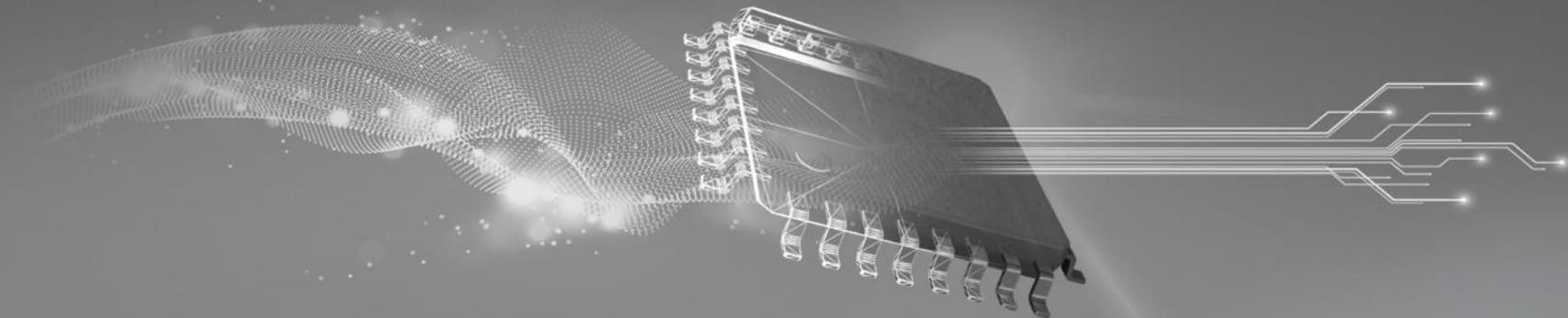


TI TECH DAYS



Addressing EMI challenges for high side switches and motor drivers in body electronics

Clark Kinnaird and Arun Vemuri

Body electronics & lighting

Abstract

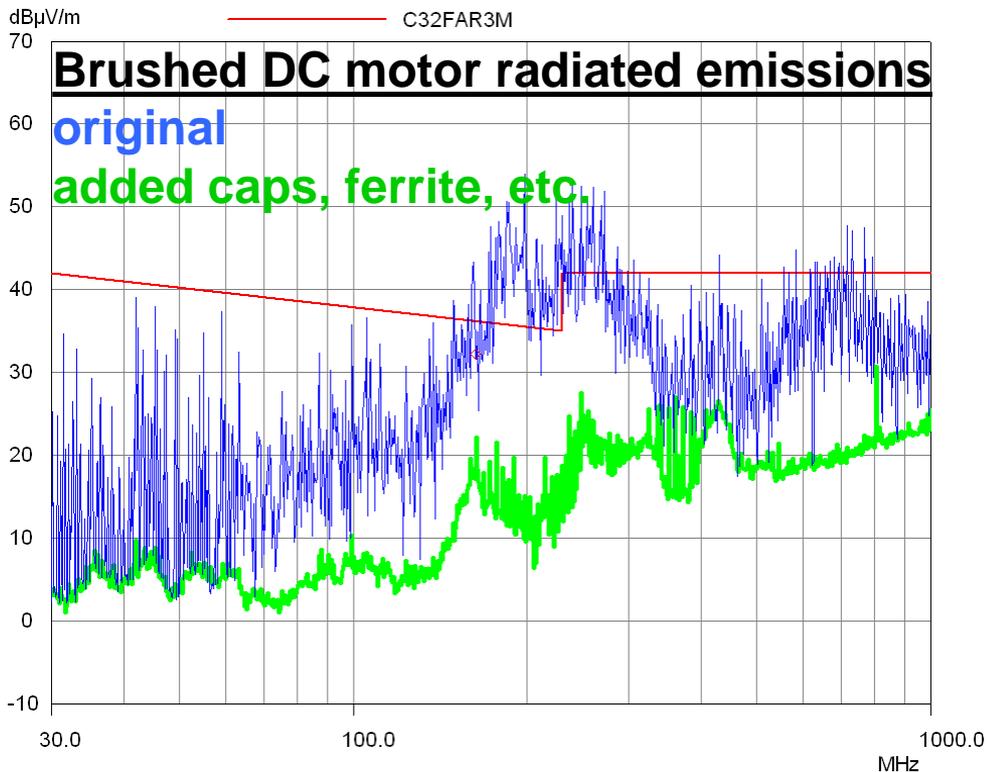
- What are all the components (“knobs”) a designer can use to improve EMC performance (especially emissions) in a design, specifically an automotive electric motor application?
 - Waveform shaping
 - Electrical filtering
 - Dithering, synchronization
 - Board layout
 - Shielding
 - Etc.
- How does each component affect the EMC performance (in general terms)?
- What cost or penalty is associated with each component?

