Analysis and Suppression of Conductive and Radiated Electromagnetic Interference for Flyback Converters

(Aug. 21th, 2025)

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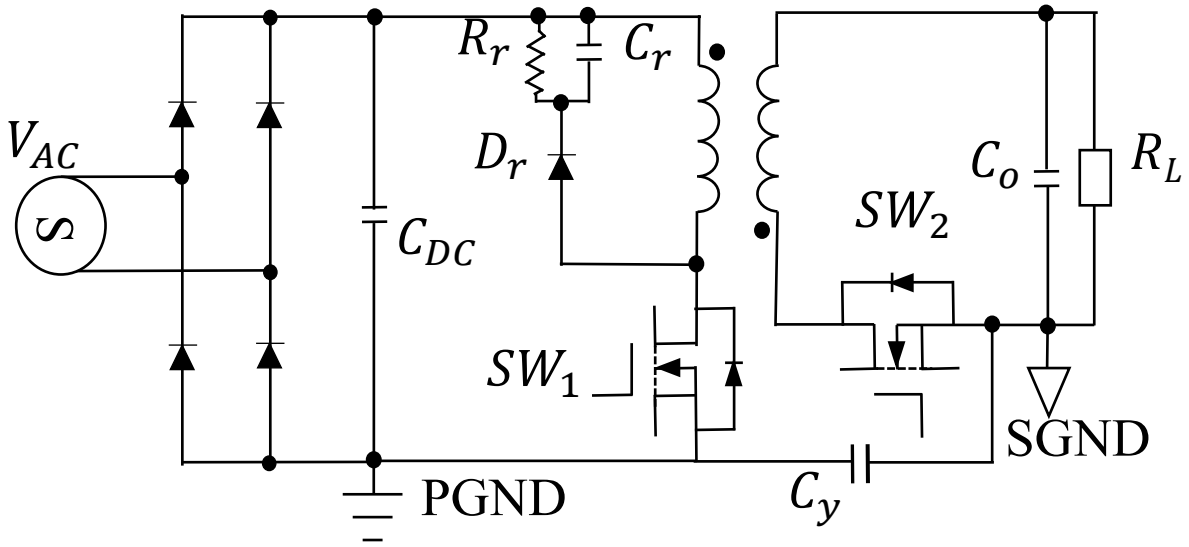
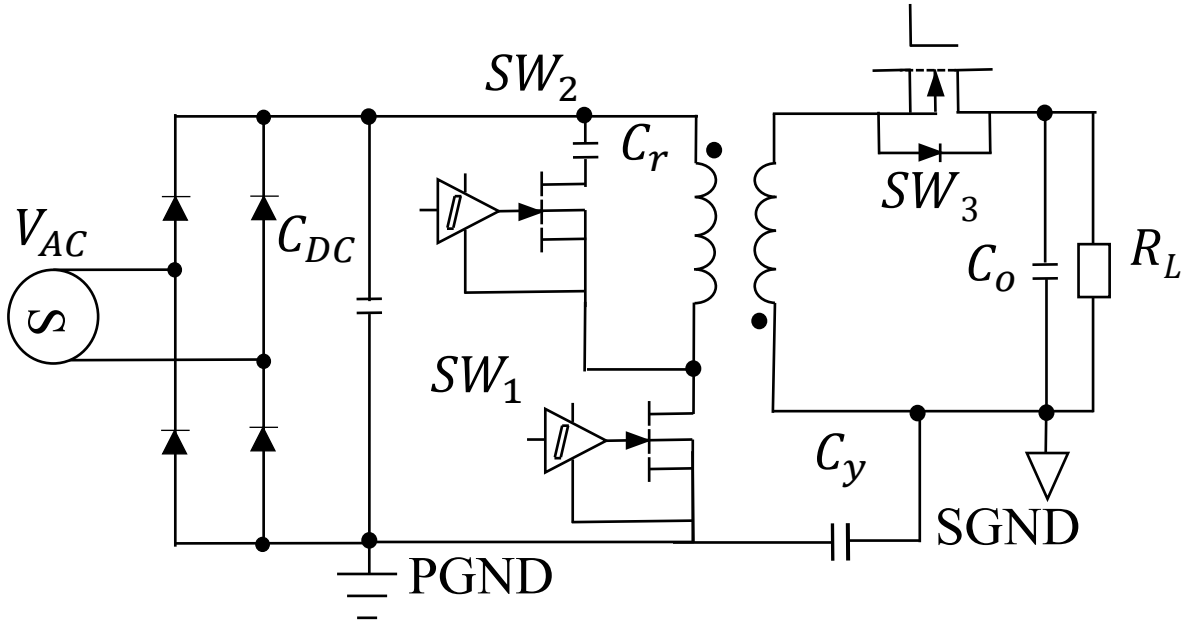
Popular Flyback Converter Topologies



Flyback Converter with Synchronous Rectifiers / Diodes

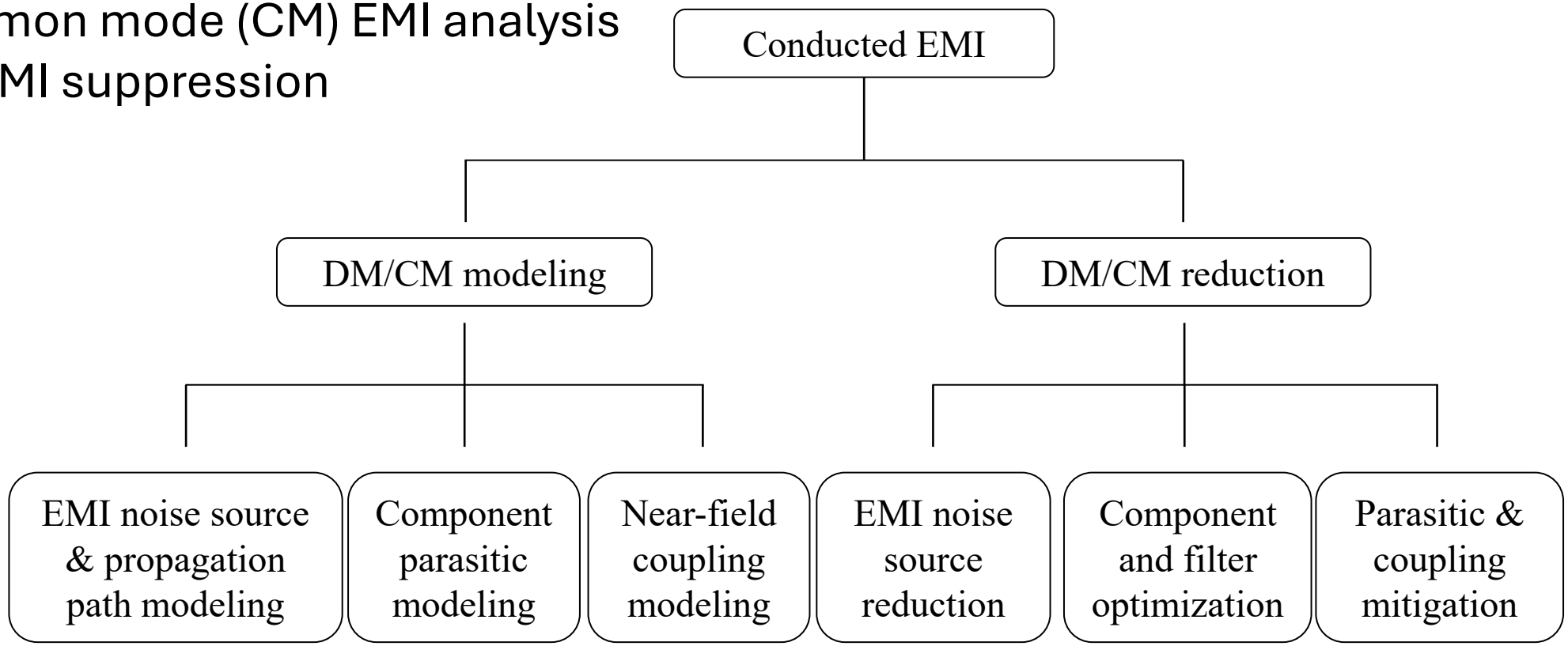
Active Clamped Flyback Converter with Synchronous Rectifiers / Diodes



Conductive EMI

Conductive EMI:

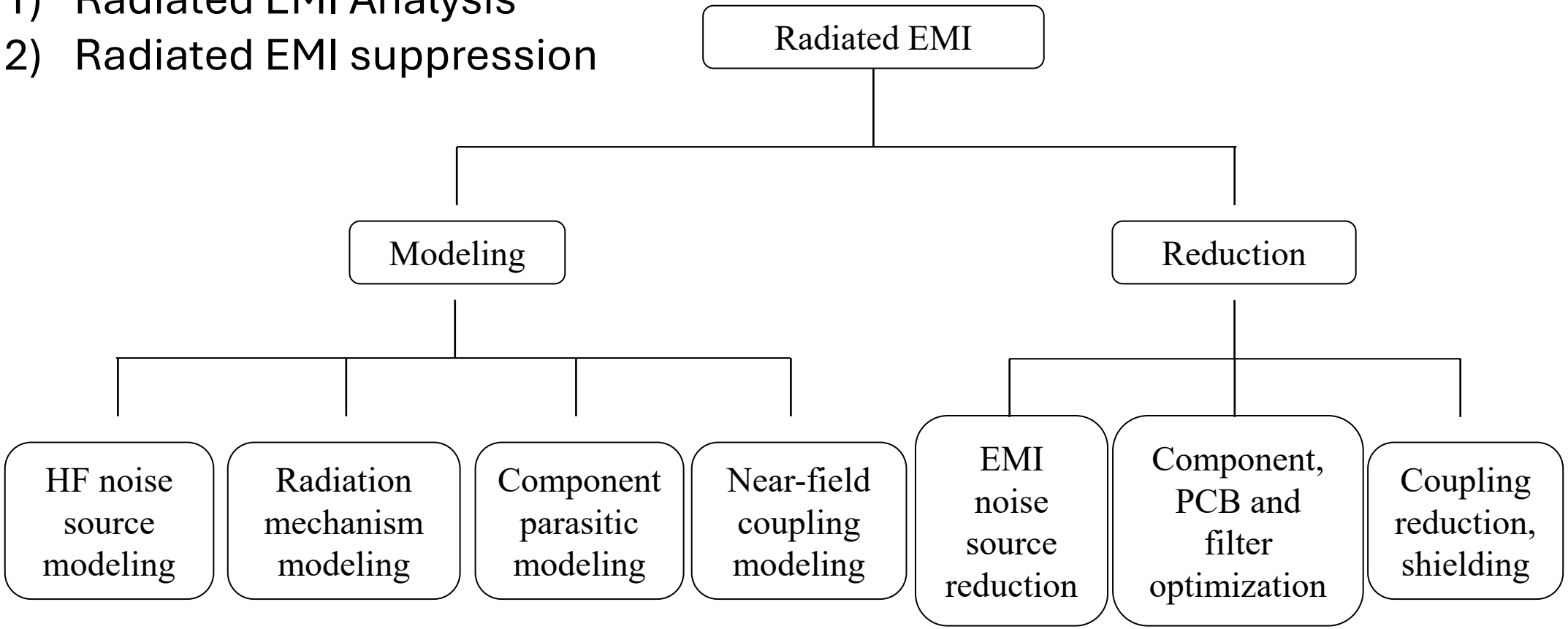
1) Differential Mode (DM) EMI analysis
2) DM EMI suppression
3) Common mode (CM) EMI analysis
4) CM EMI suppression



Radiated EMI

Radiated EMI:

1) Radiated EMI Analysis
2) Radiated EMI suppression

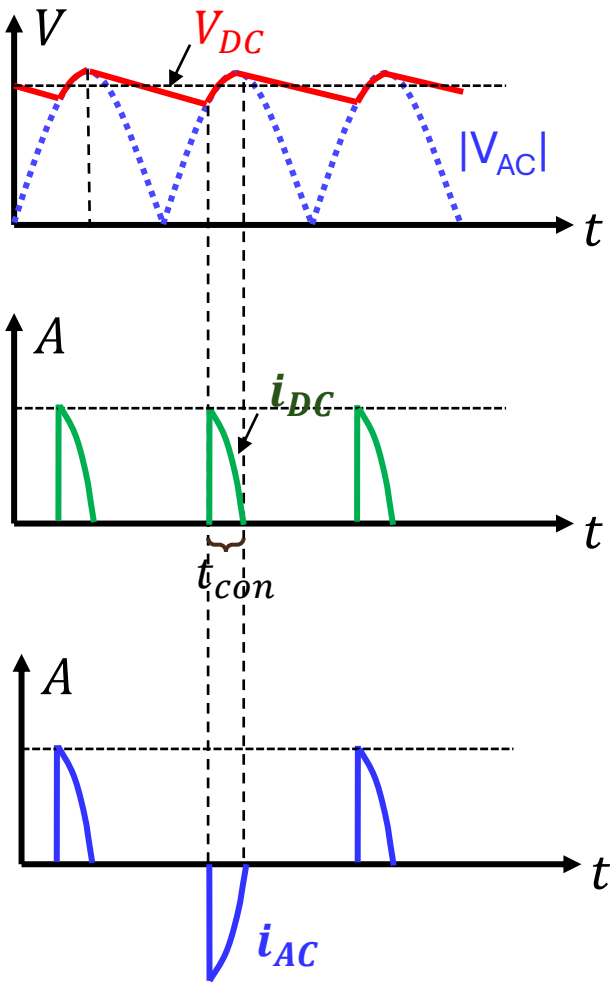


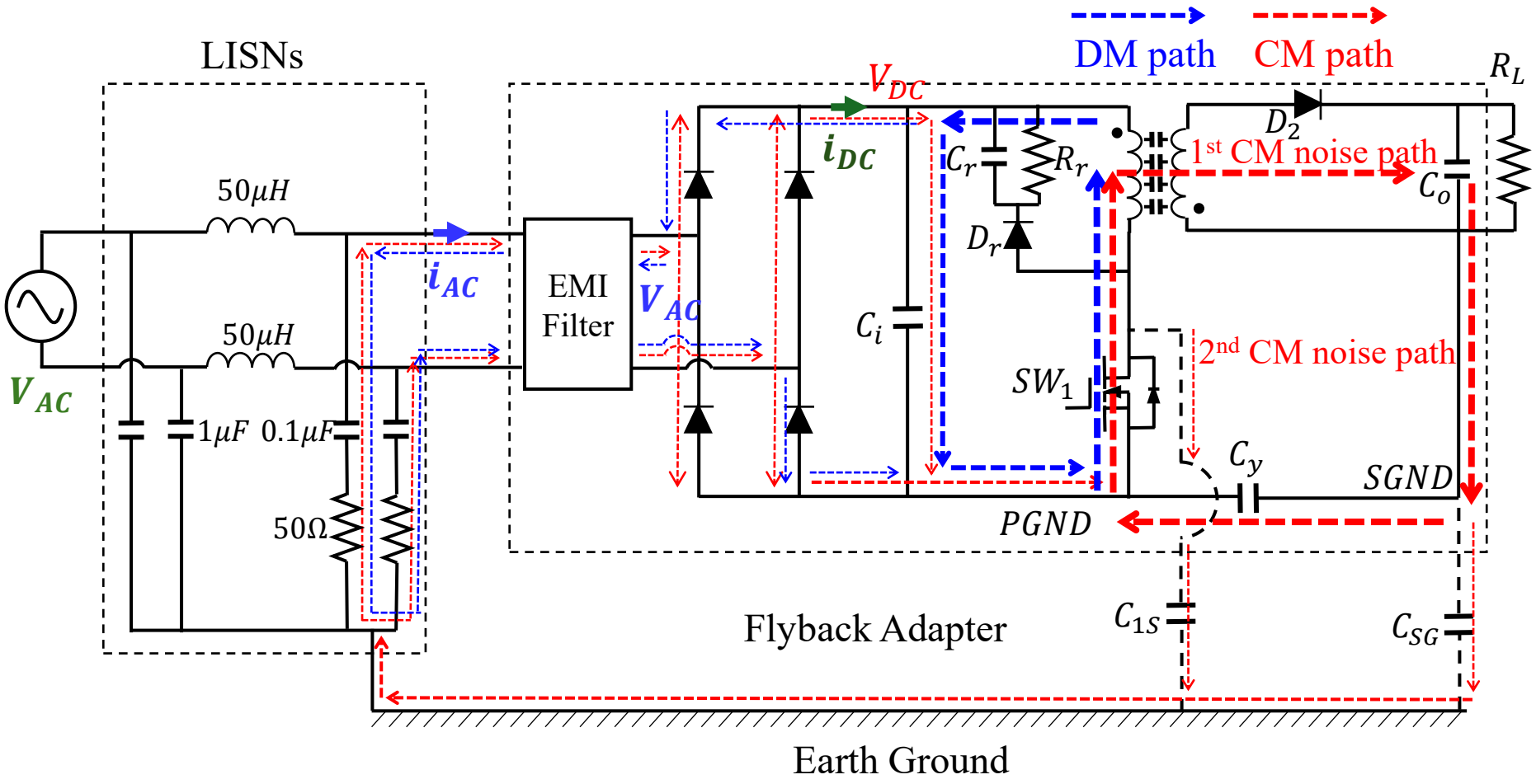
AC-line DM EMI Filters vs DC-bus DM EMI Filters

