# Design and Implementation of an EPB Diagnostic

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***Abstract*—The parking brake system fulfills a vehicle's parking function. The EPB system uses a motor that requires a self-diagnostic function for reliability. Reliability of the EPB is ensured by monitoring the status of the electric module and motor. This paper describes an EPB that consists of hardware to perform self-diagnostics after defining the DTC. The reliability of software is improved by autocode generating source code using variable tools. As the size of DTC increases, it accordingly becomes more complex. The EPB therefore uses a multiplexer because it requires many A/D ports. The EPB defines 23 DTC. The self-diagnostic function performs well and detects errors when the EPB checks the performance depending on the test conditions.**

***Index Terms*—EPB(electronic parking brake) diagnostic, reliability, fault, DTC(diagnostic trouble code)**

## I. Introduction

The parking brake system of vehicles fulfills a parking function. The EPB (Electric Parking Brake) system of a vehicle has a brake caliper that operates the brake pad. But the EPB system may not perform the parking function precisely because of the external environment and internal errors of the software module. The reliability of the EPB system's parking function is ensured by monitoring the motor status and checking the status of the electric module continuously [1]-[4]. Accordingly, the EPB system requires functions for self-monitoring such as diagnostic capabilities. In this paper, an EPB system is designed and implemented with a self-diagnostic function to ensure reliability and stability in order to protect against malfunction and failure due to system breakdown as well as to control performance [5]-[7].

## II. System Design

The EPB system is designed with both hardware and software components.

### A. Software Design

#### 1) Autocode generation

The definition of messages and functions of the self-diagnostics was created using Vector's CANdelaStudio. CANdelaStudio is a program tool to add, correct, and define the diagnostic code. The source code of the EPB system is automatically generated as a callback function after the address and function of the message are defined [8]. Fig. 1 shows the structure of autocode generation with using CAN DB (Can database) and CDD (CAN Diagnostic Database). The EPB has reliability by automatically generating source code using Vector's Geny [9]-[10].

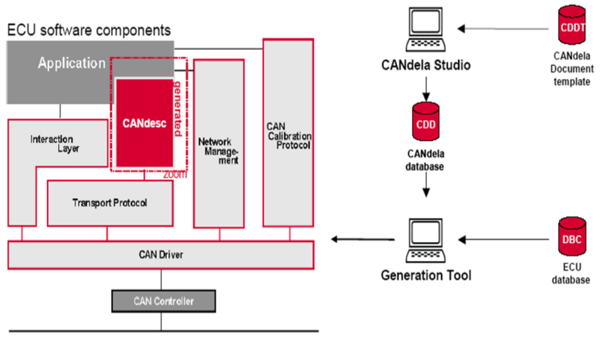


Figure 1. Software autocode generation block diagram (CANdelaStudio manual)

#### 2) Design of self-diagnostic trouble code

TABLE I. DTC(U009) Description

| Item | Description |
|---|---|
| code number | U001 |
| description | Parking brake switch, short to BAT |
| test condition | detecting switch signal(3port) |
| detecting interval | 10ms |
| failure detecting condition | switch signal : BAT detection |
| failure removing condition | switch signal : GND detection |
| operation failure | ignore parking signal |
| service manual | replace and check switch |

DTC defines the number, criteria, a detecting interval, a failure condition, operation failure, operation for removing failures, and service details [11]. Also, the DTC has only 1 code depending on the failure criteria. Therefore, it is easy to check the reason for failure in a garage. The criteria of the DTC establishes 'short to BAT', 'short to GND', 'open', 'stick', and 'over current'. The interval of the DTC ranges from 10ms to 100ms according to the DTC. The EPB defines a failure when it detects unexpected voltage and current during the reference time. EPB software protects the vehicle and the EPB system from failure by stopping the system or

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ignoring an invalid signal. When the failure mode is removed, the EPB system undergoes a software reset or operates normally. In this paper, the EPB system defines the DTC to check the switch signal, motor signals, and internal signal. Table I shows DTC (U009) descriptions of the parking brake switch [12]–[13].

