Simulate Op Amps with Load (Relay Control System)	Completed simulation. Op-amp control system was found to have various flaws. The device had too high of a load current to maintain operation for both amplifiers; the power dissipated was too high to prevent device failure; the maximum device voltage gain was insufficient for complete relay switching; and the input current required for operation could not be produced by the microcontroller. Old design was replaced with new PMOS relay control system. Op-amp is now used to
Get surfboards (Hardware testing)	Injector and relay control systems were constructed on surfboards and used in hardware testing. The injector control system data indicated that the new design would greatly increase device reliability, confirming simulation results. Relay control system hardware testing showed
Thevenin Equivalent Circuits	Thevenin equivalent circuits have been created for the fan/fuel pump relays and the injectors. Ignition circuitry was controlled by black box circuitry and could not be modeled. Input devices could also not be modeled at
EMF Voltage Surge from Injectors/Pspice Simulation	Injector circuitry has been tested in both hardware and simulation (using the Thevenin equivalent model for simulation). As expected, the injector was found to be creating a back EMF voltage surge which could damage the NMOS transistors. A feedback diode (1N4004) was
Voltage Regulator Operation Conformation	Voltage regulator was tested and found to be more than adequate for the operations required. Resistive loads added to the regulator to pull more than twice the maximum current required for net logic circuit operation on the ECU had no negative effect on regulator's operation.
Simulate Spark Operation	ECU has no direct contact with the spark plugs. ECU is instead wired to an Autronic CDI Box which operates the spark plugs based on ECU signal outputs. These outputs have been measured from the Motec ECU

Copper Heat Pads	Due to heat produced by the voltage regulators and the MOSFETs controlling the fuel injectors on the PCB, large pads were placed under the chips as suggested on the individual datasheets. The MOSFETs controlling
PCB Board Manufacturing and Population	PCB Boards have not been purchased as changes to the oxygen circuitry have been made. Once the changes are finalized, bars boards will be ordered and populated by
Supplementary Sensor Connections	One of the secondary goals of the ECU was the addition of extra sensors so that functionality such as traction control could be added at a later date without the need
Order New Board For Testing	It was decided that at the cost of $400 it was not necessary to purchase an additional board for testing. Testing code and testing the NI DAQ will both require the board, but will both require the NI DAQ system so

MOSFET Replacement/Failure Analysis Status:

Background:

Testing was completed last year by P08221 on the ECU, including results showing that the FDS6612A does produce the desired outputs during operation, but will fail on occasion for unknown reasons. The Formula Car battery produces +12.0Vdc across the injector circuit. A high voltage (+5.0Vdc) sent to the gate of the MOSFET turns it on making the device act like an open circuit, allowing current to flow across the injector through the MOSFET to ground. A low voltage sent to the device will turn the MOFET off, disconnecting the injector from ground and restricting current flow. P08221 believed that failure of the FDS6612A could have been caused by improper testing procedures, but still recommended looking into a potential replacement part. Two minor flaws were determined with the MOSFET which are more likely to cause the failures observed during operation than improper operating procedures. First, the power dissipated across the MOSFET device can cause the part to overheat. Without a heat sink, the device could fail during operation. A normal sized heat sink has been added to the PCB under each transistor to prevent this from occurring. Second, the injector contains a very large inductance, resulting in a massive emf voltage if not handled properly. To solve this problem, a 1N4004 diode has been placed across the injector to dissipate emf voltage and the MOSFET transistor has been upgraded to the more robust FDS8884.

Simulation Data:

Injector Parameters: (Constant resistance of 12.5 ohms)

Frequency	**L (Parallel)**	**L (Series)**	**Z (ohms)**
1KHz	28.7 mH	14.57 mH	128.3; 45.63°
10KHz	8.1 mH	4.217 mH	367.6; 46.2°
100KHz	2.74 mH	1.654 mH	128.3; 1.337°

Table 1: RLC Meter Measurements of Injector Impedance

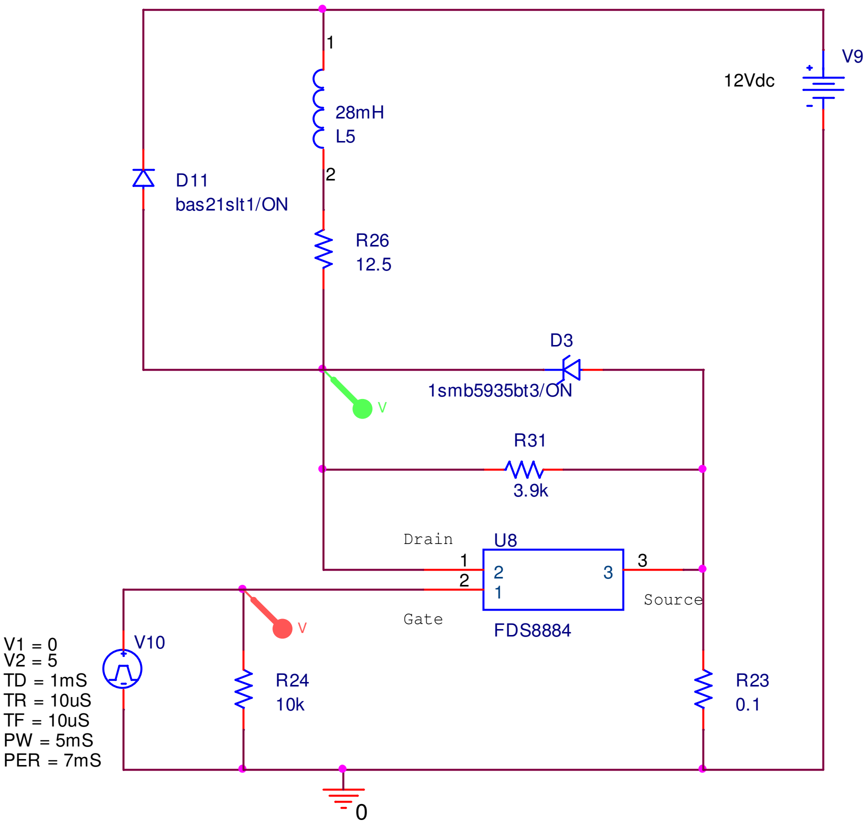


Figure 1: Injector Simulation Design with Implementation of Injector Feedback Diode

Figure 2: Injector Simulation Output Voltages with Implementation of Injector Feedback Diode

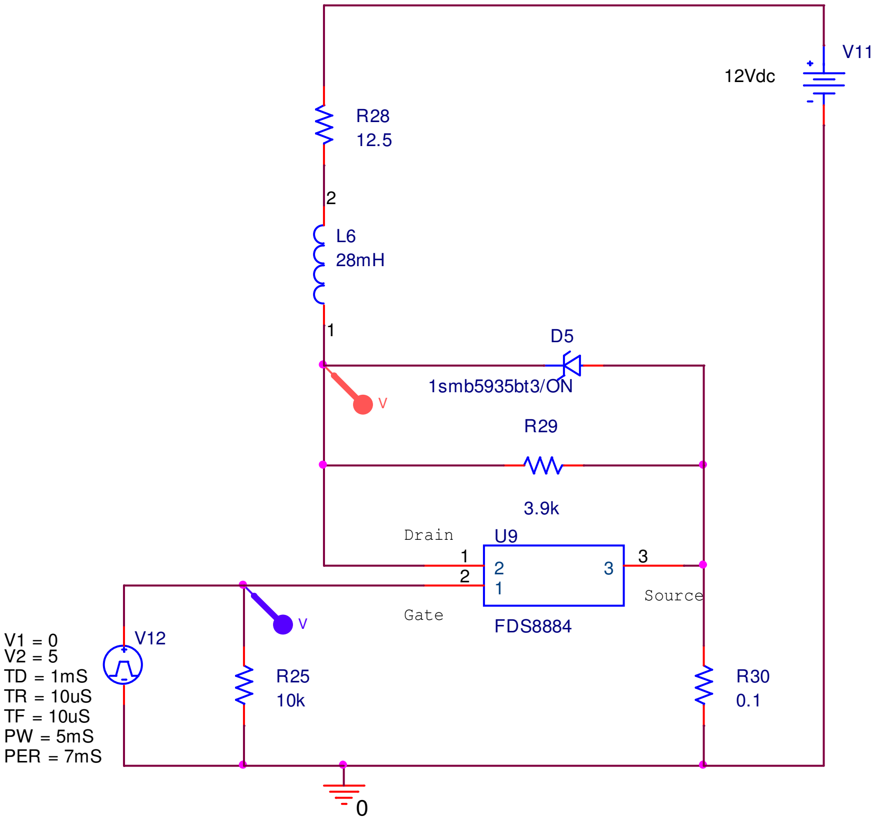


Figure 3: Injector Simulation Design without Implementation of Injector Feedback Diode