[1] Y. Li, L. Yang, S. Wang, H. Sheng, S. Lakshmikanthan, and L. Jia, "Investigation of a DC bus differential mode EMI filter for AC/DC power adapters," in *2018 IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2018, pp. 603-610.

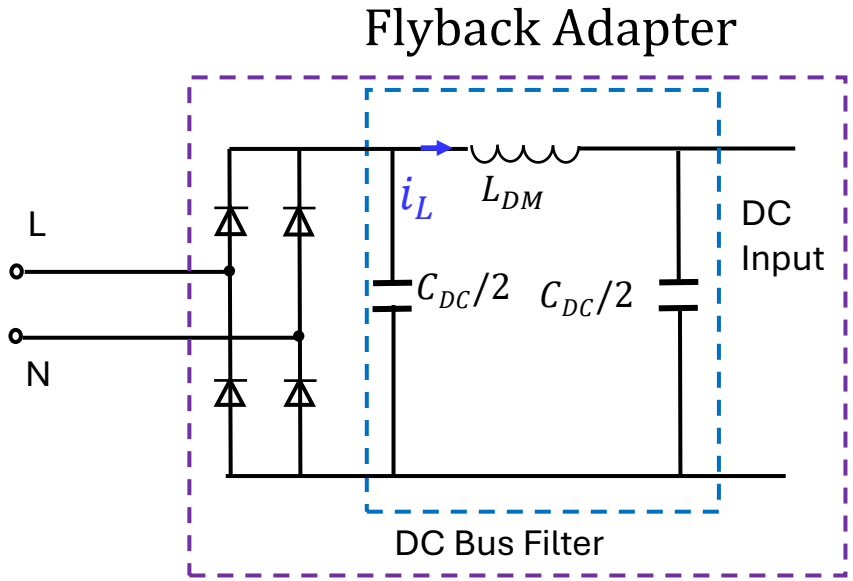
DM EMI, CM EMI and Line-frequency Currents of Flyback Converters

line-frequency power current

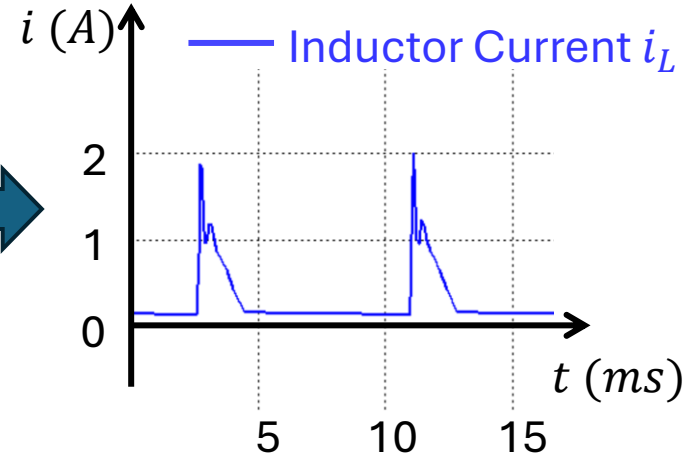


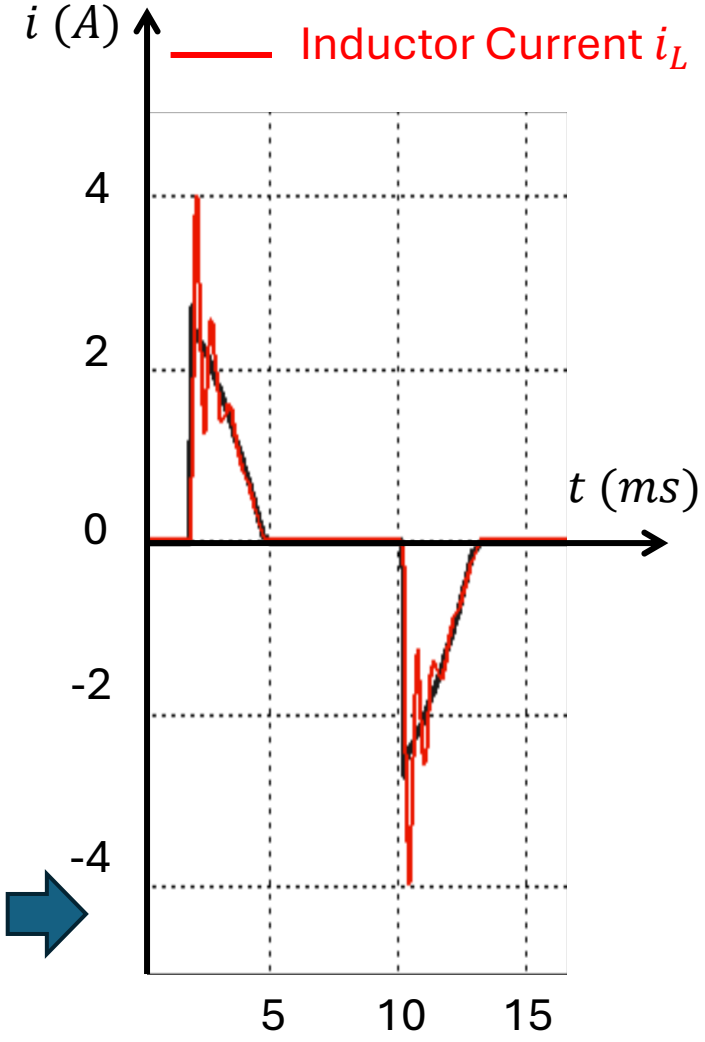


Flyback Converter's DM EMI Filter Selection based on Line-frequency Currents



DC-bus filter topology

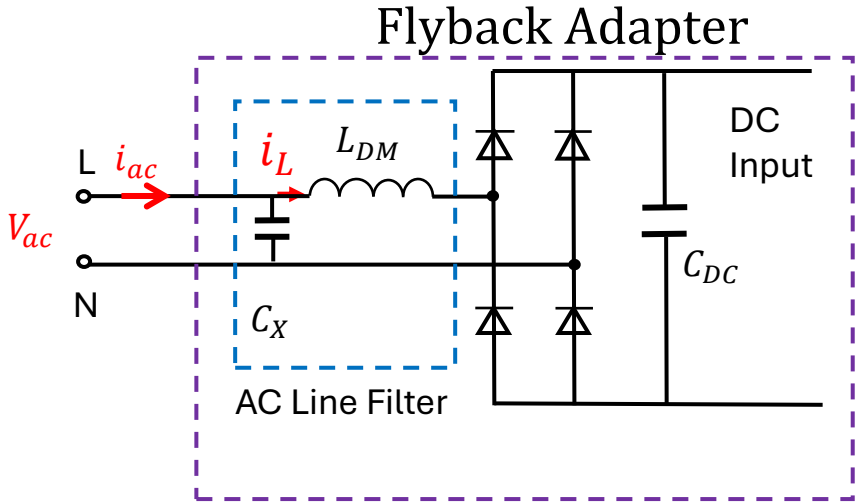




C1 absorbs part of peak currents

Conclusion:

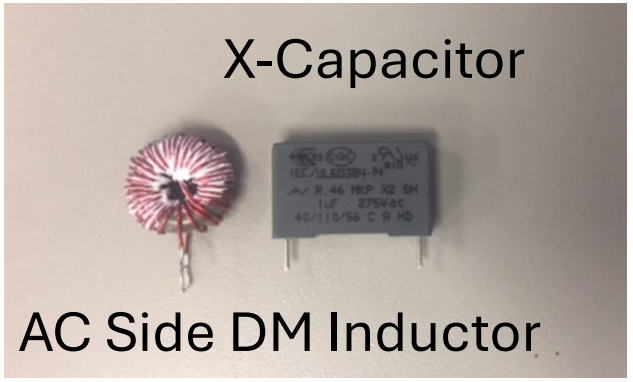
An AC-line EMI filter has much higher inductor current peaks than a DC bus filter

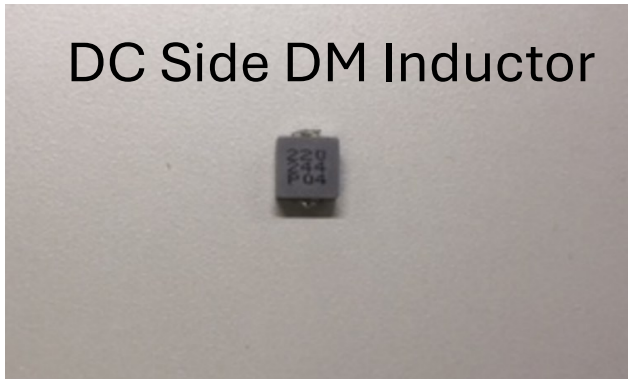


AC line filter topology

DC-bus DM EMI Filter Size vs AC-line DM EMI Filter Size

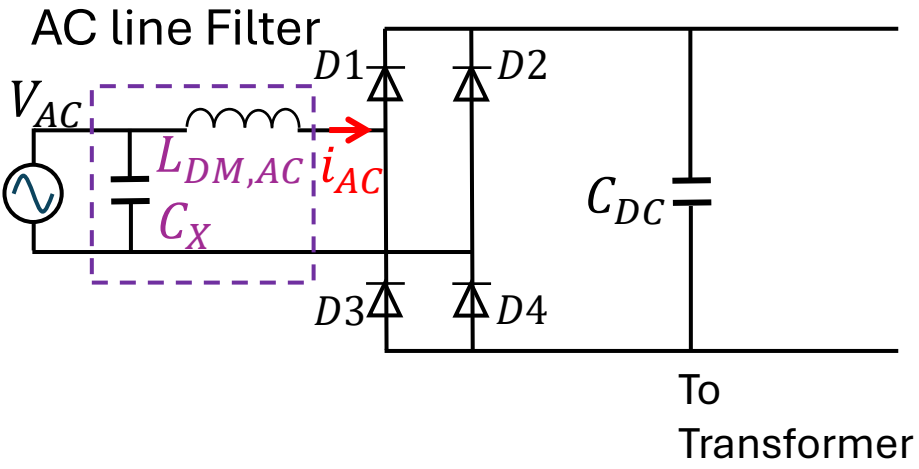
Component	AC Line Filter			DC Bus Filter		
	Value	PCB Size (mm^2)	Volume (mm^3)	Value	PCB Size (mm^2)	Volume (mm^3)
DC Capacitor	$68\mu F$	320	4000	$2 * 33\mu F$	312	4410
X Capacitor	$0.1\mu F$	90	850	N/A	N/A	N/A
DM Inductor	$100\mu H$	72	860	$22\mu H$	50	350
Total		482	5710		362	4760

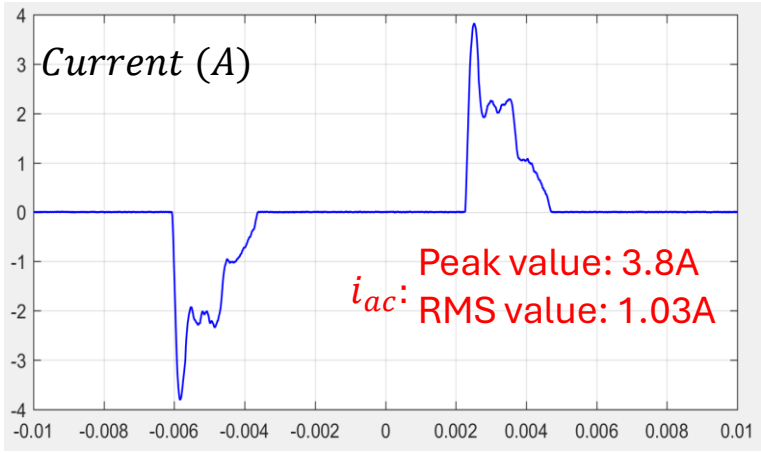




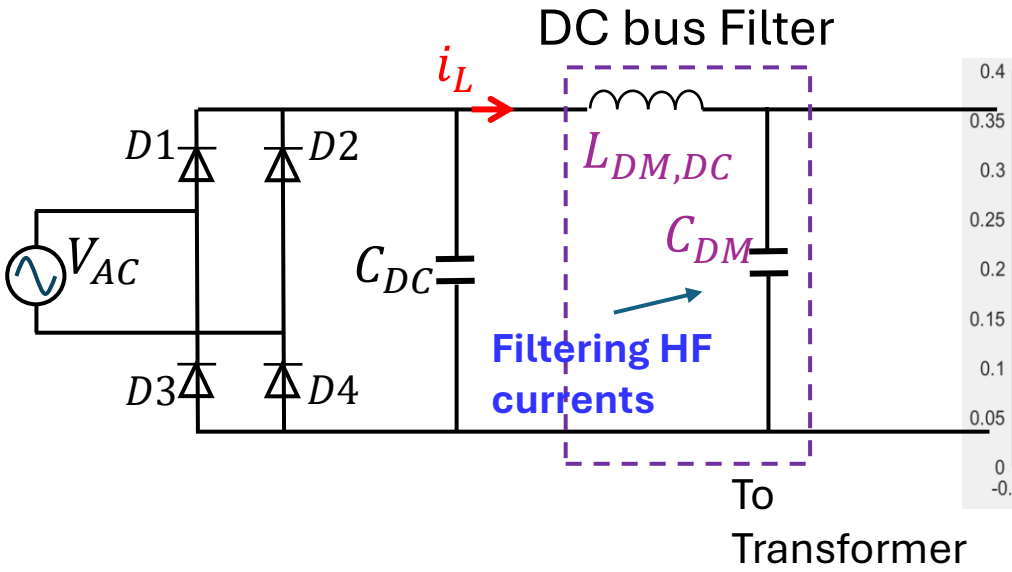
Conclusion: The size of a DC bus filter in a flyback converter is much smaller than that of an AC line filter.

