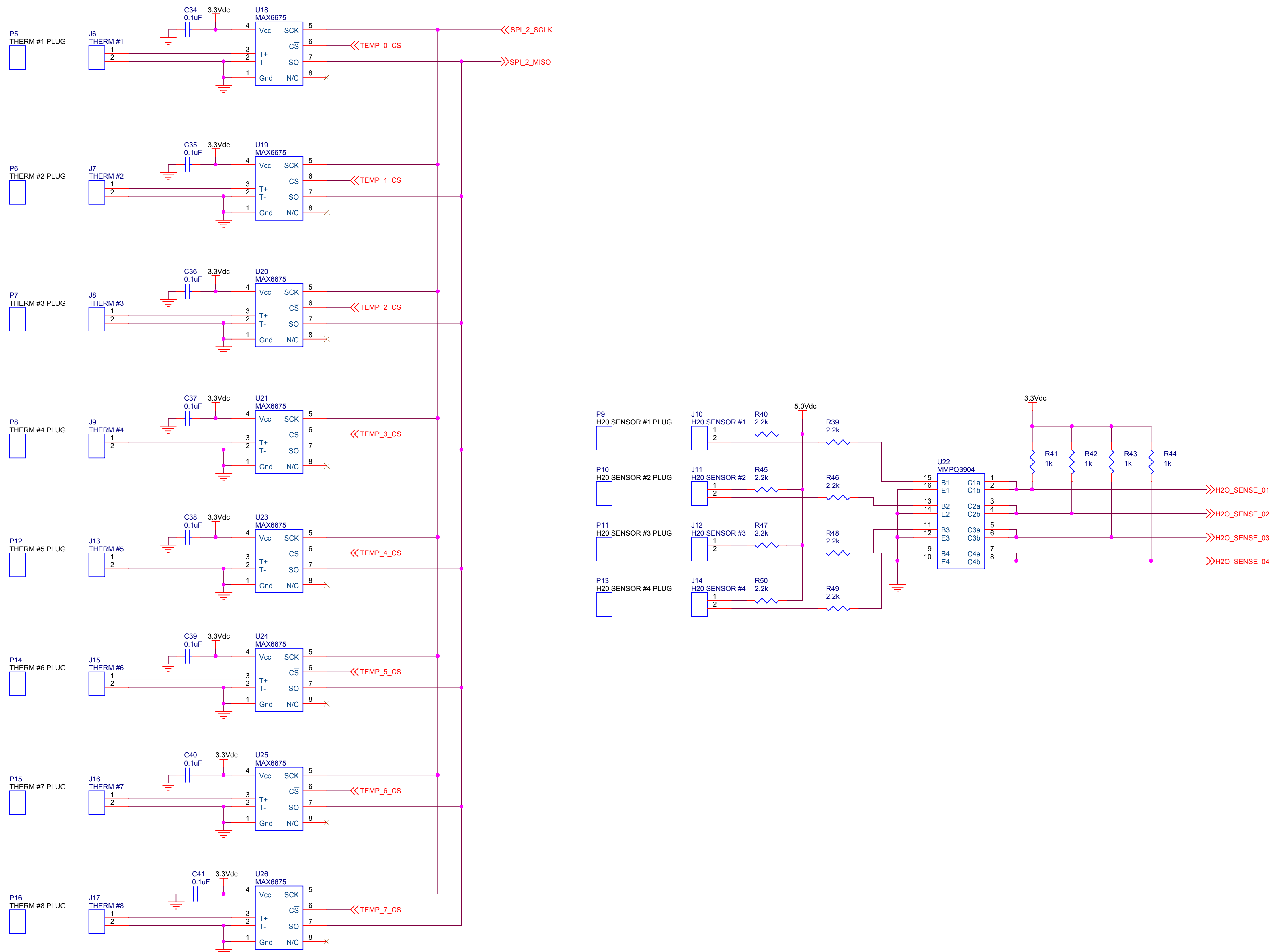
Title: FOCE Chassis Environmental Board			Number: 10020577	
Size: C	Engineer: Chad Kecy	Layout: <Layout Eng.>	Filename: <Filename>	Rev: A
Date: Thursday, August 19, 2010		Sheet 2 of 5		

Appendix B3



Operating Range: -20C to +85C