Figure 4: Injector Simulation Output Voltages without Implementation of Injector Feedback Diode

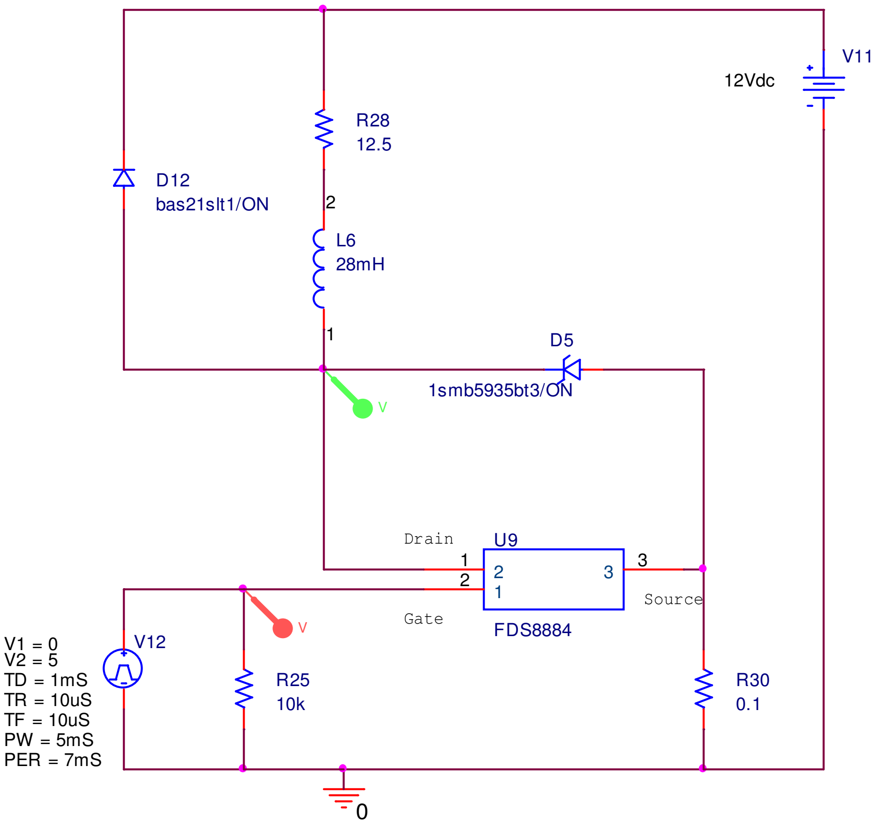


Figure 5: Injector Simulation Design with Implementation of Injector Feedback Diode but without Source-Drain Feedback Resistor

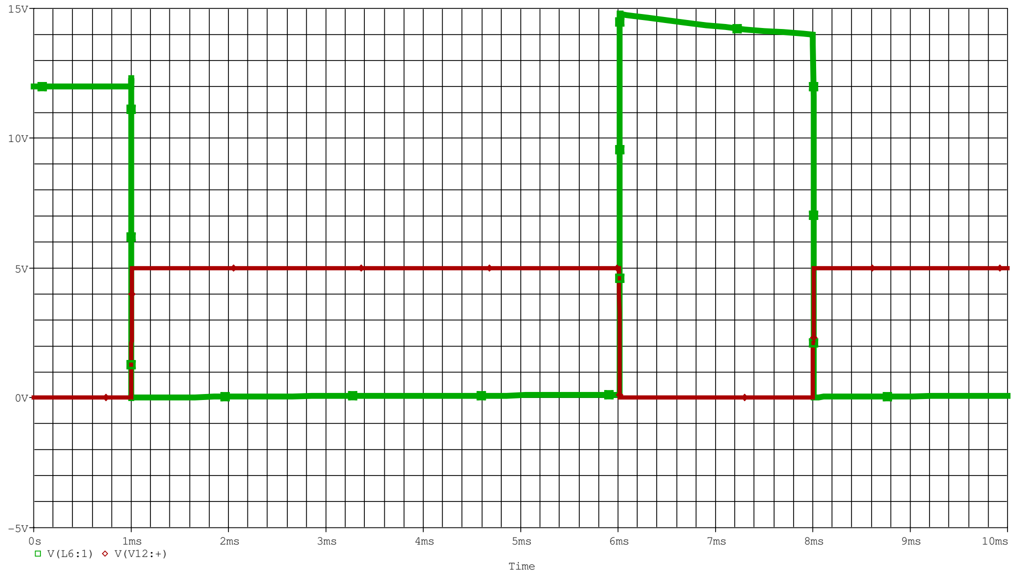


Figure 6: Injector Simulation Output Voltages with Implementation of Injector Feedback Diode but without Source-Drain Feedback Resistor

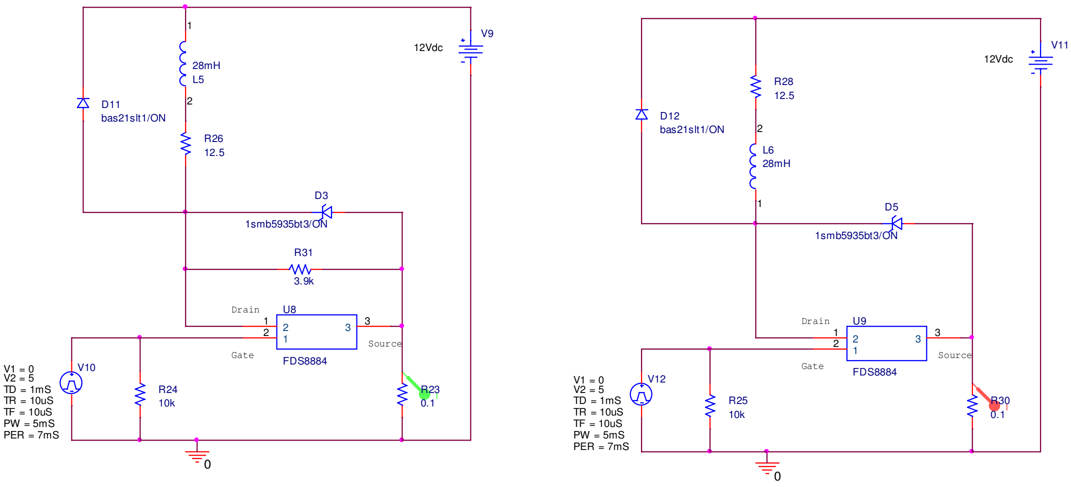


Figure 7: Comparison of Injector Simulation Designs Using Injector Feedback Diode to Observe Effect of Source-Drain Feedback Resistor

