Engine Electronics Group
MEE 487
Midterm Report

Submitted to Professor Mick Peterson

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I. Project Introduction

1. Objective

The object of the Engine Electronics group is to reverse engineer the existing stock engine control unit (ECU) on a 2003 Arctic Cat four stroke 660 cc snowmobile engine. This reverse engineering is desired in order to more properly control emissions after the addition of a catalyst. Particularly, hydrocarbon (HC) and nitrogen oxides (NOx) emissions will be monitored for optimum performance in the SAE Clean Snowmobile Challenge (CSC). Since HC and NO_x emissions are the most important to control in an engine, the CSC has based the emissions part of the competition on measurement of HC and NO_x in each of teams' sleds. One of the goals in this project is to minimize the HC and NO_x emissions for a total minimum percentage of emissions required for the greatest amount of design points. (CO emissions are also considered in the test, but are weighted less than the HC and NO_x emissions levels). Table 1 lists the operating conditions of engine emissions testing, and scoring for the emissions event is listed in Equation 1. The control on emissions will be attained by modifying the existing engine control unit.

Table 1: Operating Conditions for Emissions Testing

Mode	1	2	3	4	5
Speed, %	100	85	75	65	Idle
Torque, %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

Equation 1: Scoring for CSC Emissions Test

$$\text{Your Score} = 100 + 133\left(\frac{(HC+NOx)_{ref} - (HC+NOx)_{your}}{(HC+NOx)_{ref} - (HC+NOx)_{min}}\right) + 67\left(\frac{CO_{ref} - CO_{your}}{CO_{ref} - CO_{min}}\right)$$

Table 1 and Equation 1 courtesy of SAE CSC 2005 Rules

There are several options in modifying an ECU. A "stand alone" system allows a completely new engine control unit to be employed on the engine. This requires all new sensors, wiring and computer to allow the engine to operate. Another option is to use a "piggyback" or override for the existing ECU. The idea behind the piggyback is to allow a separate control unit or computer programmed microcontroller to bypass the existing engine control unit when certain operating conditions are met by the engine.

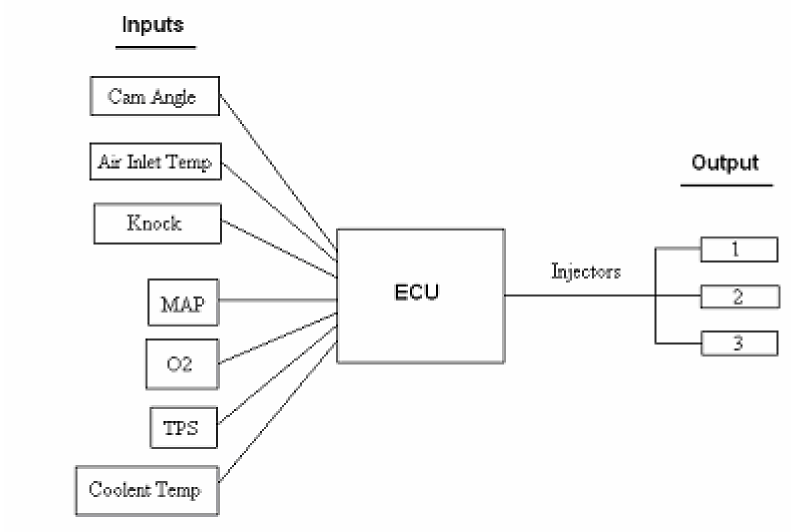
2. Piggy Back vs. Stand Alone

One way to control the emissions from the engine is to control the air/fuel mixture injected into the engine for combustion. Without using a completely new ECU with a stand alone configuration or remapping the existing ECU, which can take years of experience, the control of the air/fuel mixture can be accomplished through the use of a "piggy back" electronics system using analyzers such as a wideband O_2 sensor, dynamometer, and exhaust gas analyzer. If the stand alone option is used, electronics products from a company such as Motec would be used, and engineering the fuel maps, timing curves, and ignition curves would have to be done ourselves. Weeks of research went into making the decision between the piggy back and the stand alone system.

3. Sensor Block Diagram

Background information on the operation of ECUs is a major part of our project and a key element in decision between a piggy back system and a stand alone system. The main purpose of the ECU is to determine the pulse width of the fuel injectors. Pulse width is defined as how long the injectors stay on. The pulse width is determined by sensors which act as inputs to the ECU. The ECU looks at the incoming signals, and through programming logic and data tables determines the appropriate pulse width for the situation. Below in Figure 1 a block diagram is shown with the inputs and outputs from the ECU.

