Hardware Design And Development of Engine Control Unit For Four Cylinder Engine

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Abstract- *In automotive area use of electronic devices has been increased on a large scale and a control unit is very important for greater engine efficiency. This paper describes design of an Engine Control Unit developed for fuel injection and spark ignition control compatible with 4 cylinder engines. Engine control unit manipulates the fuel injection and spark ignition timing correctly in internal combustion engine; so that it improves drivability and fuel consumption can get reduced. This paper presents an automotive engine control unit development. The aim of the proposed system is to replace the Engine Control Units present in the cars with a fully programmable, low cost Engine Control Unit based on a standard electronic circuit. It is based on a s9keaz128 controller that can be mass produced and used in many of the on board systems present in the car. This Engine Control Unit makes use of a set of sensors for getting proper inputs and generates appropriate decision to drive the actuators in the car. In the proposed system a two layered Printed Circuit Board for Engine Control Unit is designed on the basis of Electromagnetic Compatibility standards.*

Keywords- Engine Control unit (ECU), Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI), Sensors, Printed Circuit Board (PCB), fuel injection, spark ignition;

I. INTRODUCTION

With the advancement in technology, the use of electronics in the automotive field has increased gradually. Electronic solutions have proven to be more efficient and reliable over time in order to solve problems otherwise unsolvable. Nearly all the features which were done mechanically within the past decades were effectively changed by means of electronic control units [3]. The ECU is a microcontroller based system which takes the inputs from sensors, processes it and controls the actuators in real-time. Electronic control units are mostly used for controlling the electrical systems like fuel injection system, spark ignition system, antilock brake system, air conditioner, air bag triggering, steering, skid systems, etc.

A key responsibility of an ECU is to manipulate the fuel delivery for efficient combustion to optimize the engine performance while improving the fuel efficiency and reducing exhausts gas emissions. It is expected to self-adjust to fulfil the above requirements relying on several input sensors. For managing the fuel injection into cylinder, precise amount of air-fuel mixture is injected into the combustion chamber through proper electronic control, which depends on various factors like engine speed, load, temperature, battery voltage, throttle position. Also managing the proper spark ignition in electronic ignition system for igniting the vapour of air-fuel mixture with proper timing use of factors like engine speed, load, temperature is important. Moreover, the exhaust emissions should be kept at check and the fuel consumption should be least.

As the innovation progresses, there is a need to be put huge number of electrical and electronic frameworks into automobile vehicle. Introducing a huge number of electrical and electronics into a limited space causes the issue of EMI through the radiated and conducted emissions. So electromagnetic compatibility (EMC) standards should be considered while designing PCB in order to make electronic devices secure. It is possible to prevent EM emissions through well designed PCB. So there is a need to design a multi-layered PCB for Engine Control Unit which will reduce the EMI radiations and conductions while improving engine control unit reliability.

II. ECU

Engine control unit manipulates the working parameters in order to optimize the engine performance. ECU confirms whether the engine is getting proper sensor inputs or not. According to this, the ECU actuates a series of actuators to improve engine performance. It does this by taking values from a series of sensors, manipulating data and adjusting the engine actuators accordingly.

ECU comprises from a multitude of sensors, a processor and a series of actuators. Sensors are used to check the engine status such as engine speed, load, temperature, throttle position, air pressure and give it as input to the processor. Processor then interprets this data with reference data in lookup table and takes decision to drive actuators. The actuators convert electrical signals from the processor into action. The proposed system is designed for controlling fuel injectors and spark ignition coils for four cylinder engine. Fig 1 shows the proposed system overview. Here sensors' output signals are given to signal conditioning unit which processes the signals so that it meets the requirements of processor. Using these data, processor controls drivers to actuate fuel pump, fuel injectors and ignition coils. ECU optimizes fuel injection and spark ignition to minimize fuel consumption and exhaust gas emissions.

