Engine Control Unit

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Abstract

This paper describes the design of a fully programmable, low cost ECU based on a standard electronic circuit based on a dsPIC30f6012A for the Honda CBR600 F4i engine used in the Formula Student IST car. The ECU must make use of all the temperature, pressure, position and speed sensors as well as the original injectors and ignition coils that are already available on the F4i engine.

The ECU must provide the user access to all the maps and allow their full customization simply by connecting it to a PC. This will provide the user with the capability to adjust the engine's performance to its needs quickly and easily.

Keywords

Electronic Fuel Injection, Engine Control Unit, Formula Student

I. Introduction

This project is part of the Formula Student project being developed at Instituto Superior Técnico that for the European series of the Formula Student competition.

The Formula Student competition challenges students to design, build and develop a prototype based on a autocross or sprint racing car with a cost below €21000 and for a production of 1000 units a year.

The car used (Figure 1) has a fibreglass body and uses a Honda F4i engine taken from the Honda CBR 600.

Figure 1 - FST03.

II. Electronic Fuel Injection

The growing concern of fuel economy and lower emissions means that Electronic Fuel Injection (EFI) systems can be seen on most of the cars being sold today.

EFI systems provide comfort and reliability to the driver by ensuring a perfect engine start under most conditions while lessening the impact on the environment by lowering exhaust gas emissions and providing a perfect combustion of the air-fuel mixture.

The EFI systems are composed of sensors, the Engine Control Unit and actuators.

III. Sensors

For the ECU to respond correctly to the engine's condition it must rely on an array of sensors providing information regarding speed (Engine Speed sensor), position (Camshaft Position and Throttle Position sensors), pressure (Manifold Absolute Pressure) and temperature (Engine Coolant and Intake Air temperatures).

The Engine Speed Sensor relays the engine's current angular speed, in Revolutions Per Minute (RPM), to the ECU. It uses a magnetised cog with 12 teeth attached to the engine's crankshaft (Figure 2) and a Hall effect sensor.

Figure 2 - Engine Speed sensor.

When one of the cog's teeth passes near the near the sensor it creates a magnetic field creating a voltage difference across the sensor's surface. This voltage difference is proportional to the magnetic field applied and, through the use of an operational amplifier and a comparator, the sensor's output signal is converted to a series of pulses (one pulse each time a cog's teeth passes near the sensor).

Figure 3 shows the sensor's output.

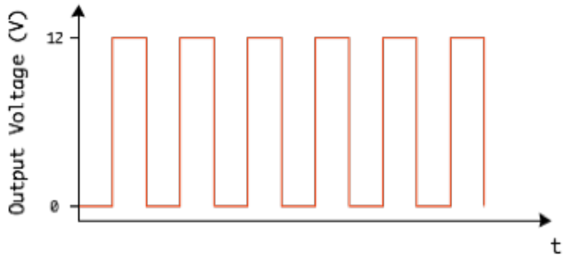

Figure 3 - Engine Speed sensor output.

The voltage output from the sensor is then lowered to 4,7V using the circuit shown in Figure 4.

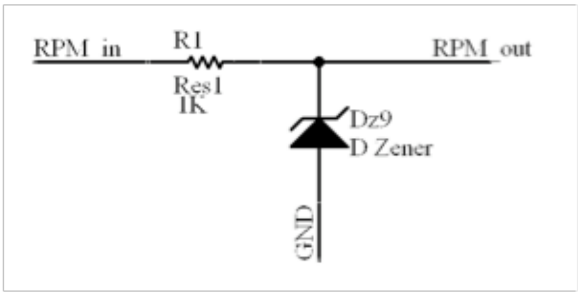

Figure 4 - Engine Speed conditioning circuit.

The Camshaft Position sensor works exactly like the Engine Speed sensor, differing only on the shape of the cog used (Figure 5) [1].

