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- ***Year 2018 Officers :***
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  - **Web Master – Joe Nghiem**
  - **Photographer – Jerry Ramie**

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Check out www.scvemc.org -> job posting

- IEEE EMC SCV members who would like to get their membership elevated to Senior Member can contact Caroline Chan . We can help you find Senior member references.

- A collection of videos consisting of a variety of lectures and instructional tutorials that the IEEE EMC society has sponsored over the years are now available for free to EMC Society member and a small fee to others.

  https://ieeetv.ieee.org/ondemand/emc

- The IEEE EMC SCV Chapter is looking for candidates for 2019 Officers.
  - Chair/Vice chair:
    - Organize adcom as needed, ensure to communicate with the host about upcoming meetings.
    - Look for speakers for the year of 2019 (allowed 3 out of town speakers, look into Distinguished lecturer from EMC-S)
    - Organize Mini Symposium, identify venues, answer questions from the vendors and attendees regarding logistics
    - Enter the meetings in advance in vtools so that they are searchable for visitors not on the mailing list
    - Present to Section the Chapter Status
    - Conduct monthly meetings
    - Post on Social Media (Facebook and Linkedin)
  - Treasurer:
    - Balance the checkbook
    - Provide a yearly budget
    - Fill in financial statements as required by Section at the end of the year

- The IEEE EMC SCV Chapter is looking for candidates for 2019 Officers.
  - Secretary:
    - Document Adcom meetings
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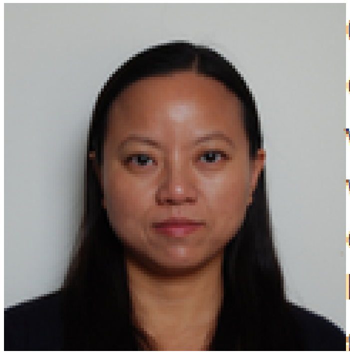
  - Institution/Marketing:
    - Emails company for chapter sponsorship and Mini Symposium Exhibitors
    - Provide benefits from the sponsorship and presence at the Mini Symposium
    - Acquire the artwork of companies logo
  - Webmaster:
    - Update upcoming speaker info
    - Create Mini Symposium Registration page
    - Maintain www.scvemc.org

Title : EMC Design Considerations for Sustainable Energy Applications

Guest Speaker : Michelle Liu

Abstract: Over the past fifteen years, there has been increased use of electronic power processing in sustainable energy applications, which includes electric vehicles, PV system, energy storage systems and other renewable applications. The emergence of faster advanced semiconductor devices provides an opportunity for a higher switching frequency of the power converters, but aggravates electromagnetic interference (EMI) problems in the system. EMI filters are unavoidable parts of power electronics systems and make up a significant portion of their total volume and weight. This presentation of author's recent research and engineering effort towards unveiling some complex EMC regulations, design process and practical design challenges. Some future research areas are also discussed regarding possible improvements in EMC design improvements through system-level optimization, circuit topology selection and EMI filter architecture..

Biography



Qian (Michelle) Liu, Ph.D. Michelle is a staff power electronic design engineer at Tesla, focusing on EMC designs for electric vehicles and Tesla energy products. Prior to joining Tesla, she worked at Intersil (acquired by Renesas Electronics) as an engineering manager. She also worked as a researcher at General Electric (GE) global research center at Niskayuna, NY. Michelle graduated from Virginia tech, Center for Power Electronic Systems (CPES) with her Ph.D degree. Her research and engineering area include EMC and EMI designs and modeling in sustainable energy applications. She has published more than 20 IEEE papers.

EMC Design Considerations for Power Electronics Systems in Sustainable Energy Applications

Michelle Liu

Tesla Inc.

Agenda

- EMC Design Challenges in Sustainable Energy Applications
  - EMC regulations
  - Application challenges
- Design for EMC
  - Topology evaluation criteria
  - EMI noise generation
  - EMI filter design process
  - EMI filter design considerations
- Future Research Areas

About Tesla Inc.

Mission: Accelerate the world's transition to *sustainable energy*

Two key components help address climate change and have a positive impact on the world:

- *Sustainable energy* generation
- Sustainable transportation

Energy Storage/Generation Power Electronics Figures of Merit

- Reliability
  - Less maintenance
  - Uninterrupted operating time
- Efficiency
- Cost
- Weight

Transportation Power Electronics Figures of Merit

- Reliability
  - Safety
  - Less maintenance
- Weight
  - Distance $\propto$ 1/Mass
- Cost

Model 3	MPGe	
126	131	120
Combined	City	Highway

EMC Limits for Electric Vehicles

- **Different regions around the world have different EMC specifications**
  - **Emissions**
    - Narrowband Emissions – Neutral
    - Broadband Emissions –Drive & Charging
    - Electric Field Requirement – Drive
    - Magnetic Field Requirement – Drive
    - Conducted Emissions – Charging
    - Harmonic Current Emissions – Charging
    - Voltage Fluctuations & Flicker – Charging
  - **Immunity**
    - Radiated Immunity – Drive & Charging
    - Surge – Charging
    - EFT/B – Charging

EMC Standards For Renewable Energy Applications

Harmonized standards are used to declare compliance with EU Directives.
Official Journal (OJ) 2018/C 246/01 of 2018-07-13:

Standard	Status
EN 61000-6-3:2007, A1:2011 & AC:2012	Harmonized
EN 61000-6-4:2007 & A1:2011	Harmonized
EN 61851-21-2: 2018-08-13 (DOP)	Not harmonized yet
EN 55011: 2016 & A1:2017 & prA2:2017, 2017-02-15 (DOP)	Not harmonized yet
EN 62920:2017, 2018-05-30 (DOP)	Not harmonized yet
EN 61000-6-1:2007	Harmonized
EN 61000-6-2:2005 & AC:2005	Harmonized

EMC Standards for Renewable applications are evolving!

PV Installations – Residential and Commercial

More challenges in EMC Design!

