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Project Number: 09222

FORMULA ECU III

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ABSTRACT

This paper describes the technical processes and designs developed for the RIT Formula Engine Control Unit (ECU). Project 09222 is a continuation of the preceding senior design projects 07222 and 08221. This project continued with the design of the ECU and test stand for electrical functionality and optimizing efficiency, testing and ensuring proper responsiveness to the racecar's conditions. The test stand design included component selection and testing, software development, development of the National Instruments Data Acquisition system (NI DAQ) for full testing functionality, printed circuit board (PCB) population and case design.
Key concepts of engine functionality required, and still require major changes to the system. These issues will also be discussed and will provide a strong starting point and greater understanding of project needs for future teams.

NOMENCLATURE

BJT – Bipolar Junction Transition
ECT – Engine Coolant Temperature
ECU – Engine Control Unit
IAR – Supplier of software environment and compiler
IAT – Intake Air Temperature
MAP – Manifold Air Pressure
MOSFET – Metal Oxide Semi-conductor Field Effect Transistor
NI DAQ – National Instruments Data Acquisition System
NMOS – N-Channel MOSFET (see above)
OpAmp – Operational Amplifier
PCB – Printed Circuit Board
PMOS –P Channel MOSFET (see above)
TPS –Throttle Position Sensor

INTRODUCTION (OR BACKGROUND)

Project 09222 served as a continuation of two previous generations of ECU design, intended to replace the Motec M400 ECU presently implemented on the SAE RIT Formula team car. The first design project, 07222, created a rudimentary electronic control circuit with a protective case slightly over design specifications. The second design project, 08221, reworked the existing control circuitry, fixing several problems with the control systems and began testing the ECU with the recently purchased NI DAQ. The design going into Project 09222 was not operational. The software code could not be completely uploaded to the ECU due to the limitations of the demo programs and limited IAR compiler used by previous design teams. The microprocessor could not be activated by the existing voltage regulation system and the ECU needed to be piggybacked onto the IAR board. The LabView programming was designed to function only in static models, not allowing for appropriate acceleration, deceleration, and start-up testing which are the most crucial period to test the ECU's specifications. Finally, several other additional problems with the circuitry, PCB, and protective case still needed to be addressed. The goal for Project 09222 was to fix the problems observed by the previous generation and get the ECU functional and interacting with the NI DAQ test equipment to prove operation at or above specifications.
The specifications are listed below provided with target values for the capabilities and precision required for the ECU. The ECU should meet these specifications in the static and dynamic test conditions.

PROCESS (OR METHODOLOGY)

Specification Number	Customer Need Number	Design Specification	Importance	Unit of Measure	Marginal Value	Ideal Value
1		Size	1	mm	174x105x40	80x50x20
2	1	Weight	1	kg	1	0.5
3		Number of digital inputs	3		8	10
4		Number of digital outputs	3		16	20
5		Serial interface	3	USB	2	2
6		Number of Analog inputs	3		16	20
7		Number of Analog outputs	3		2	4
8		Pulse width modulated outputs	3		4	6
9	2	Timing granularity	9	degrees	1	0.5
10		Processor speed	9	MHz	24	32
11		RAM memory	9	kB	512	512
12		Flash memory	9	kB	512	512
13		Burn in	3	oC/hr.	10-70/10 hrs	10-70/32 hrs
14		Battery transient protection	3	mV	0.1	0.001
15	3	Max RPM	3	RPM	12500	15000
16		Internal temperature range	3	oC	-20-85	-50-125
17		Operating voltage	1	V	9-24	6-24
18		Operating current	1	Amp	10	8
19	4	fuel calibration accuracy	9	deg	1	0.5
20	5	Ignition calibration accuracy	3	deg	1	0.5
21	6	tach output	3	RPM	15000	18000
Attributes Section	**Possible "Attributes" with Spec potential components**					
1	2	FSAE sensors compatible with calibration	3			
2	3	Controller software updatable by USB	9			
3		High RFI immunity	3			
4		Battery reverse protection	9			
5	4	Environmentally sealed electronics	9			
6	5	Display communications	3			
7	6	Tuning setup diagnostic and utility software	9			
8		cross platform usability	1			
9	7	Data logging	9			
10	8	User definable real-time display	9			
11		individual cylinder trim	9			
12	9	Adjustable fuel calibration	9			
13	10	RPM and load sites are user programmable	9			
14	11	adjustable ignition calibration	3			
15	12	Onboard wideband lambda sensor controller	3			
16	13	Driver warning alarm and shift light control	1			
17	14	gear detection	1			
18	15	Launch control	1			
19		Gear change ignition cut (for paddle shifters)	1			
20	16	Traction control capable	1			