A. Sensor Interfacing with ECU

The main responsibility of engine control unit (ECU) is to get information from sensors, process them and run actuators. The sensors are used to monitor the status of the engine such as engine speed, camshaft position, throttle position, manifold

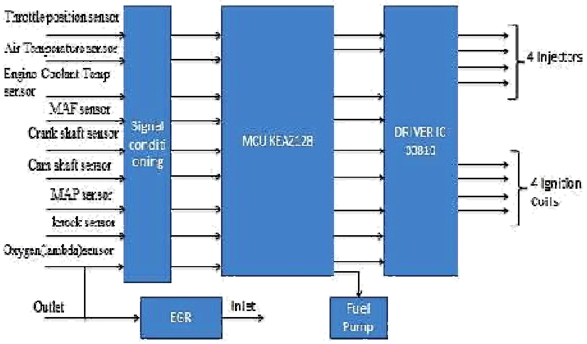

Fig. 1 System Overview

absolute pressure, engine coolant temperature and intake air temperature. For proper functioning of engine, ECU must process the input from a set of sensors.

The different sensors used in this proposed system are:

- Throttle position sensor

The throttle position sensor is used to monitor the position of the throttle valve in the engine. The injection timing and ignition timing are altered depending on the position of the throttle valve.

- Engine coolant temperature sensor

The engine coolant temperature sensor is used to tell the current coolant temperature of the engine.

- Air temperature sensor

The intake air temperature sensor is used to sense the temperature of the air that is going into the engine.

- Manifold absolute pressure sensor

The manifold absolute pressure sensor is used to detect the vacuum pressure created inside the intake manifold of the vehicle. Using these data, ECU will adjust the fuel injection timing.

- Mass air flow sensor

The Mass Air Flow sensor is used to measure the volume of air entering the engine. According to air volume, ECU will adjust injected fuel amount to maintain required air-fuel ratio.

- Camshaft position sensor

The camshaft position sensor is used to detect the current position of the camshaft. With this information, the ECU can decide the cylinder number for fuel injection.

- Crankshaft sensor

The crankshaft sensor is very similar to the camshaft position sensor in functionality. It is used to detect the location of the piston with respect to top dead centre. With this information, ECU can determine fuel injection and spark ignition timing.

- Lambda(Oxygen) sensor

The lambda sensor (O2) is used for sensing the exhaust gases and detecting the amount of oxygen. With this information, ECU adjusts the fuel quantity injected. So that fuel consumption will reduce and air-fuel ratio will be maintained.

- Knock sensor

The knock sensor is used to sense vibrations caused by knocking in the engine. ECU uses this information to adjust ignition timing and prevents the detonation in engine.

- *Actuators*

After performing all the calculations the ECU must command the fuel injectors and the ignition coils in order to inject and ignite the fuel inside each cylinder. To obtain greater power output and smooth engine operation fuel need to be precisely injected and ignition timing should be accurate. And incorrect timing setup will cause a power loss which results in significant damage to the engine.

- Injectors

The delivery of fuel to the engine is made by a set of injectors (one per cylinder) and sequence of injectors is decided using camshaft sensor. The injectors are small electronically controlled nozzles located in to the cylinder, upstream of each combustion chamber that sprays fuel into the chamber several times per second.

- Ignition coils

After injection of the fuel into the combustion chamber, the ECU must ignite the fuel at a proper timing. When the combustion chamber is at its maximum compression point, the optimum point of ignition occurs.

III. METHODOLOGY

Depending on the design requirements a schematic of ECU is designed which includes fuel injection and spark ignition systems. Schematic designs and PCB layout is designed using software Altium Designer.

A. *Hardware design of ECU*

Fig 2 shows the main schematic of proposed system for implementation of hardware. The proposed system consists of many building blocks in its block diagram viz. power supply, signal conditioning, processor, injector drivers and gear shift.

