Journal of Industrial Information Technology and Application Vol.4 No.2 *ISSN(Online): 2586-0852*

Power Integrity Analysis for EMI Reduction of Electric Hudraulic Pump Control PCB for All-Wheel Drive

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Abstract. In the past, AWD for vehicles such as pick-up trucks or SUV was used to overcome the limit of driving capacity and driving ability by road environment. Besides, there was the only mechanical manual operating gear that was suitable for the highly efficient driving force of luxury vehicles. But in recent years, as the demand of consumers for high performance and high safety vehicles is increasing, the Active All-Wheel-Drive system applies to almost all the vehicles actually. Especially, as electronic hydraulic pump actuator which is the most important part of precise torque distribution of transfer case for the four-wheel-drive vehicles applies to all the vehicles regardless of the type of vehicles or wheel position and widely applies to eco-friendly vehicles more and more, integrated automotive parts are being improved and working speed is faster. So these things cause some electrical and electronic problems. An electromagnetic field caused in the process of operating an electronic hydraulic pump controller makes electromagnetic waves and these electromagnetic waves noise are the principal cause of disrupting the other electronic components of a vehicle. Especially, because electromagnetic waves noise in the process of operating power supply or BLDC motor controller are able to cause the performance degradation of the other parts and to cause malfunction, it is important to make the optimal design. In the paper for this, we find out existent resonant frequencies through resonance analysis of electronic hydraulic pump control PCB and then modify PCB not to cause resonance in the bandwidth which can restrict electromagnetic waves. In this way, we propose a method to reduce PCB development time and cost by analyzing and correcting the cause of electromagnetic interference before making PCB

Keywords; All-Wheel-Drive; Hydraulic pump; Power Integrity; Decap; Resonance;

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Received Nov 14, 2019; Revised Dec 23, 2019; Accepted: Jun. 31, 2020

1. Introduction

Recent automobile technology development has completely changed from machinery equipment to semiconductor-based electric equipment and has been focused on the driver's safety, convenience, and eco-friendliness. Active All-Wheel-Drive introduced in this paper has the advantage of providing the best driving force and safety in various driving environments. While conventional mechanical four-wheel-drive systems have limited changes in front and rear-wheel-drive forces, active AWD systems can control the left and right wheel braking and front and rear drive forces by sensing road conditions and speeds. This enables stable driving performance on slippery roads, sharp cornering, winter snow, and ice. In the past, AWD systems had been applied to vehicles such as pickup trucks and SUVs, which are used to overcome drivability and torque limits from load capacity and the road environment. However, AWD is now being applied to virtually all models as worldwide consumer demand for high-performance and high-safety vehicles increases. In particular, as the electronic hydraulic pump controller, which is a key component of the active AWD-driven precision power distribution system, is applied regardless of the vehicle type and the position of the main wheel, and is expanded to eco-friendly vehicles, problems rising from the electromagnetic wave interference with the exiting electromagnetic parts should be considered. Besides, automobiles have a high degree of integration of electronic components and high speed of operation, causing various electrical and electronic problems [1]. Among these problems, electromagnetic interference occurs due to the impedance discontinuity of the PCB circuit, which causes malfunction and noise due to the interference of peripheral devices [2]. Therefore, in this paper, power integrity simulation, which can identify resonance, one of the causes of EMI, is applied to the electronic hydraulic pump controller driving system to minimize resonance. Through this, this study proposes a countermeasure for improving PCB electromagnetic waves by analyzing and correcting the causes of electromagnetic radiation before PCB fabrication.