*3) Diagnostic trouble code*

In this paper, 23 DTCs are defined. The DTCs are defined according to the hardware and signals. Table II presents a list of the DTCs which is defined in this paper [6]. DTC code can detect the error of left and right motor, left and right current sensor, brake and release switch, pad count, PCB temperature, RAM, EEPROM, Battery voltage and voltage sensor.

TABLE II. DTC LIST

| Code | Description |
|---|---|
| U001 | LEFT Motor short to BAT |
| U002 | LEFT Motor short to GND |
| U003 | Right Motor short to BAT |
| U004 | Right Motor short to GND |
| U005 | Left Motor over current |
| U006 | Left Motor current sensor error |
| U007 | Right Motor over current |
| U008 | Right Motor current sensor error |
| U009 | Brake switch short to BAT |
| U010 | Brake switch short to GND |
| U011 | Brake switch stick |
| U012 | Release switch short to BAT |
| U013 | Release switch short to GND |
| U014 | Release switch stick |
| U015 | Brake PAD change |
| U016 | PCB high temperature |
| U017 | PCB low temperature |
| U018 | PCB temperature sensor error |
| U019 | RAM check error |
| U020 | EEPROM check error |
| U021 | Battery high voltage |
| U022 | Battery low voltage |
| U023 | Voltage sensor error |

*4) RAM self-diagnostic software*

The software operates using an internal RAM. Fig. 2 presents a diagnostic flowchart of the RAM check process. The variables in RAM are continuously changing. Global and static variables are assigned to a permanent area in the memory. Local variables are temporarily assigned to free area in the memory, and they are removed from the memory after performing their function. The EPB system does not have reliability when the microprocessor has errors in its internal memory. The EPB system therefore periodically checks the RAM through a self-diagnostic process. A g_r_check is global variable and its value is 0x96. A l_r_check is local variable and its value is 0x55.

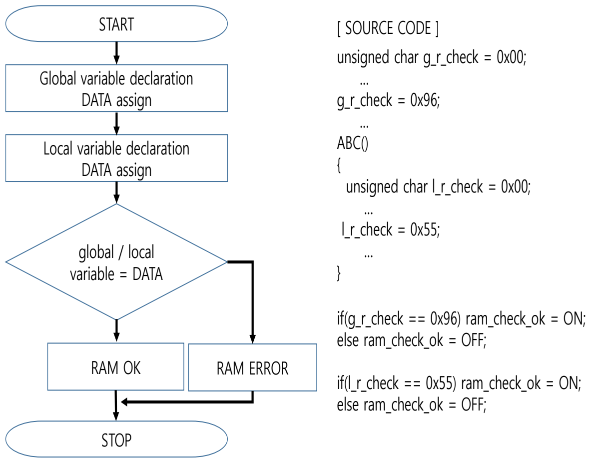


Figure 2. Flowchart of RAM check

*5) EEPROM self-diagnostic*

EEPROM can read and write data electrically. The data in EEPROM, however, can be changed forcibly due to electromagnetic noise and fluctuation of the voltage source. Reliability of the EPB system is therefore ensured by checking the fixed data periodically after writing the fixed data in a specified area.

## *B. Hardware Design*

*1) Design for detecting a switch failure*

Fig. 3 shows the circuit to detect a switch failure. This circuit uses 3 resistors which are a pull-up resistor, a series resistor and a parallel resistor. Table III shows the detecting voltage according to the switch status. Switch can detect short to BAT, short to GND according to the voltage level. Switch stick is checked when the same value (2.5V) is detected for 10sec. OPEN and CLOSE are normal status of switch.

