EMI system model for a gearbox electronic control unit

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***Abstract*— A system simulation approach to model conducted emissions of a gearbox electronic control unit (ECU) is investigated. The system is partitioned in ECU, cable harness and load. The ECU is modeled using 3D electromagnetic simulation, for the cable harness and loads analytic models are employed. Coupling effects inside the ECU housing are investigated and basic design rules for critical subassemblies on the printed circuit board inside the ECU are derived.**

I. Introduction

An electronic control unit (ECU) assembly mounted directly above an automotive gearbox is investigated. The electronic components, especially micro controller and flash memory, possess the ability to create high frequency signal components, that can travel outside the ECU housing on a cable harness and exhibit EMC problems.

In this paper, the electromagnetic coupling of stuff is investigated. Because of the extremely high complexity and diversity of the problem, a system model approach is taken, by partitioning the problem in several components and providing simplified equivalent models.

Signal coupling inside the cable harness will not be considered here, because the main interest in this study is to gain an understanding in the complex interactions between the interference source on the printed cicuit board and the metal housing of the ECU.

II. Partitioning

The system model consists of three elements:

- **ECU**: The ECU is basically the heart of the system, consisting of an electronic circuit placed in a sealed metal housing, only connected to the outside world via feed through connections.
  For modeling, a 3D geometric model of the ECU was created. A 3D time domain full wave electromagnetic simulator (Microwave Studio) is used to calculate the fields and signal leading to the outside.
- **Cable Harness**: The cable harness is modeled using simple analytic expressions. For common mode and differential mode two different characteristic impedances are obtained using numerical computations of a 4 wire cable harness.
- **Loads**: Equivalent electrical circuits for two typical loads are considered. One load is the power net replication, the other one the CAN bus.

Figure 1 shows the system model with its three elements ECU, cable harness and load.

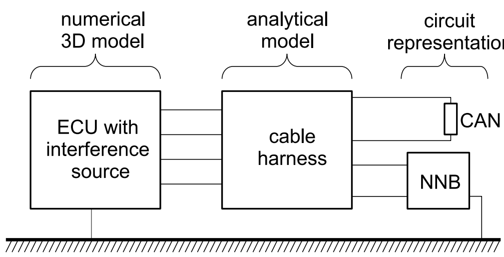

Fig. 1. Partitioning of the system model

III. Simulation Models

A. Electronic Control Unit Model

Because of harsh operation environment, with ambient temperatures exceeding 150°C, a low temperature cofired ceramic (LTCC) circuit board is used to hold the electronic circuits.. The LTCC printed circuit board is 30x55 mm with a thickness of 800 µm.

The circuit board is mounted inside a hermitically sealed metal housing with dimensions 55x57x7 mm.

The board is glued to the bottom of the housing and electrically connected to the housing with two bond wires at each edge. All signals are bonded to signal feed through in the housing. A photo of the ECU is shown in figure 2.

Because of the extremely complex and high-density circuitry, only an equivalent interference source is modeled.

The LTCC board has a ground plane. The ground plane is connected to a bond pad on the top of the PCB with C=2,2 nF parallel 5,6 kΩ. From the bond pad two parallel bond wires connect to the bottom of the metal housing. All external connections are connected from a hermetically sealed through with a aluminum wire bond to a bond pad on the top of the LTCC board.

Because of the complexity of the layout, having 8 layers to connect a dozen custom integrated circuits and a number of decoupling capacitors and further passive components directly integrated in the LTCC, the layout is not directly modeled in the solver. Instead, a equivalent interference source is used.

The interference source is modeled as a simple microstrip line having a length much less than the maximum wavelength

