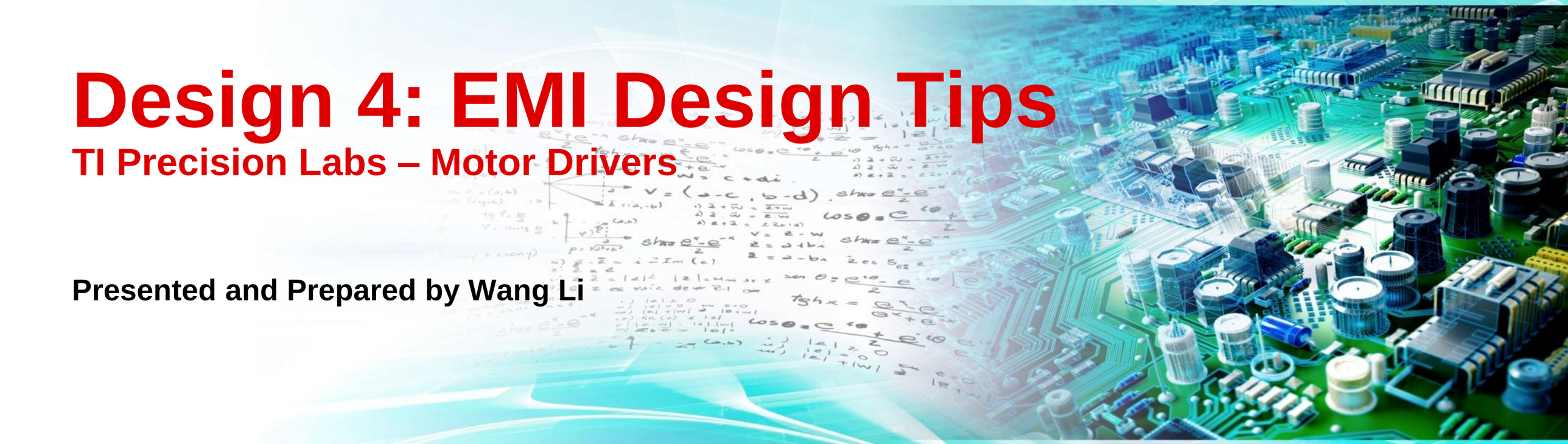
Design 4: EMI Design Tips

TI Precision Labs – Motor Drivers

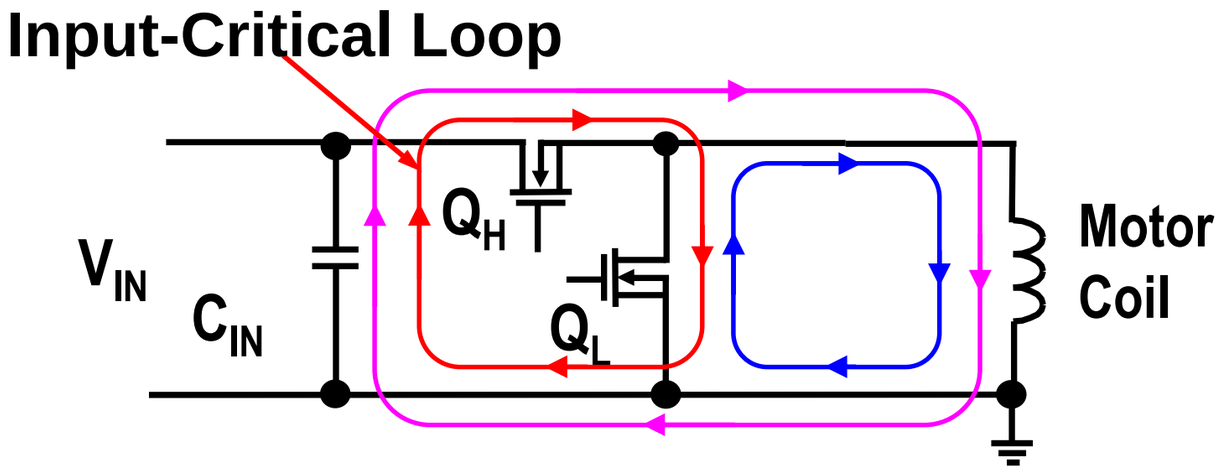


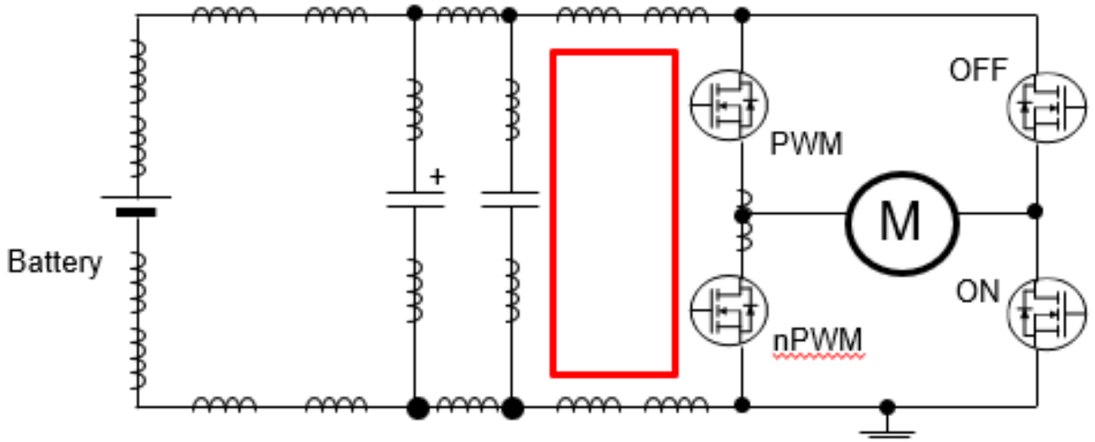
Presented and Prepared by Wang Li

Motor Driver EMI Design Tips

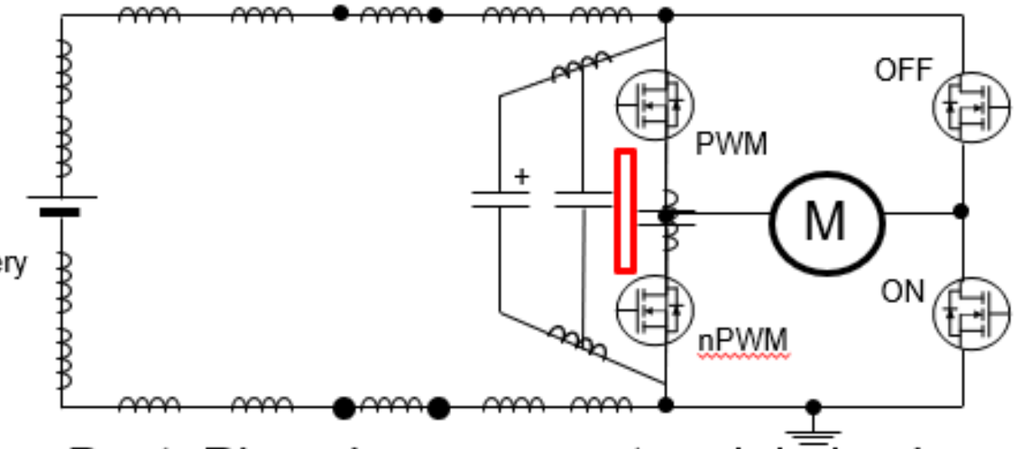
- **Reduce EMI noise from the noise source: switching circuit**
  1. Reduce the input-critical loop area
  2. Control switching node dv/dt
  3. Find high di/dt loop and set layout priority
  4. Use spread spectrum clocking technology to minimize EMI
- **Reduce EMI noise from the noise path: layout and filter**
  5. Put a ground layer near the power components
  6. Shield Parasitic Inductance coupling
  7. Add Faraday cage on a board
  8. Add small ceramic capacitor near switching FETs
  9. Add Small Capacitor on motor driver outputs to ground
  10. Add a small capacitor on brushed motor terminal
  11. Add EMI bead or common mode choke
  12. Add an input PI filter
- **Reduce EMI noise from the Motor side**
  13. Add ground connection to the motor case
  14. Connect the motor with twisted wires