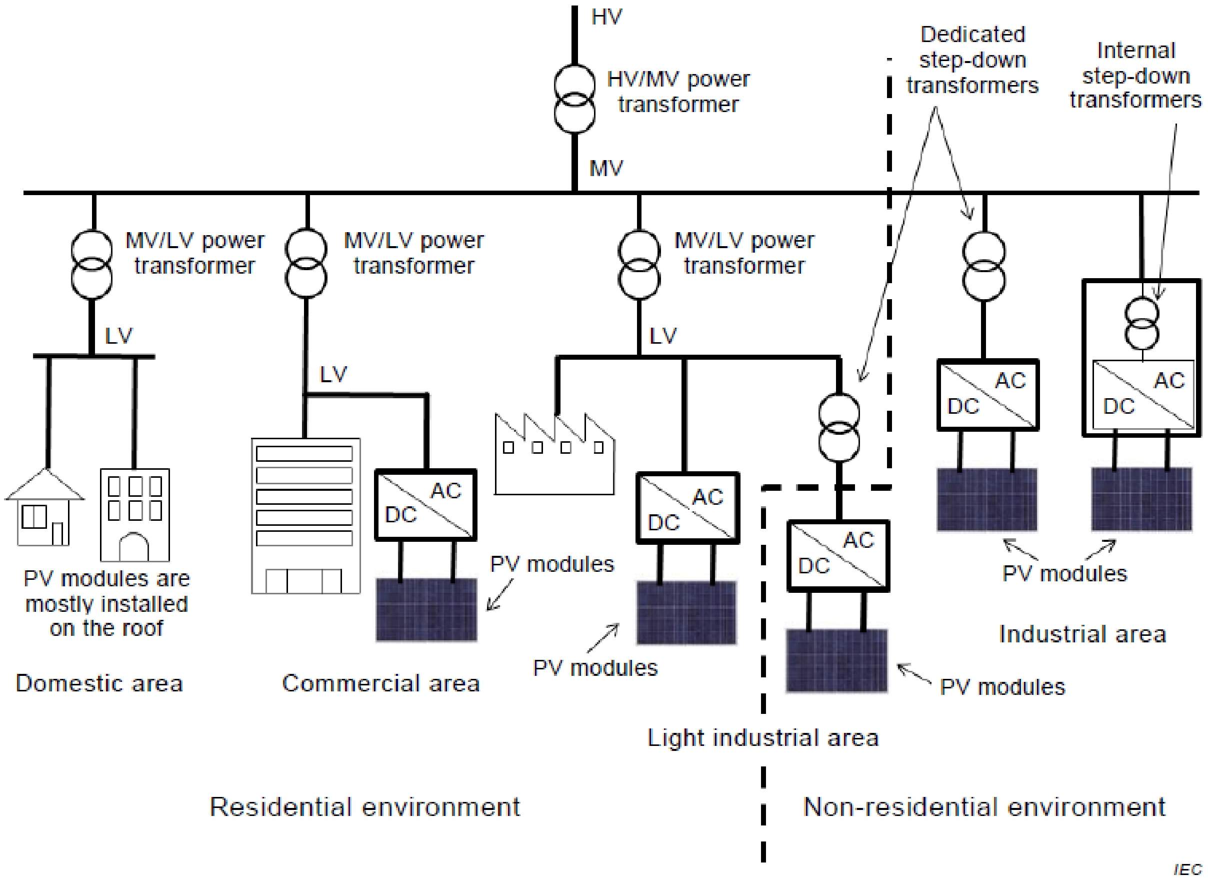
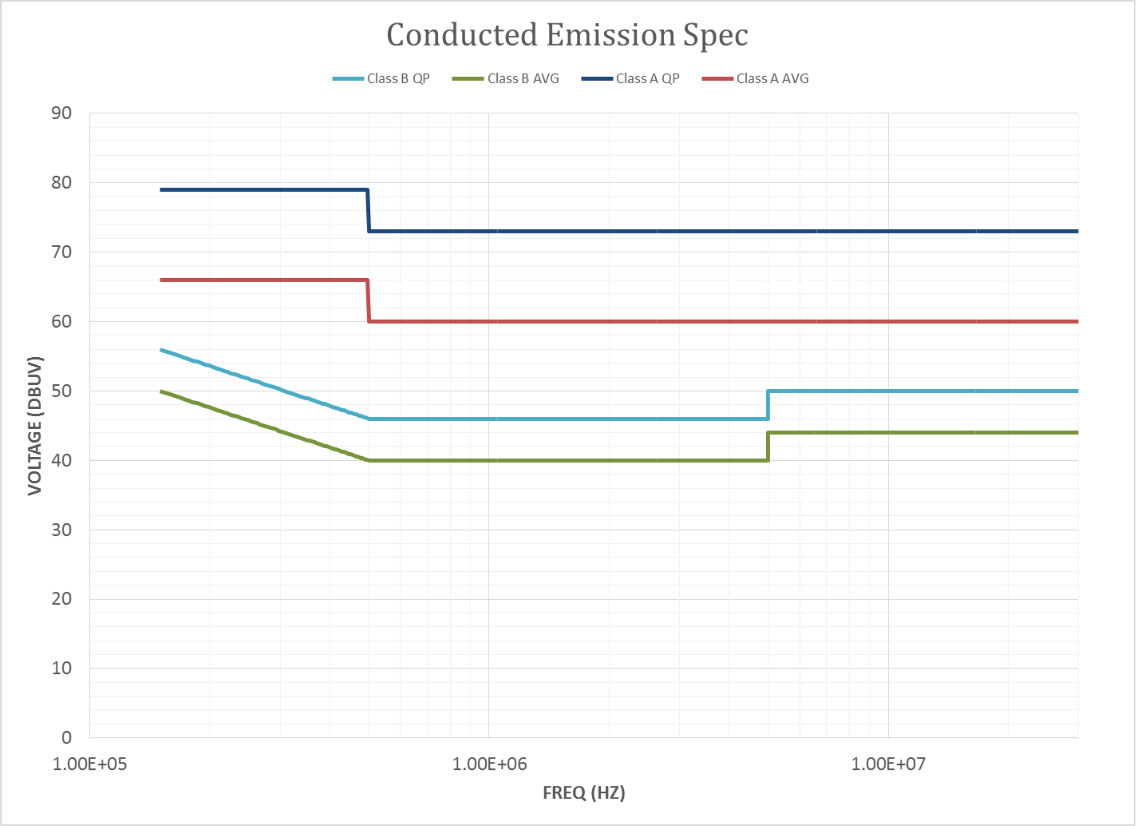


Figure 2 – Examples of installation of PV systems in both environments

AC Power Port Conducted Emission Requirements



FCC 47CFR15.107, IEC/EN 61000-6-3, IEC/EN 61000-6-4

Residential vs. Commercial: Tesla Superchargers

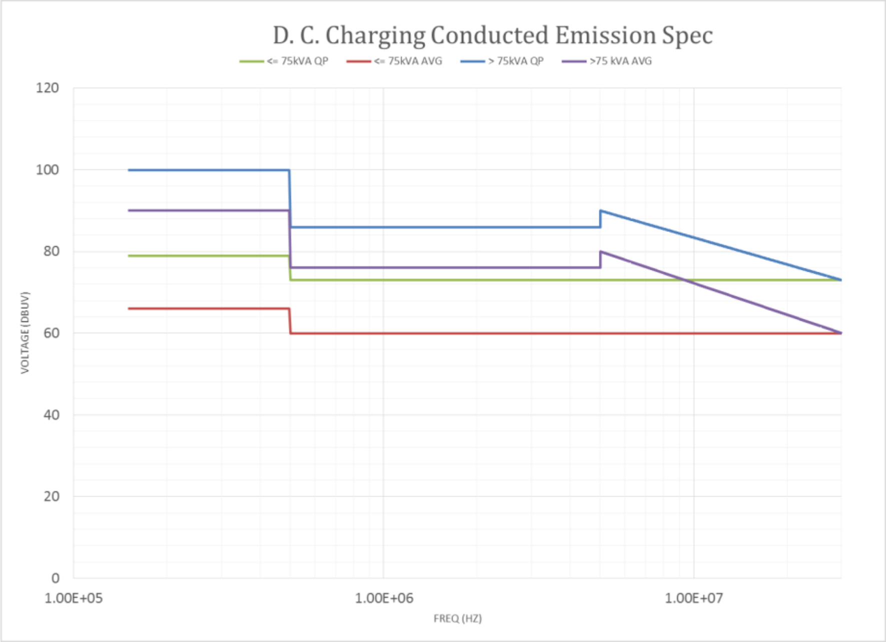
Karensmindevej 3, 5500 Middelfart, DK

1600 Laan van Europa, Dordrecht, NL

PV and Supercharging

Applicable Standards

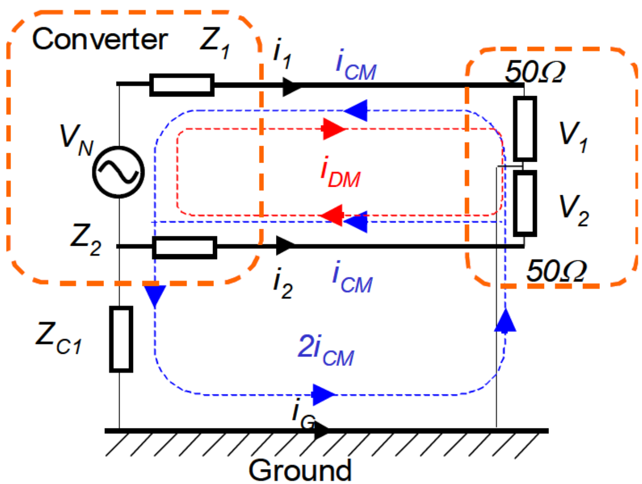
- EN62920 on PV side
- EN 61851-21-2 on Charging side