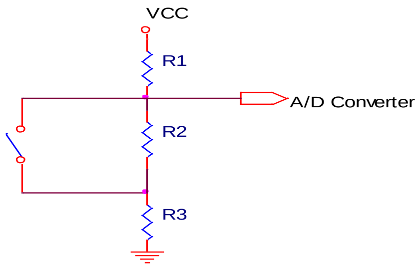


Figure 3. The circuit for switch error detection

TABLE III. SWITCH OPERATING TABLE

| Switch action | A/D voltage |
|---|---|
| Open | 3.3V |
| Close | 2.5V |
| Short to BAT | 5V |
| Short to GND | 0V |
| Stick | 2.5V for 10s |

*2) Design circuit to detect current failure of the motor*

A 4mΩ shunt resistor is installed in the EPB to detect the current of the motor. The current is detected by checking the voltage of the shunt resistor at both ends. The EPB compares the current value using the shunt resistor with that of the motor driver to detect current failure. Fig. 4 shows the circuit to detect current by using the shunt resistor. The EPB stops motor operation when it detects current that exceeds the reference current during a specified time according to the motor status. The EPB also stops motor operation when it detects an open circuit, which is when the current of the motor is zero or under the specified current. The detected current value fluctuates within a certain range because currents sensors and A/D conversion have errors. The EPB defines a sensor failure when the current value is fixed steadily or there is a difference between the current value of the motor driver and the current detected using the shunt register.

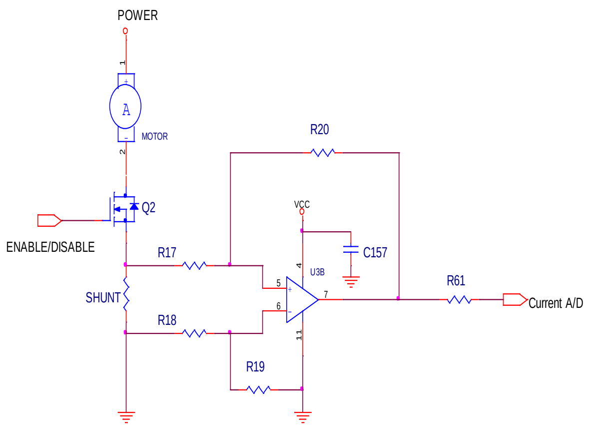


Figure 4. Current sensor circuit

*3) Design circuit to detect voltage failure of the motor*

The EPB monitors the output voltage of the motor driver to detect failures of the motor and wiring. Fig. 5 shows the circuit to detect the voltage of the motor driver.

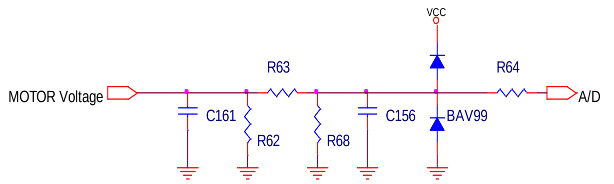


Figure 5. The circuit for detecting motor voltage

The EPB defines 'short to GND' when the motor voltage is under the specified voltage and it defines 'short to BAT' when the motor voltage exceeds the specified voltage according to the motor status. The EPB defines a valid signal after removing noise that is generated momentarily. When it has the fixed value for 1sec, EPB defines a failure of A/D port.

*4) Design circuit to detect voltage failure*

The EPB defines the normal voltage range to operate reliably. The normal operating range is from 10V to 16V. Fig. 6 shows the circuit to detect the voltage. The EPB stops the motor operation to protect the motor and the motor driver if the measured voltage exceeds the reference voltage. The EPB does not operate if the measured voltage is under the reference voltage because EPB will not have sufficient reliability in this case. When it has the fixed value for 1sec, EPB defines a failure of A/D port. So EPB uses the voltage value in CAN data.

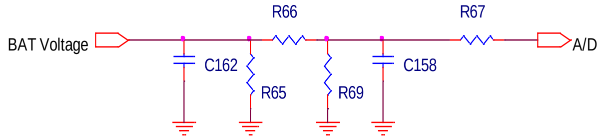


Figure 6. Circuit to detect EPB voltage

*5) Design circuit to detect temperature failure of PCB*

The EPB monitors the PCB temperature to protect the motor driver. The EPB presumes the temperature of motor driver indirectly because it is impossible to directly install a temperature sensor on the motor driver. Fig. 7 shows the circuit to monitor the temperature. A thermistor detects the PCB temperature. The EPB operates normally within the normal voltage range. However, it does not operate if the temperature is over or under the reference voltage. The EPB ignores the temperature value when the temperature sensor fails, that is when the value of the sensor does not fluctuate for 100 seconds.

