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Interim Status of Exponent's Investigation of Toyota ETCS-i Vehicle Hardware and Software

Contents

Introduction

Exponent was retained to evaluate potential causes for elevated rates of complaints of unintended acceleration in Toyota vehicles equipped with ETCS-i technology. As part of its evaluation, Exponent has initiated an investigation into potential causes for unintended acceleration that might relate to the electrical hardware and software malfunctions, or due to EMI.

Figure 1. ETCS-i considerations

Exponent has been performing tests and analyses on the hardware and software of Toyota ETCS-i vehicles to aid in the understanding of the system operation, the interaction between the hardware and software and to understand bounds present in the system, including any that affect the throttle opening angle under various operating conditions.

The hardware and software review is focused on identifying potential mechanisms that can lead to unintended increases in throttle valve angle. It is recognized that modest increases in engine speed can be obtained by means other than increasing throttle angle, such as varying the air/fuel ratio, spark and valve timing, as well as discontinuing power drains on the engine (such as air conditioning). Ultimately, however, engine power is limited by the rate of combustion air flowing through the throttle valve, so the generation of significant increases in power will necessarily be associated with increases in throttle valve angle. It is also recognized that some conditions that result in the onset of a diagnostic trouble code (DTC) may have momentary increases in engine RPM before the onset of the DTC and entering a fail-safe status.

Exponent has also performed a series of EMI tests to characterize the response of several different vehicles and components to EMI events. Exponent's work is currently ongoing and Exponent continues to perform tests on vehicles, and continues to study the hardware and software of vehicles' systems.

1. Software Review

Exponent is performing an objective and independent investigation and review of the software. The software review process has been and continues to be a multi-stage process and has involved the following components:

- Design/specification review
- Source code review
    - Flow Analysis
    - Analysis of code structure
    - Code review
    - Static Analysis
    - Dynamic Analysis
- Test Data/Validation Report Review

1.1 Design/Specification Review

Exponent has reviewed and continues to study materials to acquire a detailed knowledge of the software system and its operation. The review has included studying the specifications, control charts, architecture, design and implementation and understanding how the software system is structured, how it is designed to process inputs, control the various vehicle components and the fail safes built into the system.

1.2 Source Code Review

Exponent has performed and continues to perform both directed and exploratory review of the source code.

1.3 Flow Analysis

Exponent used custom-developed and off-the-shelf automated analysis tools to analyze the information flow and control of the throttle motor system, such as user demanded acceleration. This information flow is also being analyzed against the design specifications and diagrams.

1.4 Analysis of code structure

The software architecture, design and code structure continues to be analyzed for robustness, redundancy and fail safe operation.

1.5 Code Review

Based on its ongoing design review, flow analysis, and analysis of the code structure, Exponent is in the process of identifying critical modules that control the throttle motor and that are responsible for fail-safe operation. Exponent is performing a function-by-function, line -by-line, and instruction-by-instruction review of the software code written in the C and assembly programming languages. This code review is being used for the following:

- To identify and verify the function of the validation modules that moderate the throttle opening demands from user and other modules
- To analyze and verify the logical flow of the software
- To identify any logical or functional bugs in the software
- To study the numerous fail safe modules in the software and to analyze the bounds applied by the software on the various inputs

1.6 Static Analysis

Static analysis generally refers to automated methods that facilitate the detection of run-time errors without the actual execution of the code. The main purpose of static analysis is to detect any unexpected run time events that may cause the program execution to prematurely abort or result in non-desirable behavior by the software. Examples of run time errors which can typically be detected by static analysis include resource leaks (i.e. improper resource allocation), illegal operations (e.g. variable or buffer overflow), incomplete code, non-termination of loops, etc[1].

[1] Par Emanuelsson & Ulf Nilsson, "A Comparative Study of Industrial Static Analysis Tools", Technical reports in Computer and Information Science, Report Number 2008:3

Exponent is currently using PolySpace, an industry accepted software verification tool from Mathworks, Inc., for static analysis of the source code. PolySpace provides the ability to prove mathematically if a certain class of run-time errors does not exist in the source code and to identify parts of the code where those errors exist or the proof cannot be completed. PolySpace analysis is equivalent to running every possible test scenario, but does it in such a way that no test cases, instrumentation or actual execution of the source code are required. This allows for an exhaustive testing of the software that would otherwise require many millions of hours of drive testing to identify.

Exponent is currently processing the information from the static analysis. The PolySpace analysis has been performed on critical modules that have been identified as directly controlling the throttle opening angle. The analysis performed to date has not identified any run time errors at the language level.

1.7 Dynamic Analysis Using Simulators

Exponent is also currently performing dynamic analysis on the source code. Exponent has and continues to generate test vectors and to study the output to various input test cases devised to test the software response to different conditions (both fault and operating conditions). The dynamic analysis is being performed on a Hardware-In-the-Loop Simulator (HILS) using a tool that has been developed to verify the response of the Engine Control Unit (ECU) and its associated code to a set of inputs. The tool also provides the ability to probe the software and inspect the state of critical variables in real time. This enables Exponent to test our understanding and better evaluate the software and how the relationship between the variables ultimately controls the throttle motor.

The HILS used by Exponent is a proprietary simulator designed and developed specifically for the purpose of testing the source code on the ECU, and is owned and operated by DENSO. The software provides the capability of simulating sensor signal outputs and analyzing the actuator signals for a simulated vehicle, simulating Controller Area Network (CAN) communications signals and providing the ability to debug and analyze system response in real time. Exponent continues to specify new input test vectors and use the HILS simulator to study and characterize the software response to the inputs.

1.8 Test Data/Validation Report Review

Exponent is reviewing documentation related to the software testing performed by the manufacturer. Test documentation currently being reviewed includes:

- Modified Condition/Decision Coverage (MC/DC) test reports
- Additional static test reports including reports generated using the following tools:
  - C-Checker
  - QA-C (A deep flow static analysis tool)
  - KRS2
  - CAST
  - C Code Analyzer (CCA)
- Dynamic test reports
- Task interference test reports
- Other software reports

2. Hardware Review

Exponent is performing an objective and independent investigation and review of the hardware that controls the throttle valve. Exponent's analysis includes a detailed review of the 2007 V6 Camry hardware, which is ongoing. The hardware review process has been and continues to be a multi-stage process and has involved the following components:

- Review of documents – design and specifications
- Electrical testing
- Review of physical hardware

2.1 Design/Specification Review

The hardware schematics for the 2007 V6 Camry are being reviewed to determine the progression of the command signals from the accelerator pedal to the throttle motor, and to determine protection and fail-safe modes.

Exponent is currently in the process of analyzing a multitude of documents to identify the various hardware system operating modes, interconnection design methodologies, and fail-safe systems. The document review includes an examination of documents from various sources, including proprietary/confidential materials as well as publicly available documents. The review includes circuit diagrams, data sheets and specification block diagrams, graphs, plots, absolute maximum ratings, etc., to acquire detailed knowledge of how the hardware system is configured, and how it is implemented and designed to control the various vehicle components, including the fail safe modes built into the system.

Exponent's efforts in design review currently include:

- Analyzing the electrical circuitry
- Analysis for potential hardware issues
- Studying fail safe modes integrated within the hardware
- Studying the methods employed to suppress electrical noise within the circuit

- Determining the effects of latch up and measures implemented to provide system protection and fail safe operation
- Determining the effect of short-circuits and measures implemented to provide system protection and fail-safe operation

2.2 Test Data/Validation Report Review

Exponent is reviewing documentation related to the hardware testing performed by the manufacturer. Documentation currently being reviewed includes:

- Hardware reports
- ECU response to varying voltages
- Soldering processes
- Rework processes
- Quality and functional electrical testing performed on the ECU
- In-circuit electrical test reports
- In-vehicle test reports
- ESD test reports
- Manufacturing qualification tests

3. System Configuration

Exponent's hardware review has indicated that the system has the following high level configuration for the 2007 V6 Camry as shown in Fig. 2.

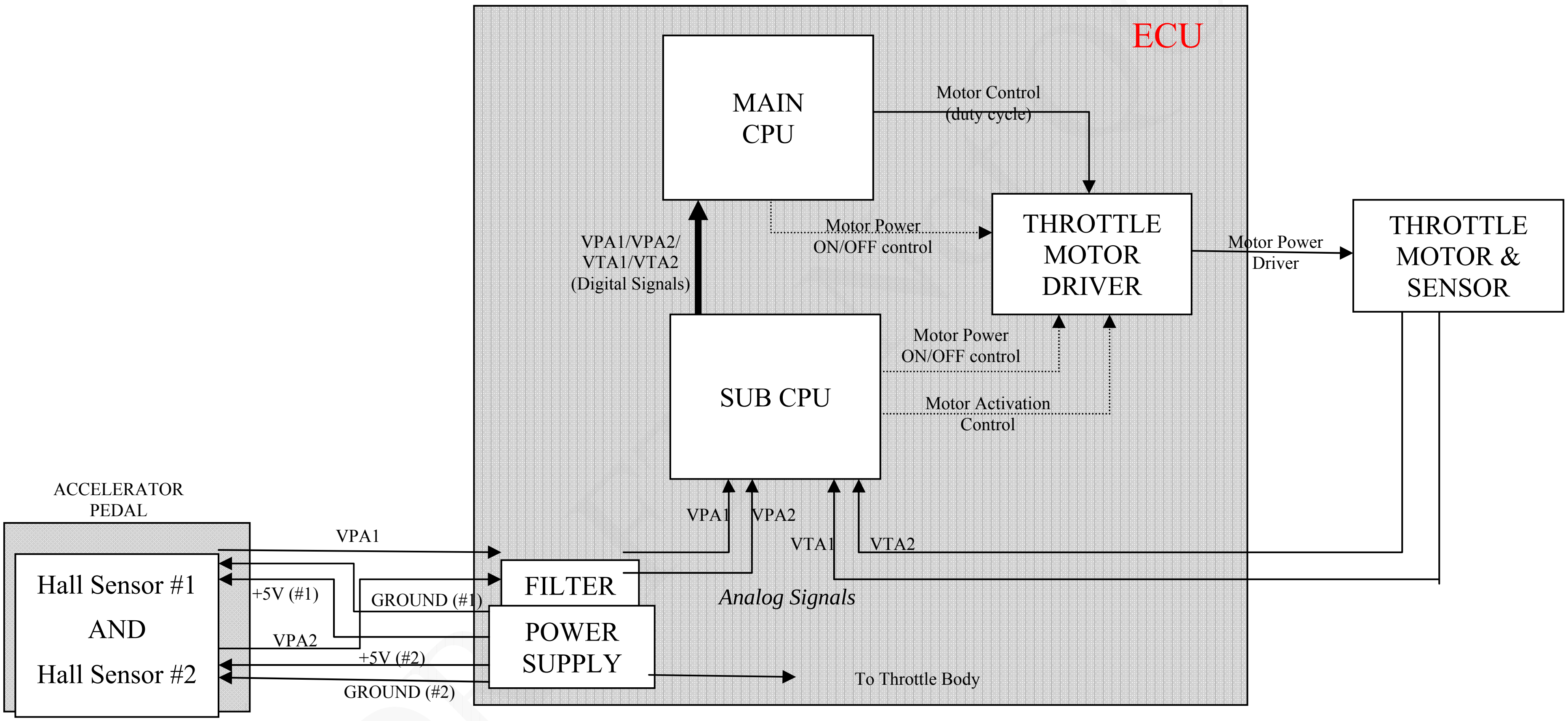


Fig. 2. Pedal to Throttle Body Block Diagram

4. Noise Immunity to EMI

Exponent reviewed the schematics received from Toyota to determine the EMI noise immunity techniques used by Toyota.

