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Experimental investigations and guidelines for PCB design for a fuel injection ECU to meet automotive environmental, EMI/ EMC and ESD standards

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Abstract: Engine Management ECU plays a vital role in controlling different important features related to the engine performance. ECU is an embedded system which includes hardware and firmware platform for control logics. However, it is necessary to verify its smooth performance by its functionality testing in the Electromagnetic environment for approval. If these requirements are not known at earlier stages, then ECU may not fulfil functional requirements during required automotive electronic test standards. Hence, focusing on EMS ECU, this paper highlights hardware, layout and software guidelines for solving problems related with Electromagnetic Interference (EMI) to comply ISO 7637, CISPR 25 standard, Electromagnetic Compatibility (EMC) to comply ISO 11452-4,5 standard, Electrostatic Discharge (ESD) to comply ISO 10605 standard and Environmental Testing to comply standards as per IEC standards. This paper specifies initially the importance, need and guidelines for reducing the EMI effect on PCB i.e. making ECU more electromagnetically compatible as per automotive standards. The guidelines are useful for the designers to avoid pitfalls at the later stage. After mentioned modifications in the paper, ECU successfully passed the requirements for all standard tests.

1. Introduction

In automobile segment, many vehicle sub-system controls are switching to electronics instead of Mechanical for add-on features. Hence, the percentage of electronic components are increasing in newly launching vehicles. To accomplish the facilities, add-on controls and comfort, Microcontrollers are being used. The EMI problem increases with the proportion of electronic components. If the system is more complex for embedded controls, then EMI effect will be more. Hence, EMI is the prime factor for the smooth functioning of complex electronics.

Electromagnetic (EM) waves due to different communication applications (like mobile waves, AM waves and FM waves etc.) are available in the environment which may distract or damage the normal functionality of the high clock based electronic circuits like ECU as EMI is proportional to the system clock rate [1].

EMI and EMC are the two opposite terminologies where EMI is the unwanted EM frequencies which may distract or interfere with the interested signal. EMC is the level of

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immunity of system to the EM frequencies. EMC is the ability of the system to withstand without disturbing system functionality in presence of EM frequencies [1].

2. EMI and EMC problems:

Engine Management ECU is the complex and very fast responsive control system using an automotive embedded microcontroller. On the automotive vehicle, like EMS ECU, a variety of electronic systems are involved to fulfil the requirements by the transducers as per specified standards. As the system responds extremely fast, its base clock frequency is also high so, high EM frequencies are generated hence, more will be the EM interference from the system. Similar way if multiple such systems are running on the road simultaneously, then overall EM interference get increased and that may cause the distraction or may lead to failure of normal functioning of any electronic system.

Vehicle environments are not same always and the engine performance will be different based on user demand. Automotive vehicles have been modifying and many advanced control systems become the key features like Airbag ECU, Anti-lock Braking System (ABS) ECU, Exhaust Gas Recirculation (EGR) system ECU, Diesel Particulate Filter (DPF) and Variable Geometry Turbocharger (VGT). But, electronic systems of the vehicle are get affected by few factors like NVH (Noise, Vibration and Harshness) parameters, increased reliability and fine cost sensitivity. It was observed that these problems can be overcome by EMI design methods. The problem of increasing EMI and reducing the immunity will be the worst of the electronic systems where output pulse frequency (output logic transactions) is increasing after certain level [1].

This paper explains the methodology to reduce the level of EM radiations and also the methodology to make the electronic system more immune to external EM interferences present in surroundings Stray capacitance is a commonly used term for capacitance between a conductor and its surroundings. One of good examples of it is transistor as a switch and head sink mounted on its surface [2]. Capacitance and Inductance effects can be observed on the PCB due to the placement of signalling path and layout for PCB.

3. Automotive EMI/ EMC:

A minute failure in electronics may lead to limitless disaster for live things and its surroundings. Hence, Reliability is the prime factor while designing the automotive electronics and one should design the systems with early identified risks and failures. Vehicular electronics is very compact and complex system. While running the vehicle many such systems pass through nearby vehicles. If the vehicle density will be greater then, more nearby the systems will work. The radiation from such systems may impact over other which is called the Electromagnetic Interference where this interference may be through conducting paths or through radiations or both. The lack of such interference in any electronic device when working in the EMI region with accomplishing the safe limits of safety is known as Electromagnetic Compatibility. It is the level of immunity of an electronic device to its faithful functioning in EM interference regions [5].

Vehicular electronics in automotive has many fear factors for EMI and EMC like power transients, RF interference for the systems under its region, ESD (Electro Static Discharge) and power lines for electric and magnetic fields. This factor called fear factors because the vehicle is mobile and it can come in contact with other vehicle/s easily, Hence considering the worst situations vehicular electronics is to be designed [1].

