Automotive MEMS Pressure Sensor Reliability Testing

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Automotive Conditions

- In Automotive industry, quality and reliability of the pressure sensors are keys and required.

- Automotive pressure sensors operate in extremely hostile environments. The temperatures under the hood is ranging from -40°C to 150°C and the pressure sensors devices are exposed to
  - Salt Water
  - Coolant
  - Fuel
  - Oil
  - Brake
  - and Transmission Fluids,

  All of the above media can clog the sensors and potentially degrade the performance, or even defeat or worsen the performance of the pressure sensors.

- Also another major impact to the performance of pressure sensors is due to electromagnetic interference (EMI) which ranges from 2 MHz to 2 GHz of exposure at 200 V/m.

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Important Factors For Pressure Sensor Under The Hood

- From the automotive conditions, there are several important factors of which design engineers must take into account in the design processes and devices must be tested for the following conditions.
  - Media Compatibility
  - Thermal Stress
  - Mechanical stress
  - ESD & EMI
- Testing sequences: each of the environmental test should follow the test sequence below.
  - Pretest
  - Environmental Test
  - Post Test

The 4 Key Factors Under The Hood

- **Media Compatibility:** MEMS pressure sensor must be able to withstand the media, such as: transmission oil, engine oil, gasoline, etc…
- **Thermal stress:** Severe temperature could cause damage, instability, drift and shift to the sensor due to the effect of materials thermal coefficient of expansion.
- **Mechanical stress:** The mechanical instability, vibration and shock could cause damage and reliability of MEMS pressure sensor and its components.
- **ESD & EMI:** Due to noisy environment under the hood, the pressure sensor must withstand the ESD and EMI (electromagnetic interference)

Media Compatibility

- It is very important that the sensors must survive conditions below :
  - Transmission oil
  - Engine oil
  - Fuel / gas
  - Brake fluid
  - Coolant

- For the test conditions: The pressure sensors must be tested with the above media at extreme temperature range with a long duration typically about 6 to 8 weeks

- The devices must have passed the environmental test. No damage or anomalies are found by visual inspection

- After environmental testing, the sensors must pass functional/parametric tests on all required electrical and mechanical parameters .

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Thermal Stress

- Cars go everywhere!
- The temperature variations are severe from cold to hot. Sensor must survive in all weather conditions.
- Here are some of the test required by the car makers
  - Temperature storage
    - To expose the sensor to low temperature without electrical operation, for example during shipment
    - The failure mode is insufficient frost resistance (e.g freezing of liquid crystal displays)

Thermal Stress (Cont.)

- High temperature storage in oil
  - To expose the sensor to high temperature for long period of time.(Typical 1 to 2 month)
  - The failure mode is insufficient heat resistance. such as: melting, warping or cracking.
- Temperature cycles
  - To test the sensor in varying temperature from low to high at multiple cycles.
  - Test Condition is typically 30 cycles; 8 hrs/cycle from min to max temperature. It is roughly 10days

Temp Shock (cont)

- Temp Shock
  - This is an accelerated test which simulate a very high number of slow temperature cycles in the vehicle. The acceleration is possible due to a much faster temperature change rate in a wider temperature range in one cycle.
  - The failure mode is cracking of material or seal failures caused by aging and different temperature expansion coefficient.
  - The test condition:
    - Temperature: -40 to 150C
    - Typical number of cycles 500
    - Transition time is less than a few second (<10)

Mechanical Stress

- Silicon MEMS pressure sensors are very stress sensitive because the membrane is thin and small.
- The car makers require some key tests to ensure the mechanical reliability of the silicon MEMS die.
- Here are some of the tests:
  - At component level (MEMS):
    - Pressure life cycles
    - Pressure cycles
    - Proof pressure
    - Burst pressure
  - At system level (Fully package MEMS)
    - Mechanical sock
    - Vibration

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Pressure Life Cycles

- Testing the life time durability of the MEMS pressure sensor.

- The testing included:
  - 3,000,000 cycles from zero to full scale
  - Cycle time : 0.5 second
  - It can be done at temperature cold to Hot (-40C to 150C)

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Pressure Cycles

- Testing the life time durability of the MEMS pressure sensor.

