Definition of Conducted Emissions

- Conducted emissions (CE) are currents that travel on circuit wiring or conductive portions of assemblies and structures.
- CE are typically from 10’s of kHz to 10’s of MHz, can occur on power and/or signal wires.
Causes and Implications of CE

• CE can occur as a result of:
  – Circuit intended design (schematic).
  – Current flow along unintended paths.

• This is a concern is for two reasons:
  – It may affect system functionality.
  – It may not meet regulatory of performance requirements.
Example of CE

- Noise from vehicle alternator is conducted along primary vehicle wiring to radio – thus affecting radio performance.
- High levels of CE may actually cause damage to components.
Additional Concern of CE

• Depending on wiring length and frequency of CE noise, this may result in a radiated emission condition.

• Proper attention to CE can prevent additional issues.
“Unseen” Causes of CE

• CE may also be due to conductive chassis as electrical paths (sometimes un-intentional).
• Example - parasitic capacitance completes current path – resulting in CE current.
Conducted Transient Emissions (CTE)

• CTE can be described as a short duration type of CE and can occur due to the use of various type of electromechanical devices (solenoid, relays).
• Extreme cases of CTE frequently cause system functionality issues.
• Is due to the inductive nature of circuit wiring or loads and is a result of “L (di / dt)".
Electric Drive Case Study

• Variable frequency electric drives (VFD) were installed on a HVAC system in a renovation of an older medical facility. During the renovation – MRI machines were also installed.
• False reading from the MRI machines were then taken by medical personnel – who were then sued for malpractice.
• Quickest solution was to install a separate electrical service for the MRI machines!
Conducted Emission Regulatory Requirements

• Legislated requirements exist that define the maximum CE levels permitted.

• Figure shows comparison of typical requirements.
Control of CE

• Since the transfer path of CE is known (compared to radiated emissions) – it may be easier to correct compared to unknown path of radiated emissions.

• CE can be addressed by application of various types of filters connected to the conductor(s) or through inductively coupled devices (such as ferrite materials – discussed later).
CE Testing With Line Impedance Stabilization Network (LISN)

• At right is a LISN and it’s connection to an equipment under test (EUT).

• The desired goal is to have a constant LISN impedance over the CE measurement range.

(neglecting the effects of C1, C2 and R1)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Equivalent Impedance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 kHz</td>
<td>5.36</td>
</tr>
<tr>
<td>20 kHz</td>
<td>7.25</td>
</tr>
<tr>
<td>40 kHz</td>
<td>11.99</td>
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<tr>
<td>50 kHz</td>
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<tr>
<td>8.0 MHz</td>
<td>50.00</td>
</tr>
<tr>
<td>30.0 MHz</td>
<td>50.00</td>
</tr>
</tbody>
</table>
Two (2) Purposes of LISN

• To provide a constant impedance to measure CE which means:
  – Measurement not dependent upon power line characteristics.
  – Assures repeatability from test location to test location.

• To provide a measurement port to determine the CE levels.
Component CE Test Set-up

- Used in component testing when all parts can be placed on a test table.
- LISN’s located away from EUT, with defined separation.

1. Excess I/O cables shall be bundled in center. If bundling is not possible, the cables shall be wound in turns. Bundling shall not exceed 40 cm in length.
2. Excess power cords shall be bundled in the center or shortened to appropriate length.
3. I/O cables which are not connected to a peripheral shall be bundled in the center. The end of the cable may be terminated if required using correct terminating impedance. If bundling is not possible, the cable shall be wound in turns.
4. EUT and all cables shall be insulated from ground plane by 3 to 12 mm.
5. EUT connected to one LISN. LISN can be placed on top of, or immediately beneath ground plane.
   5.1 All other equipment powered from second LISN.
LISN “Myth Buster”

• Sometimes it is stated that the intent of the LISN is to duplicate the wiring harness for the EUT. *This is not true!*

• Although there is empirical evidence that systems have wire harness inductance of:
  – Large systems = 50 uH (such as aircraft)
  – Small systems = 5 uH (such as automotive)

• LISN's should be selected based on the frequencies of the measurements required.
Examples of Standard LISN’s

- Different internal component values may be required depending on the application.
- Usually specified in testing requirements documentation.
Common Mode and Differential Mode Current

- Differential Mode Current – Current that flows in opposite direction on conductors in a system.
- Common Mode Current – Current that flows in the same direction on conductors in a system.
Combination of DM and CM

- Circuits may have both types of current flow.
- Important to understand methods to address each.
Addressing Common Mode CE

- In-line inductor can be incorporated to suppress CM current and not affect DM current.
- Magnetic flux created by DM current on each conductor causes cancellation of field.
Typical CM Chokes

- Consists of toroids, cylinders, or rectangles made from ferrite material.
- Frequently used to enable component to pass CE requirements without circuit modifications.
CE Diagnostic Process

• Important to understand possible contribution of CM or DM current to CE issues.
• If CE needs to be reduced after CM choke is applied – filters on DM current conductors may still be required.
• Adding a CM choke to a DM problem will not yield improved performance.
• Incorporating DM suppression may not affect CM current.
Use of Current Probe

