VICOR

Modular Solutions for Your Power System

COMPONENTS • POWER • EASE-OF-USE • PERFORMAN
INOVATION • EFFICIENCY • EXPERTISE • CONFIGURA
ME • VOLUME • RELIABILITY • FLEXIBILITY • LONGEVI
MWORK • PROVEN • DENSITY • QUALIFIED • COMPE
SOLUTIONS • INTEGRATION • SUPPORT • OPPORTUNI

전도성 EMI 개선 대책

최회광, Field Applications Engineer
Vicor Corporation
May 2019

Agenda

Conducted Emissions

- **Source of CE in Power Supplies- 3 Basic Switching Regulators**
  1. **Buck Converter**
  2. **Boost Converter**
  3. **Buck-Boost (Inverting)**
- **What Kind of Emissions are Produced**
- **How CE is measured**
- **Effect of Filters on Stability and Emissions**
- **Summary**
- **Help Offered by Vicor**

VICOR

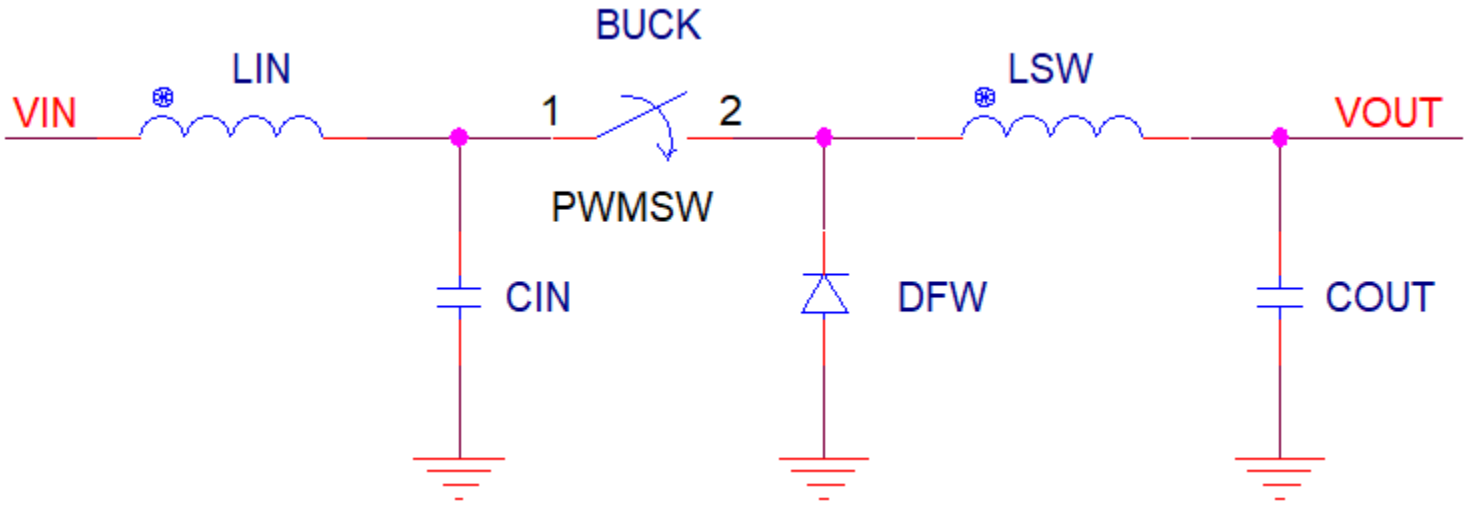
Modular Solutions for Your Power System

COMPONENTS • POWER • EASE-OF-USE • PERFORMAN
INOVATION • EFFICIENCY • EXPERTISE • CONFIGURA
ME • VOLUME • RELIABILITY • FLEXIBILITY • LONGEVI
MWORK • PROVEN • DENSITY • QUALIFIED • COMPE
SOLUTIONS • INTEGRATION • SUPPORT • OPPORTUNI

Power Supply Emission Shapes

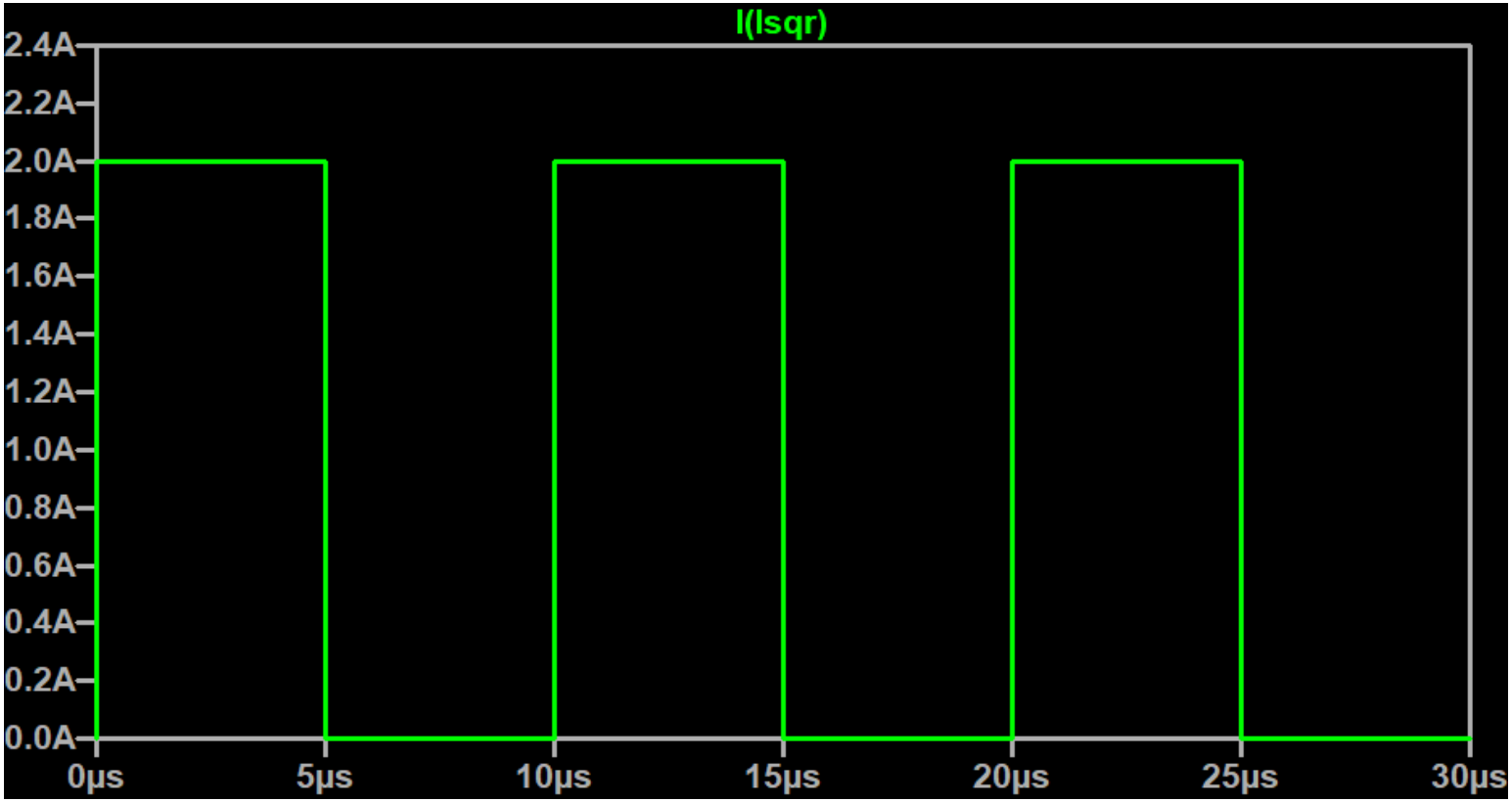
Conducted Emissions

- **Where do they come from?**
  - Switching currents on PWM inputs
- **Look at basic buck converter. Ipp through LIN is typically 10% to 50% of the average current.**
- **Input current through PWMSW rises and falls resembling a square wave as it is disconnected from the input each switching cycle.**