- The testing included:
  - 2,500,000 cycles from zero to full scale
  - Cycle time : 1ms
  - It can be done at room temperature

Proof Pressure

- This is to warrant the sensor can survive at 2x to 3x over the normal operating pressure range over temperature.
- There are two type of proof test.
  - Static:
    - Number of cycles: 100 cycles
    - Duration at high pressure: 30s
    - Temperature : 150C
  - Dynamic
    - Number of cycles: 5000
    - Cycle time: 1s
    - Duration at high pressure: 250mS
    - Temperature: -40C to150C

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Burst Pressure

- To test the MEMS pressure sensor diaphragm capability.
  - Today most of MEMS manufacture warranty minimum 3X of the normal operating pressure
  - Test condition:
    - 3X over pressure
    - Duration at high pressure: 30 seconds
    - Number of cycles: 5
    - Temperature : Room temp
    - The MEMS sensor may be permanently damaged, but pressure seal must remain.

Mechanical Shock

- This is to check for mechanical damage of the pressure transducer module while the car is in the moving condition and high acceleration.
- Such as:
  - Component falling out from PCB or housing
  - Screw getting loose
- Test Condition:
  - Three shocks in each direction of each of the three orthogonal axes (±X, ±Y and ±Z)
  - Acceleration: 700m/s (100g)
  - Shock Form (Pulse shapes) : Half sinusoidal
  - Shock pulse Duration: 11 ms
  - Temperature : Room

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Vibration

- This is to test the sensor for the rupture due to fatigue

- Test Condition:
  - Test Cycle duration: 3 days
  - Number of test per cycle: 1 cycle each axis
  - Temperature: -40 to 150C

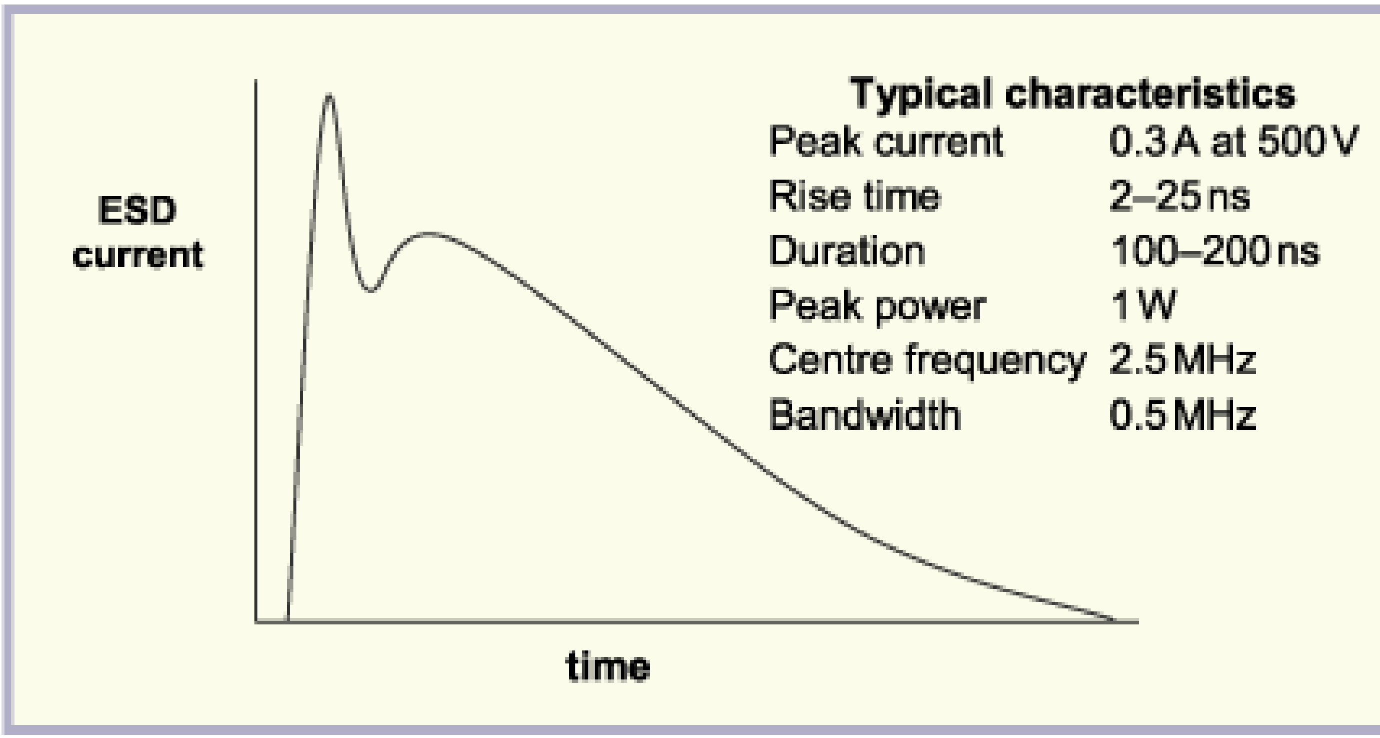
ESD

- Due to the many rotating and alternating parts under the hood generating friction, the robustness of electronics to ESD is of critical importance.