Figure 1: Input/Output Diagram for snowmobile Engine Control Unit



4. Design Matrix and Decision

As with any engineering project cost and simplicity are of great importance. It is our goal to use a system that is not only cost effective, but simple enough so that other people following our research next year can use the system we chose as well. Table 2 shows the design matrix that was put together in order to make the decision between the two different options.

After extensive ECU research and design analysis we have determined that the use of a piggy back system will work as the best option for this year. Not only is it much cheaper than a stand alone unit, but it offers the ability to have a fail safe mode that allows the factory ECU to once again take full control over the engine if we have any problems. The basic idea behind the piggy back is to look at the air inlet temperature sensor and change the resistance with a digital potentiometer. This will allow us to control what temperature the ECU believes the surrounding conditions are, and lower temperatures yield a richer fuel mixture. The digital potentiometer is to be controlled by a basic stamp microcontroller. The basic stamp will look at an input from the wideband O_2 sensor and give an output to the digital potentiometer. We will program the basic stamp with a PC. In order to program the digital potentiometer, an analog dial potentiometer is used for simplicity to determine what resistances work the best given an engine operating speed.

Table 2: Design Matrix and options for ECU, Piggyback or Stand Alone ECU

	What we have	What we can do	
	Existing ECU	**Piggyback**	**Stand Alone Engine Management**
Uses existing wiring harness	Yes	Yes	Not likely
Uses existing sensors	Yes	Yes	Possibly if same voltage range
Able to return to stock settings	Yes	Yes	Yes if using existing wiring harness
Cost estimate	$1,200	$2,000	$2000-4000
Dyno compatibility	Yes	Yes	Yes
Competition Reliability Issues	Reliable	Uses stock Ecu more reliable	Could be as reliable with proper tuning
Using our own progm'd maps	No	No, uses existing ECU map	Yes
Adjusting air/fuel ratio	No	Yes	Yes
Using second O2 sensor	Yes if Piggyback	Yes	Yes
Tech Support	None	None	Possibly depending on company
Ease of data acquisition	Need pin out	Need pin out	Easier, should have pin out or ports
Competition Requirements	Yes	Yes	Yes

Options for Stand alone Engine Management are given below

	Motec	**Simple Digital**	**Performance ECU**
Uses existing wiring harness	No	No	Yes, make adapter to fit stock harness
Uses existing sensors	No, use new ones	Won't work w/ OE crank sensor	Yes****, but can buy their sensors (GM)
Able to return to stock settings	No	No	Yes
Cost estimate	$3815*/$5261**	$1250***	$900**** (20% discount for SAE teams)
Dyno compatibility	Good, plug and play ports	Tap into wiring harness	Good, plug and play ports
Competition Reliability Issues	Less reliab, diff sensors	Less reliab, diff sensors	More reliab when using stock sensors
Using our own progm'd maps	Yes	Yes	Yes
Adjusting air/fuel ratio	Yes	Yes	Yes
Using second O2 sensor	Yes	Yes	Yes
Tech Support	Yes	Yes	Yes
Ease of data acquisition	Easy, all included	No datalogging capability	Easy, all included
Competition Requirements	Yes	Yes	Yes

*Engine Management
**Data Acquisition

***Just ECU, sensors, programmer and wiring harness, no datalogger

****Does not come with sensors. Just ECU and data acquisition

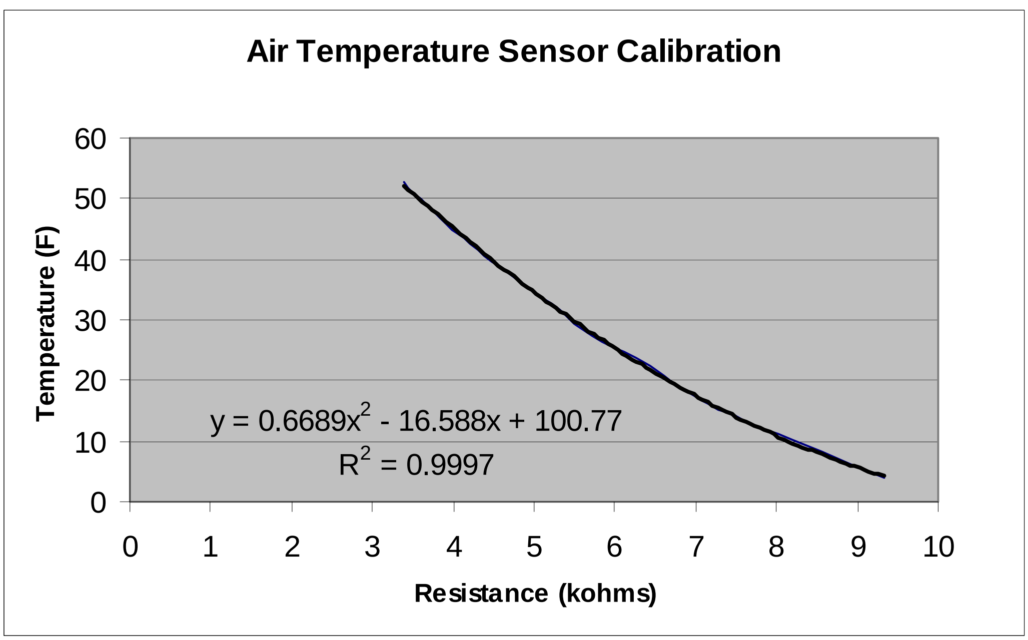
II. Development of Analog Dial Potentiometer