EMI design tips #1: Reduce the input-critical loop area





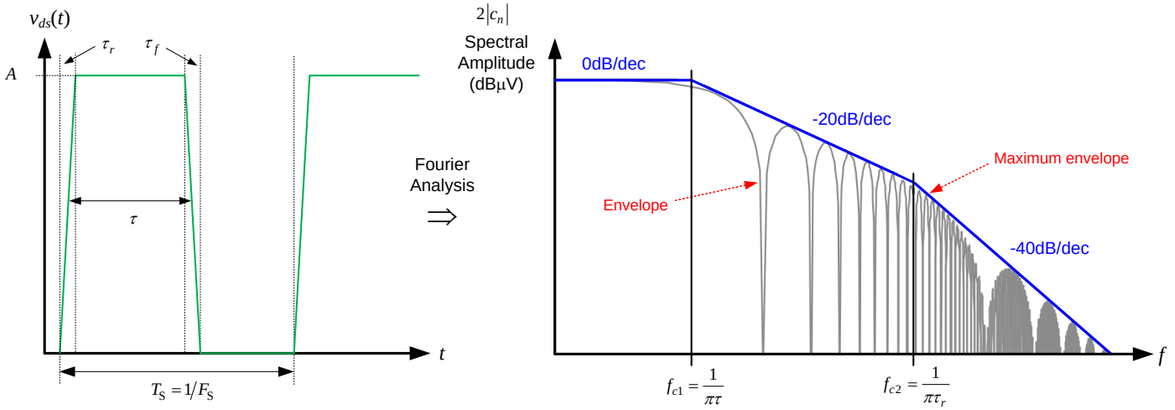
Good: Place bypass cap on PCB



Best: Place bypass cap to minimize loop

EMI design tips #2: Control SW node dv/dt

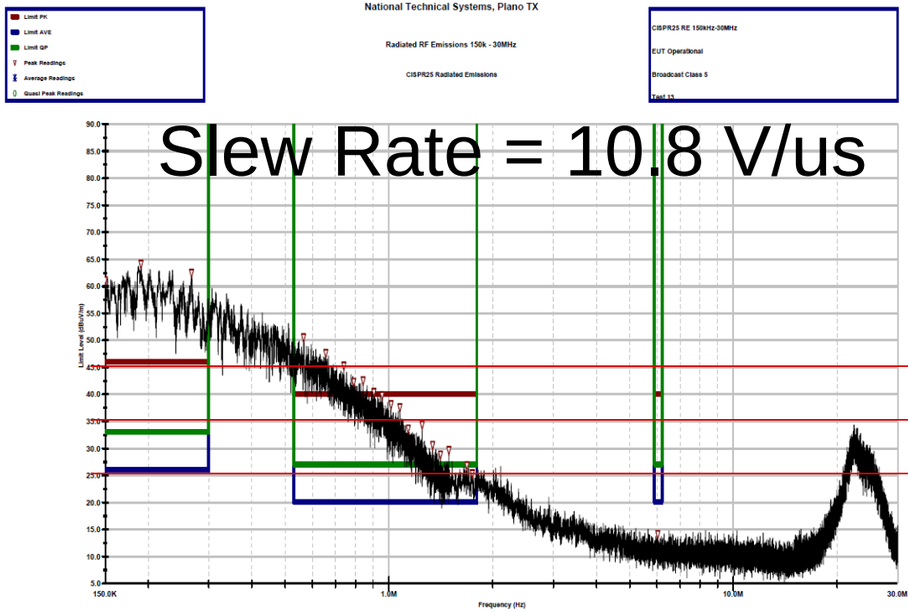
- **Slow down gate driver or add snubber on switching node can reduce EMI noise**

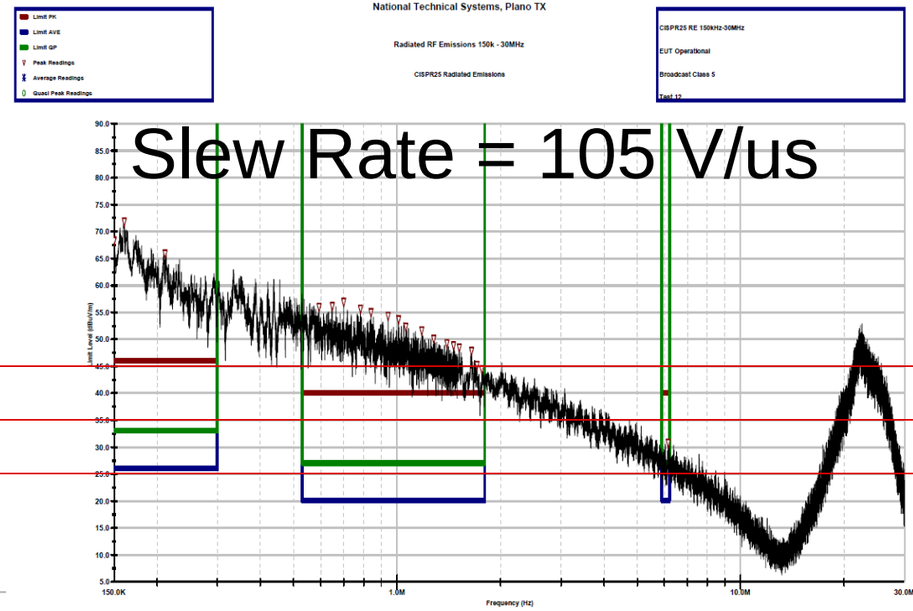


τ = pulse width (measured at half-maximum)
T_S = pulse period
D = duty cycle = τ / T_S
τ_r = rise time; τ_f = fall time of edge transition

$$|c_n| = A\frac{\tau}{T_S}\left|\mathrm{sinc}\left(n\omega_o\frac{\tau}{2}\right)\right|\left|\mathrm{sinc}\left(n\omega_o\frac{\tau_r}{2}\right)\right|$$

N. Oswald et al., “Analysis of shaped pulse transitions in power electronic switching waveforms for reduced EMI generation,” IEEE Transactions on Industry Applications, Sept 2014, pp. 2154-2165, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5953506