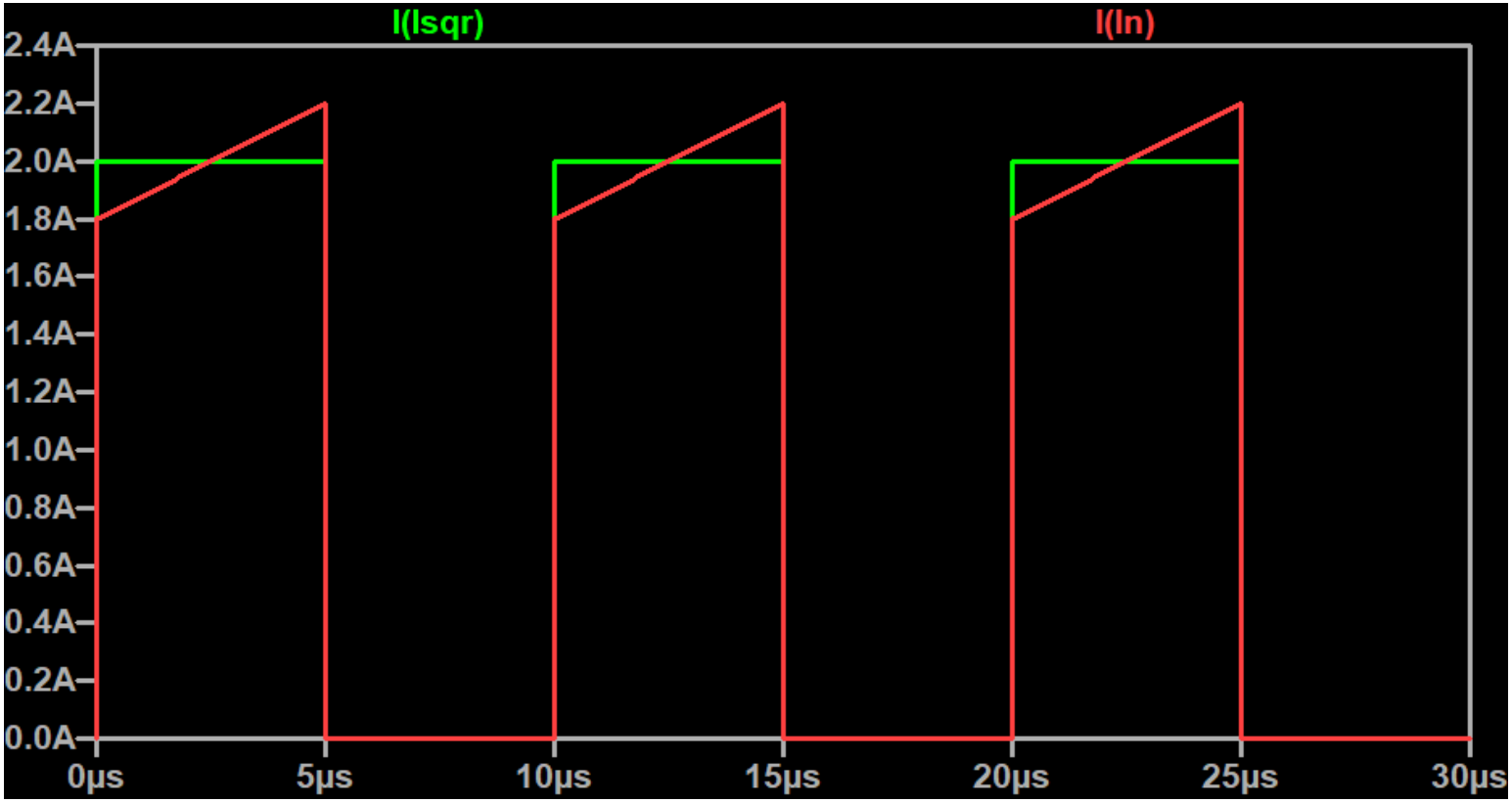
Conducted Emissions

Square wave current shape in the time domain



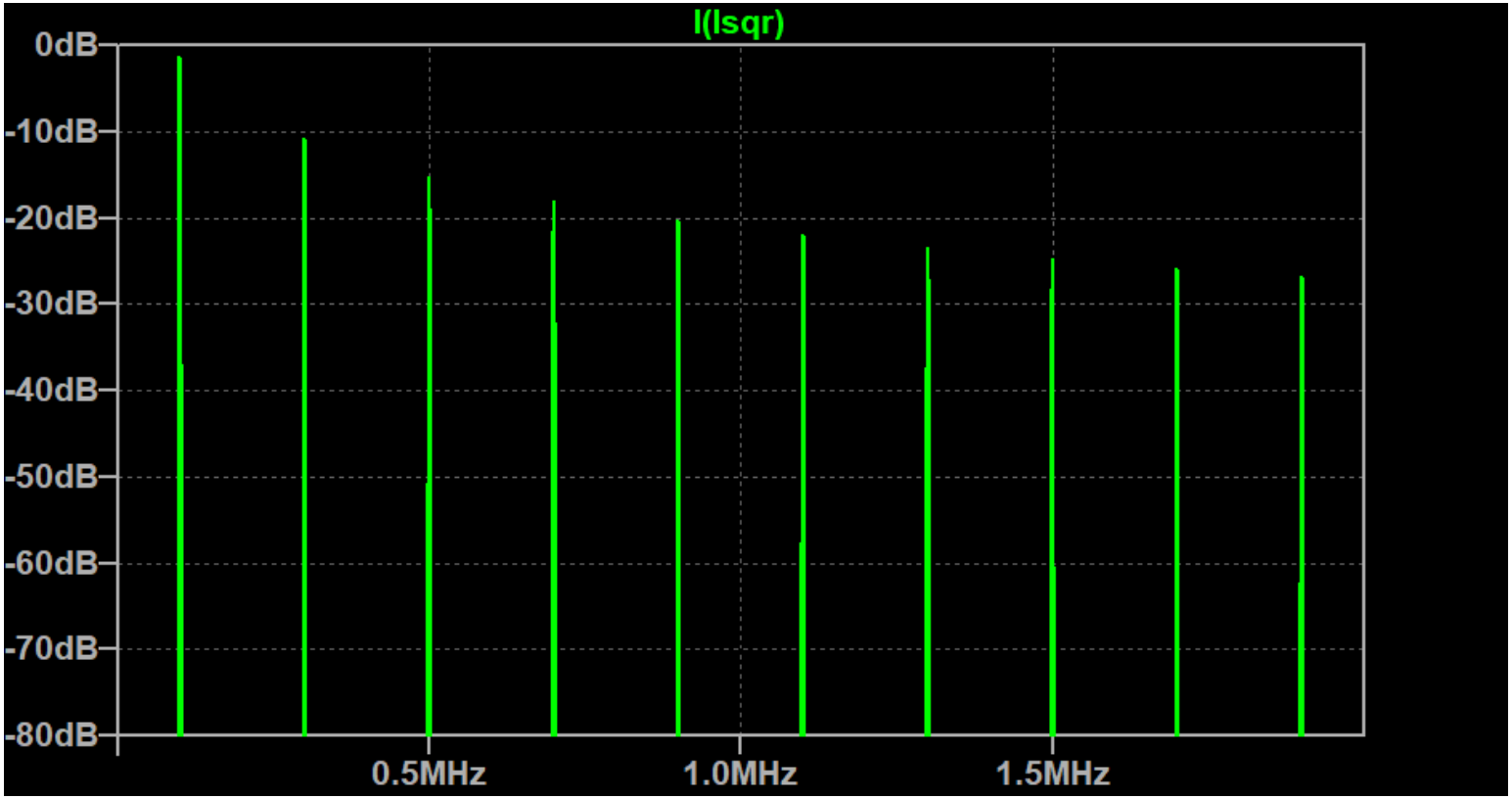
Conducted Emissions

Square vs. trapezoid current wave shape in the time domain



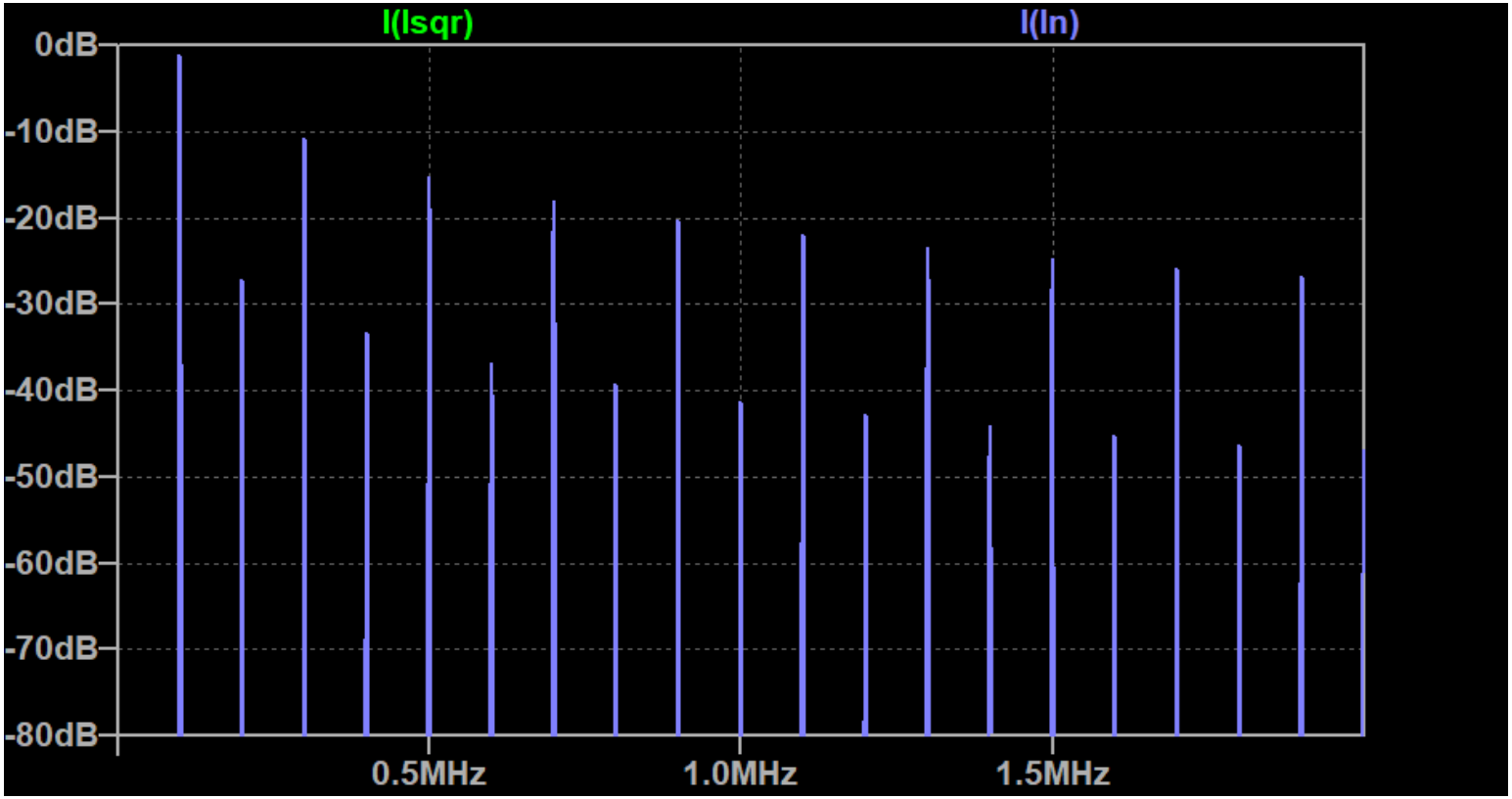
Conducted Emissions

Square current wave shape in the frequency domain:
Odd Harmonics only, peaks decrease as 1/n



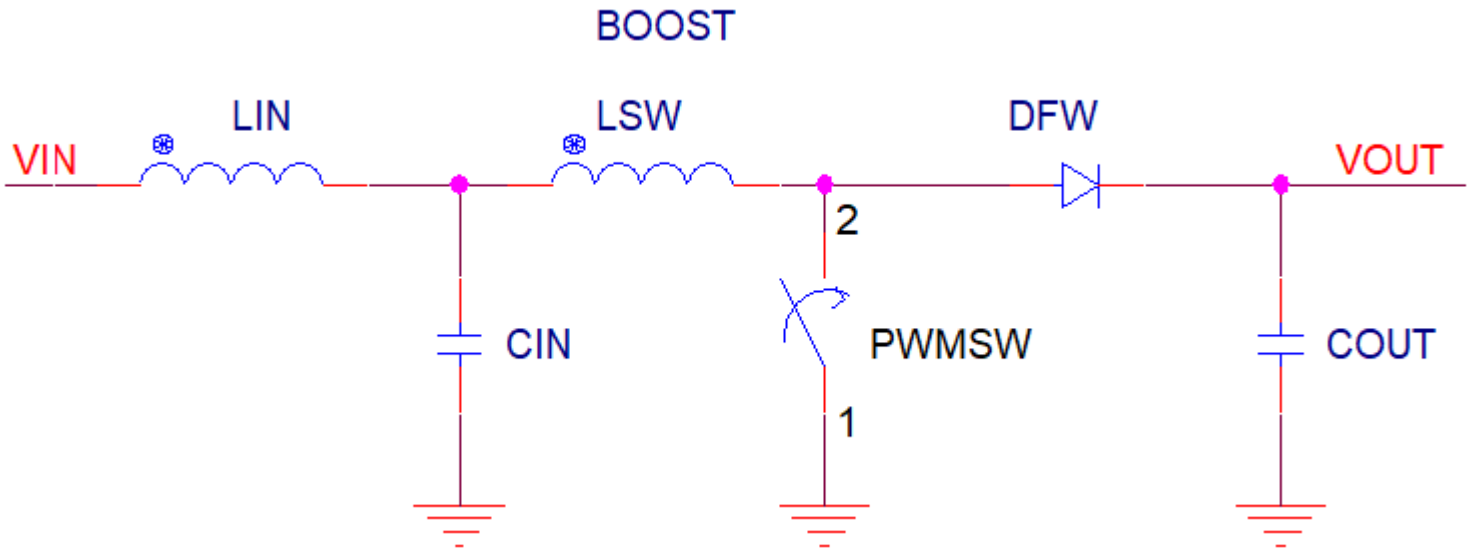
Conducted Emissions

Square vs. trapezoid current wave shape in the frequency domain: Even Harmonics 20 dB lower, peaks decrease as $1/n^2$



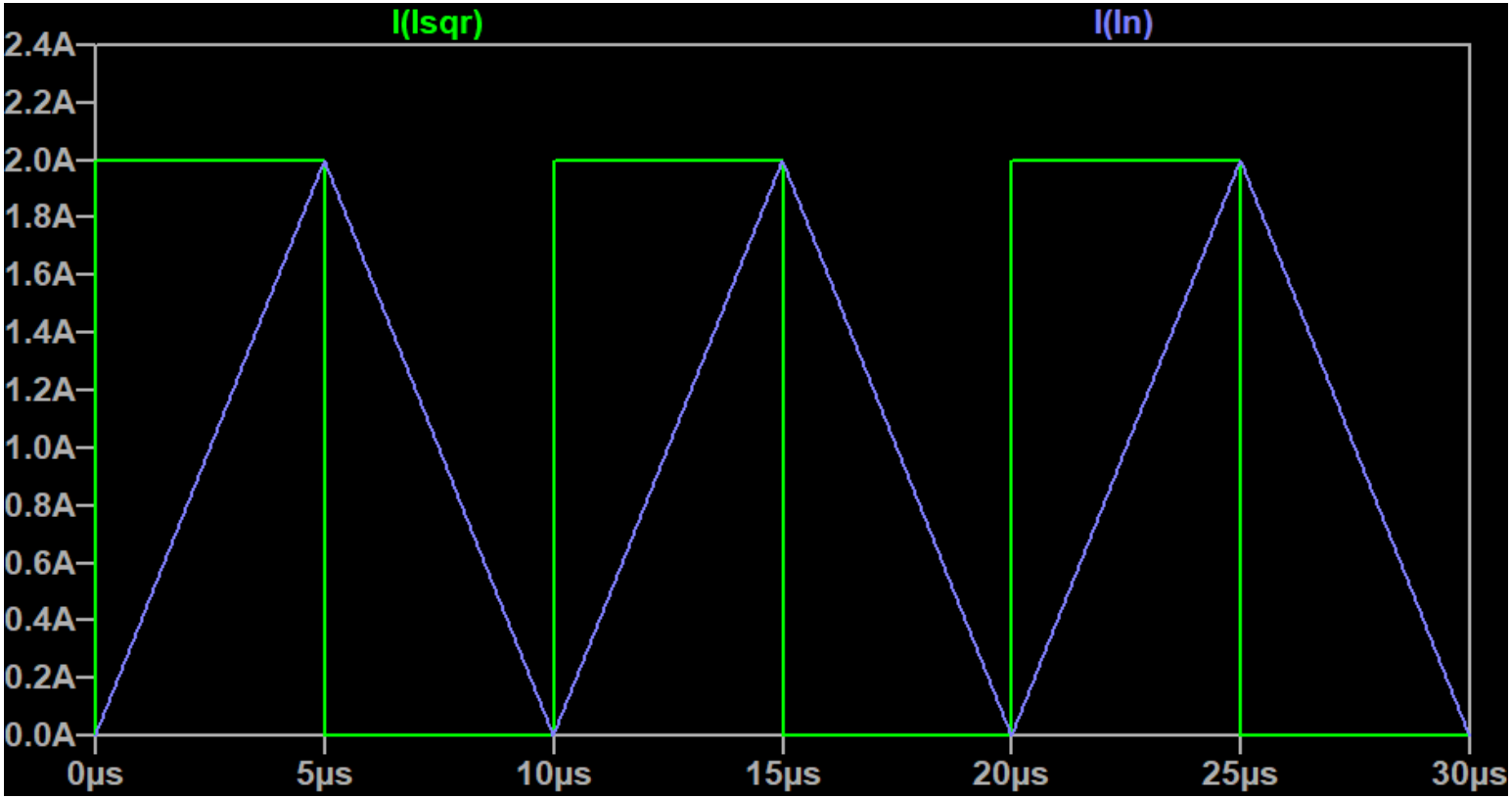
Conducted Emissions

- **Where do they come from?**
  - Switching currents on PWM inputs
- **Look at basic buck vs. boost converter:**
- **Input current through LSW rises and falls like a triangle wave, but it NEVER is disconnected from the input.**



