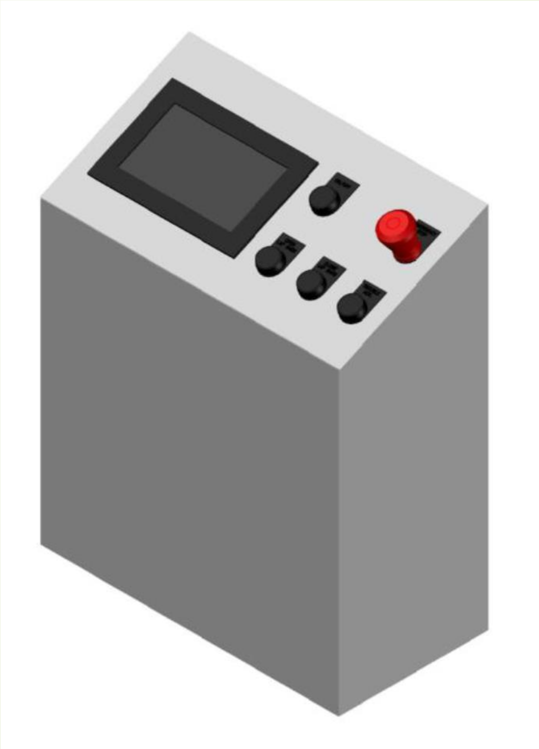
X-Car Electrical Maintenance Tool



Group 7

Alexander Washington

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Background

- The X-Car Electrical Maintenance (XEM) tester tool was designed to be used for ride vehicles at Universal Orlando's Hollywood Rip Ride Rockit (HRRR).
- The ride vehicle has circuitry onboard that act as a device under test (DUT) to the Ride Control System (RCS) at HRRR.
- When any of these DUT systems fail to respond, the RCS will stop the dispatch system for a fail-safe condition.
- The RCS interfaces with the ride vehicle through use of a bus bar and collector shoe combination.

Background (cont'd)

- Each ride vehicle has 8 separate current collector shoes which have their own purpose.
- Current collector shoe function:
  - 1- RFID Channel 1
  - 2- Ground
  - 3- RFID Channel 2
  - 4- Open Lap Bars
  - 5- Lap Bar Status
  - 6- Vehicle Present
  - 7- Signal Power
  - 8- Close Lap Bars

Motivation

- At Universal Orlando in the Technical Services department, our top goals are safety and reliability.
- Improve guest satisfaction by improving ride reliability.
- The X-Car Electrical Maintenance (XEM) troubleshooting tool was developed to eliminate troubleshooting bottlenecks.
- Current bottlenecks include a lack of high power output to operate lap bars, difficulty measuring weak connections, and testing the feedback signals from ride vehicles.
- The challenge is also a motivation to the designer because of the desire to improve, learn and apply new technical and engineering skills.

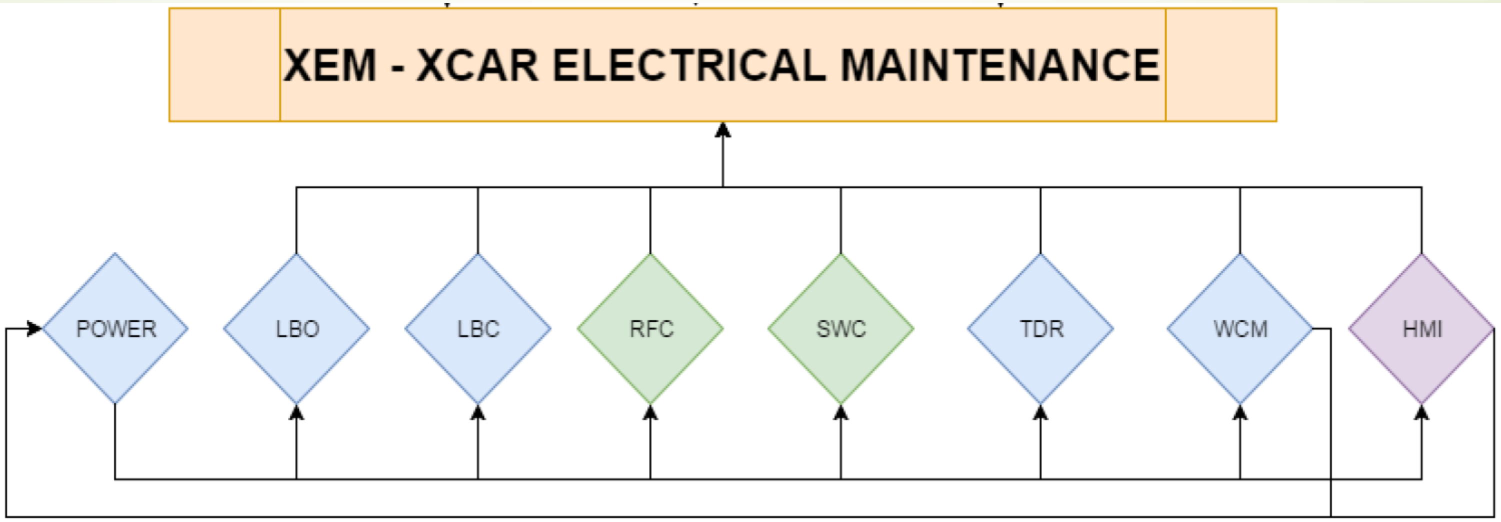
Goals and Objectives

- The XEM will simulate the RCS in the offline maintenance position allowing end users to troubleshoot more efficiently.
- The XEM has a few different connectors which allow for troubleshooting different parts of the ride vehicle onboard circuitry.
  - There is the Bus Bar Connector, the X21 Connector, and coaxial cable.
- The XEM will measure resistances, voltages, and currents being used by the ride vehicle DUT.
- The XEM will detect loose, broken, or damaged connections.
- The XEM will use the same logic in the RCS to test the ride vehicle.

Specifications

- The XEM will be powered by a 120V/20A socket.
- The XEM will provide 1.2kW of DC power at 24V.
- The XEM will detect resistances in the tenth of an ohm range.
- The XEM will detect voltages in the tenth of a Volt range.
- The XEM will detect voltages up to 28V.
- The XEM will detect currents up to 50A.
- The XEM will monitor 6 different control/signal lines on the ride vehicle.
- The XEM will operate the lap bar mechanism on the ride vehicle.
- The XEM will provide fault monitoring of the hardware and messaging.
- The XEM lap bar operation can be controlled remotely.