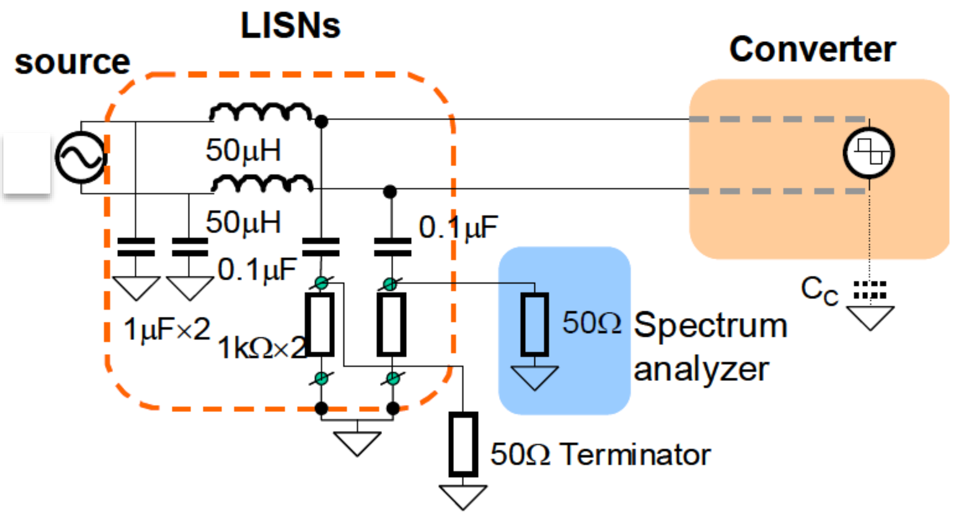


Design for EMC

- Topology Selection
- Filter Design
- Board-level and system-level
  - Layout
  - System packaging

Background: Common Mode and Differential Mode

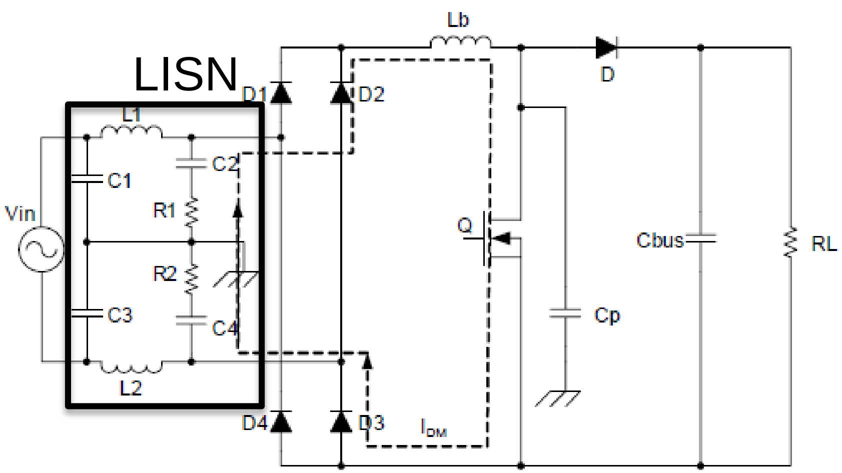


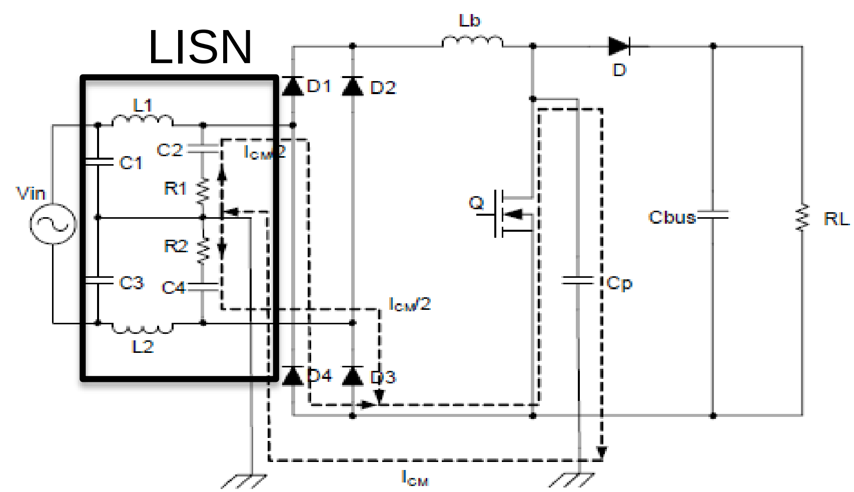


$$v_{CM} = -50 i_{CM} = \frac{v_1 + v_2}{2}$$

$$v_{DM} = 50 i_{DM} = \frac{v_1 - v_2}{2}$$

Noise Sources in Power Converters





DM noise between lines

CM noise between lines to ground

Bing Lu, “Investigation of High-density Integrated Solution for AC/DC Conversion of a Distributed Power System”, Ph. D Dissertation, 2006

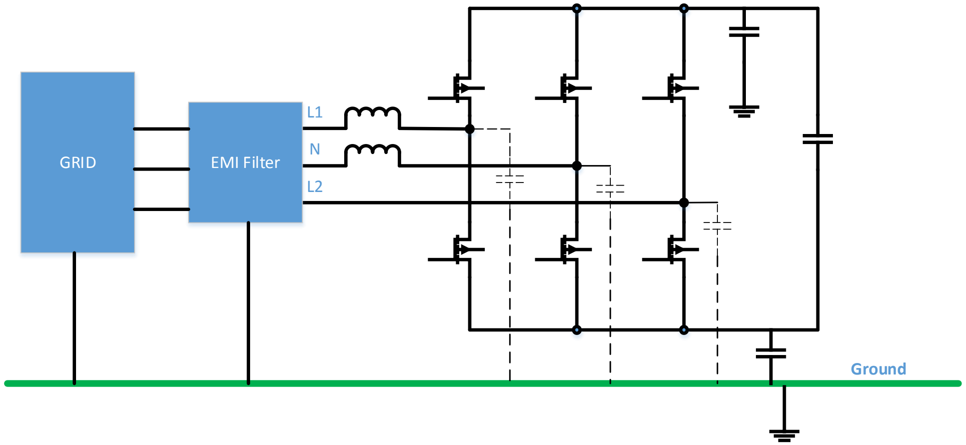
Power Converter Topology Evaluation Criteria