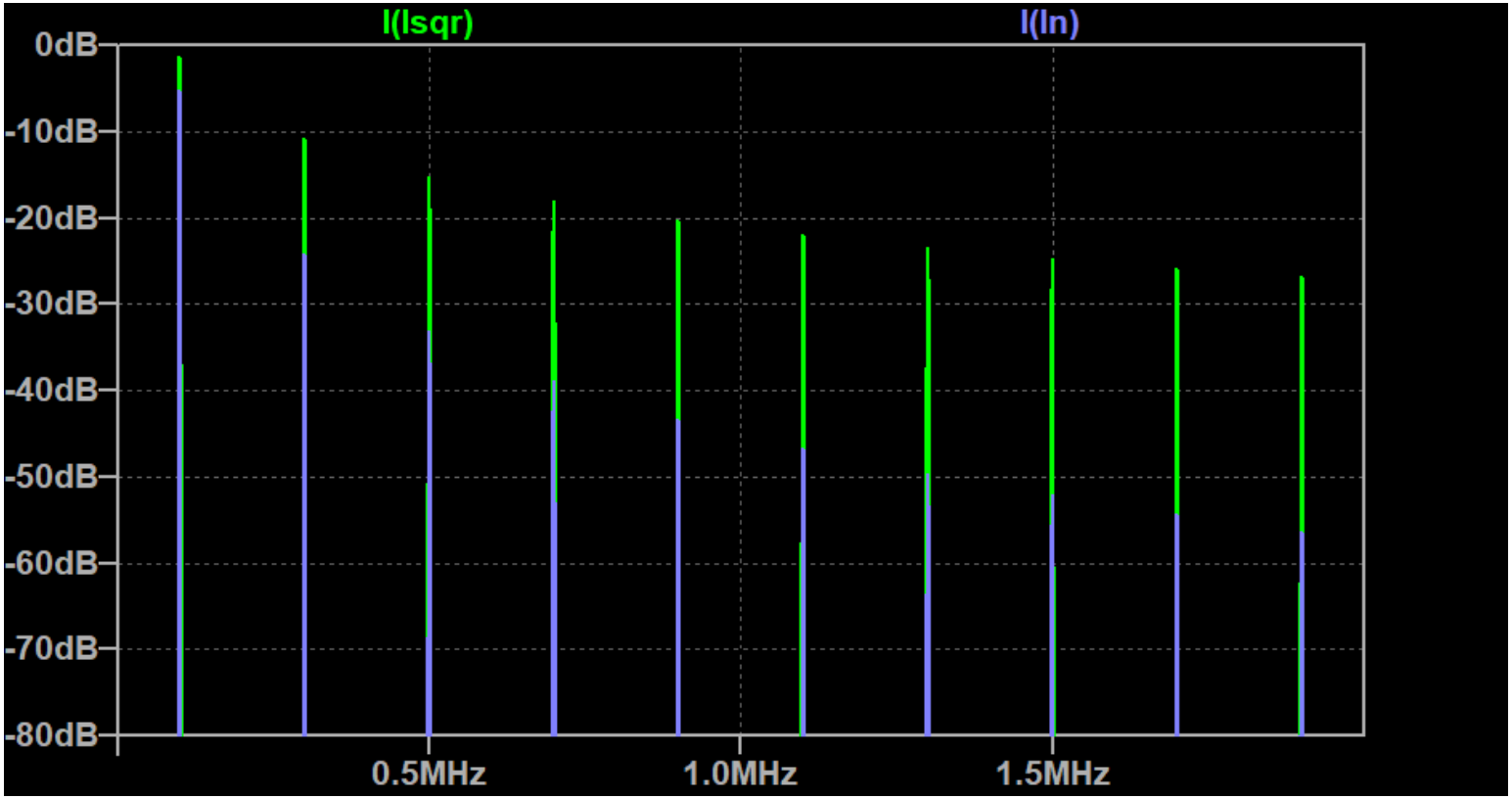
Conducted Emissions

Square vs. trapezoid current wave shape in the time domain



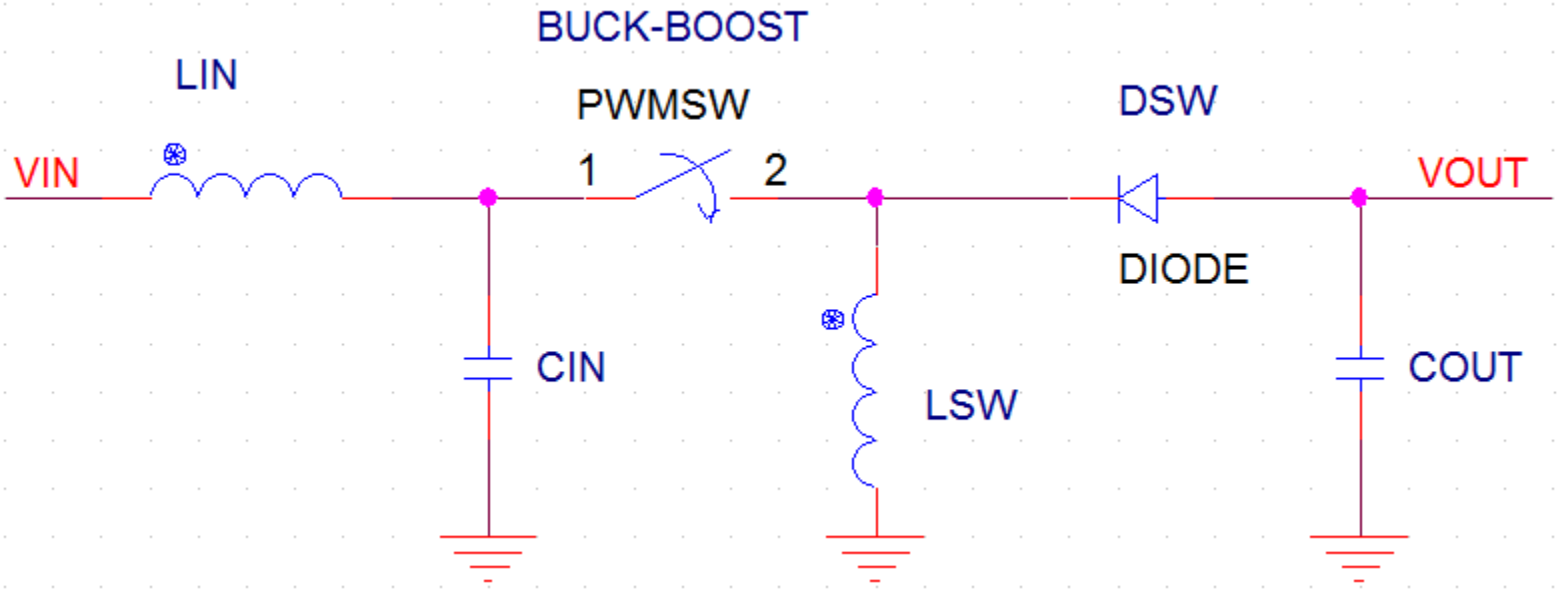
Conducted Emissions

Square vs. trapezoid current wave shape in the frequency domain: Odd harmonics with peaks decreasing as $1/n^2$



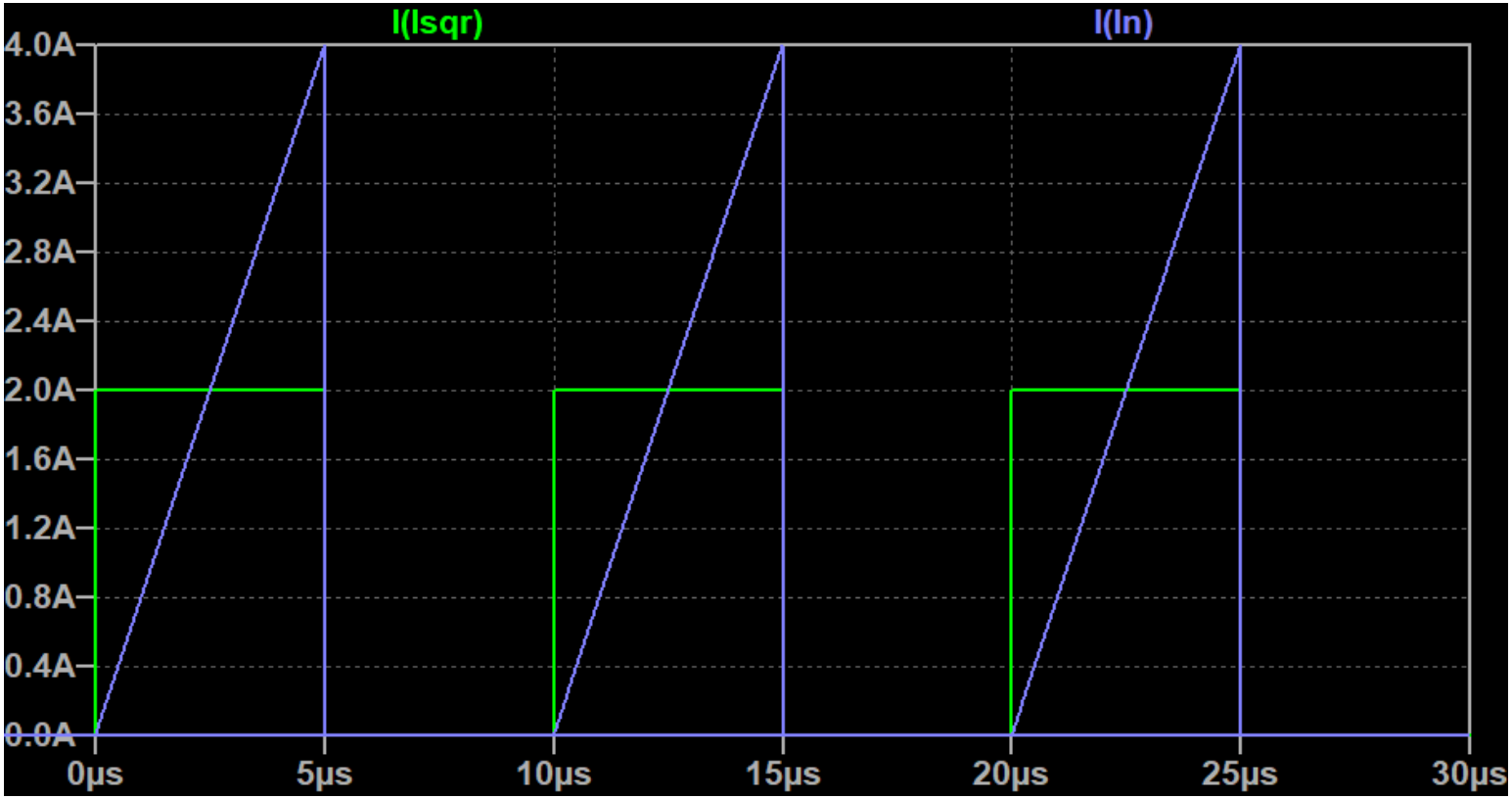
Conducted Emissions

- **Where do they come from?**
  - Switching currents on PWM inputs
- **Look at basic buck vs. boost vs. buck-boost (inverting):**
- **Input current through PWMSW rises slowly and falls instantly**



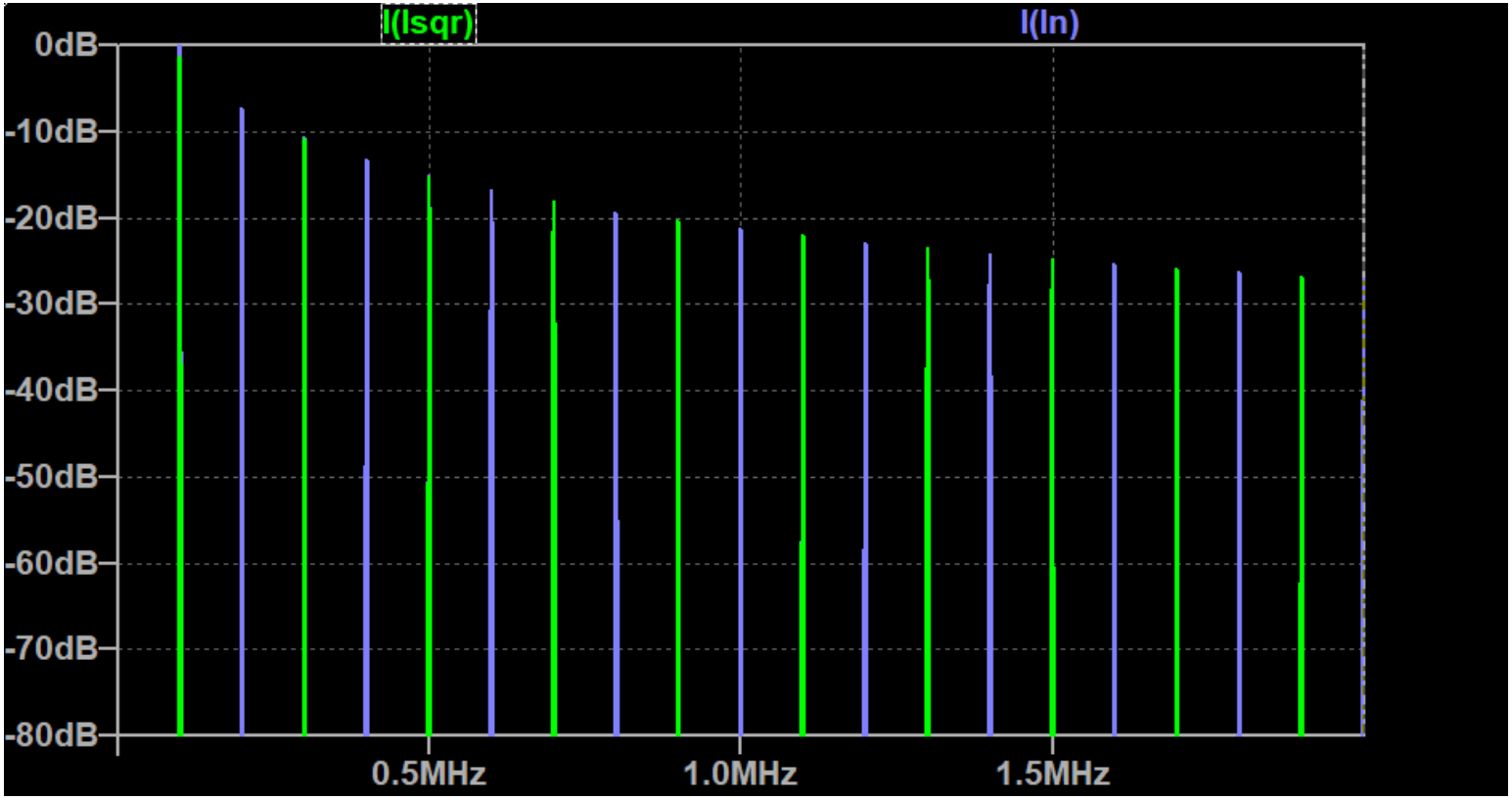
Conducted Emissions

Square vs. triangle current wave shape in the time domain



Conducted Emissions Half triangle 1/n, add even harmonics

Square wave- harm(n) α 1/n Triangle wave- harm(n) α $1/n^2$



VICOR

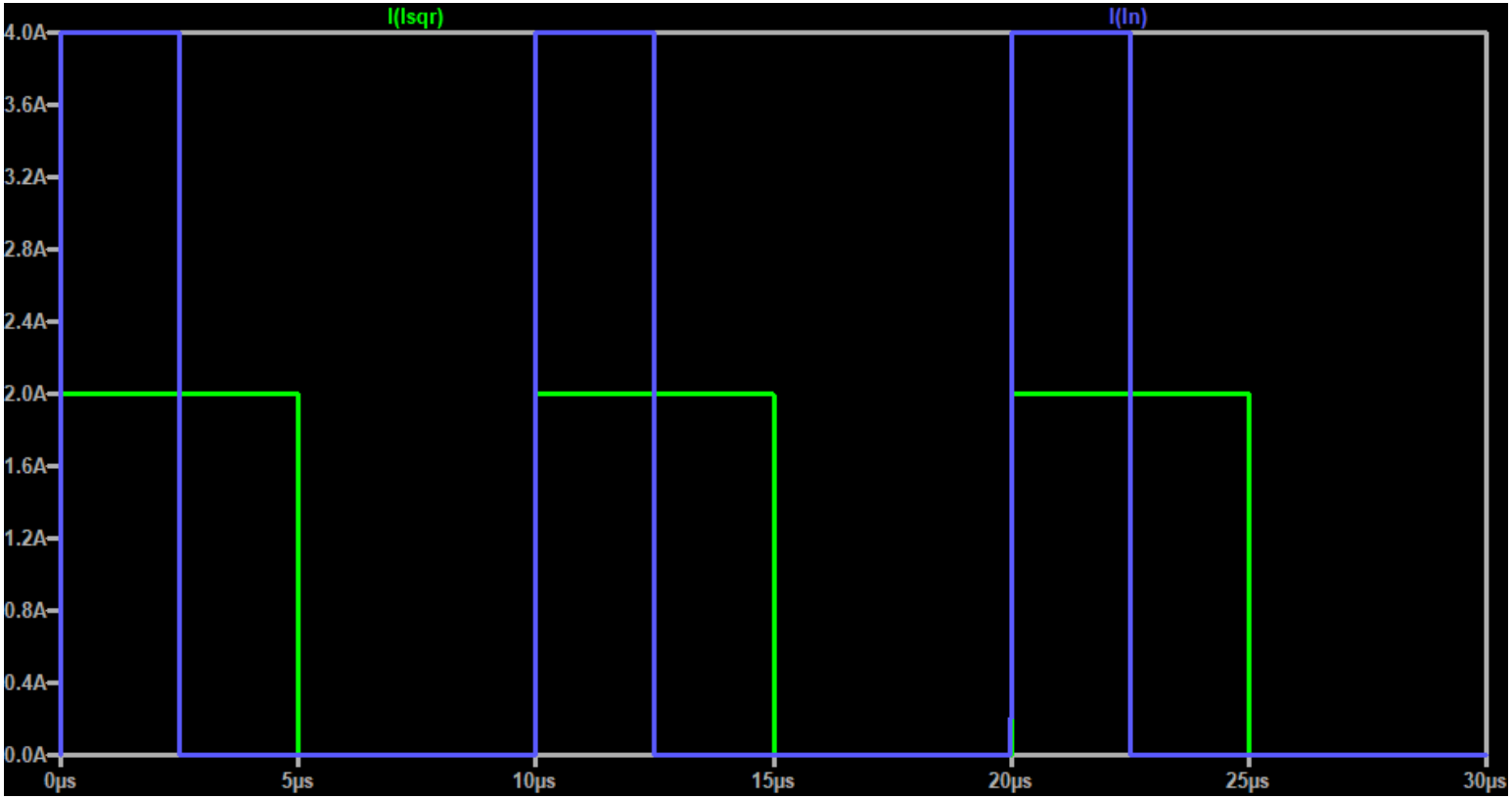
Modular Solutions for Your Power System

COMPONENTS • POWER • EASE-OF-USE • PERFORMAN
INNOVATION • EFFICIENCY • EXPERTISE • CONFIGURA
ME • VOLUME • RELIABILITY • FLEXIBILITY • LONGEVI
MWORK • PROVEN • DENSITY • QUALIFIED • COMPE
SOLUTIONS • INTEGRATION • SUPPORT • OPPORTUNI