Exponent's detailed hardware review has been primarily focused on the current hardware system for the 2007 V6 Camry. The hardware schematics were reviewed to determine the hardware techniques used by Toyota to ensure a high level of immunity to EMI for the command signals from the accelerator pedal to the throttle motor. There is no RF or wireless communication used, and all command signals are transmitted using copper conductors. The designed electrical circuits include the following means to provide EMI protection:

4.1.1 Decoupling Capacitors

Low frequency, medium frequency and high frequency decoupling capacitors are provided to improve noise immunity. The decoupling capacitors supply the transient current during switching and also suppress any electrical noise that may be generated by other components. Low frequency decoupling capacitors are provided on the ECU. Medium frequency and high frequency decoupling capacitors are provided at the IC power supply terminals.

a. <u>Pedal Electronics</u>

The pedal electronics has on-board decoupling capacitors to improve noise immunity.

b. <u>Engine Control Unit (ECU)</u>

The ECU has on-board low frequency decoupling capacitors for providing low frequency noise immunity for the ICs and other electrical circuits on the ECU circuit board.

c. <u>Processors & Other Integrated Circuits on ECU</u>

The ECU circuit board contains various integrated circuits (ICs) that help the ECU perform its function. Decoupling capacitors are used on the ECU circuit board to improve noise immunity.

4.1.2 Filter Network

Filtering is used to provide increased noise immunity to the in-coming signals to the ECU from the pedal sensors and the throttle position sensors. Pull-up and pull-down resistors are also used at the outputs of the sensors to provide default signals should a conductor become open circuit.

4.1.3 Shielded Cable

A two-conductor, shielded cable is used for the throttle motor power conductors to attenuate electrical noise to adjacent conductors.

4.1.4 Twisted Pair

The throttle position sensors are powered by a two-conductor twisted pair cable for increased noise immunity.

4.1.5 Additional Measures

Additional measures taken to minimize EMI include: proper placement of ground and power planes on the PCB, minimizing trace lengths, and minimizing pathways to ground. This list is not complete and Exponent's review is ongoing.

4.1.6 EMI Testing

Exponent, as part of its comprehensive investigation of unintended acceleration (UA) claims in Toyota and Lexus vehicles equipped with electronic throttle control (ETCS-i) technology, initiated an evaluation of the susceptibility of these vehicles to electromagnetic interference (EMI). Exponent conducted tests in an effort to identify conditions that would a) result in increases in engine speed in operating vehicles, or b) cause changes in throttle or pedal sensor outputs that might lead to engine speed increases. The testing is ongoing and is being performed in conjunction with other analyses, including detailed reviews of the hardware and software implemented in the subject vehicles.

The EMI testing program to date has included a review of the state-of-the-art in vehicle EMI testing; testing of vehicles on dynamometers in anechoic chambers subjected to intense EM fields; subjecting components and subassemblies to even more intense EM fields in anechoic chambers and transverse electromagnetic (TEM) cells; and testing components with magnetic fields.

The anechoic chamber vehicle testing included testing according to the European Directive (EU Directive 2004/104/EC), though at twice the field intensity and duration. The EU Directive specifies testing in the range of 20 MHz to 2,000 MHz. There is no equivalent Federal Motor Vehicle Safety Standard (FMVSS) for EMI testing. Additional vehicle testing for EMI susceptibility was also performed, including changes in illumination, modulation, increases in intensity, simulation of radar pulses, and manual vs. cruise control operation. Seven different Toyota & Lexus cars and trucks, and five different cars from different manufacturers were tested. Testing was conducted in three different anechoic chamber facilities (operated by Chrysler, GM and Toyota), with some vehicles being tested in multiple facilities to ensure consistency. No increase in engine speed resulted from EMI in any test of any vehicle.

Electronic Control Units (ECUs), throttle bodies, and pedals were harvested from four operational Toyota and Lexus cars and trucks for component testing. Three of the four vehicles from which parts were collected had been tested previously for EMI as described in the previous paragraph. These components were tested for EMI and magnetic susceptibility at the EMCES facility at Denso in Nagoya, Japan. In Denso's anechoic chamber, the pedal, throttle body, and ECU from each vehicle were wired together and to a simulator (to provide the other signals required for proper operation of the ECU) and subjected to very intense EM radiation, with different frequencies, modulations and polarizations, including a radar pulse simulation. Aside from monitoring of signals, a dedicated camera was continuously focused on the throttle body to detect any visual evidence of throttle body movement. For the TEM cell tests, an ECU, throttle body, and two pedals (one Denso, one CTS) were subjected to intense EM fields with different frequencies, modulations, and polarizations. No movement of the throttle body valve was observed in any of the testing, and the throttle and pedal position sensor outputs remained steady. Magnetic field testing, conducted according to MIL STD-461E RS101, was performed on one throttle body and two pedals (one Denso and one CTS pedal, both using Hall effect sensor technology) over the frequency range 50 Hz to 100,000 Hz while monitoring the sensor outputs. Multiple orientations were tested. No movement of the throttle body valve was observed in any of the testing, and the throttle and pedal position sensor outputs remained steady. After the testing, the components were returned and installed in their respective vehicles.

Exponent plans to conduct additional testing. Such testing may include bulk current injection testing (where electrical fields are directly injected into the subject wiring), and chatter box relay testing (where electrical noise in different forms is introduced directly into the power supply for the ECU). Exponent is also collecting data on background EM radiation levels. Further, as part of its investigation into UA claims, Exponent plans to collect EM radiation measurements at locations where UA incidents reportedly occurred. Presently, such measurements are limited since Exponent does not have access to information on the specific locations. As more information becomes available, Exponent may conduct additional EMI testing in its efforts to address the susceptibility of Toyota and Lexus ETCS-i equipped vehicles to EMI.

4.1.6.1 Test Detail

A detailed listing of the vehicle test conditions, vehicles tested, anechoic chambers used, and resulting test reports are provided in Tables 1-16. Details of the components used in the component testing and the test report numbers are provided in Tables 17-19. The individual test reports are provided in Attachment A.

4.1.6.2 Tables of EMI Testing

Table 1: EMI Immunity - BASELINE Test Conditions

Metric	Value	Notes	Standard
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
Modulation to Frequency			
20-800 MHz	AM modulation, 80% modulation depth, 1000 Hz		EU Directive 2004/104/EC, Annex VI, para. 3
800-2,000 MHz	Pulse modulation, 577 microsec on, pulse period 4,600 microseconds		EU Directive 2004/104/EC, Annex VI, para. 3
Frequency steps	Linear steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
Vehicle Condition			
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2010	Honda Civic Hybrid	JHMFA3F20AS000621	Chrysler - Auburn Hills	23-Feb-10 to 24-Feb-10	V10105
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1BU4EE2AC299197	Jacobs - Milford (GM Proving Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 1. Baseline Test Conditions

Table 2: Supplemental EMI Immunity - 100V/m, Base Test Conditions

Metric	Value	Notes	Standard
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
20-800 MHz	AM modulation, 80% modulation depth, 1000 Hz		EU Directive 2004/104/EC, Annex VI, para. 3
800-2,000 MHz	Pulse modulation, 577 microsec on, pulse period 4,600 microseconds		EU Directive 2004/104/EC, Annex VI, para. 3
Frequency steps	Log steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	10 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	100 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Open	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Toyota Camry	4T1BK46KX7U001643 ECU used: taken from 4T1BK46K57U033450	Hanamoto EMC Chamber, Toyota Test facility	4/14/10-4/15/10	100422-100Vm

Table 2. 100V/m, Base Test Conditions

Table 3: Supplemental EMI Immunity Tests - DRIVER SIDE Test Conditions

Metric	Value	Notes	Standard
Antenna Position	**Driver Side Illumination**	Supplemental	
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
20-800 MHz	AM modulation, 80% modulation depth, 1000 Hz		EU Directive 2004/104/EC, Annex VI, para. 3
800-2,000 MHz	Pulse modulation, 577 microsec or, pulse period 4,600 microseconds		EU Directive 2004/104/EC, Annex VI, para. 3
Frequency steps	Linear steps		ISO 11451-1 2005(E), Section 4.5
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1 2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Conditon		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2010	Honda Civic Hybrid	JHMFA3F20AS000621	Chrysler - Auburn Hills	23-Feb-10 to 24-Feb-10	V10105
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1EU4EE2AC299197	Jacobs - Milford (GM Proving Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 3. Driver Side Test Conditions

Table 4: Supplemental EMI Immunity Tests - 100V/m, DRIVER SIDE Test Conditions

Metric	Value	Notes	Standard
Antenna Position	**Driver Side Illumination**	Supplemental	
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
20-800 MHz	AM modulation, 80% modulation depth, 1000 Hz		EU Directive 2004/104/EC, Annex VI, para. 3
800-2,000 MHz	Pulse modulation, 577 microsec on, pulse period 4,600 microseconds		EU Directive 2004/104/EC, Annex VI, para. 3
Frequency steps	Log steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	**10 seconds**	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	**100 V/m**	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Open	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Toyota Camry	4T1BK46KX7U001643 ECU used: taken from 4T1BK46K57U033450	Hanamoto EMC Chamber, Toyota Test facility	4/14/10-4/15/10	100422-100Vm