- Efficiency
- Weight
  - Passive components: inductors, capacitors, chokes
  - Heatsink
- Volumetric Density
  - Passive components: inductors, capacitors, chokes
  - Heatsink
- Cost

Power Electronic Topology EMC Evaluation

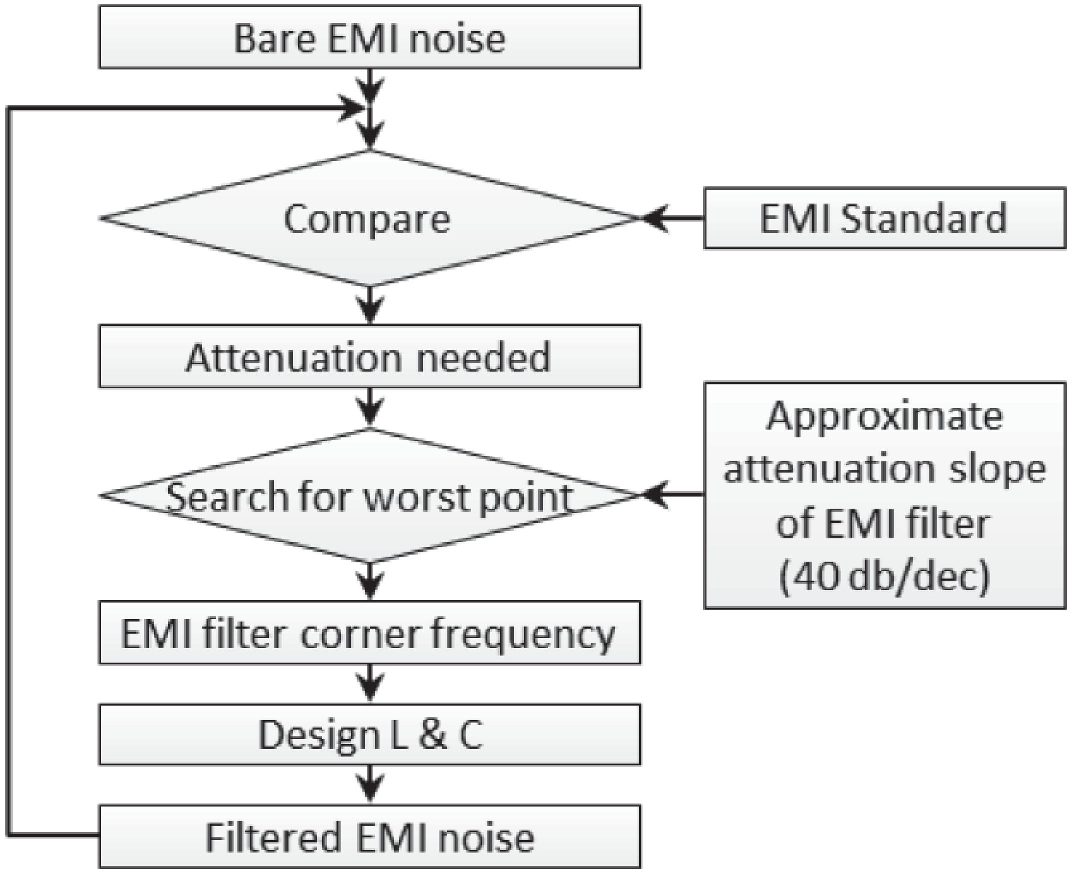
- Totem-pole topology presents highest efficiency and median EMC challenge
- Bi-directional PFC topology for energy storage application

PFC topology	Efficiency Rank	CM Voltage Rank	CM Current Rank
Boost PFC	6	1	1
Dual Boost PFC	4	5	5
Bidirectional Switches PFC	5	5	5
Two-boost–circuit PFC	2	1	1
Pseudo Totem-pole PFC		3	3
Totem-pole	1	3	3



* Qingnan Li, Michael A. E. Andersen, Ole C. Thomsen “Conduction losses and common mode EMI analysis on bridgeless power factor correction,” 2009 International Conference on Power Electronics and Drive Systems (PEDS) , pp 1255 -1260

EMI Filter Design Procedure

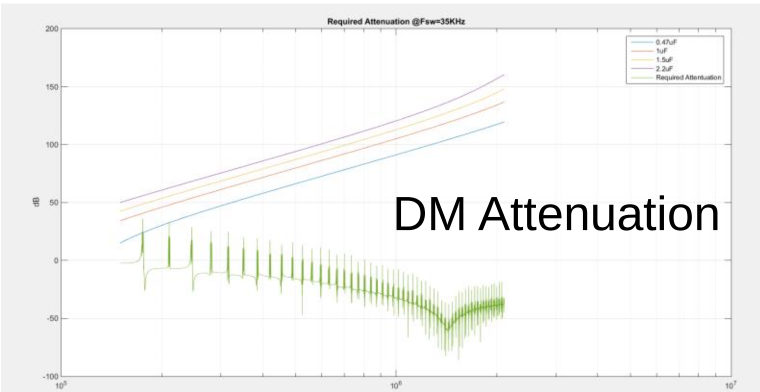


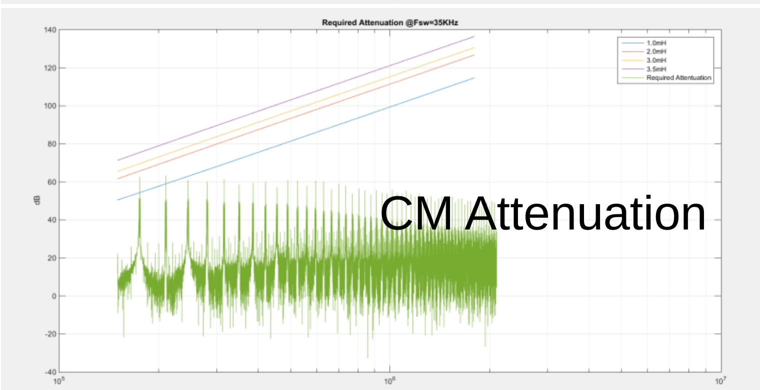
F.-Y. Shih, et al., "A procedure for designing EMI filters for AC line applications," *IEEE Trans. Power Electron.*, vol. 11, pp. 170-181, 1996

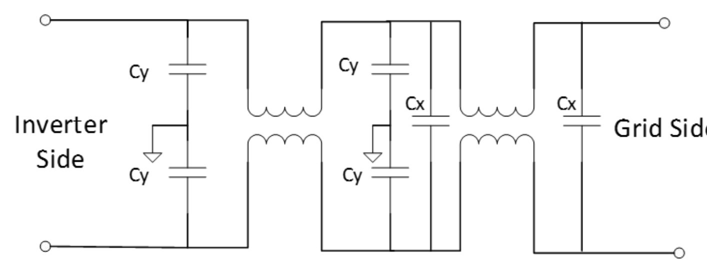
Filter Constraints & Non-Idealities

- Maximum leakage current
  - Safety spec
- Core Saturation
- Core Permeability as a function of Frequency & Temperature