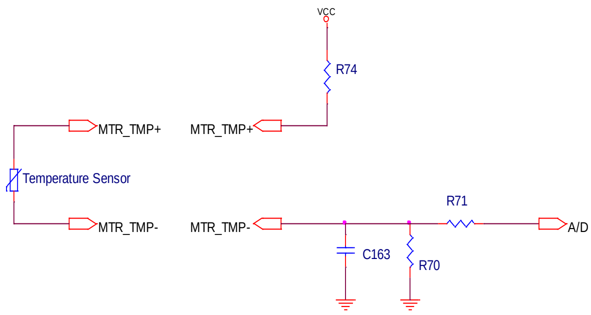


Figure 7. The circuit to detect EPB temperature

*6) Circuit design of the expansion of A/D port*

The EPB uses many A/D ports to detect signals. The microprocessor does not have enough A/D ports for detecting signals. Expansion of A/D ports is therefore necessary to detect many signals and validate the 8ch analog multiplexer IC that is used in this paper. Fig 8 shows the circuit to handle 8 A/D ports to 1 A/D port using HEF4051B. 8 A/D ports are BAT monitoring, MOTOR_L, MOTOR_R, Temperature, Apply switch, Release switch, MOTOR_L current, MOTOR_R current. The EPB can use a low cost microprocessor because the proposed system requires fewer A/D ports. However the checking interval is increased. BAT monitoring and Temperature monitoring signal is measured slowly. Apply and release switch signal is measured fast. MOTOR_L, MOTOR_R monitoring and MOTOR_L, MOTOR_R current monitoring are measured more as quickly. The select pin (A, B, C) can select the input signal and an enable signal in HEF4051B can control the operation of it.

 

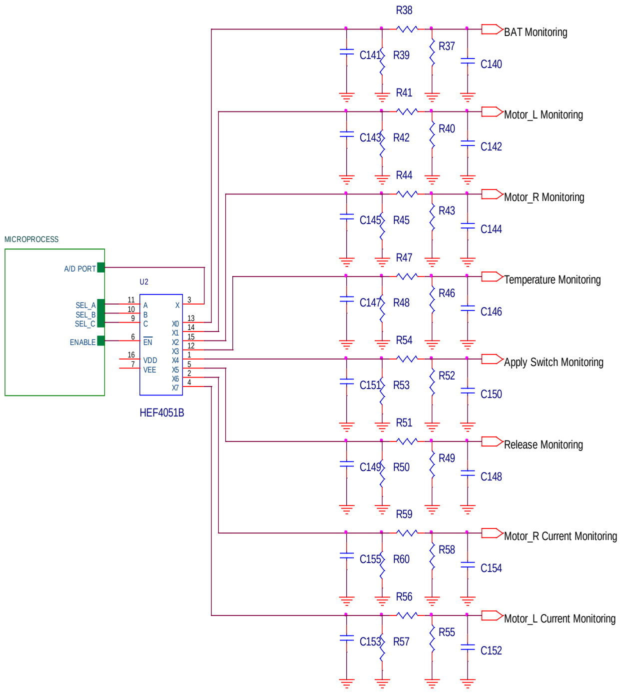


Figure 8. The circuit of HEF4051B

## III. Implementation of Verification of System

### A. *Implementation of System*

The EPB system consists of a control board, a monitoring PC, vector canoe, power supply, a wire interface, brake caliper and a switch box, as shown in Fig 9. A power supply can supply from 5V to 20V. The EPB system is verified by a CAN signal and a debugging tool which is a Trac32. Also the EPB function is checked using a check list. The system operates well without errors. The software of the EPB is verified by QAC and Poly-space, which are software validation tools. The EPB software is corrected according to MISRA rule.