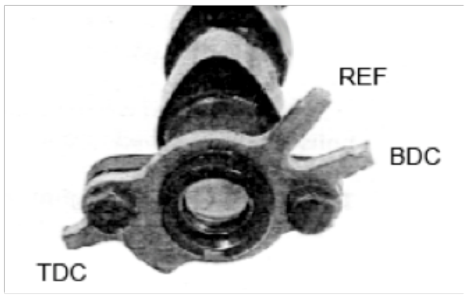

Figure 5 - Camshaft Position sensor.

The 3 reference teeth of the cog help the ECU determine the current position of the engines cylinders. TDC or Top Dead Centre occurs when cylinders 1 and 4 are at the highest point in the combustion chamber and BDC or Bottom Dead Centre occurs when cylinders 2 and 3 are at the highest point.

Figure 6 shows the Camshaft Position sensor's output.

Figure 6 - Camshaft Position sensor output.

The Throttle Position Sensor (TPS) is attached to the throttle valve (Figure 7) and relays the current throttle pedal position to the ECU.

Figure 7 - TPS sensor.

The TPS sensor is composed by a potentiometer connected to the valve's axis. When the driver accelerates, the valve is opened and the potentiometer's wiper arm moves along the resistor changing the output voltage of the sensor.

Figure 8 shows the TPS sensor's voltage output.

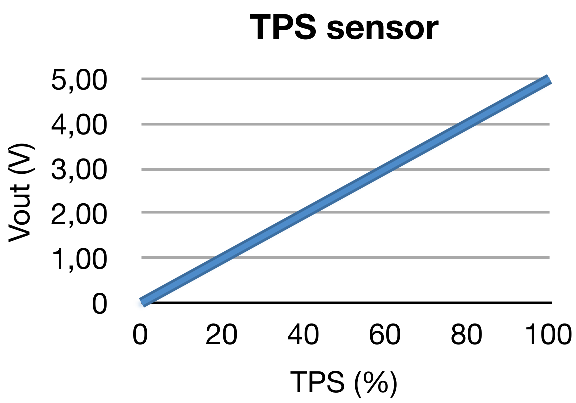

Figure 8 -TPS output.

The TPS sensor's output is filtered to reduce the noise that might affect the sensor.

The Manifold Absolute Pressure Sensor (MAP) measures the pressure inside of the intake manifold. This provides the ECU with an accurate measure of the load being applied to the engine.

Inside the MAP sensor is a small silicon chip (Figure 9) placed between a vacuum chamber and a line leading to the intake manifold. As the pressure increases inside the manifold, the silicon chip flexes, acting like a strain gauge and changing its resistance [2].

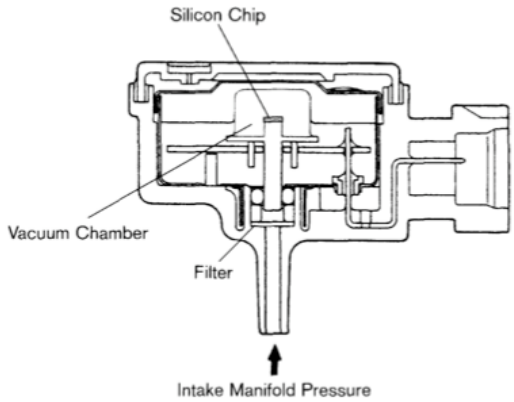

Figure 9 - MAP sensor.

The chip is inserted in a Wheatstone bridge for a more accurate reading.

The MAP sensor's output is always dependant of the atmospheric pressure, therefore a calibration measurement is made prior to starting the engine and the engine load value is given in the form of a percentage where a load of 100% is equal to the atmospheric pressure and a load of 0% means the engine is in a perfect vacuum.

The temperature sensors measuring the Engine Coolant Temperature (ECT) and Intake Air Temperature (IAT) are comprised of a Negative Temperature Coefficient (NTC) thermistor. The NTC thermistor decreases it's resistance when it is heated. Figure 10 shows the relationship between the ECT's thermistor resistance and it's temperature.