Table 4. 100V/m, Driver Side Test Conditions

Table 5: Supplemental EMI Immunity Tests - Manual Throttle

Metric	Value	Notes	Standard
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
20-800 MHz	AM modulation, 80% modulation depth, 1000 Hz		EU Directive 2004/104/EC, Annex VI, para. 3
800-2,000 MHz	Pulse modulation, 577 microsec on, pulse period 4,600 microseconds		EU Directive 2004/104/EC, Annex VI, para. 3
Frequency steps	Linear steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	OFF	Manual Throttle, Supplemental	
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1BU4EE2AC299197	Jacobs - Milford (GM Proving Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2010	Toyota Tacoma	5TENX4CN2AZ676662	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 16-Feb-10	EMC-120
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 5. Manual Throttle

Table 6: Supplemental EMI Immunity Tests - Manual Throttle & Driver Side Illumination

Metric	Value	Notes	Standard
Antenna Position	Driver Side Illumination	Supplemental	
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
20-800 MHz	AM modulation, 80% modulation depth, 1000 Hz		EU Directive 2004/104/EC, Annex VI, para. 3
800-2,000 MHz	Pulse modulation, 577 microsec on, pulse period 4,600 microseconds		EU Directive 2004/104/EC, Annex VI, para. 3
Frequency steps	Linear steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	OFF	Manual Throttle, Supplemental	
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1BU4EE2AC299197	Jacobs - Milford (GM Proving Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2010	Toyota Tacoma	5TENX4CN2AZ676662	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 16-Feb-10	EMC-120
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 6. Manual Throttle & Driver Side Illumination

Table 7: Supplemental EMI Immunity - RADAR, Front Illumination, Cruise Control

Metric	Value	Notes	Standard
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
	Modulation to Frequency		
Frequency Range	1,200 - 1,400 MHz		
Pulse Modulation	3 microseconds on, 3.333 micoseconds Off (300 Hz pulse repetition rate)	Simulated Air Traffic Control Radar	
Frequency steps	40 MHz		
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	600 V/m	Simulated Air Traffic Control Radar Exposure	
	Vehicle Conditon		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Lexus ES 350	JTHBJ46G972060879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1BU4EE2AC299197	Jacobs - Milford (GM Proving Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	18-Feb-10 & 20-Feb-10	EMC-121

Table 7. RADAR, Front Illumination, Cruise Control

Table 8: Supplemental EMI Immunity - RADAR, Side Illumination, Cruise Control

Metric	Value	Notes	Standard
Antenna Position	**Driver Side Illumination**	Supplemental	
	Modulation to Frequency		
Frequency Range	1,200 - 1,400 MHz		
Pulse Modulation	3 microseconds on, 3,333 micoseconds Off (300 Hz pulse repetition rate)	Simulated Air Traffic Control Radar	
Frequency steps	40 MHz		
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	**600 V/m**	Simulated Air Traffic Control Radar Exposure	
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Provng Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Provng Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1BJ4EE2AC299197	Jacobs - Milford (GM Provng Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Provng Grounds)	16-Feb-10 & 20-Feb-10	EMC-121

Table 8. RADAR, Side Illumination, Cruise Control

Table 9: Supplemental EMI Immunity - RADAR, Front Illumination, Manual Throttle

Metric	**Value**	**Notes**	**Standard**
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
	Modulation to Frequency		
Frequency Range	1,200 - 1,400 MHz		
Pulse Modulation	3 microseconds on, 3,333 micoseconds Off (300 Hz pulse repetition rate)	Simulated Air Traffic Control Radar	
Frequency steps	40 MHz		
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	600 V/m	Simulated Air Traffic Control Radar Exposure	
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	OFF	Manual Throttle	
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1BU4EE2AC299197	Jacobs - Milford (GM Proving Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Tacoma	5TENX4CN2AZ676662	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 16-Feb-10	EMC-120

Table 9. Radar, Front Illumination, Manual Throttle

Table 10: Supplemental EMI Immunity - RADAR, Side Illumination, Manual Throttle

Metric	Value	Notes	Standard
Antenna Position	**Driver Side Illumination**	Supplemental	
	Modulation to Frequency		
Frequency Range	1,200 - 1,400 MHz		
Pulse Modulation	3 microseconds on, 3,333 micoseconds Off (300 Hz pulse repetition rate)	Simulated Air Traffic Control Radar	
Frequency steps	40 MHz		
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	600 V/m	Simulated Air Traffic Control Radar Exposure	
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	OFF	Manual Throttle	
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2003	Toyota Camry	4T1BF30K23U061207	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 21-Feb-10	EMC-119, EMC-124
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Corolla	2T1BU4EE2AC289197	Jacobs - Milford (GM Proving Grounds)	15-Feb-10, 19-Feb-10 & 20-Feb-10	EMC-118, EMC-123
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2010	Toyota Tacoma	5TENX4CN2AZ678662	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 16-Feb-10	EMC-120

Table 10. Radar, Side Illumination, Manual Throttle

Table 11: Supplemental EMI Immunity - No Modulation, Front Illumination, Cruise Control

Metric	Value	Notes	Standard
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
Modulation	None	Continuous Wave	
Frequency steps	Linear steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2010	Honda Civic Hybrid	JHMFA3F20AS000621	Chrysler - Auburn Hills	23-Feb-10 to 24-Feb-10	V10105
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 11. No Modulation, Front Illumination, Cruise Control

Table 12: Supplemental EMI Immunity - 100 V/m, No Modulation, Front Illumination, Cruise Control

Metric	Value	Notes	Standard
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
Modulation	None	Continuous Wave	
Frequency steps	Log steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	10 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	100 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Open	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Toyota Camry	4T1BK46KX7U001643 ECU used: taken from 4T1BK46K57U033450	Hanamoto EMC Chamber, Toyota Test facility	4/14/10-4/15/10	100422-100Vm

Table 12. 100 V/m, No Modulation, Front Illumination, Cruise Control

Table 13: Supplemental EMI Immunity - No Modulation, Side Illumination, Cruise Control

Metric	Value	Notes	Standard
Antenna Position	**Driver Side Illumination**	Supplemental	
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
Modulation	None	Continuous Wave	
Frequency steps	Linear steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2010	Honda Civic Hybrid	JHMFA3F20AS000621	Chrysler - Auburn Hills	23-Feb-10 to 24-Feb-10	V10105
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G072080870	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 13. No Modulation, Side Illumination, Cruise Control

Table 14: Supplemental EMI Immunity - 100V/m, No Modulation, Side Illumination, Cruise Control

Metric	Value	Notes	Standard
Antenna Position	**Driver Side Illumination**	Supplemental	
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
Modulation	**None**	**Continuous Wave**	
Frequency steps	Log steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	**10 seconds**	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	**100 V/m**	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	On		EU Directive 2004/104/EC, Annex VI, para. 2
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Open	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Toyota Camry	4T1BK46KX7U001643 ECU used: taken from 4T1BK46K57U033450	Hanamoto EMC Chamber, Toyota Test facility	4/14/10-4/15/10	100422-100Vm

Table 14. 100V/m, No Moulation, Side Illumination, Cruise Control

Table 15: Supplemental EMI Immunity - No Modulation, Front Illumination, Manual Throttle

Metric	Value	Notes	Standard
Antenna Position	Front Illumination		EU Directive 2004/104/EC, Annex VI, para. 4
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
Modulation	None	Continuous Wave	
Frequency steps	Linear steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	OFF	Manual Throttle, Supplemental	
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2007	Toyota Camry	4T1BK46K57U033450	Jacobs - Milford (GM Proving Grounds)	14-Feb-10 & 20-Feb-10	EMC-116, EMC-122
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2010	Toyota Tacoma	5TENX4CN2AZ676662	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 16-Feb-10	EMC-120
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 15. No Modulation, Front Illumination, Manual Throttle

Table 16: Supplemental EMI Immunity - No Modulation, Side Illumination, Manual Throttle

Metric	Value	Notes	Standard
Antenna Position	Driver Side Illumination	Supplemental	
Frequency Range	20 MHz - 2,000 MHz		EU Directive 2004/104/EC, Annex VI, para. 3
	Modulation to Frequency		
Modulation	None	Continuous Wave	
Frequency steps	Linear steps		ISO 11451-1:2005(E), Section 4.6
Time at each freq.	2 seconds	1 sec min. specified	ISO 11451-1:2005(E), Section 4.5
Polarization	Vertical		EU Directive 2004/104/EC, Annex VI, para. 3
Field Strength	60 V/m	30 V/m specified	EU Directive 2004/104/EC, paragraph 6.4.2.1
	Vehicle Condition		
Wipers	On, High speed		EU Directive 2004/104/EC, Annex VI, para. 2
Lights	On, Low Beam		EU Directive 2004/104/EC, Annex VI, para. 2
Turn Signal	On, Left		EU Directive 2004/104/EC, Annex VI, para. 2
Vehicle Speed	50 km/hr for all except 70 km/hr for Civic Hybrid		EU Directive 2004/104/EC, Annex VI, para. 2
Cruise control	OFF	Manual Throttle, Supplemental	
Doors	Closed		EU Directive 2004/104/EC, Annex VI, para. 2
Windows	Fully Open	Supplemental	
Moonroof/Sunroof	Closed	Supplemental	

Vehicles Tested

Model Year	Brand & Model	VIN	Test Facility	Test Date	Report #
2007	Honda Accord	1HGCM66447A031918	Chrysler - Auburn Hills	28-Feb-10	V10109
2007	Hyundai Sonata	5NPEU46F97H212910	Chrysler - Auburn Hills	25-Feb-10 to 26-Feb-10	V10108
2007	Lexus ES 350	JTHBJ46G972080879	Chrysler - Auburn Hills	26-Feb-10	V10114
2007	Lexus ES 350	JTHBJ46G972080879	Jacobs - Milford (GM Proving Grounds)	13-Feb-10 & 15-Feb-10	EMC-115
2007	Nissan Altima	1N4BL21E37N404354	Chrysler - Auburn Hills	25-Feb-10	V10107
2003	Toyota Camry	4T1BF30K23U061207	Chrysler - Auburn Hills	4-Mar-10 & 16-Mar-10	V10116
2007	Toyota Camry	4T1BK46K57U033450	Chrysler - Auburn Hills	2-Mar-10 & 16-Mar-10	V10115
2010	Toyota Prius	JTDKN3DU3A0110275	Chrysler - Auburn Hills	1-Mar-10	V10110
2010	Toyota Prius	JTDKN3DU3A0110275	Jacobs - Milford (GM Proving Grounds)	16-Feb-10 & 20-Feb-10	EMC-121
2010	Toyota Tacoma	5TENX4CN2AZ676662	Jacobs - Milford (GM Proving Grounds)	15-Feb-10 & 16-Feb-10	EMC-120
2007	VW Jetta	3VWEF71KX7M142891	Chrysler - Auburn Hills	24-Feb-10	V10106