Design Results - Example



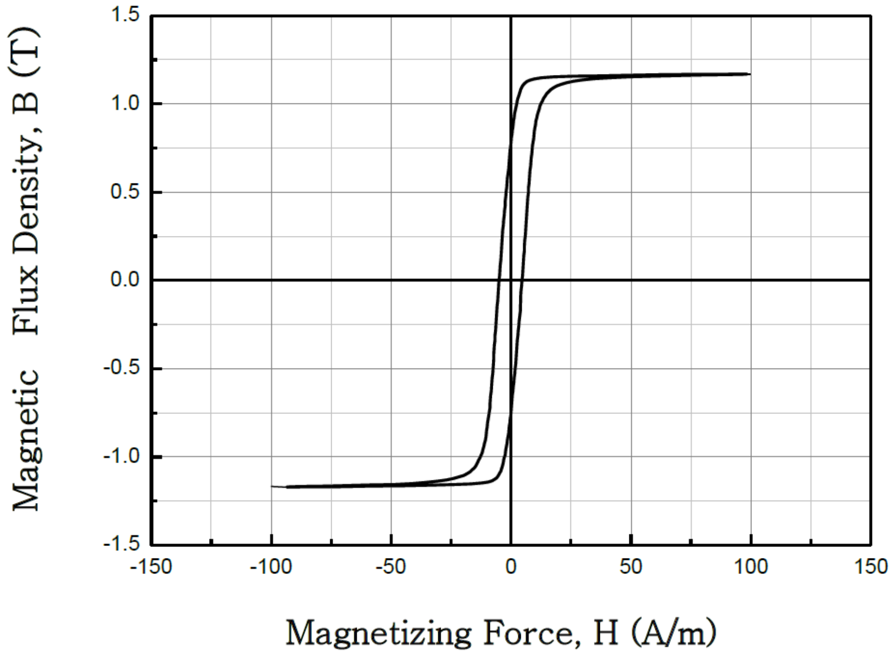




- Ldm = 10uH from CM choke leakage inductance
- Cx=1uF is sufficient
- Lcm=2.5mH, Cy=2x4.7nF meet Class B requirement
- Leakage ground current: 2.6mA <5mA

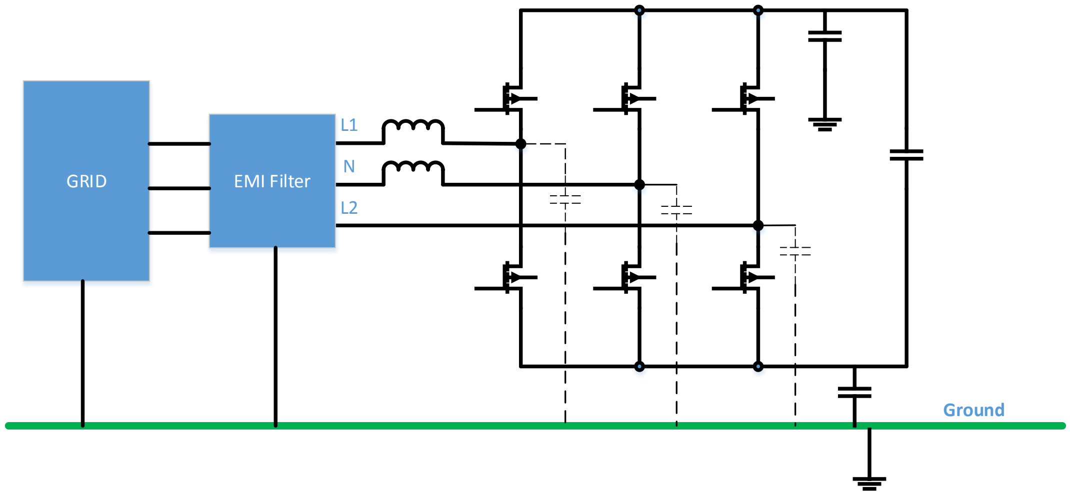
EMI Filter CM Choke Saturation

- EMI CM Choke
  - Nanocrystaline material
  - N = 12 Turns
  - Choke Isat = 300mA



- Choke saturation current is significantly high, compared with leakage current (5mA).
- Will the circuit reach 300mA CM current?

Choke Saturation in Totem Pole Topology



- Adding Y-caps to contain CM current inside converter is a common practice
- A 500pF Y capacitor between DC to ground can easily generate 750mA ground current, which could saturate the common mode choke
- Removing Y capacitor between DCbus to ground will have consequences on EMI noise containment
    - More attenuation needed for suppress CM CE noise
    - More challenging for radiated emission

What Else Could Saturate Core?

- Use leakage inductance as DM Inductor
  - No additional component added on board, especially beneficial to high-power application
  - How to choose leakage inductance? More turns to achieve higher inductance?

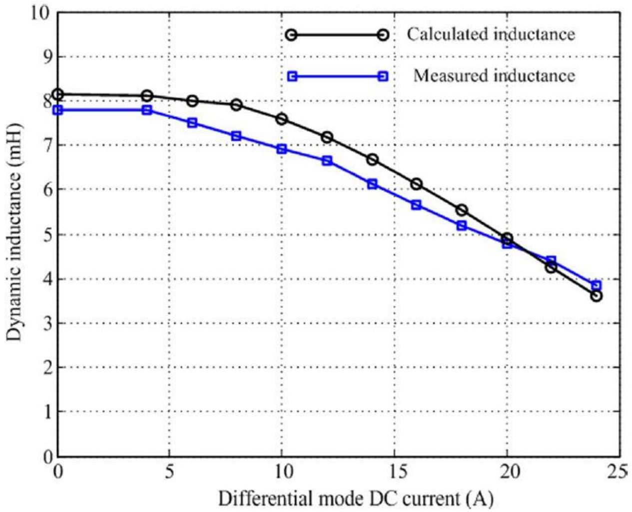
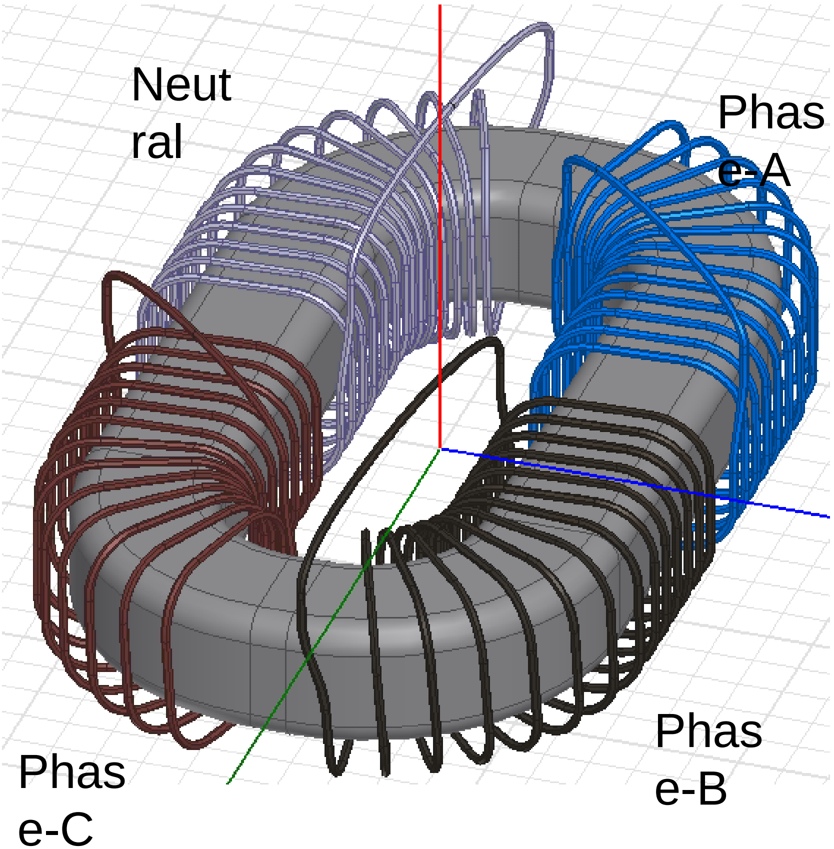


Fig. 7. Comparison of calculated and measured dynamic inductances.