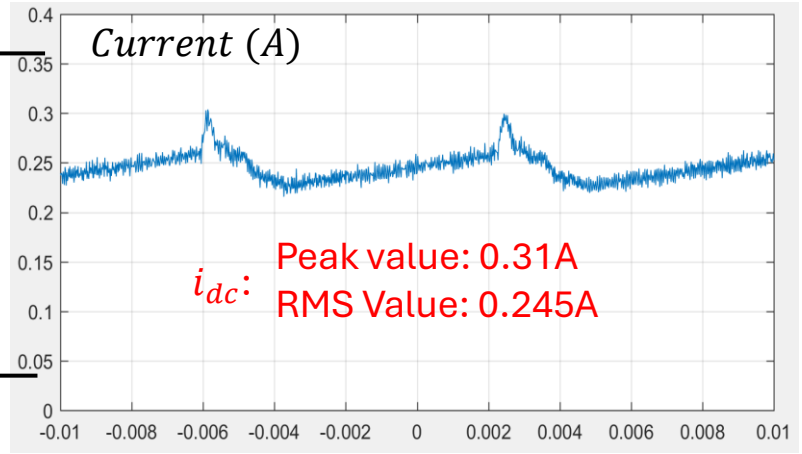
Further Improving DC-bus DM EMI Filter Design





AC Line Filter	Size (mm^2)	Volume (mm^3)
0.47uF/275VAC Film X Capacitor	180	2898
300uH Inductor, High Flux Core	148	2133
Total	328	5031





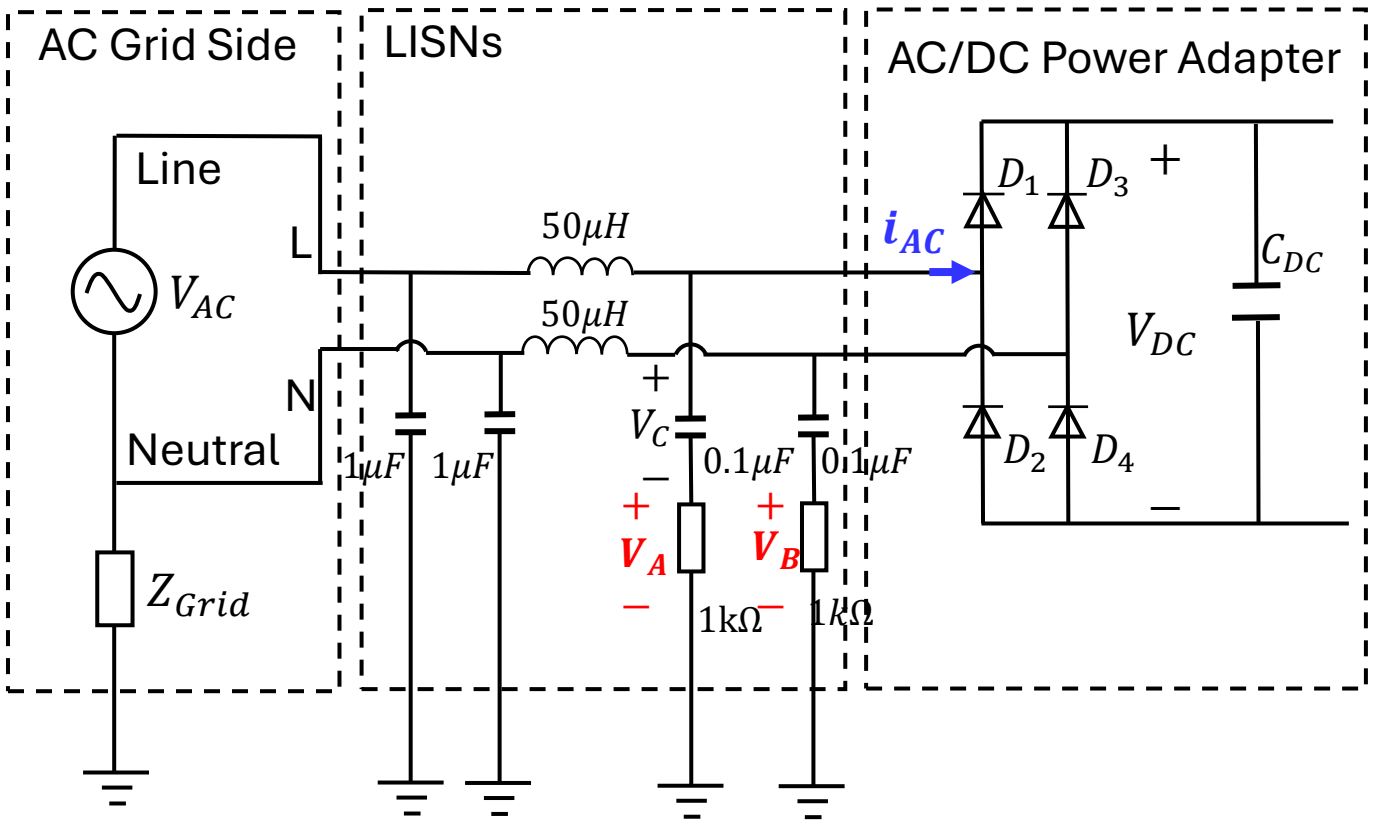
DC bus Filter	Size (mm^2)	Volume (mm^3)
1.0uF/630VDC X7R DM Capacitor	30	165
300uH Inductor, MPP Core	52	327
Total	82	492

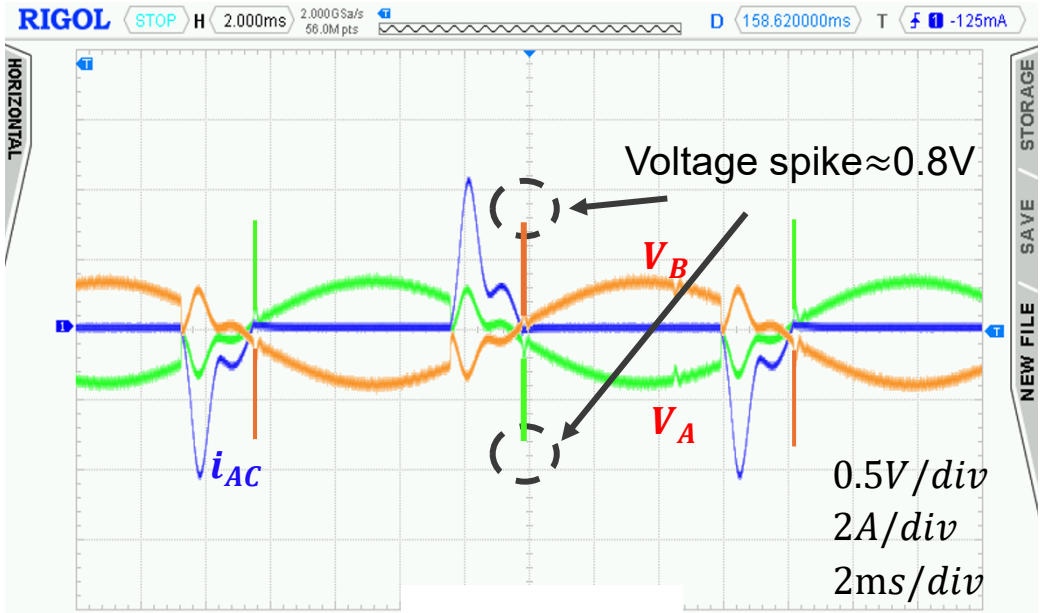
Conclusion: Both the volume and cost of DC filters are much lower than those of AC filters.

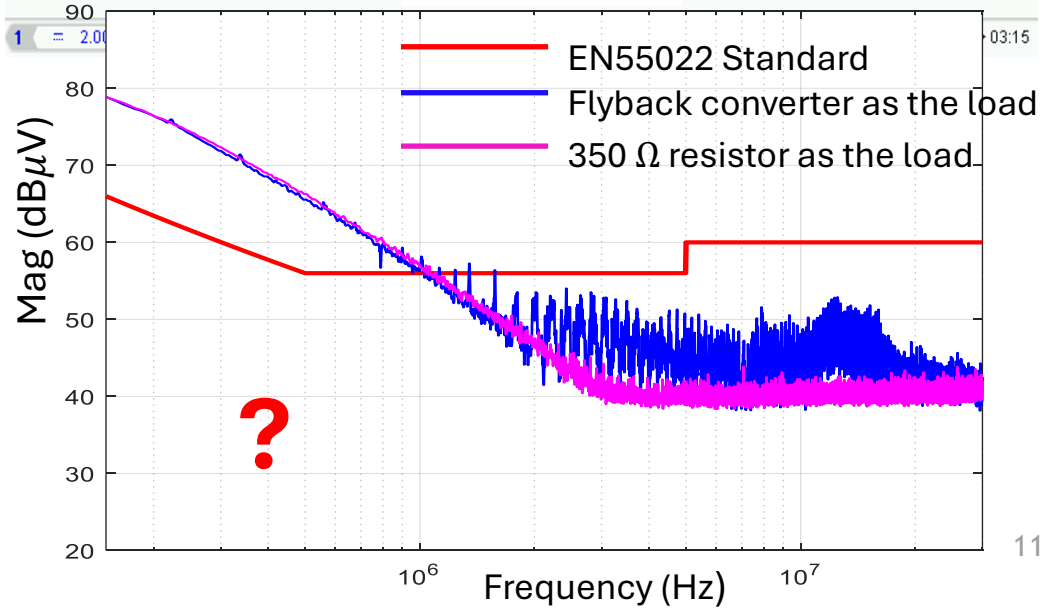
DM EMI Noise due to Diode Bridge Reverse Recovery

[2] Z. Ma, Y. Li, S. Wang, H. Sheng, and S. Lakshmikanthan, "Investigation and Reduction of EMI Noise Due to the Reverse Recovery Currents of 50/60 Hz Diode Rectifiers," *IEEE Journal of Emerging and Selected Topics in Industrial Electronics,* vol. 3, no. 3, pp. 594-603, 2022.

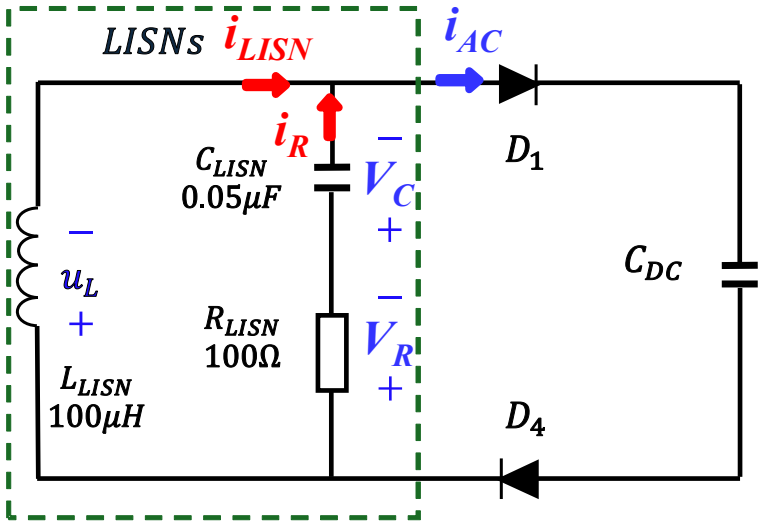
High DM EMI Noise with a 50/60Hz diode Bridge