Table 16. No Modulation, Side Illumination, Manual Throttle

Table 17: Component Anechoic Chamber Tests

Anechoic Chamber Tests				
Metric	**Value**	**Notes**		
Components	**ECU, Pedal, Throttle Assembly connected together**	ECU connected to simulator for other inputs		
Antenna Position	Front Illumination	Anechoic Chamber		
Frequency Range	400 MHz - 2,000 MHz			
	Modulation to Frequency			
400-800 MHz	AM modulation, 80% modulation depth, 1000 Hz			
800-2,000 MHz	Pulse modulation, 577 microsec on, pulse period 4,600 microseconds			
400-2,000 MHz	Continuous wave	Tests run with unmodulated wave		
Frequency steps	Logarithmic steps			
Time at each freq.	2 seconds			
Polarization	Vertical and Horizontal			
Field Strength	**200 V/m**			
	Radar Pulse	2007 Camry and 2007 Lexus ES350		
Frequency Range	1200-1400 MHz			
Modulation	PRR=300 Hz, PD=3 μsec			
Time at each freq.	2 seconds			
Polarization	Vertical and Horizontal			
Field Strength	**600 V/m**			
Test Report	Denso REP10-3010			
Vehicle	**Vehicle VIN**	**Throttle Body**	**Pedal**	**ECU**
2007 Camry (V6)	4T1BK46K57U033450	22030-0P050	78110-07010 (CTS)	89661-06C21
2007 ES350 (V6)	JTHBJ46G972080879	22030-31030	78110-33020 (Denso)	89661-3T831
2010 Tacoma (L4)	5TENX4CN2AZ676662	22030-75020	78120-04060 (Denso)	89661-04E90
2002 Camry (L4)	4T1BE30K32U594362	22030-0H010	78010-33010 (Denso)	89666-06220

Table 17. Component Anechoic Chamber Tests

Table 18: Component TEM Cell Tests

TEM Cell Tests

Metric	Value	Notes
Components	**ECU, Pedal, Throttle Individually**	ECU connected to simulator for other inputs
Antenna Position	TEM cell	
Frequency Range	20 MHz - 400 MHz	
	Modulation to Frequency	
20-400 MHz	AM modulation, 80% modulation depth, 1000 Hz	
20-400 MHz	Continuous Wave	
Frequency steps	Linear steps	
Time at each freq.	2 seconds	
Polarization	Three orientations of each device	
Field Strength	**200 V/m**	
Test Report	Denso REP10-3010	

Vehicle	Vehicle VIN	Throttle Body	Pedal	ECU
2007 Camry (V6)	4T1BK46K57U033450	22030-0P050	78110-07010 (CTS)	89661-06C21
2007 ES350 (V6)	JTHBJ46G972080879		78110-33020 (Denso)	

Table 18. Component TEM Cell Tests

Table 19: Component Magnetic Field Immunity Tests

Magnetic Field Immunity Tests

Metric	Value	Notes
Components	**ECU, Pedal, Throttle Individually**	ECU connected to simulator for other inputs
Frequency Range	50 Hz to 100,000 Hz; 60 Hz	
Test Setup	See MIL STD-461E RS101	
Modulation	Modulation to Frequency Continuous Wave	
Frequency steps	50 Hz (50-1000 Hz) 500 Hz (1000-10000 Hz) 5000 Hz (10000-100000 Hz)	
Time at each freq.	2 seconds	
Orientation	Four surfaces for the throttle body Five surfaces for pedals	
Field Strength	per MIL Standard	
Test Report	Denso REP10-3010	

Vehicle	Vehicle VIN	Throttle Body	Pedal
2007 Camry (V6)	4T1BK46K57U033450	22030-0P050	78110-07010 (CTS)
2007 ES350 (V6)	JTHBJ46G972080879		78110-33020 (Denso)

Table 19. Component Magnetic Field Immunity Tests

5. Error Code Correction (ECC)

Exponent has performed a detailed review of the Integrated Circuits and memory that are used for storing information and programs in the Engine Control Unit (ECU). Exponent's analysis to date indicates that the use of Error Correcting Codes ("ECC") in the main processor will catch and correct single bit errors (1 bit flip, e.g. due to a soft error). In the ECU's main CPU RAM, the ECC will correct 1 bit per byte. When an error is detected, the data output will be corrected by the ECC code. Note that random bit flips are not associated with older 0.25 and 0.35 um technology nodes. ECC RAM checks were introduced with the advent of 0.15 um technology.

In addition to ECC, the Main CPU in the ECU also mirrors critical variables used to determine throttle opening angle and can detect when a RAM error causes a corruption of these variables. This is done by creating a mirror value (by flipping bits) of calculated variables immediately after the global variable value is assigned. The mirror values are checked against the retrieved values from RAM and a diagnostic Trouble Code (DTC) is set if an error is detected. This technique has the ability to detect extraordinarily rare events, such as errors on multiple bits.

Notes on ECC

- When the engine is started, a RAM check is performed to ensure that the memory is not corrupted
    - RAM is of two types – NRAM and SRAM
        - SRAM checking occurs during startup and also periodically (65 ms)
        - NRAM check performed when the battery is reconnected.

6. Tin Whisker Testing

Tin whiskers are a phenomenon where tiny filaments form and grow from tinned surfaces. The concerns with tin whisker formation arose with the switch to lead-free solders. Many factors contribute to the determination of whether tin whiskers will form, grow and cause a problem. These include (among other factors): lead content, whether boards are conformal coated, temperature and humidity, conductor spacing, tinning process, material under the tin, and substrate controlling thermal expansion.

Whether tin whisker formation can be a possible cause of unintended acceleration was studied from multiple perspectives. Exponent's ongoing study includes:

- Optical stereomicroscope inspection of printed circuit boards from different generations of ECUs and components
- Scanning Electron Microscopy (SEM) of soldered joints
- Energy Dispersive Spectroscopy (EDS) of soldered joints
- Review of documents on solder technology employed by Toyota and its suppliers
- Pin-to-pin testing of ECUs

Inspections were performed per NASA and JESD22-A121A guidelines. Pin-to-pin tests are described in the following section.

7. Pin-to-Pin Testing

Testing, which is currently ongoing, involves shorting adjacent pins on the processor and sub-processor of a vehicle that is then operated. Two forms of shorts are used: a hard short (0 Ω) and a resistive short (~30 Ω). The specific test protocol is described in the following sections.

7.1.1 Selected Resistance based on Range of Whisker Size

In the 2007 Camry, for the main CPU, the measured pitch is ~ 500 μm and the measured pad-to-pad spacing is ~ 100 μm. The dc resistance of a tin whisker with a diameter of 1 μm (expected smallest diameter) and L ~ 100 μm (pad-to-pad spacing) is ~ 15 Ω. A tin whisker with a diameter of 1 μm and whisker length L ~ 200 μm will have a resistance R ~ 30 Ω.

7.1.2 Test Conditions

The Tin Whisker test will be conducted for the following test conditions summarized below and listed in more detail under the Test Procedure:

- Engine off, resistive short applied, start engine, while at idle, observe and record engine rpm, note and record any DTC, note if any indicator lamps come on
- Press gas pedal, set rpm to 2,000 – 2500. Record rpm, note and record any DTC, note and record if any indicator lamps come on
- Turn engine OFF, move to next set of pins.

The testing will be conducted for two values of resistive shorts:

- R ~ 0 Ω using a flexible wire lead
- R ~ 30 Ω to simulate a whisker between pads with whisker diameter of 1 μm (smallest diameter) and whisker length L ~ 0.2 mm

7.1.3 Test Setup

- Use flexible leads to connect to the Agilent wedge probe. (Without the flexible leads, the weight of the leads will most likely cause the Agilent wedge probe adapter to disconnect from the IC.)
- It is preferable to use the 8 signal wedge probe.
- Prior to each test, DMM resistance measurements are conducted from the IC pin to its respective wedge probe pin to verify proper contact.
- At the end of each test, DMM resistance measurements are conducted from the IC pin to its respective wedge probe pin to verify proper contact.

7.1.4 Test Procedure

1) Conduct Test # 1 with R = 0 Ω as follows:
   a) Turn off engine, put vehicle in Park.
   b) Check that the Agilent wedge probe pins are not deformed. If they are deformed, straighten them per the manufacturers' procedure listed in the manual.
   c) Start from one end and carefully seat the wedge probe on CPU under test.
   d) Visually determine that the wedge probe is seated correctly, with no CPU pins shorting and the wedge pins are not deformed.
   e) Conduct DMM resistance measurements from the IC pin to its respective wedge probe pin to verify proper contact.
   f) Apply short circuit using alligator clip leads across the two pins under test - pin N and pin N+1
   g) Start engine
   h) While at idle, observe and record engine rpm
   i) Note and record any DTC
   j) Note and record if any indicator lamps come on
   k) Press gas pedal, set rpm to 2,000 – 2500. Record rpm
   l) Note and record any DTC
   m) Note and record if any indicator lamps come on

n) Turn OFF engine

o) At the end of each test, conduct DMM resistance measurements from the IC pin to its respective wedge probe pin to verify proper contact.

p) Move alligator clip leads to pin N+1 and pin N+2

q) Repeat above items.

r) After testing all 8 pins, remove clip and carefully seat it on the next 8 pins.

s) Continue the process till all pins are done.

2) Repeat the above test procedure using flexible clip leads with the above value of inserted resistance listed under Test Conditions.

3) Repeat items 1) and 2) and for the sub CPU.