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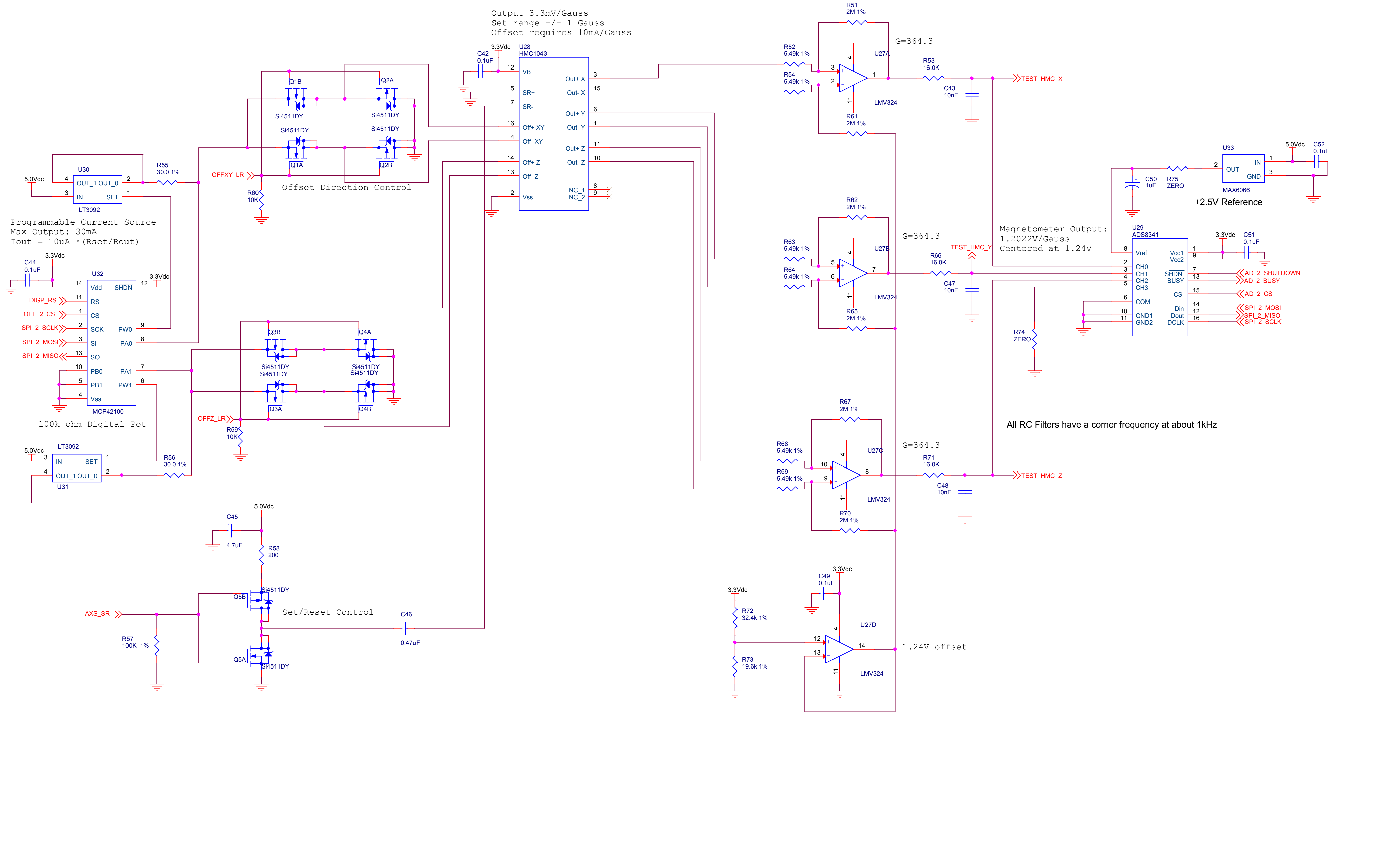
Title **FOCE Chassis Environmental Board**			Number **10020577**	
Size **C**	Engineer **Chad Kecy**	Layout **<Layout Eng.>**	Filename **<Filename>**	Rev **A**
	Date: Tuesday, July 27, 2010	Sheet 3 of 5		