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Below are the few guidelines are given to minimizing the effect of EMI, ESD and making ECU more EM compliant:

3.1 Radiated EMI test using CISPR 25 standard:

CISPR is the "International Special Committee for Radio Protection". In CISPR chamber Radiated Emissions i.e. EMI and Radiated Immunity i.e. EMC tests are conducted using different antennas. The EMI threshold is specified as per type of ECU. If emissions from ECU are observed greater than set threshold on a Spectrum analyzer, ECU just qualified in EMI test because, the peak EMI level for this first proto ECU was just below a threshold level as per standard. As per safer practice for the designer, EM emissions should be much lesser than the mentioned threshold, so, modifications were expected to achieve this target.

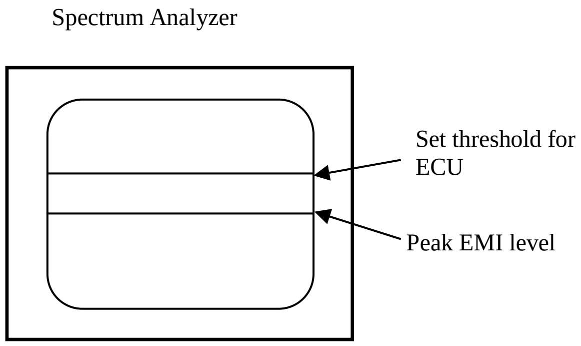

Figure 1. Spectrum Analyzer with threshold and EMI level

The reason for radiated EM emissions was the open conducting points on PCB which were working as an RF antennas. Maximum test points were kept on PCB for testing ease and also components used were through hole i.e. non-SMD.

3.1.1 Test Procedure:

For radiated emission measurement, the arrangement of the DUT, test harness, load simulator and measuring equipment is as per CISPR25 [3].
The measurement is carried out using linearly polarized electric field antenna that has a nominal 50Ω output impedance.

a) 30MHz to 200MHz (Biconical antenna)
b) 200MHz to 2500MHz (Log-Periodic antenna)

The DUT is placed on non-conductive low relative permittivity material at 50± 5 mm above the ground plane. The total length of the test harness between DUT and load simulator is 1500mm.
The phase center of the measuring antenna is 100mm above the table ground plane for Biconical and log periodic antenna. The height of the counterpoise of the rod antenna is +10 /-20 mm relative to the table ground plane and is bounded to it [4].

30MHz to 2500MHz measurement is performed in vertical and horizontal polarized. Hence, as per guidelines second prototype PCB was designed with minimum test points and SMD components were used. As conducting points or media is lesser, radiated EM emission level observed much lesser and ECU passes radiated EMI test successfully with much difference as shown with figure 2 [5].

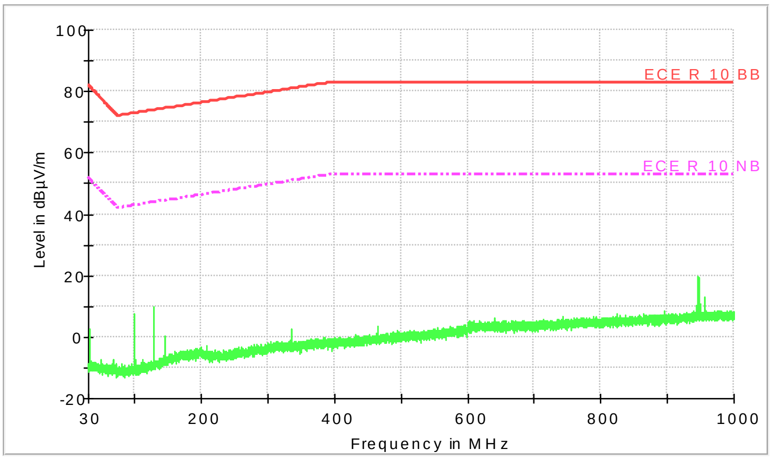

Figure 2. Test result of Test Result Narrow Band Radiated Emission (Frequency range 30 MHz – 1000MHz, Antenna Polarization: vertical)

3.2 Conducted EMC as per ISO 7637, SAE J1113 standards:

The ECU working setup was arranged with all functional loads using in-house developed bench Engine simulator. Engine speed at lower RPMs were not detected by ECU which was observed the missing functioning of actuators due to which engine was not starting easily and needs many cycles of crank also.

