Oscilloscope Skills

CM AND DM NOISE – OPTIMIZING EMI FILTER AND DEBUG WITH OSCILLOSCOPES

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Application Engineer

ROHDE & SCHWARZ
Make ideas real
Introduction

INDEX

- CM DM noise and EMI filter.
- EMI debugging with R&S Oscilloscopes.
CM DM NOISE AND EMI FILTER
THE CHALLENGES IN TODAY’S ELECTRONIC DESIGN

Trend for Embedded System Design

► Faster clock speed
► Smaller form factor
► More data lines for communications
► More design include RF technology
► Power has more impact on signals with smaller amplitude

More EMI issues

► Switched mode power supply causes the most EMI issue.
► Higher speed design introduces EMI issues
► Bad PCB Layout (stacking) causing worse EMI
► RF features impact & be susceptible to EMI
► Driven by the discontinuities and resonances of the transmission path
► Extends to much higher harmonics than SI issues

CM and DM noise-optimizing EMI filter and debug with Oscilloscopes
SWITCHED MODE POWER SUPPLY PRINCIPLE

Introduction

Advantages
- Efficiency is as high as 85 to 95%
- Device is small and compact

Disadvantages
- Noise present due to high switching frequency
- It produces electromagnetic interference

Advantages | Disadvantages
--- | ---
Efficiency is as high as 85 to 95% | Noise present due to high switching frequency
Device is small and compact | It produces electromagnetic interference
IMPACT OF SWITCHING AND FAST EDGES OF CONVERTER ON EMI EMISSIONS

**Time Domain**

- 16kHz Square wave with 1µs rise/fall time
- 16kHz Square wave with 10ns rise/fall time

**Frequency Domain**

- High frequency Harmonics come with higher levels

**Graphs**

- dB vs kHz
- Fundamental (16kHz)
- 3rd Harmonic of 16kHz
- 5th Harmonic of 16kHz
- 7th Harmonic of 16kHz
- CM and DM noise-optimizing EMI filter and debug with Oscilloscopes
The choice of the converter topology depends on various design parameters like power level, efficiency and each topology come along with its typical EMI behaviour.

The EMI filter design depends on the selected topology.
TRANSMISSION MODES

- Propagation methods of noise

**Differential Mode**
noise or signals on a line(s) with a return path

**Common Mode**
noise on all lines propagating in the same direction with respect to earth
EMI INPUT FILTER STRUCTURE

X-Capacitor    DM-Inductors    X-Capacitor

CM-Choke        Y-Capacitor

Power supply    DC/DC converter

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RESULT OF PRE-EMI COMPLIANCE TEST

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CONDUCTED EMISSION SETUP

In case of a failed CE test, this setup is not sufficient for EMI debugging purpose.
COMMON AND DIFFERENTIAL MODE THEORY

\[ V_P = (I_{CM_a} + I_{DM}) \times Z_{LISN} \]

\[ V_{CM} = \frac{|V_P + V_N|}{2} \]

\[ V_{DM} = \frac{|V_P - V_N|}{2} \]

\[ V_N = (I_{CM_b} - I_{DM}) \times Z_{LISN} \]

For optimizing EMI Filter very important
ENHANCED MEASUREMENT SETUP FOR DEBUGGING

- Requires a Dual-LISN or 2 x a single LISN
- Requires a measurement instrument with 2 input channels

Oscilloscope with powerful and multichannel FFT
ENHANCED MEASUREMENT SETUP FOR DEBUGGING

Measurement Solution

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EMI DEBUGGING WITH R&S OSCILLOSCOPE
PERFORMANCE LEVELS OF INSTRUMENTATION
SELECTING THE RIGHT TOOL

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EMI receivers compliant to CISPR 16-1-1, FCC (40 GHz), MIL-Std

Compliance EMI testing CISPR 16-1-1, 26 GHz

EMI testing referring to limits

Diagnostic measurements without relation to limits

Diagnostic measurements in engineering and pre-compliance EMI testing

Pre-compliance measurement or compliance measurements to CISPR 16-1-1 Ed. 3

Full compliance measurement

3rd level

2nd level

1st level

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EMC DEBUGGING WITH OSCILLOSCOPES?
YES, WE CAN! (AND ITS VERY HELPFUL)

► Available on every R&D engineers desk
  – Easy debugging of EMI problems in R&D
  – Improvements can easily be tested

► Oscilloscopes show both time and frequency domain
  – Correlation between unwanted spectral emission and time-domain signal parameters easily possible
  – Time-domain trigger has advantages for capturing intermittent signals

► Today’s oscilloscopes provide excellent sensitivity and usability
  – 1 mV/Div corresponds to DANL ~0dBuV
    (R&S®RTO at 500 MHz, 120 kHz RBW, 50 Ω)
  – Direct input of frequencies and resolution bandwidth