Henglin Chen, Zhaoming, Qian, Shaodong Yang, Christian Wolf ," Fiinite-Element Modeling of Saturation Effect Excited by Differential-Mode Current in a Common-Mode Choke", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 24, NO. 3, pp. 873-876,MARCH 2009

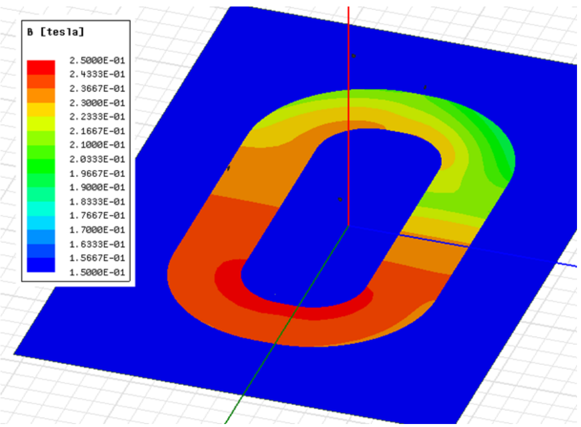
Impact of Leakage Inductance



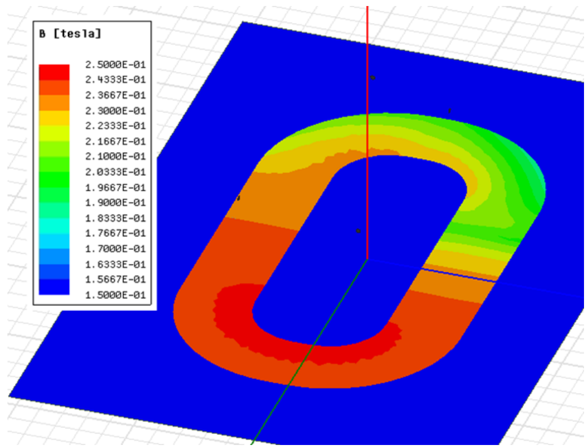
- 4 Winding 3 PH CM choke
- Core material : Ferrite
  - Bsat <= 0.25T
- Operating condition:
  - Three phase Y connection
  - Single phase
  - Three phase delta connection

Impact of Leakage Inductance

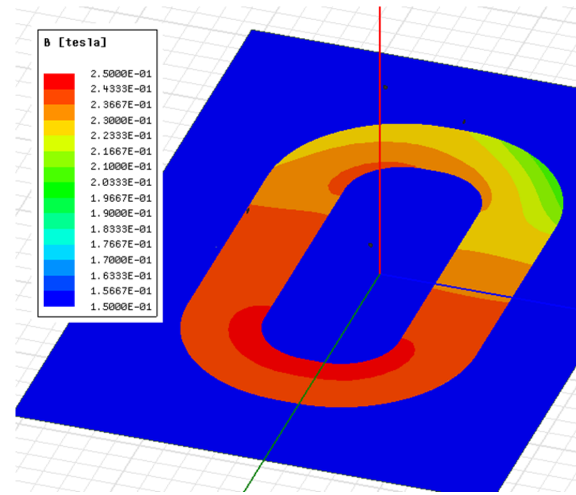
12 Turns



14 Turns



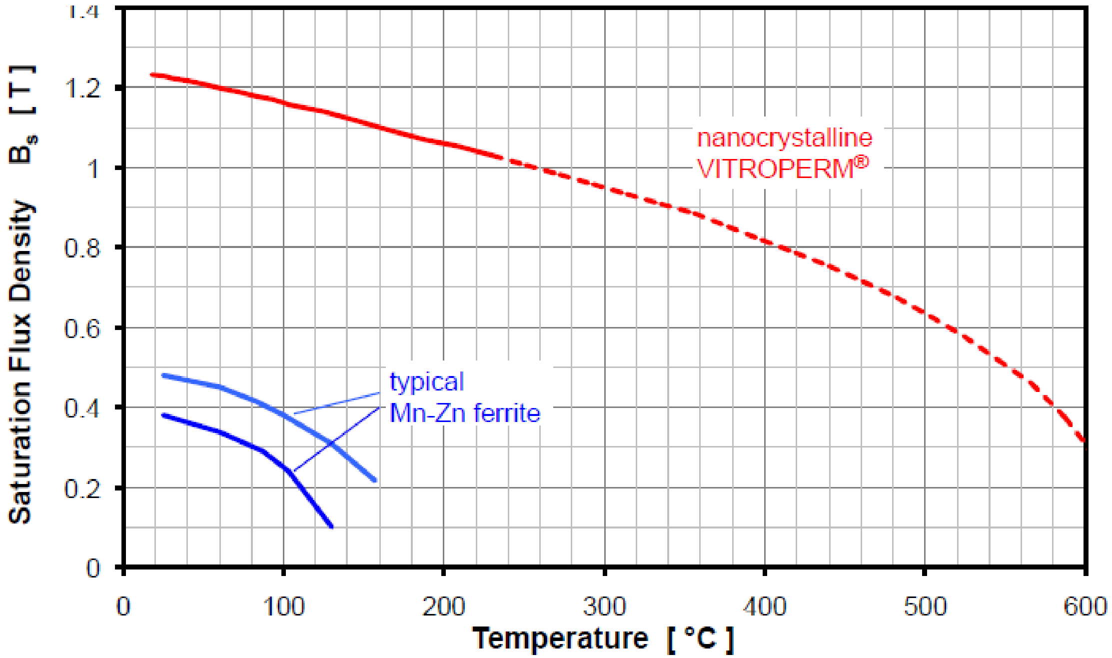
16 Turns



- Phase A is at peak current, Phase B and C carries return current
- Leakage inductance increases with more turns
- All cases saturate the core as the max Bsat = 0.25T. More turns, core saturates more