It was observed that pulses coming from the engine were with low amplitudes from 0.8V to 2V from crank at around 400 to 600 RPM. The amplitude of pulses increases with increase in engine speed from 1V to 15V for RPM 600 to 6000 respectively. So, at higher engine speeds, RPM detection was carried out smoothly due to larger amplitudes. At lower engine speeds, detection of rpm was found little crucial where voltage need to be detected by signal conditioning circuit for all pulses. The problem of detection of RPM was not under considerations previously which was shaping it into square waves by using 2.5V as a threshold for the comparator. After problem detection, comparator threshold was corrected to ~0.8V to 1V. In figure 3. filtering circuitry after comparator was included which also helped for Bulk Current Injection (BCI) test [6].

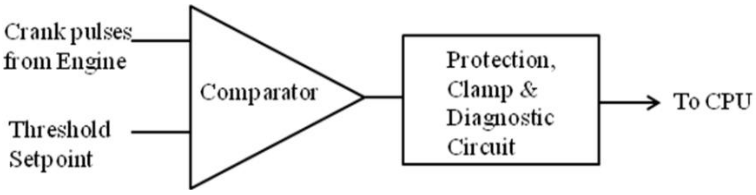

Figure 3. Engine Speed signal Conditioning Circuit

For conducted immunity ECU set-up was with all the electrical loads. The ECU functionality was monitored during test conduction with the help of K-line diagnostic communication. This communication of ECU was meant for PC based Calibration utility.

Communication of ECU is a very important phenomenon for live parameter display for all the standard tests. As per ISO-7637-2, Annexure-01, different pulses were applied to DUT (here ECU). Live functionality monitoring of ECU was based on K-line communication circuitry. The problem found was, for conducted immunity the pulse 1, 2, 3a, 3b, 4, 4b and 5 are on the supply line [7]. Hence, supply variation for any pulse was reflected variation in K-line communication supply. This variation, in turn, disconnecting communication. Hence, communication supply should be isolated and from battery or supply and not from conducted immunity pulse generator system. Now, for all conducted immunity pulses ECU responds well.

For power isolation, Ferrite Beads were found effective for EMI and EMC tests. Another method to filter out power supply noise could be ferrite bead in series with the regulator circuitry with capacitors. If proper layout, filtering can be carried out with good terminations then Zero ohm resistance can be used and need of ferrite bead can be eliminated [8].

3.3 *Electrostatic Discharge (ESD) to comply ISO 10605 standard:*

During Electrostatic discharge (ESD) testing, ECU gets failed to function normally for 5KVA and above air discharge values. Component placement was found very important for ESD testing and by few experimentation it was observed that ECU gets failed due to improper component placement during layout. Consideration of EMI/EMC guidelines is very important before designing the hardware [9]. If these guidelines are not followed, then the system may fail during validation.

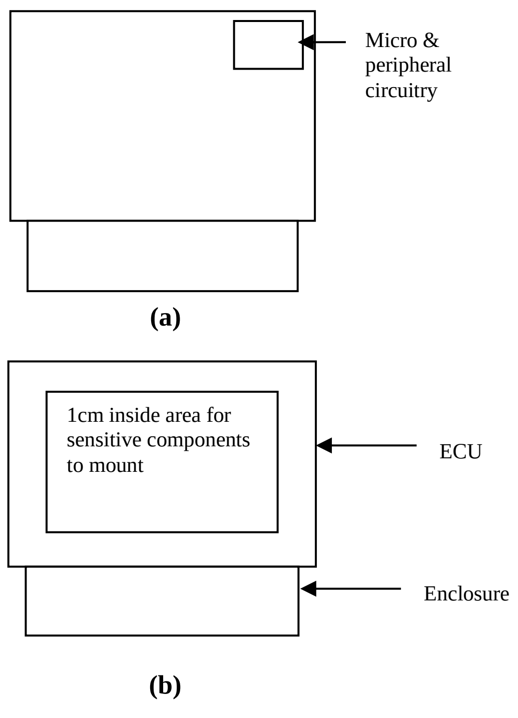

Figure 4. Earlier incorrect PCB layout (a) and revised corrected layout (b) for ECU components

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ECU layout was shown in figure 4 (a) was designed earlier, where sensitive components of ECU i.e. Microcontroller and peripherals were placed near the enclosure edges. During the 5KVA ESD pulse through the air, ECU malfunctioned from normal functionality which was not recovered after reset. This is the permanent damage which cannot be corrected.

The only solution is to place the sensitive components 1cm inside the boundary of enclosure-PCB contact. This is because from 5KVA as we increase the ESD intensity level, that ESD may jump till 1cm from the enclosure. Hence, no sensitive placements should be in the 1cm vicinity [10].