Duty Cycle Modulation

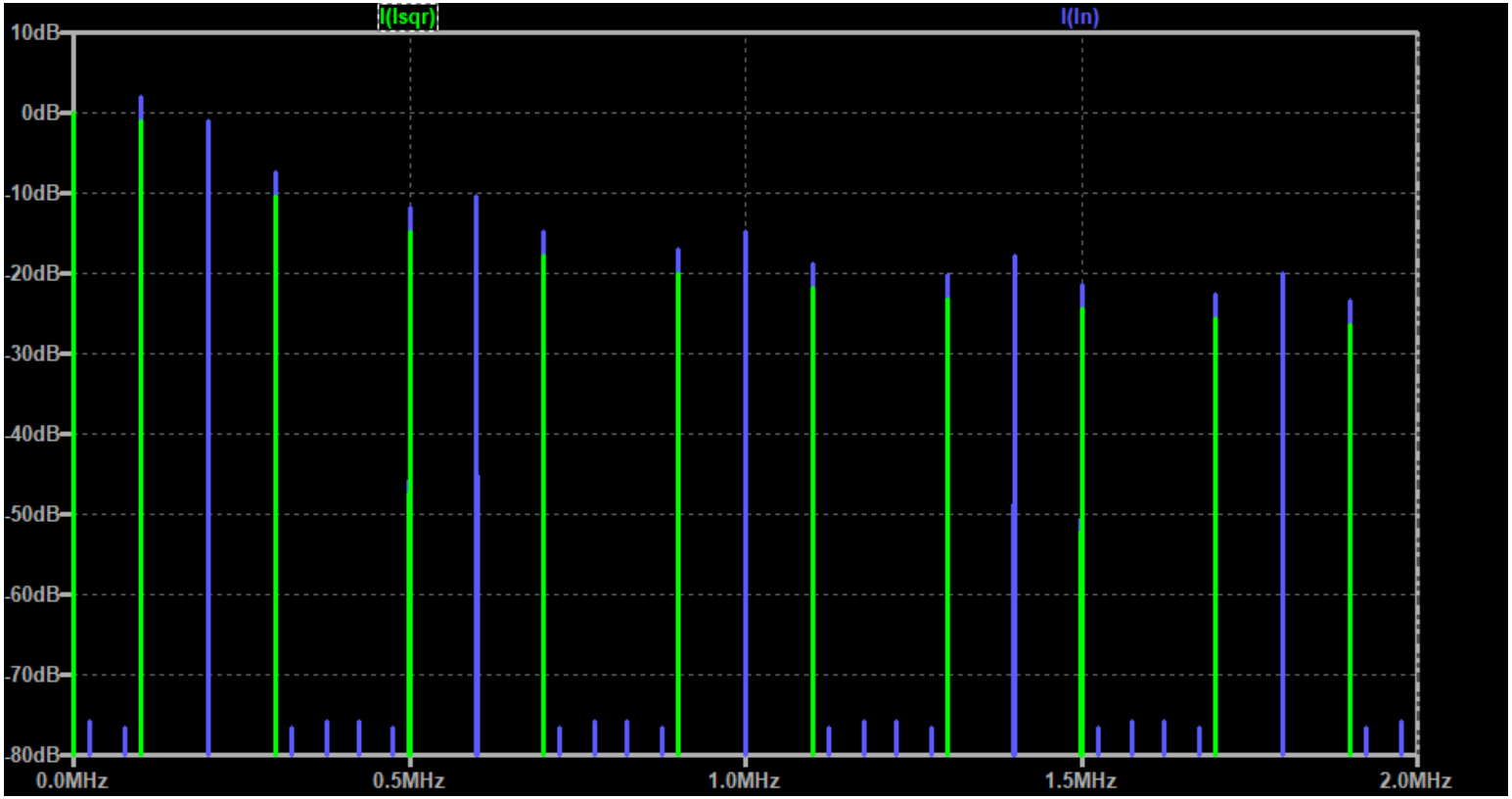
Conducted Emissions

Square wave 50% vs. 25% duty cycle, same average



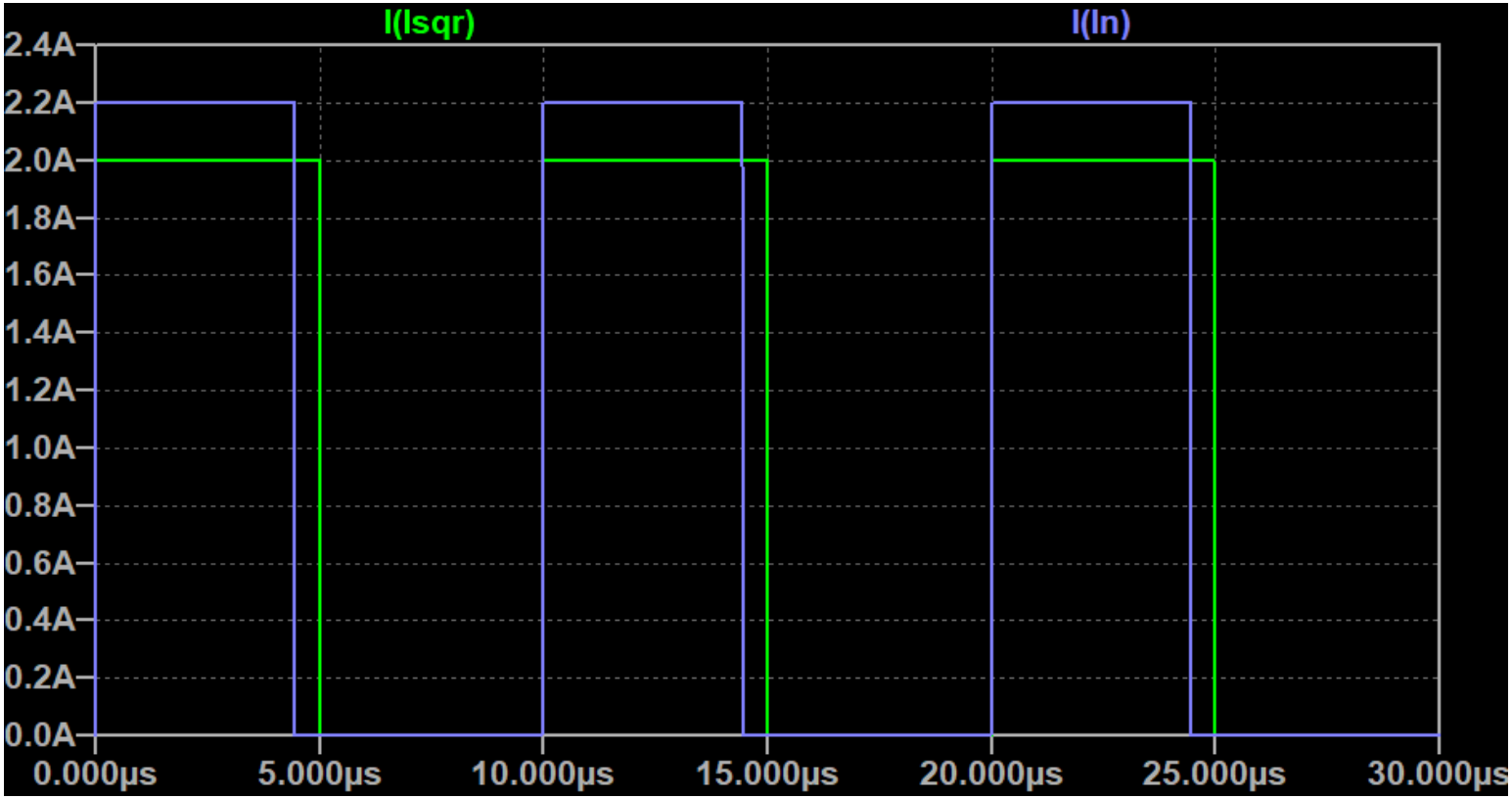
Conducted Emissions

Square wave 50% duty cycle vs. 25% duty cycle
25% duty cycle add some even harmonics, 2nd, 6th, 10th, etc….



Conducted Emissions

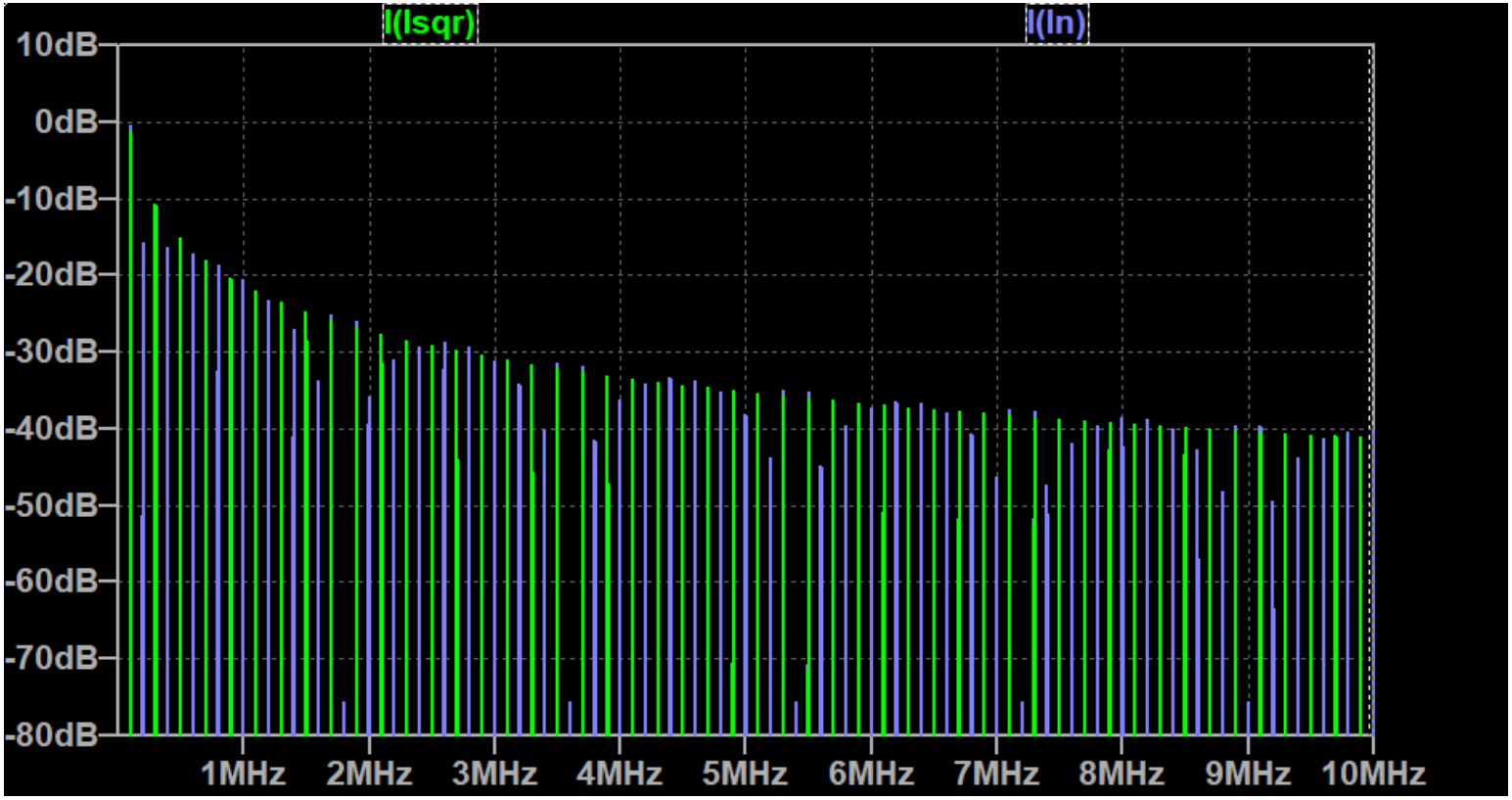
Square wave 50% vs. 45% duty cycle



Conducted Emissions

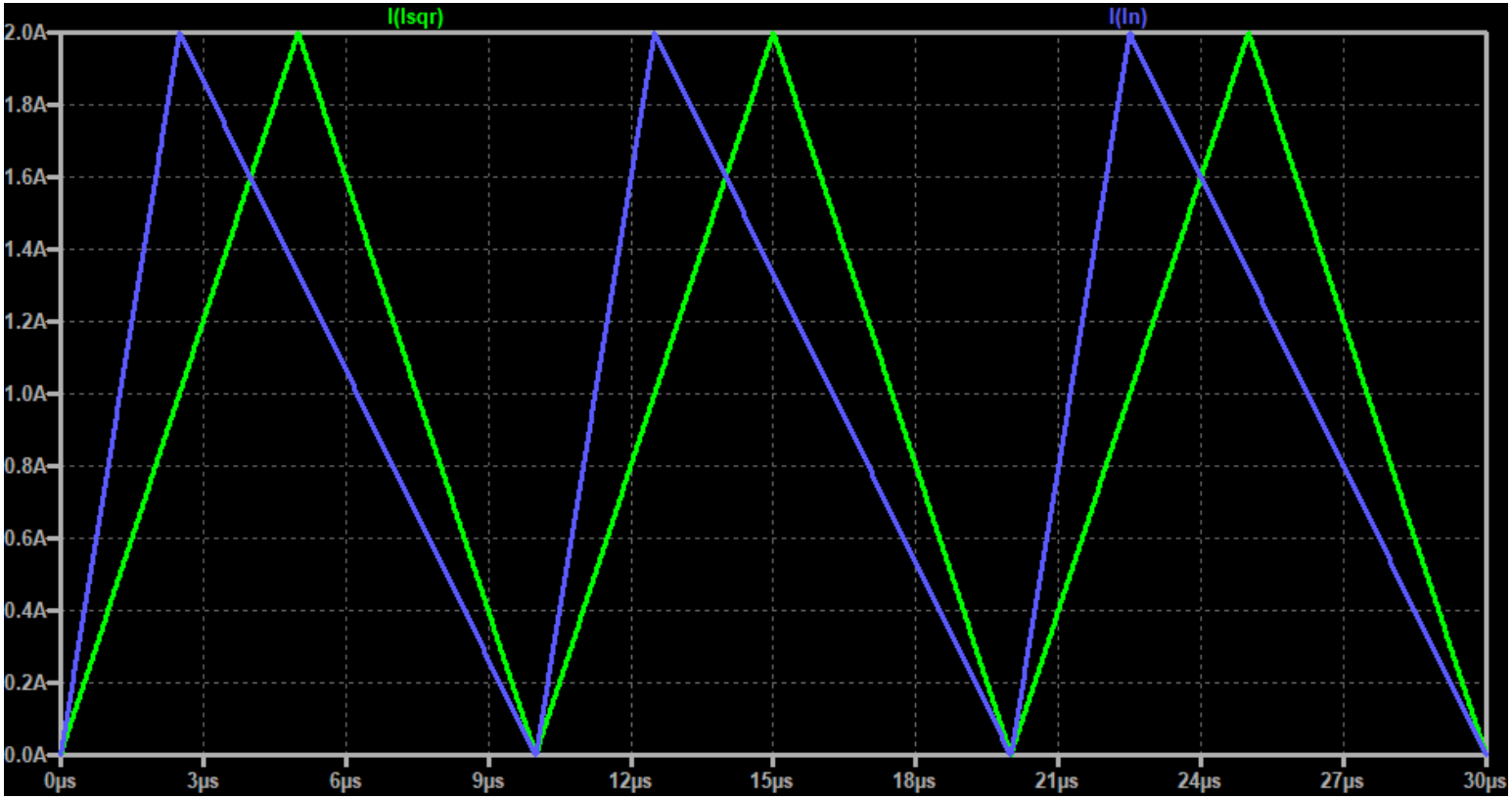
Square wave 50% duty cycle vs. 45% duty cycle
45% duty cycle has an envelope and added odd harmonics.