- Most ESD requirements are based on the ``human body model'', which characterizes typical voltages, currents, and rise times associated with a human ESD event. Although ESD discharges are usually specified in ``predischarge'' voltage levels, it's actually the current pulse that causes most of the problems.

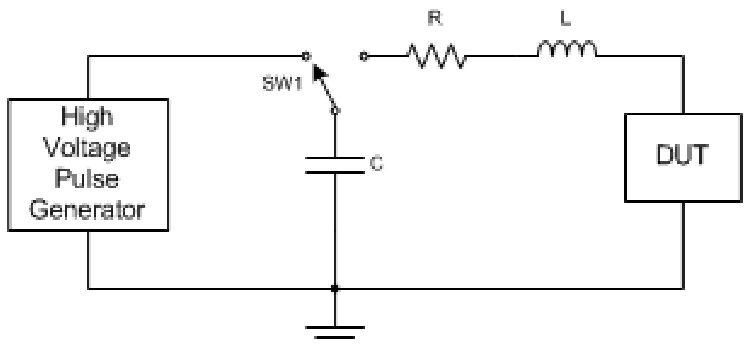
- The ESD current can upset or destroy any vulnerable electronics in its path. Also, the electromagnetic field associated with the ESD event can also radiate into nearby electronics systems, causing even more upsets. This is known as the **``indirect effect''** of ESD.

ESD cont.


ESD current
time
Typical characteristics
Peak current 0.3 A at 500 V
Rise time 2–25 ns
Duration 100–200 ns
Peak power 1 W
Centre frequency 2.5 MHz
Bandwidth 0.5 MHz

ESD Cont.

- Typical Test Setup for ESD



Test	Discharge Method	Network	Test Severity Level	No. of Discharges
Unpowered or Handling	Contact	150pF/2kΩ	±8kV	5
	Air	330pF/2kΩ	±15kV	
Powered	Contact	150pF/2kΩ	±8kV	
	Air	330pF/2kΩ	±25kV	

- Most automotive electronics are designed to withstand at least15 KV, a severe level that actually exceeds most human ESD levels.

EMI (Electromagnetic Interference)

- Electronics content of automobiles and other vehicles has grown rapidly in recent years. Embedded microcontrollers are used in a wide range of vehicle applications for control, convenience, and comfort.

- As the electronics content of vehicles have increased, so have the electromagnetic interference (EMI) problems. The problems are expected to get worse as system clock speeds and logic edge rates increase, due to increased EMI emissions and decreased EMI immunity

- They are divided into two broad classes: susceptibility (also referred to as immunity) and emissions. In the first case, the automotive electronics are the victim of EMI, and in the second case, the automotive electronics are the source of EMI.

EMI Testing

EMC Testing

- Bulk current injection (BCI), which is utilized for EMC testing, is a particularly rough on the system being tested. Although BCI testing specifications and methods vary among automotive manufacturers, they generally involve strong external fields across frequencies from few MHZ up to 1GHz.

<table>
<tr><th rowspan="2">Frequency Range (MHz)</th><th rowspan="2">Test Method</th><th rowspan="2">Modulation</th><th rowspan="2">Polarisation</th><th colspan="2">Application Group I</th></tr>
<tr><th>Limit</th><th>Pass Criteria</th></tr>
<tr><td>1 - 400</td><td>ISO 11452-4: BCI</td><td>CM/AM</td><td>Not applicable</td><td>200mA</td><td>A</td></tr>
<tr><td>20 - 1000</td><td rowspan="2">ISO 11452-2: ALSE</td><td>CW/AM</td><td>Vertical & Horizontal</td><td rowspan="2">200V/m</td><td rowspan="2">A</td></tr>
<tr><td>800 - 5000</td><td>PWM</td><td>Vertical</td></tr>
</table>

Continuous Wave (CW) applied only below 1GHz.