Sensor	Unit of Measure	ECU Input Signal Range
Throttle Position Sensor (TPS)	V	0 - 5
Manifold Absolute Pressure (MAP)	V	0 - 8
Intake Air Temperature (IAT)	V	0 - 5
Engine Coolant Temperature (ECT)	V	0 - 5

Figure 1: Project Specifications

ECU DESIGN IMPROVEMENTS

1.Engine Dynamics

Large gains were made by the team in the understanding of engine dynamics as they relate to this project. Many key concepts which were learned through team advisor Mr. Todd Fernandez resulted in fundamental changes in the system design. The most pertinent of these issues is the differences at low RPM versus high RPM. The code controlling the timing of injection and ignition is based off of the speed the engine is running (RPM) and this data is collected through a cam sensor. The RIT formula race car currently uses a two-tooth cam wheel and as a result, the software can calculate the RPM twice per revolution. As the speed of the engine increases, the time from tooth to tooth decreases. With this short time frame, the engine can change its speed by a smaller amount between RPM calculations from the cam readings than it could at low RPM. The lower RPM results in a longer time window for the engine speed to change more drastically and it is therefore more difficult to accurately predict when injection and ignition should occur on the next cycle. When evaluating models to predict RPM, attention should be given to studying the accurate RPM prediction at low RPMs.

Efforts were made to develop a new model to accurately predict the RPM, Track data recorded by the Motec system was used to analyze the models. This data which is collected by the Motec ECU during all engine operations is uploaded by the Formula after each driving session. This data is opened in Motec's i2 Standard Software [7] contains readings from all inputs at 1000Hz frequency. This data was manipulated in Excel to create input variables: RPM(n-1), ΔRPM(n-2), RPM(n-3), ΔRPM(n-4), as well as linear and polynomial forms of IAT, ECT, TPS, MAP and O2 to predict the output variable RPM. The variables that were insignificant were then removed from the MiniTab model to provide a lean, more accurate prediction of the RPM and therefore more accurate fuel injection and ignition. The model determined that the previous 3 RPMs and a linear coefficient of the throttle position were needed to accurately predict the next RPM.

This model was compared against data for the entire fifteen minute run and results validated the effectiveness of the model currently being used in code. The error in predicting the next cam head for injection and ignition purposes exceeded the 0.5 degree difference required in the specifications.

Eq. 1) $\Omega_{exp} = A\acute{\alpha} \pm \sqrt{(A^2\acute{\alpha}^2 + 2B\acute{\alpha} + \omega_n^2)}$

The optimization of this model can be tested further by determining values of constants A and B in equation 1 above. This modeling can be done by determining the linear relationships with A and B and analyzing Formula runs against those to fine optimal values for A and B to predict the RPM.

With the model optimized, additional accuracy can be obtained through mechanical changes to the car. The greatest opportunity for improvement comes in replacing the current two-tooth cam wheel with an n-tooth wheel would allow the software to calculate RPM n times per cycle. This in-turn requires greater processor performance on the PCB to run the calculations for every tooth sensed. Note that wheels with a greater number of teeth are very common.

2. Software Design

The ECU software is responsible for reading the MAP, ECT, IAT, TPS, crank, and cam sensors and provide proper outputs to the fan, fuel pump, injectors, and spark plugs. A linear acceleration model was used for extrapolating the RPM of the engine at the time of an event, where the key events are ignition and injection start. This model was used to define two-dimension lookup tables, indexed by current and previous RPMs, used to predict the timings of ignition and injection. The range of current RPM spans the operating RPMs, from 500 RPM to 15000 RPM, in 500 RPM increments. Since the range of previous RPMs is restricted based on the current RPM, the range of the previous RPM is $[RPM_n - k * \Delta RPM, RPM_n + k * \Delta RPM]$, where k is the number of intervals around the current RPM, and ΔRPM is the resolution of the table, ranging from 100 RPM intervals at low RPM to 5 RPM at high RPM. The current acceleration model does not account for MAP, IAT or TPS. The MAP sensor is used for determining the injection duration. A statistical model based on data from the Motec system uses all these parameters, but was not utilized during the development of the lookup tables.