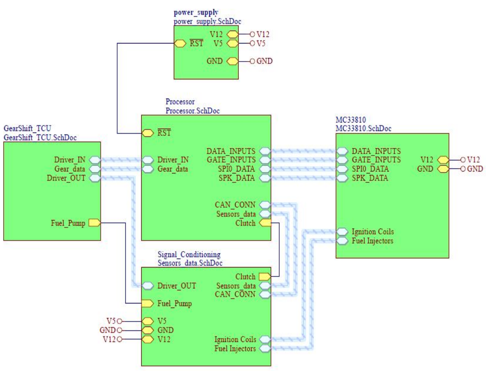

Fig. 2 Proposed System Schematic

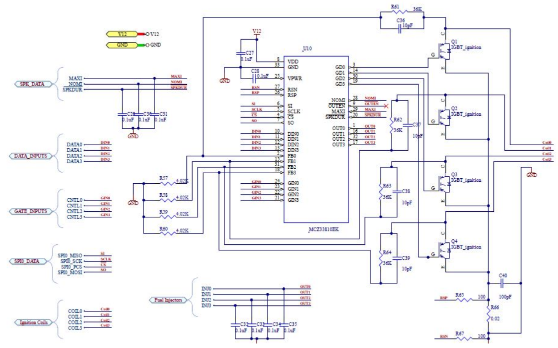

Fig. 3 Schematic of Fuel Injection and Spark Ignition System

The power supply of 5V and 12V is designed for the proposed system. The signal conditioning block collects sensor data, processes it and gives it to processor. The processor used here is S9keaz128 which is product family of ARM Cortex M0+ MCUs aimed for automotive markets. It receives sensor data and runs actuators for fuel injection and spark ignition. Also there is a system for gear control. Quad low-side solenoid driver IC DRV8803 is interfaced with processor in order to control gear shifting.

- *Fuel Injection and Spark Ignition System*

Fig 3 shows the schematic diagram of fuel injection and spark ignition system. It includes IC 33810 for driving fuel injectors and Ignition IC IRGB14C40L for driving ignition coils. This system can drive up to 4 fuel injectors and 4 ignition coils.

In the fuel injection system, fuel injection is done by means of injectors. Fuel injection can be direct or indirect. The objectives of fuel injection system are power output, fuel efficiency, emissions performance. These objectives are optimized for better performance of engine and lowering exhaust gas emissions. In the spark ignition system, a spark is generated from a spark plug to ignite the air–fuel mixture in internal combustion chamber. And the fuel injection and spark ignition timing is decided by the controller on the basis of outputs coming from the sensors.

- *EMC Standards*

Electromagnetic compatibility is the ability of a system or circuit to not become affected by the radiated and conducted EMI emissions in the system where it is used. Electromagnetic Compatibility (EMC) is very important for getting correct functioning of and avoiding any damage to electronic devices. A well-designed PCB by using EMC standards will secure electronic devices in turn our vehicles as it will be less susceptible high electromagnetic emissions.

ECU board is very complex system placed in very confined space. Each component or line on the board can radiate the electromagnetic waves and also susceptible to the noise. Component selection and circuit design techniques are major factors that will affect board level EMC performance. Some of them are

- The leadless or surface mount components are having less parasitic effects as compared to leaded one.
- Placement of resistors should be as close as possible to the active devices.
- Bypass capacitors should be used to supply transient current demand of power supply unit.
- Coupling capacitors should be used near the power pins to decouple the switching noise.
- The capacitors should have low equivalent series resistance value.
- Ferrite beads should be used to suppress high switching noise.
- The diodes should be used at the source of interference in order to suppress the transient voltages generated at the sources.
- Integrated circuits should be from same logic family to avoid switching noise.
- Floating pins of the integrated circuits must be connected to ground.

EMC performance is an important factor while designing PCB. EMC standards will have major impact on the performance of the PCB.

- For an EMC-free design, components on the PCB need to be grouped according to their functionality, such as analog, digital, power supply sections, low-speed circuits, high-speed circuits, and so on.
- The ground area on a PCB should be increased in order to reduce the inductance of ground on the board so that it becomes less susceptible to electromagnetic emissions and crosstalk.
- The separation between tracks should be increased to minimize crosstalk introduced by capacitive coupling.
- Sensitive and high frequency tracks must be placed far away from high noise power tracks.
- The signal return path should be as short as possible in order to minimize the coupling between current loops.