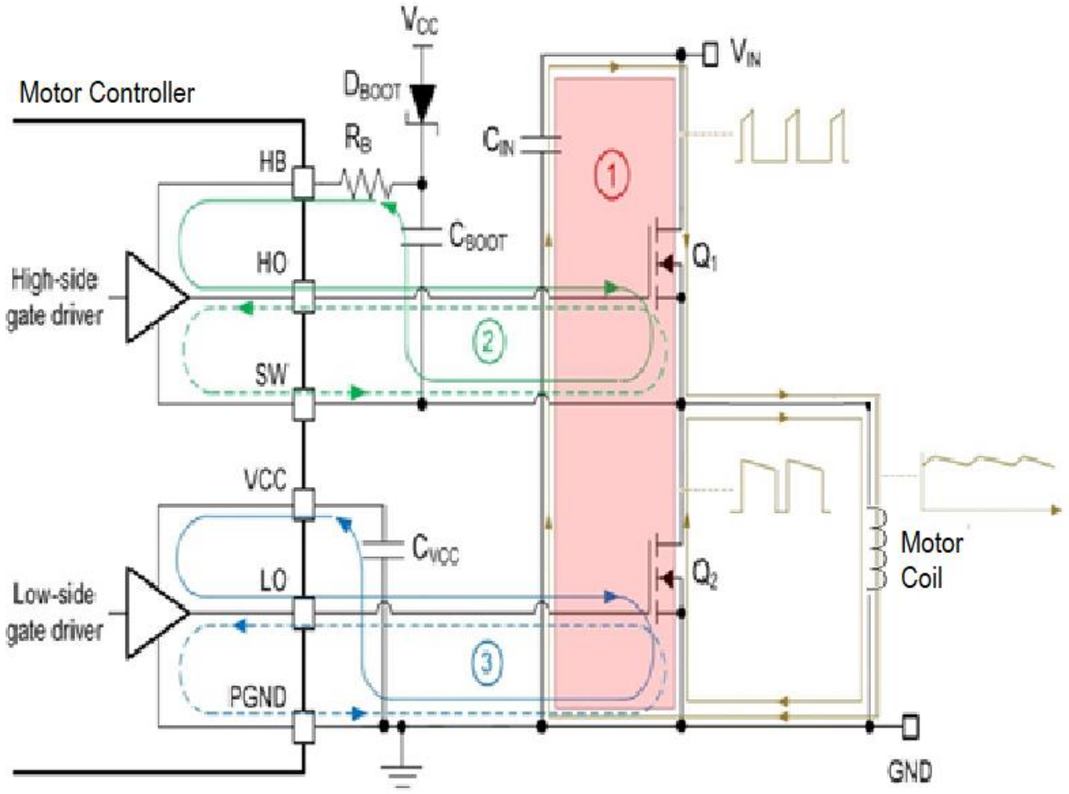


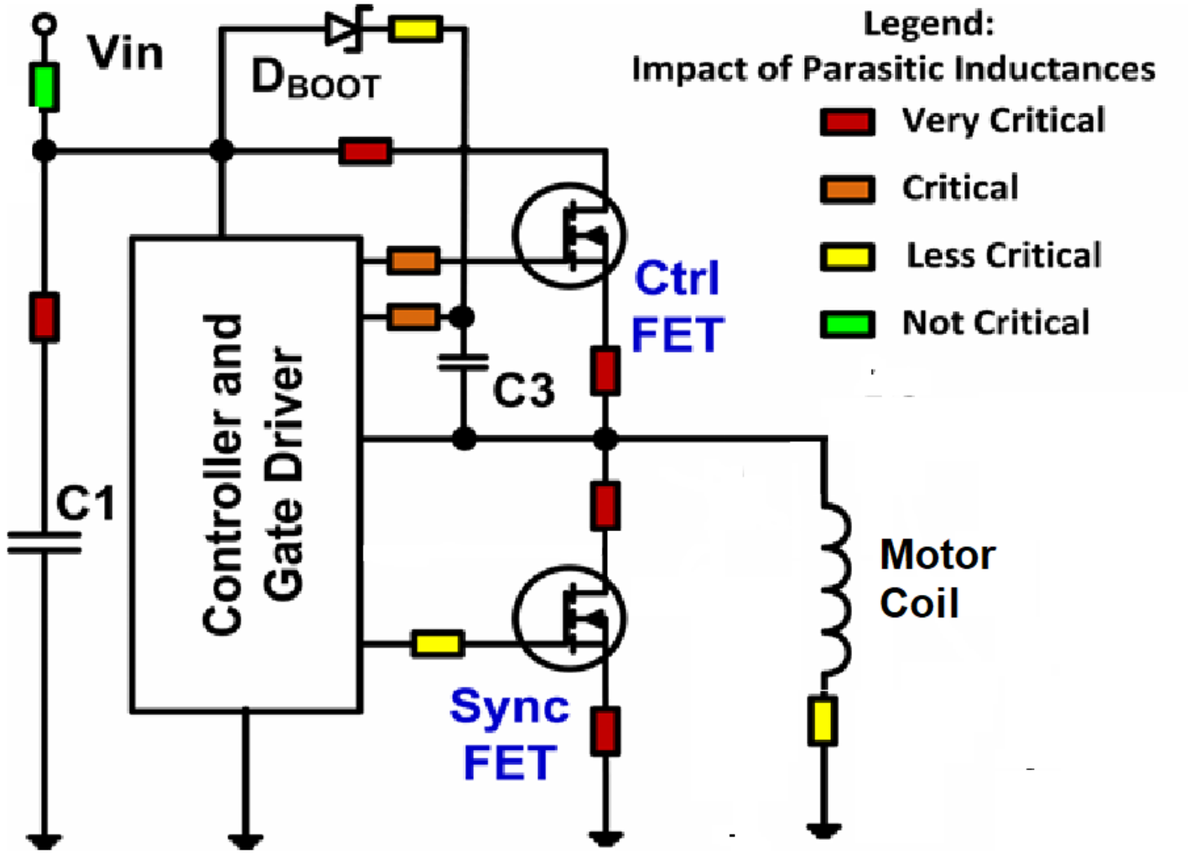


45dB
35dB
25dB

EMI design tips #3: Find high di/dt loop and set layout priority

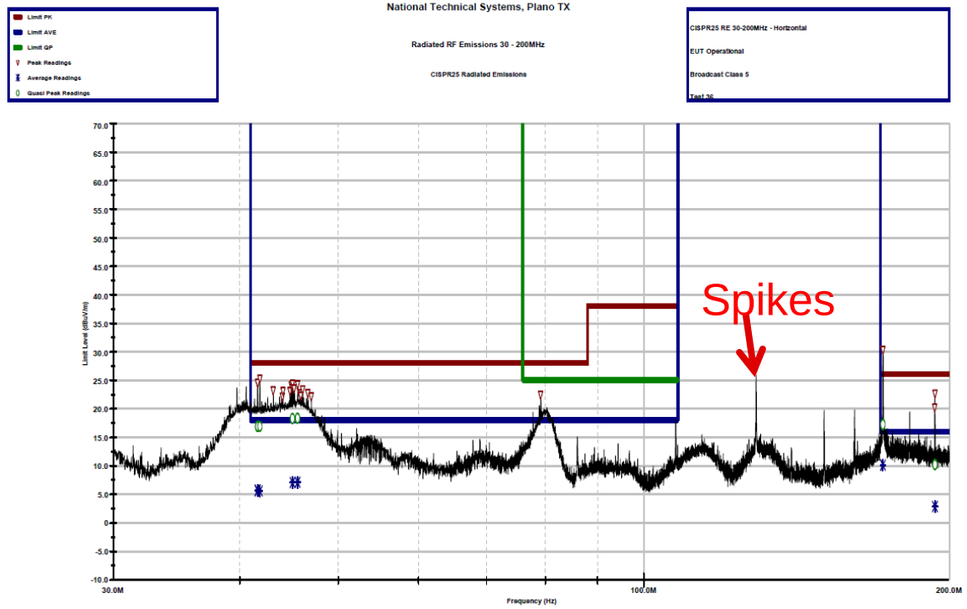
- Layout priority is decided by reducing high di/dt loop area
  - Reduce the main power high frequency current loop area
  - Reduce charge pump circuit loop area

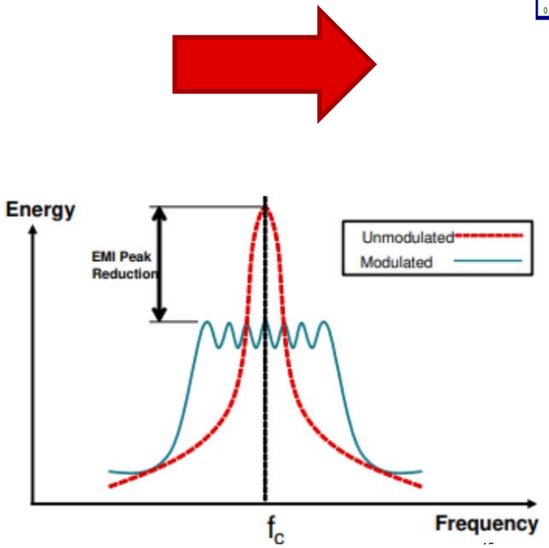




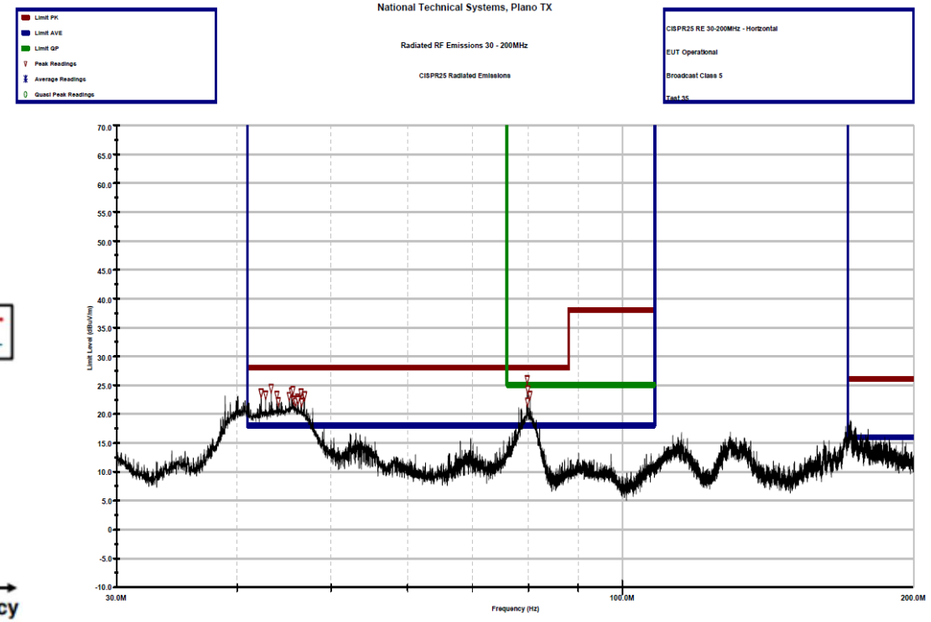
EMI design tips #4: Use spread spectrum clocking function