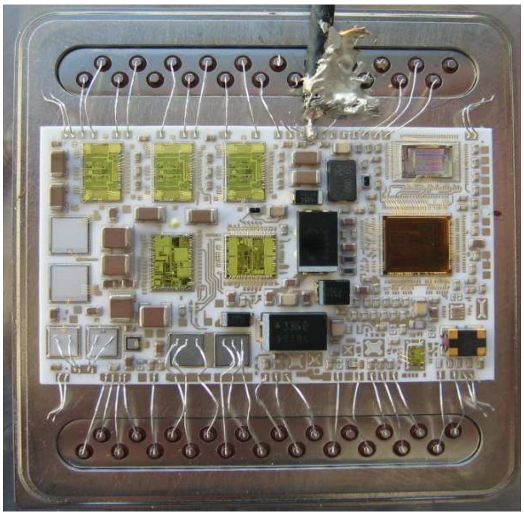

Fig. 2. Picture of the electronic control unit

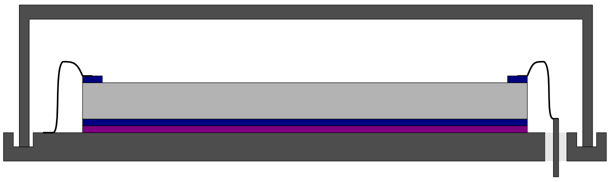

Fig. 3. 2D cutplane of electronic control unit

of the signals investigated. Therefore, a length of 10 mm has been chosen. A typical interference source is the interface between a microcontroller and flash memory. The microcontroller has a low output impedance and the memory has a very high input impedance. Therefore a microstrip line with an open end has been selected.

Figure 4 shows the 3D model used inside the electromagnetic solver.

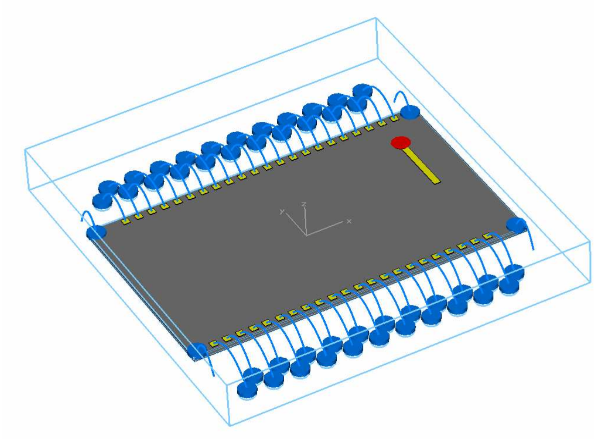

Fig. 4. 3D model of electronic control unit

The output signals of the ECU come through special pins at the bottom of the metal housing. Viewing the currents flowing at two pins, as shown in figure 5 common and differential mode operation can defined. The common mode current I_C and differential mode current I_D are defined as:

$$I_C = \frac{1}{2}(i_1 + i_2) \tag{1}$$

$$I_D = \frac{1}{2}(i_1 - i_2) \tag{2}$$

The currents are referenced to the metal housing of the ECU. In the setup considered here, the housing is connected to an infinite ground plane.

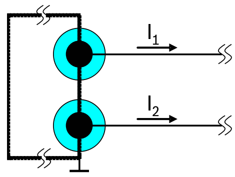

Fig. 5. Current definition at pins

B. Cable Harness

The currents on the cable harness are described using simple analytic equations. For a cable length l, the incident current at the end of the cable can be given as:

$$I_i(z = l) = I(z = 0) \cdot e^{-(\alpha + j\beta)z} \tag{3}$$

The reflected current can be derived, using the reflection coefficient for the connected load:

$$I_r = -\Gamma I_h \tag{4}$$

Because the standard definition of the reflection coefficient is for voltages, an additional negative sign is added to correctly describe the current reflection coefficient. The load models are described in the next section.

Two different cases have to be taken into account, the differential mode and the common mode. In differential mode, the current in a wire is flowing relative to another wire in the cable harness, as e.g. for a CAN bus. In common mode, the current in a wire flows relative to a ground plane. In this case the ground plane is thought to be infinite an in an distance of 2 cm to the wire. Figure 6 and 7 show the fields and computed impedances for the common and differential mode.