Agenda

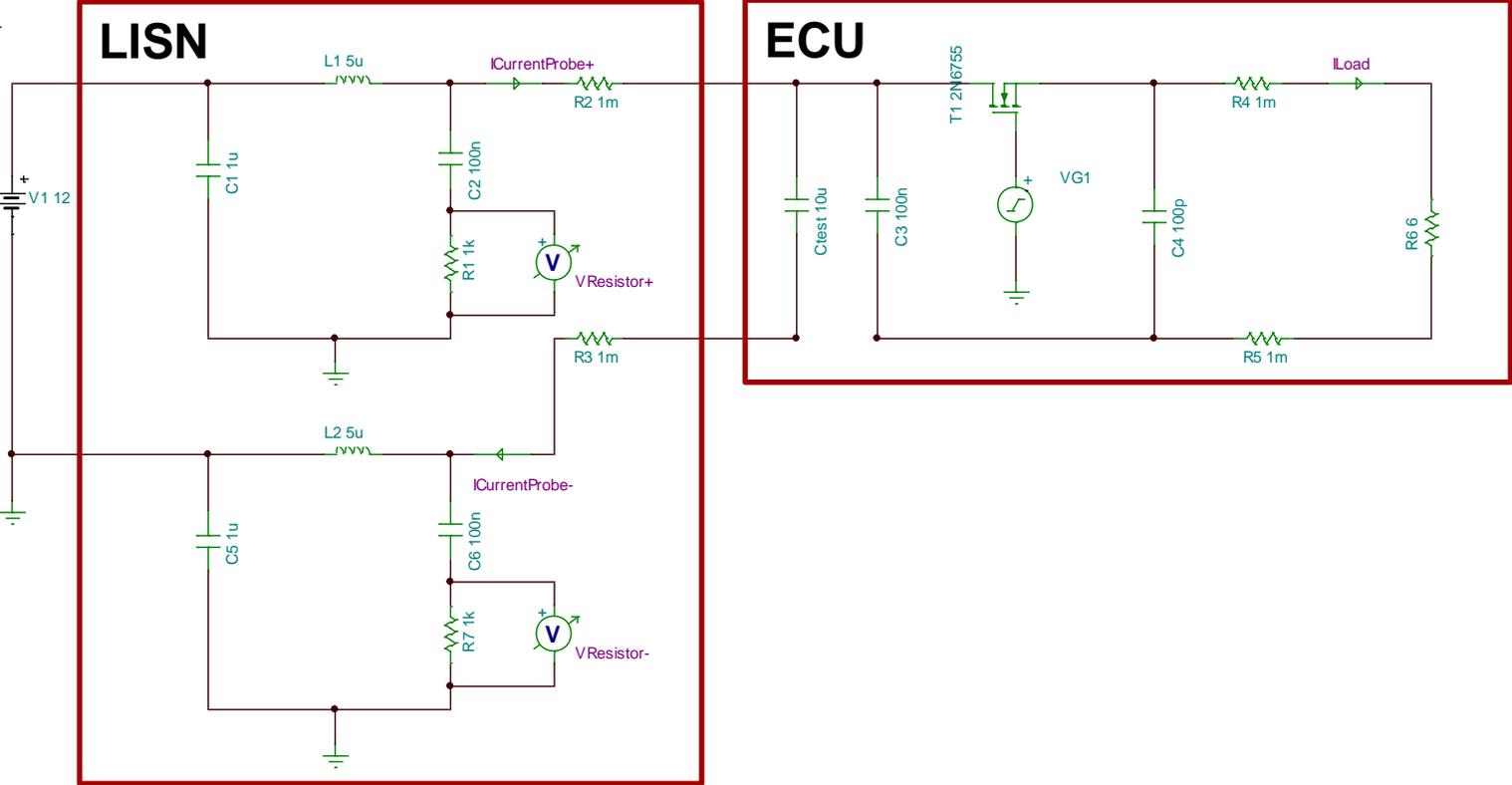
- Sources of emissions
- CISPR25 LISN model
- Signal shape frequency spectra
- Filtering
- Board design
- Shielding
- Conclusions

Sources of emissions: DC motor drives

- Brushed DC motor
- Brushless DC motor
- PWM drive
- Charge pumps
- Clocks and switching logic