Appendix B4



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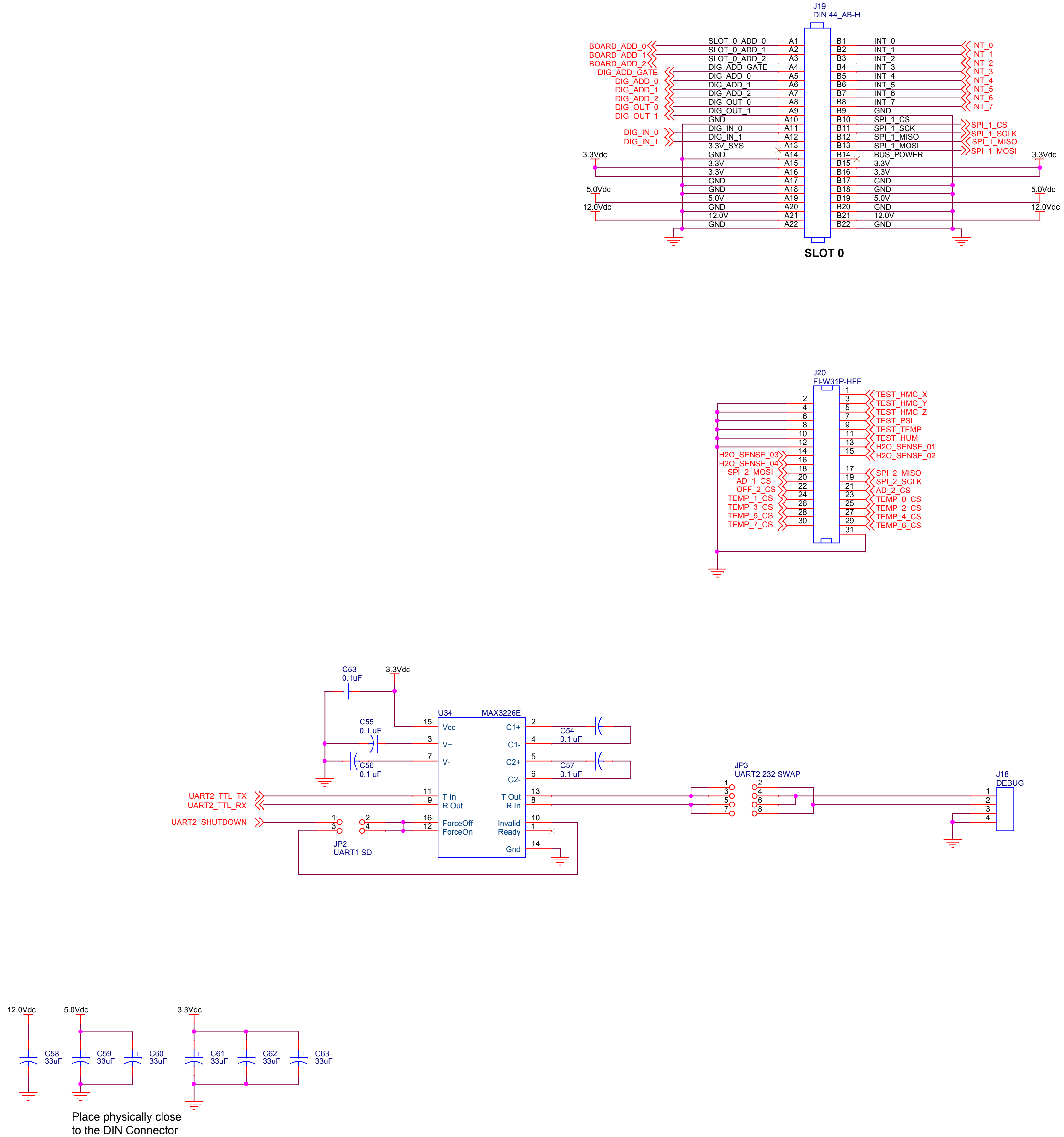
Title FOCE Chassis Environmental Board			Number 10020577	
Size C	Engineer Chad Kecy	Layout <Layout Eng.>	Filename <Filename>	Rev A
Date: Monday, August 02, 2010		Sheet 4 of 5		