2. Analysis and interpretation of control PCB power integrity

A. Specification of hydraulic pump controller

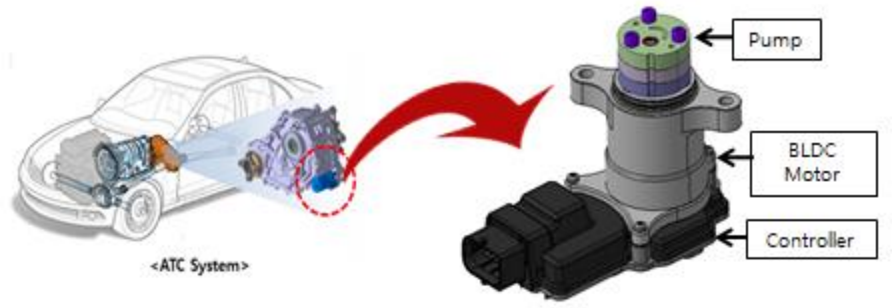

Fig 1. Hydraulic pump controller for AWD

The device configuration of the active AWD electronic hydraulic pump controller consists of a gerotor pump, a BLDC motor, and a controller. The device operates via an actuator system in which the BLDC motor and the hydraulic pump are driven by external operation commands through the CAN communication of the controller. Through the clutch connected to the actuator, the engine driving torque can be distributed in real-time according to the road surface condition and the driving situation for the front and rear wheel driving force. Active AWD electronic hydraulic pump controller is currently under development as an integrated product combining hydraulic pumps, BLDC motors, and controllers. These products do not require a harness between the motor and the controller, thereby enhancing the convenience of repair and replacement in the event of failure [3].

B. PI analysis method

Common methods for solving EMI included shielding, blocking, filter, and PCB artwork. However, these common methods require extensive time and money to solve the EMI problem in new product development. Therefore, to improve this, a new method of using the tool of the simulation technique called PI was developed. PI analysis is a method to pre-simulate and improves the EMI problem by using the high impedance at the resonance part through the resonance analysis of the PCB using the electromagnetic analysis method .

PI analysis consists of process steps of resonance analysis, resonance frequency confirmation, and impedance analysis, decap addition, and PCB improvement. First, resonance analysis is performed to determine the structural resonance of PCB power and ground. Resonance affecting high-frequency sensitivity in the PCB refers to resonance occurring between the ground-power plane or ground-ground plane [4], and the large resonant waveform indicates that the corresponding area is vulnerable to voltage noise. Second, from the result of the resonance analysis, the resonance frequency can be read via real frequency, and the Q value can be used to estimate the sensitivity and persistency of the resonance. A higher Q is a mode that reacts very sensitively to a specific frequency, while a lower Q indicates less sensitivity and wider resonance. Third, in the impedance analysis, a measurement port is added to a region where resonance occurs, and the impedance change for each frequency is then confirmed through the analysis. Rapidly increasing impedance at a certain frequency indicates a point where resonance is large, and even small current noise can be multiplied by large impedance to generate voltage noise. Therefore, to reduce noise by lowering the impedance of a specific frequency, the target impedance value is required, and the decoupling capacitor, VIA addition, and layout are changed to achieve the desired value. Fourth, a decoupling capacitor is used to maintain a constant voltage by suppressing voltage variations. A decoupling capacitor is a capacitor used to disconnect noise from other circuits or ICs and is used to separate bounce noise between ICs sharing the same power line. The decoupling capacitor should be selected in consideration of the capacitor's capacitance (C), equivalent serial resistance (ESR), and equivalent serial inductance (ESL). The equivalent serial inductance (ESL) of the capacitor is connected in a series with the capacitance (C), and there is a frequency showing the serial resonance, above which it cannot operate as a decoupling capacitor because of the higher increase of impedance by inductance (L).

3. Measures design of the product

C. Resonance analysis

As resonance analysis result shown in the TABLE 1, 0.3162MHz and 13.070MHz resonant frequencies occur in the Mode 1,2. The orange area shown in the figure 2 is the resonant point. In the figure 2, when the noise signal occurs around orange area, 0.3162MHz, 13.070MHz EMI and PCB noises are generated. The Q value with high frequency in the resonance area can be identified from the resonance analysis. The Q value indicates whether the resonance distribution is sharp and narrow, or wide. Especially, slightly higher voltage noise can be generated by resonance with a narrow and sharp Q value. The area generating resonance according to the used frequency was found by resonance analysis as shown in Figure 2. In this part, the target impedance should be set and the value should be adjusted below the target impedance.