8 Latch-up

i Principle of Latch up - Parasitic SCR

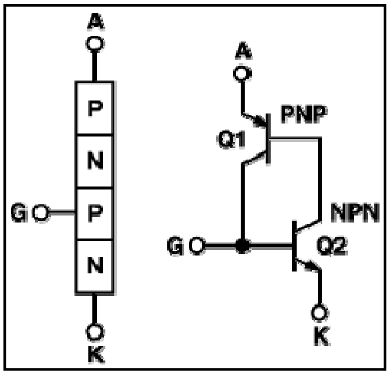
Latch-up[2] pertains to a failure mechanism wherein a parasitic thyristor (such as a parasitic silicon controlled rectifier, or SCR) is inadvertently created within a circuit, causing a high amount of current to continuously flow through it once it is accidentally triggered or turned on. Depending on the circuits involved, the amount of current conducted by this mechanism can be large enough to result in permanent destruction of the device due to electrical overstress.

Latch-up[3] may be defined as the creation of a low-impedance path between power supply rails as a result of triggering a parasitic device. In this condition, excessive current flow is possible, and a potentially destructive situation exists. After even a very short period of time in this condition, the device in which it occurs can be destroyed or weakened; and potential damage can occur to other components in the system. Latch-up occurs as a result of triggering a parasitic device, in effect an SCR (silicon controlled rectifier), a four-layer pnpn device formed by at least one pnp and at least one npn transistor connected as shown in Fig. 3.

When triggered into its conducting state as a result of excitation applied to the gate, the SCR is said to be "latched". It enters this state as a result of current from the gate injected into the base of Q2, which causes current flow in the base-emitter junction of Q1. Q1 turns on causing further current to be injected into base of Q2. This positive-feedback condition ensures that both transistors saturate; and the current flowing through each transistor ensures that the other remains in saturation. If, however, the current can be reduced to a point where it falls below a holding-current value, the SCR switches off. Fig. 4 shows the current-to-voltage transfer function for an SCR.

[2] Latchup, www.Siliconfareast.com

[3] "Winning the Battle Against Latch-up in CMOS Analog Switches", by C. Redmond, Analog Dialogue 35-05 (2001).



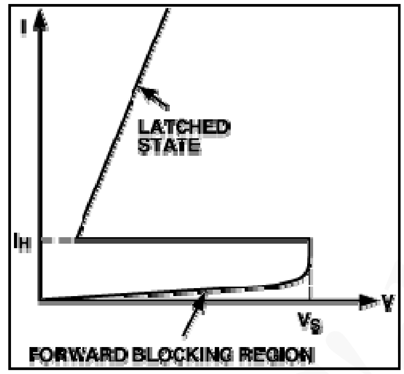


Fig. 3 Transistor equivalent of an SCR [5].   Fig. 4. Current - voltage characteristic of an SCR [5]

Latch-up may be caused by a number of triggering factors such:

- *Supply voltages exceeding the absolute maximum ratings*
- *Input/output pin voltage exceeding either supply rail by more than a diode drop*
- *Poorly managed multiple power supplies.*

The Toyota ECU is designed, with: 1) means for voltage regulation, 2) transient protection including decoupling capacitors, and 3) properly managed power supplies, minimizing the likelihood for a latch-up condition to occur.

Exponent's electrical tests indicate that for the Vc = +5.0 Vdc power supply to collapse to 1.1 Vdc, an additional load current of ~ 400 mA is required. This load is in addition to the normal load current requirement of the ECU supplied by the Vc = + 5.0 Vdc power supply. Thus, the parasitic SCR elements would have to be capable of carrying ~ 400 mA continuously to collapse the Vc= + 5 Vdc power supply to 1.1 Vdc during the alleged sudden acceleration event.

Testing is ongoing to evaluate issues associated with Latchup.

8.1 Notes

- If the PWM driver IC latches up due to a parasitic p-n-p-n path in the driver IC, the parasitic p-n-p-n path behaves like a silicon controlled rectifier (SCR) and forms a conducting path between the +5V bus and ground.
- Latch-up requires certain conditions to trigger it, such as operating a device beyond its absolute maximum ratings, or poor transient protection, etc.
- The 2007 Toyota Camry ECU has appropriate voltage regulation, transient protection including decoupling capacitors, and properly managed power supplies, minimizing the likelihood for a latch-up condition to occur.
- Work is in progress to further evaluate latch-up conditions.

8.2 Power Supply Vc = 1.1 Vdc

- The + 5 Vdc supply that is common to the two accelerator sensors, the two throttle position sensors, the Main CPU and the Sub CPU is the Vc = + 5.0 Vdc supply.
- The throttle motor driver IC has an under-voltage threshold voltage for Vc = 2.2-3.2 Vdc. Thus when Vc collapses to 1.1 Vdc, it is expected that the throttle motor driver IC will not operate. The throttle motor driver IC also provides the trigger pulse to ignition coils # 1-4. Consequently, in a 4-cylinder engine, non-operation of the throttle motor driver IC will result in no high voltage at the spark plugs and the engine will shut off. In a 6-cylinder engine, with only two cylinders operating, it is expected that the vehicle will rapidly slow down[4].
- Exponent conducted tests on a 2007 Camry, 4-cylinder to determine engine operation at Vc = + 1.82 Vdc and at Vc = 1.0 Vdc. At Vc = 1.82 Vdc, and at Vc = 1.0 Vdc, the engine would not start.
- Additional tests were conducted with the engine operating normally first; subsequently, Vc was collapsed such that Vc = 1.85 Vdc. The engine turned off. The same result was obtained with Vc = 1.0 Vdc.

[4] Work is on-going to determine if IC SE745 which supplies the trigger pulse to ignition coils #5, #6 will also shut-down at Vc = 1.1 Vdc.

- Additional testing is ongoing.

8.3 Throttle motor IC latch-up

8.3.1 Selective latch-up

- If a selective latch-up occurs, the throttle motor driver IC is not functional, and the MOSFETs[5] in the H-bridge[6] controlled by the IC are latched on.
- The throttle motor IC also provides the trigger pulse to the ignition coils # 1-4. The non-functional IC now no longer can generate the trigger pulses for the ignition coils. Consequently, in a 4-cylinder engine, non-operation of the throttle motor driver IC will result in no high voltage at the spark plugs and the engine will turn off. In a 6-cylinder engine, with only two cylinders operating, it is expected that the vehicle will rapidly slow down.

8.3.2 Full Latch-up – all four MOSFETs latch-up

- Under full latch-up conditions, all four MOSFETs will be permanently turned on. The scenario described in the "Selective Latch-up" section above will be repeated and in a relatively short time (less than a second), one or more of the MOSFETs and/or the throttle motor driver and/or copper traces, and/or the fuse will open due to high current
- It is expected that the ECM will sustain permanent damage and the throttle valve will return to its fail-safe mode. In fail- safe mode, the current to the throttle motor is cut off and the return spring sets the throttle angle to 6 degrees.

8.4 Latch-up Condition Response

1. **<u>Voltage - Current Characteristics of Vc = +5 Vdc Power Supply</u>**

<u>Investigate</u>:

[5] MOSFET – Metal Oxide Semiconductor Field-Effect Transistor
[6] The principle of an H-bridge is described in a subsequent section.

   i. Current capability of Vc = +5 Vdc supply
   ii. Power supply V-I characteristics
   iii. Current carrying capability of parasitic p-n-p-n junction and the IC interconnects (including bond wire(s))

i. Testing of Power Supply Vc by Exponent on 2007 Camry, 4-cylinder[7]
   a. A 30.4 Ω load[8] causes Vc = 5.01 Vdc to reduce to 4.97 Vdc. Load current ~ 163 mA.
   b. A 16.6 Ω load causes Vc = 5.01 Vdc to reduce to 4.93 Vdc. Load current ~ 297 mA.
   c. A 5.3 Ω load causes Vc = 5.01 Vdc to reduce to 2.1 Vdc. Load current ~ 396 mA.
   d. A 4.5 Ω load causes Vc = 5.01 Vdc to reduce to 1.82 Vdc. Load current ~ 404 mA.
   e. A 2.7 Ω load causes Vc = 5.01 Vdc to reduce to 1.0 Vdc. Load current ~ 370 mA

Electrical tests on a vehicle indicate that for the Vc = +5.0 Vdc power supply to collapse to 1.1 Vdc, the additional load current has to be ~ <u>400 mA</u>.

8.5 Maximum Current Capability of Throttle Motor Driver IC

The throttle motor driver (IC SE 742) data sheet indicates that for the Vc = + 5 Vdc power supply, the absolute maximum current for the Vc = + 5 Vdc, P1 - P5 drivers = <u>60 mA</u> for a ground short with protection resistor.

Further investigation is in progress to assess whether the Vc pin of the throttle motor driver IC can carry a current of 400 mA without damage to the bond wire(s).

8.6 Throttle Motor Driver Operation at Vc = 1.1 Vdc

As mentioned earlier, the throttle motor driver IC has an under-voltage threshold voltage for Vc = 2.2-3.2 Vdc. Thus when Vc collapses to 1.1 Vdc, it is expected that the throttle motor driver IC will not operate. The throttle motor driver IC also provides the trigger pulse to ignition coils # 1-4. Consequently, in a 4-cylinder engine, non-operation of the throttle motor driver IC will

[7] 2007 Camry, 4-cylinder, VIN JTNBE46KX73061175

[8] The load resistor in each of these tests is an additional load superimposed on the normal ECU load supplied by the Vc = 5.0 Vdc power supply.

result in no high voltage at the spark plugs and engine will shut off. In a 6-cylinder engine, with only two cylinders operating[9], it is expected that the vehicle will rapidly slow down.

8.7 Normal Engine Operation during Latch-Up

The 2007 Camry V-6, 3.5 L has six ignition coils, IGT1 through IGT6. Each ignition coil receives a trigger pulse from the ECU. The schematics indicate that the trigger pulse for four of the six ignition coils is obtained from the throttle motor driver IC, in the P1-P4 drive section powered by Vc = + 5 Vdc.

As mentioned earlier, since the throttle motor driver IC has an under-voltage threshold voltage for Vc = 2.2-3.2 Vdc, it is expected that when Vc collapses to 1.1 Vdc, the throttle motor driver IC will not operate. Under normal conditions, the throttle motor driver IC also provides the trigger pulse to the ignition coils # 1-4. However, the non-functional IC no longer can generate the trigger pulses for the ignition coils.

Consequently, in a 4-cylinder engine, non-operation of the throttle motor driver IC will result in engine shut down. In a 6-cylinder engine, with only two cylinders operating[10], it is expected that the vehicle will rapidly slow down.