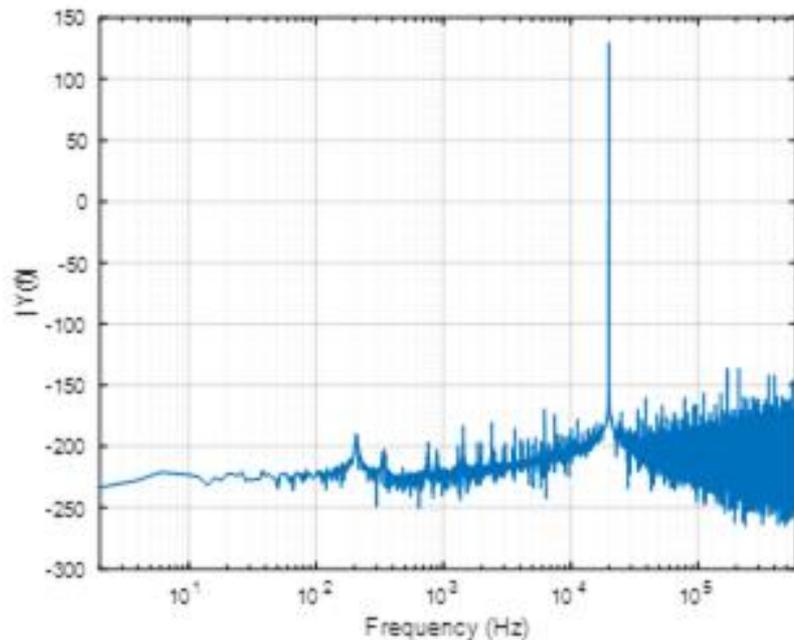
EMI test circuit model



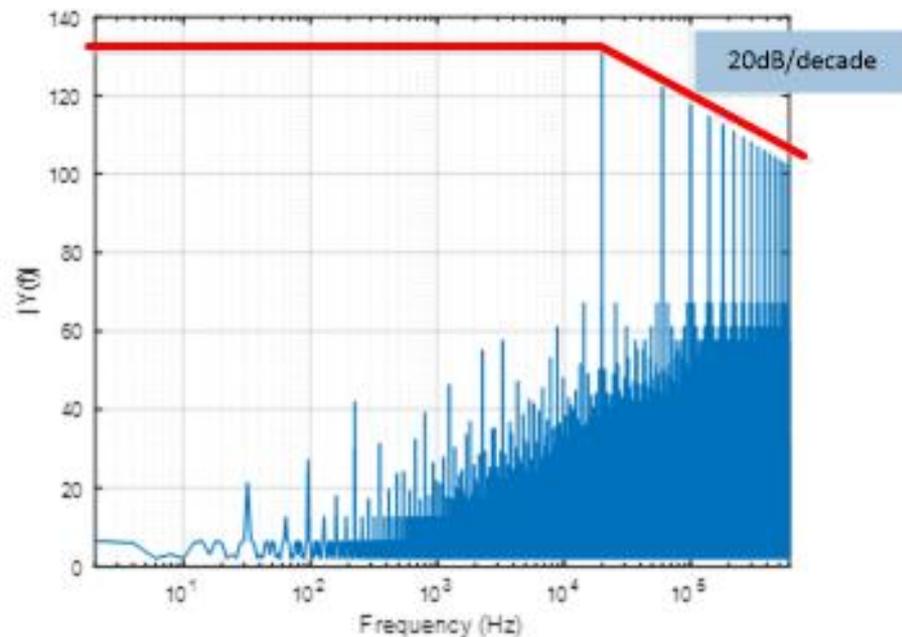
SIGNAL SHAPING

Frequency spectra of waveforms – wave shape

20KHz Sine

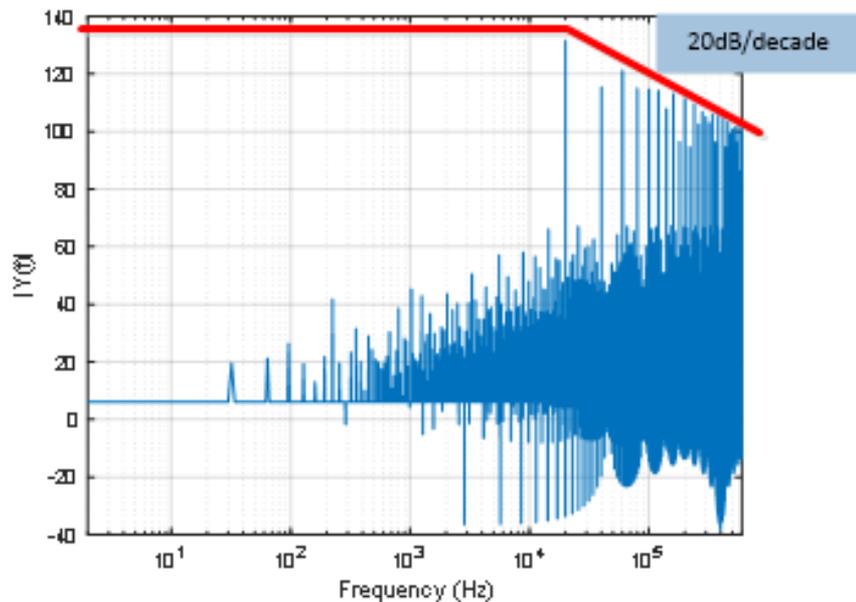


20KHz 50% duty cycle Square

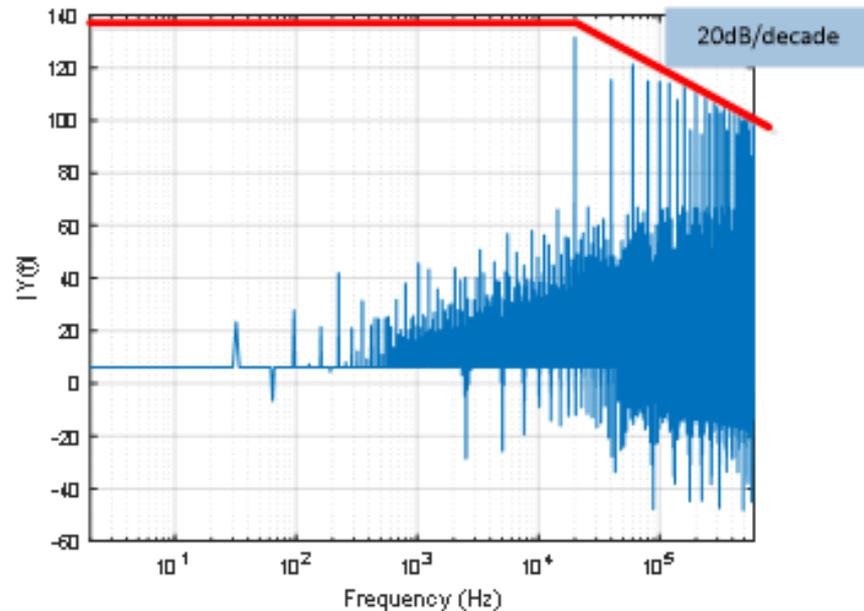