Overall amplitudes still drop off at 1/n rate.



Conducted Emissions

Triangle wave 50% vs. 25% duty cycle

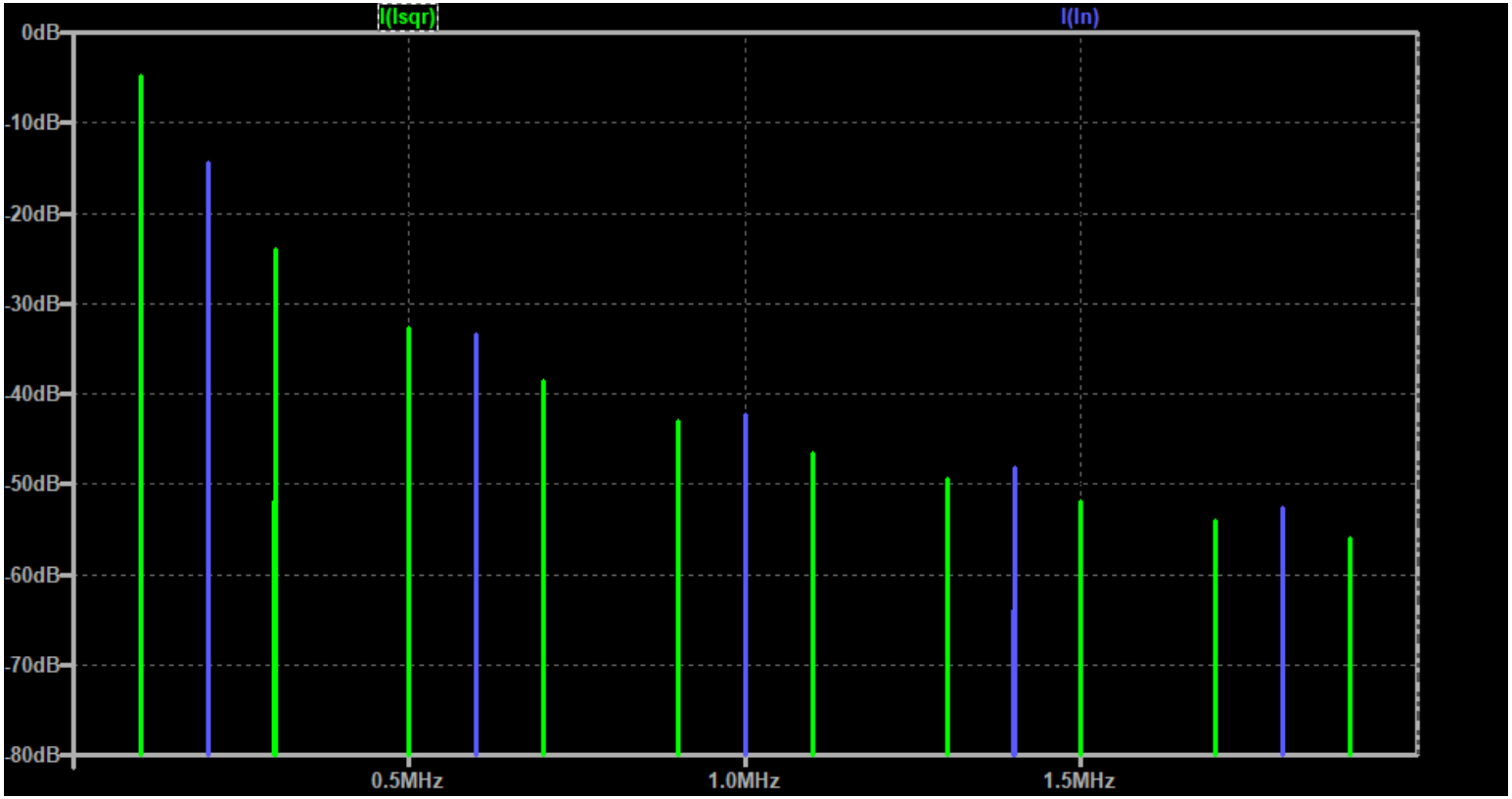


Conducted Emissions

Triangle wave 50% vs. 25% duty cycle.

Similar to 25% square wave, only 2^{nd}, 6^{th}, 10^{th} even harmonics appear in 25% triangle.

Overall amplitudes still drop off at $1/n^2$ rate.

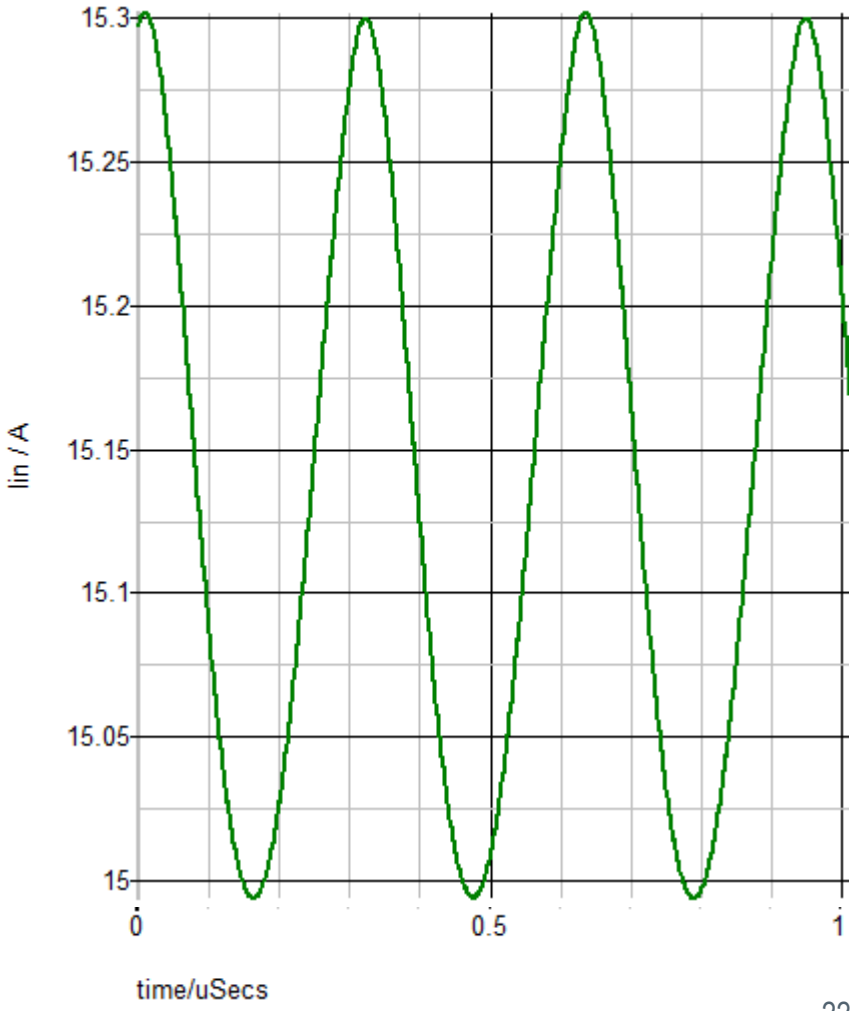


SINE AMPLITUDE CONVERTER

- **This topology is used in:**

  BCM, HVBCM, UHVBCM, VTM, MCM

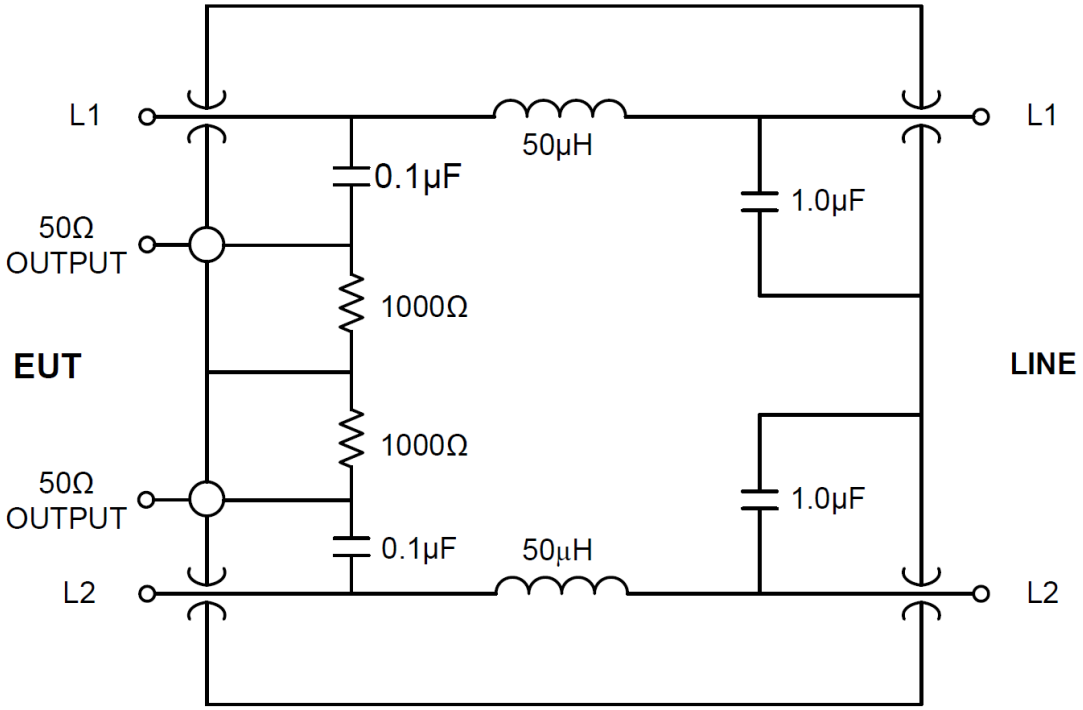
- **Fixed ratio bus converters, FIXED 50% duty cycle**
- **Input power modulated at resonant tank frequency of main power transformer**
- **Input currents are mostly SINUSOIDAL due to resonance, harmonics drop quickly**
- **Recommended for applications with lowest noise requirements**
- **Still creates CE due to rectified output, square gate drives.**



Measuring Power Supply Emissions

Typical LISN Operation

- Conducted Emissions are measured with a LISN
- Purpose of LISN - provide standard impedance to make tests repeatable from one test location to another

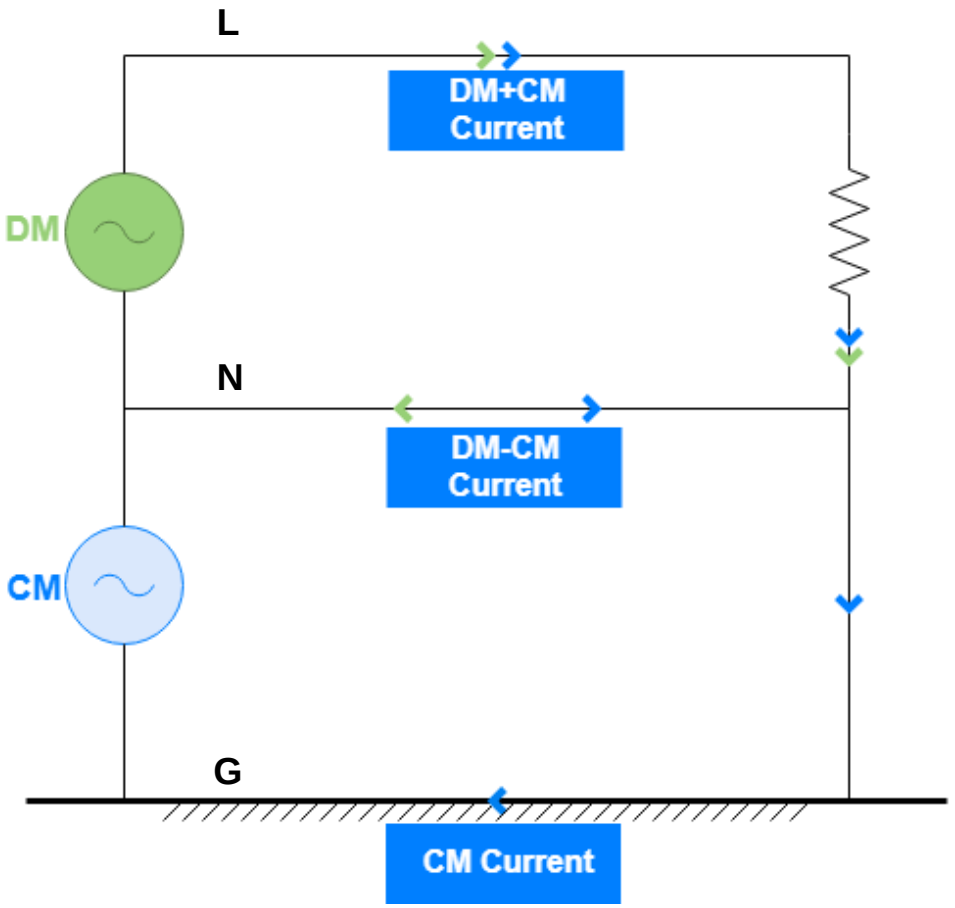


Conducted Emissions

- **With a Line Impedance Stabilization Network, you measure noise on HOT and NEUTRAL or POSITIVE and NEGATIVE conductors.**
- **Emissions, however, are differential mode and common mode.**
  - What are they?
  - Why should you separate them?
  - How do you separate them?