Appendix B5



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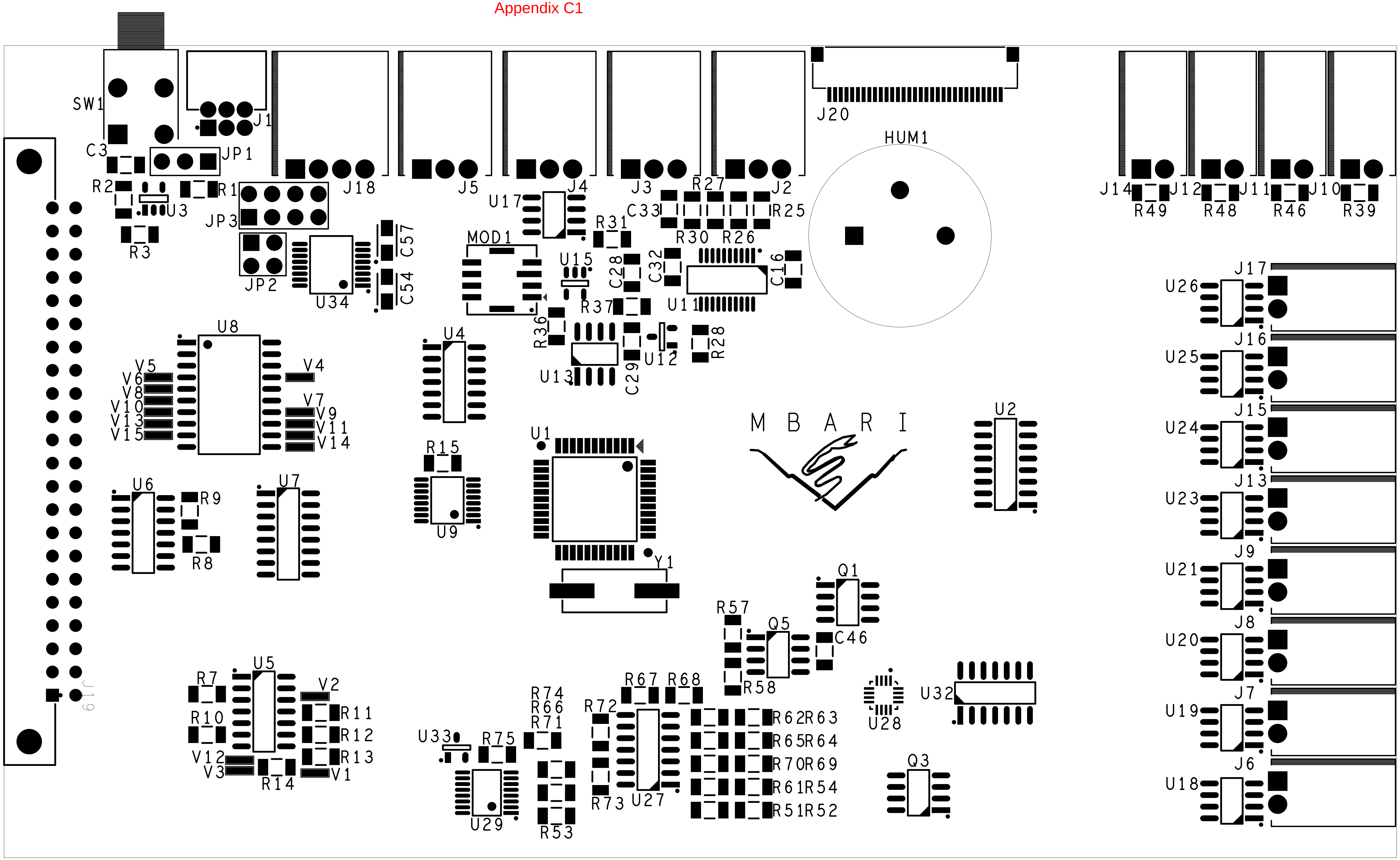
Title: FOCE Chassis Environmental Board			Number: 10020577	
Size: C	Engineer: Chad Kecy	Layout: <Layout Eng.>	Filename: <Filename>	Rev: A