Frequency spectra of waveforms – duty cycle

20KHz 45% duty cycle Square

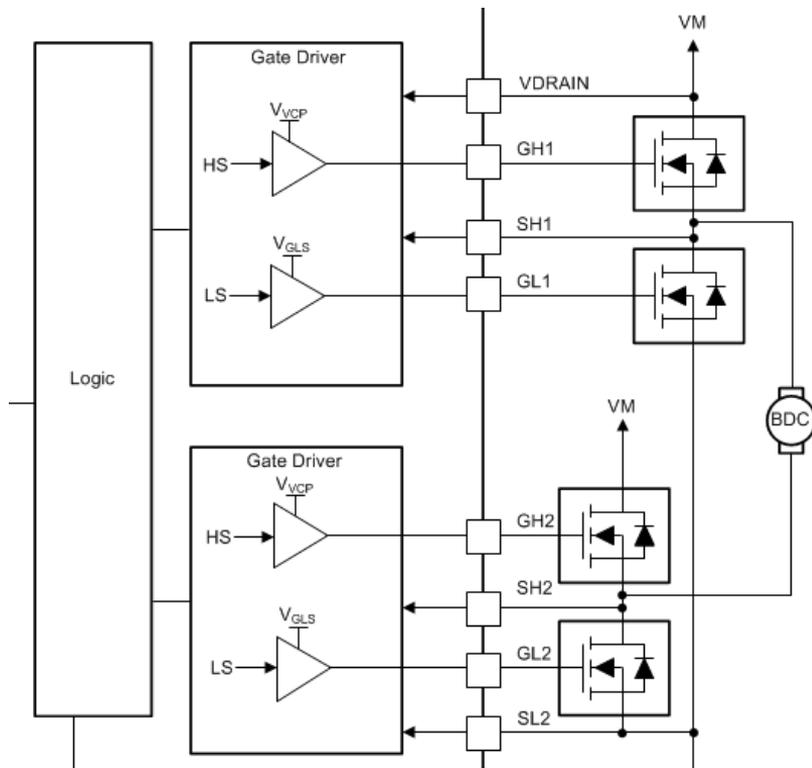


20KHz 55% duty cycle Square

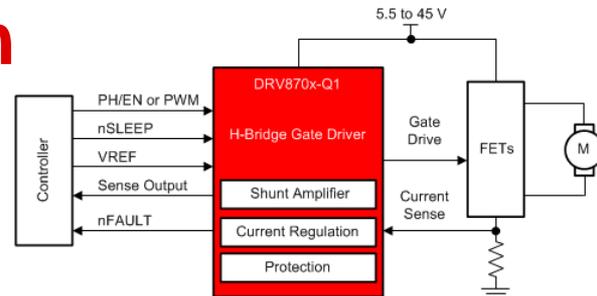
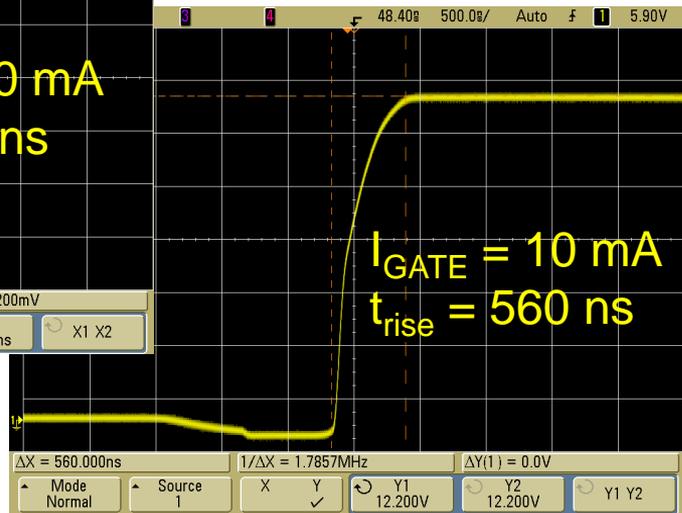
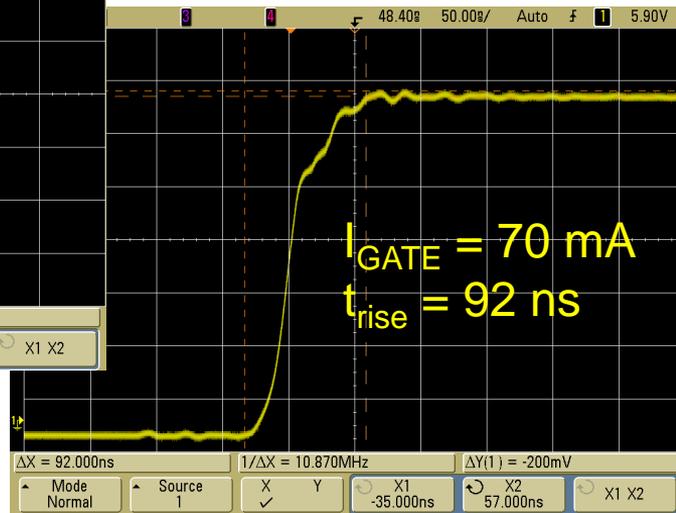
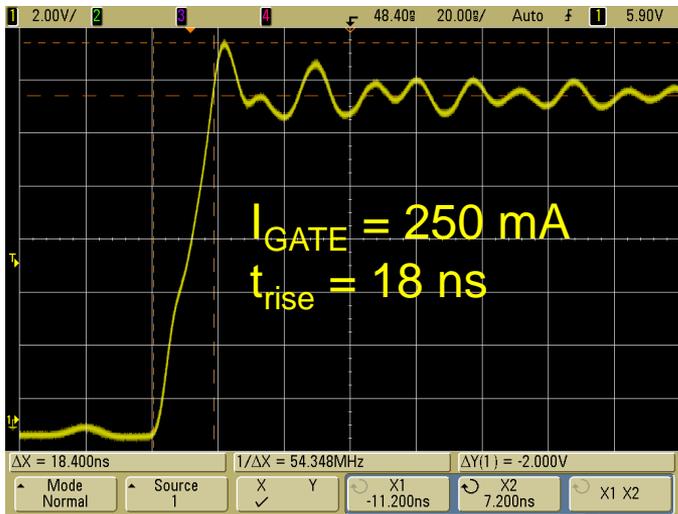