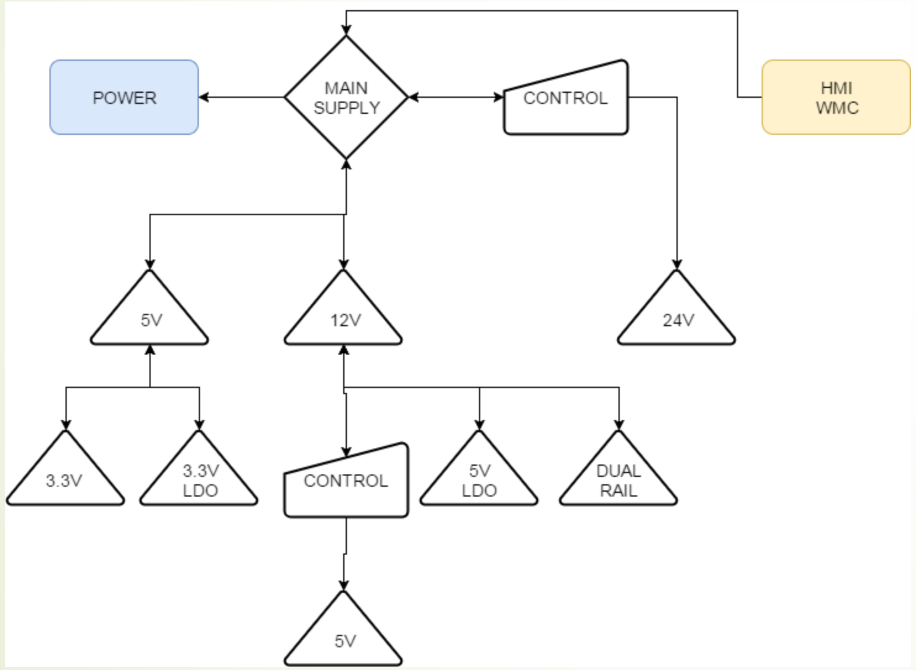
Overall System

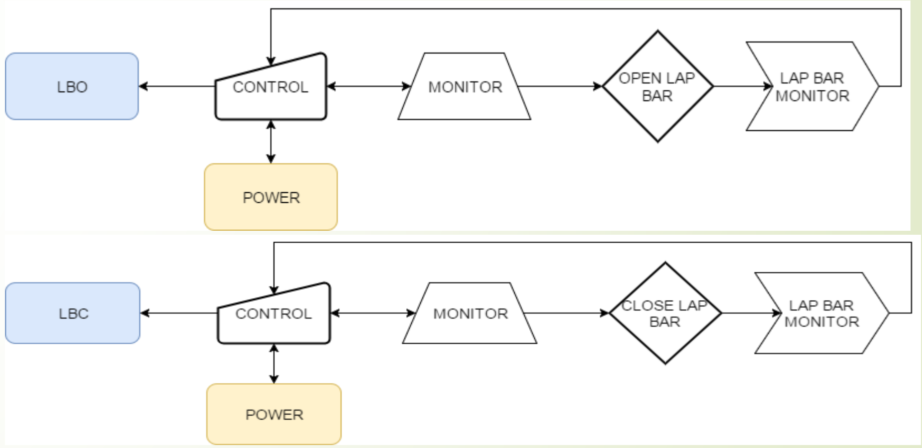


Definitions

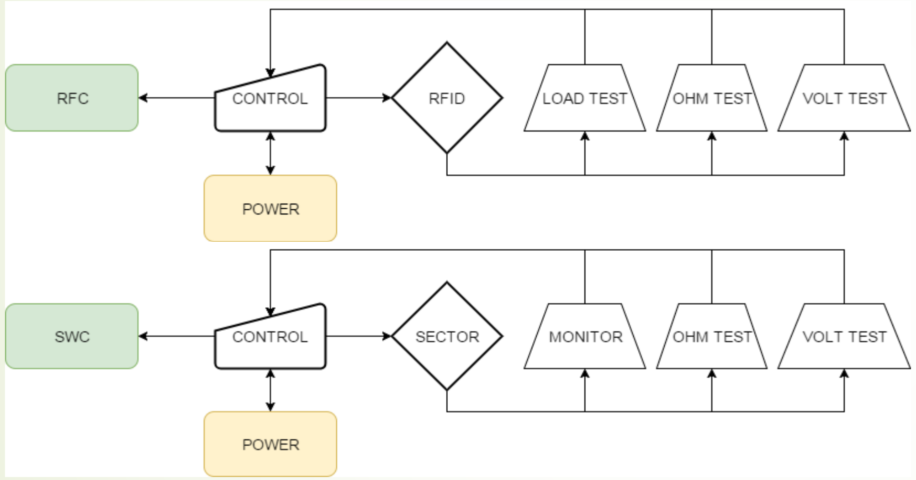
LBO - Lap Bar Open Circuit
LBC - Lap Bar Close Circuit
RFC - RFID Check Circuit
SWC - Sector Wiring Check Circuit
TDR - Time Domain Reflectometry Circuit
WCM - Wireless Control Module Circuit
HMI - Human Machine Interface Circuit

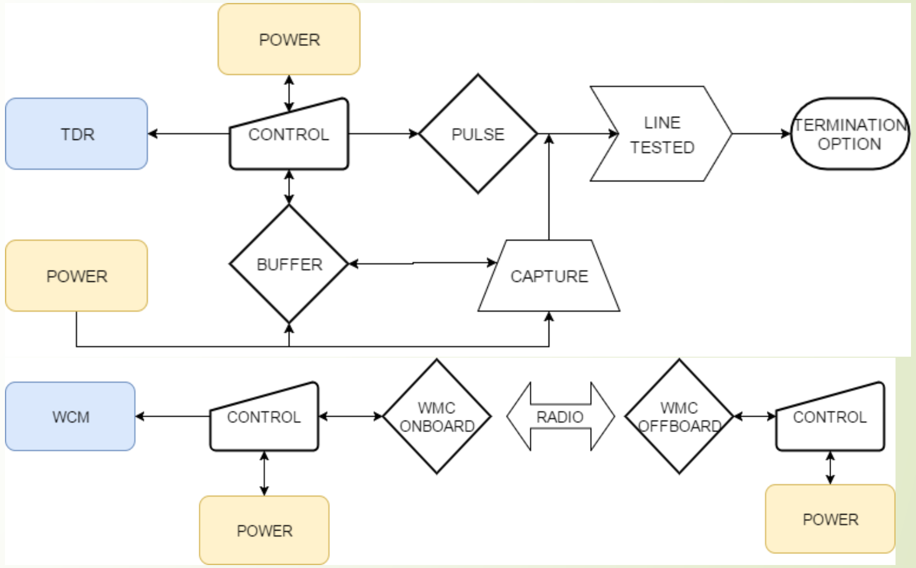
Sub-Systems – Power, Lap Bar Open/Close





Sub-Systems – RFID Check, Sector Wire Check, TDR, Wireless Control Module

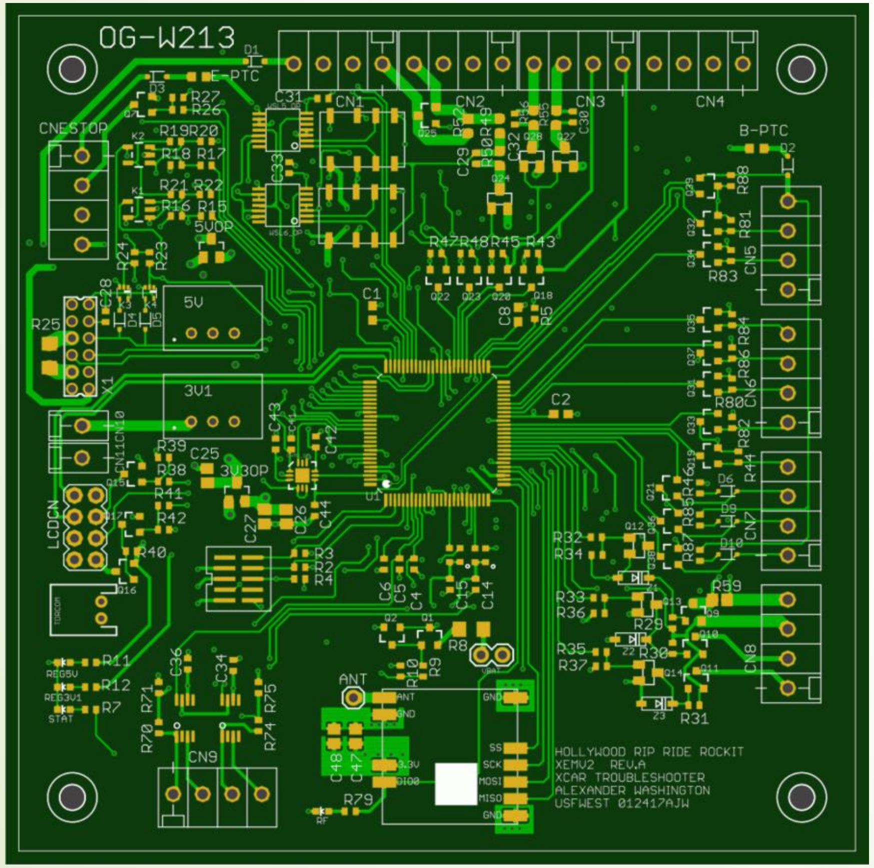


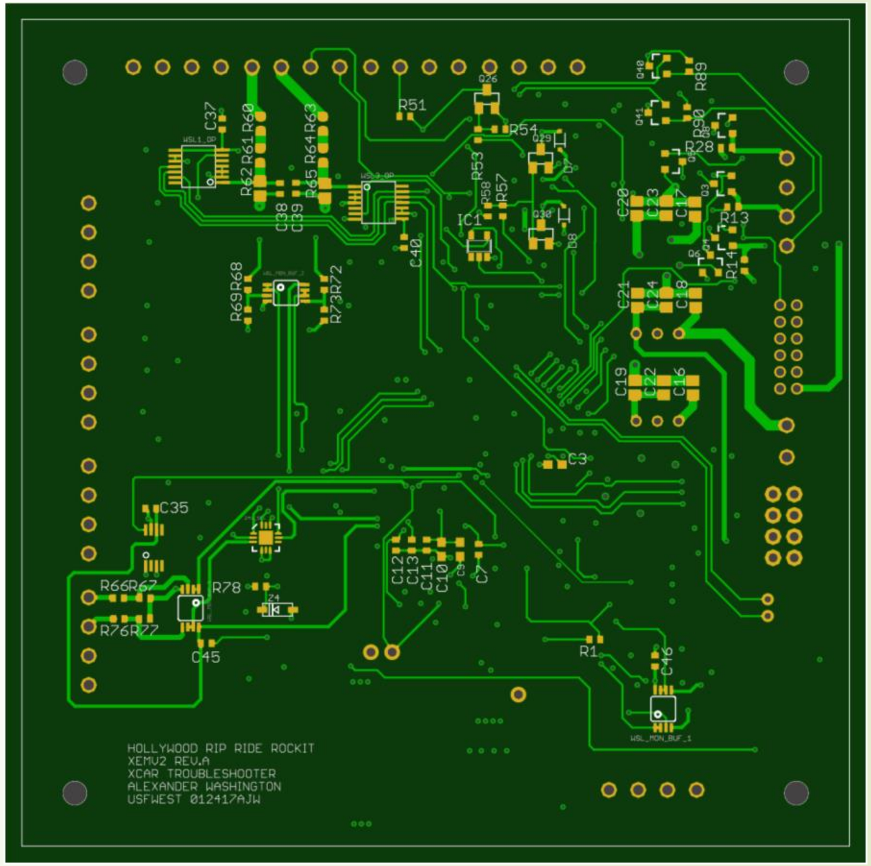


Overall Main Circuit Board

- Main controller with inputs and outputs for control onboard.
- Simulates the RCS logic.
- Provides safety functions.
- 1.6mm thick FR4 PCB.
- 4 Layer board
  - Upper – Signals and Components
  - Upper Middle – Power
  - Lower Middle – Ground
  - Lower – Signals and Components