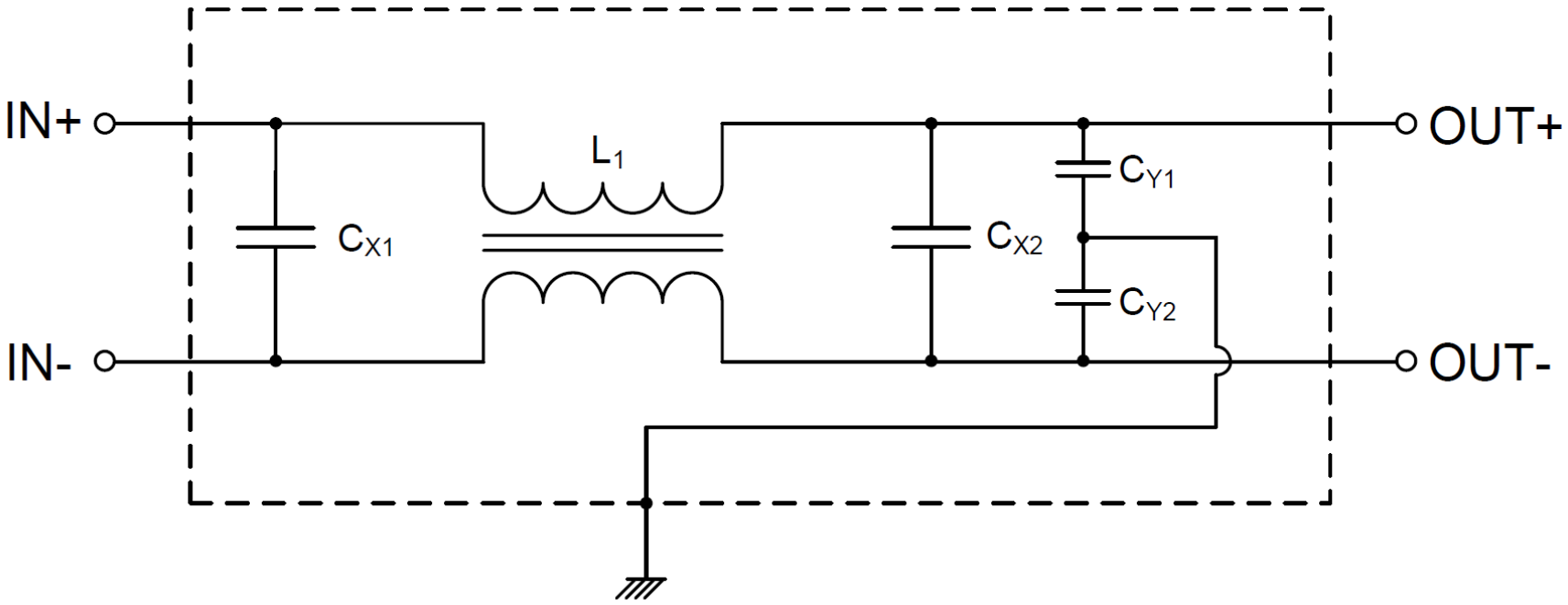
Common Mode vs Differential Mode Emissions

- **Differential Mode** currents: only L to N
- **Common Mode** currents: same on L and N
- Ground has CM current only



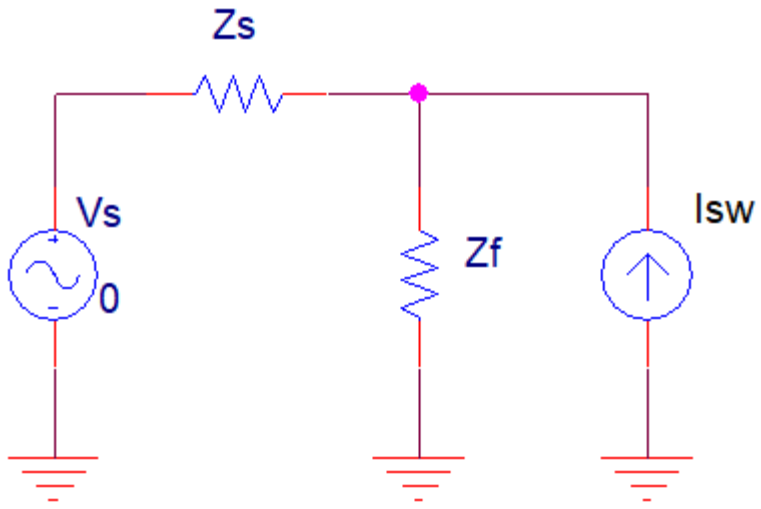
Single Stage Power Design

› **Typical EMI filter schematic diagram**



Basic Current Divider Operation

Noise Source: Isw
Input Voltage: Vs
Conducted emissions magnitude determined by how much switching noise appears at Vs



Isw is noise source
Zs is source impedance
Zf is filter shunt impedance

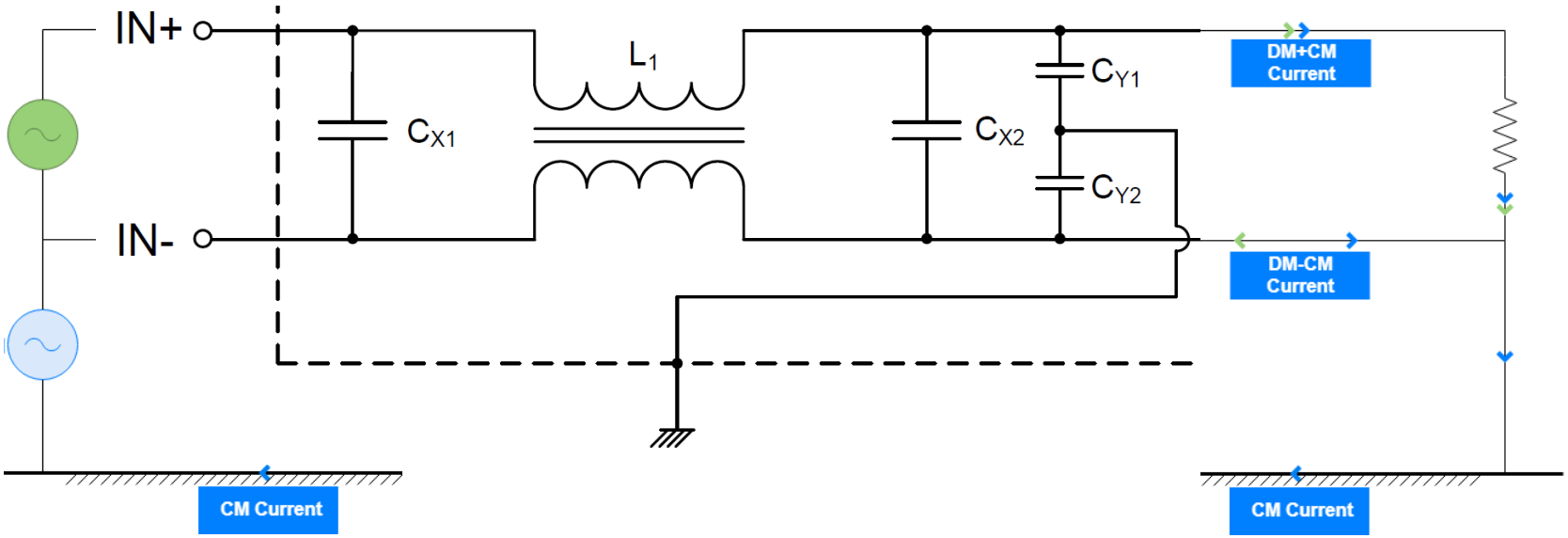
$$\frac{Is}{Isw} = \frac{1}{(1 + Zs/Zf)}$$

For Zs << Zf, Is/Isw ~ 1
For Zs >> Zf, Is/Isw ~ Zs/Zf

Common Mode vs Differential Mode Emissions

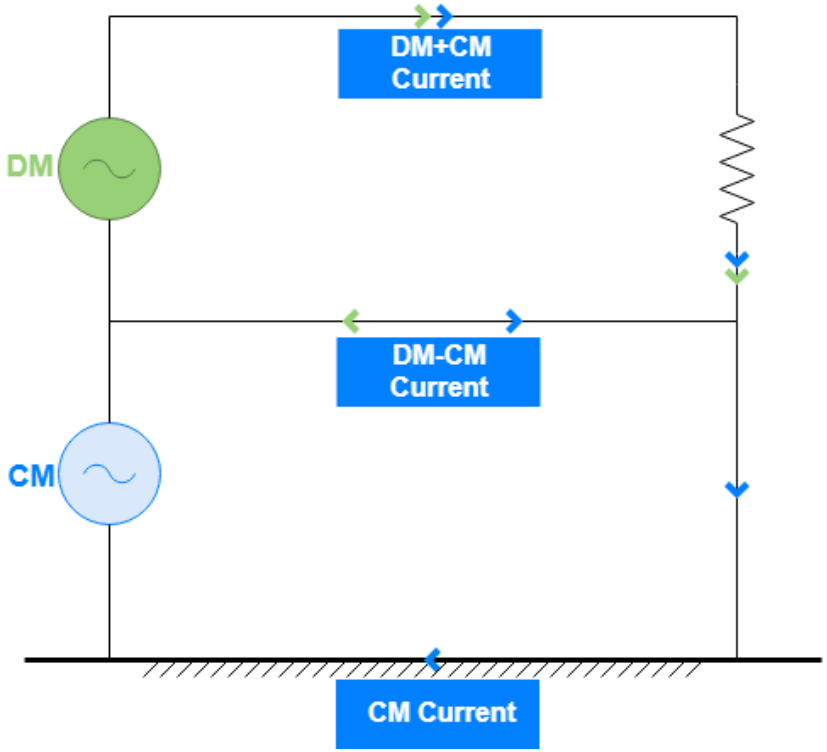
Why should you separate them?

- **Causes and fixes are different**
- **Diff Current- use bigger X cap leakier CM inductor**
- **Common Mode Current- higher Z CM inductor, larger Y caps, better impedance balance, larger ground impedance.**



Common Mode vs Differential Mode Emissions

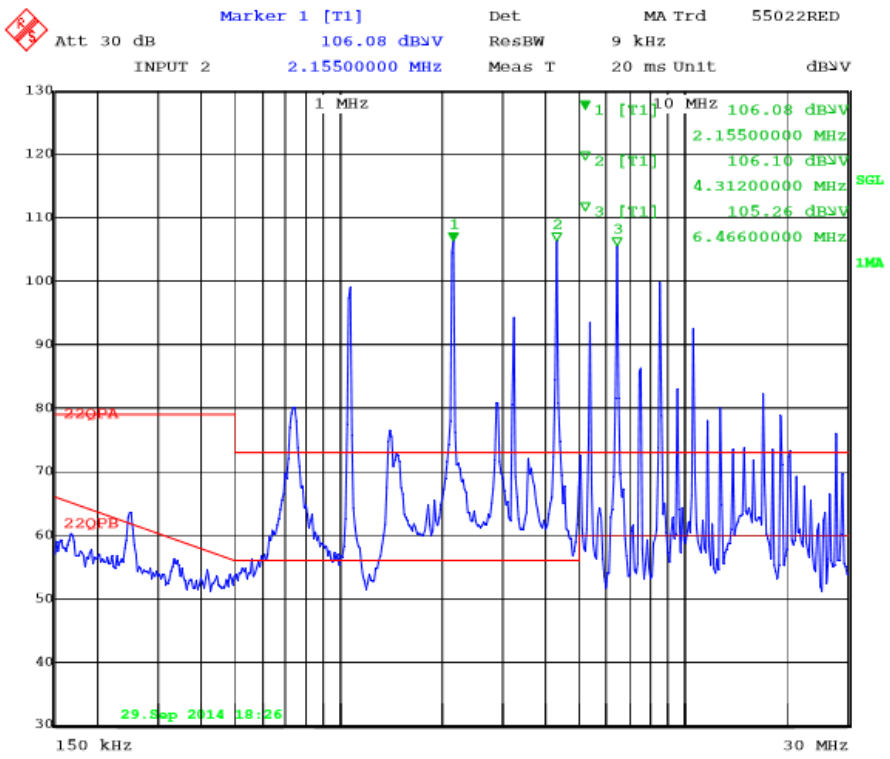
- How do you separate them?
- Use a balun to add/subtract LISN voltages
- Use a current probe, put L+N into probe, or ground current.
- Add clamp on common mode ferrite bead on L+N or ground.
- Connect/Disconnect ground connection- Effective even with no advanced equipment