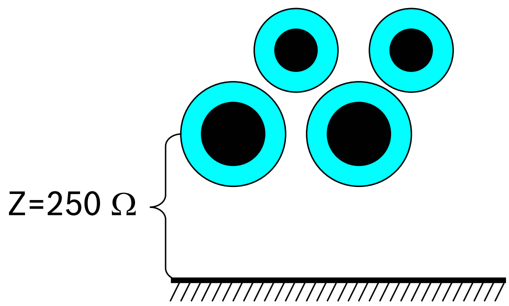

Fig. 6. Common mode in cable harness over reference ground

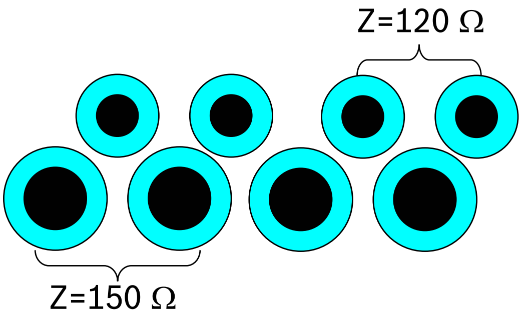

Fig. 7. Differential mode in cable harness for CAN bus and power lines

TABLE I
PROPAGATION CONSTANTS FOR THE CABLE HARNESS

Type	**Impedance**	α	β
CAN common	250 Ω	0,1 dB/m	10 1/m
Power common	250 Ω	0,1 dB/m	10 1/m
CAN differential	120 Ω	0,1 dB/m	10 1/m
Power differential	150 Ω	0,1 dB/m	10 1/m

For the cable harness, simple typical characteristic propagation properties have been evaluated:

Different impedances for common and differential mode can be seen. The measurement setup is as follows: The ECU is placed on a conducting plane

C. Loads

For simplicity, only two different load types are considered in this simulation. In a typical measurement setup, a power load replication is used, therefore a equivalent circuit model for this load is considered. Starting from the CISPR standard [1] power load equivalent circuit, an improved circuit model shown in figure 8 has been created. It has been validated from measurements up to several hundred Megahertz.

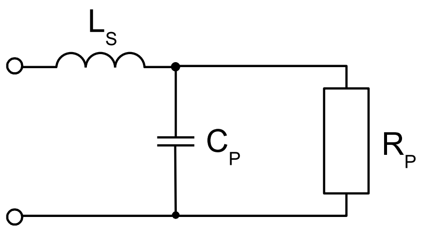

Fig. 8. Equivalent circuit model for common mode can bus input load

Another very common type of load is represented by the CAN bus interface. For differential mode operation an impedance of Z=120 Ω is the standard load. However, for common mode operation this is not valid. For this case Neibig [2] provides a simple equivalent circuit model, as shown in figure 9. For a typical CAN bus interface values of R_S=31 Ω, R_P=9 kΩ and C_P=73 pF can be used.

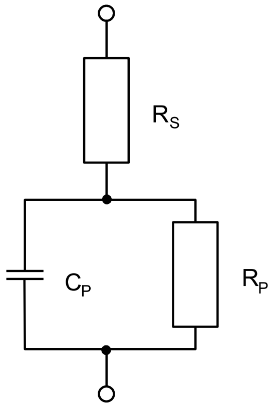

Fig. 9. Equivalent circuit model for common mode can bus input load

IV. Simulation Results

A. Ground Resonances

Two significant resonances can be observed, one at 53 MHz and one at 640 MHz. The current over the bond wires as a function of frequency is shown in figure 10.

The lower resonance frequency is determined by the inductivity of the ground bond wires and the capacity of the metal ground to LTCC ground RC combination.

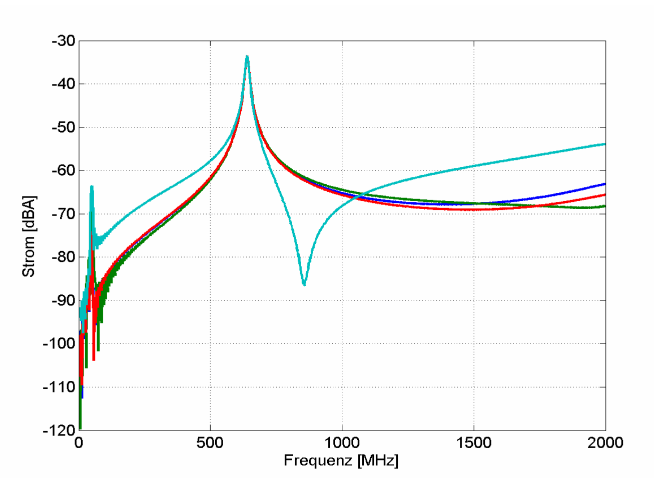

Fig. 10. Currents of the ground bonds

The higher resonance at 640 MHz is determined by the resonant circuit compromising of the ground wire bond inductivity and the capacity between the LTCC ground layer and the bottom of housing. Figure shows the magnitude of the magnetic field at the LTCC ground layer and the bottom of the housing.