TABLE I. RESONANT MODES SIMULATION

Mode#	Frequency (MHz)	Q
1	0.3162[a]	218.09
2	13.070	55.69

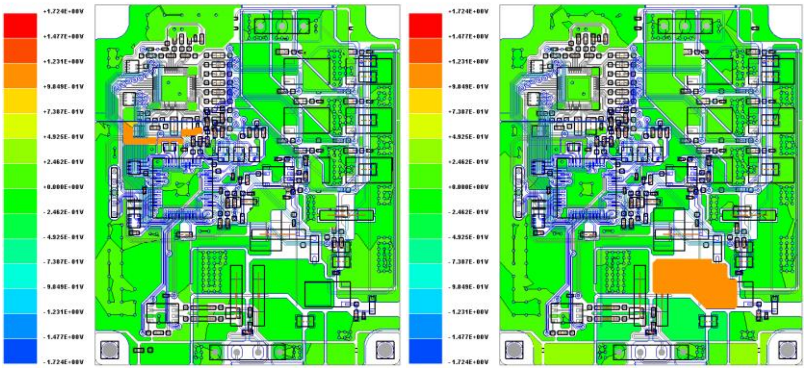

Fig 2. Resonance of Mode 1 and Mode 2 in Table 1

D. Impedance analysis

As shown in Figure 3, the lowest value compared to target impedance is the most ideal in the PCB impedance analysis. However, because most of the resonance PCB impedance target values are not so low, it is important to lower the PCB impedance as much as possible below the standard value until it reaches operation frequency.

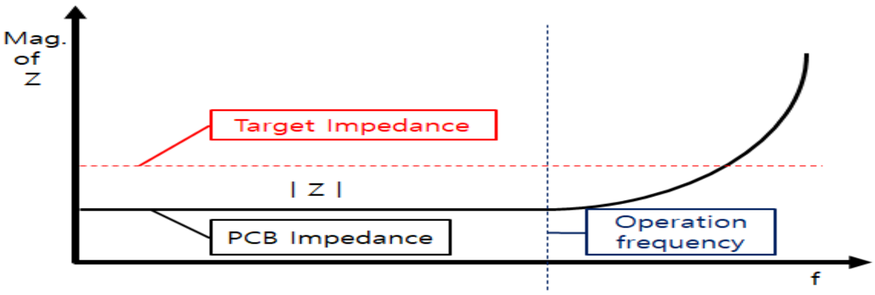

Fig 3. Target impedance standard

The target impedance can be calculated with the formula shown in Equation (1). In this system, with a power supply voltage of the hydraulic pump controller of 12V, a conventional allowed ripple of 5%, and the maximum current of 10A, the calculation result is 0.06Ω

$$Z\_target = ((Power\ Supply\ Voltage) \times (Allowed\ Ripple))/Current \quad (1)$$

$$Z\_target = ((12V) \times (5\%))/10A = 0.06\Omega$$

Figure 4 shows the impedance result of resonance occurring at 13.070MHz; the values exceed 0.06 Ω in most of the frequency range.