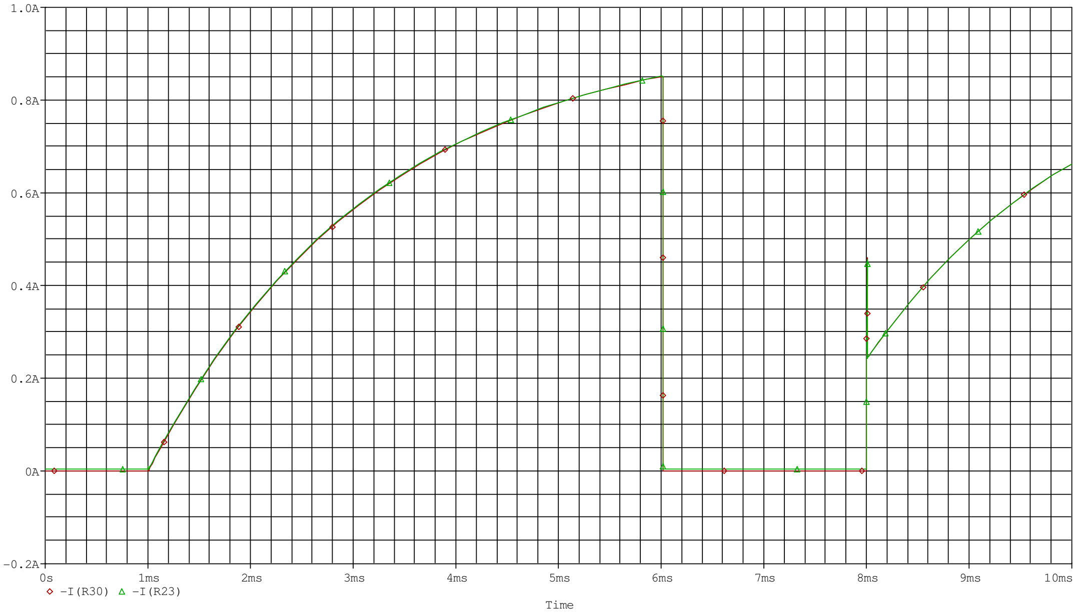


Figure 8: Comparison of Injector Simulation Output Currents with Use of Injector Feedback Diode to Observe Effect of Source-Drain Feedback Resistor

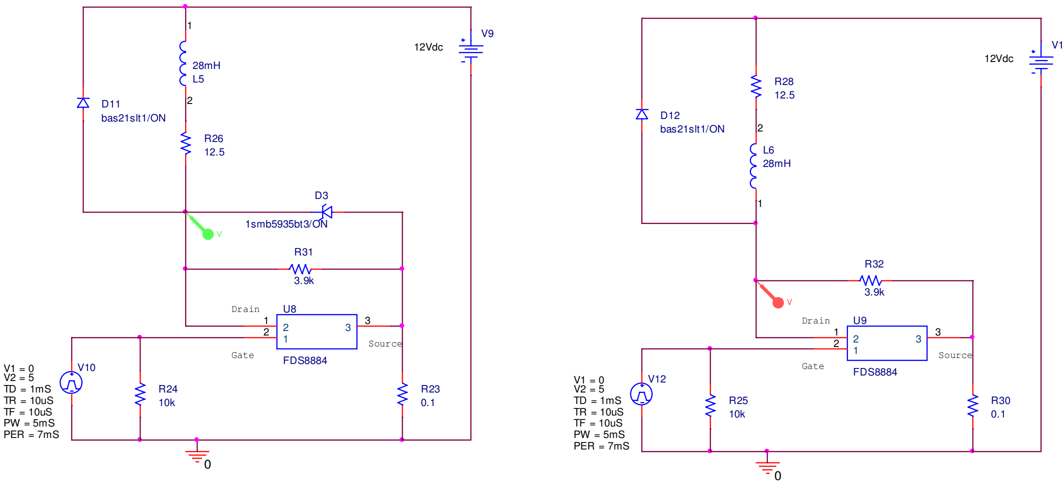


Figure 9: Comparison of Injector Simulation Designs Using Injector Feedback Diode to Observe Effect of Source-Drain Feedback Zener Diode

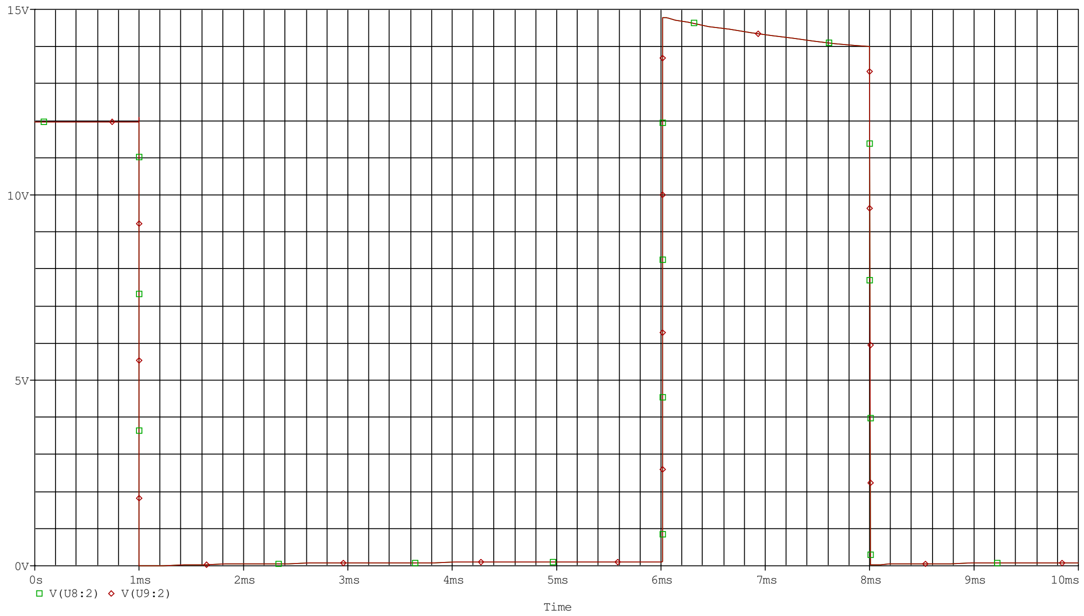


Figure 10: Comparison of Injector Simulation Output Voltages with Use of Injector Feedback Diode to Observe Effect of Source-Drain Feedback Zener Diode

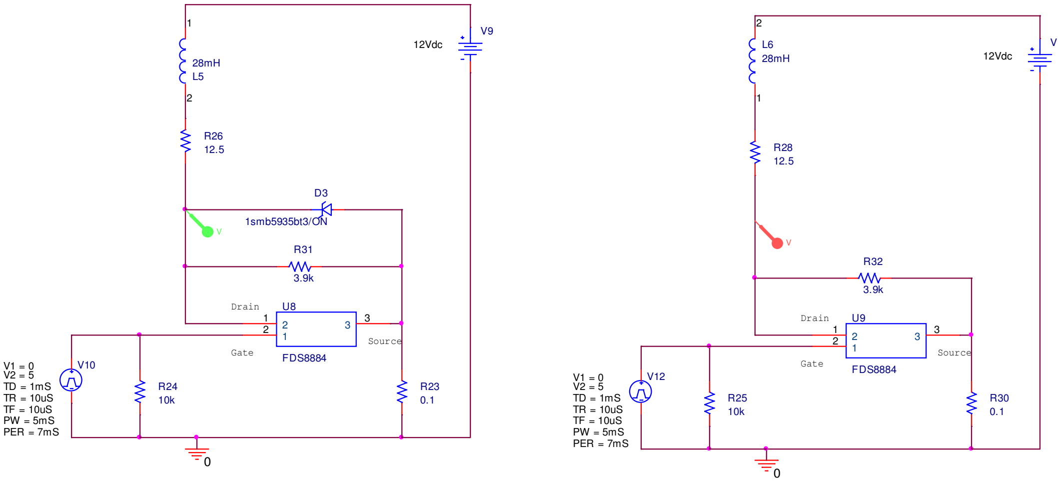


Figure 11: Comparison of Injector Simulation Designs without Injector Feedback Diode to Observe Effect of Source-Drain Feedback Zener Diode