	Date: Monday, August 02, 2010		Sheet 0 of 5	

Appendix C1



SW1
J1
C3
JP1
R2
R1
U3
JP3
R3
JP2
J18
J5
U17
J4
J3
R27
J2
C33
R25
R31
R30
R26
J20
HUM1
J14
J12
J11
J10
R49
R48
R46
R39
C57
C54
U34
MOD1
U15
C28
C32
C16
U11
R37
R36
U13
C29
U12
R28
J17
U26
J16
U25
J15
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J13
U23
J9
U21
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U20
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U18
U8
V5
V6
V8
V10
V13
V15
V4
V7
V9
V11
V14
U4
R15
U9
U1
Y1
M B A R I
U2
U6
R9
R8
U7
Q1
R57
Q5
C46
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Q3
U5
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R13
V12
V3
R14
V1
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R61
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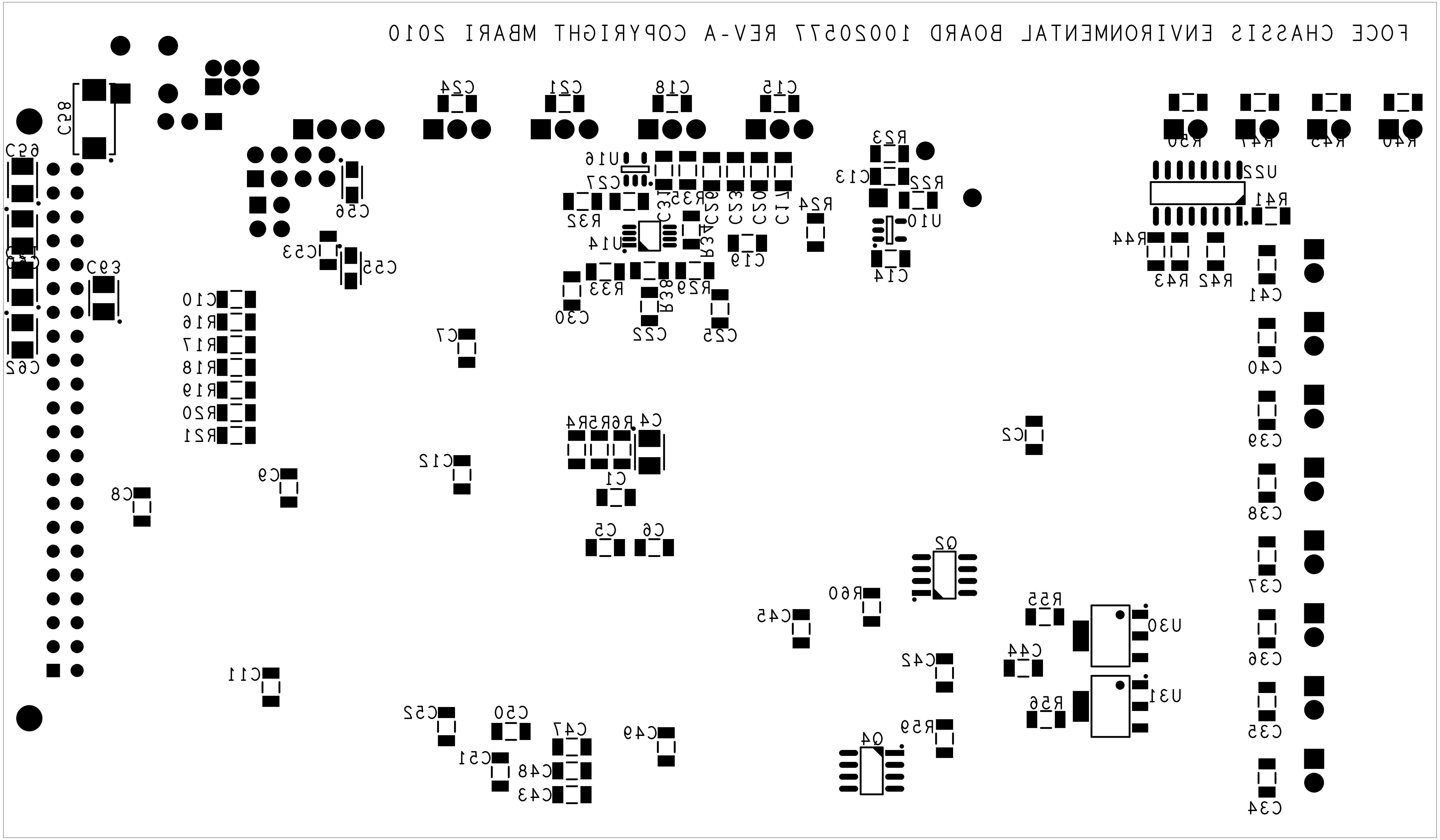
R52
J19