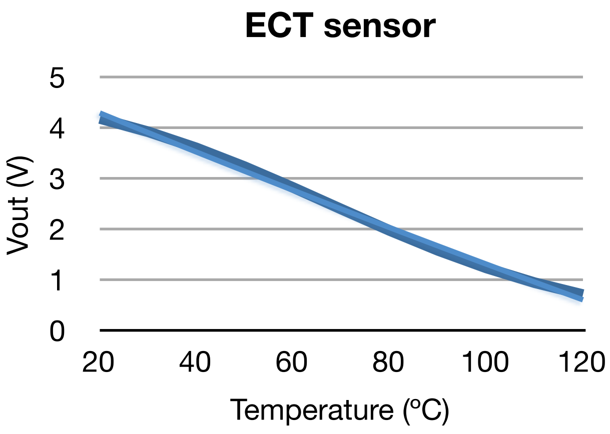

Figure 10 - ECT output voltage.

The IAT sensor follows the same relationship but is used in smaller temperature ranges (up to 45ºC)

Using the circuit in Figure 11, the resistance of the NTC thermistor can be turned into a voltage that can be converted to a digital value by the dsPIC.

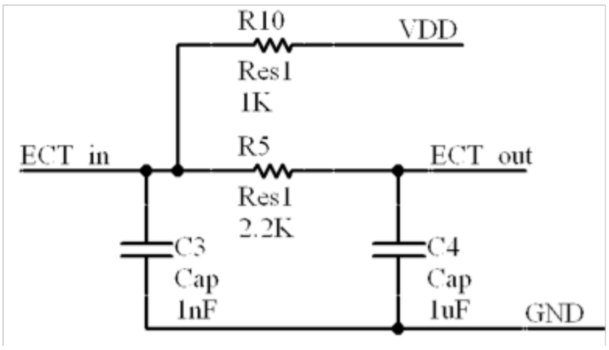

Figure 11 - ECT conditioning circuit.

IV. Engine Control Unit

Once the ECU has collected all of the information from the sensors in the engine, it has to determine when and how much fuel to inject in the combustion chambers.

It achieves this by indexing predetermined tables, or maps, set by the user for that specific engine.

The maps used are the Base Fuel and the Base Ignition maps.

The Base Fuel map is used to determine how long the injector has to be opened for a given engine speed and engine load and the Base Ignition Map is used to determine when the ignition advance must begin charging so that the spark happens exactly when needed.

Although the number of values in the maps is finite there are infinite combinations of engine speed and engine load that can occur during normal engine operation. The use of a bilinear interpolation algorithm solves this problem.

The bilinear interpolation algorithm uses 4 known points located around the unknown point and uses them to first interpolate the points along one of the axis and the along the other.

All injection and ignition timings are synchronised using the camshaft's signal.

V. Actuators

As soon as the new injection and ignition advance timings are known, the ECU must generate the injector and ignition control signals (Figure 12).

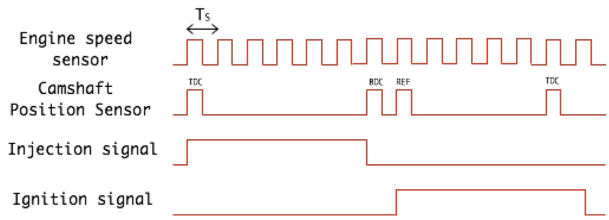

Figure 12 - Injection and ignition signals

Precise injection and ignition timing can provide the engine a greater power output and smooth operation while an incorrect timing setup can result in a significant loss of power and efficiency and subsequently cause severe damage to the engine.

The fuel is delivered to the combustion chamber through the injectors. The injectors are electromagnetically controlled nozzles that atomize the fuel so that it mixes with the air inside the chamber and ignites more easily (figure 13).