With Spread spectrum clocking off



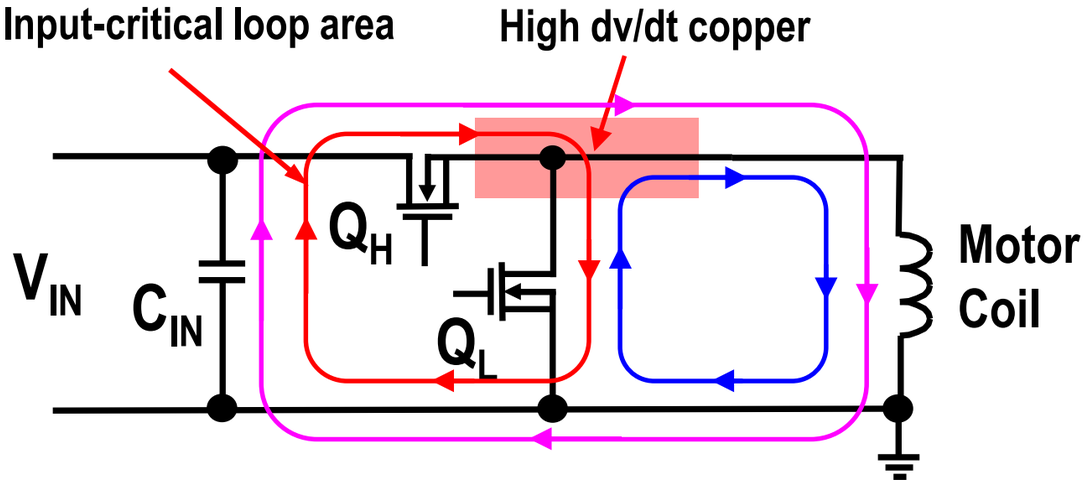


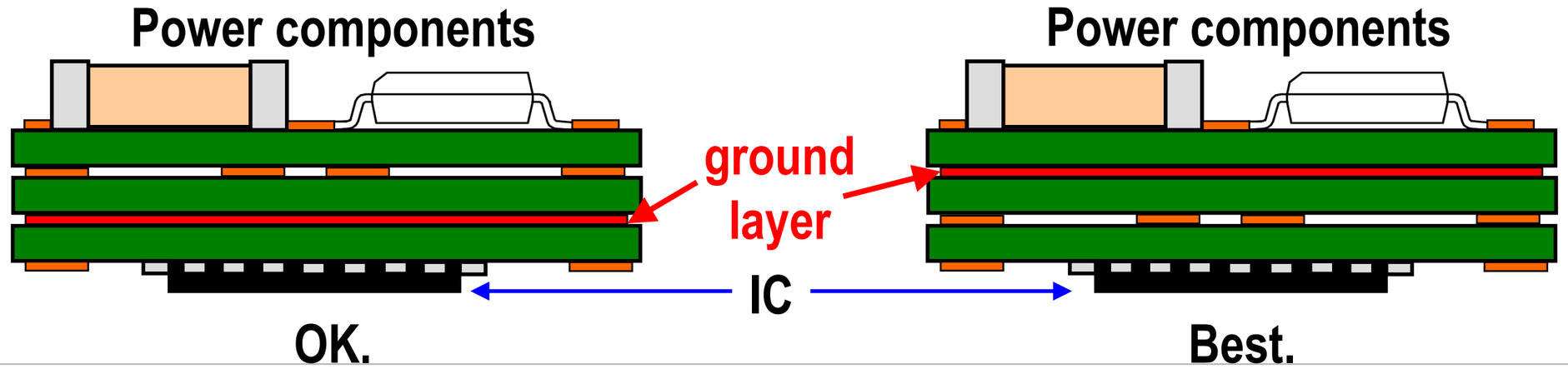
With Spread spectrum clocking on



EMI design tips #5: Ground layer near the power components

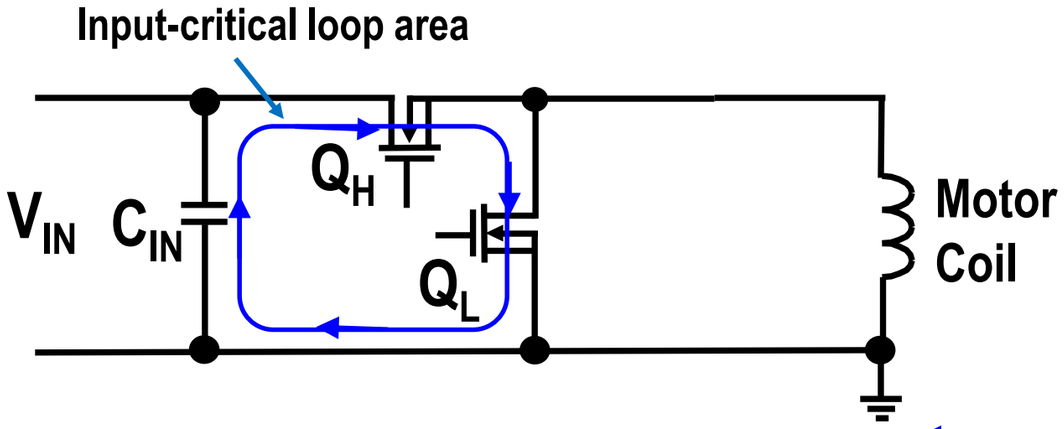
- Ground layer near power component layer can reduce:
  - inductive and capacitive coupling noise.

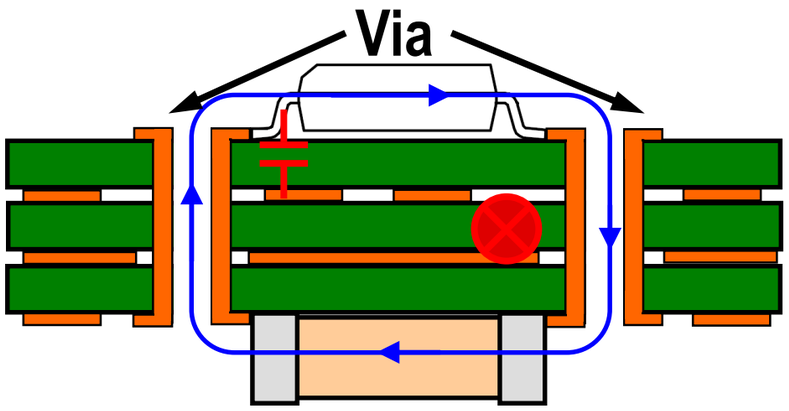




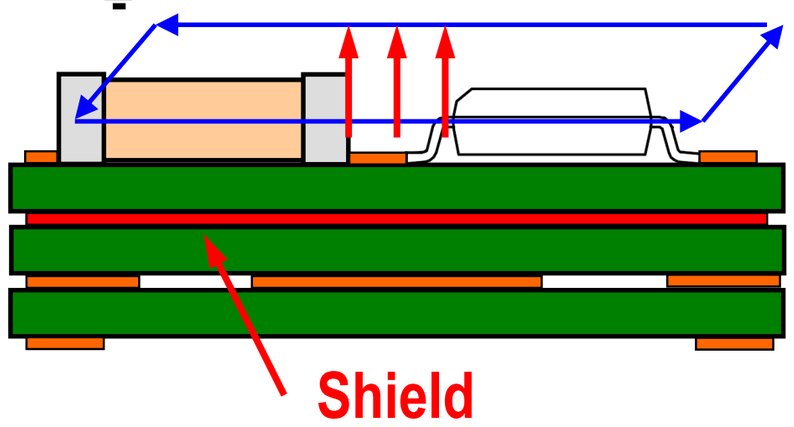
EMI design tips #6: Shield Parasitic Inductance coupling