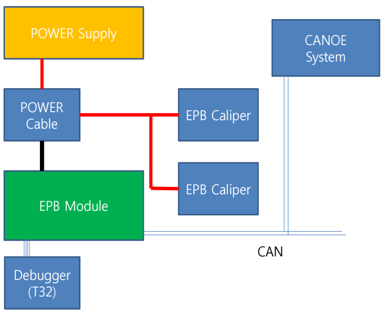


Figure 9. EPB system

### B. *Implementation of System*

The fault and error signal is inserted to verify operation according to the DTC. Variables are adjusted using an offset function in the diagnostic function. The value of the sensor is fixed to verify failure of the current sensor by modifying the software. It is easy to adjust the switch signal so that the input signal is inserted forcibly. The EPB uses an offset function to perform a diagnostic check of the motor. The value of the sensor is fixed to verify failure of the current sensor by modifying the software. The brake pad count is saved in the EEPROM to verify the diagnostic function of pad count. Whenever EPB becomes an applied status, EPB save the pad count in the EEPROM. The temperature diagnostic is verified in a chamber which can control the temperature from -20℃ to +80℃. After temperature chamber storages EPB for a long time, the operation of EPB is checked. The DTCs of RAM and EEPROM functions are checked by changing the variable using a debugging tool. Debug tools can control variable of RAM and EEPROM. After stopping the EPB, variable of RAM and EEPROM is changed. The DTC of the battery voltage is checked by controlling the voltage of the power supply. The DTC of software is checked by fixing the value of the sensor after modifying the software. Table IV presents the result according to the DTC. The diagnostic function operates very well according to each test case.

TABLE IV. Results of DTC Test

| CODE | CONDITION | RESULT |
|---|---|---|
| U001 | Connect BAT to LEFT motor line<br>No action switch | DTC detecting |
| U002 | Connect GND to LEFT motor line<br>push or pull switch | DTC detecting |
| U003 | Connect BAT to RIGHT motor line<br>No action switch | DTC detecting |
| U004 | Connect GND to RIGHT motor line<br>push or pull switch | DTC detecting |
| U005 | Using offset value | DTC detecting |
| U006 | Changing software | DTC detecting |
| U007 | Using offset value | DTC detecting |
| U008 | Changing software | DTC detecting |
| U009 | Connect BAT at brake switch | DTC detecting |
| U010 | Connect GND at brake switch | DTC detecting |
| U011 | Push / pull brake switch forcibly | DTC detecting |
| U012 | Connect BAT to brake switch | DTC detecting |
| U013 | Connect GND to brake switch | DTC detecting |
| U014 | Push / pull release switch forcibly | DTC detecting |
| U015 | Changing the data in EEPROM | DTC detecting |
| U016 | Operating module in high temperature in chamber | DTC detecting |
| U017 | Operating module in low temperature in chamber | DTC detecting |
| U018 | Correcting the software | DTC detecting |
| U019 | Changing the variable forcibly | DTC detecting |
| U020 | Changing the data in EEPROM | DTC detecting |
| U021 | Battery supplies 16V to module | DTC detecting |
| U022 | Battery supplies 9V to module | DTC detecting |
| U023 | Correcting the software | DTC detecting |

 

## IV. CONCLUSION

An EPB that operates the brake function using a motor requires a self-diagnostic function to provide reliability. The reliability of the EPB system's parking function is ensured by monitoring the motor status and checking the status of the electric module continuously. The DTC is thus defined to check the diagnostic function and hardware for DTC is also designed. The EPB can check the left motor status and current, the right motor status and current, brake and release switch, temperature, temperature sensor, RAM, EEPROM, battery voltage, voltage sensor, pad count. There are 23 DTCs in this paper. The complexity of hardware rises as the DTC number is increased. The EPB requires many A/D ports. The issue of A/D port count is solved by using a multiplexor IC. The error and fault injection is inserted by changing the main software or connecting the BAT, GND voltage at the motor control line. So EPB detected the DTC error and saved the DTC in EEPROM. The EPB is checked to verify the DTC and self-diagnostic function of EPB goes well.

## ACKNOWLEDGMENTS

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