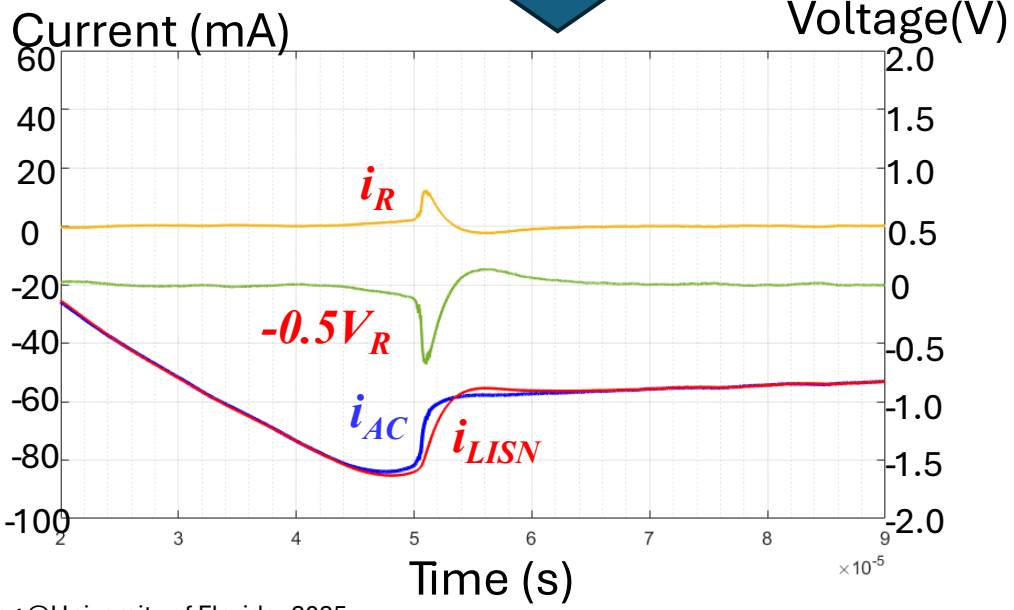


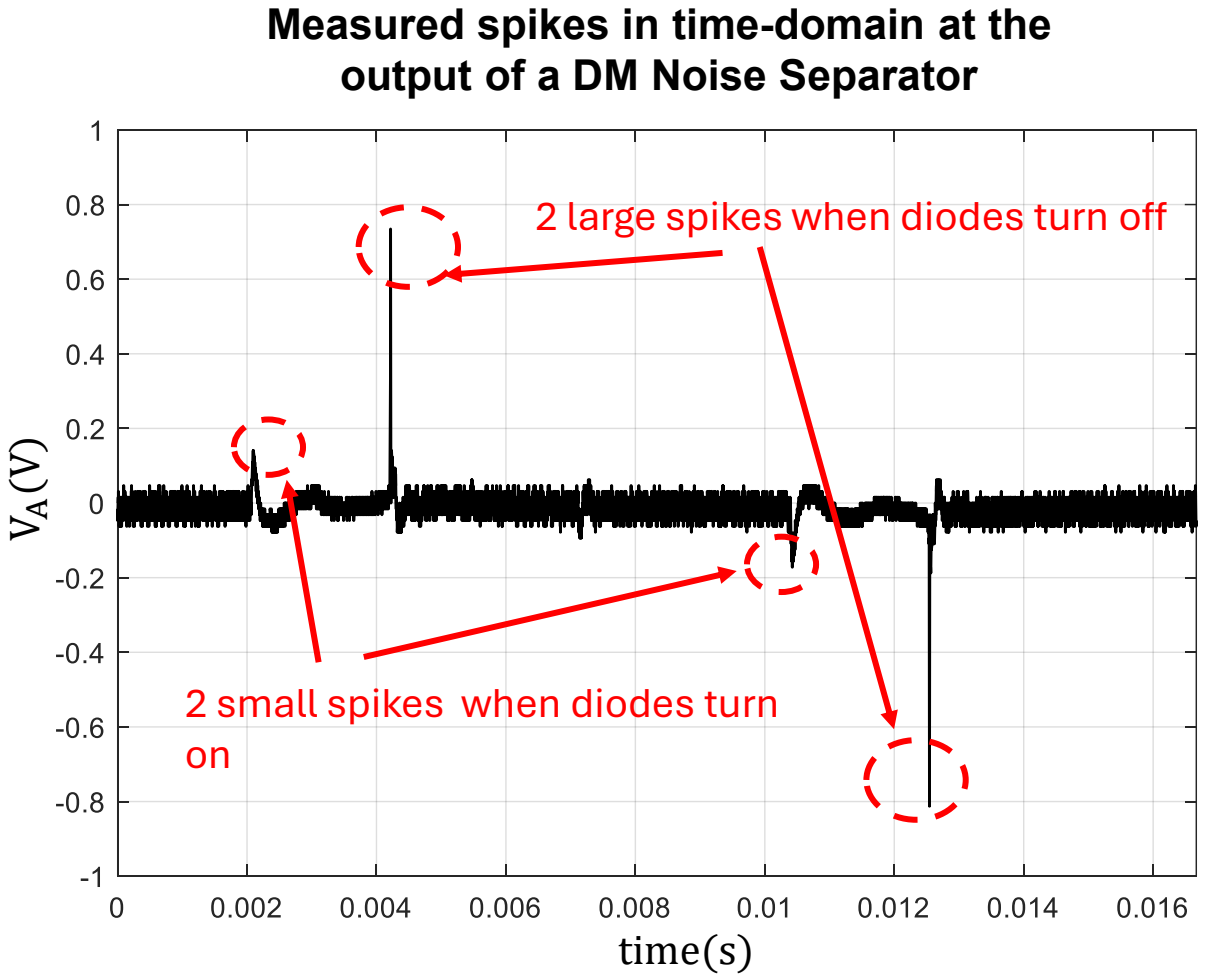




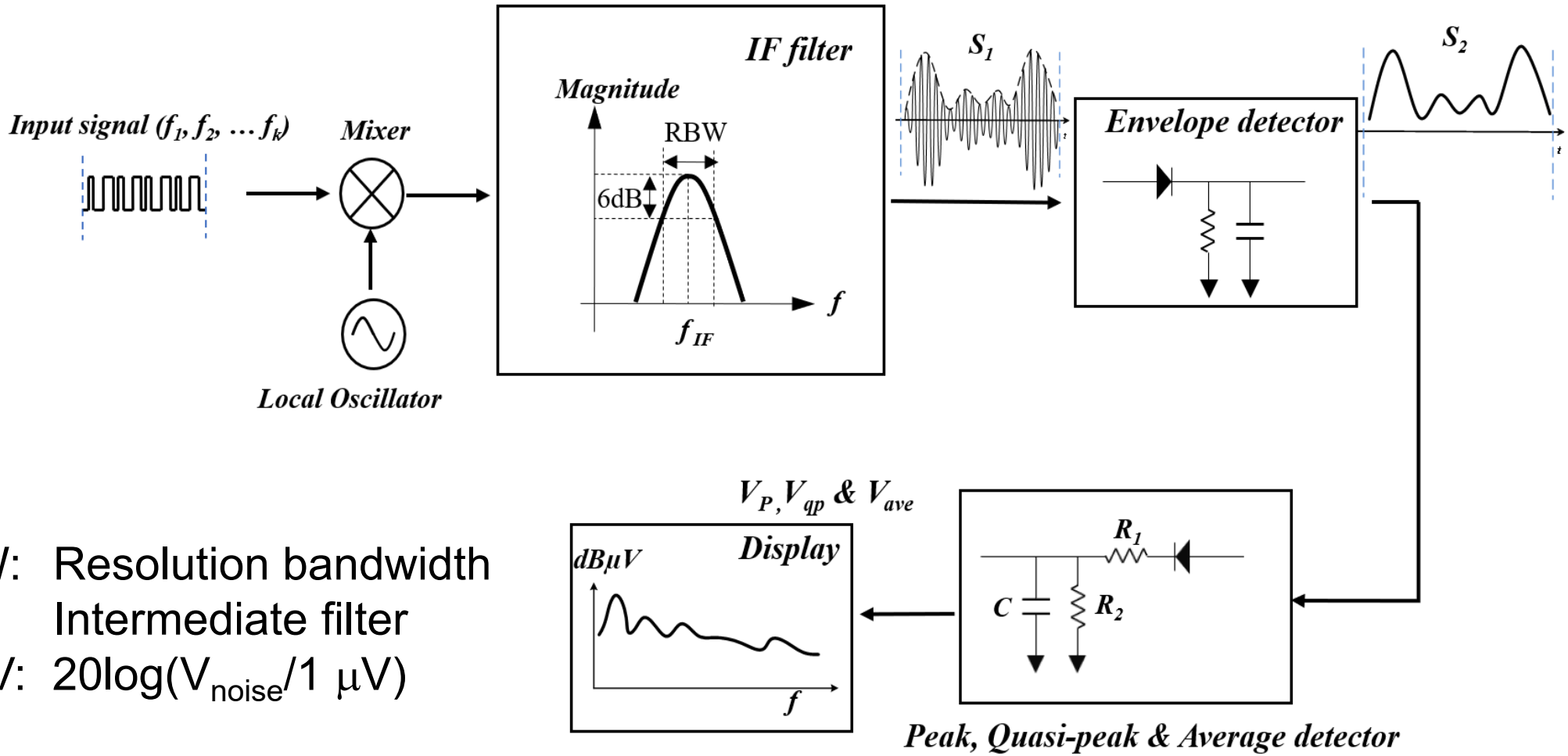
Voltage Spikes on LISNs due to Diode Reverse Recovery





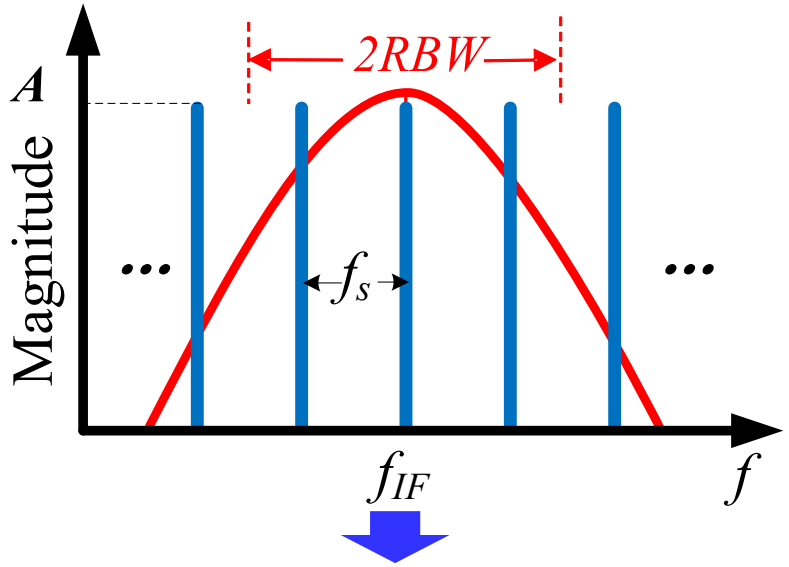


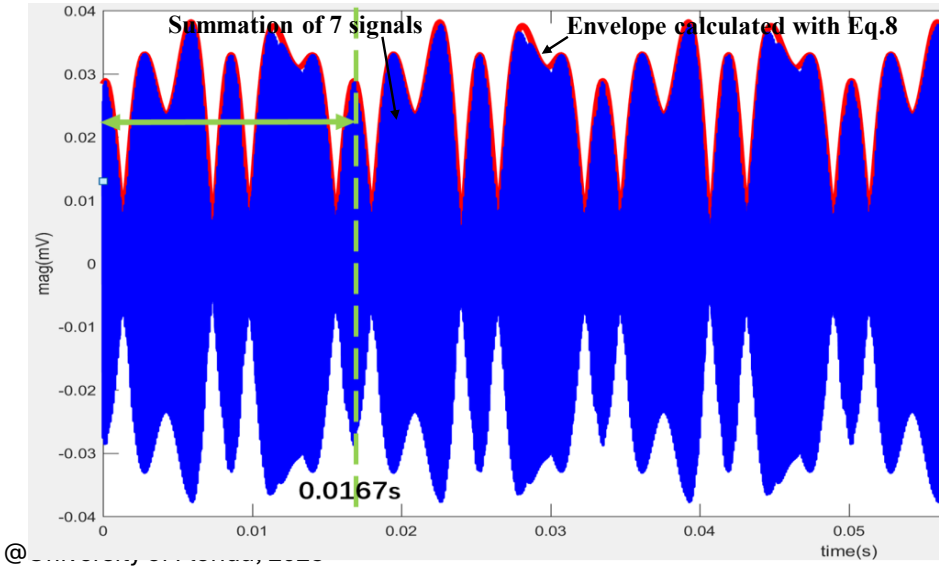
Operating Principle of A Spectrum Analyzer

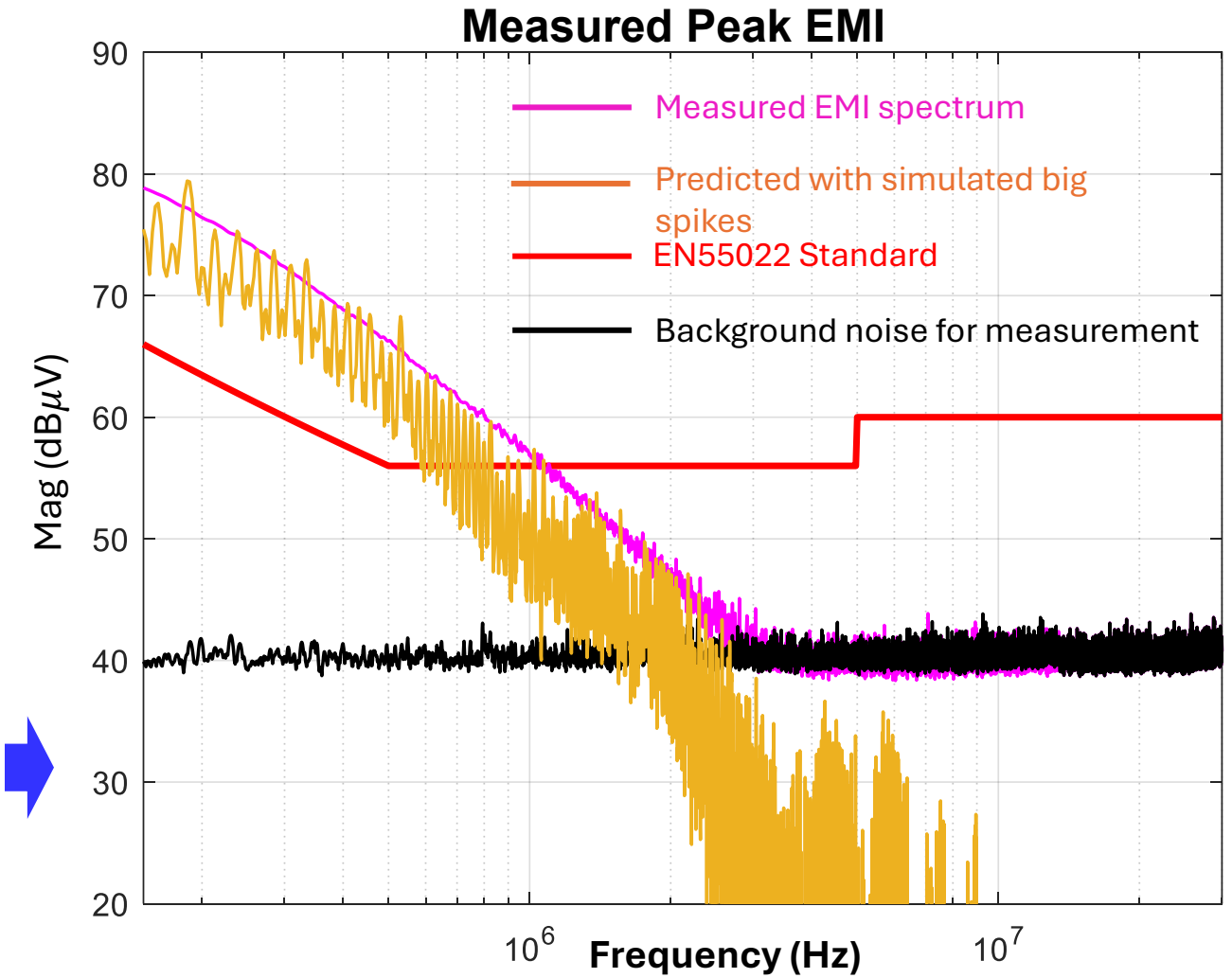


RBW: Resolution bandwidth
IF: Intermediate filter
dBμV: $20\log(V_{noise}/1\ \mu V)$

Many Orders of 50/60Hz Harmonics Contribute to Measured High DM EMI at a Single Frequency





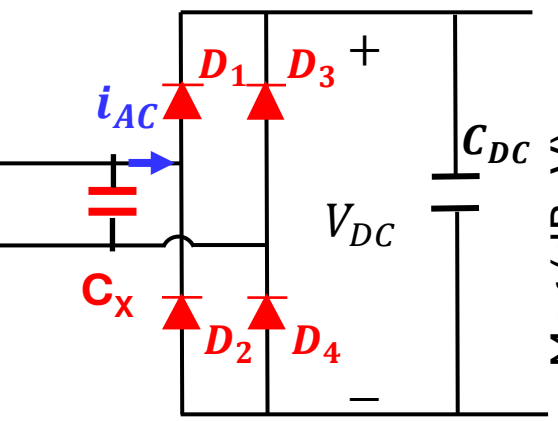


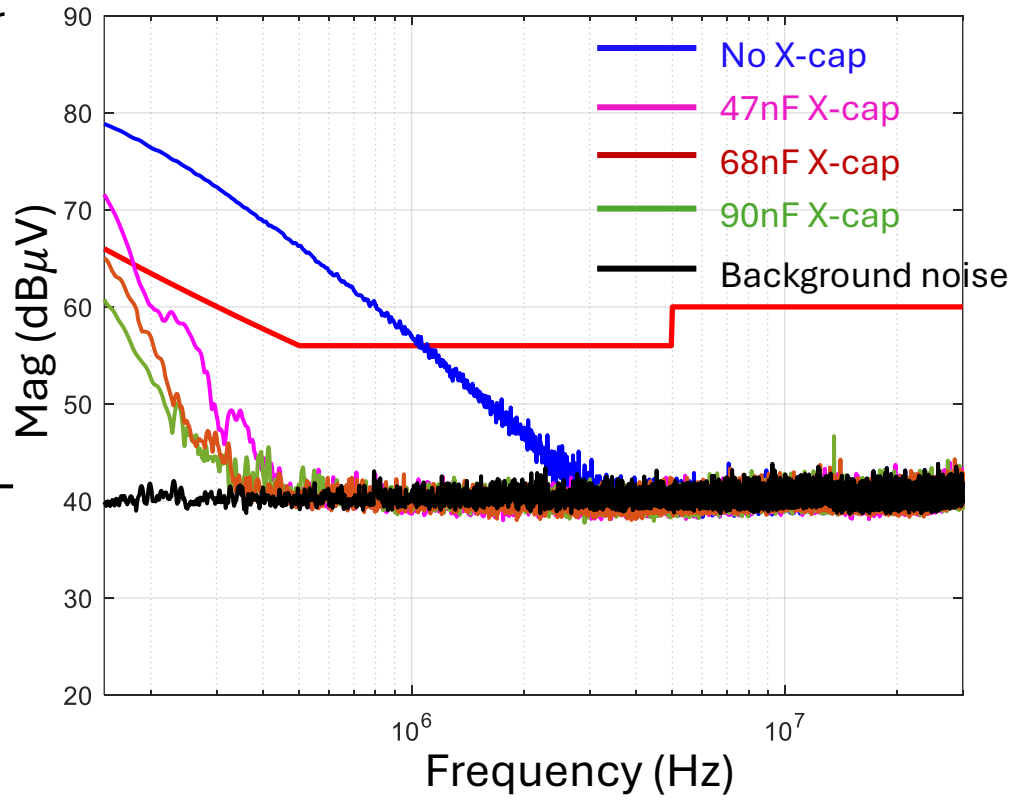
[3]: L. Yang, S. Wang, H. Zhao and Y. Zhi, "Prediction and Analysis of EMI Spectrum Based on the Operating Principle of EMC Spectrum Analyzers," in *IEEE Transactions on Power Electronics*, vol. 35, no. 1, pp. 263-275, Jan. 2020, doi: 10.1109/TPEL.2019.2914468.