1. Air Temperature Sensor Calibration

One of our goals in controlling the sleds performance is to control the air/fuel mixture being burned in combustion. Without completely remapping the ECU fuel maps, an idea of tricking the ECU with the inlet air temperature sensor (IAT) was mentioned. Since the IAT sensor is calibrated for temperatures vs. resistance, given a temperature of the inlet air, the sensor gives a certain resistance that is read by the ECU. The ECU takes that resistance and then makes decisions, based on the fuel map, and sends the correct voltage pulse to the injectors to inject the right amount of fuel into the cylinders. If the temperature of the inlet air decreases, the IAT resistance increases, and vice versa. If the resistance read by the ECU from the IAT can be controlled, the ECU will read a different inlet air temperature and send more or less fuel to the injectors by adjusting the injector pulse width. By adding a variable resistor, or potentiometer, in series loop with the IAT and ECU, the resistance increases so that inlet air temperature drops, and the ECU adjusts the pulse width to send more fuel to the combustion chamber.

To know how much resistance the IAT sensor sends the ECU, the IAT sensor was calibrated in a controlled environment. A cooling source was needed, a thermocouple for temperature measurement, along with a multimeter to measure the resistance across the IAT sensor leads. A beaker of approximately 500 ml of methyl alcohol was put into a freezer for two hours to cool. After the two hours, the beaker was taken out of the freezer and the sensor was slightly immersed in the fluid. As the beaker warmed back to room temperature, the resistances were recorded with temperature. Figure 2 displays the IAT calibration curve in the graph below.