Amplitude Modulated (AM) using 80% modulation with a 1kHz sine wave.

Pulse Width Modulated (PWM) with a pulse width of 577us and a period of 4600us.

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EMC Testing

- **EMI Testing**
  - **Radiated Emissions :** primarily utilizes antennas and checks a system's ability to radiate through free space to other systems
  - **Conducted Emissions:** is primarily done with voltage and current probes on a system's power-supply line

Band	Frequency Range (MHz)	Broadband (Peak) Limit (dBuV/m)	Narrowband (Quasi-Peak) Limit (dBuV/m)
1	0.15 – 0.30	76	63
2	0.30 – 0.53	76 - 36.41 log (f / 0.3)	63 – 36.41 log (f / 0.3)
3	0.53 – 2.0	67	54
4	2.0 – 5.9	76 - 40.44 log (f / 2)	63 – 40.44 log (f / 2)
5	5.9 – 54	48	35
6	54 – 76	48 – 97.60 log (f / 54)	35 – 97.60 log (f / 54)
7	76 – 1000	37	24
8	1000 – 5000	48	35

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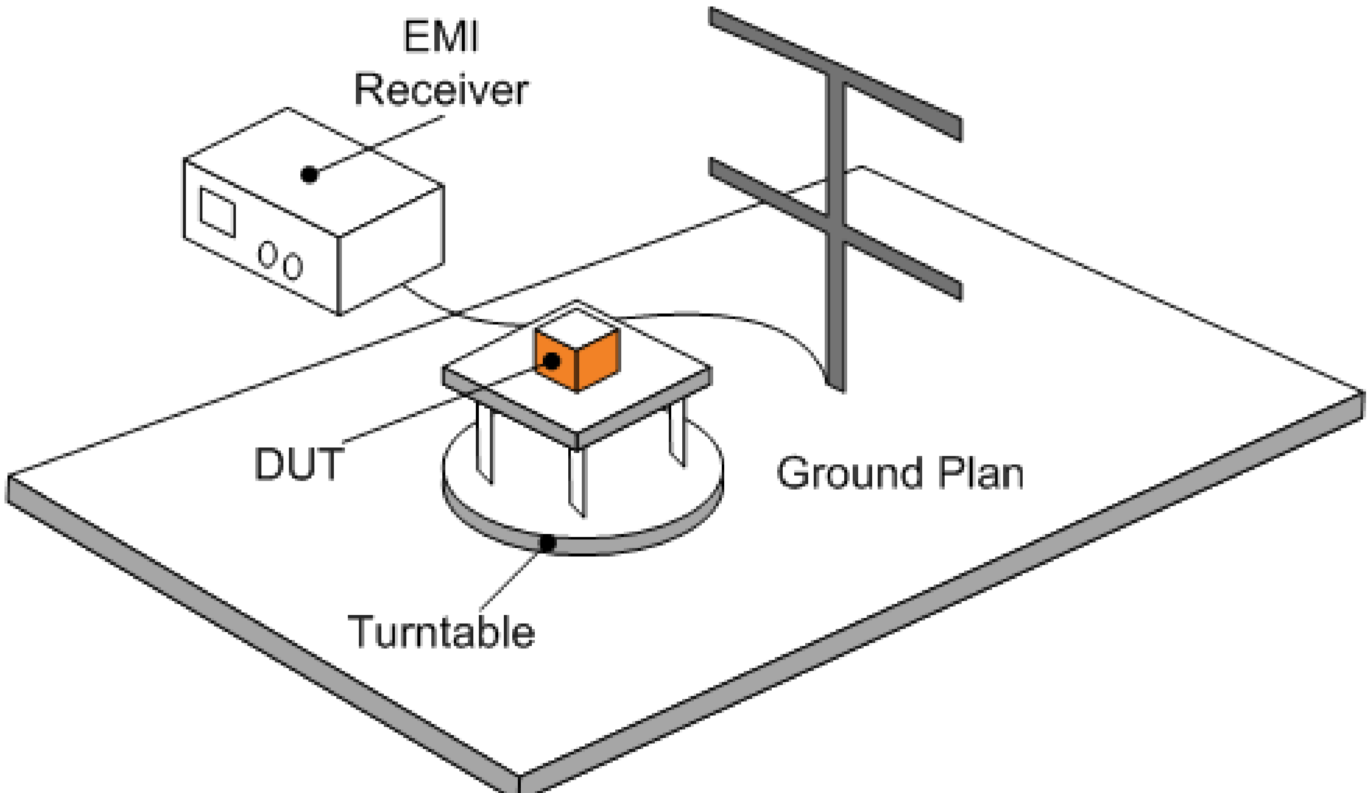
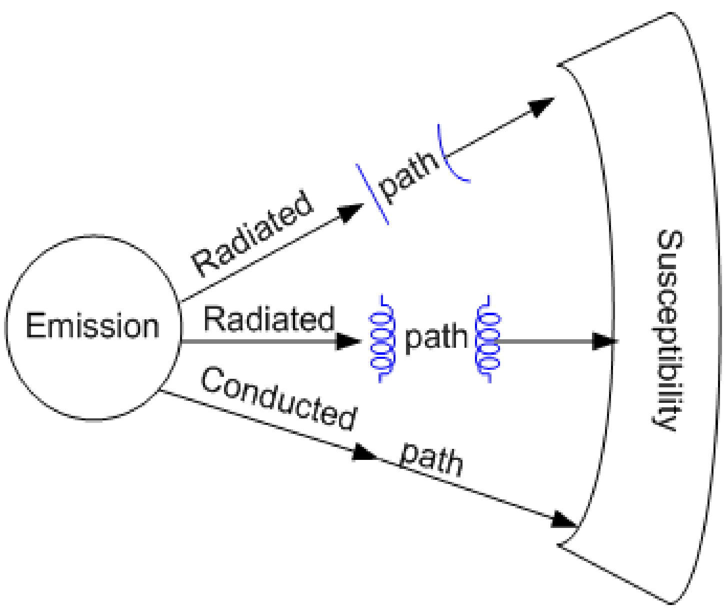
EMI/EMC - Test Setup