Figure 12: Comparison of Injector Simulation Output Voltages without Use of Injector Feedback Diode to Observe Effect of Source-Drain Feedback Zener Diode

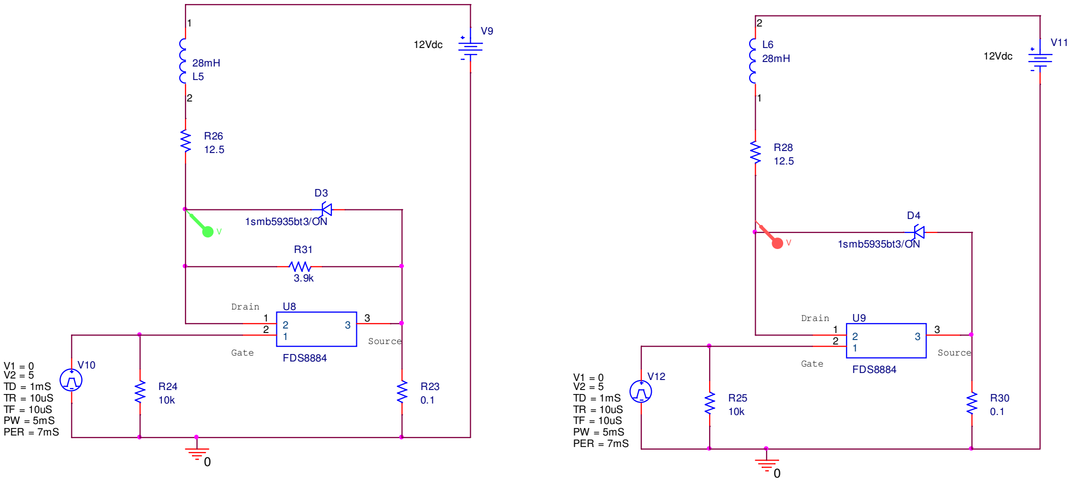


Figure 13: Comparison of Injector Simulation Designs without Injector Feedback Diode to Observe Effect of Source-Drain Feedback Resistor

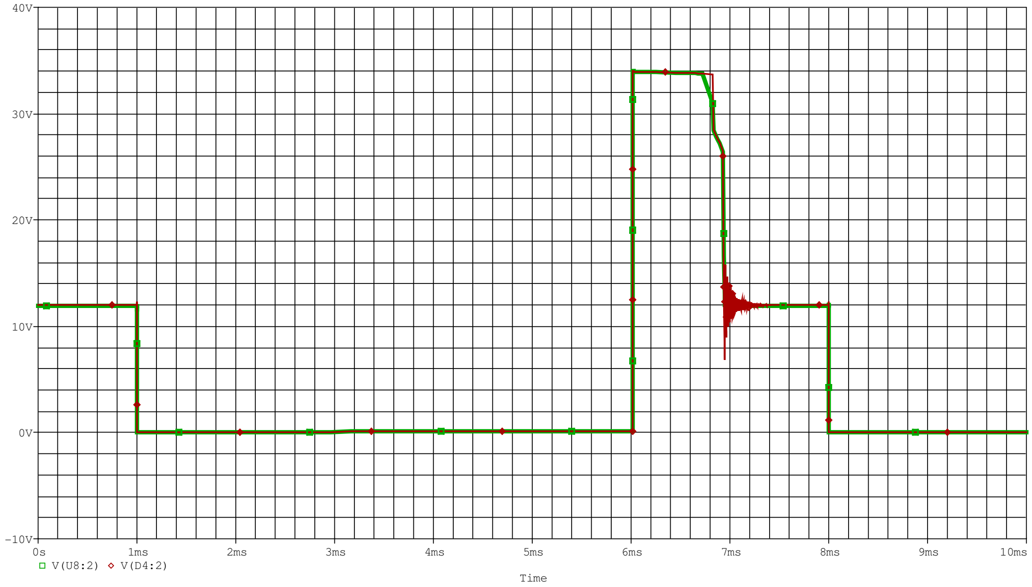


Figure 14: Comparison of Injector Simulation Voltages without Injector Feedback Diode to Observe Effect of Source-Drain Feedback Resistor

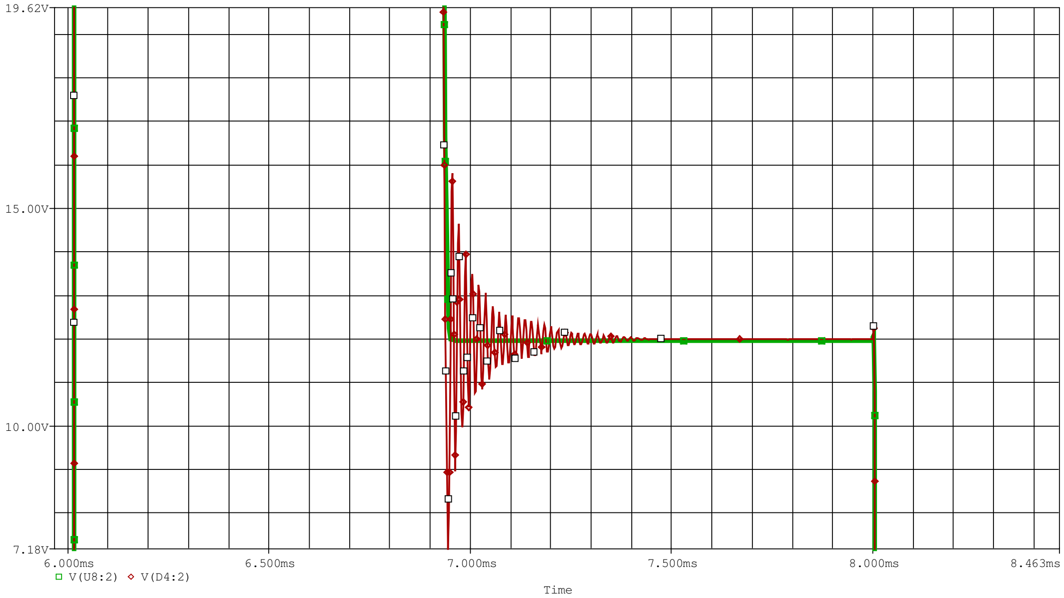


Figure 15: Comparison of Injector Simulation Voltages without Injector Feedback Diode to Observe Effect of Source-Drain Feedback Resistor (Detailed View)

Hardware Data:

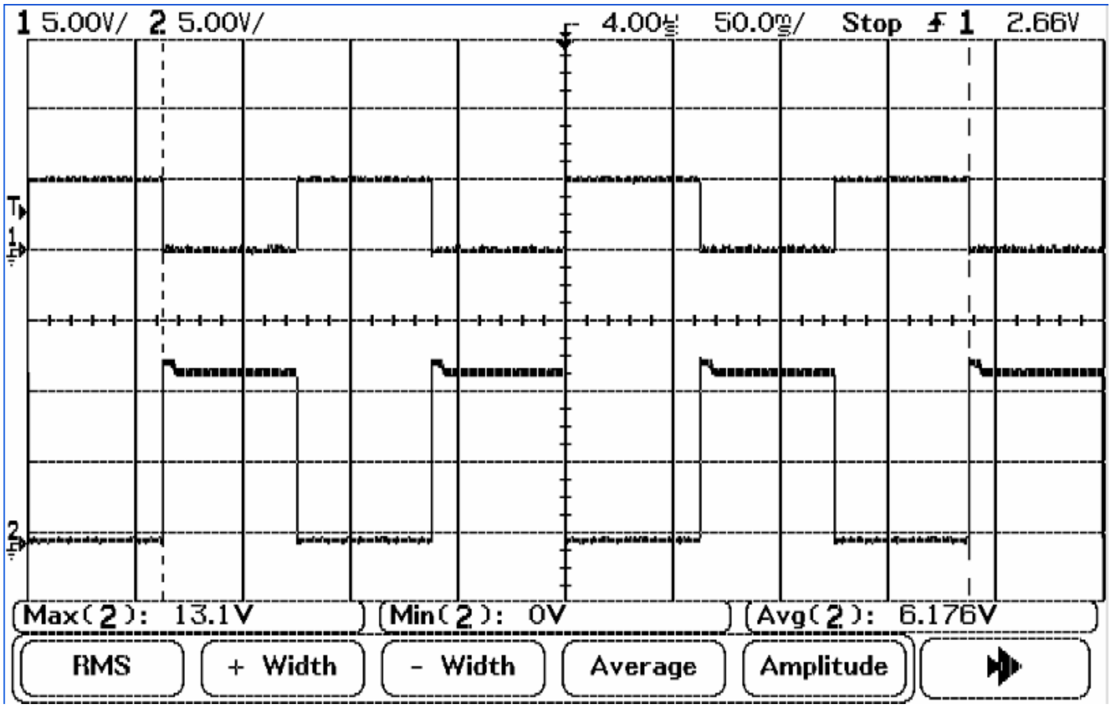


Figure 16: Injector Hardware Output/Input Voltages with Implementation of Injector Feedback Diode (Measured Voltages are Output)

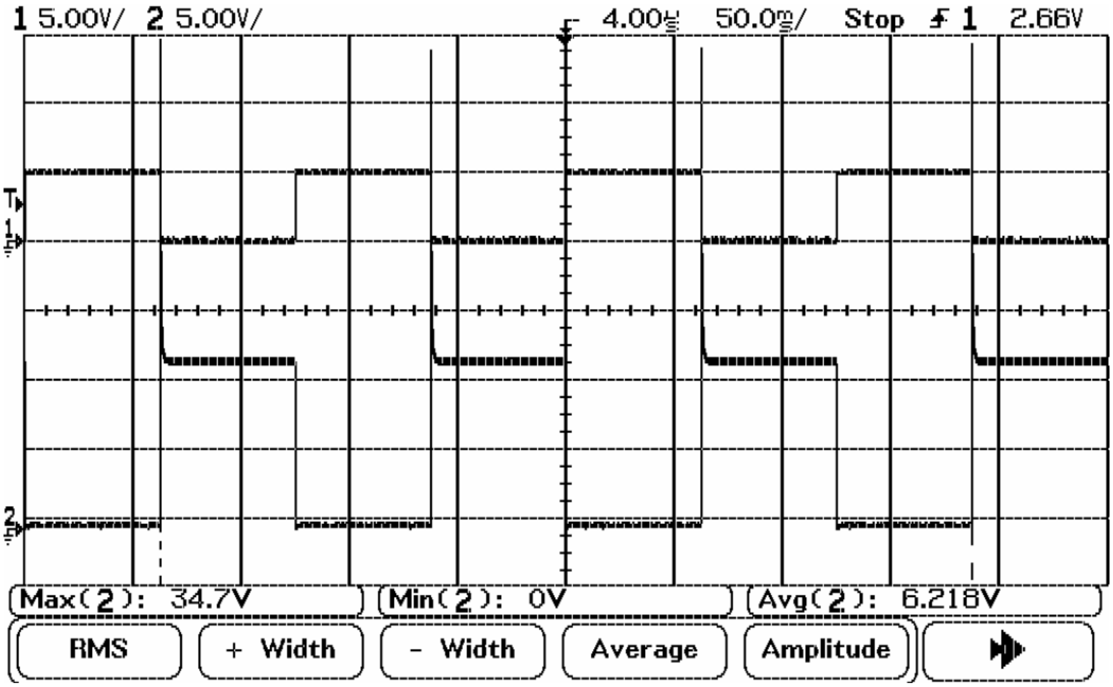
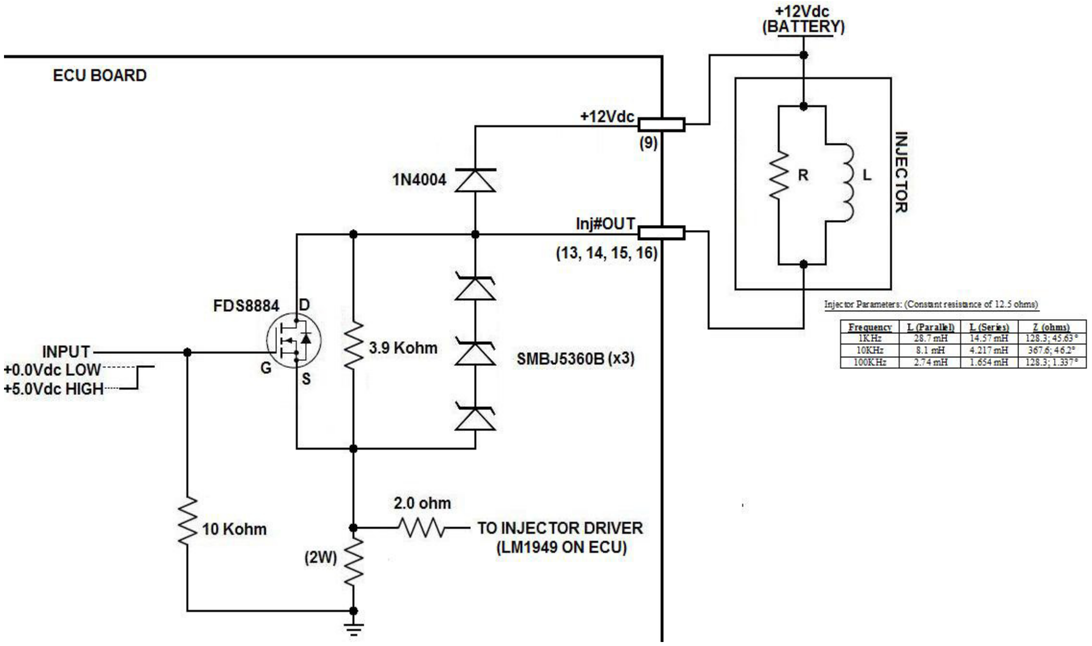


Figure 17: Injector Hardware Output/Input Voltages without Implementation of Injector Feedback Diode (Measured Voltages are Output)

Data Analysis:

Based on the Hardware and Software results, the addition of a feedback diode across the injector will allow for more reliable operation for the injector. While the FDS8884 transistor can handle higher currents than the previous FDS6612A, the +40Vdc emf voltage observed in simulation and the +34.7Vdc emf voltage pulse observed during hardware would destroy either device. The addition of the injector feedback diode may make the source-drain feedback zener diodes/resistors obsolete. The zener diodes eliminate some of the emf voltage, but not as well as the injector feedback diode. The feedback resistor cleans up some of the oscillation observed during operation, but again not as well as the injector feedback diode. However, these parts may have some additional purpose with the injector driver circuit, not included in hardware or software. Due to the relatively low cost of the parts and their potential for use in tandem with other devices on the board, the source-drain feedback system will remain unchanged.



Injector Parameters: (Constant resistance of 12.5 ohms)

Frequency	L (Parallel)	L (Series)	Z (ohms)
1KHz	28.7 mH	14.57 mH	128.3; 45.63°
10KHz	8.1 mH	4.217 mH	367.6; 46.2°
100KHz	2.74 mH	1.654 mH	128.3; 1.337°

Figure 18: Final Design of the Injector Control Circuit (MOSFET Device Section Only)

Op-Amp/Relay Failure:

Background:

The AD8397 op-amp used to control the fan, fuel pump, relay 1, and relay 2 (additional relay systems to be added during a future design), while assumed to be operational, was replaced multiple times by P08221 during their testing due to repeated burn-outs on the device. P08221 could not determine the exact cause of the failure and had no suggestions/recommendations for continuation as the original design had been created by the original ECU design team. Analysis of the relay control scheme indicated that not only would the AD8397 fail during operation, the design scheme would be near impossible to implement properly. The microcontroller sends +3.3Vdc to the AD8397 op-amp to turn off the relay. This voltage is increased and sent to the output of the relay. The +12Vdc input to the relay would theoretically be countered by a large enough voltage at the relay's output node (connected to the AD8397's output), reducing current flow and turning off the relay. The microcontroller would then shut down the +3.3Vdc input to turn the relay back on. Various flaws in this scheme were detected during analysis and simulation testing. A new design implementing PMOS transistors has been tested and is in the process of being finalized.