8.8 Response of Sensors at +1.1 Vdc

i. Data sheet for CTS pedal sensor states minimum operating voltage = 4.5 Vdc
    a. CTS sensor is dual programmable and has linear analog ratiometric output voltage proportional to supply voltage
    b. Power-on-reset = 1.5 – 3.8 Vdc
ii. Denso Pedal/Throttle Position Sensor

[9] Work is on-going to determine if IC SE745 which supplies the trigger pulse to ignition coils #5 and #6 will also shut-down at Vc = 1.1 Vdc.

[10] Work is on-going to determine if IC 745 which supplies the trigger pulse to ignition coils # 5 and 6 will also shut-down at Vc = 1.1 Vdc.

a. Data sheet for Denso pedal and throttle position sensor states:

   i. The HAL 805 is of the Micronas family of programmable linear Hall sensors.

   ii. Sensor has ratiometric output

   iii. Operates from 4.5 V up to 5.5 V supply voltage in specification and functions up to 8.5 V

   iv. Undervoltage Behavior

      1. In a voltage range below 4.5 V to approximately 3.5 V, the operation of the HAL 805 is typically given and predictable for the most sensors. Some of the parameters may be out of the specification. Below about 3.5 V, the digital processing is reset. If the supply voltage once again rises above about 3.5 V, a startup time of about 20 us elapses for the digital processing to occur. As long as the supply voltage is still above about 2.8 V, the analog output is kept at its last valid value ratiometric to VDD. Below about 2.5 V, the entire sensor will reset.

iii. Normal Operation

- At normal operating power supply voltage, and with no pedal operation, the output of the sensors were measured as:
  - VPA = 0.8
  - VPA2 = 1.6
  - VTA = 0.6
  - VTA2 = 1.5
- With a normal operating power supply voltage, if:
  - VPA = > VPA2, a DTC will be set
  - VPA ~ 0 a DTC will be set
  - VPA2 ~ 0, a DTC will be set
  - VTA = > VTA2, a DTC will be set
  - VTA ~ 0, a DTC will be set
  - VPA2 ~0, a DTC will be set

8.9 Principle of H-Bridge

Fig. 5 presents the functional diagram of an H-Bridge. For example, for clockwise rotation, electronic switches U1 and U4 are closed, and U3 and U2 are open. Current conducts from the battery through U1, motor and through U4 to ground. For counter-clockwise rotation, U1 and U4 are open and U3 and U2 are closed, and the motor current is reversed.

In the ECU, the power stage to the throttle motor includes an H-Bridge with the four electronic switches being four MOSFETs. In the ECU, the top 2 MOSFETs (U1 and U3) are located in throttle motor driver IC. The two bottom MOSFETs are external to the throttle motor driver IC. During normal operation, the main CPU sends a PWM signal to the throttle motor driver IC which supplies a PWM voltage to the throttle motor. The direction of rotation is selected by the main CPU which commands the throttle motor driver IC to switch on a particular pair of MOSFETs, whether U1 and U4 or U3 and U2

If U1 and U2 are both on at the same time, there is a low resistance short from the battery positive terminal to ground. Similarly if U3 and U4 are both on at the same time, there is again a low resistance short to ground. This low resistance short would result in a comparatively high current in the MOSFETs.

Regarding the latch-up, two possible scenarios are evaluated:

- Selective latch-up
- Full latch-up

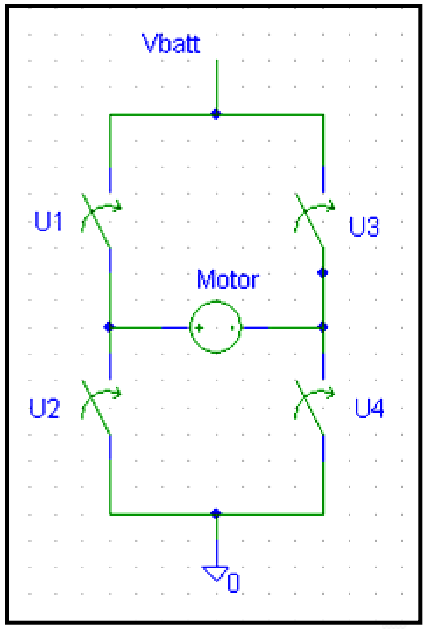


Fig. 5. Principle of H-Bridge motor drive.

8.10 Selective Latch-Up

If the main and sub CPUs have no control of the throttle motor driver IC and/or due to the latch-up, the throttle motor driver IC also does not respond to the main or sub CPU commands.

Two conditions are evaluated:

a. Main and sub CPUs have control of the throttle motor driver IC which is functional[11].
b. Main and sub CPUs have no control of the throttle motor driver IC and/or due to the latch-up, the throttle motor driver IC is not functional and does not respond to the main or sub CPU commands.

Assume at time t_0, vehicle is traveling at 30 mph, and the throttle motor is receiving the PWM voltage from the throttle motor driver IC. U1 and U4 are PWM controlled by the throttle motor driver IC. U3 and U2 are off.

[11] As mentioned earlier, at Vc = 1.1 Vdc, the throttle motor driver IC is in an under-voltage condition and will not operate. However, it is assumed for this analysis that the throttle motor IC still operates at Vc = 1.1 Vdc.

At time t_0^+, due to a hypothetical event, the selective latch-up occurs and U1 and U4 are latched on. The throttle motor is connected across the battery and ground and operates at full rpm opening the throttle.

- <u>If the main and/or the sub CPUs have control of the throttle motor driver IC</u>, the high VTA and VTA2 signals from the throttle position sensors will result in an error signal. The software in the main and/or the sub CPUs will command the throttle motor driver IC to turn off U1 and U4 and turn on U3 and U2 and also set a DTC. However, assume during this failure mode that U1 and U4 are latched on and will not turn off.
- The CPU command will cause throttle motor IC to command U3 and U4 to turn on and will result in a hard short circuit from Battery + to Ground. The motor terminals are also shorted together. Depending on the magnitude of the short circuit current, and its duration, it is expected that one or more of the following events will almost instantly occur resulting in catastrophic destruction:
  - MOSFETs U1 and U3 will fail open circuit
  - MOSFETs U2 and U4 will fail open circuit
  - Throttle motor driver IC will fail open
  - One or more of the copper traces on the ECU board will be destroyed
  - A fuse will open
  - One or more conductors will open
  - Motor winding will fail open
  - Connector pins will fail open

  Any one or more of the above catastrophic failures will almost instantly result in the throttle motor receiving no dc power and the return spring will force the throttle valve to go to 6 degree fail-safe mode.

  Note that the above events would occur rapidly and in a relatively short time (probably < 1 sec), the throttle valve will return to its fail-safe mode. Due to the high fault current, it is expected that the ECM will sustain permanent damage.

  Fig. 6 shows the throttle motor voltage and current waveforms for a supply voltage of ~ 14 Vdc, current limited to 20 A. The following is the probable sequence of events:

- At the instant of turn-on, the peak current (bottom trace) is ~ 11 A.
- In ~ 80 ms the current decreases to its steady state value of ~ 2 A.
- The hypothetical latch-up now occurs; the motor is full on and reaches its end of travel.
- Approximately 100 ms later (simulated by opening the connection), the motor current decreases to zero. It is a fair assumption that the high fault current will result in one or more components being destroyed in less than 1 sec.
- The motor return spring now returns the motor to its initial position which sets the throttle angle to 6 degrees. This is indicated by the negative voltage (top trace) due to re-generation (motor acts as a generator) that occurs for ~ 200 ms.

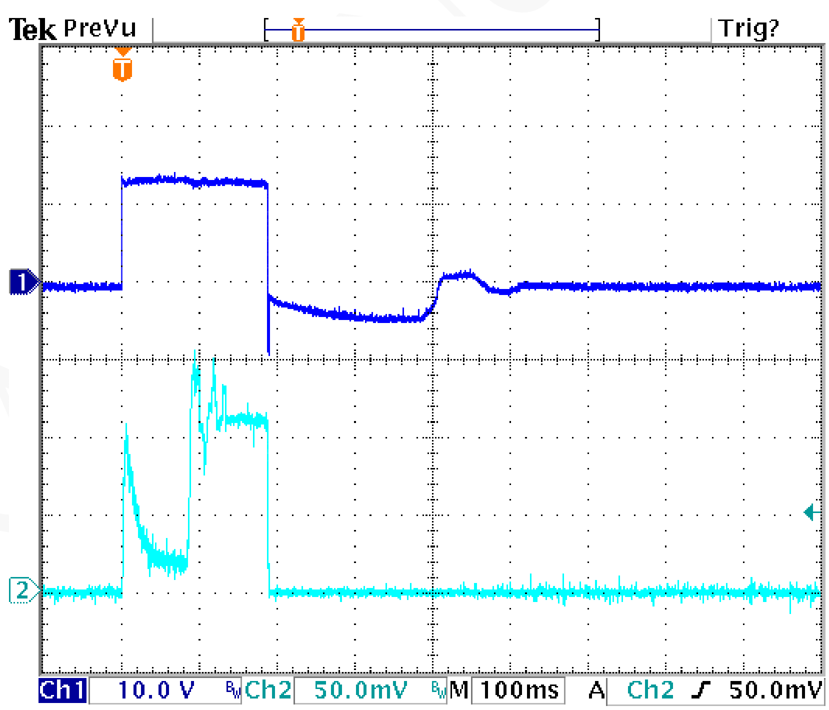


Fig. 6. Throttle Motor Waveforms – Bench Tests

Top waveform: Throttle Motor Voltage: 10 V/div
Bottom waveform: Throttle Motor Current: 5 A/div
Time: 100 ms/div

Assume now that the main and sub CPUs have no control of the throttle motor driver IC and/or due to the latch-up, the throttle motor driver IC is not functional and does not respond to the main or sub CPU commands.

- As mentioned earlier, under normal conditions, the throttle motor IC also provides the trigger pulse to the ignition coils # 1-4. The non-functional IC now no longer can generate the trigger pulses for the ignition coils.
- Consequently, in a 4-cylinder engine, non-operation of the throttle motor driver IC will result in no high voltage at the spark plugs and the engine will shut off. In a 6-cylinder engine, with only two cylinders operating, it is expected that the vehicle will rapidly slow down.

8.11 Full Latch-up

Under full latch-up conditions, all four MOSFETs, U1-U4 will be permanently turned ON. The scenario described previously will be repeated and in a relatively short time (less than 1 sec), one or more of the MOSFETs and/or the throttle motor driver and/or copper traces, and/or the fuse will open. Due to the high fault current, it is expected that the ECM will sustain permanent damage, the throttle motor power section will have an open circuit, and the throttle valve will return to its fail-safe mode. In fail- safe mode, the current to the throttle motor is cut off and the return spring sets the throttle angle to 6 degrees.