The software measures the time between falling edges on the crank Hall Effect sensor using the pulse count (PCNT) instruction on the high end timer (HET); each falling edge triggers an interrupt. The interrupt is used by the software to read the number of pulses and calculate the current RPM. The current and previous RPM values are used in conjunction with the acceleration model lookup tables to predict the RPM injection start and ignition. The predicted RPM values, along with the MAP sensor, are used to index timing lookup tables. The acceleration model and timing lookup tables are kept separate to allow the acceleration model to change without affecting the injection and ignition timings.

A watchdog timer is set up to detect engine stalls. Each time the crank sensor is measured, the timer is reset. If the crank interrupt does not occur, the watchdog interrupt occurs, incrementing the stall counter. If the stall counter reaches the maximum, the fuel pump is turned off.

3. Hardware Design

Injector Control Scheme Replacement/Failure:

Testing completed last year by P08221 on the ECU produced results indicating that the FDS6612A did produce the desired outputs during operation, but would fail on occasion for unknown reasons [1]. The original suspected cause of failure was a build-up of voltage on the injector, which would discharge into the injector control circuitry when switching and damage the FDS6612A MOSFET device. The FDS6612A was also flagged this year for obsolescence by its manufacturer [2]. Testing completed by the P09222design team showed that there was a voltage surge of approximately +35Vdc that occurred during switching, large enough to potentially damage the FDS6612A [1]. Further examination of the injector control scheme indicated a second problem with the design. The MOSFET device is intended for use in digital circuits while the LM1949 injector driver should be used in analog circuits. The result is an approximately four times higher current draw to power the injectors than is actually required for operation. Also, the LM1949's control feedback system cannot function properly with a MOSFET device and could result in premature shutdown of the injectors as the LM1949 attempts to shift its voltage output from "ON" to "HOLD". The original design control circuitry for each injector was still using the default values recommended off of the LM1949 datasheet and for a much larger current draw application [3]. Even with all of these additional problems the existing configuration could still function, but would be reckless and has the potential to damage other parts on the board.

A new design, switching over from the MOSFET to a BJT and altering some of the component configurations, was developed on proto-board and connected to the PCB to reduce power consumption and increase overall ECU efficiency. The new design can function at frequencies up to 500Hz, although the engine will not exceed 125Hz, and can implement the full range expected of duty cycles while running. However, the injectors cease to fire if battery voltage drops below +10Vdc. Since the injector driver includes a "cold-crank" system to counter such a problem, the timer circuitry is likely shutting down the transistor base current before injector saturation occurs [3]. This can be countered by increasing the power supplied to the injector driver, altering the switching resistor attached to the BJT transistor to allow for a higher current draw during hold operations; or increasing the timer length on the injector driver so the injector can reach saturation before switching to "hold" voltage levels. A combination of two or more of these improvements will need to be implemented before the ECU can meet specification.

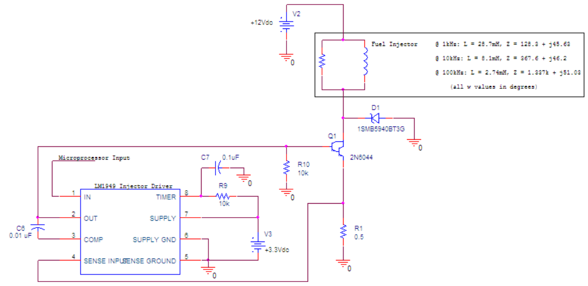

Figure 2: Revised Injector Control Circuit

Op-Amp/Relay Control Circuit Failure:

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 [1]. The original relay control scheme took the +3.3Vdc output from the microprocessor and amplified it to +8Vdc. The difference in voltage levels between the output of the op-amp and the battery voltage would be too low to produce the current necessary to turn on the transistor. Analysis of the relay control scheme indicated that not only would the AD8397 fail during operation due to exceeding the maximum recommended current flow during operation, the existing design scheme would be near impossible to implement properly due to the variations in battery voltage [4].