Switching slew rate control

- PWM operation – repetitive high-current transitions
- Slew rate (rise/fall time) controlled by gate drive current level
- Effect of reduced slew rate
 - high-frequency harmonics
 - reduced power efficiency & thermal impact



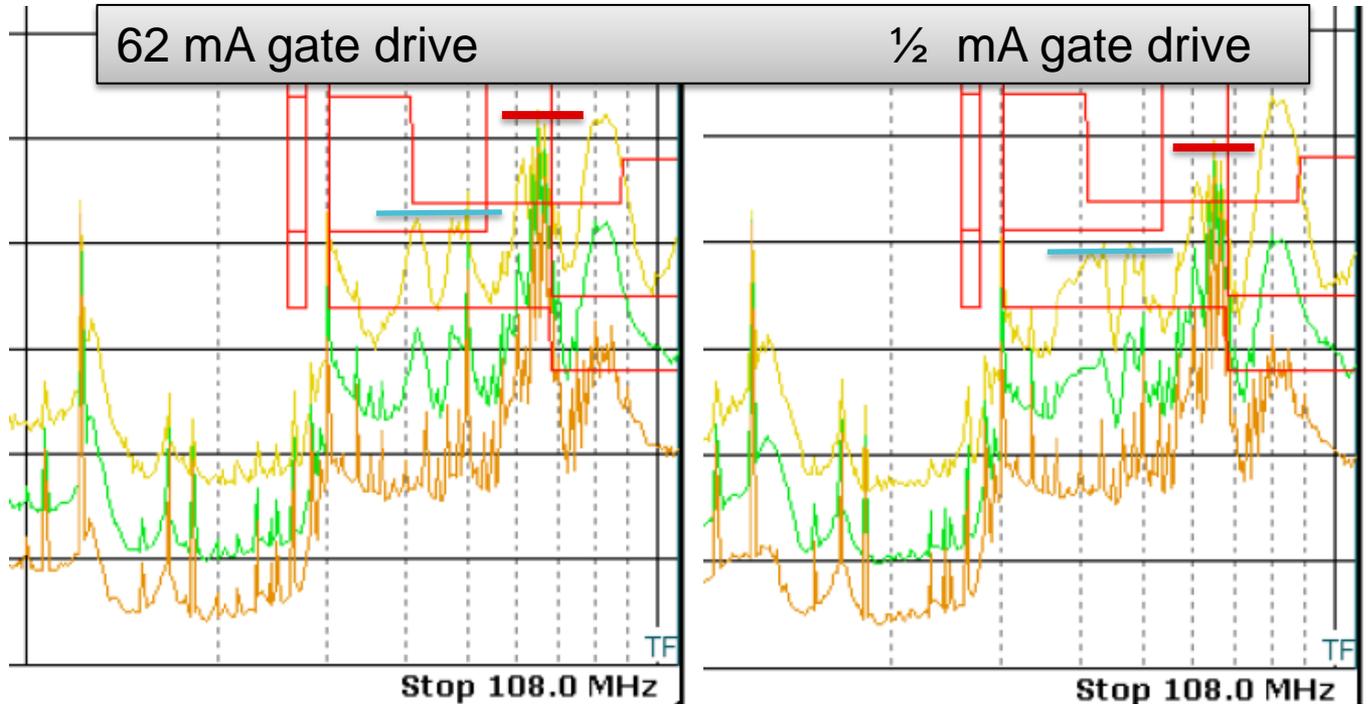
Effect of gate current in time domain



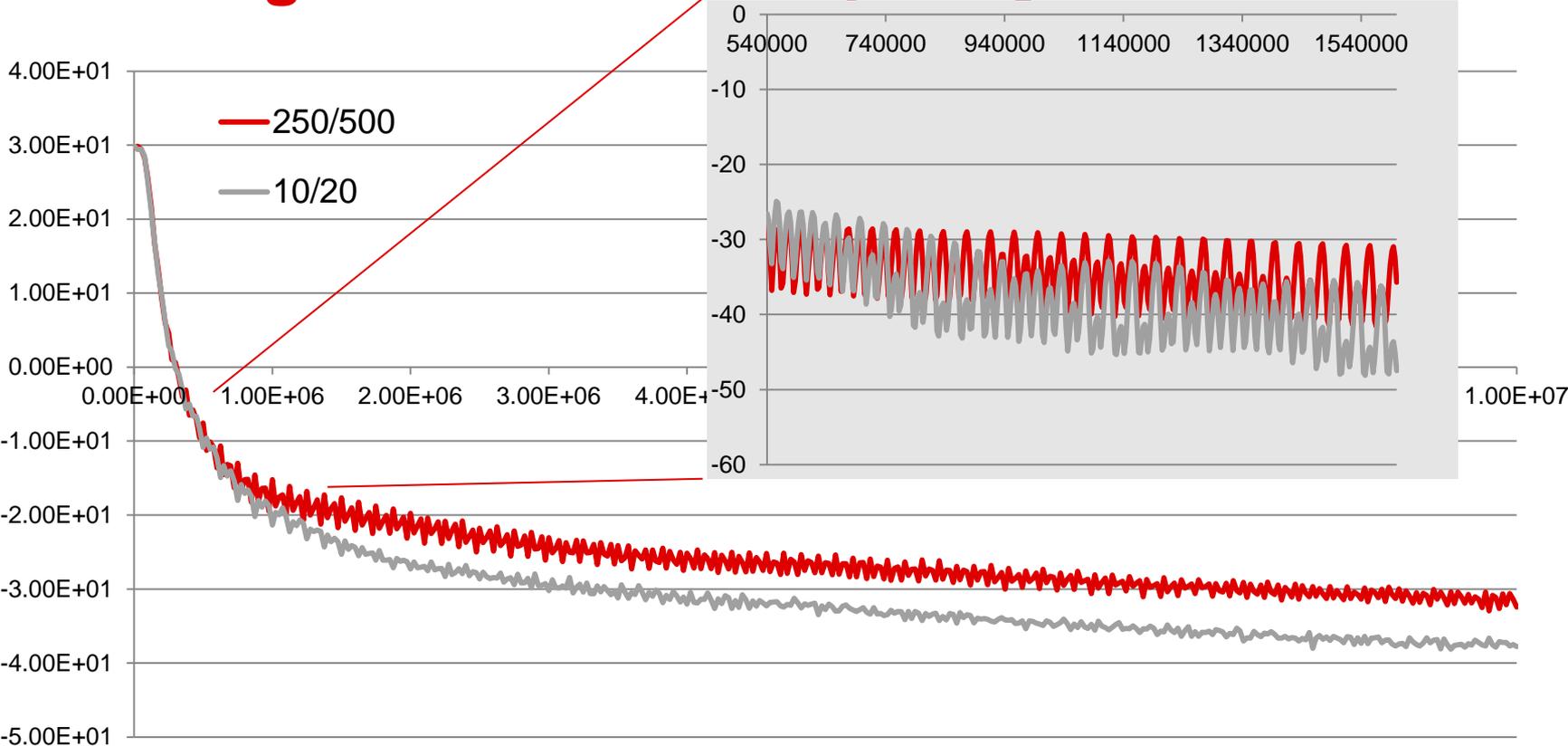
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Effect of gate current in frequency domain

- Change the rise time of PWM edges at 20 kHz
- Reduced emissions at > 10 MHz frequencies