- **Put Power Components In Same Layer.**





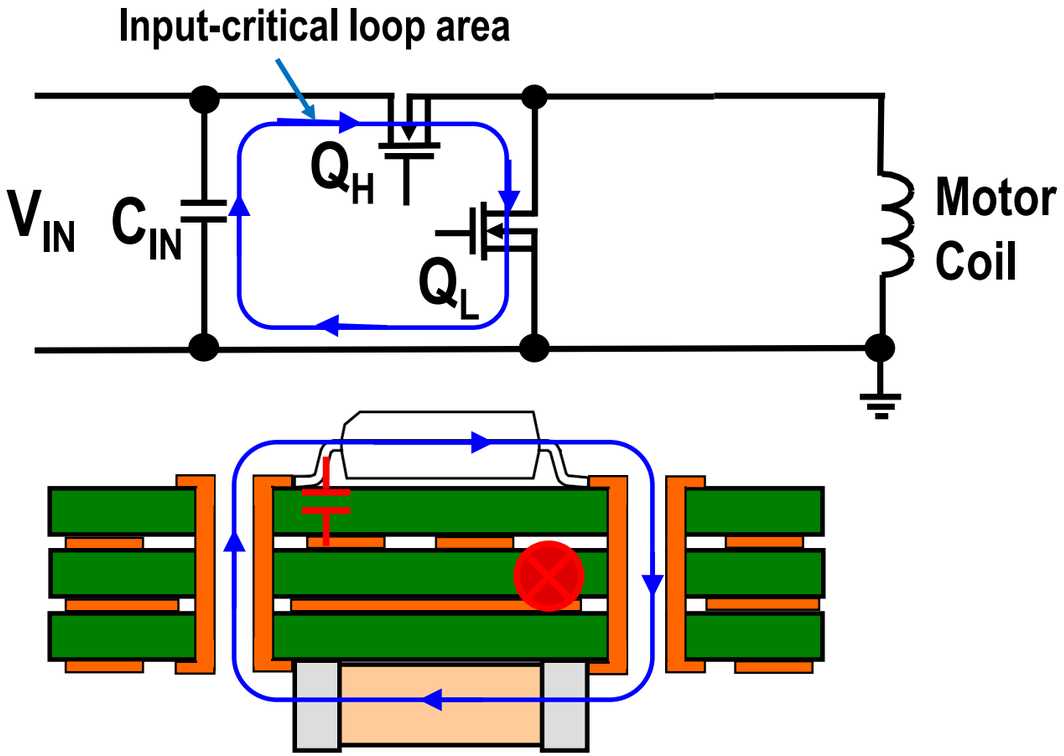
Internal layer trace has coupling (inductive and capacitive)

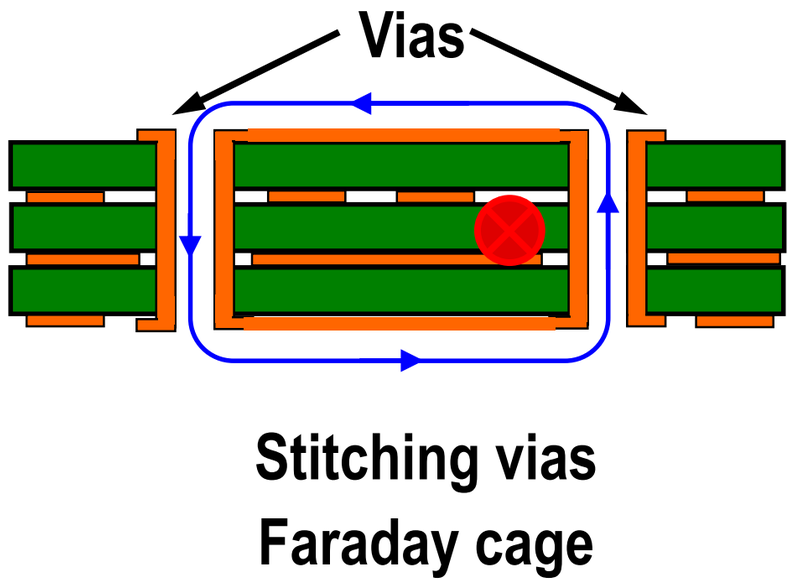


Can use ground plane to reduce inductive and capacitive coupling.

EMI design tips #7: Faraday cage

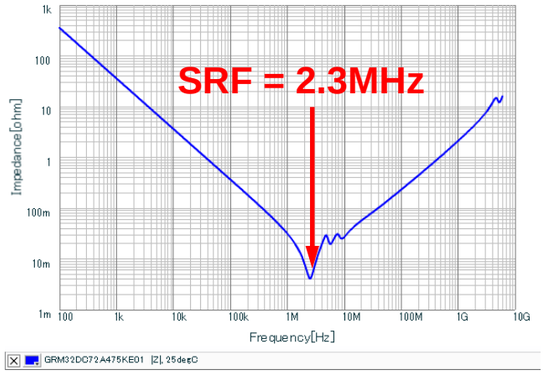
- The stitching vias can provide a current loop to against the high frequency horizontal magnetic noise which is generated from the input-critical loop.
- Use Layout stitching via tool to put ground stitching vias all the way around the board to build a Faraday cage and reduce on the horizontal magnetic noise.

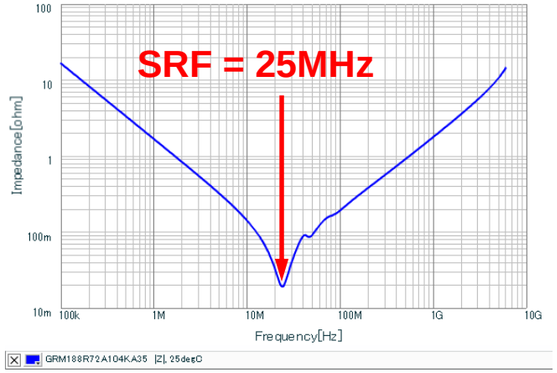


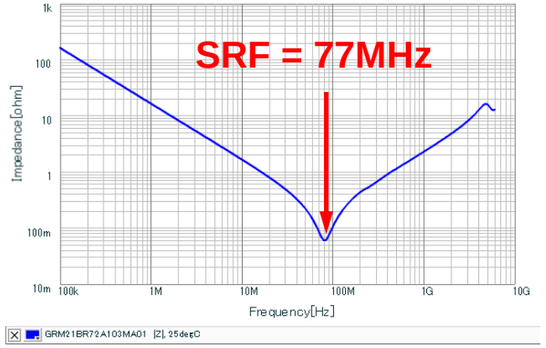


EMI design tips #8: Adding small ceramic capacitor near switching FETs

- **A small capacitor can provide lower impedance at high frequency**
- **Put 10nF ceramic capacitor between HIFET's drain and LOFET's source.**







4.7µF, 100V, X7S, 1210 (1.5µF @ 48V)

SRF = 2.3MHz (Z_C = 4mΩ)

ESL = 0.4nH

Z_C = 237mΩ @ 100MHz

0.1µF, 100V, X7R, 0603

SRF = 25MHz (Z_C = 20mΩ)

ESL = 0.35nH

Z_C = 195mΩ @ 100MHz

10nF, 100V, X7R, 0603

SRF = 77MHz (Z_C = 60mΩ)