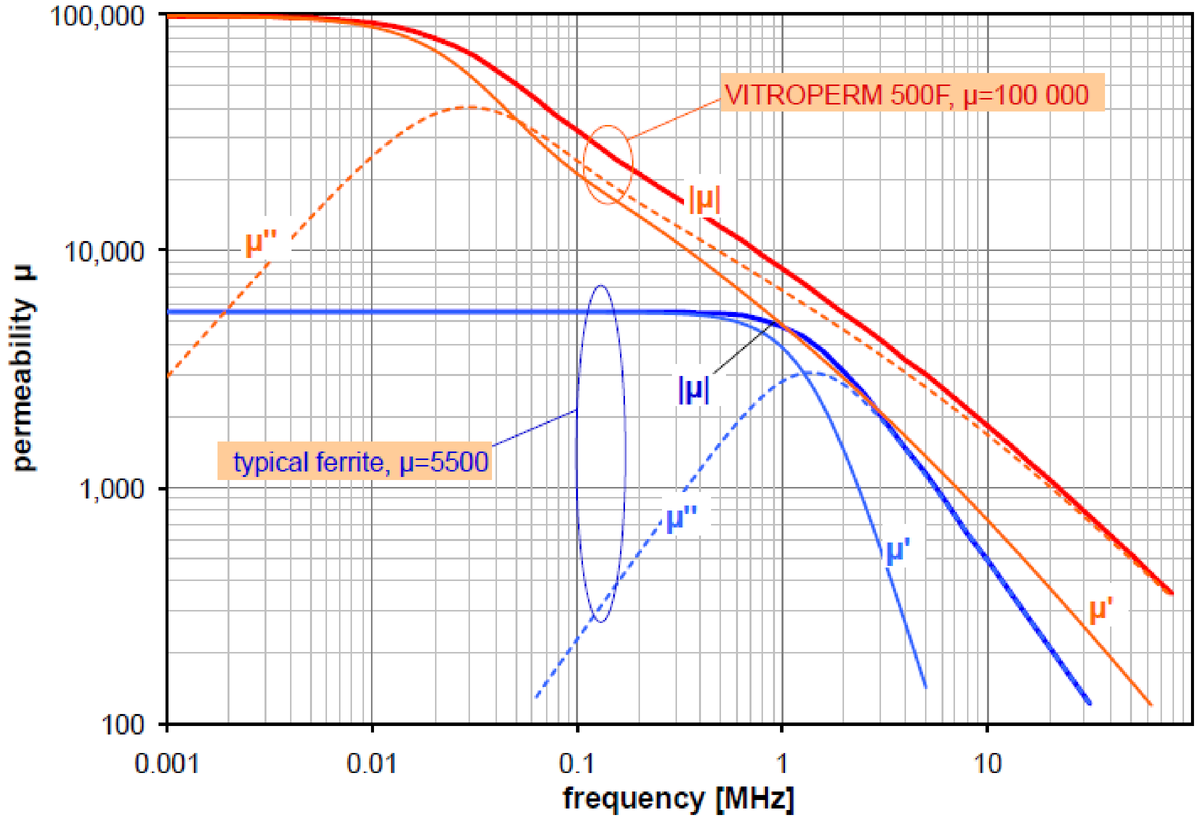
Core Saturation Flux Density Vs Temperature

- Ferrite and Nano crystalline cores



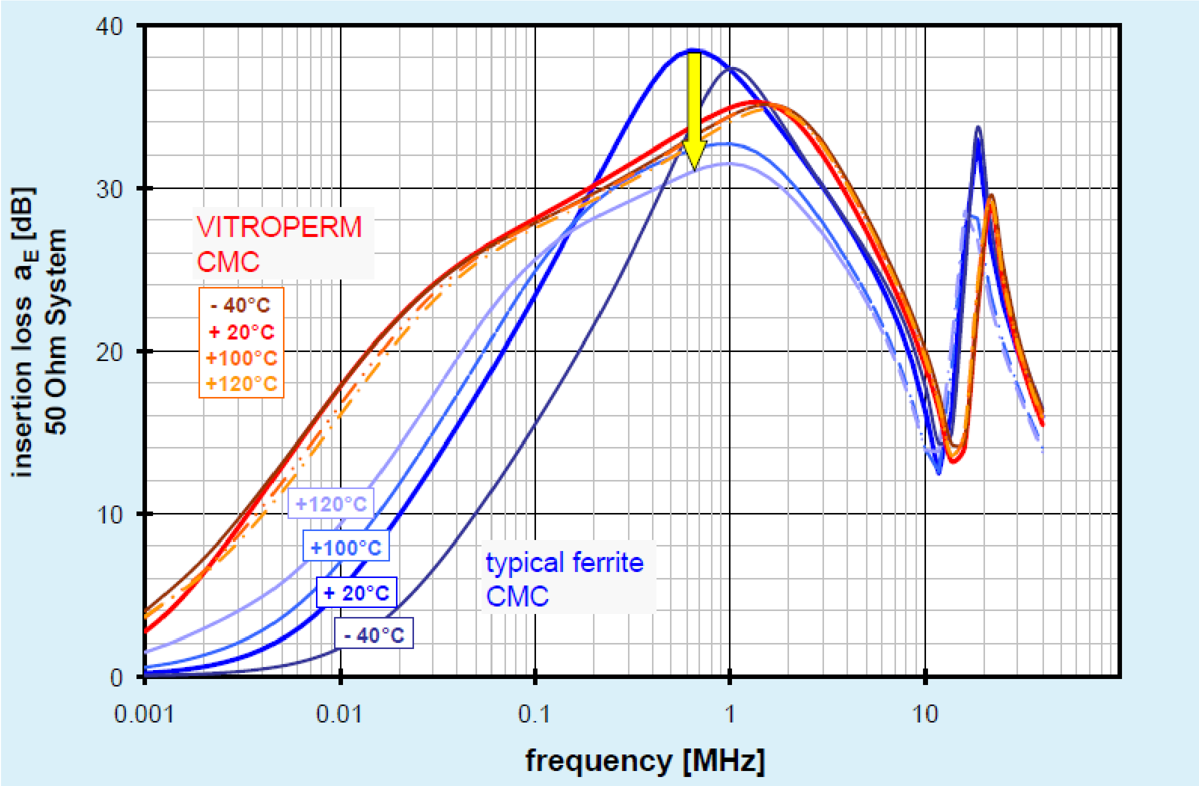
Nano-crystalline cores have better temperature characteristics

Core Permeability Vs Frequency



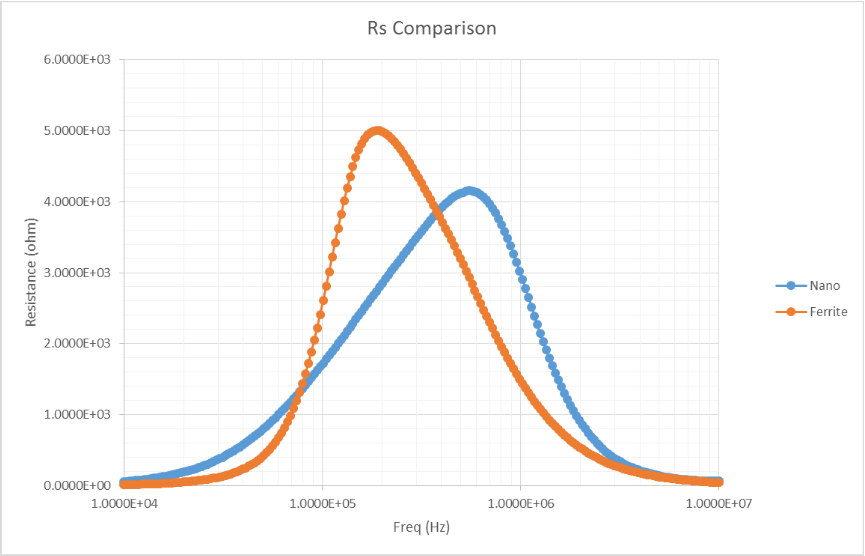
Permeability of Ferrite and Nano crystalline materials decreases at higher frequencies

Core Material Insertion Loss Vs Frequency



CM choke with Nano-crystalline cores have more attenuation in the lower frequency range, but less attenuation towards high-end of Conducted Emissions range