A basic replacement design using PMOS transistors was tested in hardware with the intent to create a replacement circuit that would not require any changes in the operating program. The new design required more voltage to function than could be provided by the microcontroller without the aid of external circuitry and implementation of a level shifter was considered. Hardware testing with the FDS8884 MOSFET provided an alternative control scheme similar to the early injector design and could operate independently within the microcontroller's range of operation. This required some slight change to the operating code as the FDS8884 is an NMOS device with reversed ON/OFF characteristics compared to the PMOS [5]. The new design has been implemented on the PCB and no additional problems occurred during testing, although finding some means of switching implementing a PMOS transistor would decrease overall power consumption; alternative control schemes that could be considered in the event of this system's failure include a voltage level shifter to amplify the MOSFET gate voltage or a totem-pole configuration. However, both of these systems would require additional space on an already overcrowded

PCB.

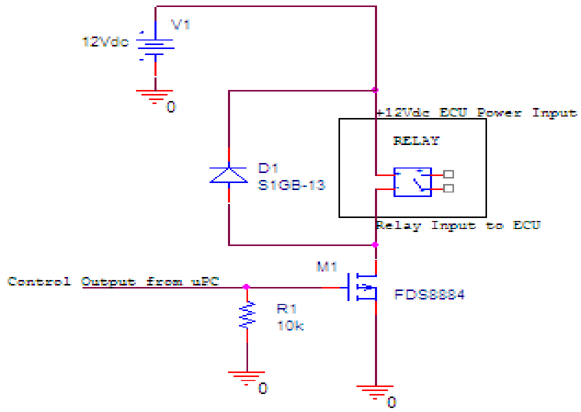

Figure 3: Revised Relay Control Circuit for Fan and Fuel Pump

With a successful test run of the new relay control system, the circuit is ready for implementation on the final version of the engine control unit.

Replacement Voltage Regulator:

P08221 was unable to get the existing ECU voltage regulator start-up sequence to operate properly during testing. Failure was found by the P09222 design team to be caused by timing issues, as the previous circuit's 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), resulting in the 1.9V reaching the microcontroller before the 3.3V [1]. For proper startup of the microcontroller, the 3.3Vdc must reach the device first, followed by the 1.9Vdc and within a limited time frame. Upon both of these voltages reaching the microprocessor, a 'Power-On Reset' command needs to be sent to confirm a successful voltage operation. Hardware testing and analysis showed that the TPS70302 voltage regulator would not only be sufficient to power the microcontroller start-up sequence, but also the additional logic circuits located on the board, replacing two existing voltage regulators with a single chip device. The TPS70302 would also be able to send the necessary 'Power-On Reset' command without requiring any external systems. The present design on the PCB is intended to function with the programmable TPS70302, but minor changes to the design would allow for the fixed voltage TPS70351 regulator to be implemented in its place [6]. However, only the programmable voltage regulator has been tested at this time. Testing on the new voltage regulator indicated that the design has no noticeable flaws and is more than adequate for providing voltage regulation for the ECU. It can function over the marginal and ideal specified voltage ranges (+9Vdc to +16Vdc and +6Vdc to +24Vdc, respectively) and supply sufficient current to keep all devices under its control operational.

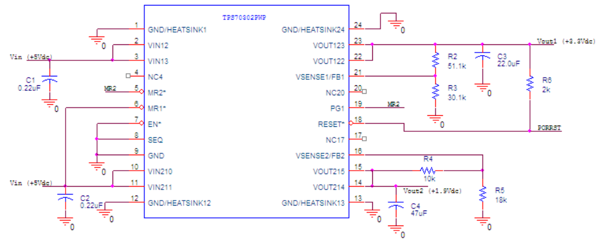

Figure 4: Revised Voltage Regulator System

O2 Sensor design:

The addition of the Oxygen or O2 sensor circuitry will provide the ECU with the ability to more accurately adjust the fuel to air ratio which will in turn improve upon the overall performance of the engine. The O2 sensor works by measuring the oxygen content of the exhaust of the engine. Based on this measurement the fuel to air ratio of the engine is adjusted in order to optimize performance. There are three systems needed in order for the O2 sensor to be integrated into the ECU. The first is an internal resistance circuit. In order for the O2 sensor to work properly it needs to be heated to approximately 750 degrees Celsius which corresponds to an internal resistance of 80 ohms. Therefore a circuit is needed in order to measure the internal resistance of the sensor. This is done by using AC coupling to apply a higher frequency square wave to the pump cell and measuring the amount of displacement from the reference level voltage. Square wave levels above this level represent resistances above 80 ohms and square wave levels below the reference level represent resistances below 80 ohms.