Simulation Data:

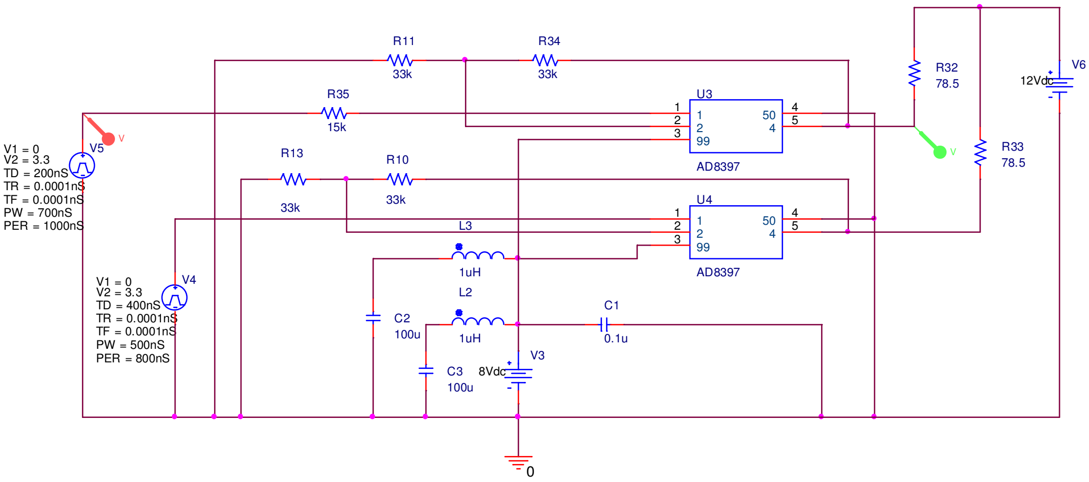


Figure 19: Simulation Circuit for Original ECU Relay Control Scheme

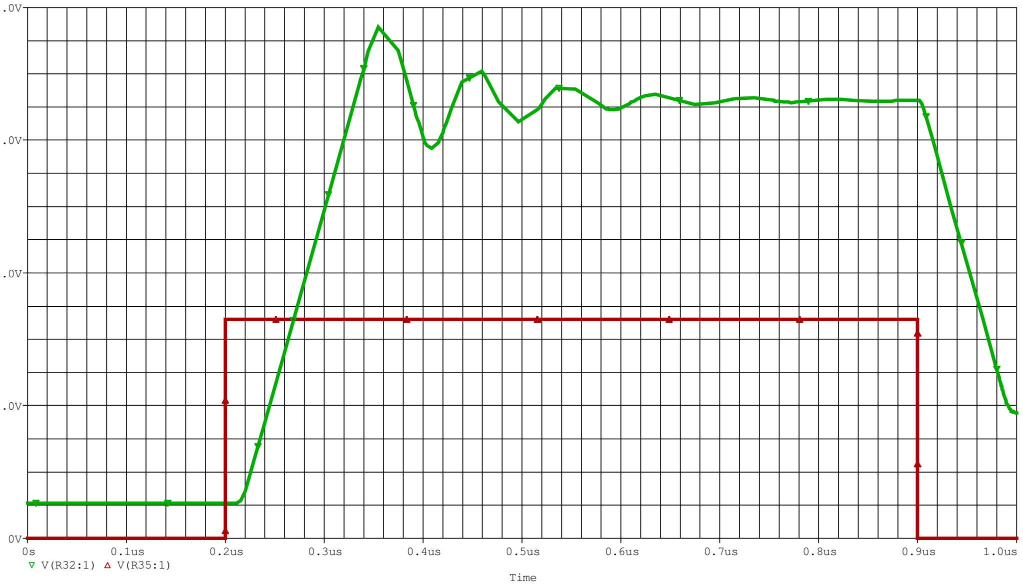


Figure 20: Simulation Voltage Outputs for Original ECU Relay Control Scheme

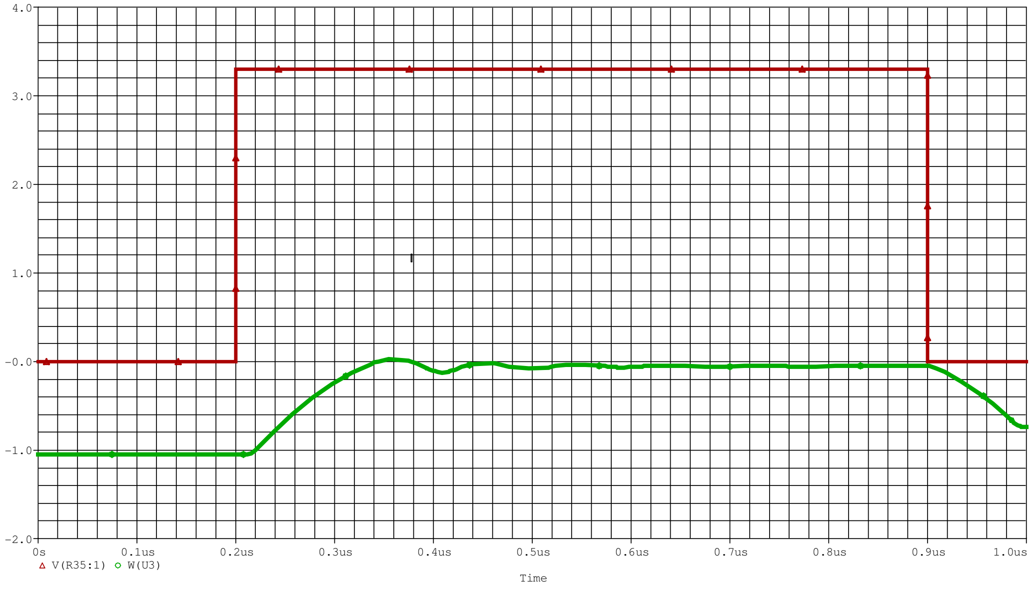


Figure 21: Simulation Power Dissipation for Original ECU Relay Control Scheme

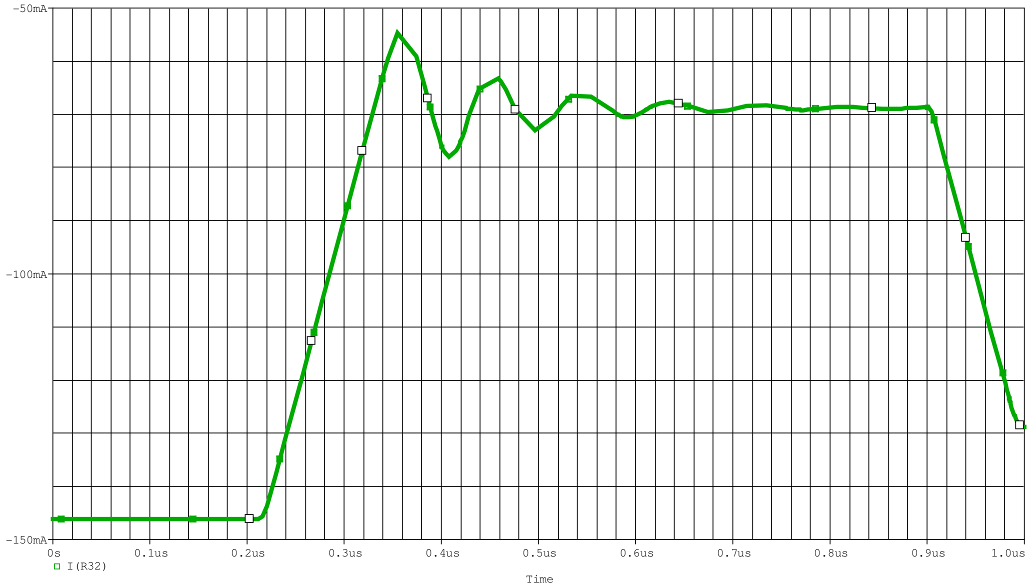


Figure 22: Simulation Output Current for Original ECU Relay Control Scheme

Hardware Testing Data:

Measured Resistance of Fan/Fuel Pump Relay: **78.5ohms**

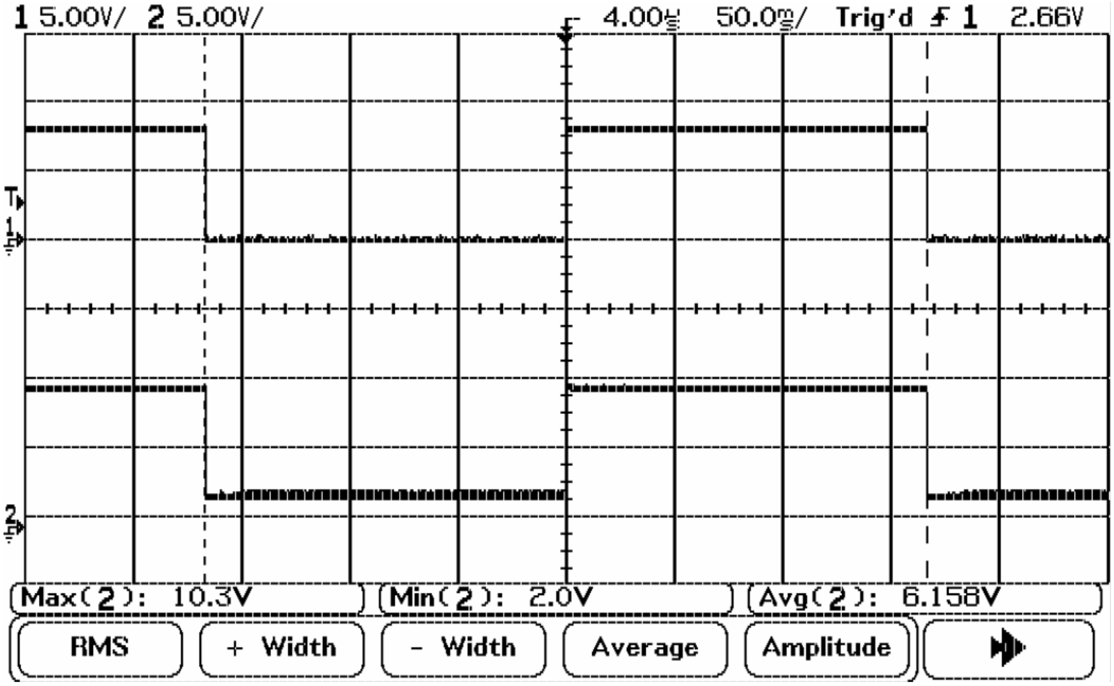


Figure 22: Hardware Output Voltages Measured During Testing of New PMOS Design (8.0Vp-p Input)

Data Analysis:

Basic theoretical and simulation analysis of the AD8397 op-amp design scheme indicated numerous flaws:

The AD8397 can only handle a maximum of 250mA total output current (125mA/Amp). The 78.5 ohm resistance of the relay is not enough to reduce the output current that low during operation and this value will only decrease during operation (the relay is represented by a constant resistance in parallel with a wire coil – resistance for the coil will decrease as more power is applied). According to simulation, each amplifier will take more than their maximum value during normal operation.

The voltage gain/output is flawed. During operation, the amplifier will have (according to simulation) near unity gain, producing far less than +12.0Vdc and preventing the relay from turning off. Even if the resistance loop is changed to allow for higher gain, the +8.0Vdc supply will prevent the critical +12.0Vdc output value from being reached.

Each amplifier is already dissipating almost 2.0W of power during operation, resulting in approximately 4.0W net power dissipation. Even if a heat sink is added to the amplifier, it cannot handle any more than 2.75W during operation. The present ECU PCB does not use a heat sink and can only deal with a net loss of 1.0W at room temperature, resulting in near instantaneous failure.

With these problems apparent and the success of the Injector Control scheme, a new design using PMOS FDS6673 devices to control the relay was implemented in hardware testing. The voltage from the microcontroller was fed into the gate of the FDS6673 instead of the AD8397 op-amp. The use of a PMOS transistor allows for the same operational code to be used as before with the same results: a “high” output turns off the relay while a “low” output turns on the relay. Hardware testing revealed that the maximum output voltage of the microcontroller (+3.3Vdc) is insufficient to activate the PMOS; at least +7.5Vdc is necessary for nominal operation. Returning the AD8397 amplifiers to the board will allow for magnification of the microcontroller signal and allow for ideal operation in conjunction with the FDS6673 PMOS transistors. A Pspice simulation of the circuit shown below in Figure 23 is in process to determine the ideal resistor values for operation.

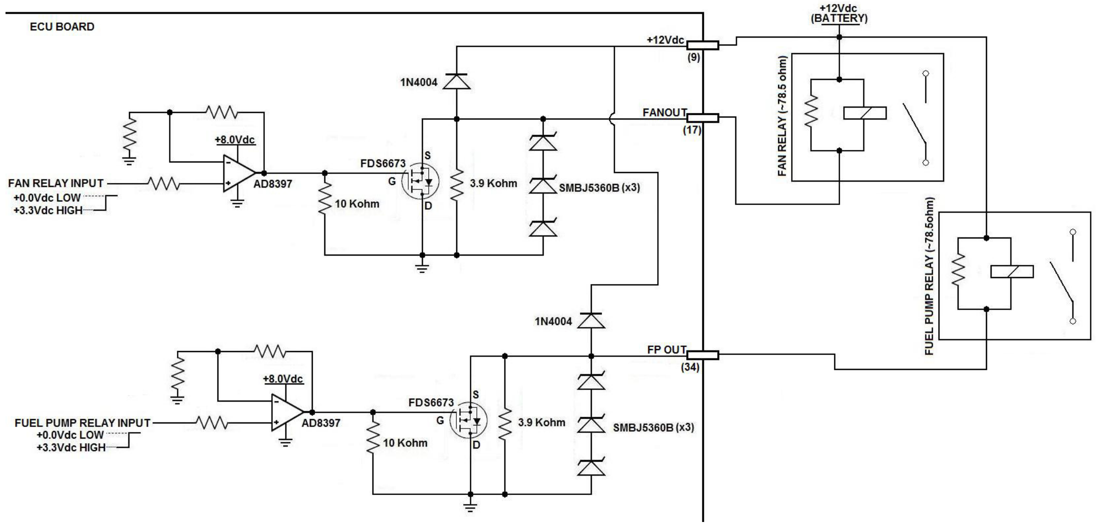


Figure 23: Circuit Schematic for New Relay Control Scheme

Replacement Voltage Regulator Status:

Background:

P08221 was unable to get the existing ECU voltage regulator start-up sequence to operate properly during testing. Failure was likely caused by timing issues, as the 1.9V supply required a single voltage regulator (12V to 1.9V) and the 3.3V supply required two different voltage regulators (12V to 5V to 3.3V). For proper startup of the microcontroller, the 3.3Vdc must reach the device first, followed by the 1.9Vdc within a limited time frame. Detailed testing has shown that the TPS70302 voltage regulator will not only be sufficient to power the microcontroller start-up sequence, but also the additional logic circuits located on the board.