Figure 2: Air Temperature Sensor Calibration

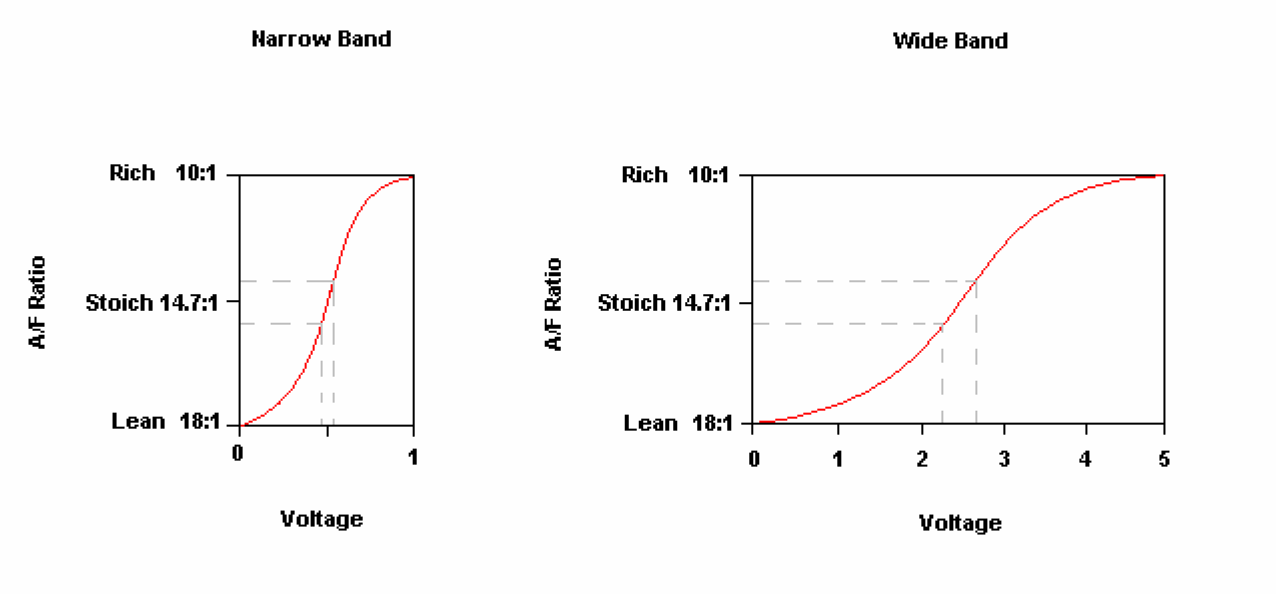


2. Air Fuel Ratio theory with Pre-Cat O_2 sensor

Once the ECU injects fuel into the cylinders based on the resistance from the IAT sensor, the ECU needs to know if the air/fuel mixture is too rich or too lean for the operating conditions. An oxygen sensor is placed in the exhaust stream to measure the amount of O_2 in the mixture after combustion. The O_2 sensor is calibrated for O_2 concentration vs. voltage. The voltage signal is sent back to the ECU as feedback to tell the ECU if the mixture has too much O_2 in it or too little, hence if the air/fuel ratio is too lean or too rich. If the mixture is too rich, the ECU will adjust the injector voltage pulse width so that the mixture is leaner, and vice versa.

In order to tune the engine through mixture adjustment with the O_2 sensor, there are two types of O_2 sensors to choose from based on voltage output. A narrow band O_2 sensor uses a 0-1 V range of output, and a wideband O_2 sensor uses a 0-5 V range of outputs. This range of voltage is calibrated for voltage vs. air/fuel ratio, based on voltage and O_2 content in the exhaust stream. Because of the greater range of voltage, a wideband O_2 sensor allows for more fine adjustment of the A/F mixture. This range adjustment can be seen in the O_2 sensor comparison in Figure 3.

Figure 3: Comparison of Narrow and Wideband O_2 sensor Calibration



The wideband O_2 sensor will be first examined in stream before the catalytic converter where the existing narrow band sensor is located.

A Bosch wideband O_2 sensor was purchased from PLX Devices online. If there is any question to what is happening in the cat, the O_2 sensor can be moved to the post cat stream position, where a program will need to be written for the microprocessor version of the piggyback.

3. Air Temperature Sensor Modification

The air temperature sensor was modified so that the dial potentiometer could be wired in series loop from the sensor to the ECU. Using standard three prong electrical connectors and soldering lead plugs onto the wiring, the air temperature sensor side and ECU side of the wiring were fitted with connectors, as well as both ends of the potentiometer. This would allow the potentiometer to be taken out of the circuit if not needed.

The dial potentiometer was put in line with the IAT and the ECU and proved to be fail safe. The sled ran with no effects at 0 kΩ resistance. The resistance was varied to see if there were any effects at idle and at low engine speeds, but since the clutch and track were not on the sled at the time, it was hard to judge the effects of the potentiometer with no engine load. The sled would need to be tested on the dynamometer, preferably the engine water brake dyno, so the sled can be tested under load. To measure the effects of the potentiometer, an exhaust gas analyzer measuring the exhaust gases, primarily HC and NO_x, will be used to determine the optimum resistance for the potentiometer, given a certain engine operation speed for the sled.

4. Problems with Fall Semester Testing

When setting up the EMS-5500 exhaust gas analyzer, there were problems with calibrating the machine. The CO and NO_x readings were displaying an error code. After troubleshooting, reading the manual and trying to recalibrate several times, the manufacturer was contacted. The manufacturer shipped us a new O_2 sensor for the gas analyzer. The new sensor was installed and the machine was calibrated again. Unfortunately, the error code still flashed on the CO and NOx readings. After troubleshooting again with the manufacturer, and determining that the O_2 sensor was functional, the exhaust gas analyzer was shipped to the manufacturer in Illinois for repair, most likely of its main electronics control board.

The sled was tested with the exhaust gas analyzer to see if the HC emissions levels were any different with the potentiometer than without, but no data was taken because of the uncertainty in the HC calibration on the exhaust gas analyzer. Also, testing on the dyno with an uncalibrated gas analyzer would give skewed results, especially when the effects should not be obvious on the sled.