Appendix C2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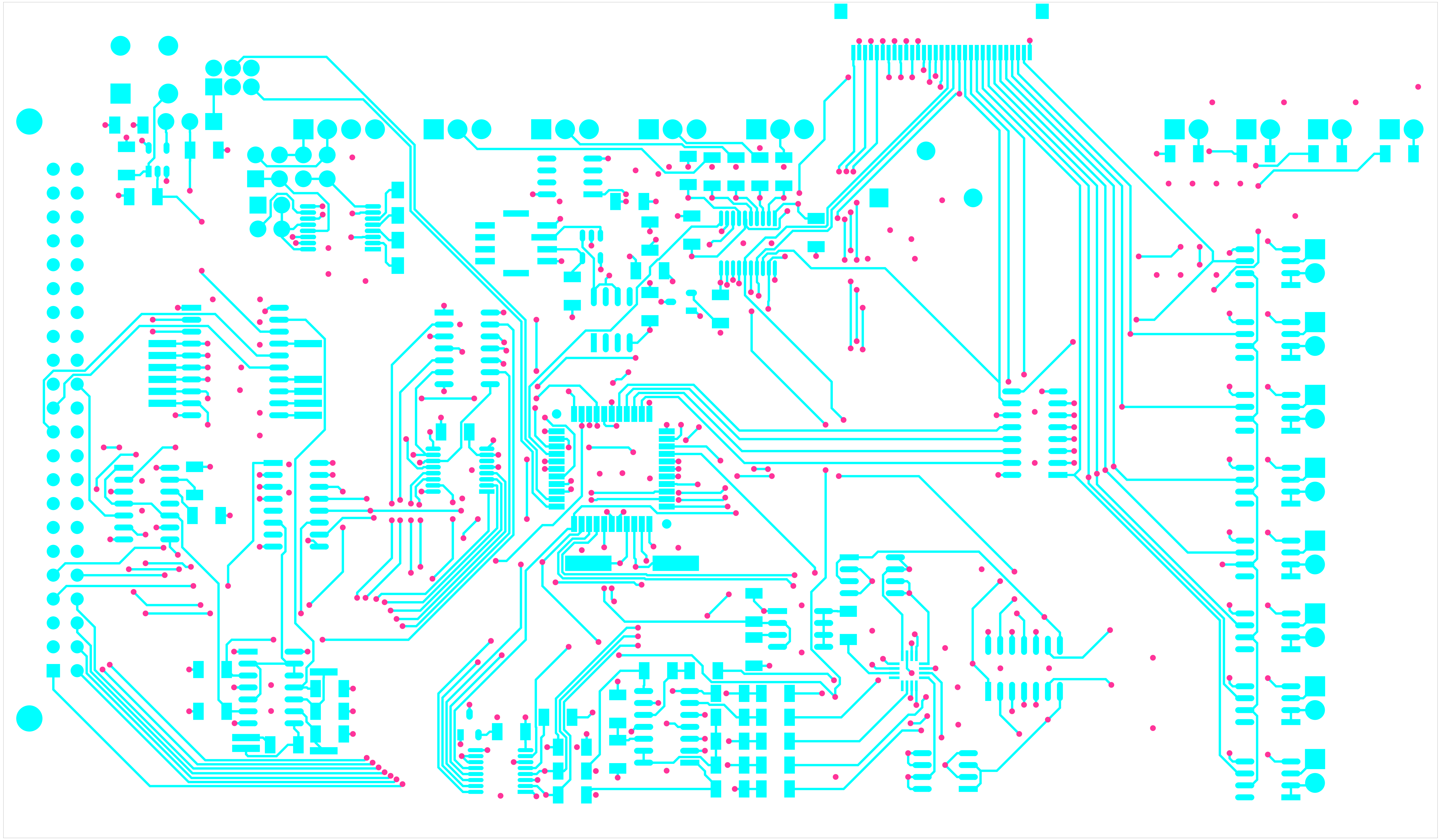
Appendix C3



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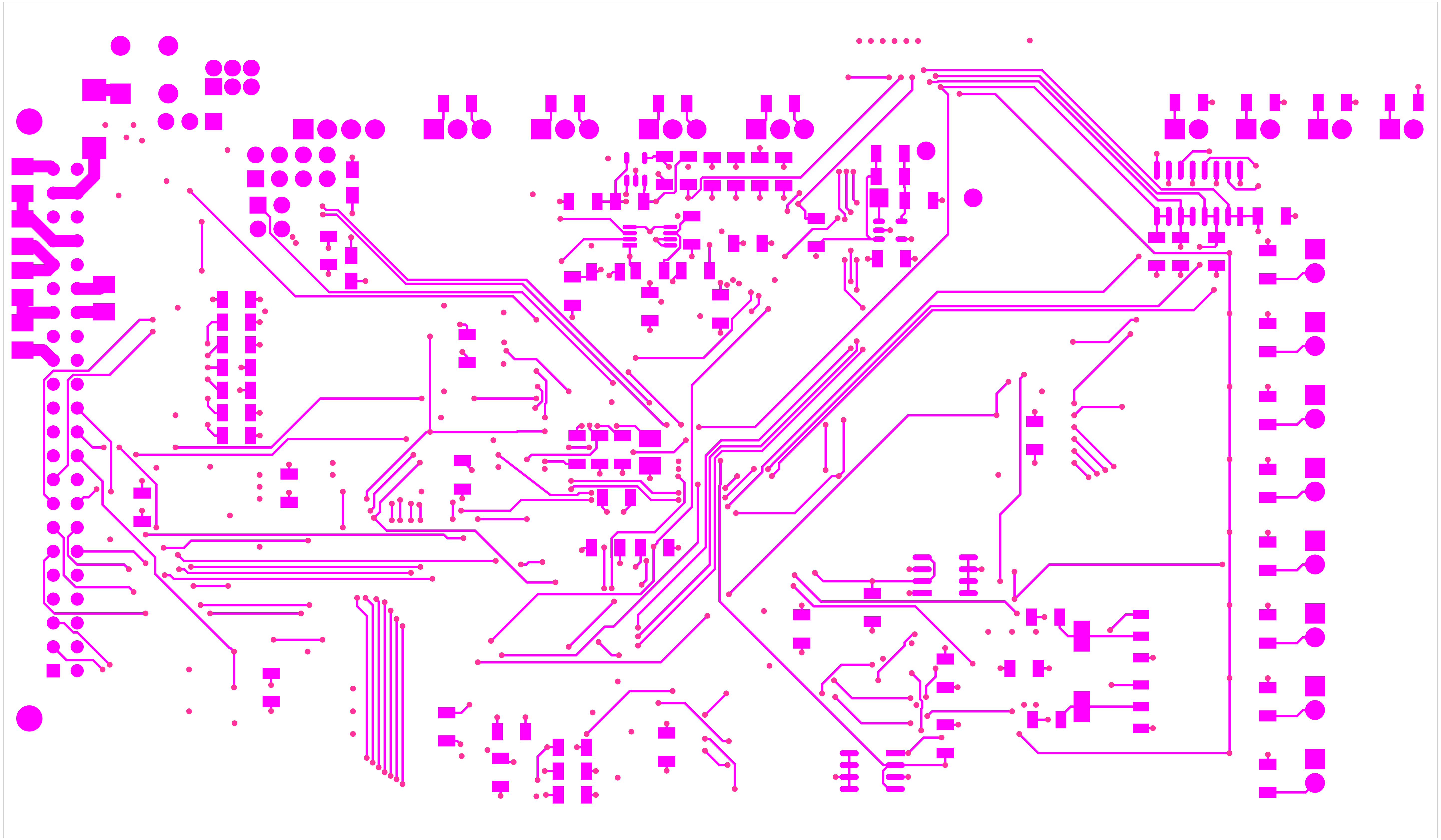

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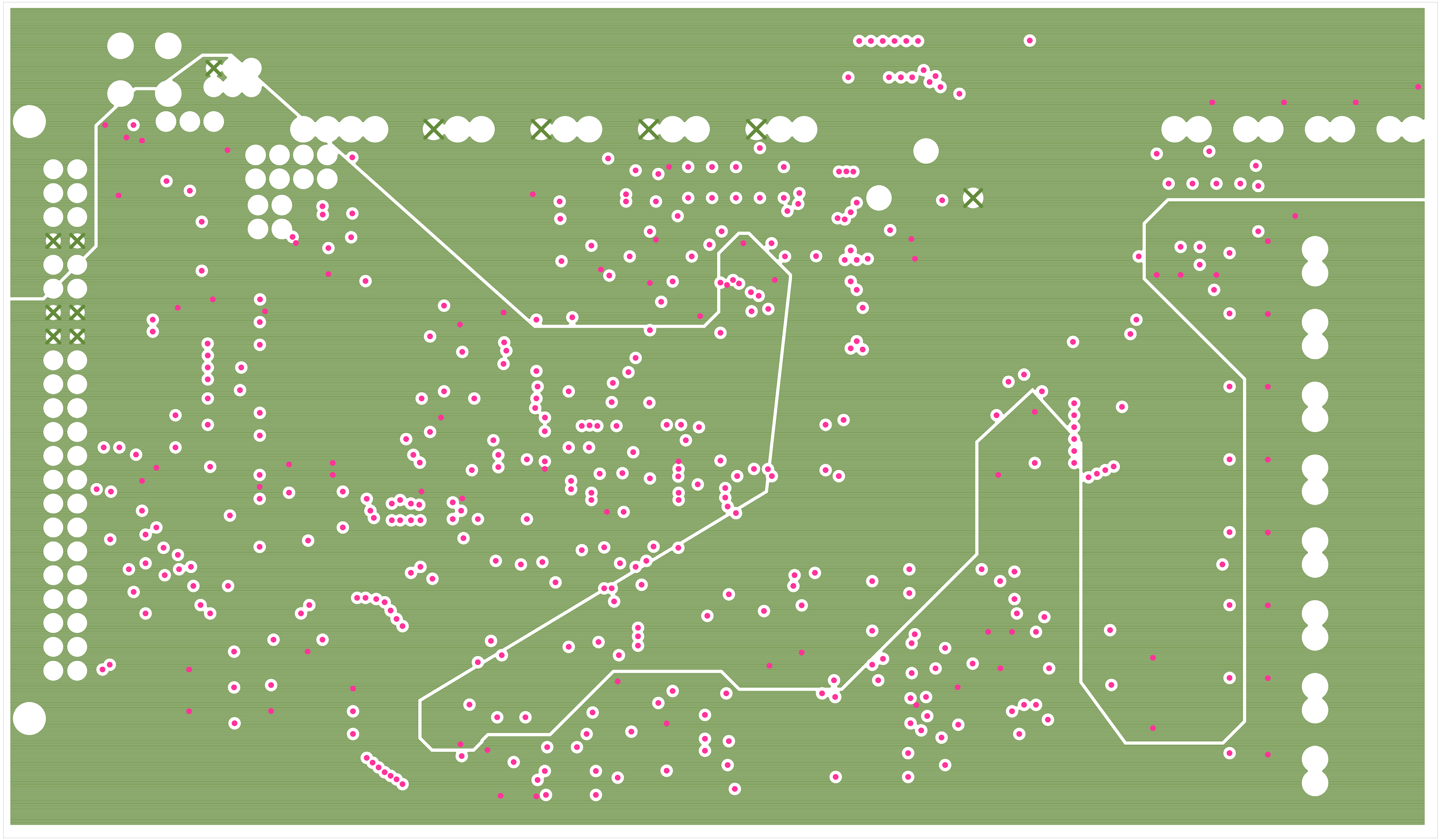

Appendix C6