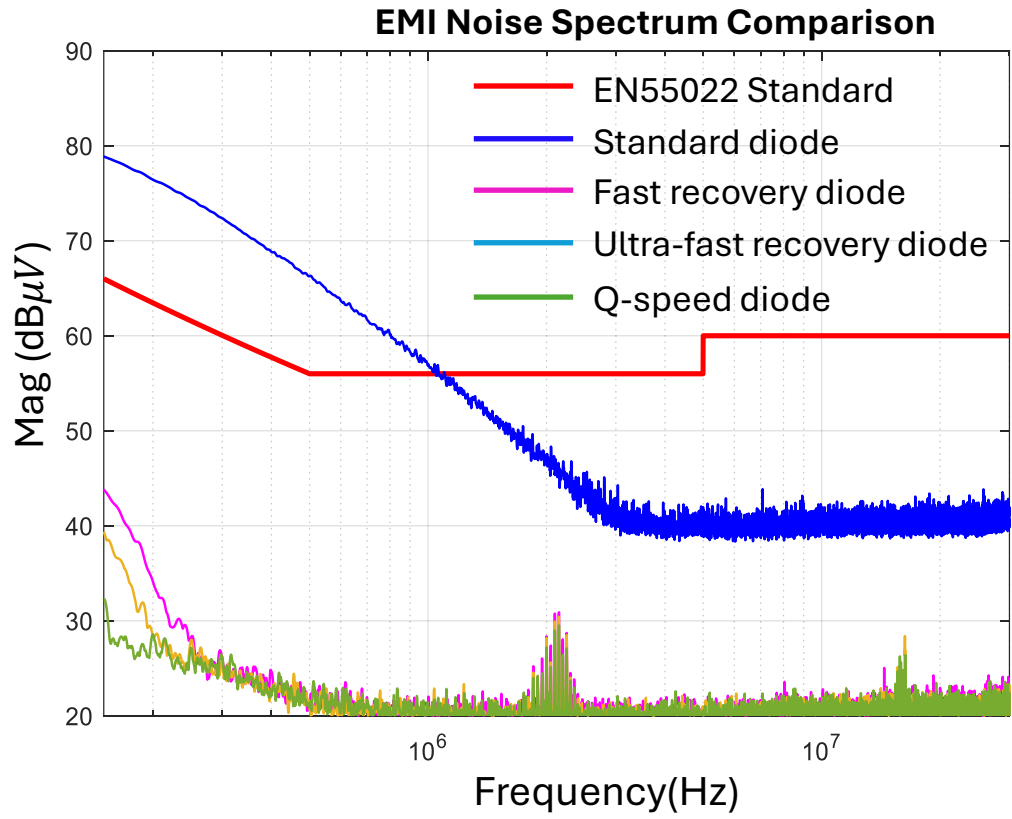
DM EMI Suppression Solutions

1) Add a X-cap: Cx to filter out HF harmonics
2) Use fast recovery rectifier diodes to eliminate the effects of reverse recovery currents

AC/DC Power Adapter



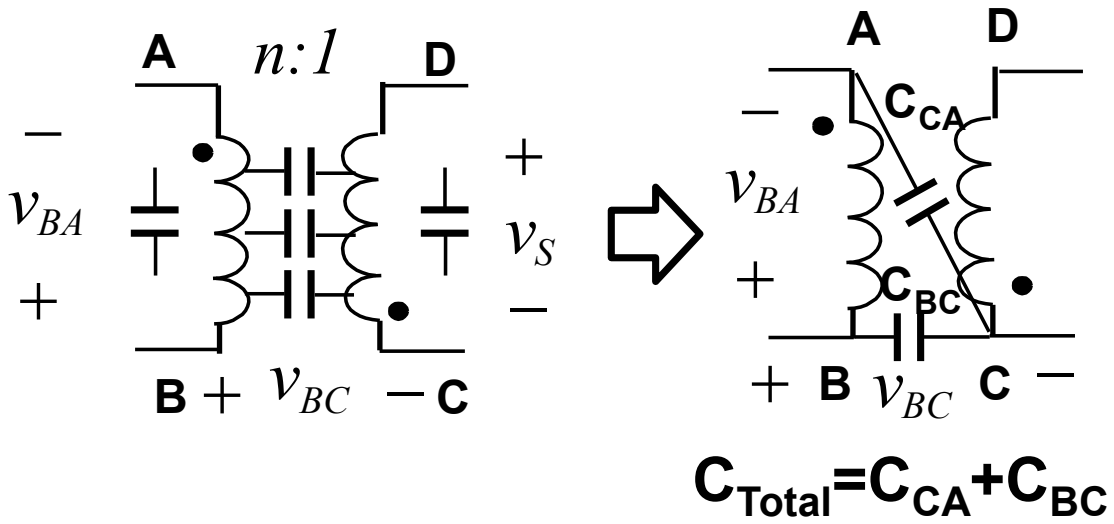




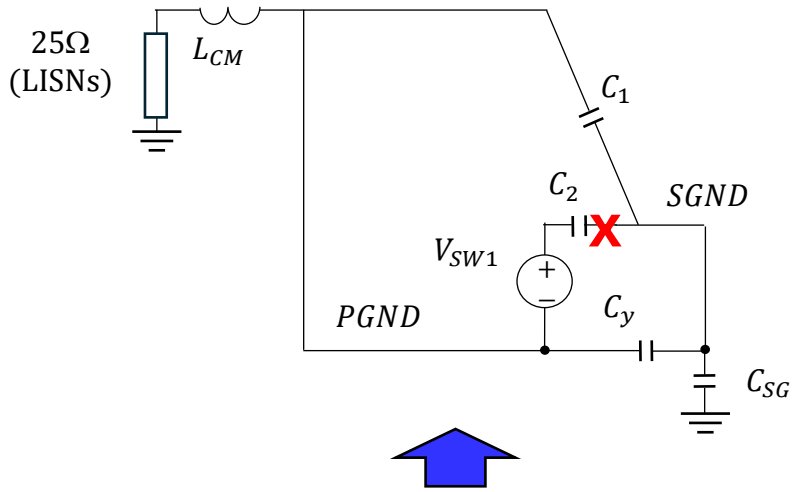
CM EMI Noise due to Switching Transformers

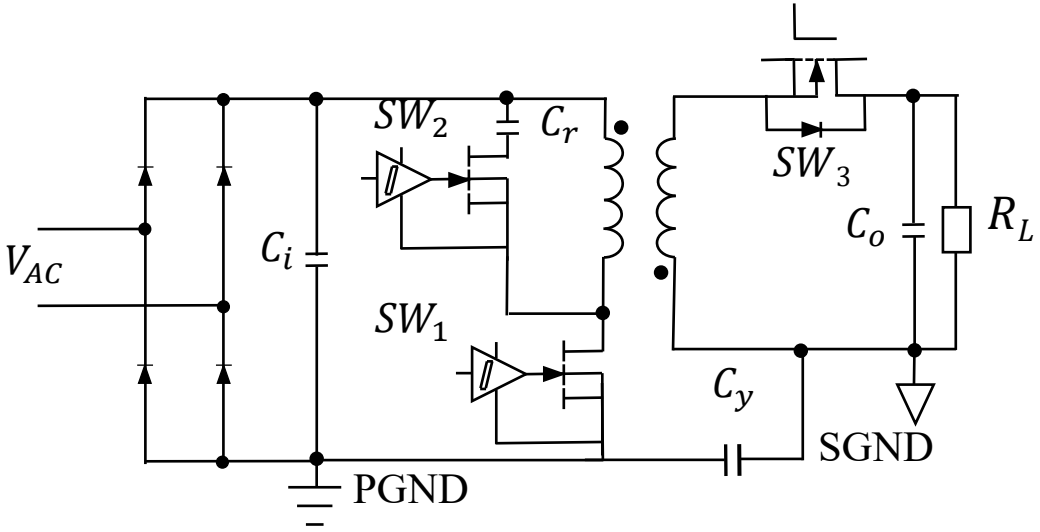
[4] Y. Li, H. Zhang, S. Wang, H. Sheng, C. P. Chng, and S. Lakshmikanthan, "Investigating Switching Transformers for Common Mode EMI Reduction to Remove Common Mode EMI Filters and Y-Capacitors in Flyback Converters," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 6, no. 4, pp. 2287-2301, 2018

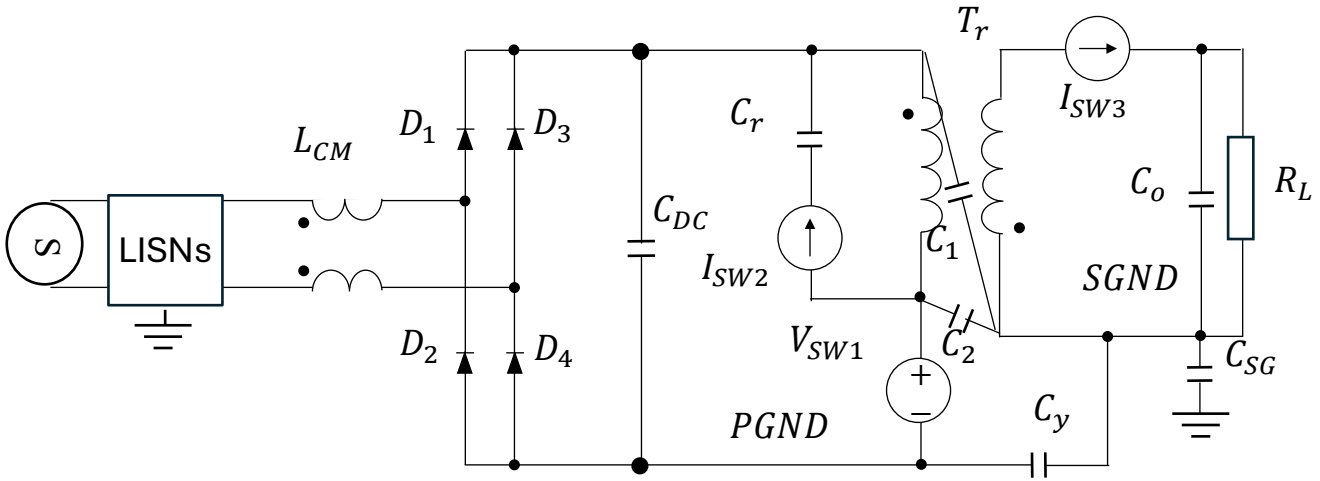
CM EMI Model of Switching Transformers



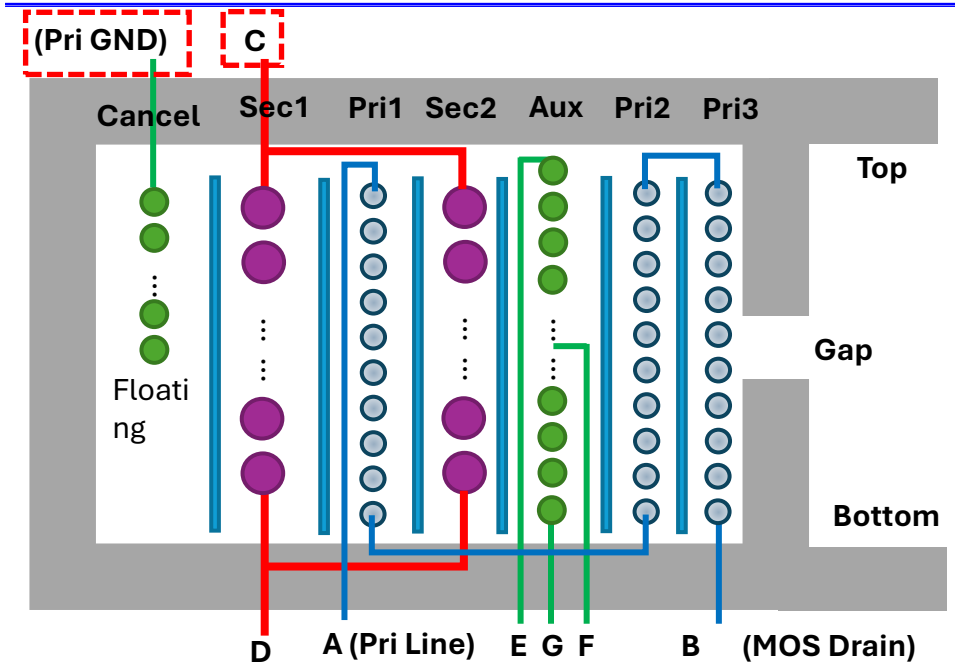
[5] H. Zhang, S. Wang, Y. Li, Q. Wang and D. Fu, "Two-Capacitor Transformer Winding Capacitance Models for Common-Mode EMI Noise Analysis in Isolated DC–DC Converters," in *IEEE Transactions on Power Electronics*, vol. 32, no. 11, pp. 8458-8469, Nov. 2017.