Effect of gate current in frequency domain



Quiz question 1:

A recent (2019) study in the Czech Republic found that broadband radio frequency electromagnetic radiation can:

- A. Slow down the internal body clocks (circadian rhythms) of cockroaches
- B. Increase the appetite of small birds, but only the females
- C. Promote the growth of mold on wet surfaces
- D. Enhance the taste of citrus fruit

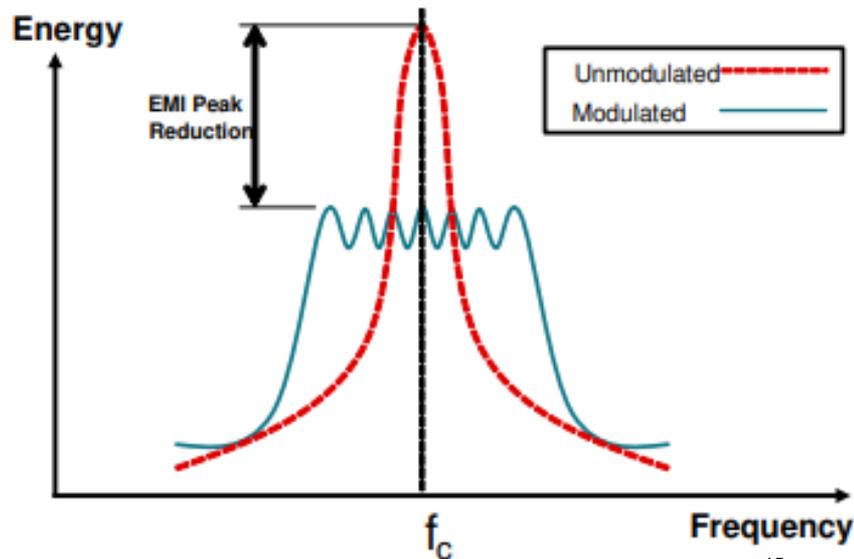
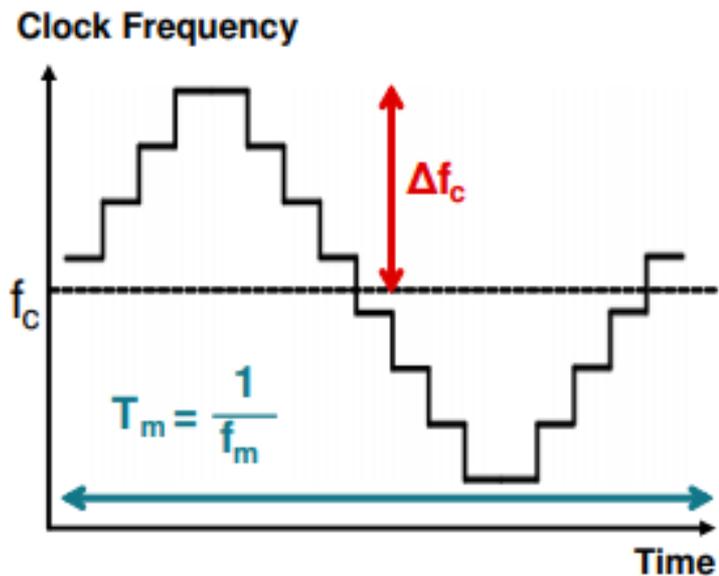
Polling question 1:

During this pandemic, about how many hours per day are you spending on phone calls for work?