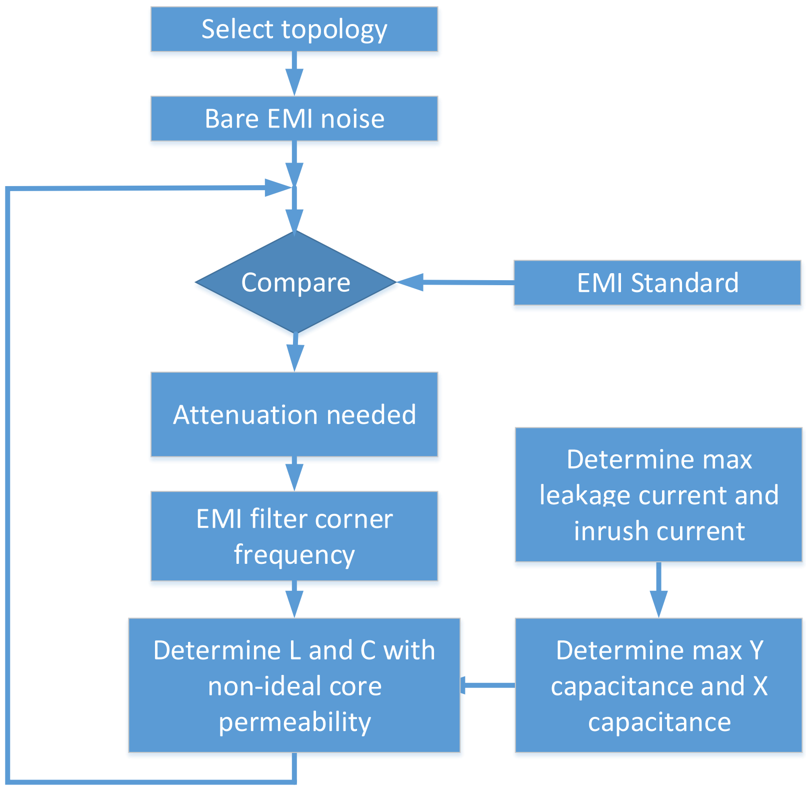
Ferrite Vs Nano Common Mode Choke Comparison



- Each choke has different frequency response, circuit-level attenuation effectiveness is also affected by bare noise profile
- Permeability change vs. frequency & choke parasitic need to be built in design program

Summary of EMC Filter Design Process

Consider non-ideal circuit operation and material characteristic during design process

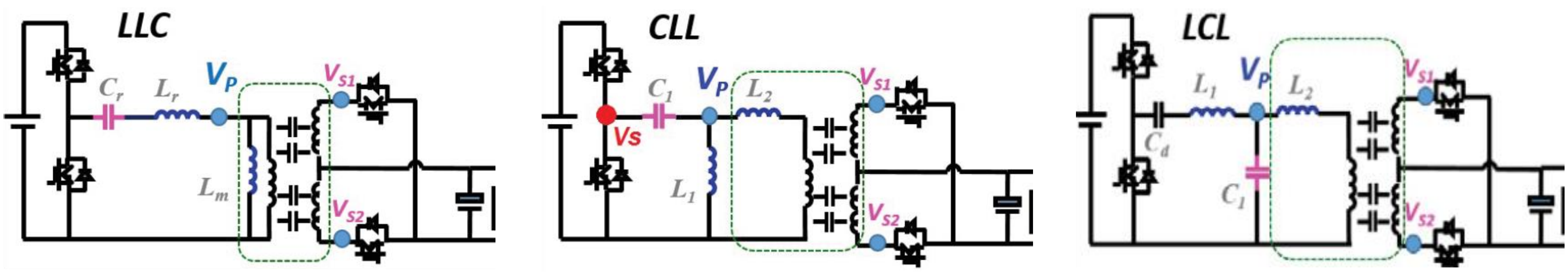


Future Areas of Research in EMC Design

- EMC challenges in systems with multiple converters
  - Understand and model noise interactions among converters
  - Centralized EMI filtering strategy vs. distributed strategy

Future Areas of Research in EMC Design

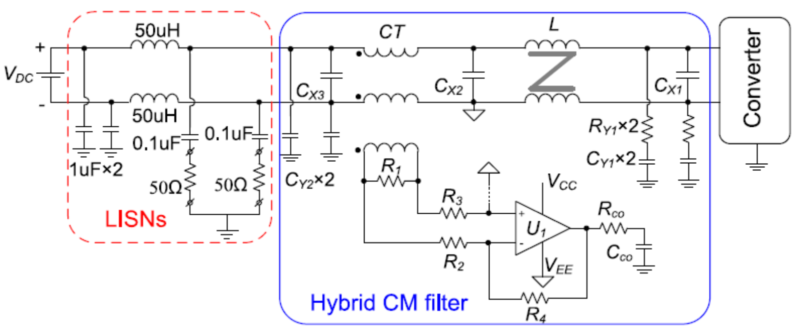
- Soft-switching/resonant converter topologies
  - Higher switching frequency
  - Different implication of noise profile
    - Varying DM current and CM voltage
    - Define worst case of noise generation

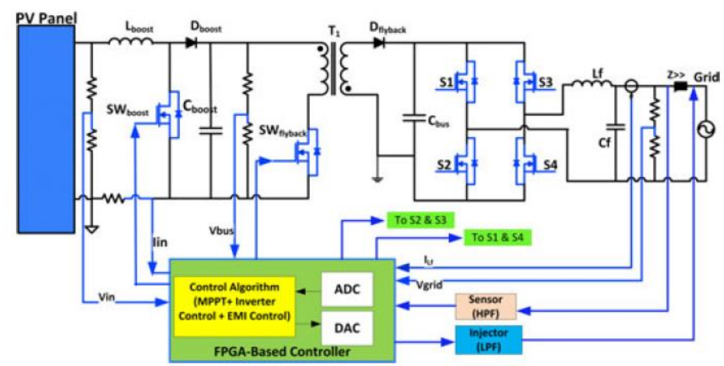


Yuchen Yang; Daocheng Huang; Fred C. Lee; Qiang Li; "Analysis and reduction of common mode EMI noise for resonant converters", 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014, pp. 566 - 571

Future Areas of Research in EMC Design

- Decrease EMI filter weight and volume
  - Hybrid Filter Design
  - Novel control schemes to optimize EMI noise profile





- Yongbin Chu, Shuo Wang, and Qinghai Wang, "Modeling and Stability Analysis of Active/Hybrid Common-Mode EMI Filters for DC/DC Power Converters", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 31, NO. 9, SEPTEMBER 2016, pp. 6254 - 6263
- Djilali Hamza, Mei Qiu, and Praveen K. Jain, "Application and Stability Analysis of a Novel Digital Active EMI Filter Used in a Grid-Tied PV Microinverter Module", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 6, JUNE 2013, pp. 2867 – 2874
- Dushan Boroyevich, Xuning Zhang, Hemant Bishinoi, Rolando Burgos, Paolo Mattavelli, Fred Wang, "Conducted EMI and Systems Integration", CIPS 2014, February, 25 – 27, 2014, Nuremberg/Germany

Summary

- Reviewed applicable EMC standards for sustainable energy applications
- Reviewed CE EMI noise containment
  - Topology evaluation criteria
  - EMI filter design procedure
  - EMI filter design considerations
- Areas of research

Thank You!