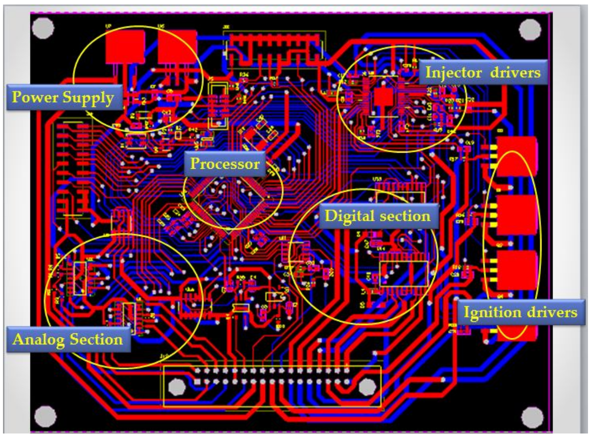

Fig. 4 PCB layout

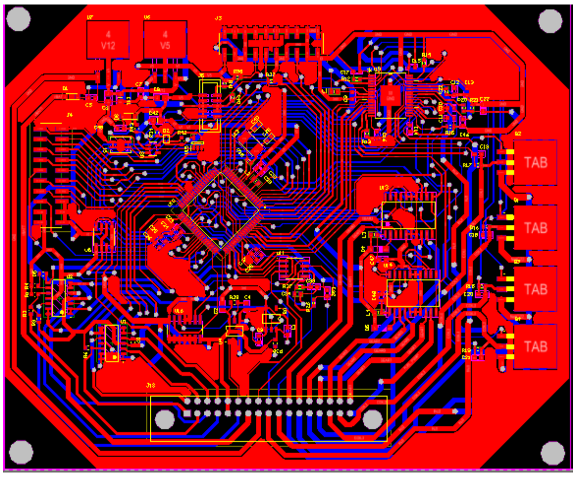
Fig. 5 PCB layout with ground polygon pours

- *PCB Layout*

In the proposed system a two layered PCB is designed using EMC standards. The components are placed based on their functionality and separated from each other using filters. A copper layer of 70 um thickness is used in this system. The traces are used for electrical interconnections or routing the signals. The width of traces is decided depending on the current value flowing through them. For analog section, the current flowing through signals is 2A maximum, so the trace width of 0.762 mm is used. The maximum current limit for the injector and ignition drivers is up to 4.5A maximum; hence a trace width of 1.27 mm is used here. Also for power signals 1.27 mm of trace width is used. For the digital signals that carry currents in the orders of mA, the trace width of 0.381 mm is used.

Appropriate sized vias are used at proper places to establish connections between top and bottom layer. For vias, the hole size of 0.61 mm and diameter of 1.27 mm is used. A standard JTAG connector is used for debugging in the system. Also testpoints are added to the PCB layout in order to check the short or open circuits present in the circuit if any. Fig 4 shows the designed PCB layout. On top layer of PCB layout, a solid polygon pour is placed to define a ground-connected area for providing electro-magnetic shielding. Fig 5 shows the PCB layout with polygon pour connected to ground on top layer.

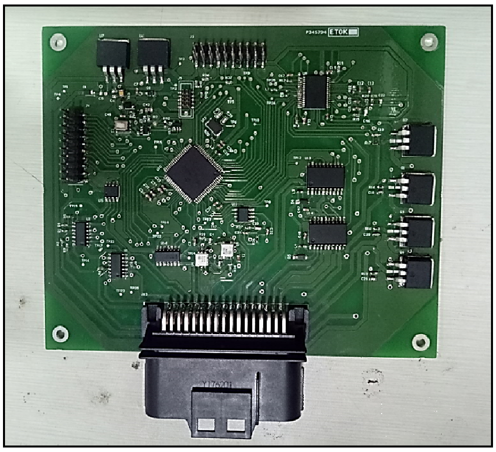

Fig. 6 Developed Engine Control Unit Board

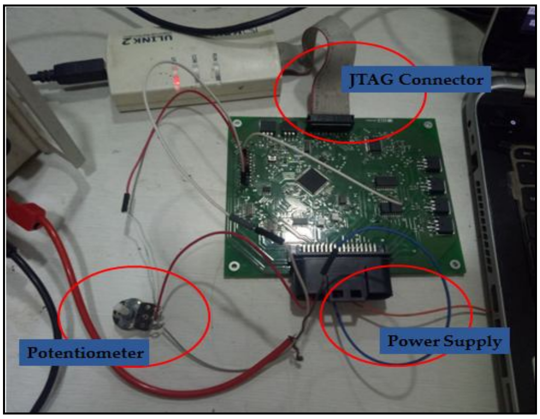

Fig 7 Setup of the proposed system

IV. RESULTS

The Engine Control Unit PCB layout using EMC standards is implemented. The Design Rule Check (DRC) is done in Altium Designer, which has zero violations. Fig 6 shows a developed Engine Control Unit board. Fig 7 shows the setup of the proposed system. In this a potentiometer is interfaced for giving an analog input (as a Throttle Position Sensor's Output) to the Lm2902 op amp IC which is used as a buffer. Then the output of buffer is given to PTF6 which is the channel 14 of ADC of processor. The digital output of ADC is taken at PTD5 pin which is input to the Pulse Width Timer (PWT) to obtain pulse output on CRO.