Overall Main Circuit Board

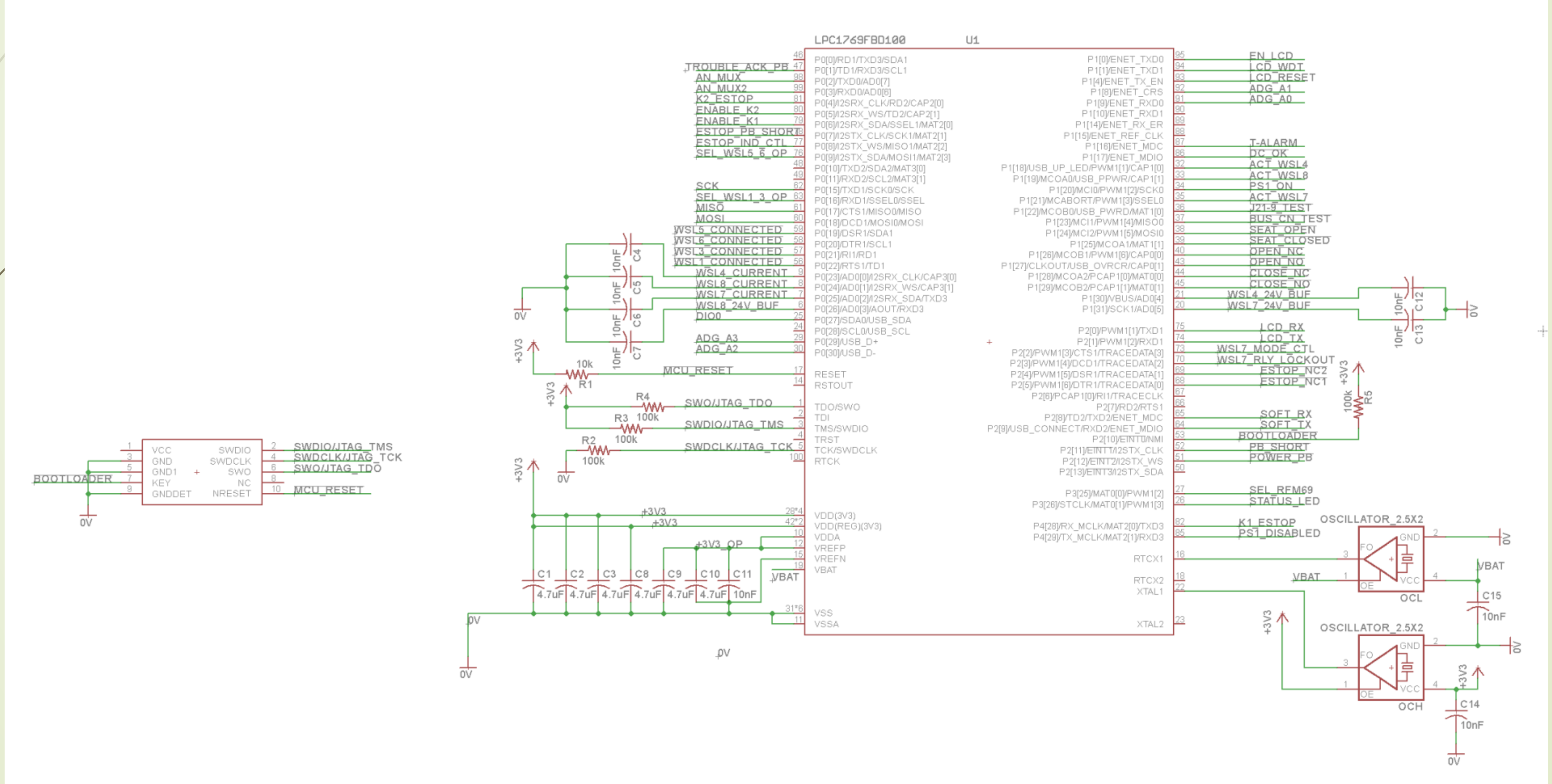




Microcontroller

- XEM uses NXP's LPC1769 microcontroller
- ARM architecture
- 100 Pin LFQP package
- 120MHz clock frequency
- Operates at 3.3V
- Handles 5V inputs

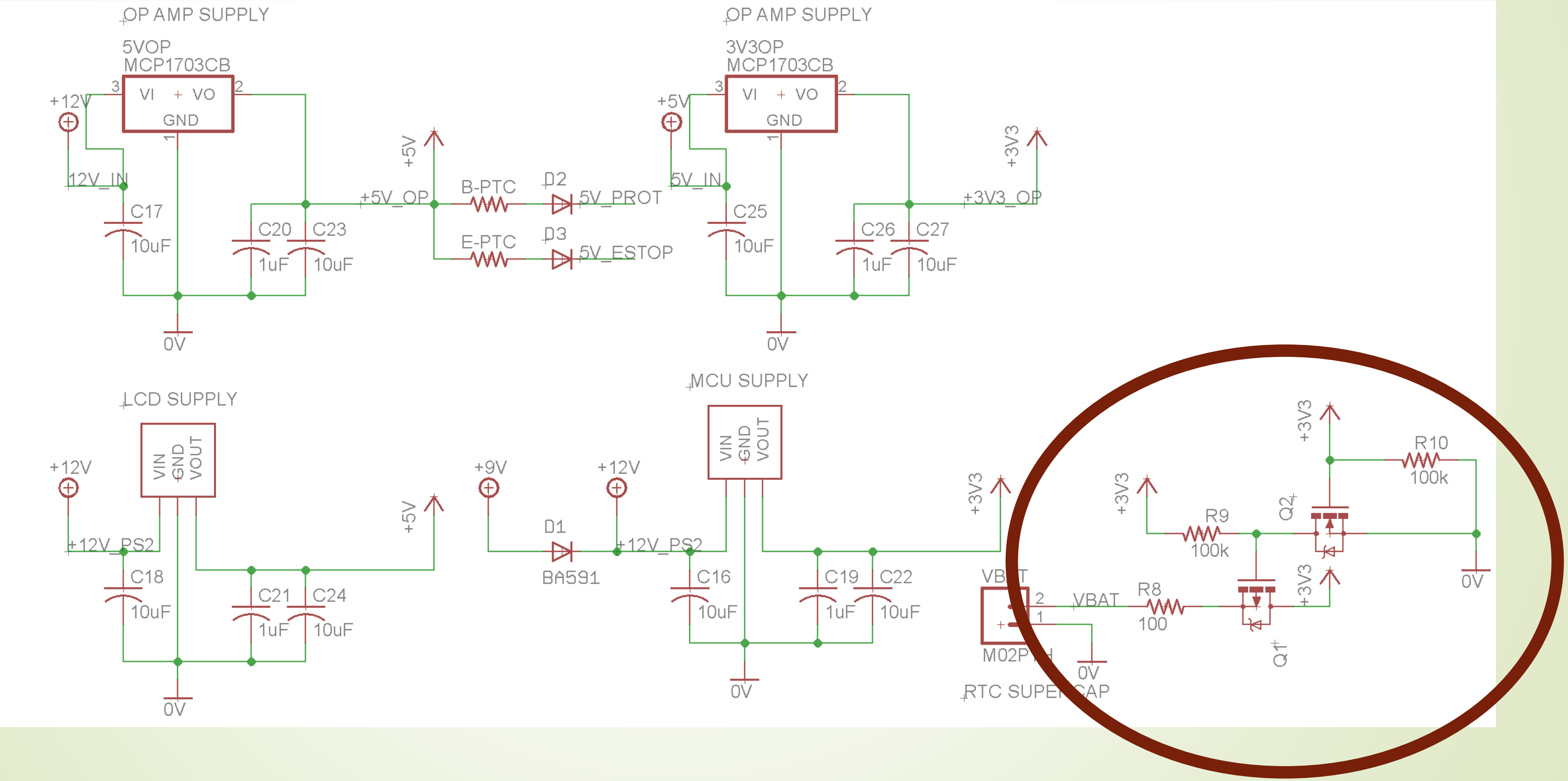
Microcontroller Circuit



Power Supply

- The XEM has an intricate power supply system.
- The power supply system involves a high power 24V system, a low power 24V supply, a moderate 12V supply, a low power 5V supply, and low power 3.3V supply.