The second circuit needed is a heater power circuit that uses the measure internal resistance of the sensor and applies a pulse width modulated signal with varying amplitude to a power MOSFET in order to maintain the proper heater temperature of the oxygen sensor. This circuit uses a MOSFET with its gate being driven by a pulse width modulated signal created by the microprocessor. The amount of time that the signal is high relates to the heater increasing temperature and vice versa the amount of time that the signal is low relates to the heater cooling.

The third and final circuit needed is the cell voltage circuit which is used to measure the actual fuel to air ratio of the exhaust. The cell voltage circuit is used to measure the Nernst cell voltage of the circuit using a differential amplifier with its output connected to a fixed resistor connected to the pump cell of the oxygen sensor. The cell voltage of the sensor is ideally 450mV which corresponds to a pump current of 0 amps and a lambda value of 1. The lambda value is the ratio of the measure fuel to air ratio to the stoichiometric fuel to air ratio. This ratio is calculated in the microprocessor based on the measured pump current and cell voltage. A lambda of greater than one, a cell voltage greater than 450mV, and a positive pump current relate to the engine running lean, meaning that there is too much oxygen mixing with the fuel. Conversely, a lambda less than one, a cell voltage less than 450 mV, and a negative pump current means that the engine is running rich, meaning that there is not enough oxygen mixing with the fuel. The ECU uses this data to adjust the injector and spark timing to improve engine performance.

PCB Design Considerations:

In designing a printed circuit board, many factors need to be taken into consideration. First, the physical size of the PCB needs to be determined, as board size can play a major role in certain design parameters. In this project, there was not a strict restriction on how small the unit needed to be, however lighter is preferred. The board size was chosen to be 4 inches by 6 inches giving the new ECU a similar size to the existing ECU used by the Formula team. To start the design, one needs to account for the nature of electrical circuits, being especially mindful of noise and interference. In general, one wants to reduce the distance which high current or high frequency signals travel to reduce noise in adjacent circuits. Dedicated ground and power planes reduce noise and help isolate the sensitive signals on the board from noise.

PCB Layout;

The PCB design for this project is a continuation of the previous work done. PCB Artist software was used to continue the schematic and PCB design. Custom part libraries were updated from the previous years to reduce the number and simplify the design. The design from the previous year had numerous issues that were corrected in the current revision of the board. A proper ground plane was implemented and power traces were diverted away from noise sensitive sensor signals. The PCB was increased from 4 layers to 6 layers to help with signal separation and to ease the layout of the board. All traces were run by hand without the use of the auto-route, primarily due to the way the auto-route feature handles vias and noise considerations. Many spare input and output pins were added to the final design for feature expansion in future versions of the software.
With the design complete, boards were ordered from Advanced Circuits. Much time was spent populating a board with all components, many of which were ordered from DigiKey and Mouser. Once the board was populated, hardware and software testing was done to determine the viability of the design. In testing the hardware, several problems with the design were discovered and rework was done to correct the issues and allow continued testing. Schematics were updated with the changes necessary. With the hardware determined to be working, software testing could be done and verified using the National Instruments test bench.

4. Test Bench
Test bench Data Acquisition System:

The test bench developed by the previous year's team is used to analyze the operation and functionality of the ECU. A data acquisition device developed by National Instruments commonly called the NIDAQ is used as the test bench for the ECU. The NIDAQ is not only used to generate the input signals used by the ECU but is also used to measure the output signals from the ECU. A Motec connector is wired to the NIDAQ device in order to allow for easy connection to the ECU as well as easy interchangeability between the ECU and the IAR development board.
The inputs to our ECU include cam sensor, crank sensor, throttle position sensor (TPS), manifold air pressure (MAP), intake air temperature (IAT), and engine coolant temperature (ECT). These readings would be obtained from sensors in the car, but for testing purposes are set as inputs through the LabView testing program. The ECU then generates outputs for two pairs of ignition signals, and four injection signals through the software.
There are two LabView programs that are used to analyze the ECU. These two programs are the Signal Quality and the Timing Testing programs.