- Less than 2 hours
- 2 to 4 hours
- 4 to 6 hours
- 24 hours!

Spread spectrum & dithering

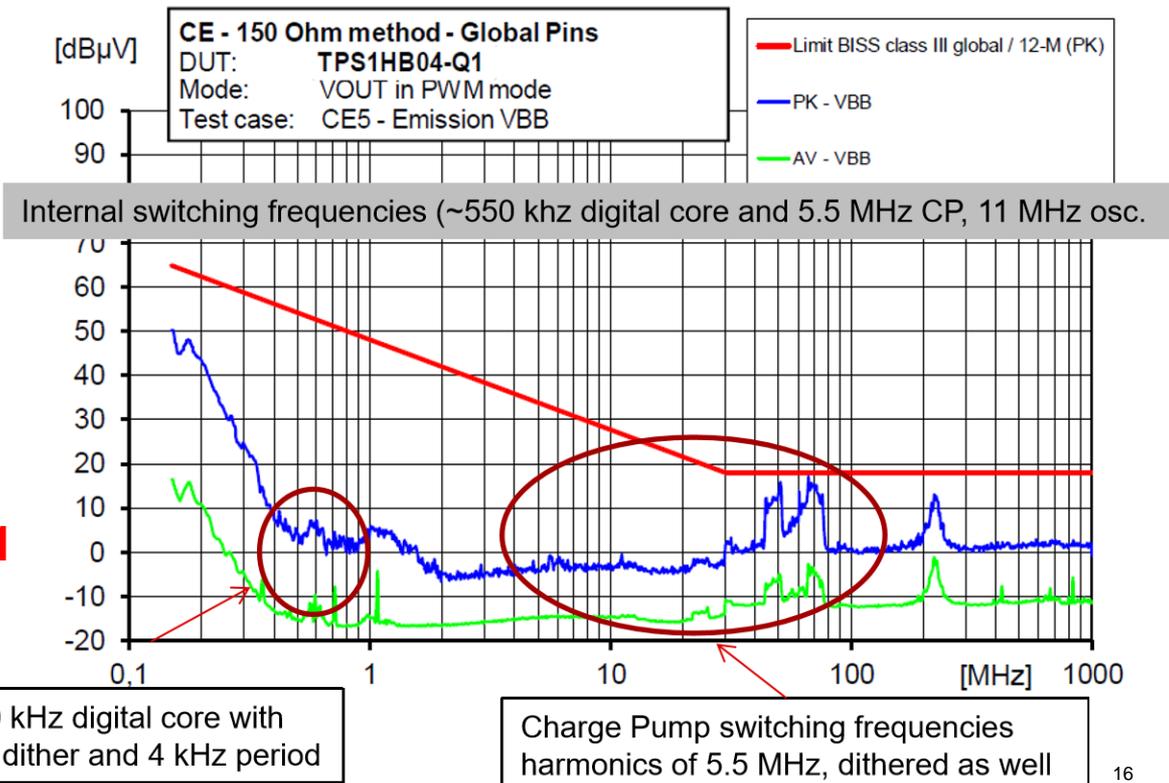
- Clocks
- Power supplies
- Motor drive

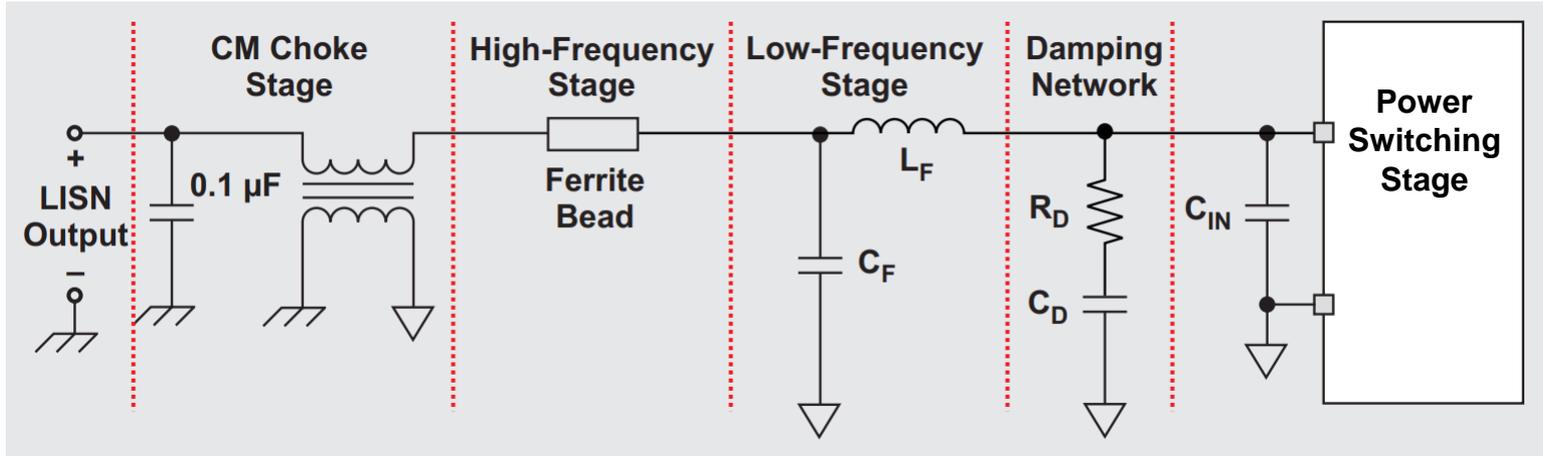


Integrated FET high side switch - dithering

Dithering or spread spectrum reduces the peak amplitude of periodic signals.