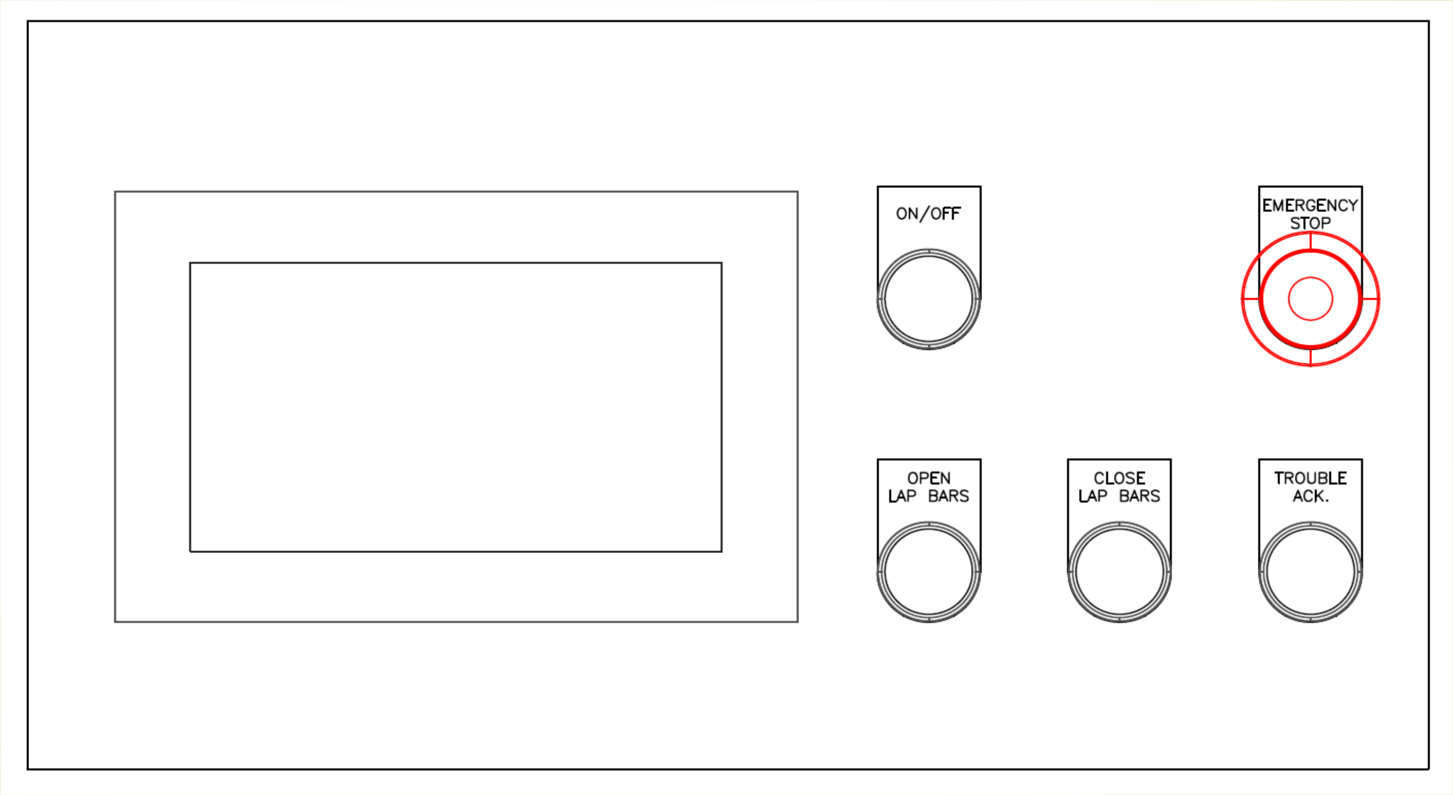
Low Power Supply Circuits



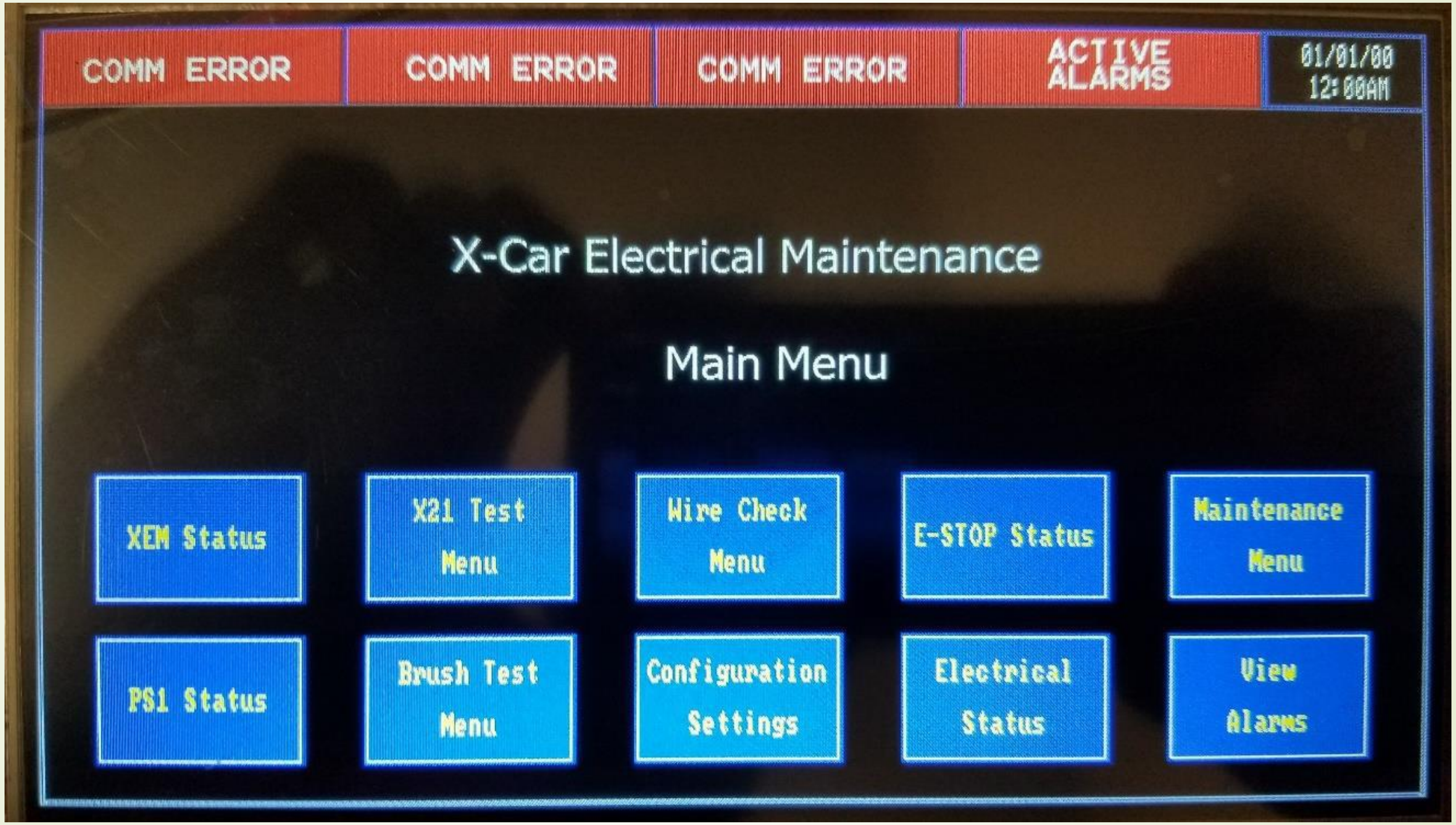
Human Machine Interface (HMI)

- Provides interface for end user control
- Has hardware buttons for inputs to the XEM circuitry
- Test modes and configuration settings are modified using the HMI
- Alarms and other informational messages are displayed through the HMI
- Safety circuit is tied in to the HMI through hardware push button and software push buttons

Human Machine Interface (HMI)



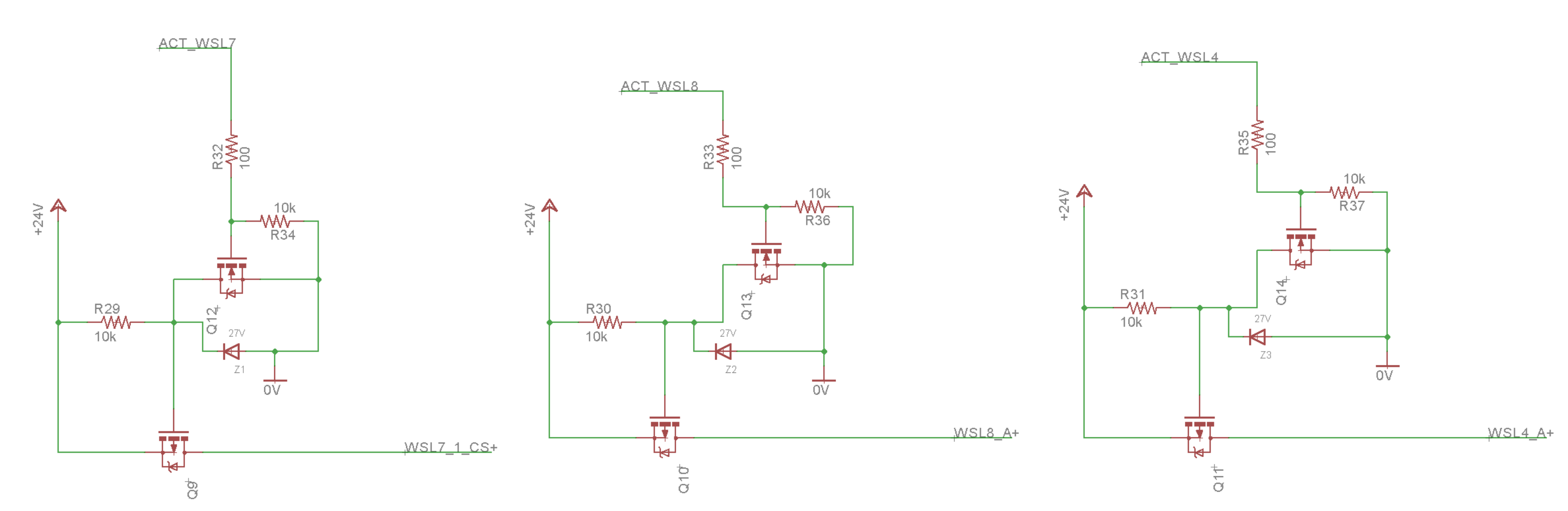
Human Machine Interface (HMI)



Lap Bar Control

- There are separate controls for opening the lap bar and closing the lap bar.
- The open lap bar circuit uses the most power in the system.
- Solid state relays were used for reliability and ease of control.