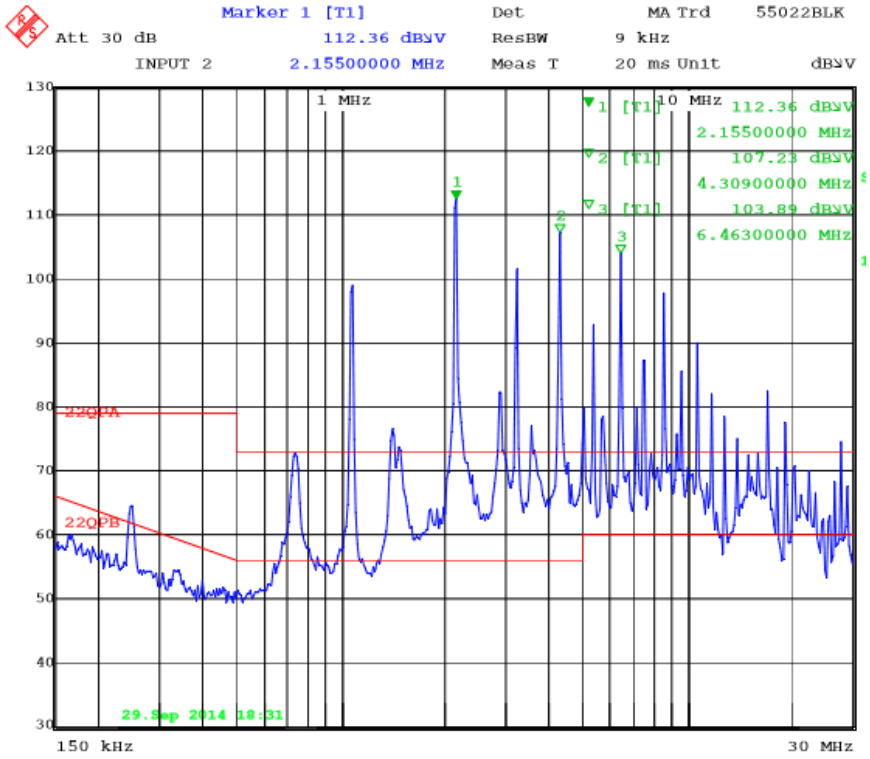


Common Mode vs Differential Mode Emissions

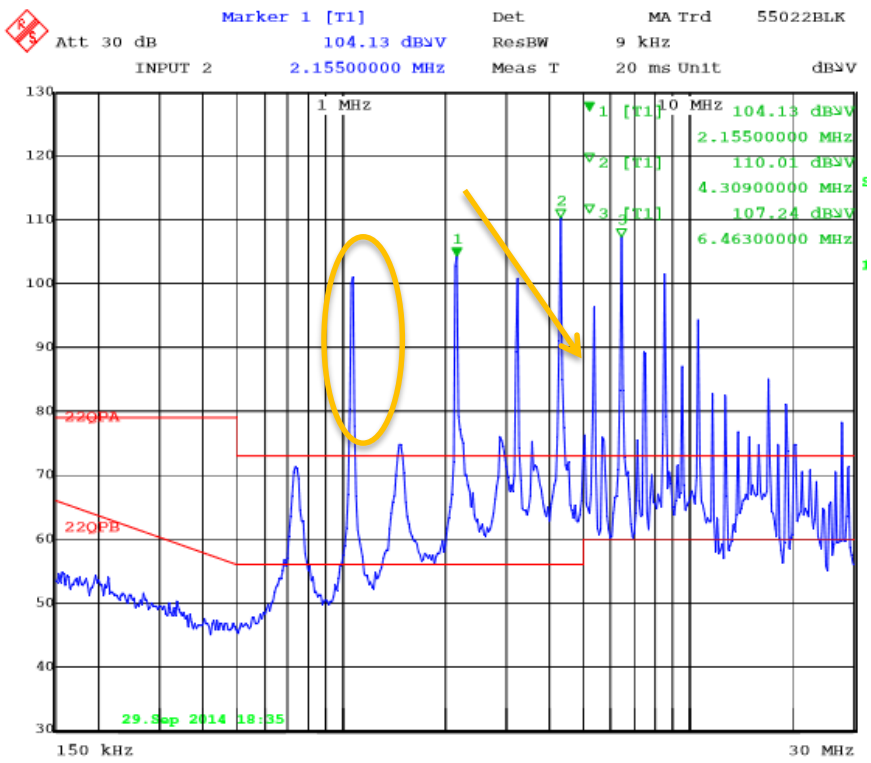
- 50 ohm baluns used to add and subtract line currents: ZSC-2-2
  This part isn't on the minicircuits website anymore
- Newer parts: ZMSC-2-2: 0° ZFSCJ-2-2: 180° SMA connectors

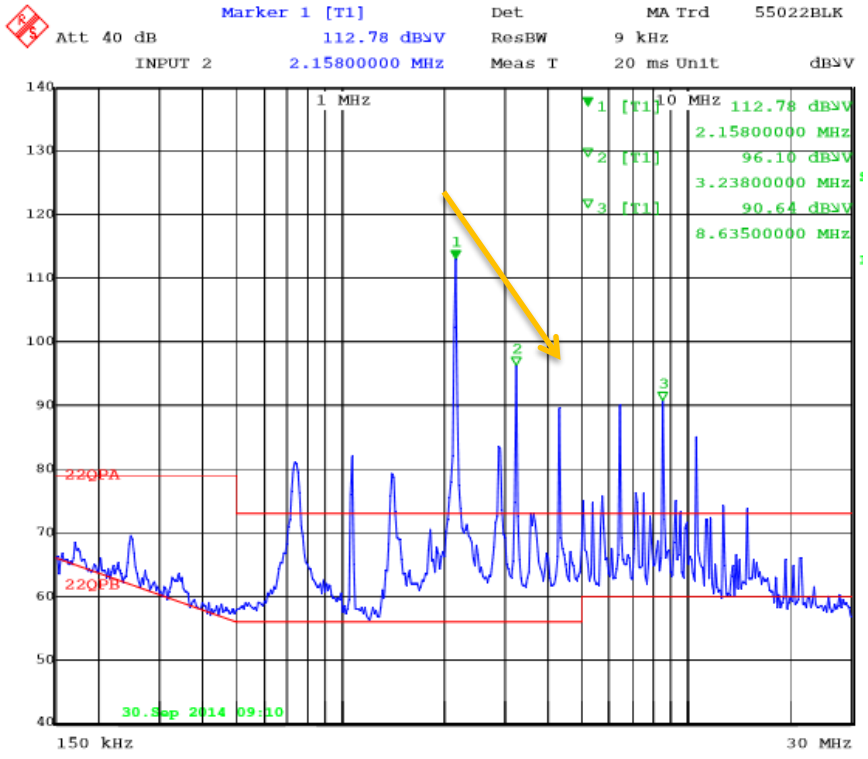
L1 and L2 CE, NO FILTER, 400Vin, 1.8kW 32A out





CM and DM CE, NO FILTER, 400Vin, 1.8kW 32A out





VICOR

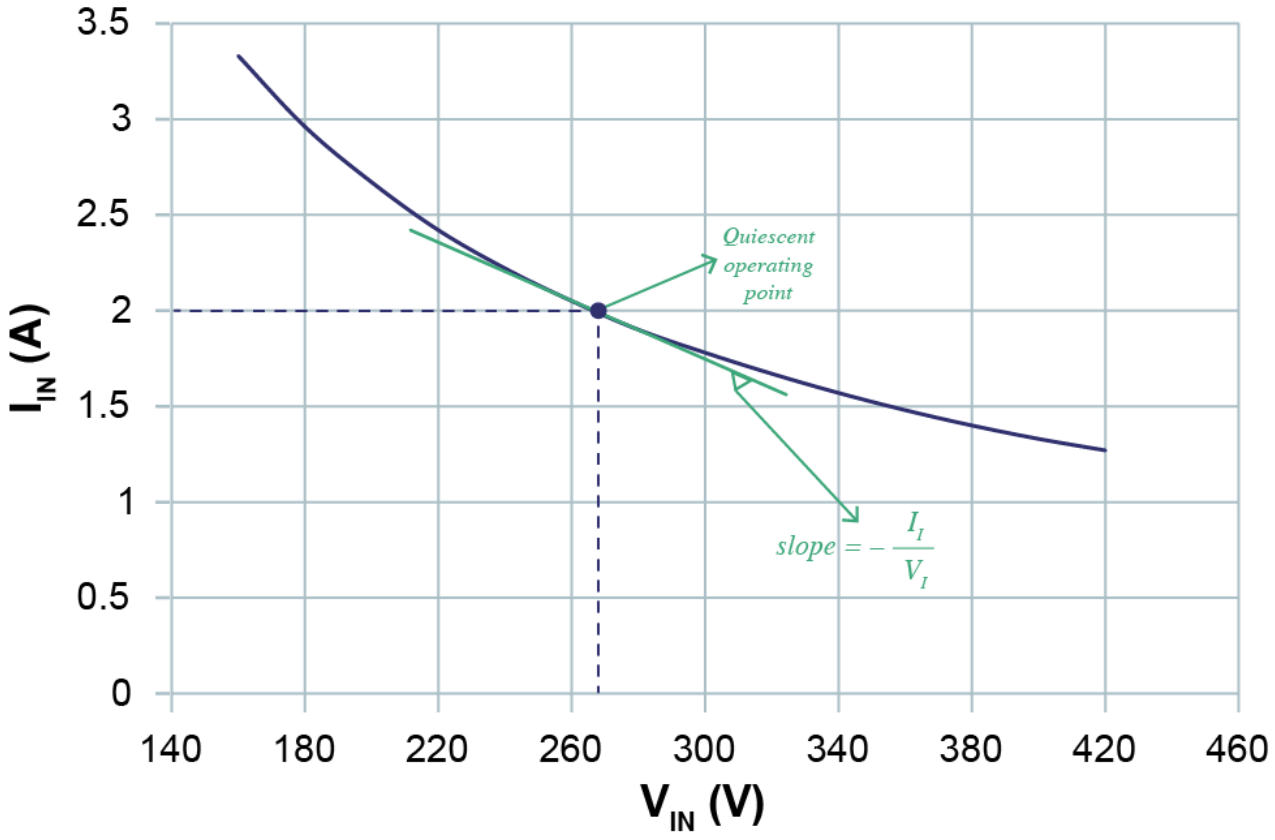
Modular Solutions for Your Power System

Input Impedance/Stability Effect on Conducted Emissions

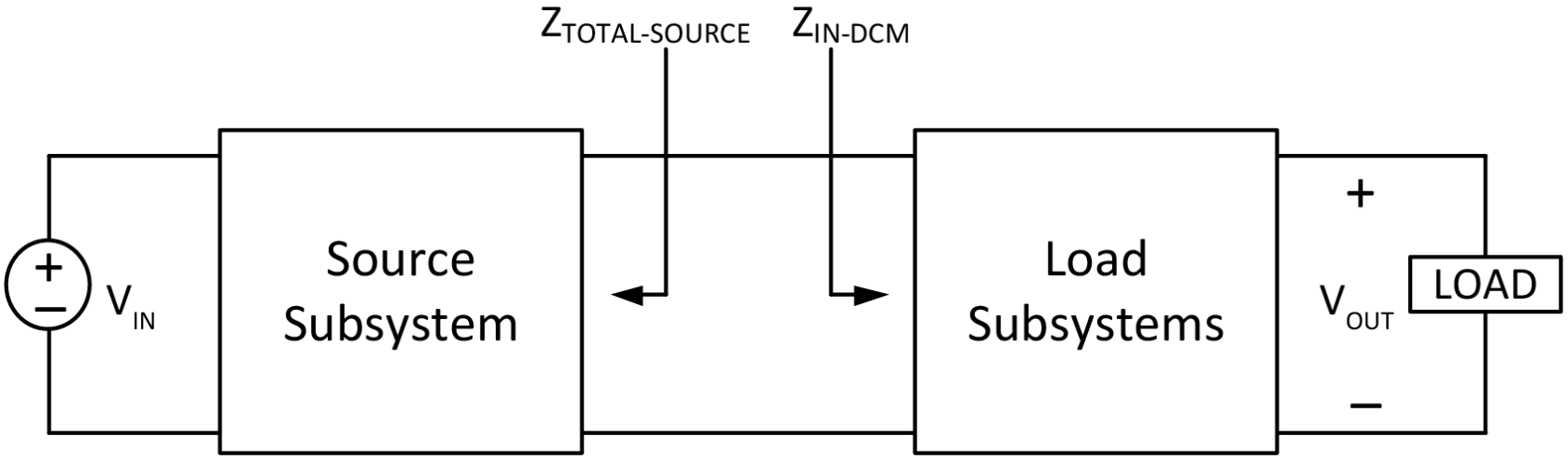
Filters Can Cause Conducted Emissions Failures

- **Filters can cause instability problems with AC/DC and DC/DC converters due to negative input impedance**
- **Oscillation due to instability can sometimes be seen on conducted emissions tests**
  - The key characteristic is a wide frequency span of high noise currents.
  - PWM based noise currents typically have a narrow frequency span that is smaller than the EMI receiver bandwidth.
- **The other important identifying characteristic is that PWM based noise currents have clear harmonics**
  - Filter stability issues typically don't, although they can MIX with PWM noise

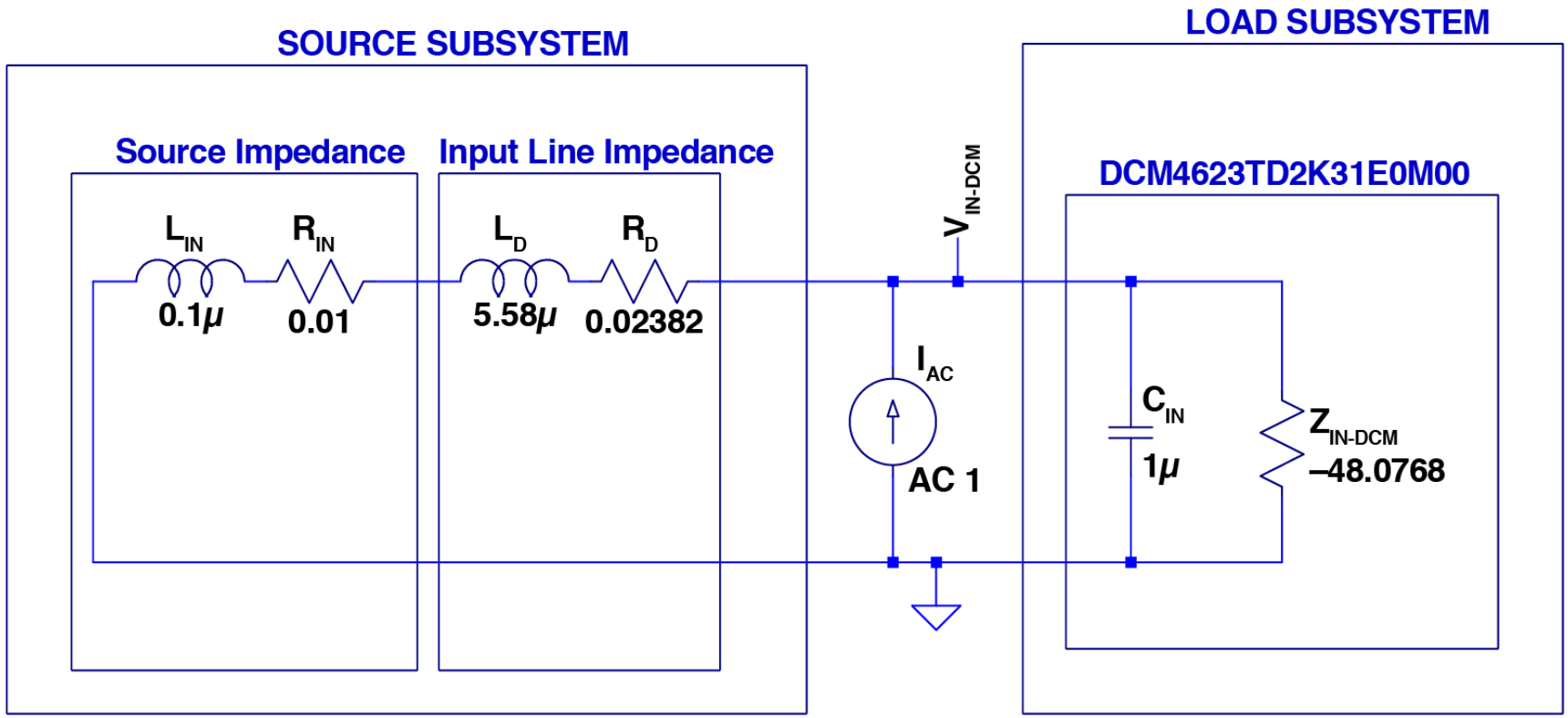
Vin Vs. Iin at a DC-DC Converter with constant Pout