III. Development of the Digital Snowmobile Piggyback

1. Basic I/O Diagram

Figure 4: Input/Output diagram for digital potentiometer piggyback

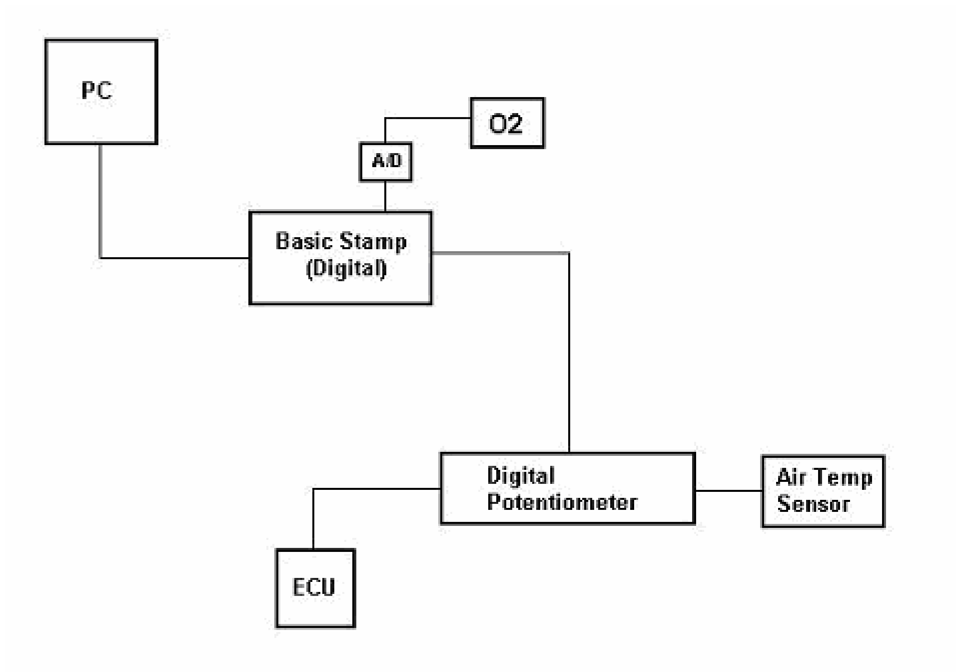


Figure 4 is a diagram of a basic piggy back for the snowmobile. It will allow us to change the A/F ratio on the snowmobile by using a microcontroller. The following is a description of the parts:

- PC – A computer used to program the basic stamp
- Basic Stamp – A microcontroller
- A/D – Analog to digital converter
- Digital Potentiometer – Changes the resistance
- ECU – Main computer which operates the snowmobile
- Air Temp Sensor – Measures inlet air temperature on the snowmobile
- O_2 Sensor – Measures the amount of oxygen in the exhaust system

2. Theory and Control of the Microcontroller

The basic stamp is a microcontroller developed by Parallax, model BS2P24IC. It can easily be programmed using a form of the BASIC programming language, called Stamp. After the program is written, the microcontroller connects to a computer through a serial cable, and the program downloads into the basic stamp's memory (EEPROM).

The only input to the microcontroller thus far is a Bosch LSU4.2 wideband O_2 sensor. This sensor will be mounted before the catalytic converter in the exhaust system to monitor the gas mixture. A program will be written and sent to the microcontroller based on the relationship between the O_2 sensor and the air temperature sensor. Notice in Figure 1, an analog to digital converter is used since the output of the O_2 sensor is analog and the microcontroller is digital.

A digital potentiometer will be wired in series between the ECU and air temperature sensor. A catalytic converter was installed on the snowmobile, since the A/F ratio has been lean. Using a digital potentiometer to change the resistance of the air temperature sensor the A/F ratio can be changed. Changing the resistance tricks the ECU, and will allow the fuel mixture run a little richer.

3. Fail Safe Design

The digital potentiometer which will be run in series with the stock snowmobile IAT sensor to the ECU must go to a fail safe mode should the potentiometer fail. It will need to be tested to assure that should the input from the microcontroller fail or the entire system fail that the resistance will remain at a level suitable for the engine to finish the event without causing engine damage or breakdown. Ideally the digital resistor would turn to a short circuit and the IAT sensors stock reading would be sent to the ECU.

IV. Plans for the Spring Semester

The main objective of the spring semester is to complete the micro controlled digital potentiometer and tune it to increase efficiency and decrease emissions. Using the input from the wideband O_2 sensor the microcontrollers program will be formatted to gain maximum benefits for different competition events. 25, 50, 75 percent and wide open throttle will be examples of such areas that could be focused on in testing the engine with both potentiometers.

A basic program will be written for the micro controlled digital potentiometer and testing along with the analog potentiometer will be performed on the exhaust gas analyzer and either the resistance dynamometer or water brake engine dyno. The water brake is the choice dyno to use because it measures the engine output shaft power, rather than the track output power measured by the resistance dynamometer. By testing different engine operating ranges with the analog potentiometer and gaining an idea of what resistances give us the lowest emissions at those ranges it will give us a better idea of how the microcontroller should be programmed to properly vary the digital potentiometer through the RPM range of the engine.

Once testing is complete and the micro controlled digital potentiometer is setup properly a write up of the tuning specs for different competition events will be made. A backup of all the programs will also be created for reference by future groups.