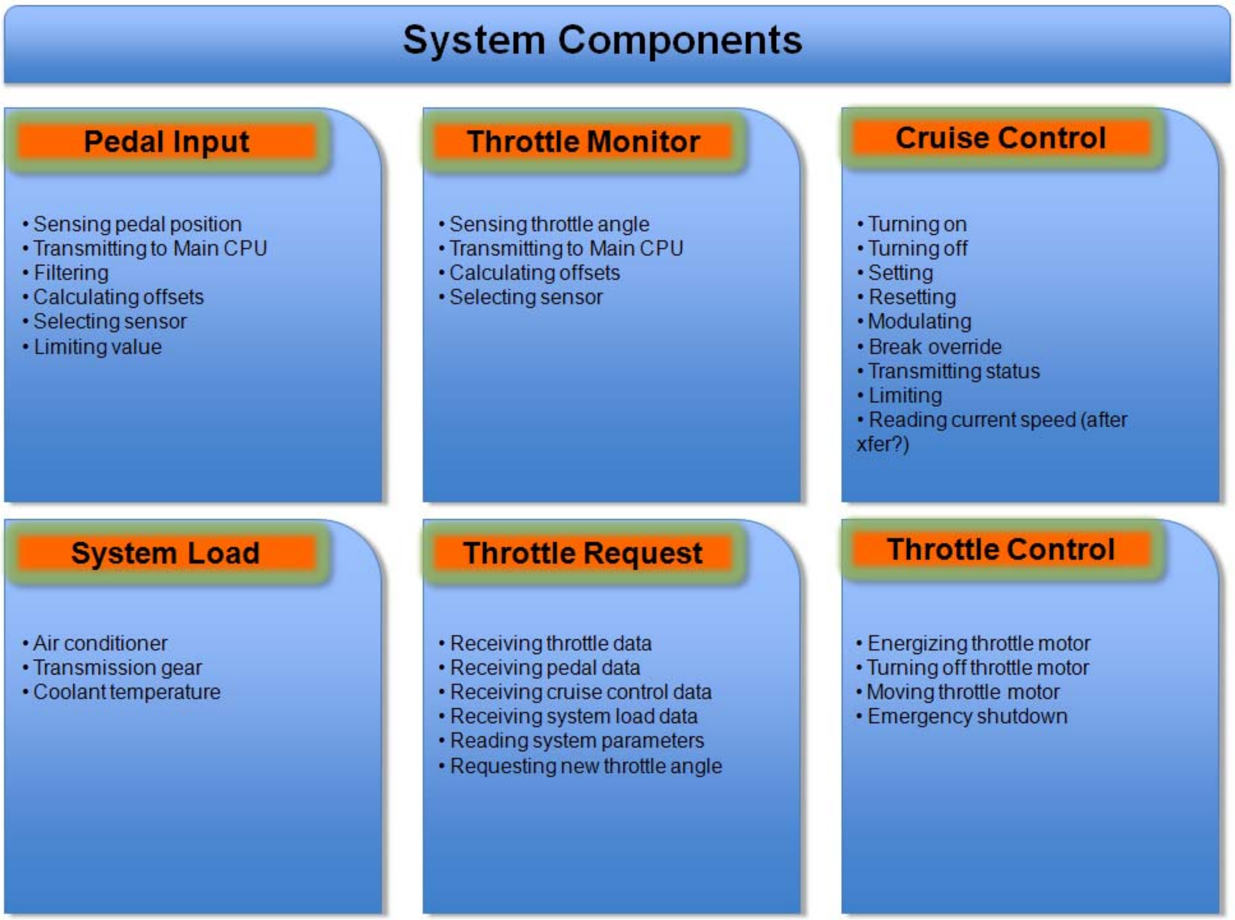
Work is in progress to conduct a tests on a vehicle to verify the above scenarios.

8.12 Findings

To date, Exponent has not identified a mechanism whereby latch-up would result in a sudden sustained acceleration event.

9 Fault Analysis

Based on the software review performed, Exponent is in the process of analyzing the software system's response to single and double fault conditions. The figure below shows a snapshot of the work in progress.



10 Laboratory Testing

10.1 In-vehicle testing protocol

- Test Equipment
  - Use an inline cable with measurement wires to make the measurement. The in-line cable will permit power and signals to go from the ECU harness to the accelerator pedal and at the same time permit access for measurement purposes.
  - <u>Construct in-line cable as follows:</u>
    - Connect ~ 8 inch length of 6 wires to male accelerator pedal connector on one end and female connector on other end. The six wires are VPA1, Gnd1, +5 V1, VPA2, Gnd2, and +5 V2). Cut 18-24 in length of four different colored measurement wires. Splice the original four pedal connector in-line wires (VPA1, Gnd1, +5 V1, and VPA2). Connect the four measurement wires to the spliced four in-line wires. The measuring equipment will be connected to these measurement wires.
  - Use C clamp and 2 x 4 wooden blocks of appropriate size such that when inserted behind the accelerator pedal and pedal is depressed, VPA 2 ~ 3.00 Vdc
- Measuring instrumentation:
  - Portable 3-channel data acquisition system (DAS) capable of measuring dc voltages to 6.00 Vdc, with a resolution of 1.0 mV, or
  - Three digital multimeters (DMMs)
- Decade resistance box:
  - Phipps & Bird Inc., Model 236 A, 0.5 W 1% resistors, or
  - Equivalent resistance box with different resistors
- Test Protocol
  - Turn ignition OFF
  - Photograph accelerator pedal. Determine if the pedal is a CTS pedal or a Denso pedal
  - Remove accelerator cable connector from ECU

- Install the inline connector. Attach female end of in-line cable to pedal connector and male end to cable harness from ECU
- Connect DAS or DMMs as listed above under Test Equipment
- Verify that +5 V1 terminal is at ~ 5 Vdc
- Verify that VPA1 and VPA2 has $\Delta V = \sim 0.8$ V
- Connect decade resistance box from VPA1 to +5 V1. Use measurement wires for connections
- Set decade resistance value to 4 MΩ
- Turn on engine
- Place the wooden block supported by the C clamp under the pedal
- Adjust wooden block so that when pedal is depressed, VPA2 ~ 3.00 Vdc
- During the test, the pedal will be pushed by an operator on to the wooden block, and held at that specific position by foot pressure, such that VPA2 is ~ 3.00 Vdc
- Monitor and record all voltages using the DAS or DMMs
- Set decade resistance value to 4 MΩ
- Monitor and record all voltages using the DAS or DMMs
- Repeat items 11-16 for test condition VPA1 to +5 V1 with decade box resistance values RL = different resistances
- Turn off ignition
- Connect decade resistance box from VPA2 to Gnd2. Use measurement wires for connections.
- Turn on engine
- Repeat items 11-16 for resistance values of RL = different resistances

10.2 Resistance between pedal sensor

10.2.1 Setup

Type of Device Tested	Denso Hall Sensor in the Pedal
Bench or In-vehicle Testing	Bench Test
In-vehicle test car model, year	N/A
Bench test equipment	
Test Setup	Vc=5V, lab power supply

10.2.2 Results

10.2.2.1 Test 1

R to GND	VPA1	VPA2
82	1.551	1.546
110	1.926	1.926
148	2.252	2.311
199	2.259	2.67
293	2.259	3.02
500	2.26	3.025
1000	2.26	3.026
OC	2.263	3.025

10.2.2.2 Test 2

R between VPA1 and VPA2	VPA1	VPA2
82	1.15	1.57
110	1.05	1.58
148	0.93	1.57
199	0.82	1.58
293	0.79	1.58
500	0.79	1.58
1000	0.79	1.58

OC	0.79	1.58

10.2.2.3 Test 3

R to 5V	VPA1	VPA2
82	4.23	4.25
110	4.01	4.02
148	3.71	3.72
199	3.31	3.33
293	2.68	3.02
500	2.21	3.01
1000	2.21	3.01
OC	2.21	3.01

10.3 Pedal Isolation Experiment

10.3.1 Setup

Type of Device Tested	CTS Pedal Position Sensor
Bench or In-vehicle Testing	Bench Test
In-vehicle test car model, year	N/A
Bench test equipment	
Test Setup	Pedal was not fully deflected during this test, used bench clamp to hold the pedal position

10.3.2 Resistance between VPA1 and Ground

DMM Model	Fluke 189	Fluke 87 II	Fluke 187	Fluke 73 III	
Output Voltage (R measurement)	1.08	0.65	1.107	0.76	i

Resistance VPA1-GND1	VPA1-GND1	+5V1- GND1		VPA2-GND2	+5V2- GND2
Open	2.04	4.98		2.853	5.00
1M	2.04	4.98		2.853	5.00
100k	2.03	4.98		2.851	5.01
10k	2.03	4.98		2.851	5.01
1k	2.00	4.98		2.851	5.01
500	1.96	4.98		2.854	5.01
300	1.33	4.98		2.854	5.01
100	0.46	4.98		2.853	5.00
50	0.23	4.98		2.854	5.00
25	0.11	4.98		2.854	5.00
10	0.05	4.98		2.853	5.00

10.3.3 Resistance between VPA2 and Ground

DMM Model	Fluke 189	Fluke 87 II	Fluke 187	Fluke 73 III	
Output Voltage (R measurement)	1.08	0.65	1.107	0.76	i

Resistance VPA1-GND1	VPA1-GND1	+5V1- GND1		VPA2-GND2	+5V2- GND2
Open	2.04	4.98		2.853	5.00
1M	2.04	4.98		2.853	5.00
100k	2.03	4.98		2.851	5.01
10k	2.03	4.98		2.851	5.01
1k	2.00	4.98		2.851	5.01
500	1.96	4.98		2.854	5.01
300	1.33	4.98		2.854	5.01
100	0.46	4.98		2.853	5.00
50	0.23	4.98		2.854	5.00
25	0.11	4.98		2.854	5.00
10	0.05	4.98		2.853	5.00

10.3.4 Resistance between VPA2 and Ground

Resistance VPA2 to +5V	VPA1-GND1	+5V1- GND1		VPA2-GND2	+5V2-GND2
Open	2.03			2.847	
1M	2.02			2.842	
100k	2.02			2.843	
10k	2.02			2.845	
1k	2.02			2.861	
500	2.02			2.873	
300	2.02			3.264	
100	2.03			4.426	
50	2.03			4.720	
25	2.03			4.839	
10	2.03			4.958	