Lap Bar Control Circuit

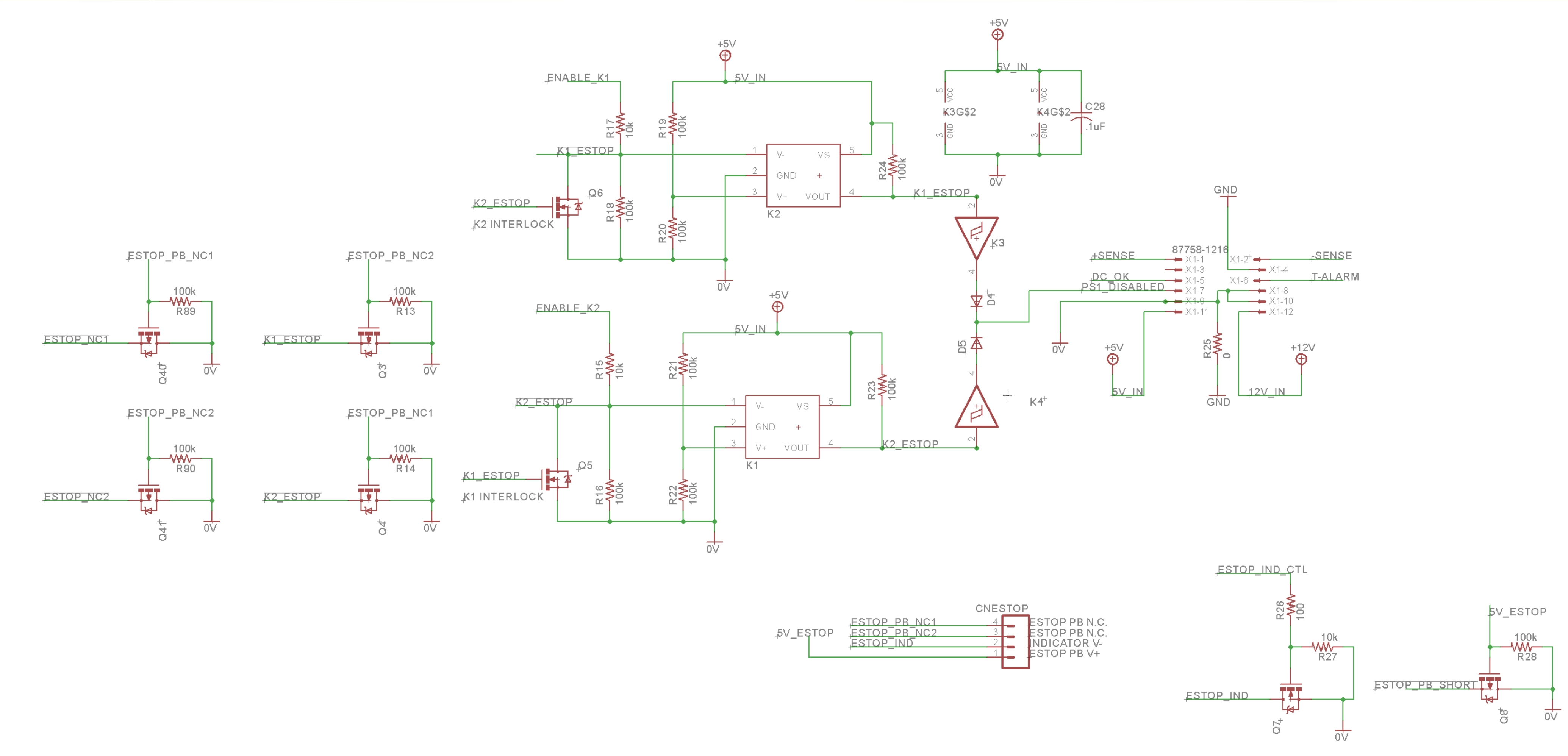


User/Equipment Safety

- There is hardware and software limitations to ensure the XEM is always in a controlled and safe state
- The software monitors for hardware failures and unsafe electrical states.
- The HMI also includes a hardware emergency stop button which can also prevent any failure or unsafe electrical state.
- The emergency stop circuit stops the high power outputs and 24V outputs.
- There are circuit breakers and fuses external to the circuit board that also protect the hardware.

ENABLE K1 ON	ENABLE K2 ON	ESTOP PB NC1	ESTOP PB NC2	PS1 ON
0	x	x	x	0
x	0	x	x	0
x	x	0	x	0
x	x	x	0	0

User/Equipment Safety Circuit



Measurement Circuits

- The XEM uses multiple measurement circuits to find potential errors
  - Voltage
  - Current
  - Resistance

Amplifier Comparison

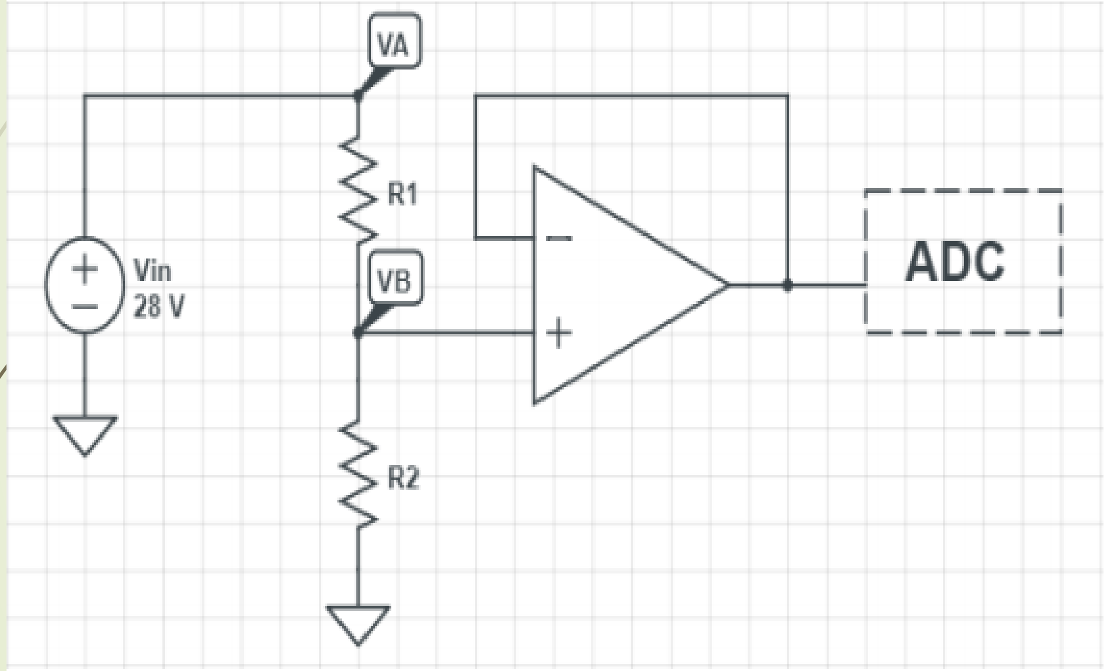
AD8626

- 500 microvolt offset
- 1 picoamp input bias
- 5 MHz bandwidth

TL084

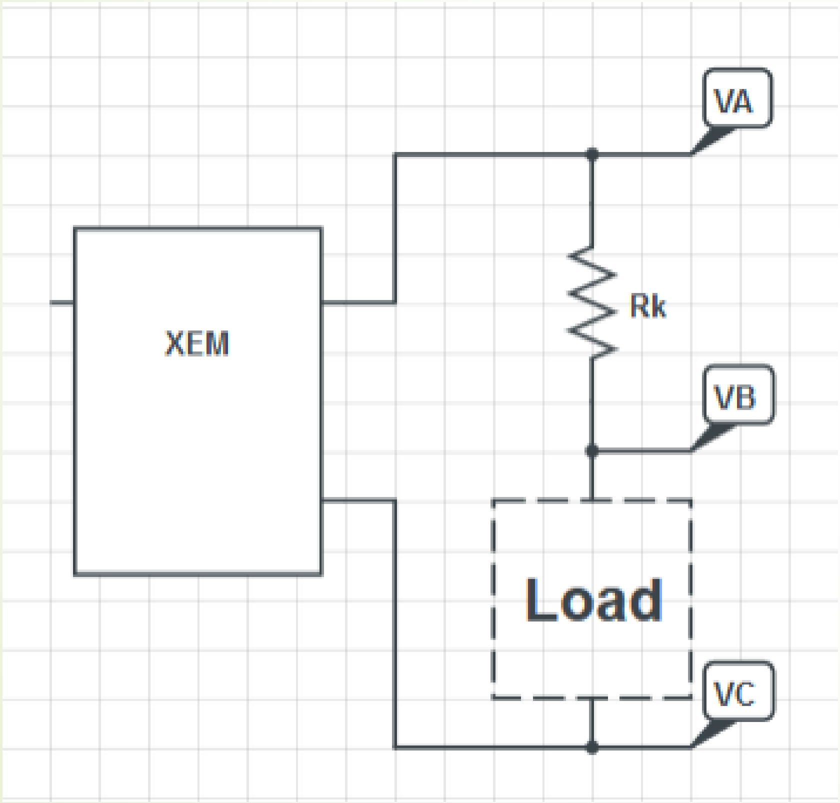
- 15000 microvolt offset
- 400 picoamp input bias
- 3 MHz bandwidth

Voltage Measurement



- Uses the ADC of the LPC1769
- Voltage divider driven, uses 20k and 180k resistors to divide the voltage by 10
- Buffer using AD8626 to protect the ADC from direct connection to the system

Current and Resistance



- Simple design, but not the best way to determine resistance or current
- Using known resistance value
- Read voltages to determine voltage changes
- Infer current and resistance