Test Bench Signal quality VI:
The signal quality LabView program is used to analyze the shape of the input and output waveforms to the ECU. The amplitude or voltage level of the input and output signals can be measured using this program. The main purpose of this LabView program is to verify that the proper type of signals are being input and output to and from the ECU as well as to examine the quality of each signal. There are two front panels in this program. The panel on the left side consists of the user adjustable TPS, ECT, IAT, and MAP sensor signals as well as an RPM gauge and a settable RPM value. The right panel consists of four main tabs. The first tab is labeled channel parameters and in this tab the basic parameters such as sampling rate and duty cycle are displayed. The second tab is called sensors and allows the user to view a graph of the TPS, ECT, IAT, and MAP sensors. The third tab is called Crank/Cam and this tab is used to analyze the crank and cam signals generated by the NIDAQ and measure the duty cycle, pulse duration, and period. The fourth tab is called Injection and is used to graphically display the 4 injector outputs from the ECU measured by the NIDAQ. In this tab the injector signals can be view individually or all at once in order to compare their operational characteristics. The measurements in this tab can also be logged to a TDMS file for later view and data manipulation. The fifth and final tab on the right panel is called Ignition and is identical in functionality to the Injector tab except the two ignition signals are being analyzed. Overall, the signal quality program allows for the

shape of the input and output signals of the ECU to be evaluated.

Test Bench Timing VI:

Building on the previous year's Timing LabView program several things were added to the program in order to improve upon the testing of the ECU. The timing program now has the ability to model a linear acceleration and deceleration of an engine as well as for a static rpm. The program begins in a static state from which the user can enter specific rpm values to be tested, or the user can select either the acceleration or deceleration option. The acceleration and deceleration models operate by entering a starting rpm, a finishing rpm, and an rpm rate. The LabView program will provide the ECU with signals representing a linear acceleration or deceleration based on the specified rpm start, stop, and rate values. Similar to the signal quality VI the timing VI has the option to log the measured data to a tdms file for later viewing and data manipulation. The tdms files are opened using a downloaded add-on to Microsoft excel. The size of the tdms files are limited to the number of cells available in an excel spreadsheet which is approximately 140000 cells. The restricted size of data collection means that smaller segments of time can be logged during the use of the acceleration and deceleration models. However, this limited amount of logging will still provide enough data to accurately analyze the operation of the ECU.

The Timing program also consists of two main front panels. The left panel is used for the TPS, ECT, IAT, and MAP sensor input settings as well as the RPM gauge just as in the signal quality program. However, in the timing program the left panel also consists of a combo box that is used to select either a static RPM operation, the linear acceleration model, or the linear deceleration model. The static RPM, start RPM, finish RPM and RPM rate control values are also entered in this part of the program. The right panel is also very similar to the signal quality program's right panel. This portion contains 4 tabs with the first being a channel parameters tab that is used to enter and display the data parameters for the overall program operation such as the logging file path, the number of crank revolutions per read, the clock frequency, among various other settings. The second tab is called Sensors and is the same as the signal quality program which is used to graphically display the TPS, ECT, IAT, and MAP sensor values entered in the left panel. The third tab is called Digital Graph and this tab is the main tab of this program. The Digital Graph tab is used to display the Crank and Cam sensor signals as well as either the two ignition signals or two of the injector signals at a time. Originally, the crank, cam, the two ignition signals, and the four injector signals were all displayed at once, but because the computer could not make all of the necessary measurements for all of these signals fast enough the number of signals viewed at one time had to be limited. In the Digital Graph tab the timing relationships between the different signals can be measured, logged, and analyzed. The final tab on the right panel is the signal processing tab. This tab consists of a graph that can display each sensor signal one at a time for analysis. In all, the timing program is mainly used to measure and analyze the critical timing characteristics of the ECU input and output signals to meet specifications 19 and 20 as listed in figure 1: Project Specifications.

5. Mechanical Enclosure Design:

The mechanical design for the new enclosure is an integration of the previous team's design successes and new concepts introduced by the current team's designer. The main constraints for the enclosure include waterproofing, protection from harmful vibrations, weight reduction, and most importantly, effective heat dissipation to prevent the PCB from overheating during operation.

The previous team's design provided excellent protection at the connection interface as well as effective heat dissipation by adding fins to the base of the enclosure. The design also included the use of vibration absorbing bushings from GelTech® for additional protection. These bushings were sufficiently tested by attaching a three-axis accelerometer to the chassis of the vehicle and revving the engine to 12,000 RPM.