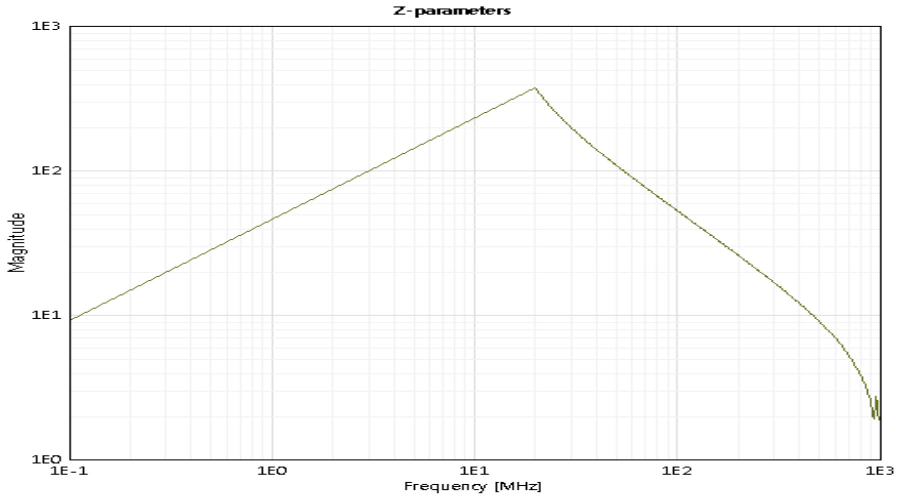

Fig 4. Mode 2 Impedance measurement results in Table 1 (13.070MHz)

E. Decoupling capacitor

So far, the resonance was analyzed and the impedance of the generated resonance point was calculated. The next step applies a decoupling capacitor to adjust the excess impedance to within the target impedance range. To use the decoupling capacitors, capacitors with a self-resonant frequency (SRF) equal to the resonance frequency of the PCB are connected in parallel to GND to send voltage noise to GND. Figure 5 shows the removal of the resonance point by using decoupling capacitors (cap) of 13.070MHz. The applied decoupling in Figure 6 used parts with the same impedance and frequency property, resulting in values lower than the target impedance as shown in Figure 7. This indicates that the PI problem that can arise in PCB can be reduced.