Current Sense Comparison

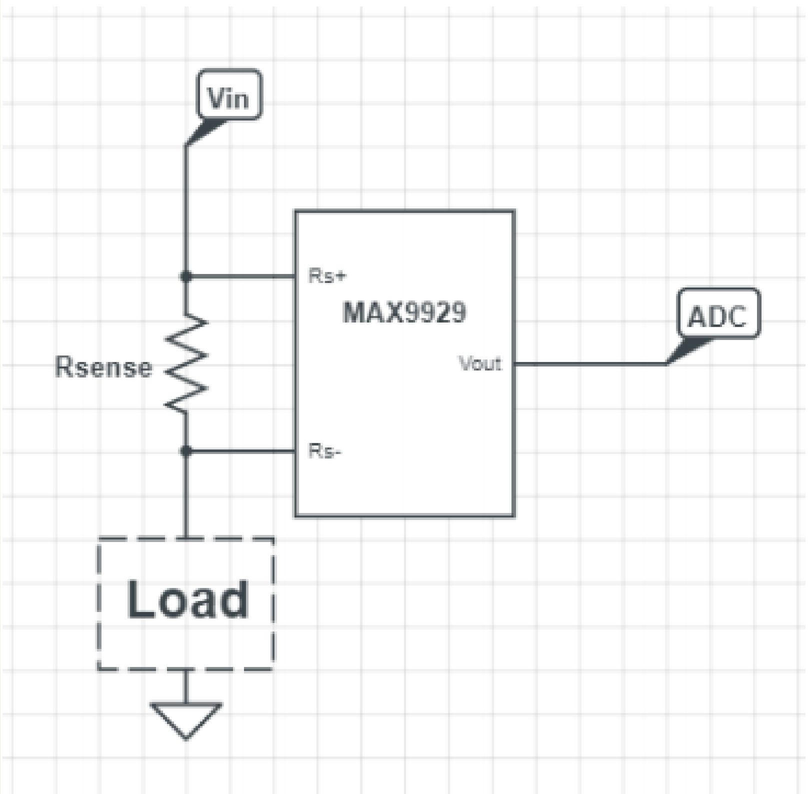
MAX9929

- Maxim Integrated
- -0.1 to 28 V
- 50V/V gain
- Voltage output

LTC6101

- Linear Technology
- 4 to 60 V
- Configurable gain
- Current output

MAX9929 Current Measurement



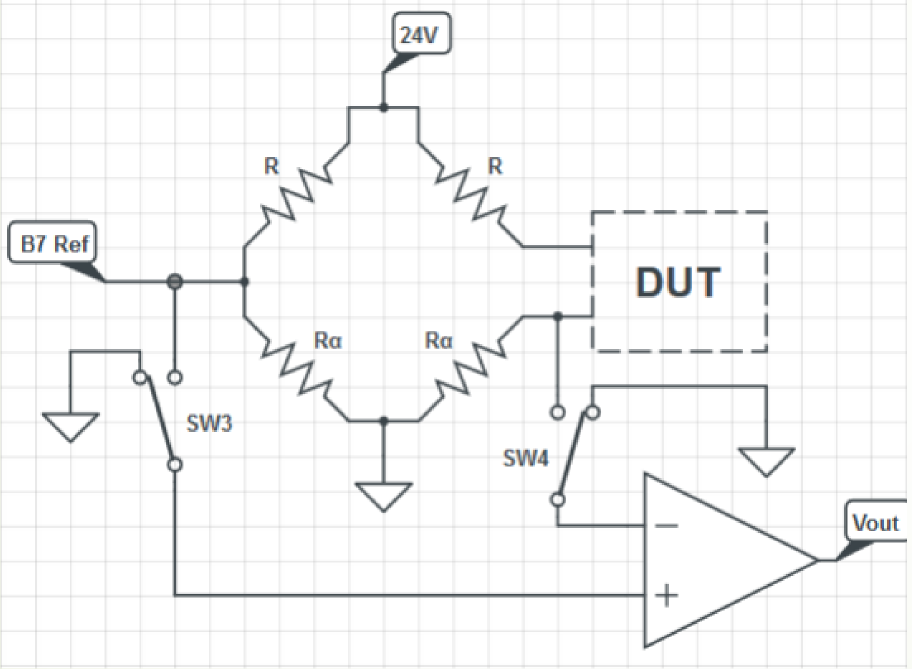
- Current Sense Amplifier
- High side, between source and load
- Internal comparator, output voltage
- R sense determines the output voltage
- Polarity across R sense is maintained

Sense Resistor

	Ω				
Parameter	**100**	**2500**	**5700**	**8000**	**10000**
mV	237.624	9.596	4.21	3	2.4
Gain sense	47524.75	1919.232	841.958	599.925	479.952
mV/mΩ	0.238	0.01	0.004	0.003	0.002
mV/mΩ gain	47.524	1.919	0.842	0.6	0.48
Steps/mΩ	58.973	2.382	1.045	0.744	0.596
mA	237.62	9.6	4.21	3	2.4
mW sense	56.47	0.09	0.02	0.01	0.01
mW resistor	5646.51	230.22	101.02	71.98	57.59
Error mΩ	0.21	5.21	11.877	16.669	20.835

- Higher resistance allows for more accurate measurement given a lower current
- High current through the sense resistor dissipates more power and is inefficient, and could possibly affect the MAX9929
- A tradeoff is made to determine the best choice

Wheatstone Bridge Resistance



- Wheatstone Bridge setup
- DUT added on the right side
- Causes the resistance to differ on the two sides
- Differential voltage measured and output to the ADC
- Low offset voltage needed

Wireless Control Module

- Utilizes an ATMega238P and RFM69HCW
- Simple input output application
- Typically disabled, until enabled by the XEM
- Three different signals
  - Open LB
  - Close LB
  - E-Stop
- The functions of each are the same as if executed by the main system

RFM69HCW

- Wireless transceiver, operating in the unlicensed ISM (Industry, Science, and Medicine) band.
- Operates on the 915MHz frequency
- Capable of transmitting up to 100mW and up to 300kbs, configurable
- Simple wire antennae could transmit signals through an office building, or over 500 meters in open air
- Transmits data packets up to 66 bytes long
- Features AES encryption (Advanced Encryption Standard)

- ATMega328P and RFM69HCW communicate through Serial Peripheral Interface
- The ATMega had three input buttons that when triggered will send the signal to the RFM69HCW
- The RFM then sends a signal to the XEM
- The XEM then executes the proper commands

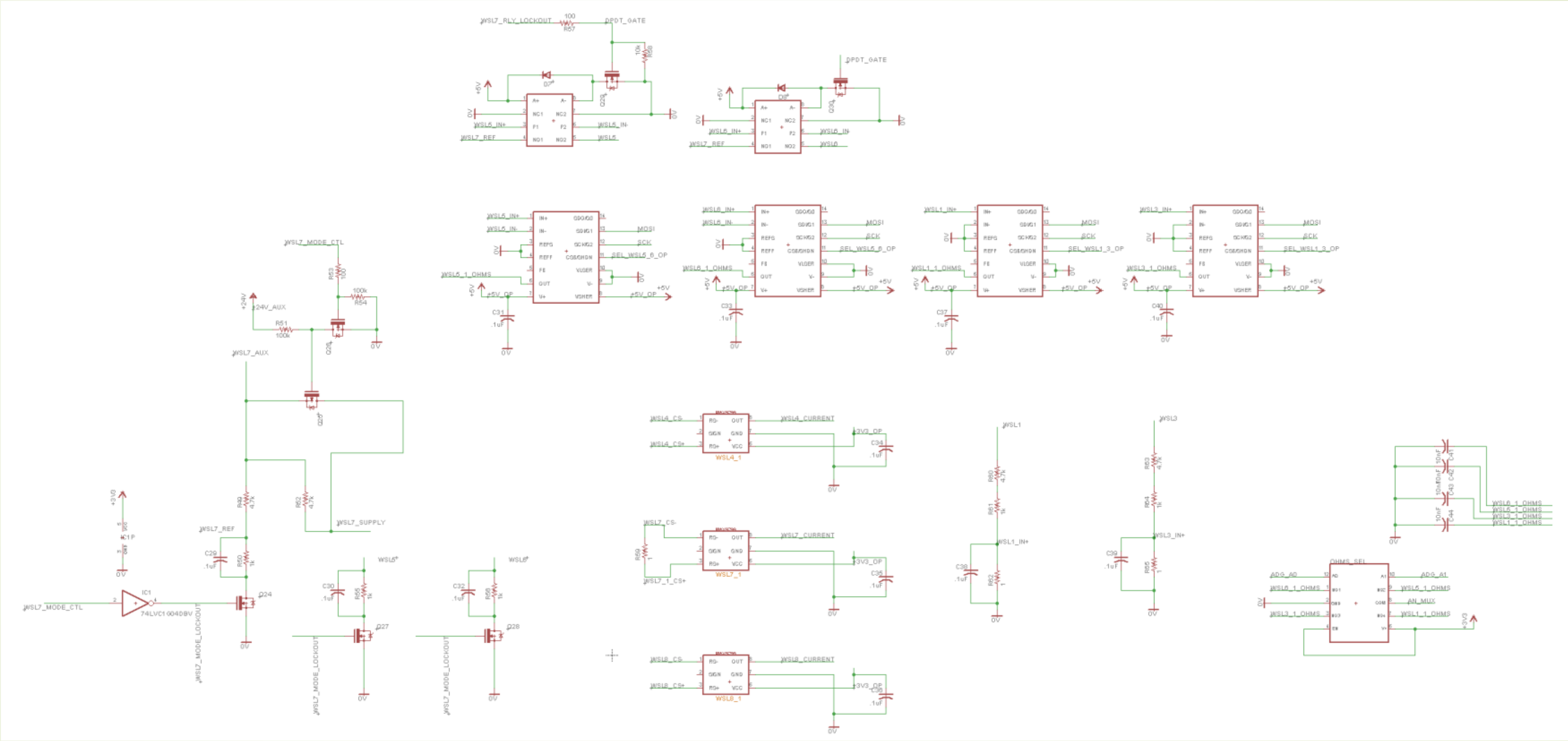
Power

- Lithium polymer battery, low power consumption
- External charging circuit
- Under voltage protection to prevent damage to the battery
- Battery level monitored by an LTC2944
  - A coulomb counter integrates current through a sense resistor between the battery's positive terminal and the load

Programming

- The WCM has two possible ports for programming
- By treating ATMega as slave, programming through SPI is possible
- The RFM can also be selected as slave
- The other option for programming is using USART