B. Signal Coupling

Finally, the coupling from the interference source to the output signal pins was investigated. Therefore, the position of the interferer was calculated for different positions and the induced currents on two neighboring pins were recorded.

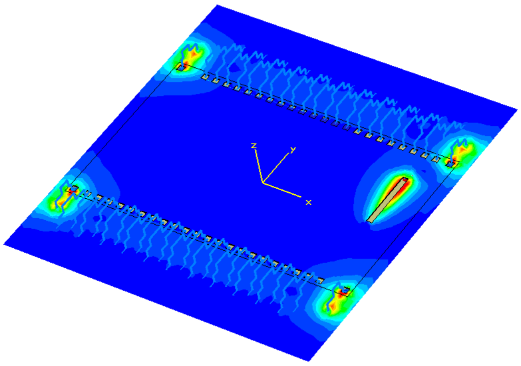

Fig. 11. Magnetic field strength for resonance at 640 MHz

Looking at figure 4 the pin positions are in the left top, whereas the interferer is placed on different positions on the right side of the LTCC substrate. Figure 12 shows the

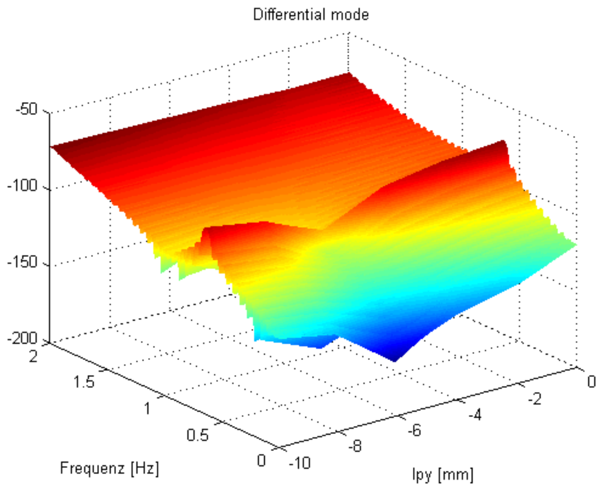

Fig. 12. Current magnitude for different X positions of interference source

current magnitude over frequency for different positions of the interference source on the X axis. There is one position, where a minimum can be achieved, however this is only valid for a certain pin pair and not for all signal pins.

Figure 13 shows the current magnitude over frequency for different positions of the interference source on the Y axis. It can be clearly seen, that the magnitude increases with when coming in close proximity to the edge of the circuit board.

V. Conclusions

System simulations to investigate conducted emissions of a gearbox ECU setup have been carried out.

There is no optimum position, however ist can be shown, that critical parts should be placed away from circuit board edges. It can also be seen, that there are resonances of the ground signals.

To consider radiated emissions, an advanced model of the cable harness will be incorporated.

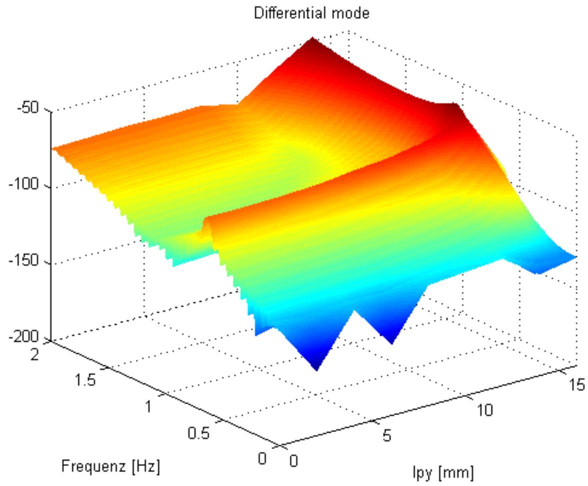

Fig. 13. Current magnitude for different Y positions of interference source

References

[1] ANSI, CISPR standard, 2004.
[2] U. Neibig, Internal research report, 2004.