ESL = 0.33nH

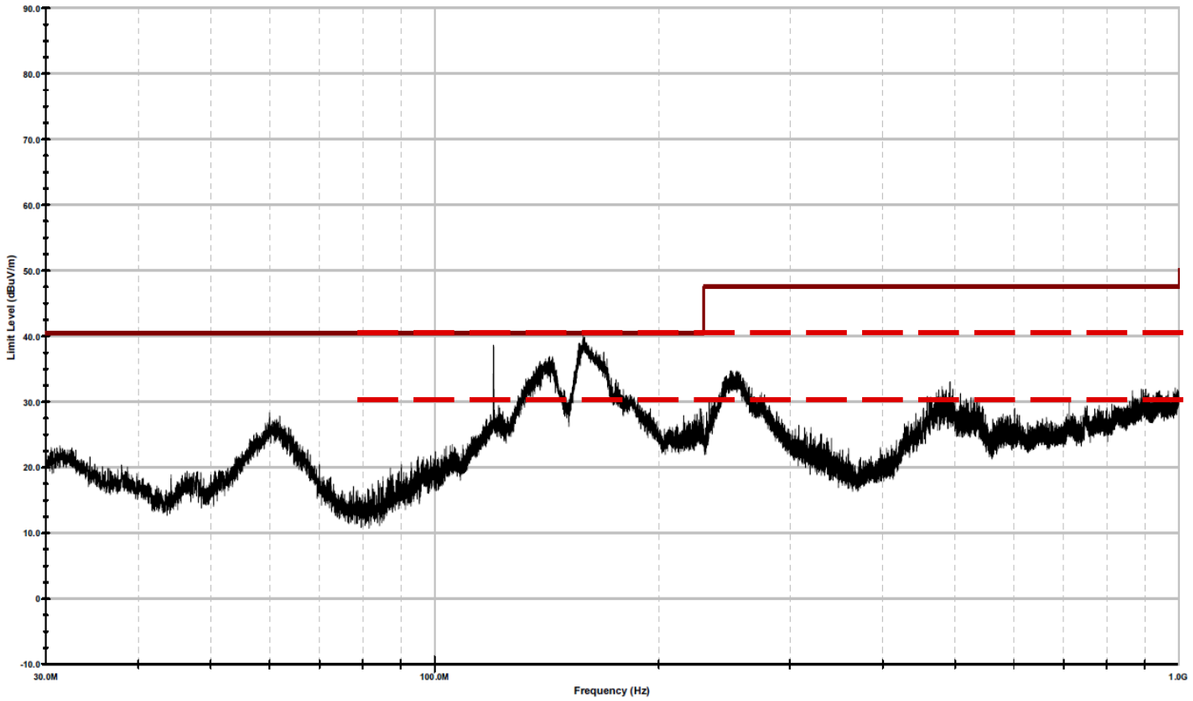
Z_C = 110mΩ @ 100MHz

[9] Murata Simsurfing tool, http://ds.murata.co.jp/software/simsurfing/en-us/index.html

EMI design tips #9: a small capacitor on motor driver outputs to ground

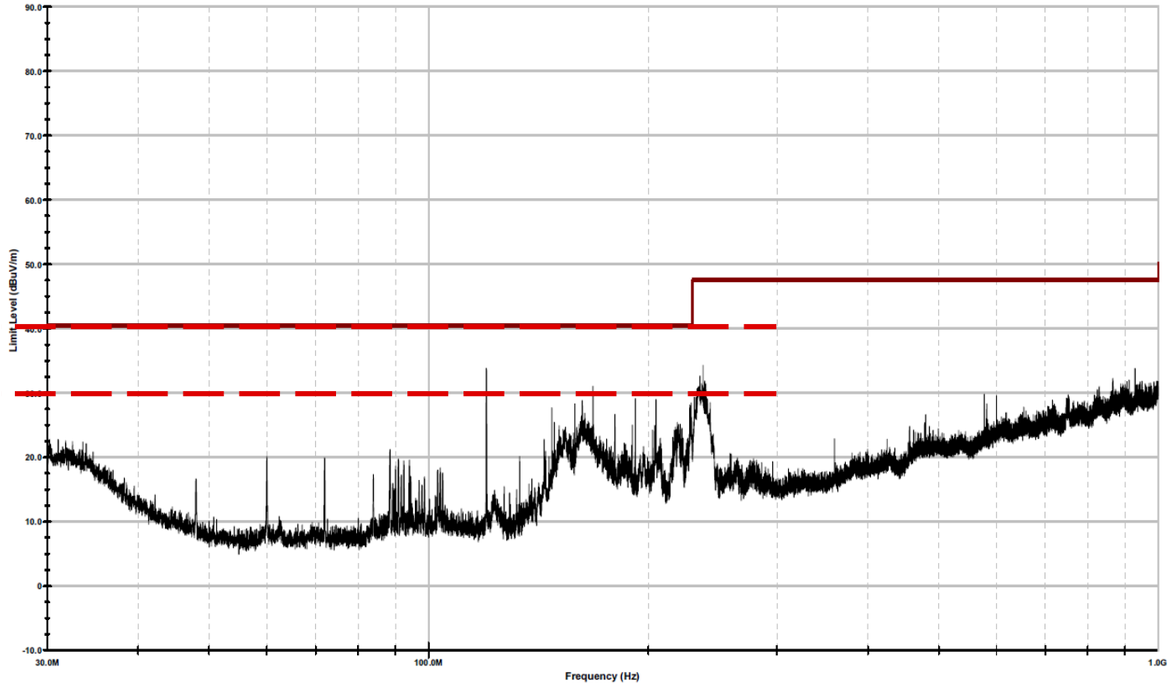
- **A small capacitor is like a short wire for high frequency noise which can eliminate the noise passing to the output cable.**

DRV8424EVM with a 3A stepper motor (3.6mH/1.05ohm); 24Vin; 2AIFS; 1/16uStep;Smart Tune Ripple Control decay



40dB

30dB

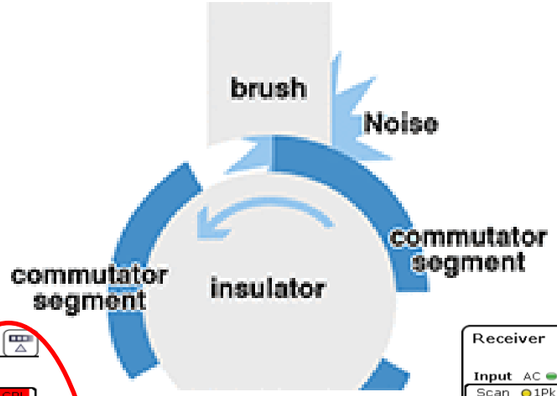


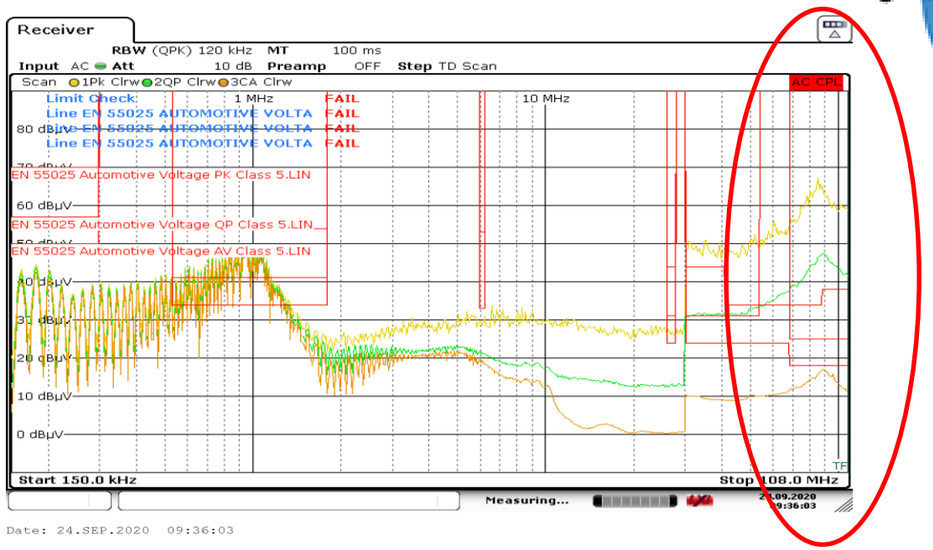
No output capacitor to ground

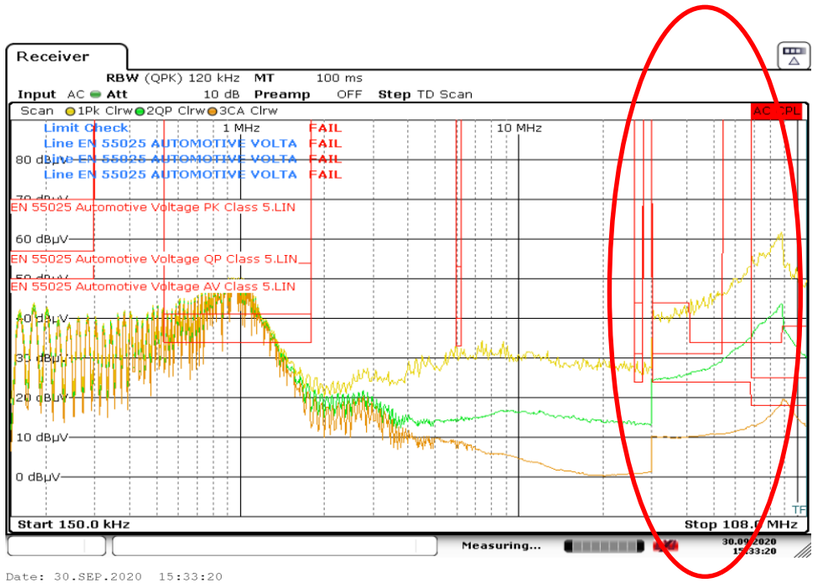
3.3nF capacitor between OUTx to ground

EMI design tips #10: Add a small capacitor between brushed motor output terminals

- A small capacitor on brushed motor terminal can reduce the EMI noise caused by arcing between the brushes and commutators when the motor is spinning.