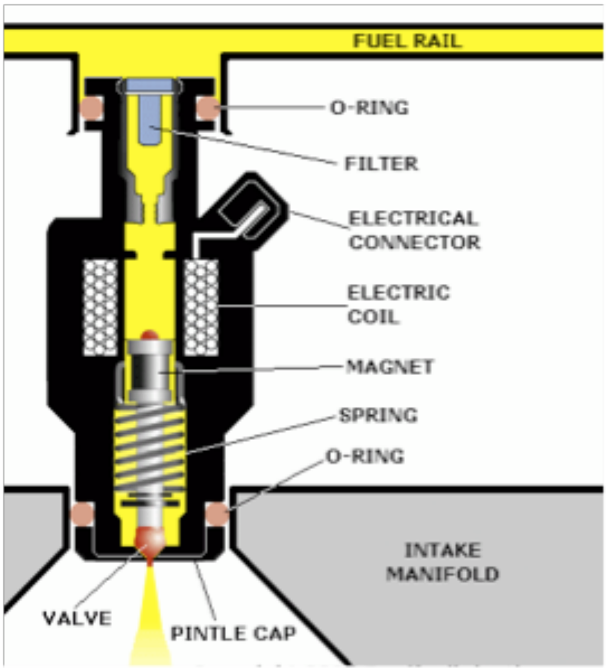

Figure 13 - Injector [3].

The injectors are driven by an LM1949 injector driver integrated circuit that commands the passage of current through the injector (Figure 14).

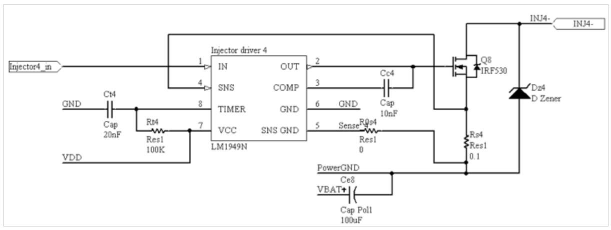

Figure 14 - Injector driver.

The LM1949 also monitors the injector current, and reduces it when the injector is fully opened or more than 2ms have passed. This preserves the injector's life since the current needed to keep the injector opened is lower than the current needed to open it.

After the fuel has been injected into the combustion chamber it must be ignited. To do so the ECU sends the ignition signal to the pretended ignition coil. The ignition coils (Figure 15) store an electromagnetic charge that is later discharged in the form of a spark at the tip of the sparkplug.

Figure 15 - Ignition coils.

The time taken for the spark to occur from the moment current starts passing through the coil is called dwell [4].

Dwell time (Figure 16) depends of the ignition coils used and, for the coils used, the dwell is equal to 3 milliseconds [1]. Increasing the dwell (over-dwell) will not only overheat the coil and shorten its life span but also provide no additional energy.

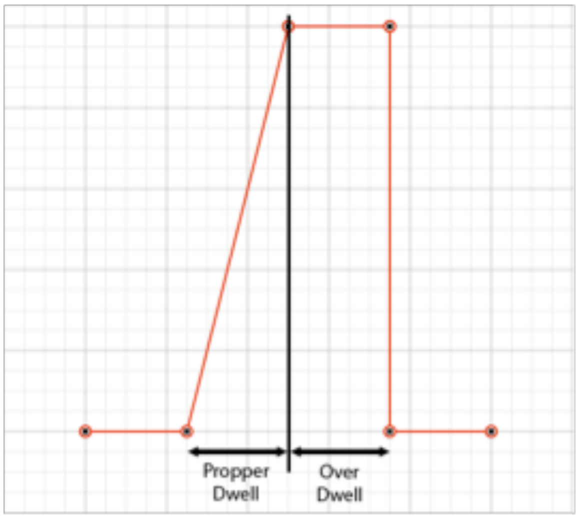

Figure 16 - Dwell.

The circuit used to drive the ignition coils is shown in Figure 17.

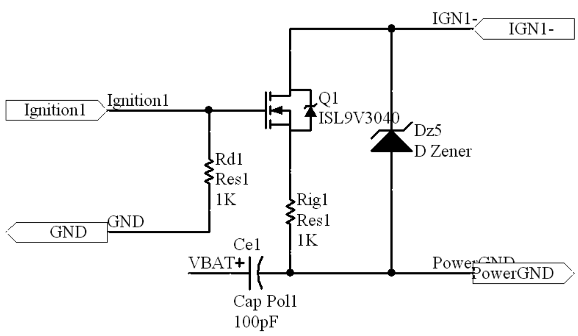

Figure 17 - Ignition driver.