Monitoring Circuits



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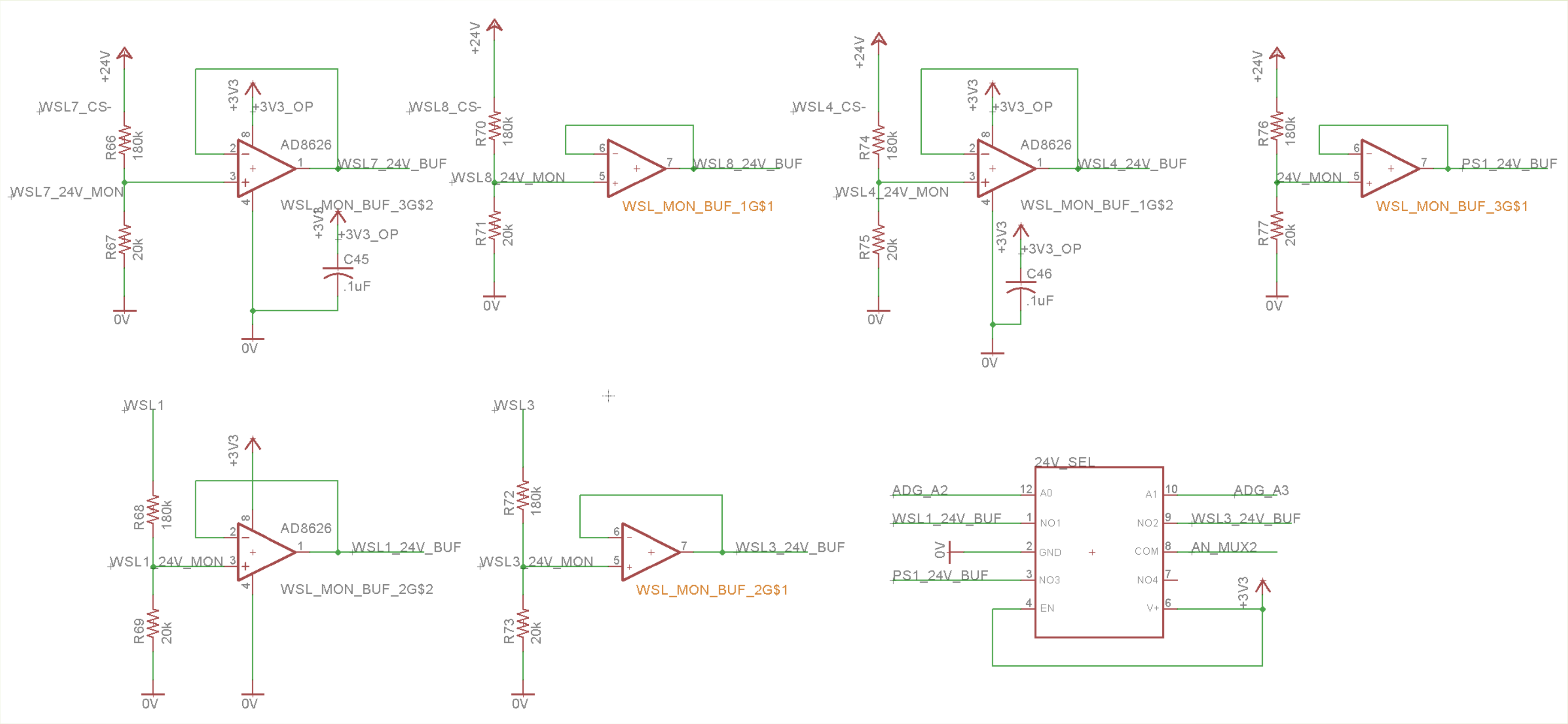

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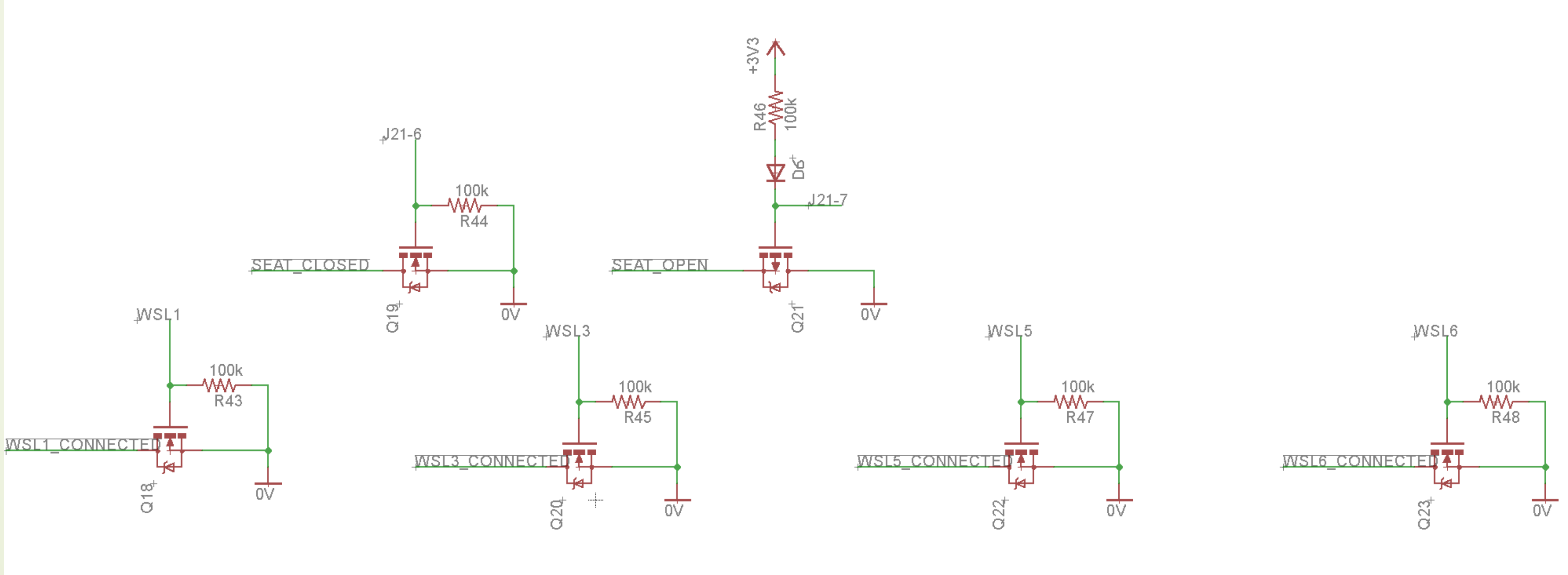

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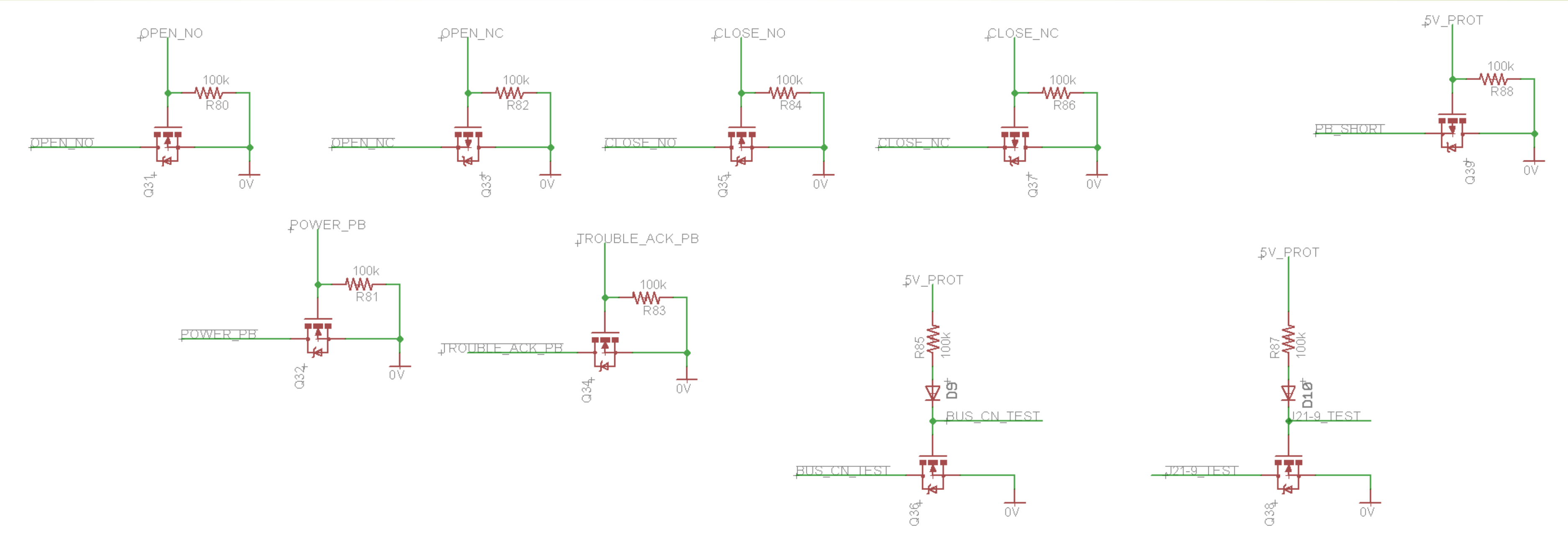
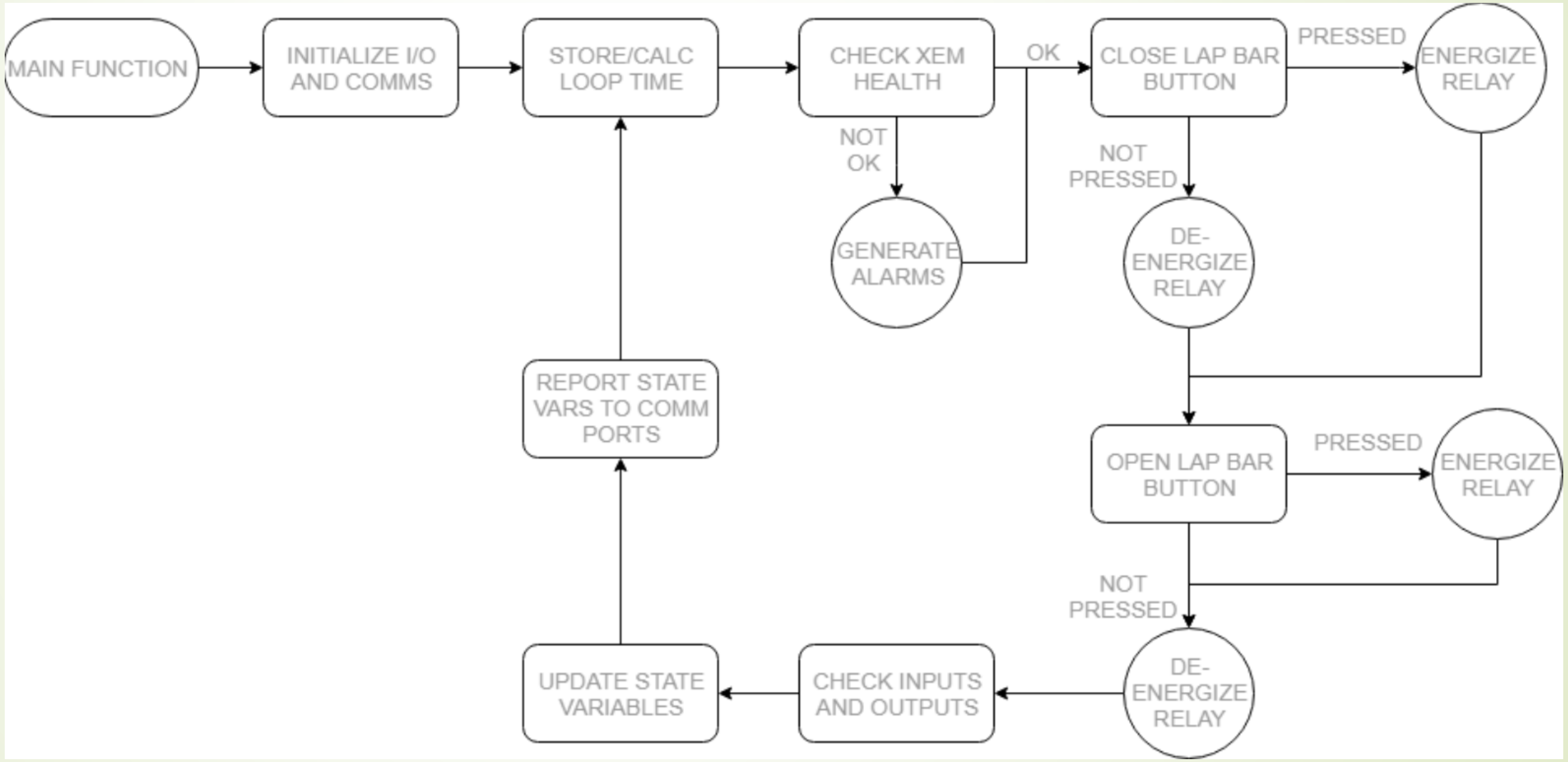