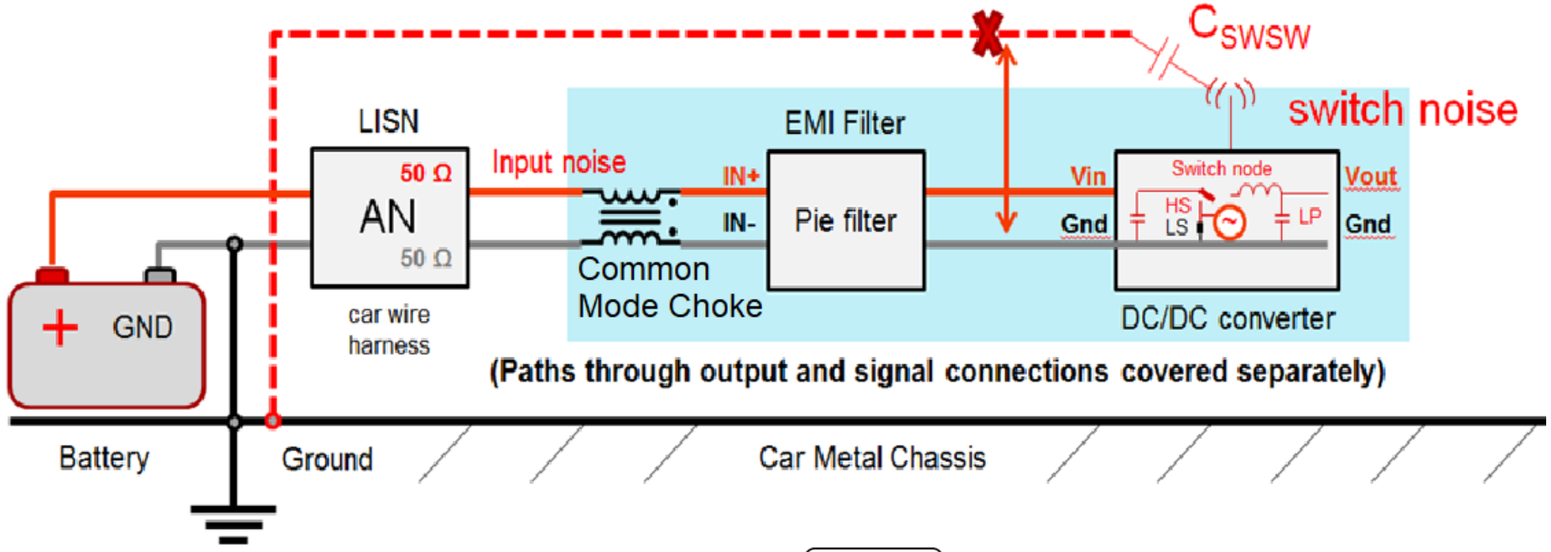


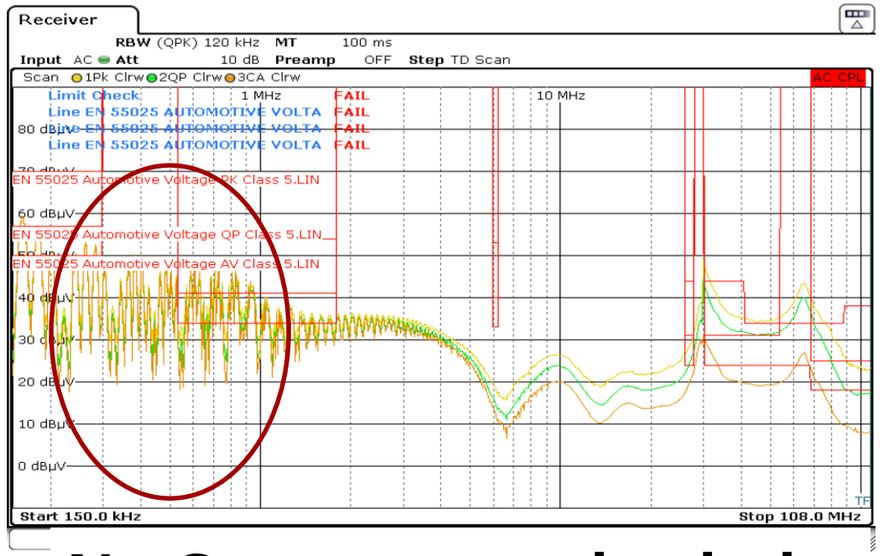


No output caps

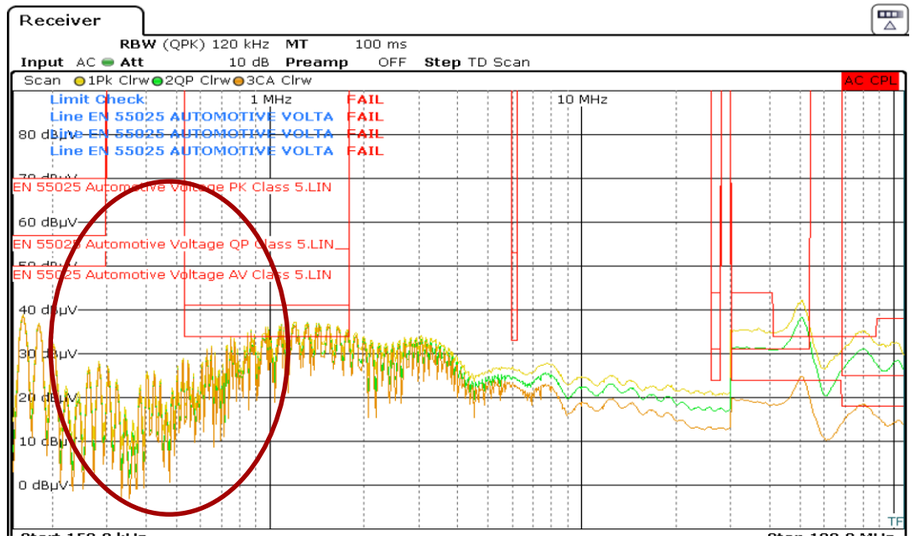
10nF cap across terminals, 2 x 10nF caps to PCB gnd