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EMI DEBUGGING WITH OSCILLOSCOPES

- Radiated Emission
  Debugging after failed Pre-Compliance or Compliance

- Conducted Emission
  Pre-test and debugging in the R&D lab

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EMI DEBUGGING WITH OSCILLOSCOPES – ACCESSORIES

**Near-Field Probes**

Complete Sets  
E- and H-field

H-field-only Sets

LISNs

**30 MHz – 3 GHz**

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ENHANCED MEASUREMENT SETUP FOR DEBUGGING

Measurement Solution

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RTO2000

LISN

DUT

Power Supply

DUT

Channel 1
FFT(|Ch1+Ch2|/2)
Common mode

Channel 2
FFT(|Ch1-Ch2|/2)
Differential mode
EMI SPECTRUM - NO FILTERING

Differential Mode
Common Mode

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Case Study

EMI SPECTRUM – DM FILTER APPLIED

DM-Inductor
2 x X-Cap

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Case Study

EMI SPECTRUM – CM AND DM FILTER APPLIED

CM-Choke

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EMI SPECTRUM – WITH AND WITHOUT FILTER

Case Study

Without filter

With filter

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CONCLUSION

► To split differential mode signals from common mode (CM) is valuable for EMI Filter optimization.
► A powerful multiple channels FFT may help to differentiate between common mode and differential mode noise.
EMI DEBUGGING ANALYSIS STEPS
HOW TO USE NEAR-FIELD PROBES

A) Far-field measurement

B) “Know your DUT”: List of potential interferer sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clock frequency</td>
<td>e.g. 25 MHz + Multiples</td>
</tr>
<tr>
<td>Ethernet PHY</td>
<td>e.g. 125 MHz + Multiples</td>
</tr>
<tr>
<td>Voltage converter / power adapter</td>
<td>broadband</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

C) Reference measurement without DUT

D) Interferer current measurement to find out the coupling type

E) Nearfield probe to localize the interferer source

F) Analysis of counter-measures

EMI Debugging / R&D

EMI compliant testing / Test lab

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EMI DEBUGGING ANALYSIS
NEAR-FIELD PROBES

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SPECTRUM MEASUREMENTS
OSCILLOSCOPE USES FFT

- Calculate FFT over entire acquisition
- Conventional Scope usually acquire one RL and reconstruct FFT then go on to acquire the next RL to compute the next FFT → Missing sporadic event

Disadvantages of conventional FFT:
- Very slow speed / update rate
- Limited RBW due to insufficient RL
- Complex configuration (TD settings)

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Advantages of R&S approach:

- Higher speed / update rate
- Good RBW without magnification
- Flexible configuration
- Multiple overlapping FFT able to find spurious faults
ADVANCED EMI DEBUGGING
OVERLAPPING FFT FUNCTIONALITY

Record length

FFT 1

Record length = FFT Length

1 FFT
ADVANCED EMI DEBUGGING
OVERLAPPING FFT FUNCTIONALITY

• The time structure of the signal becomes visible (color coding) by overlapping FFT.
• High sensitivity for short emissions
• Correlated time-frequency analysis
• Semi-independent control of time domain and frequency domain
ADVANCED EMI DEBUGGING
TIME-GATED FFT APPLICATION

130MHz

100MHz 180MHz 200MHz

400ns Pulse

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BASIC EMI DEBUGGING WITH OSCILLOSCOPES

Waterfall diagram helps to show short emissions

dBuV scaling like in EMI measurements

Color coding display for better visibility

Directly set start, stop and resolution bandwidth

Time-frequency correlation of emissions

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ADVANCED EMI DEBUGGING WITH OSCILLOSCOPES

Waterfall diagram (not shown here)

Flexible scaling, dBuV, dBm

Color coding display shows how often disturbance happens

Time-frequency correlation of emissions

Spectral mask allows „stop-on-violation“
RECORDING OF OSCILLOSCOPES FFT FUNCTION
REAL TIME

- Time Zone waveform
- Waterfall diagram
- Frequency Zone waveform
CONCLUSION

► Switched mode power supply causes the most EMI issue, EMI filter is important.
► EMI filter design depends on the selected topology.
► CM and DM noise can be analyzed separately with R&S Oscilloscope, to optimizing EMI filter.
► Oscilloscope is a general equipment and available on every R&D engineers desk.
► R&S Oscilloscope performs powerful EMI debugging ability with the advanced FFT technology.
► Both radiated and conducted emission can be tested well.
► R&S Oscilloscope is an excellent measurement equipment for EMI debugging.
THANK YOU!