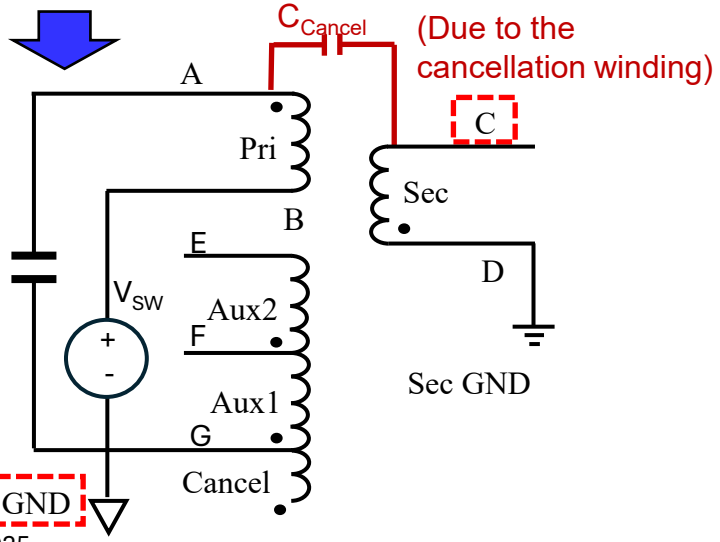


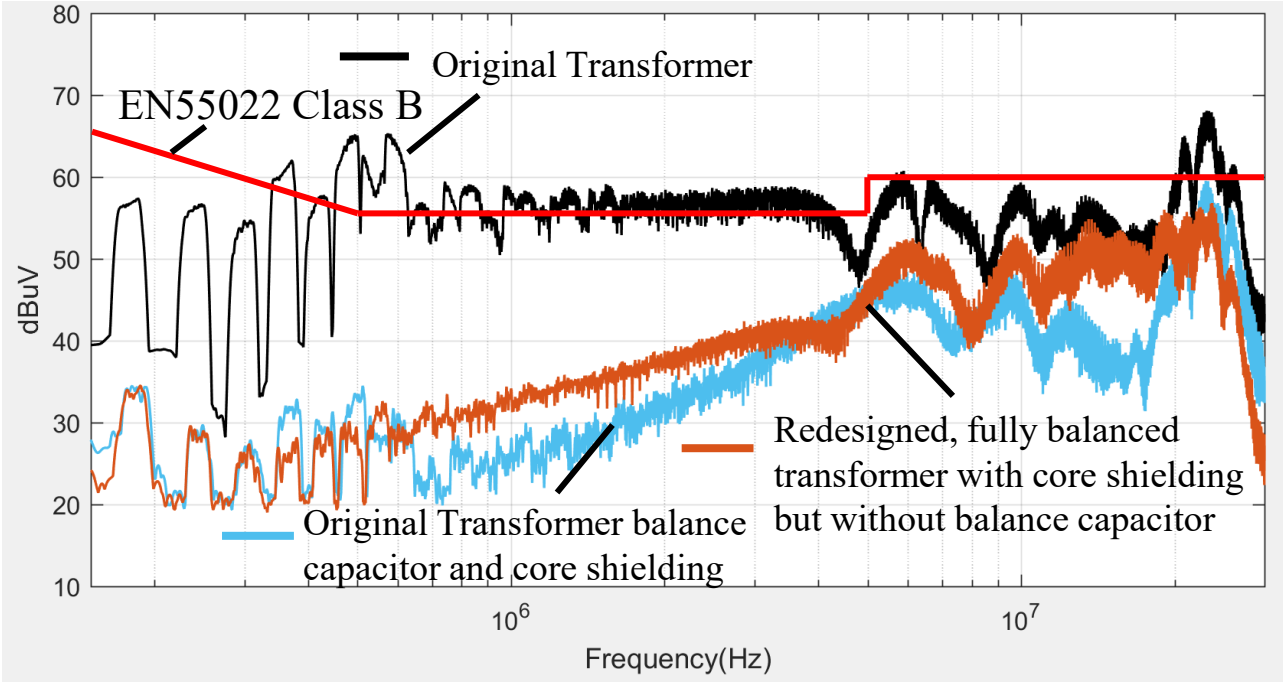




Transformer Design to Suppress CM EMI







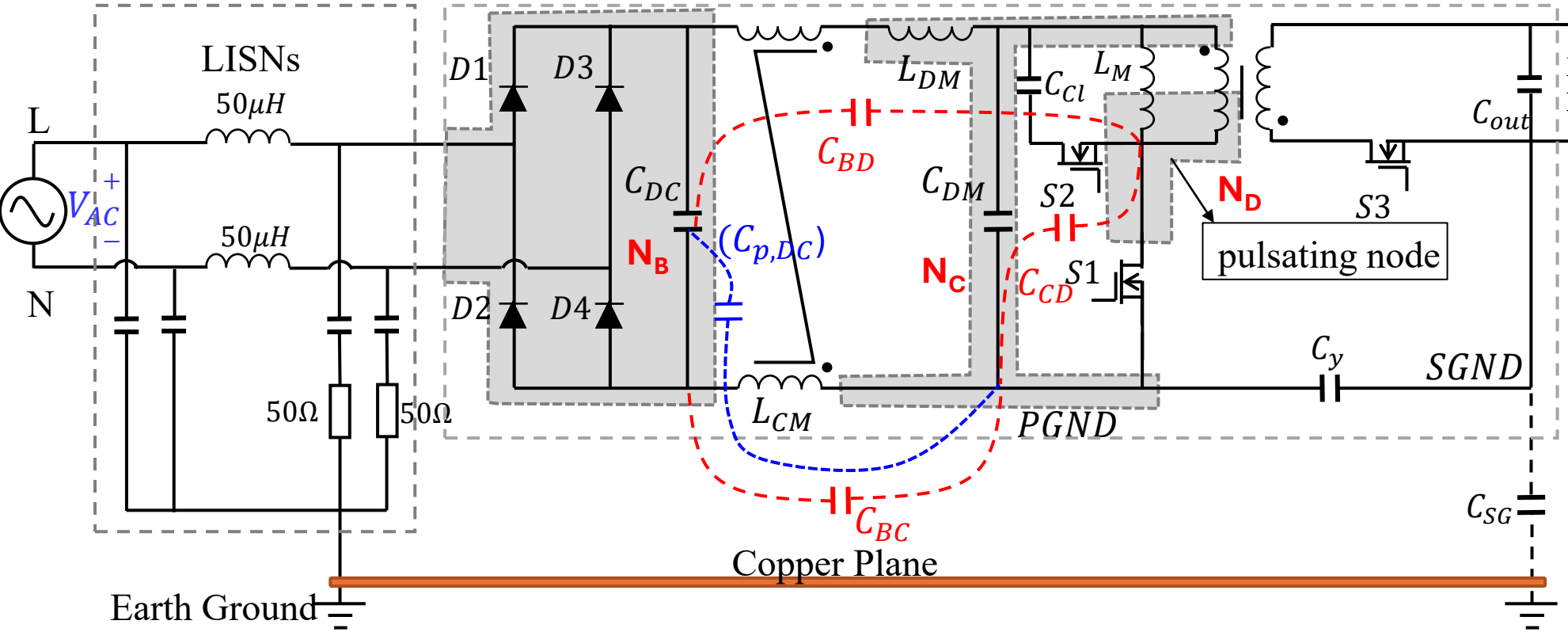
1. The adjacent windings between the primary and secondary should have small voltage difference
2. A cancellation winding can be used to generate reverse currents to cancel CM currents
3. An external cancellation capacitor can be used across primary and secondary to cancel CM currents

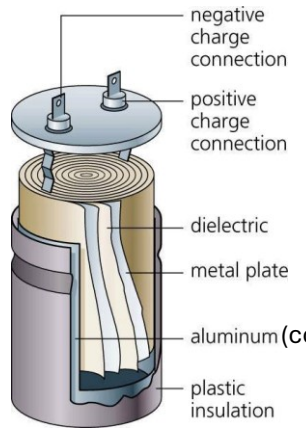
CM EMI Noise due to Near Electric Field Couplings

[6] Y. Li, S. Wang, H. Sheng and S. Lakshmikanthan, "Investigate and Reduce Capacitive Couplings in a Flyback Adapter With a DC-Bus Filter to Reduce EMI," in *IEEE Transactions on Power Electronics*, vol. 35, no. 7, pp. 6963-6973, July 2020

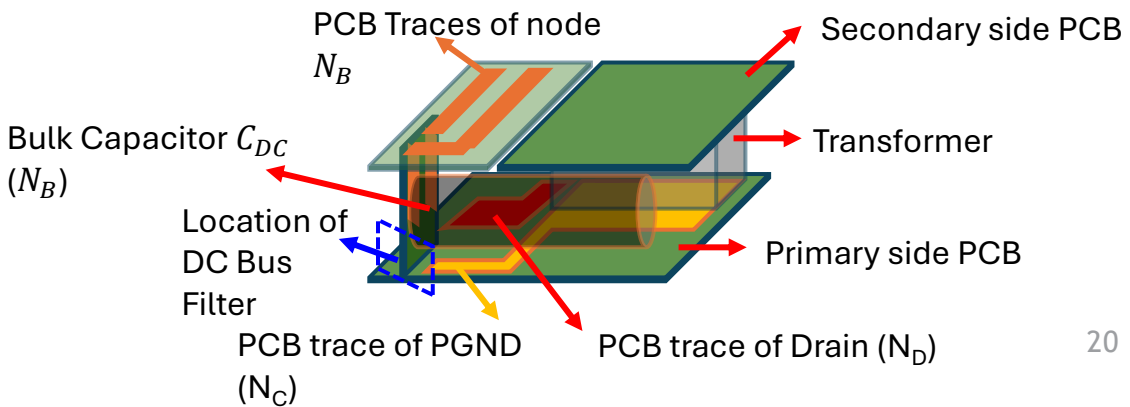
A Flyback Converter with A DC Bus Filter

(Coupling with the Electrolytic Capacitor's Metal Shell)

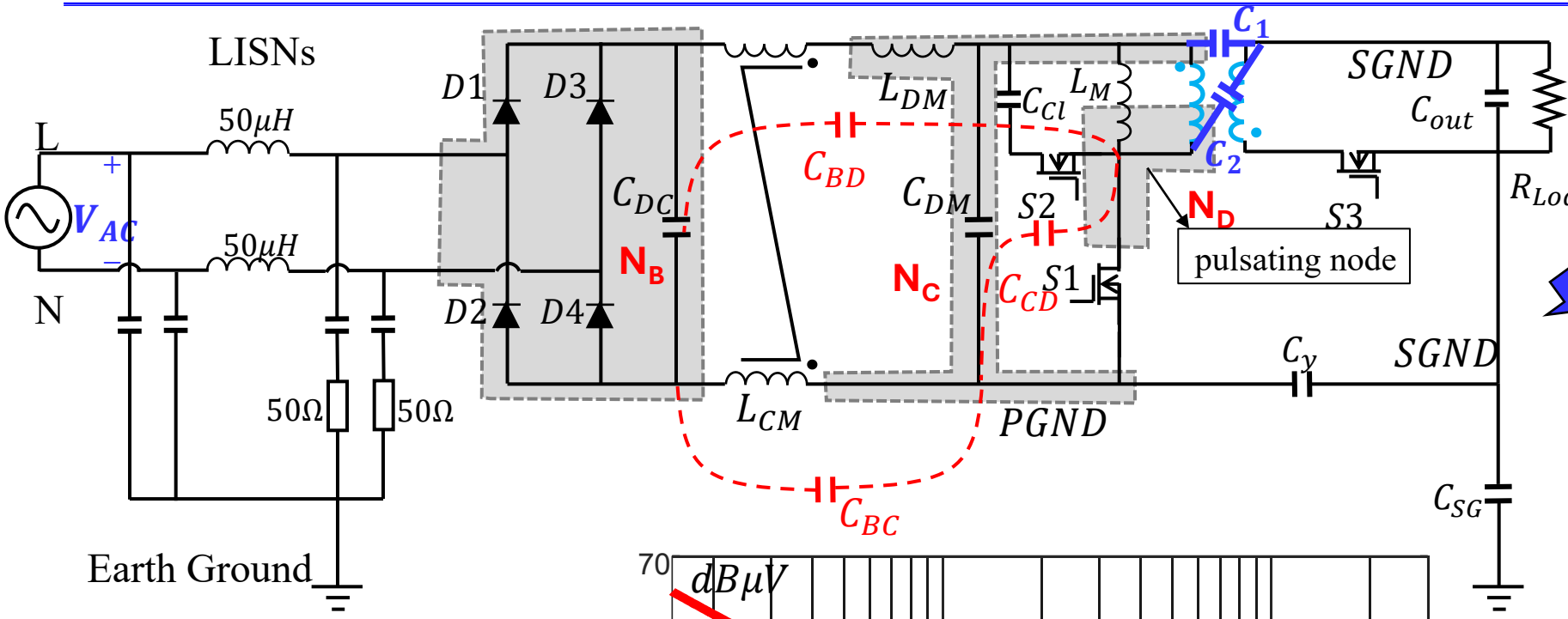


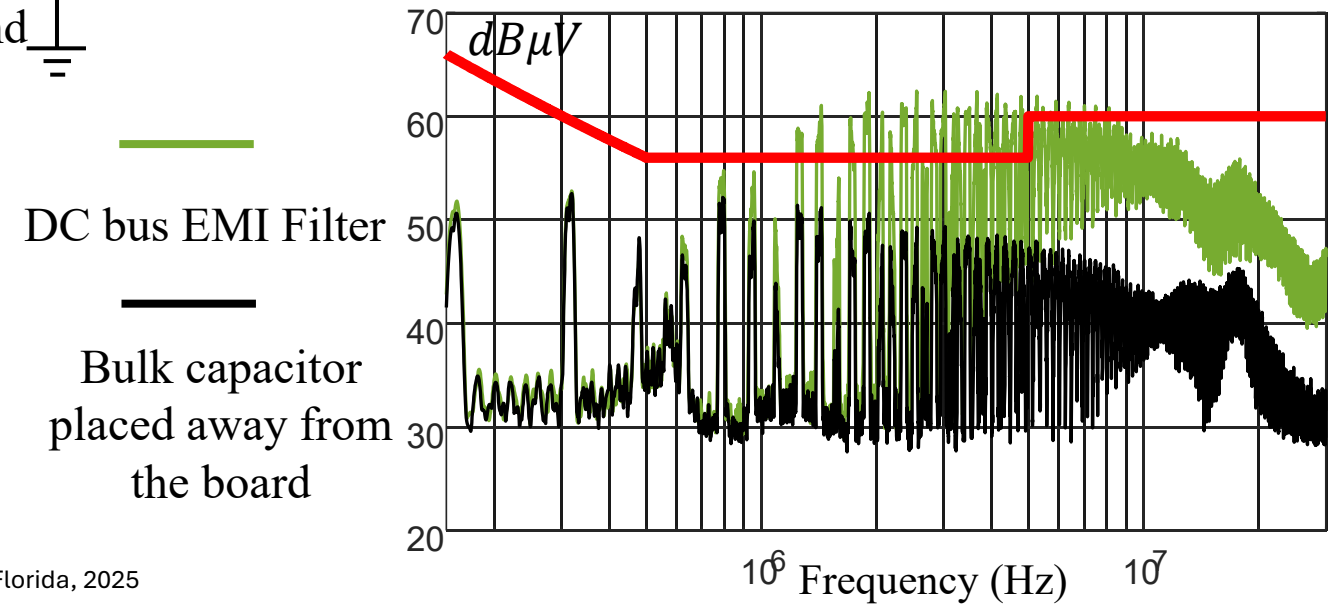


Electrolytic capacitor's metal shell couples to N_C: $C_{p,DC}$
It bypasses L_{CM} and can be combined with C_{BC}.