EMI design tips #11: Add a bead or common mode choke





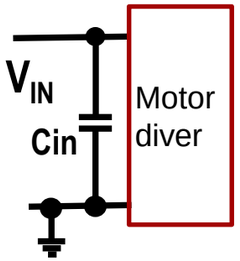
No Common mode choke

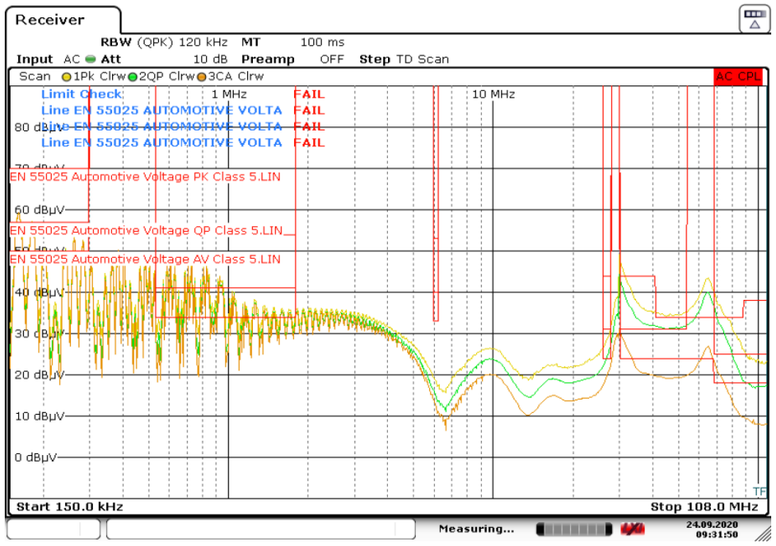


With a Common mode choke

EMI design tips #12: Add an Input PI filter

Without PI filter





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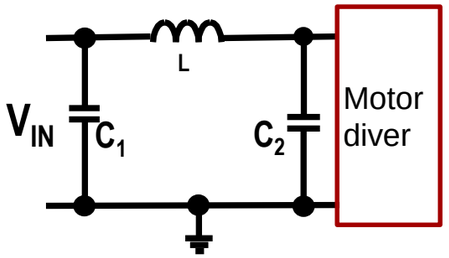
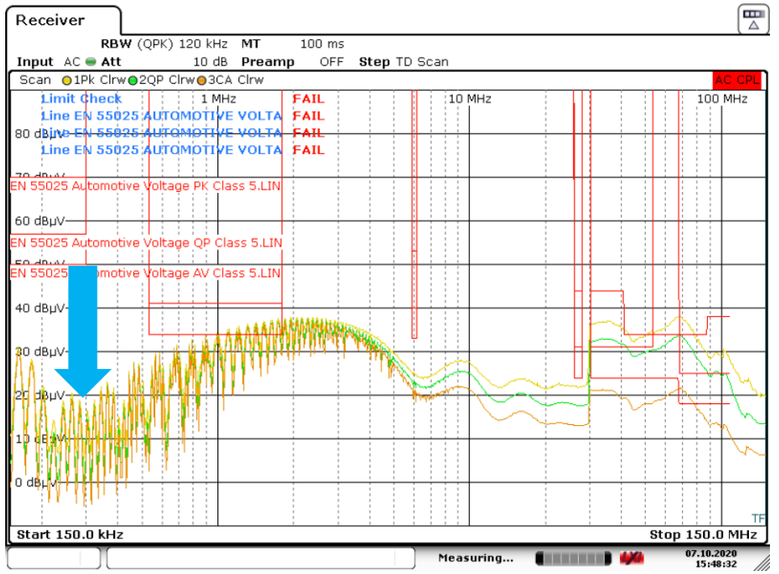
PI filter



With PI filter



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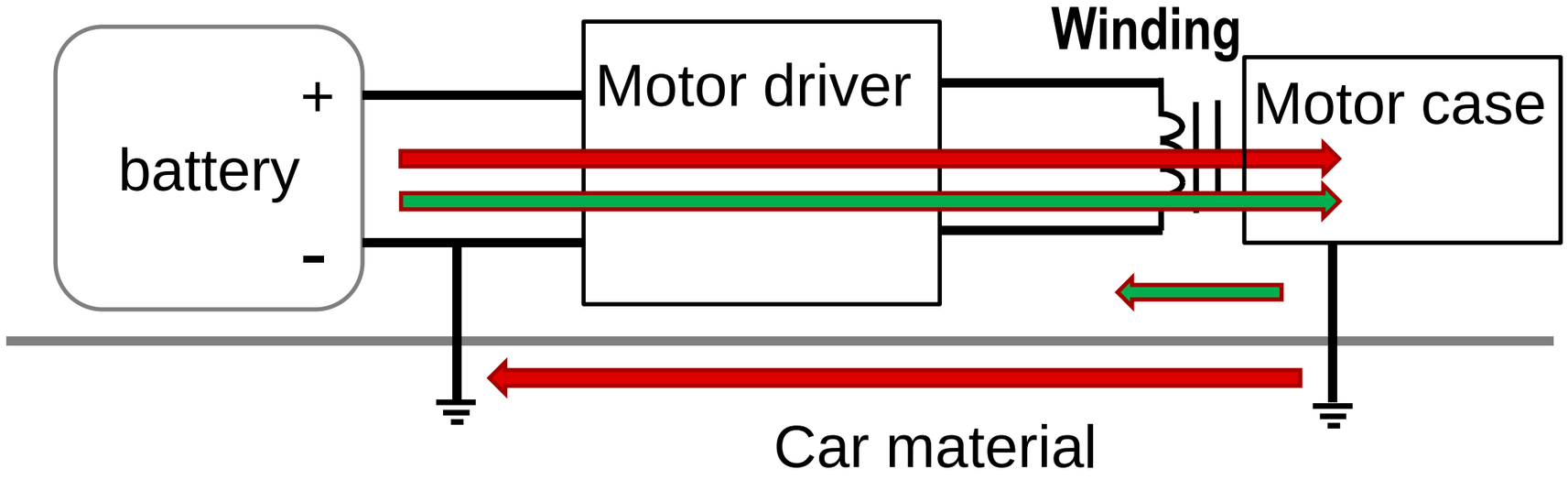
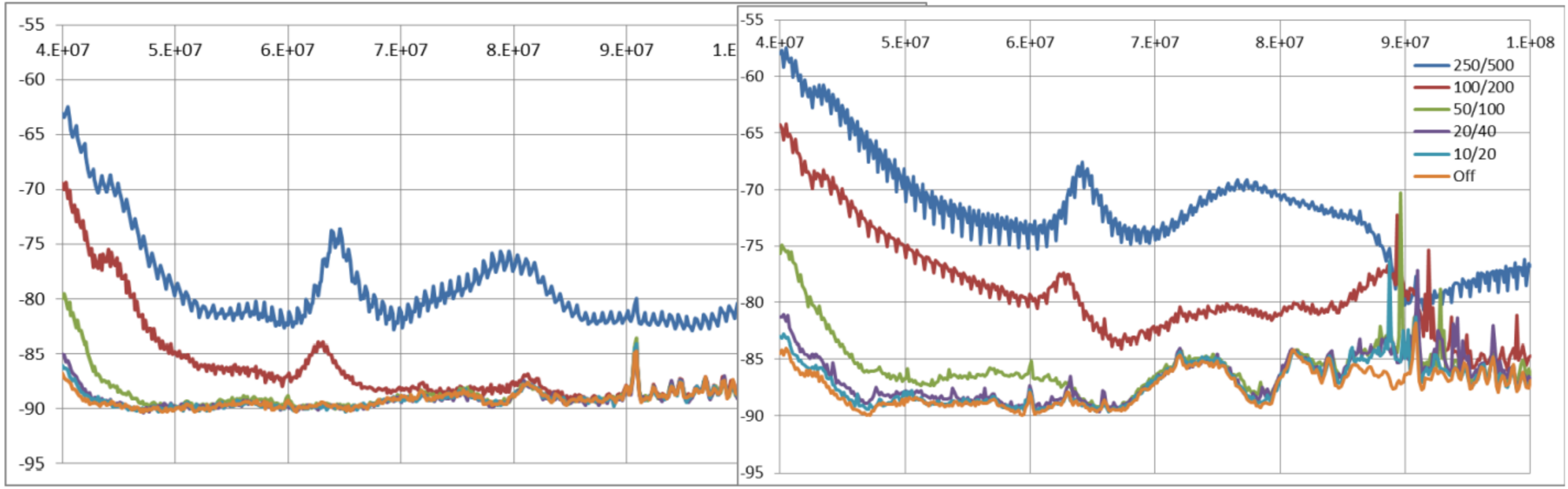
EMI design tips #13: ground connection to the motor case

- The motor coil is isolated from the motor case. But, the common mode displacement current can pass the motor isolated boundary due to the parasitic capacitor between the motor coil and the motor case.
- A ground connection from the motor case to the motor driver ground can make the common mode displacement current back to the motor driver circuitry with a minimized loop area which can reduce the EMI noise.



EMI design tips #14: Connect the motor with twisted wires

- Radiated emissions from 40 MHz to 1 GHz
- Variable gate drive current, 10 mA to 500 mA



To find more stepper driver technical resources and search products, visit https://www.ti.com/motor-drivers/overview.html

Reference

1. Addressing EMI challenges for high side switches and motor drivers in body electronics
2. Input Filter Design for Switching Power Supplies
3. Analysis of shaped pulse transitions in power electronic switching waveforms for reduced EMI generation
4. Texas Instruments FAE Summit 2021: PASS CONDUCTED EMISSIONS FOR AUTOMOTIVE BODY MOTOR DRIVE APPLICATIONS