Hardware Testing Data:

Device	Max Supply Current	Number of Devices on ECU
AD8604	1.3mA/Amplifier	3 devices/12 amplifiers
LM1949	54mA	4

SN74AHCT125	50mA	2
TMS470	20mA	1
Net Supply Current Required: **215.6mA**		

Table 2: +3.3Vdc Powered Logic Devices and Their Required Supply Currents

Device	**Resistance**	**Voltage**	**Current**	**Power**
Power Supply	-	5.038 Vdc	0.31 A	1.5618 W
3.3Vdc Load	9.96 Ω	3.281 Vdc	329.4 mA	1.0765 W
1.9Vdc Load	48.26 kΩ	1.907 Vdc	0.0403 mA	0.07535 mW
1.9Vdc Divider A	9.936 kΩ	0.684 Vdc	0.0688 mA	Negligible
1.9Vdc Divider B	17.80 kΩ	1.214 Vdc	0.0682 mA	Negligible
3.3Vdc Divider A	32.39 kΩ	1.213 Vdc	0.0374 mA	Negligible
3.3Vdc Divider B	55.05 kΩ	2.069 Vdc	0.0376 mA	Negligible
TPS70302	-	-	-	**0.485W**

Table 3: Test Results for Voltage Regulator Design (Large 1.9Vdc Load)

Device	**Resistance**	**Voltage**	**Current**	**Power**
Power Supply	-	5.0277 Vdc	0.41 A	2.0614 W

3.3Vdc Load	9.96 Ω	3.239 Vdc	325.2 mA	1.0533 W
1.9Vdc Load	17.497 Ω	1.882 Vdc	104.1 mA	0.2024 mW
TPS70302	-	-	-	**0.8057W**

Table 4: Test Results for Voltage Regulator Design (Small 1.9Vdc Load)

Data Analysis:

Analysis of the results from hardware testing shows only minor difficulties with the new voltage regulator design. The most difficult problem to overcome will be the high power dissipation through the device, although a heat sink pad under the regulator is being added to the PCB. Even when drawing near 100mA over the ECU's maximum expected current, the regulator performed as expected. Since the regulator is designed to handle up to 1.0A of current per voltage output, there should be no difficulties in using this design on the ECU. The SEQ pin controls the activation sequence of the two voltage outputs, starting up the +3.3Vdc, then the +1.9Vdc after the +3.3Vdc has reached 80% of its intended voltage output. Should this sequence need to be reversed for any reason, the SEQ pin can be connected to a positive voltage. Additional designs for the regulator involving constant voltage levels (the TPS70351 will output a constant 3.3Vdc and 1.8Vdc without the resistor biasing scheme) and a voltage reset switch are being taken into consideration.

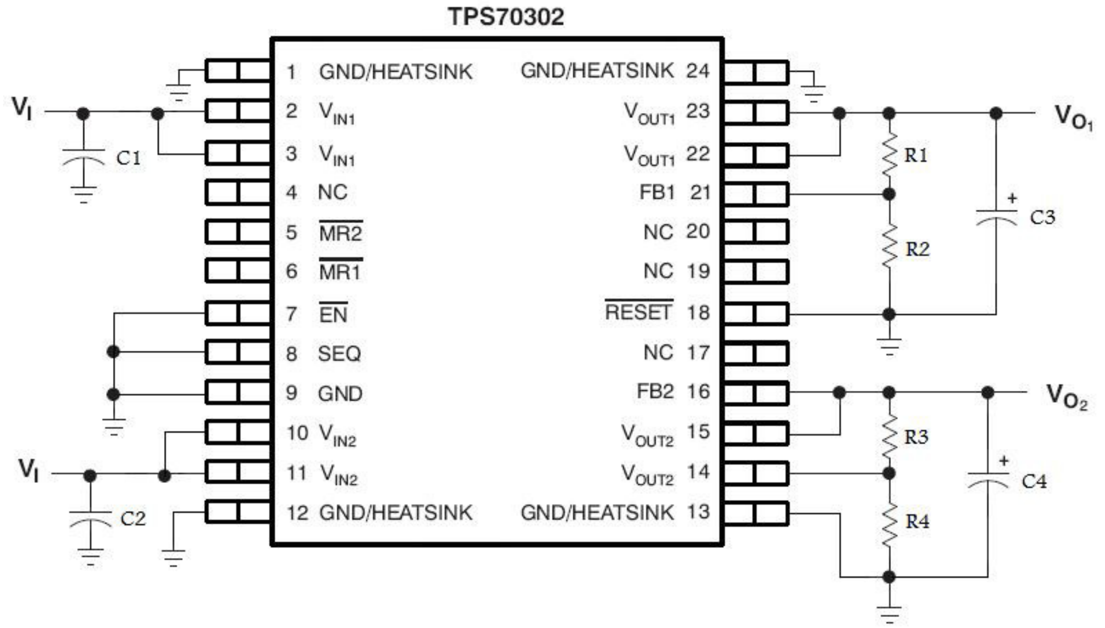
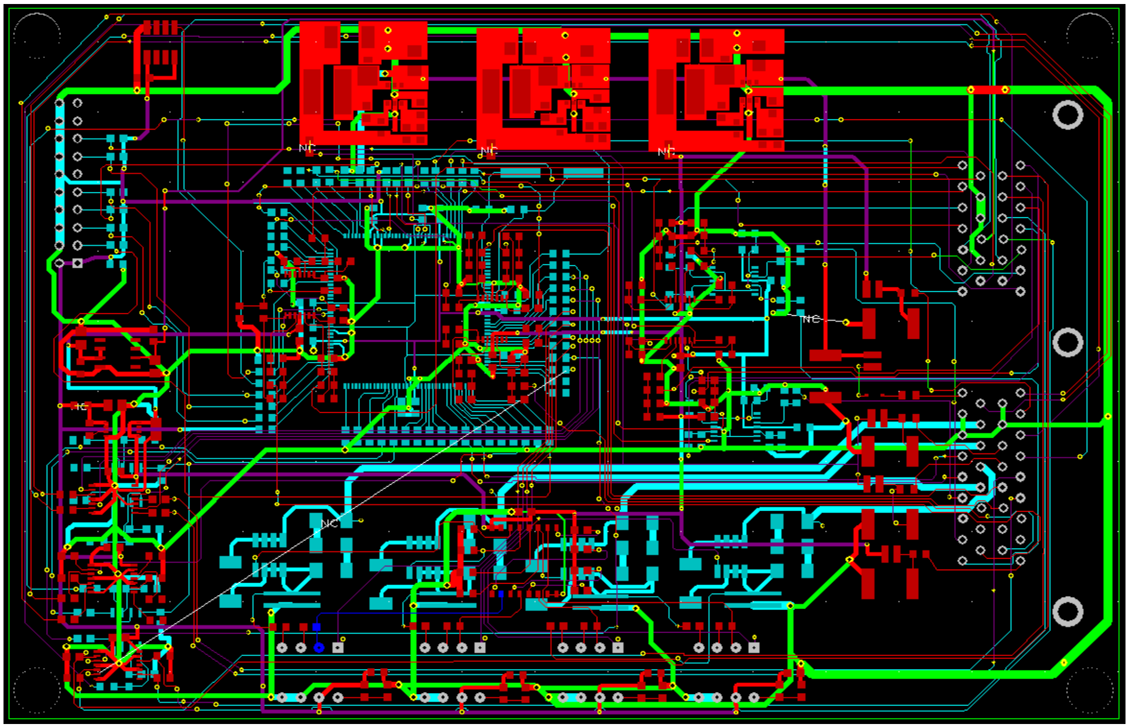


Figure 24: Circuit Schematic for New Voltage Regulator Scheme

Resistor	Resistance		Capacitor	Capacitance
R1	51.1 kΩ		C1	0.22 uF
R2	30.1 kΩ		C2	0.22 uF
R3	10 kΩ		C3	22.0 uF
R4	18 kΩ		C4	47.0 uF

Table 5: Resistor and Capacitor Values for Figure 24

PCB Board - P08221



Latest Revisions - P09222