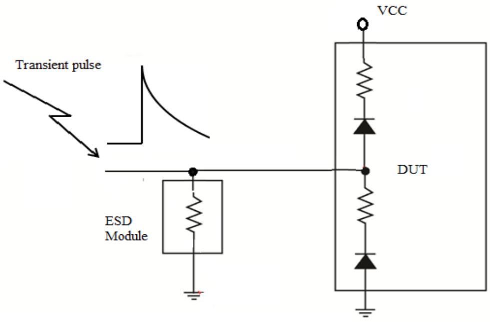

Figure 5. ESD Testing for DUT

As per EMI/EMC guidelines, no sensitive components like microcontroller with its peripherals and their tracks should not be placed within a 1cm area from all the boundaries of the PCB. As per experimental results, PCB border which is going to be finally in direct contact with enclosure shall be grounded with ground track. This track will be helpful for providing the minimum impedance path to Electrostatic Discharges (ESD pulse/s) to ground. As per base rule, current will prefer low impedance path, minimum impedance path if provided, circuit protects CPU or microcontroller from ESD surges. Below are the test details for test:

Test: Electrostatic Discharge Test
Test Standard: ISO 10605
Test Set up: The ECU functionality test is carried out before & after the tests on calibration tool. The default values from simulator are being set for verification after the test. Test is carried on-

- Enclosure
- Microcontroller I/O pins

Test Result: Test failed.
Microcontroller reset is observed while discharging for 5KV (+ve & -ve).

Observations:

- The layout is improper and the component arrangement would be such that min 0.8 mm distance (or 1 cm for safer side) should be empty or sensitive components/ its tracks should not present.
- Normally the RC type of filter between enclosure & Signal ground is used. Impedance in this filter is very low such that discharge takes this low impedance path through a filter to Ground.

TVS diode (i.e. Transorb) found very useful against ESD and other overvoltage pulses, mainly if the inductive loads are in use.

3.4 Environmental Testing to comply with IEC standard:

Frequent observation indicates that during Vibration testing, ECU gets failed by breaking few through hole (leaded) components. Few more considerations are to be taken regarding Environmental testing like Salt-Spray test, Dust Test and storage temperature tests which are given below:

i. Select the components for mentioned Minimum and Maximum ratings so that practically there would not be the effect of temperature on its functionality i.e. operation will be within safe limits.
ii. The enclosure design should be such that in small engine automotive applications, it will be immune to ESD peaks and direct environmental contact. The enclosure should be sealed properly with an accurate proportion of sealant and if required conformal coating too.
iii. Communication and power pins should be isolated.
iv. Clock selection will be in accordance with time critical accuracy but too much frequency will raise the RF frequency for EMI and also it will be decreasing EM compatibility level (i.e. If the frequency is greater the radiated coupling path efficiency is greater and for lower frequency, the greater the conducted coupling path efficiency will cause EMI [11].
v. The Use of clamp circuitry in sensors signal conditioning circuit protects the CPU for overvoltage from sensor side as shown in figure 6.

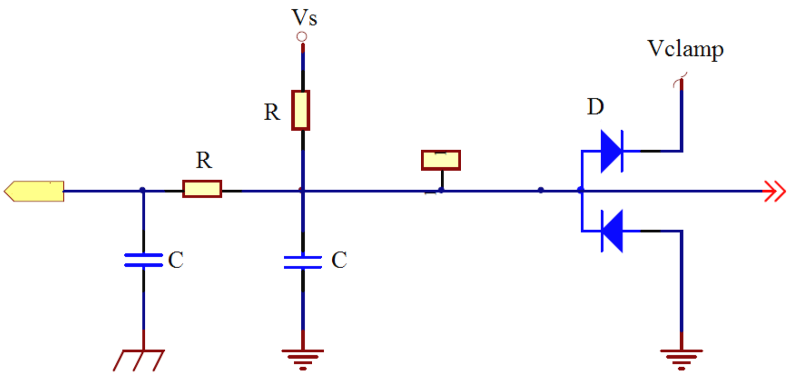

Figure 6. Clamp circuitry in sensor signal conditioning

vi. Microstrip and Stripline routing considerations to route the signals are explained for the lesser impact of EMI and EMC on the DUT to make its performance more rugged [12].

4. Conclusion

From the experimental investigations, the above- mentioned guidelines to be considered at early stages of PCB designing of ECU. These are important to focus on reducing the development time and boost the rate of successful design in First Time Right (FTR). For small automotive engine applications, while designing PCB, an important area to focus is the Ignition. Spark Plug actuation i.e. ignition is the phenomenon which affects many inductive loads functionality and introduces many RF effects over its functionality. Multiple times, its effect can be observed on recorded pulses on Digital Oscilloscope. Hence, functionality throughput after fitment of ECU on a vehicle is varying for Electro-Magnetic effects. Many PCB designs, layout, fitment and testing guidelines are discussed which helped ECU to successfully pass EMI as per ISO 7637, CISPR 25 standard, EMC as per ISO 11452-4,5 standard, ESD to comply ISO 10605 standard and Environmental Testing to comply standards as per IEC standards.

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