10.4 Throttle Wire Series Resistance

10.4.1 Setup

Type of Device Tested	Throttle Sensor
Bench or In-vehicle Testing	In-Vehicle
In-vehicle test car model, year	Camry 4-Cyl. '07 (VIN JINBE46KX73061175)
Bench test equipment	
Test Setup	Potentiometer, manually changing it and monitor vehicle response

10.4.2 Results

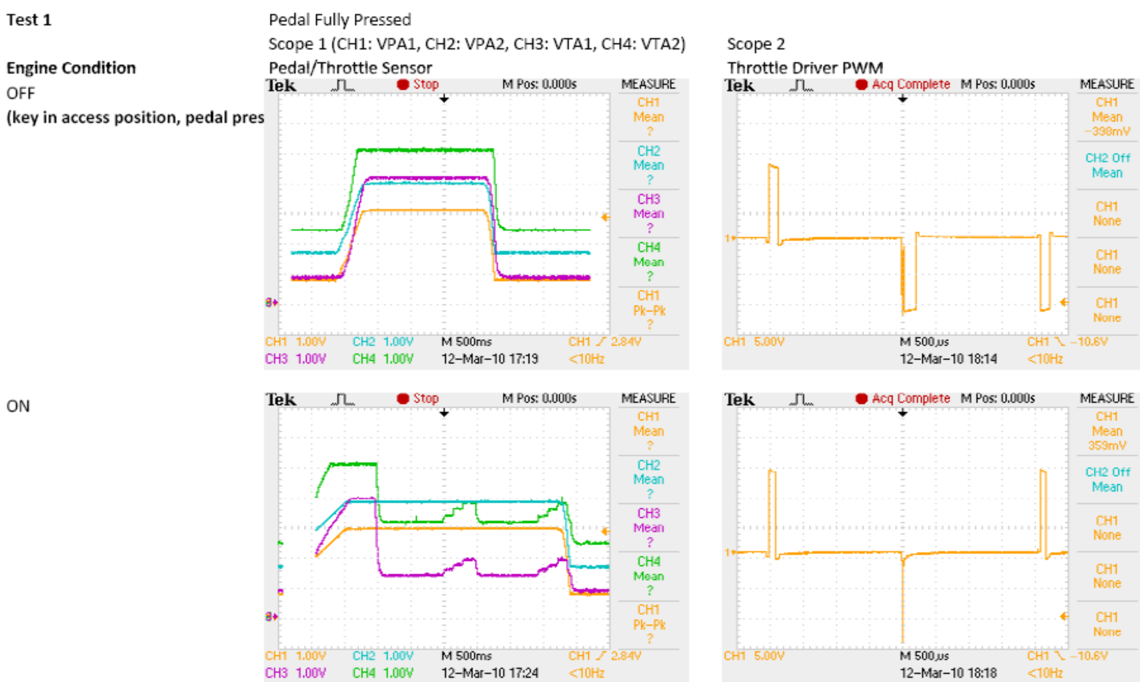
Experiment #	Series Resistances (Ohms)				Comment
	VTA1	VTA2	VC	GND	
1	0	0	0-60	0	With increasing series resistance: From Idle, begins to increase RPM, Then Camry enters failsafe mode, Check Engine Light, DTC P0121
2	0	0	0	0-60	With increasing series resistance: From Idle, begins to decrease RPM, Camry cuts out. No DTC
3	0-12k	0	0	0	With increasing series resistance: From Idle, begins to decrease RPM, then enters failsafe DTC 2111

10.5 Throttle-Pedal Signal Waveforms

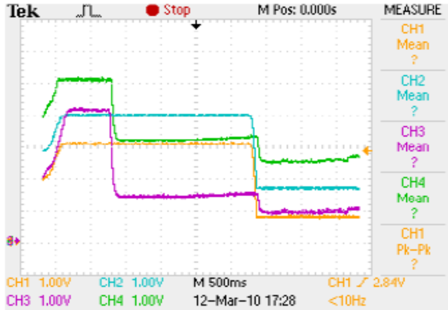
10.5.1 Setup

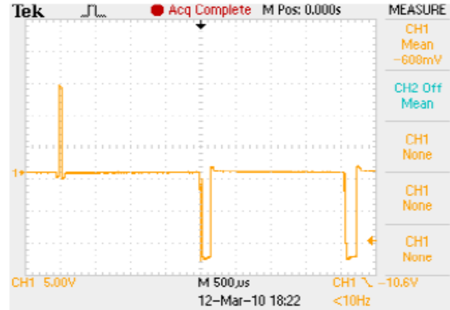
Type of Device Tested	CTS Pedal Position Sensor/ Denso Throttle Position Sensor
Bench or In-vehicle Testing	In-Vehicle
In-vehicle test car model, year	Camry 4-Cyl. ’07 (VIN JINBE46KX73061175)
Bench test equipment	
Test Setup	Voltage between M+ and M- was measured on the throttle motor side using a breakout cable. VPA/VPA2/VTA/VTA2 was measured with reference to Ground using breakout cables.

10.5.2 Results



ENGINE ON, AC ON





10.6 Resistance between Vc and Ground

Type of Device Tested	CTS Pedal Position Sensor
Bench or In-vehicle Testing	In Vehicle
In-vehicle test car model, year	Camry 4-Cyl. '07 (VIN JINBE46KX73061175)
Test equipment	Fluke 76 III (0.7ohms leads)

Test Setup	Start the car first, then insert the R, pedal not pressed?, car idle			
Test Date	4/9/2010			
Resistance (ohms)	VC-EP (V)	VTA	VTA2	Notes
OPEN	5.01	1.00	2.60	-
4.5	1.85	1.85	1.85	engine stopped, no DTC code
2.7	1.02	1.02	1.02	engine stopped, no DTC code

Test Setup	Insert the R, then start the car, pedal not pressed?, car idle			
Test Date	4/8/2010			
Resistance (ohms)	VC-EP (V)	VTA	VTA2	Notes
OPEN	5.01	0.94	2.58	
30.4	4.97	n/a	n/a	
16.6	4.93	n/a	n/a	
6.6	2.54	2.54	2.54	car did not start, no DTC
5.3	2.10	2.10	2.10	car did not start, no DTC
4.5	1.82	1.82	1.82	car did not start, no DTC
2.7	1.00	1.00	1.00	car did not start, no DTC

10.7 Pedal Electronics – Vehicle Test Data

Determine Thevenin output impedance of CTS circuit.	Test using resistance values from open circuit, 1 Mohms, down to 5 ohms. Test Conditions: 1) RL between VPA and + 5 Vdc, 2) RL between VPA2 and Gnd, and 3) RL between VPA 2 and +5Vdc	• Use data to generate Test Protocol for incident vehicle testing. Test condition # 3 also provides information on the resistance value required for VPA1 to go to +5 Vdc. • For the CTS pedal, for RL = < 500 ohms, between VPA 1 and +5 V, the check engine light comes on • For the CTS pedal, for RL = < 300 ohms between VPA2 and GND, the check engine light comes on • However, for the Denso pedal, for RL = < 50 ohms between VPA2 and GND, the check engine light comes on
Determine Thevenin output impedance of Denso circuit.	Test using resistance values from open circuit, 1 Mohms, down to 5 ohms. Test Conditions: 1) RL between VPA and + 5 Vdc, 2) RL between VPA2 and Gnd, and 3) RL between VPA2 and +5 Vdc	• For the CTS and Denso pedals, for RL = < 500 ohms, between VPA 1 and +5 V, the check engine light comes on • For the CTS pedal, for RL = < 300 ohms between VPA2 and GND, the check engine light comes on • However, for the Denso pedal, for RL = < 50 ohms between VPA2 and GND, the check engine light comes on
Effect of one of the two +5 Vdc supplies to accelerator pedal circuit increases substantially.	Accelerator pedal circuit connector is a 6-pin connector. Two terminals are VPA and VPA2, two other terminals are +5 Vdc terminals, VCP and VCP2, and remaining two are Gnd terminals, EPA and EPA2. At the ECU, VCP and VCP2 have the same node, Vc = 5 Vdc. Also at the ECU, Gnd terminals, EPA and EPA2 have the same node, E1.	• For VCP to be not equal to VCP2, the VCP conductor from the ECM to accelerator pedal has to break and make contact with a different voltage. • Alternatively, for VCP to be not equal to VCP2, the VCP 2 conductor from the ECM to the accelerator pedal has to break and make contact with a bare conductor at a different voltage. • Since the maximum voltage in the six conductors in the accelerator pedal wiring harness is 5.0 Vdc, this scenario is extremely unlikely. If one of the conductors breaks and there is a resistive connection on the ECM connector such that pins VPA, VPA2, and VCPA are connected, then a flag will be set.
Effect of both +5 Vdc supplies to	Accelerator pedal circuit connector is a 6-pin connector.	• If VCP = VCP2 increases substantially above +5 Vdc, then VC has the same increase, since on the ECU, Vc has the same node as VCP and

accelerator pedal circuit increases.	Two terminals are VPA and VPA2, two other terminals are +5 Vdc terminals, VCP and VCP2, and remaining two are Gnd terminals, EPA and EPA2. At the ECU, VCP and VCP2 have the same node, Vc = 5 Vdc. Also at the ECU, Gnd terminals, EPA and EPA2have the same node, E1.	VCP2.Further, Vc = 5.0 Vc supplies +5.0 Vdc to a number of components on the ECU including the Main Processor, and the Sub Processor. • Some of the Main Processor + 5 Vdc pins are pins 43, 17, 179, 201. • Some of the Main Processor Gnd pins are pins 41, 42, 180, 181, 182, 200. • Some of the Sub Processor + 5 Vdc pins are pins 109, 92, 30, 81, 155. • Some of the Sub Processor Gnd pins are pins 32, 87, 137, 183. The Sub Processor data sheet states that at 25 C ambient, the Absolute Maximum Voltage Vdd = 7.0 V. • If the +5 Vdc increases to the Sub Processor's absolute maximum value of 7.0 Vdc, then VPA and VPA2 will ratiometrically increase. • If, at Vc = 5.0 Vdc, VPA = 0.82 and VPA 2 = 1.6, then with Vc = 7.0 Vdc, VPA = 1.12 and VPA2 = 2.24.