Heat Analysis

Another consideration that was fully implemented in this year's version is the use of Therm-A-Gap manufactured by Chomerics™. This thermal interface material is applied to the heat generating components on the PCB; it conducts the heat to the enclosure where it can then be dissipated into the external environment. This material is an excellent candidate for the current application due to its high thermal conductivity (3W/m-K), high tack surface which reduces contact resistance, and its dense, porous composition- adding further protection against vibration. The current rev PCB emits a total of 62 Watts of heat. The maximum allowable chip temperature for the board components is 85°C. In order dissipate heat quick enough to conserve the PCB and its components; a complete heat analysis was performed with the thermal interface material in place as well as fins along the base of the enclosure (reduced significantly from the previous version.) Assuming a worst case scenario of stagnant ambient air at 52°C with no forced convection at steady state, the surface temperature of the PCB will reach 72.5°C, well below the maximum allowable temperature. The reduction in fin length and base thickness also allows for a significant reduction in the overall weight of the enclosure.

Waterproofing:

The current plan for waterproofing the enclosure includes the application of a clear RTC silicon-based sealant. Permatex® silicone adhesive sealant is designed to seal and secure a variety of materials including metals. It is capable of operating in a wide temperature range without failure (-55 - 204°C) and is resistant to numerous substances including oil, water, weather, vibration, and grease- all substances/factors the enclosure will encounter during operation. The enclosure will not be able to be sealed until all testing and refinement of the PCB is completed.

6. Results and Testing:

Testing of the PCB
The test plan included testing at low, moderate and high end static rpm, start-up acceleration and regular linear acceleration and deceleration. Testing at static RPM was successful in reporting the output signals from the NI DAQ to match the signal on the oscilloscope.
The model used to predict RPM was tested over an entire 15 minute sample of data from an actual Formula Team training session. The input signals were exported from the Motec Standard i2 software [7] to an Excel file where the newly created RPM predictor equations were used to determine degree error from the actual next RPM that occurred. This test proves the maximum error in injection and ignition assuming the software is coded to correctly interpret these engine speeds. The test data was extracted at 100Hz, an equivalent of 3000 RPM. Though the average error in degrees for predicting the time of the next cam head was 0.53x10E-3, the highest error was 6.10 degrees which is far beyond the limit specifications. The accuracy was out of specification on 6790 predictions on a total of 65531. The one percent of predictions that are outside of specification occur most commonly during periods of greatest acceleration.

Conclusions and Recommendations:

This year there were a significant number of issues found in previous designs that were insufficient for completing the required work. Many of these issues were resolved including the ECU enclosure, injector control circuitry, relay control circuitry, microcontroller voltage regulation, oxygen sensor implementation, an updated PCB layout, functionality of the timing VI test bench and acceleration functionality of test bench. Other issues have arisen in later stages of the project and are at different stages of correction. These issues will be covered in detail in the pre-read document for next years team and be conveyed to key members of the formula race team (eg. Taylor Hattori) to provide a well rounded introduction for those involved in the future projects.

The current PCB board is revision 15 and changes described above have been made as a result of testing thus creating revision 16 which next years team will start with. This board may experience changes as a result of requirements from the new programming and should not be reprinted until the code is updated sufficiently.
There are a number of issues and engine dynamic concept that the code developers should understand prior to completing the code. One of the most fundamental concepts is the changing engine dynamics during acceleration and deceleration. The current formula car uses a two-tooth cam wheel and thus data can only be collected twice per revolution of 360 degrees. Considering the initial rpm to be low values such as 500 and accelerating at a rate of up to 15000 rpm per second when not under load, the rpm of the cam will change significantly from one cam tooth to the next, resulting in the injection and ignition occurring at ineffective times. The code model must be written to allow for the necessary accuracy in these scenarios. The IAT, MAP, ECT and TPS are all current inputs that can and should be built in to the code. Data from existing runs should model these inputs against the change in RPM to determine how each has an affect. In the statistical analysis linear regression may be suitable. This will help determine how much accuracy can be added to the model through the inclusion of these variables.
For final testing, the Motec ECU and the student manufactured ECU shall be run through the same course while hooked up to the NI DAQ and LabView test bench. The acceleration model can be driven by spreadsheet data for times based on the length of the spread sheet. Text files may also be suitable for this and may allow for longer period runs. Facing the same inputs from the NI DAQ the student built ECU should perform within a range of the Motec ECU.

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