Note: this is one example of the test setup

EMC Paradigm

Emission, Susceptibility, and Path are the three constituents of EMC, with <u>Emission</u> being the one causing the most incompatibilities, while yielding the greatest number of solutions. <u>Susceptibility</u> on the other hand, is more subtle in its effect and its solutions. Finally, the <u>Path</u> can be the arbiter of both.



1. Radiation (electromagnetic field)
2. Inductive Couple (magnetic Field)
3. Capacitive Couple (electric Field)
4. Conduction (electric current)

Radiated EMI is most often <u>measured</u> in the frequency range from 30 MHz to 10 GHz (according to the FCC).

Conducted EMI is most often <u>measured</u> in the frequency range of several kHz to 30 MHz (according to the FCC).

EMI/EMC (Cont.)

RADIATED

Emission Sources: Clocks, clock lines, data lines; switching power supplies,	**Susceptibility:** Clock lines & data lines poorly laid out, improperly terminated;
Solutions: Balanced transmission lines, proper terminations, ground planes, shielding, limited rise & fall time drivers	**Solutions:** Shielding, layout, filtering, ground planes, differential line receivers,

CONDUCTED

Emission Sources: Power supplies (switching), power rails, motors, relays,	**Susceptibility:** A.C. power cord poorly filtered, power rails poorly decoupled,
Solutions: Good bypassing & decoupling practices, layout, ground planes, shielding,	**Solutions:** Good bypassing & decoupling practices, <u>layout</u>, ground planes, <u>shielding</u>, power line <u>filtering</u>

EMC – Role of Capacitors

The role of capacitors

- Coupling capacitors: Separates circuits with DC, couples circuits with AC.

- Bypass capacitors: Bypass unnecessary signals to GND for transistors.

- Decoupling capacitors: Sets between power lines and GND lines to prevent voltage from changing.

Today's EMC engineers have seen Power ground issues are major sources of EMC problems, Decoupling capacitors have played a major role in solving the problems.

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Some of The Challenges

- How to protect MEMS dies from damages caused by high pressure spikes in the system?
- How to protect the bond wires from getting broken from vibration or mechanical shock?
- How to protect the MEMS die from harsh media?

CONCLUSION

- While these conditions pose formidable challenges, they are nonetheless manageable and solvable. A good sensor design engineer must equip himself with state-of the-art solutions for all these factors in every facet of his design process.

- The media compatibility, the mechanical stress, thermal stress, and EMI are important factors for pressure sensors under the hood. So, I would like to emphasize that the reliability testing must be done carefully and thoroughly to warrant the ***sensor design, packaging technique, and the material selection*** for the sensor to work properly in the car hostile environment.

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