Software Design

- Four software programs needed to be written
- The XEM and TDR have NXP LPC microcontrollers and are written in C using LPCXpresso version of Eclipse IDE
- XEM's software was written to be similar to PLC ladder logic (outputs and states are actively written)
- The WMC uses ATMEGA328p and is written with Arduino software
- The HMI is written using proprietary language by 4D Systems, it is similar to C

Software Design – Flow Chart

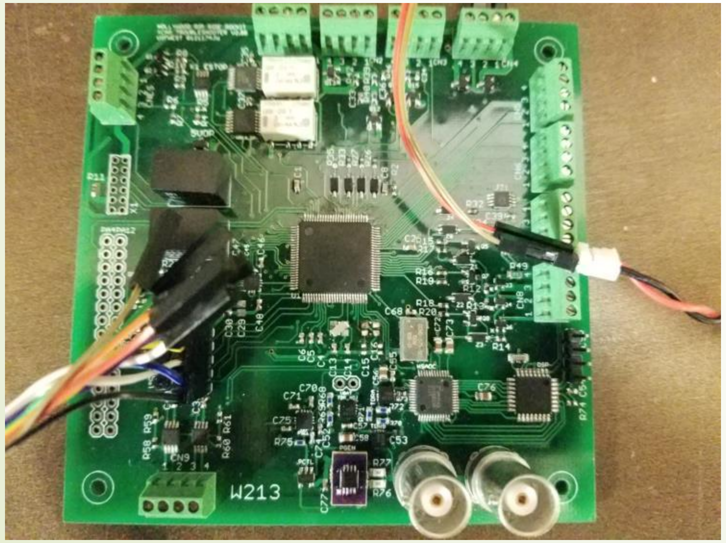


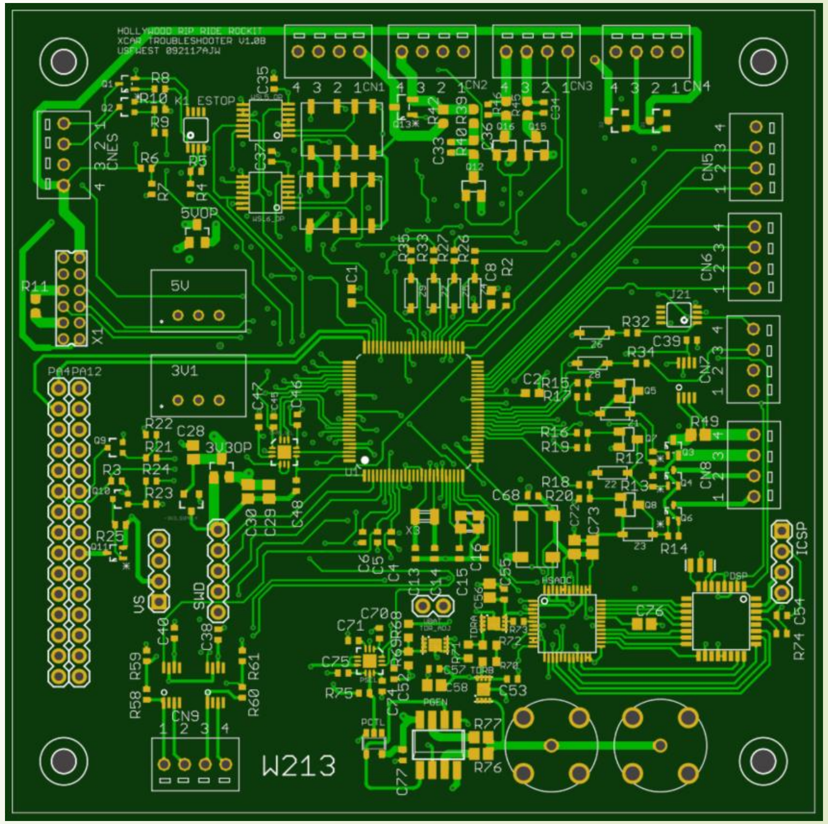
Software Design – Alarm Management

- Alarms are generated on the Main XEM program
- Alarms can be either warnings which disable a function or emergency stops which halts all operations
- Alarms are displayed on the HMI
- Alarms can only be cleared through the HMI

Design Failures & Improvements

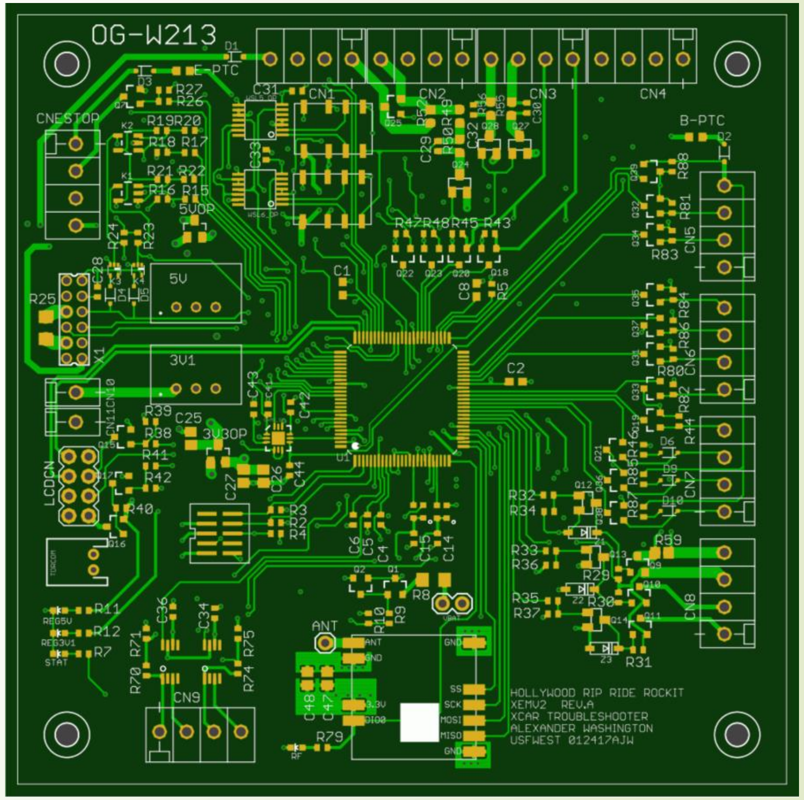
- Weak Programming Port Design
- Small Terminals
- Incorrect Footprints
- Poor TDR performance





Design Failures & Improvements

- Improved Programming Port Design
- Larger Terminal Blocks
- Corrected Footprints
- Added wireless control
- Improved TDR performance over five times the speed
- Improved power and grounding
- Added more signal isolation/protection
- Added more robust fail-safe hardware
- Added status LEDs



Budgeting & Sponsorship

- The budget was estimated and split in to 5 sections
- The XEM Chassis is the enclosure housing the XEM MAIN PCB and XEM TDR PCB
- The XEM REMOTE PCB is contained in the XEM REMOTE CHASSIS
- Sponsorship was provided by Universal Orlando

PART	COST
XEM MAIN PCB	$800.00
XEM CHASSIS	$2,500.00
XEM TDR PCB	$800.00
XEM REMOTE PCB	$200.00
XEM REMOTE CHASSIS	$300.00
TOTAL SPONSORSHIP:	$4,600.00

XEM Tool – Questions?