- Current probes may be used to measure noise current directly without need for LISN.
- Can be especially useful in diagnostic work.
Using Circuit Loading for DM - CM Diagnostics

• Circuit loading can be changed to help determine if the dominant CE noise is DM or CM.
• If the load is changed – and the CE levels does not change, most likely cause is NOT DM current.
• DM current is the “functional current” and is affected by the load, CM current not affected by intended load.
A Simple CE Detector

- Portable radio’s can be used as a simple CE detectors.
- Best ones for EMC work are the lowest selectivity, analog receivers.
- Can detect both NB and BB noise.
Types of Power Supplies

• Two (2) types of power supplies in use today.
  – Linear
  – Switch Mode Power Supply (SMPS)

• Each type has characteristic that can impact EMC performance.
  – Linear power supplies are inherently quieter with regard to EMC emissions due to the method used to generate the output power.
  – Switching power supplies can be effectively designed to meet EMC requirements
Linear Power Conversion

- Key to the power supply is the conventional transformer.
- Operation is based upon conversion of the primary power sine wave into output voltage and current.
Linear Supply Construction

• It is important to comprehend appropriate circuit layout and wiring practices to avoid capacitive or inductive coupling to the input leads of the power supply.
  – Coupling noise from the secondary to the primary side can result in not passing CE requirements!
  – A classic mistake is to assume that the input power leads are intended to carry only low frequency AC and cannot have any CE!
Operation of SMPS

• Typical SMPS in use today are using switching frequencies from 100’s of kHz to 1 MHz.
• Can have very high efficiency at the higher frequency.
• CE issues also increase due to the currents that may flow due to the very efficient capacitive coupling at the high frequency.
Square Waves and Rise Time

- Each pulse is essentially a square wave (with an infinite number of harmonics beginning at the switching frequency).
- Equally important, high frequency ringing can occur at the rising or falling edge causing additional harmonic content.
Resulting “EMC” Issue

• Square waves are a common source of high frequency noise.

• Even low frequency square waves contain many harmonic - which may extend far into the radio spectrum.
Power Supply Filtering

• Regardless of type of power supply technology, attention to proper filtering can eliminate much of the cause of CE problems.

• Effective filtering is intended to:
  – Prevent noise from being conducted into the rest of the circuit being powered.
  – Prevent noise from being conducted back onto the primary power lines.
Power Supply Filter Theory

- Goal is to provide maximum suppression of conducted noise.
- This can be accomplished by designing for a maximum impedance mismatch from the circuit to the filter. (High Z source – Low Z input to filter.)
DM Suppression Methods

• Can be used when CE is caused by DM noise current.
• Typically consist of series inductance and parallel capacitance.
• Can be designed to have minimal impact upon desired current.
Input / Output Filtering

• A simple method of filtering for CE is to utilize ferrite beads and bypass capacitors on both the input and output leads.
• This should be located where the power leads exits the assembly.
SMPS Transformers

• The key component in a SMPS is the transformer that is used which is made from ferrite material due to the high efficiency of the power conversion process.

• Care does need to be taken to understand the parasitic capacitance that may be experienced due the ferrite material so that high parasitic capacitance does not allow significant noise from being conducted out of the SMPS onto the primary power lines.
Controlling SMPS CE

- Incorporation of “X” and “Y” capacitors in the input filter design can address CE caused by DM current.
- $C_{dm} = “X”$ capacitor, $C_{cm} = “Y”$ capacitor
The above are baseline measurements on a SMPS outputs without any filtering applied.

Emissions exceeding the requirements were seen at both low (left side) and high (right side) frequencies.
• This shows the CE noise present on the return lines for the SMPS.
• The noise exceeded the requirements.
Filter Design Case History - 3

- The common mode currents were also measured – and showed that they exceeded the requirements.
- Significant high frequency content is seen.
Filter Design Case History - 4

- Common mode filtering was applied.
- 2,000 pF “Y” capacitors added.
- Common model choke also implemented.
• “X” capacitance added to CM filtering techniques.
• Significantly reduced noise across most of spectrum.
• Provides insight that the CE are due to a combination of BOTH DM and CM.
• Incorporation of 100 uH choke to further filter DM noise.
• SMPS now meets requirements!
Completed Filtering Methods

- Final filtering methods utilized to meet CE requirements.
- Allowed “off the shelf” standard SMPS to be used to meet stringent CE requirements!
Frequency Dithering

- Another method to reduce emissions from a SMPS is by use of a “dithering method”.
- This effectively spreads out the energy from a narrowband peak to a wider frequency of lower value.
Emerging Issues in CE

• High voltage and high current distributed systems that are being designed today may have significant CE issues due relatively high values of parasitic inductance and capacitance 
  even though the functional frequency is “low”.

• In addition, the “miniaturization” of electronic systems may cause CE issues due to higher frequencies 
  even with low system “parasitics”.
Conducted Emissions Summary

- Conducted Emissions (CE) are caused by noise on wires or conductive assemblies.
- Regulations define the maximum levels of CE that are permitted.
- Differential mode (DM) and Common mode (CM) current can cause CE.
- Power supply filtering can determine the ability to meet CE requirements.