A program is written to receive analog input from sensors (Potentiometer) and generate a pulse output. Programming is done in Keil5 uVision software using Embedded C language. Here some sample results are shown for different angle of rotations of potentiometer's wiper.

Part 'a' of figures 8, 9 and 10 shows the PWT output i.e. the positive and negative pulse width in hex whereas part 'b' shows the pulse output on CRO. In this way we can receive inputs from different sensors and using processor/ some programming we can manipulate this data to decide when and how much fuel to be injected. Also the spark ignition timing will be decided to improve fuel efficiency.

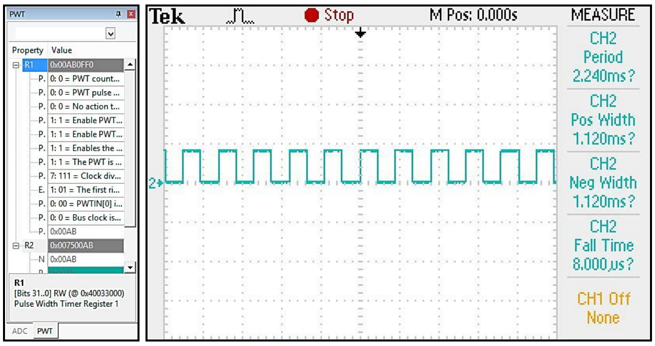

Fig. 8 (a) PWT output (b) Pulse output at CRO when potentiometer's wiper is at extreme left position

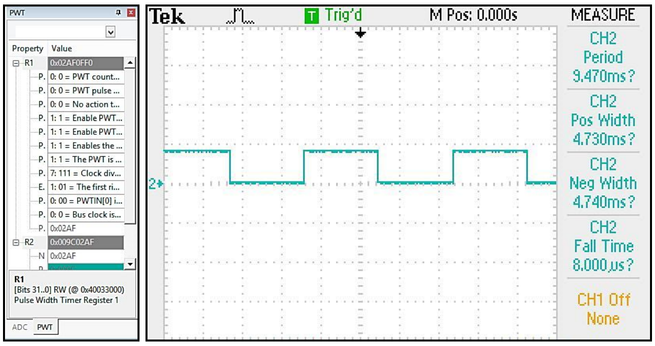

Fig. 9 (a) PWT output (b) Pulse output at CRO when potentiometer's wiper is at middle one position

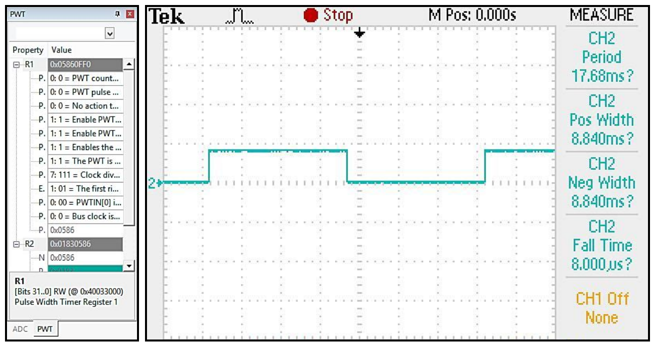

Fig. 10 (a) PWT output (b) Pulse output at CRO when potentiometer's wiper is at extreme right position

V. CONCLUSION

The Electronic Control Unit (ECU) which is compatible for 4- stroke engine is developed and the output waveforms are tested. The Engine Control Unit developed is capable of creating all the necessary signals to operate the engine based on the input sensors. By varying the resistance of the potentiometer, we can control the pulse width of injection timing at output i.e. by increasing the resistance by rotating wiper of potentiometer clockwise, the output pulse width of PWM signal generated by ECU can be increased and vice versa.

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