Near Electric Field Couplings Lead to High CM EMI

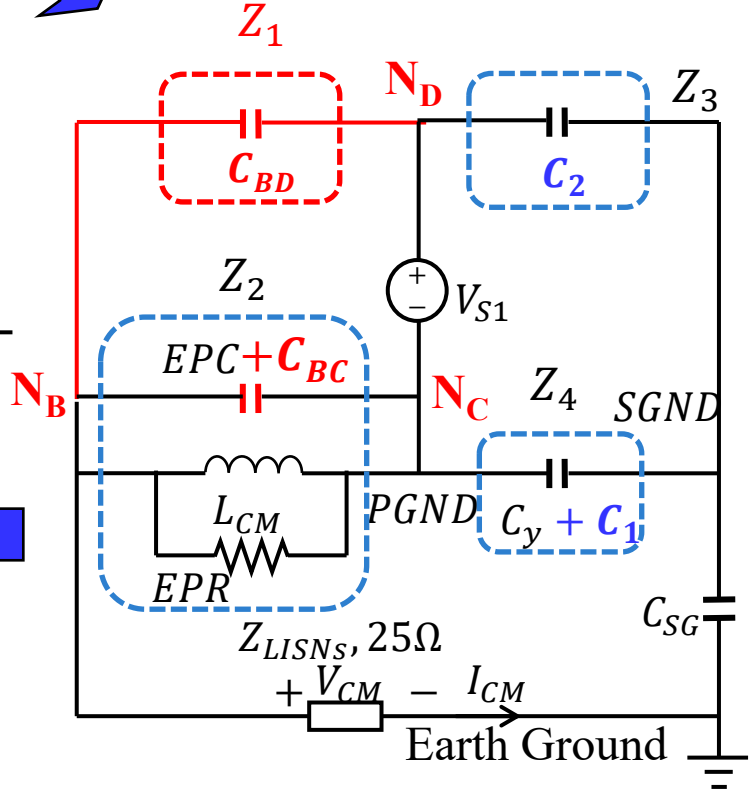




DC bus EMI Filter

Bulk capacitor placed away from the board

Unbalanced bridge leads to CM EMI

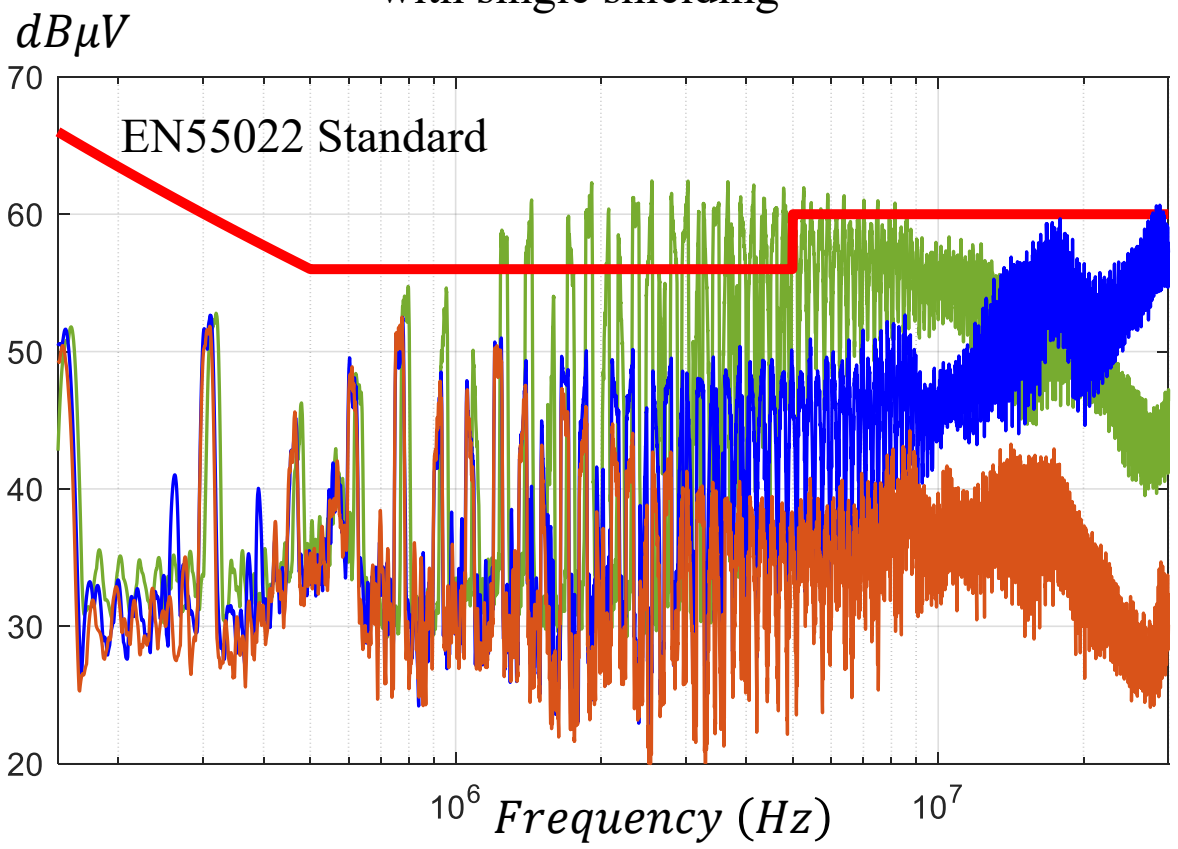


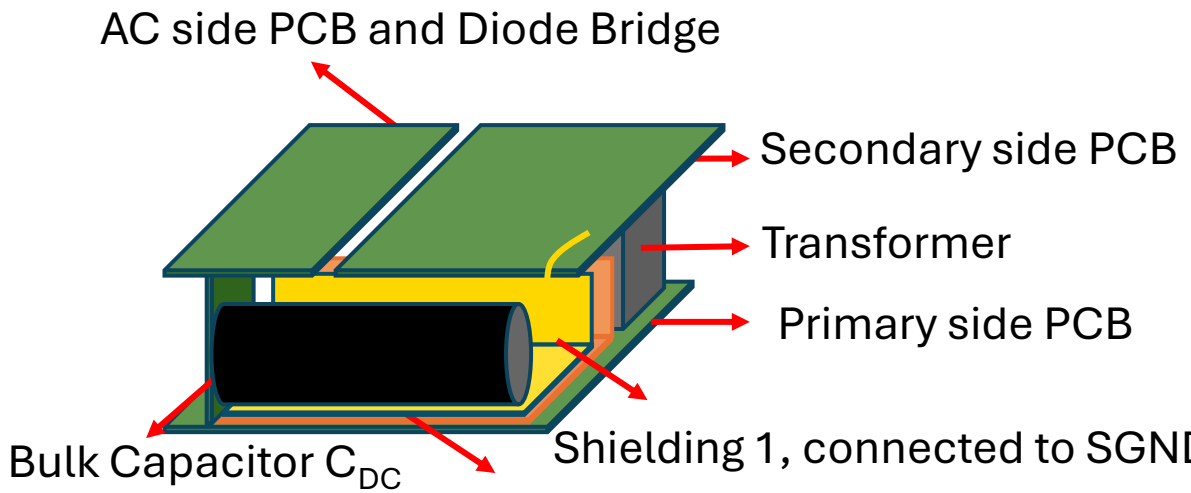
EMI Reduction by Shielding the DC Capacitor

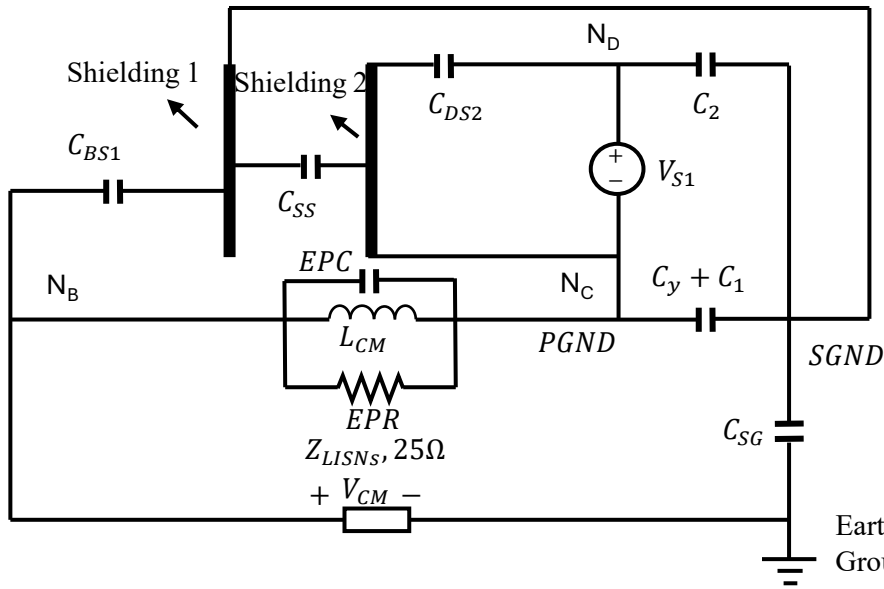
DC-bus EMI Filter

DC-bus EMI filter with single shielding

DC-bus EMI filter with double shielding





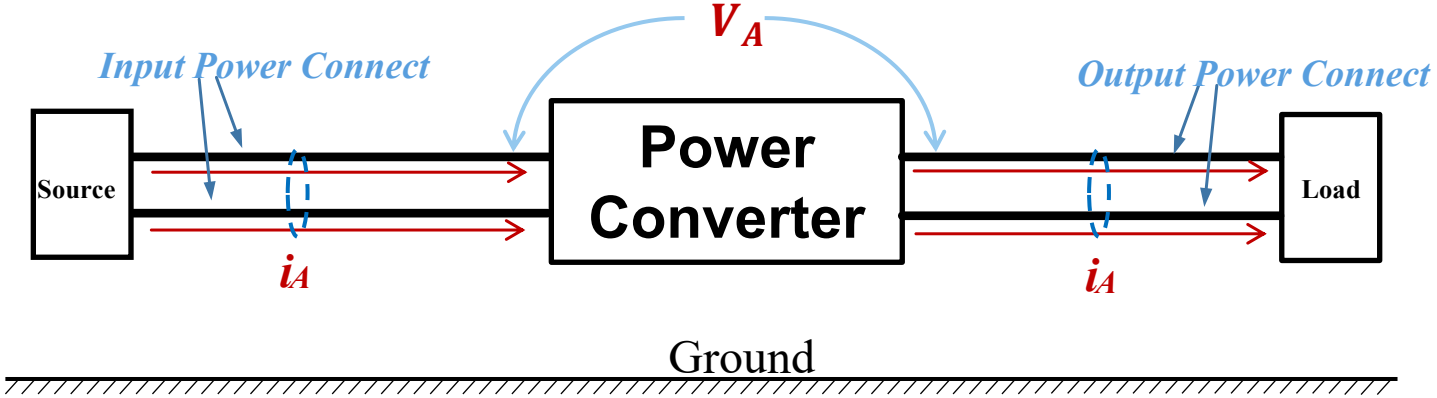


Both C_{BD} and C_{BC} are eliminated

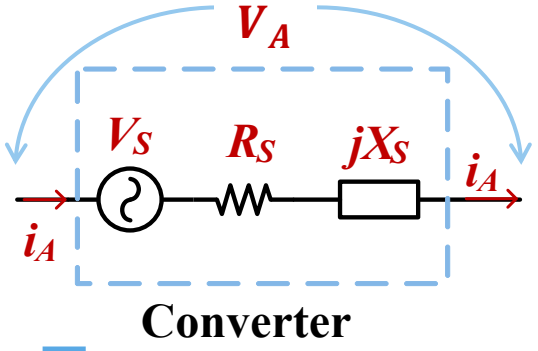
Radiated EMI of A Flyback Converter

[7] J. Yao, Y. Li, S. Wang, X. Huang, and X. Lyu, "Modeling and Reduction of Radiated EMI in a GaN IC-Based Active Clamp Flyback Adapter," IEEE Transactions on Power Electronics, vol. 36, no. 5, pp. 5440-5449, May 2021.

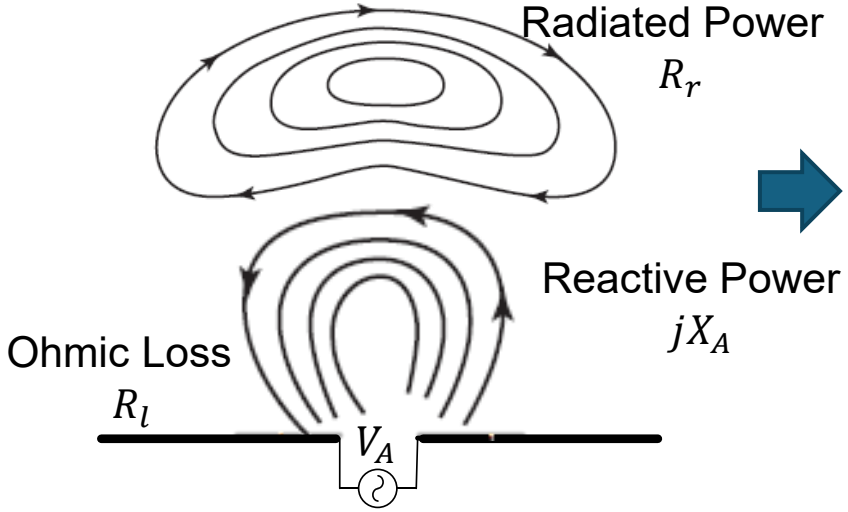
Radiated EMI Model for Power Converters with Input and Output Cables

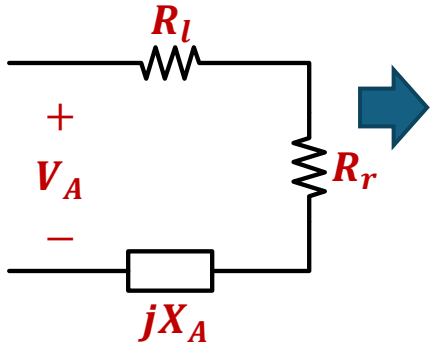


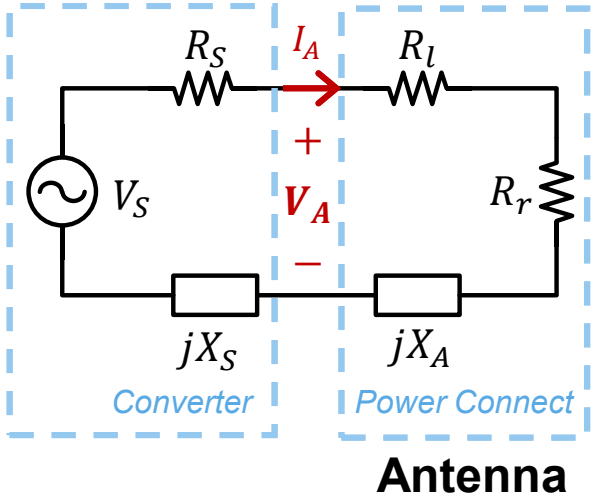
Converter Thevenin Equivalence



Cables: Asymmetric dipole antenna:







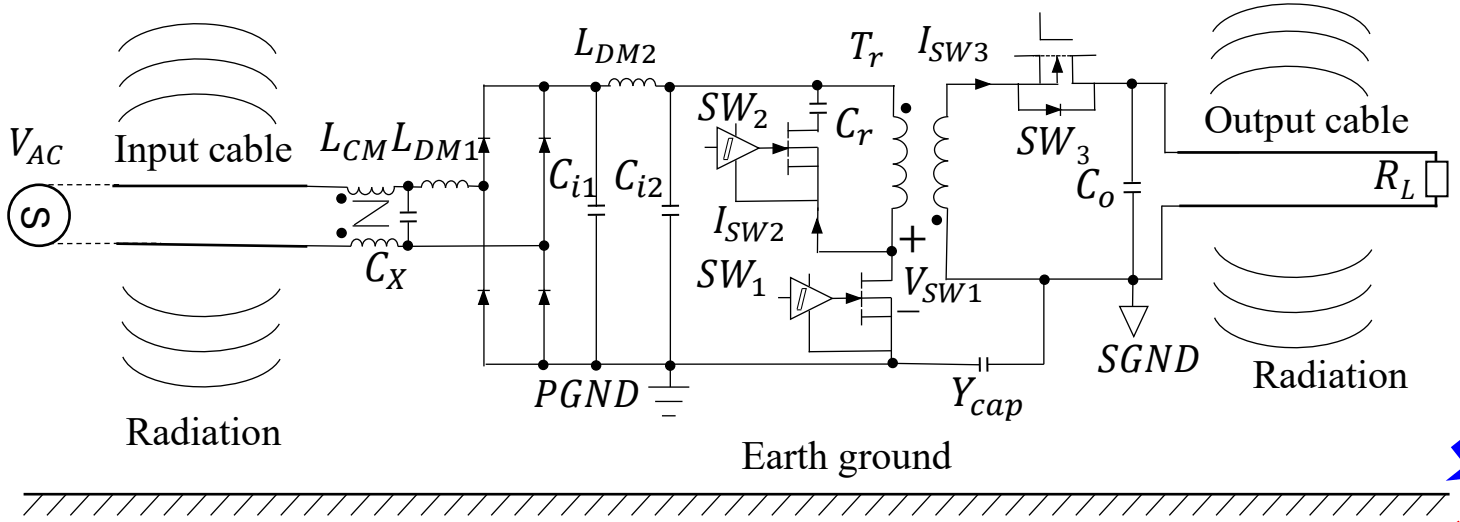
$$E_{max} = \sqrt{\frac{R_r \eta D}{4\pi r^2}} \times |I_A| = \sqrt{\frac{\eta D}{4\pi r^2}} \times |V_S| \times \frac{\sqrt{R_r}}{\sqrt{(R_S + R_r + R_l)^2 + (X_S + X_A)^2}}$$

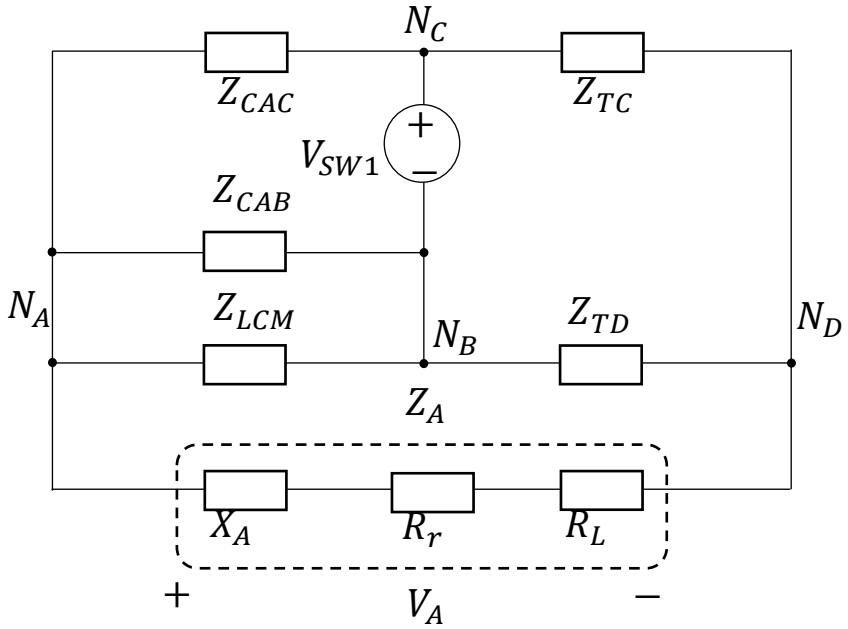
Noise source

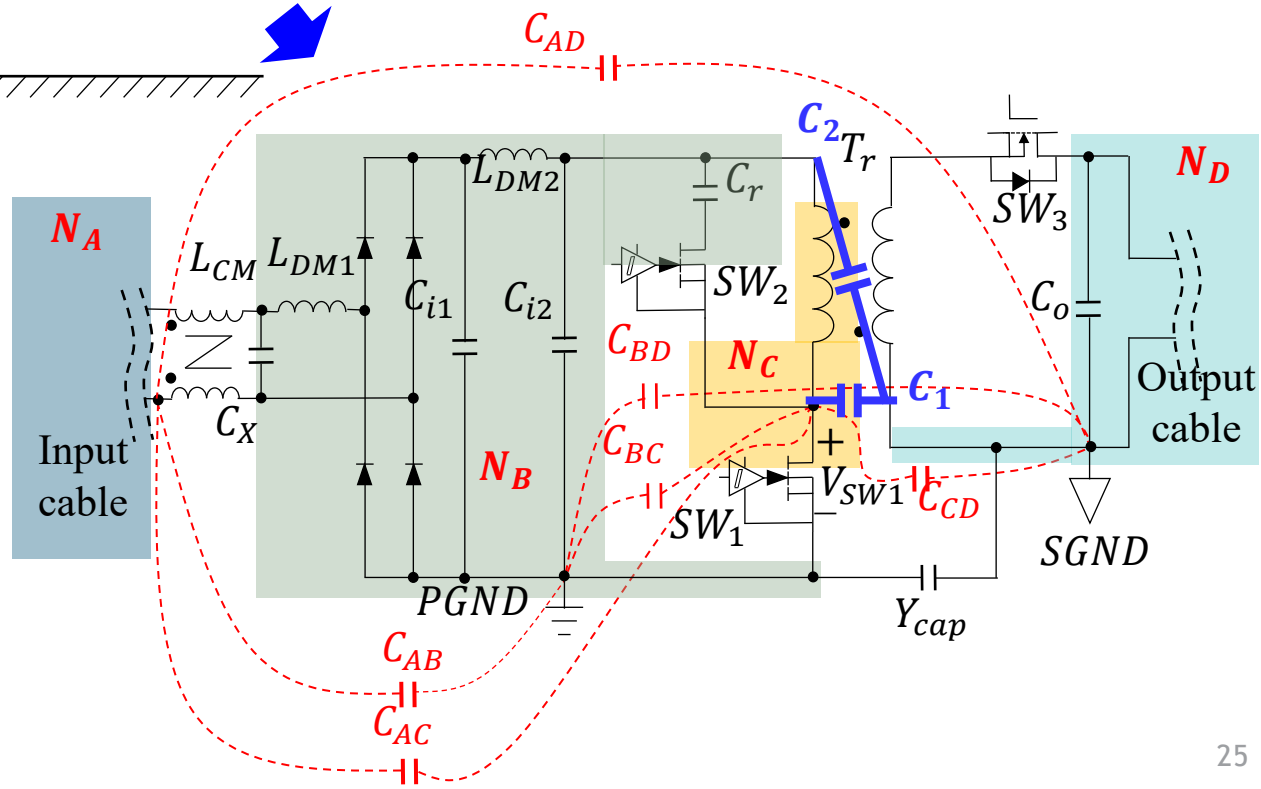
Due to impedances

[8]: Y. Zhang, S. Wang and Y. Chu, "Investigation of Radiated Electromagnetic Interference for an Isolated High-Frequency DC–DC Power Converter With Power Cables," in *IEEE Transactions on Power Electronics*, vol. 34, no. 10, pp. 9632-9643, Oct. 2019.

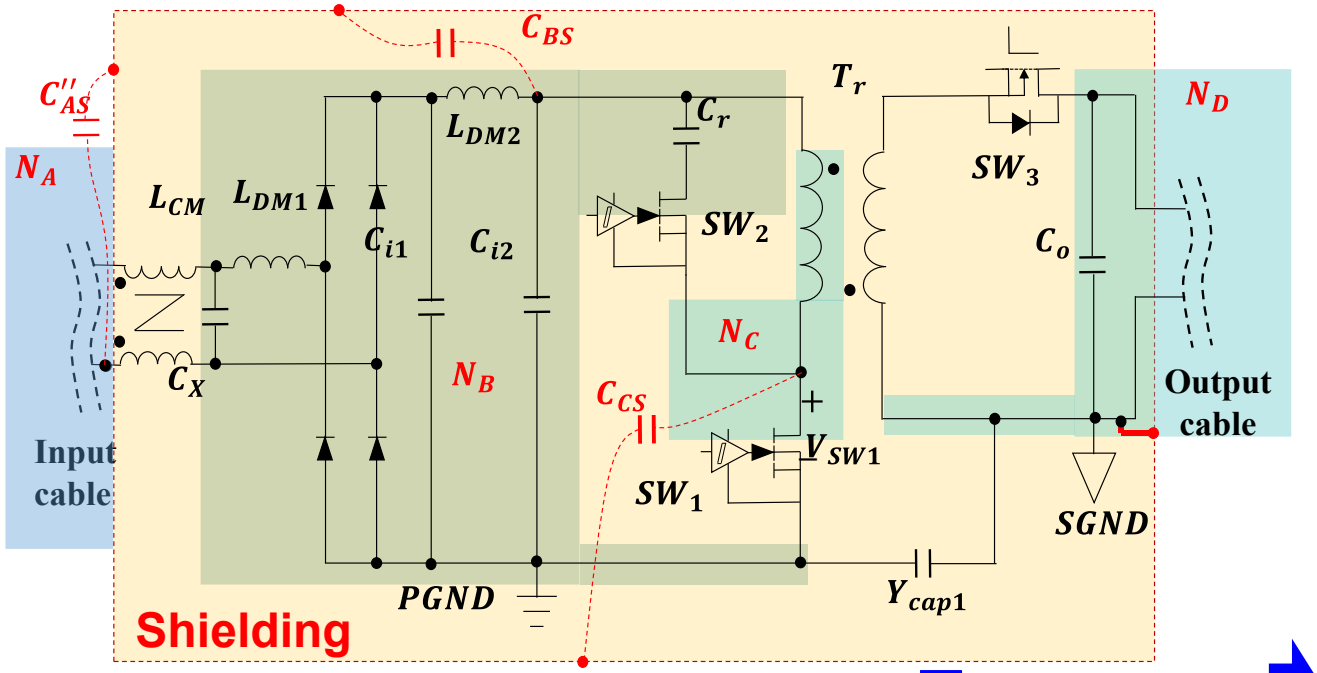
Radiated EMI Model of A Flyback Converter

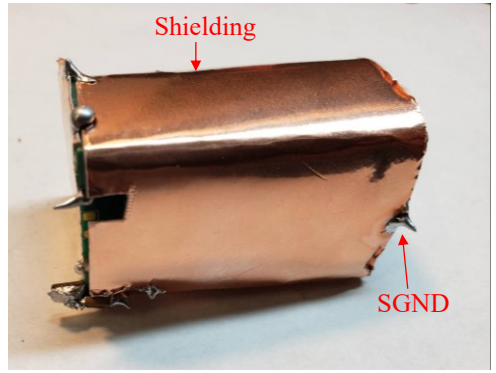


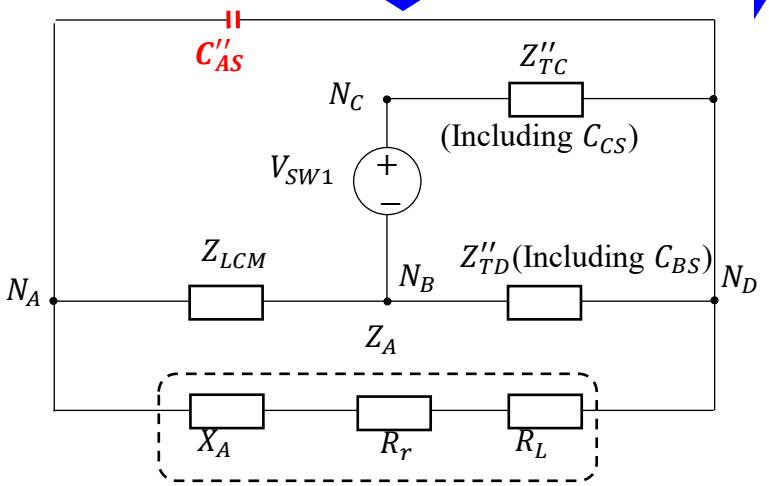


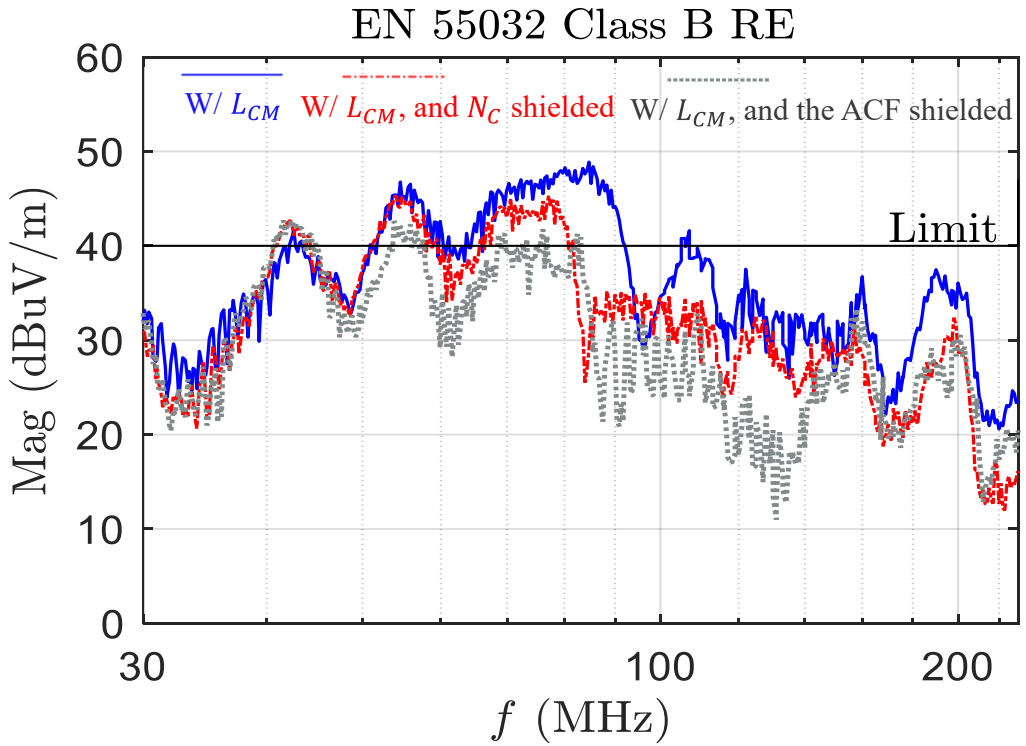


Radiated EMI Reduction with A Shielding









Q & A

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