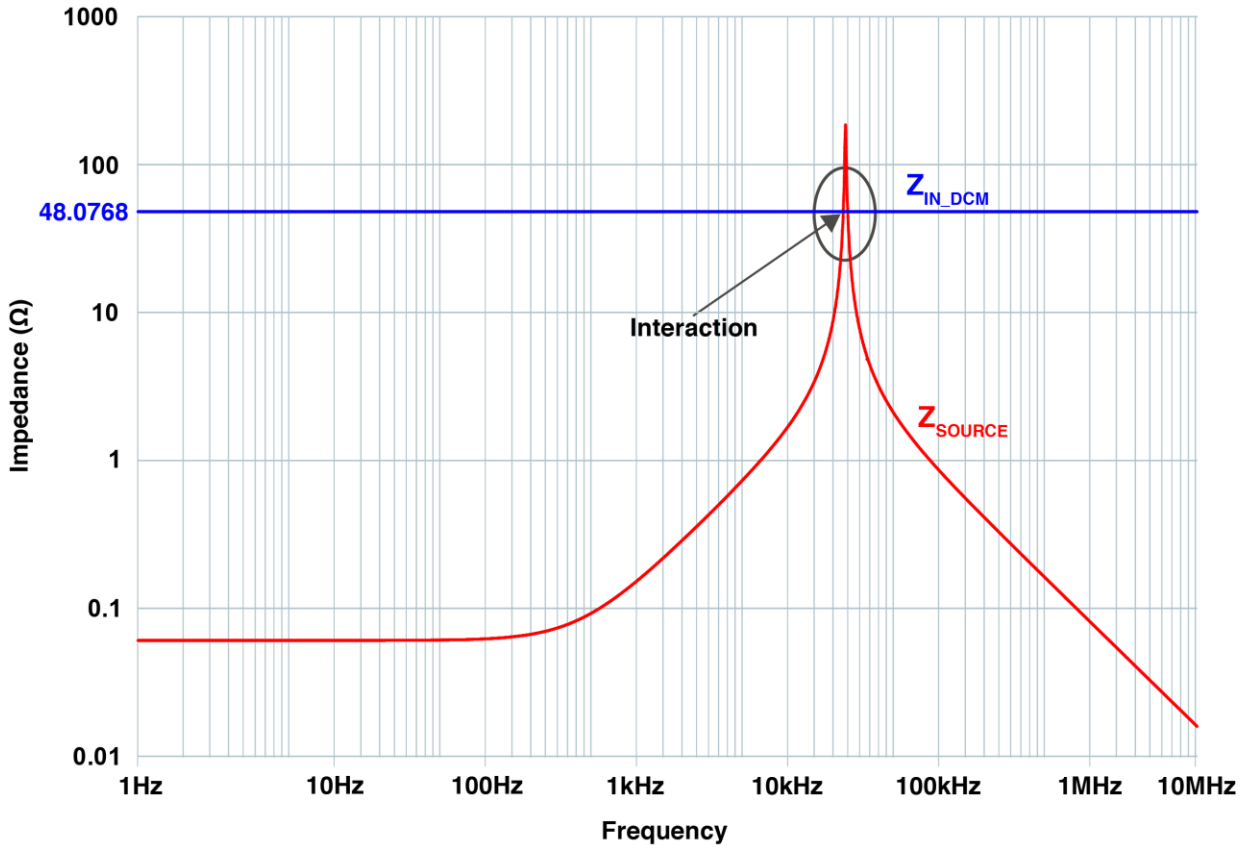
Interacting Source and Load Systems



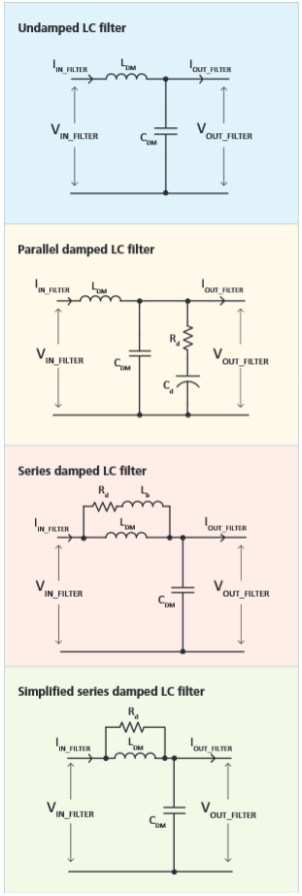
Source and Load subsystems without decoupling Cap, input EMI Filter

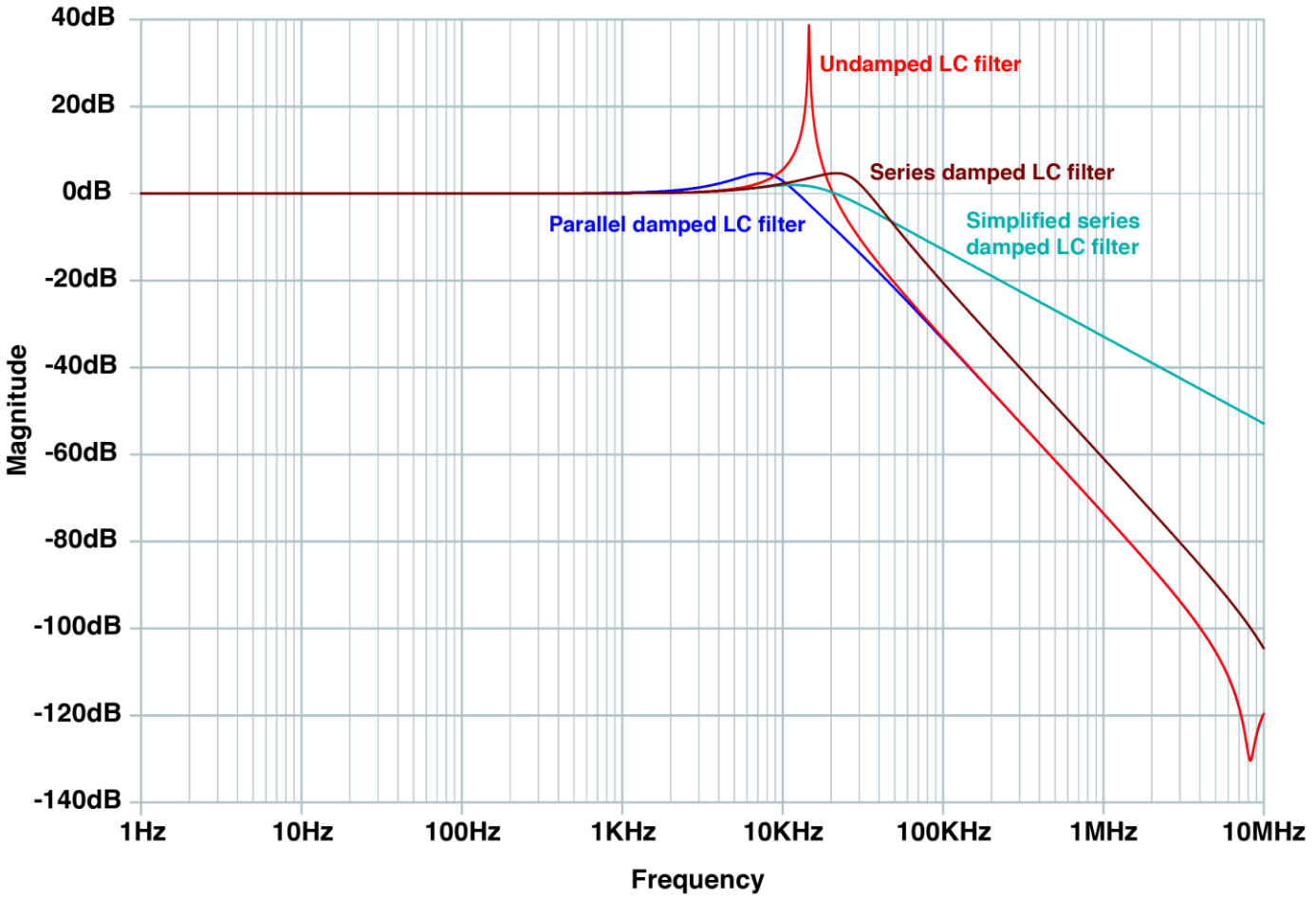


Filter Output Impedance interaction with DCM input Impedance



Filters Frequency Response Plots





VICOR

Modular Solutions for Your Power System

COMPONENTS • POWER • EASE-OF-USE • PERFORMAN
INOVATION • EFFICIENCY • EXPERTISE • CONFIGURA
ME • VOLUME • RELIABILITY • FLEXIBILITY • LONGEVI
MWORK • PROVEN • DENSITY • QUALIFIED • COMPE
SOLUTIONS • INTEGRATION • SUPPORT • OPPORTUNI

Summary

Conducted Emission Troubleshooting Summary

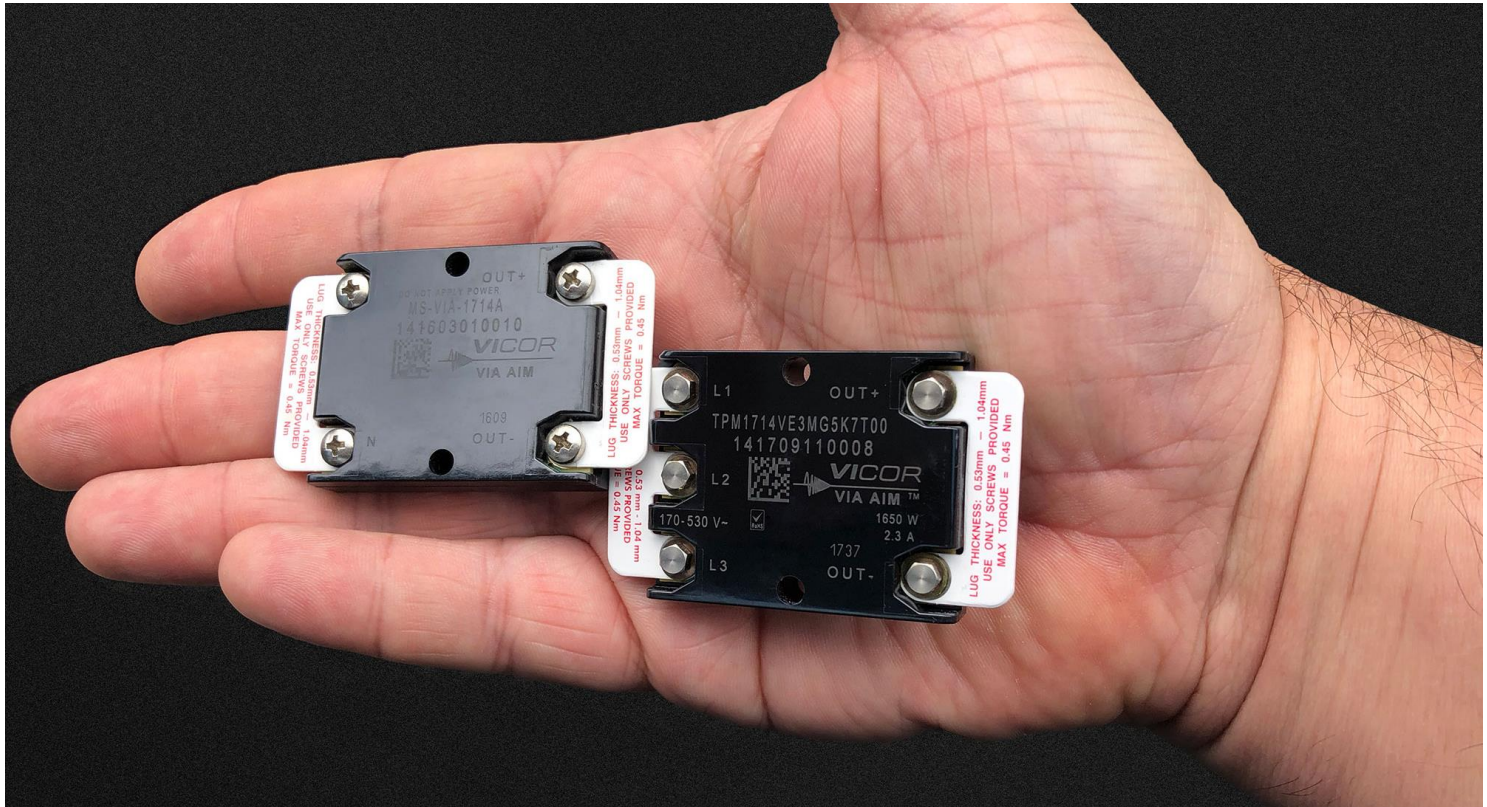
- **To identify the noise generating suspects:**
  - Make note of the noise spectrum from each noise source
  - Consider fundamental frequency, even/odd pattern, amplitude decrease in series, width of each spectral line to organize noise data and simplify.
  - Shapes can indicate source, narrowest spectral lines from crystal based oscillators, wider from RC oscillators, still wider from L's and C's with high sensitivity due to value swing.
  - If two converters switch with the same signature, change input voltage, output voltage, load current, or switching frequency to give them unique signatures.
  - Match shapes to failed CE test report to find suspects.
  - Outstanding noise signatures may be due to mixing, giving f1+f2 or f1-f2 spurs.
  - Look through layout to find points of contact between suspects. The path of conducted emissions may be unintended.

Conducted Emission Troubleshooting Summary

- **To effectively filter noise currents:**
  - Understand whether noise coupling is common mode or differential mode
  - Measure to confirm high frequency impedance of filter components
    - High frequency is defined by the test standards, not your switching frequency
  - Measure at varying load current levels, input voltage, output voltage combinations to ensure performance under all operating conditions
  - Consider CM chokes to reduce saturation effects from DC current
  - Consider unintended coupling from parallel conductors which can have area reduced, or from magnetic coupling that can be changed due to spacing or axis

Conducted Emission Summary

- **Vicor addresses the solutions by:**
  - Providing filter modules such as the MFM and FIAM, with support for CE102
    - These are building blocks, multiple supplies still may need more filtering.



Conducted Emission Summary

Vicor addresses the solutions by (cont):

- **Providing noise levels on module datasheets to provide filter input data**
- **Providing a filter design tool to calculate attenuation and peaking, taking negative input resistance of the downstream DC/DC converter into account.**

Vicor can provide technical review with one of our experts around the globe.

For more support connect with a Vicor Expert at www.vicorpower.com/contact-us

COMPONENTS • POWER • EASE-OF-USE • PERFORMAN
INNOVATION • EFFICIENCY • EXPERTISE • CONFIGURA
ME • VOLUME • RELIABILITY • FLEXIBILITY • LONGEVI
MWORK • PROVEN • DENSITY • QUALIFIED • COMPE
SOLUTIONS • INTEGRATION • SUPPORT • OPPORTUNI

Thank you.

Questions?