The ignition driver IGBT is able to monitor and limit the current passing through the ignition coil without the use of additional external components.

VI. CAN-Bus

The Controller Area Network Bus (CAN-Bus) is a broadcast protocol bus mainly used in the automotive industry.

The ECU uses the CAN-Bus to update the values in the Base Fuel and Base Ignition maps during normal operation. This allows the use to adjust the maps while on the dynamometer. The CAN-bus messages used are from the Dataframe type [5] and are comprised of:

- An Arbitration field that is 11 or 29 bits long and contains the message identifier.

- A Data field with up to 8 bytes of data.

- A Ciclic Redundancy Check field that contains a checksum of the message.

- An Acknowledge slot used by the nodes receiving the message to confirm its arrival. This does not ensure that the correct node received the message.

Upon the reception of the message, the corresponding value is updated in the dsPIC's RAM and EEPROM versions of the maps.

VII. Map creator software.

Adjustments to the fuel and ignition maps of the ECU are made using a specifically built windows application. This application communicates with the ECU via a USB to CAN converter.

Within the application users can modify the ECU maps in real-time just by changing the values of the maps presented on the application's user interface.

All values changed in the user interface are automatically updated in the ECU (if connected) as soon as the user is finished editing them.

The application implements a simple transmission protocol to ensure the correct arrival of the messages. Base fuel values are sent with message identifier 1 while Base Ignition values are sent with message identifier 2. Before transmitting the next value the application waits for a returning message with identifier 3.

VIII. Results

Using this ECU it was possible to observe the injection and ignition pulses for all 4 cylinders.

Figure 18 shows the injection pulses for all 4 cylinders.

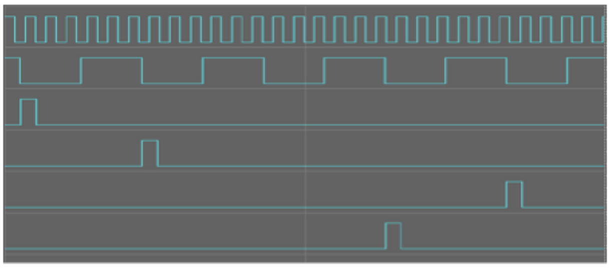

Figure 18 - Injection pulses.

Figure 19 shows the ignition pulses for all 4 cylinders.

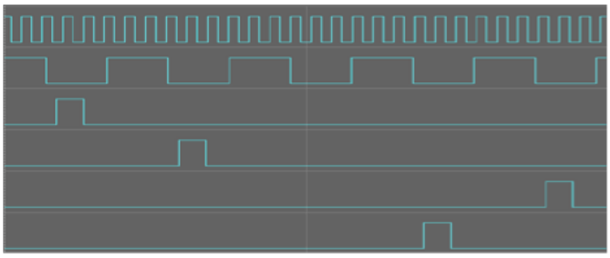

Figure 19 - Ignition Pulses.

IX. Conclusions

The work presented, the ECU is capable of creating all the necessary signals to operate the engine according to the fuel and ignition maps stored in its memory. It also enables the user to change both maps while the engine is running. This is useful when tuning the engine on a dynamometer and empowers the user to change the ECU's settings according to its preferences.

X. Future work

Future work on the ECU can focused on improving its overall performance.

The ECU's performance can be improved by adding additional maps to make small corrections in the fuel injection and ignition advance based on throttle variations, engine temperature and intake air temperature.

These maps can help the engine run more smoothly and respond better.

The ECU has to be configured while the car is placed on a dynamometer. This will set the correct values in the ECU's maps allowing the engine to run smoothly and correctly.

XI. References

[1] Honda Motor Company, 2003, *CBR600 F4i service manual*

[2] Toyota university, *Pressure sensors*, Toyota Motor Sales, U.S.A., available from http://autoshop101.com/forms/h35.pdf

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[4] Motec, 2004, *Engine Management & Data Aquisition Systems*, Formula SAE seminar, Detroit

[5] Kvaser, *The CAN Bus*, available from http://www.kvaser.com/can/intro/index.htm