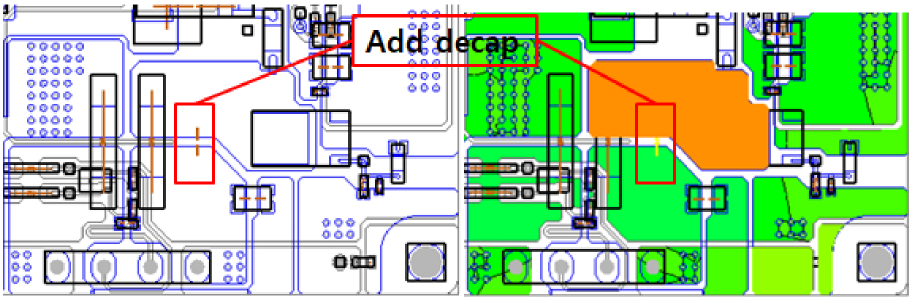

Fig 5. Add decap to mode 2 resonance area

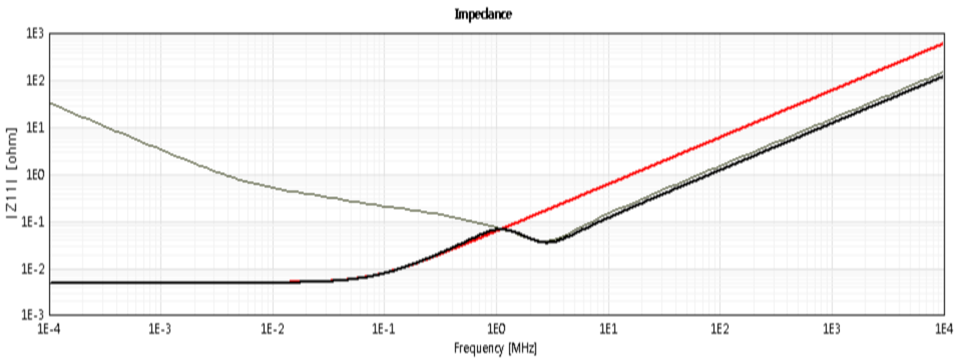

Fig 6. Impedance of decoupling capacitor

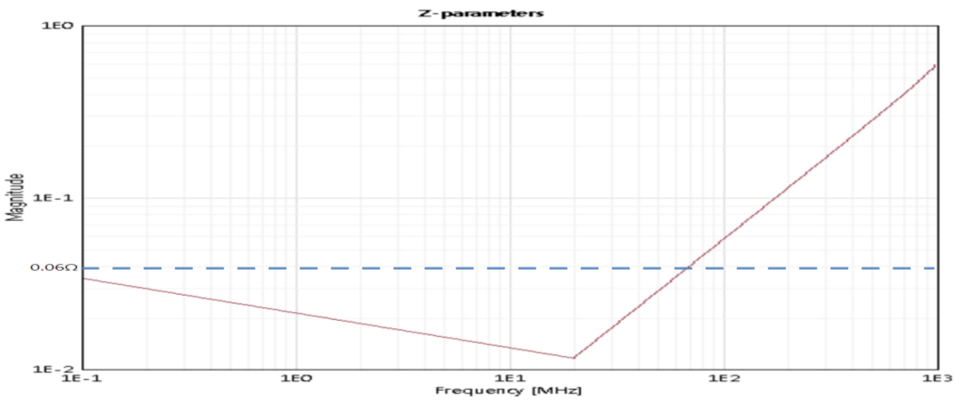

Fig 7. Impedance measurement results with decap (13.070MHz)

F. Method using VIA

For the area where the decap application is difficult due to the structure of the PCB layout among areas with high impedance, there is a method that identifies the number of cases in which the impedance can be lowered by adjusting the size, number, and location of VIA. The left side of figure 8 shows Mode 1 of the resonance analysis, in which the resonance point occurred between the top and bottom planes. VIA was applied to remove the resonance part indicated on the right side of Figure 8. The VIA location and number between VDD and GND play an important role in stabilizing the power source.

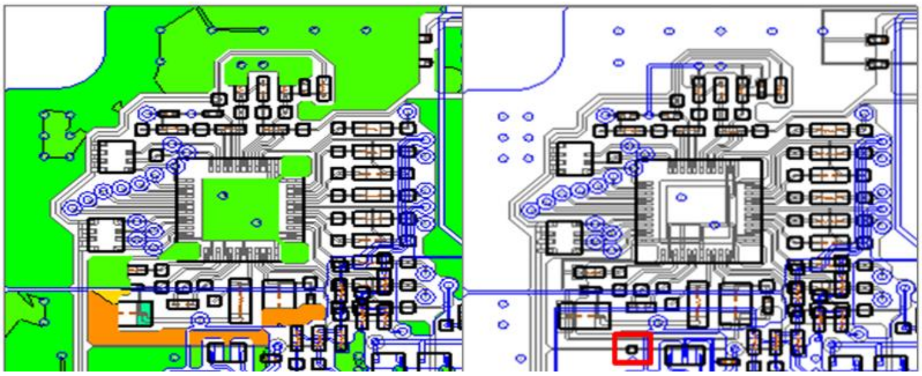

Fig 8. Add VIA to mode 1 resonance area

4. Results

This paper analyzed the PCB resonance through PI simulation modeling of an automotive hydraulic pump BLDC motor control PCB and improved the resonance impedance within the target impedance range by applying a PCB layout with decoupling capacitors and VIA to attenuate the PCB resonance. The proposed method can reduce the time and cost by simulating the EMI problem of newly developed PCB manufacturing. In order to satisfy the automotive electromagnetic wave specification of the integrated active AWD hydraulic pump controller for future development, the PI analysis technology can be used prior to development to reduce the development time and cost.

Acknowledgment

This study is the results of the research conducted by the regional-led R&D project (P0006077) for the 2019 Regional Cooperation Area Industry Promotion Project, which is supported by the Ministry of Trade, Industry and Energy.

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