This example is **TPS1HB04-Q1**

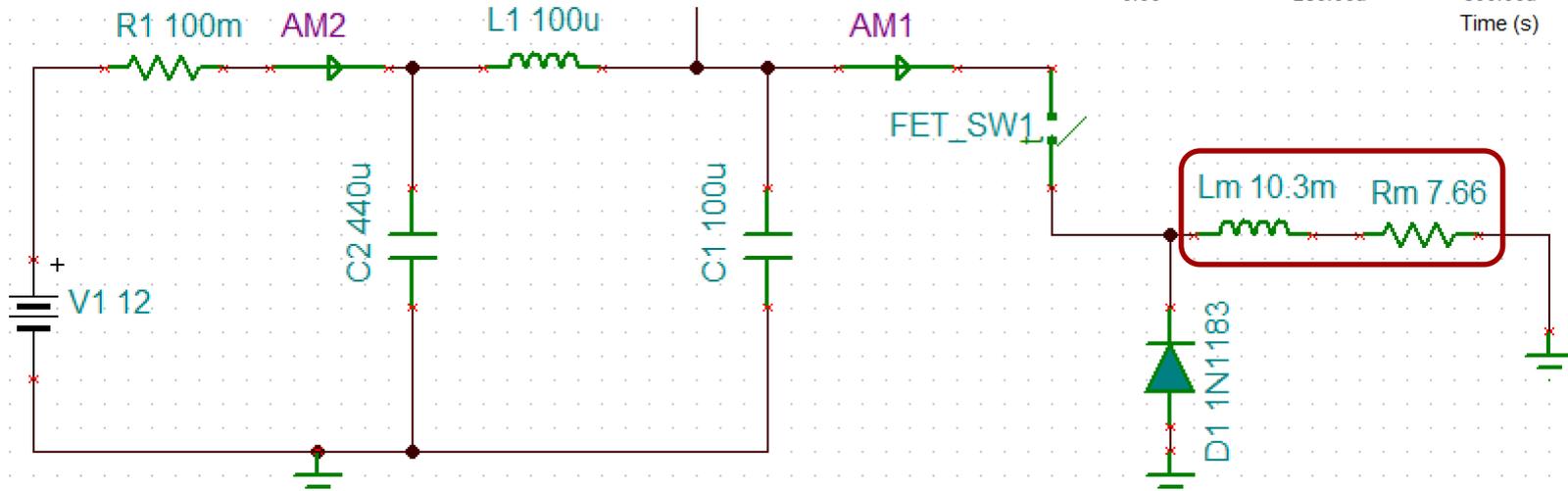
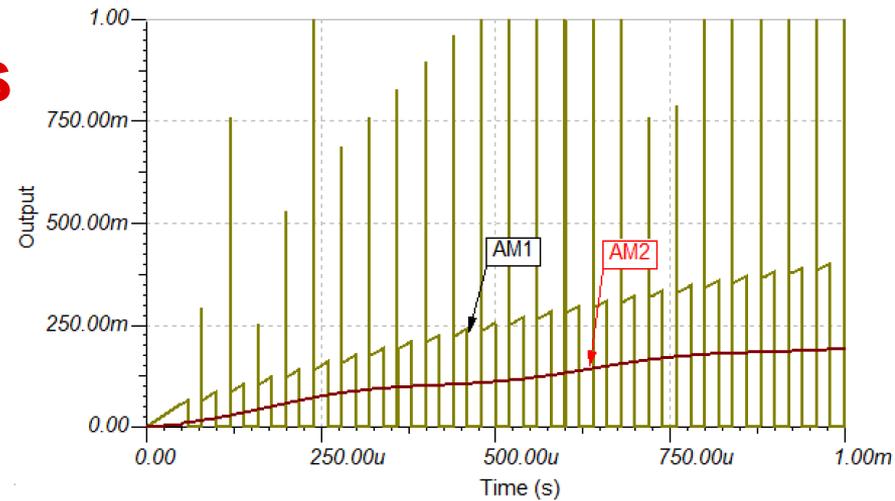




FILTERS

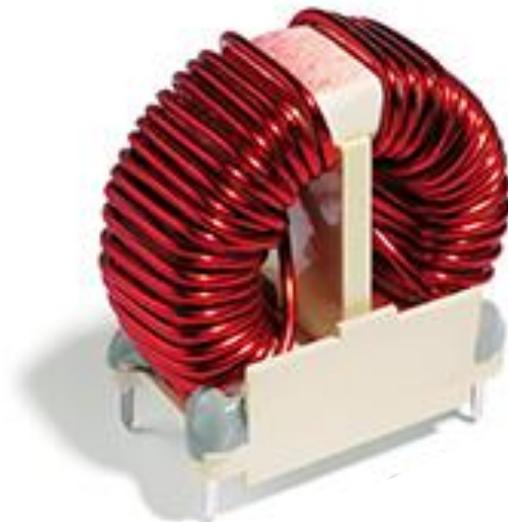
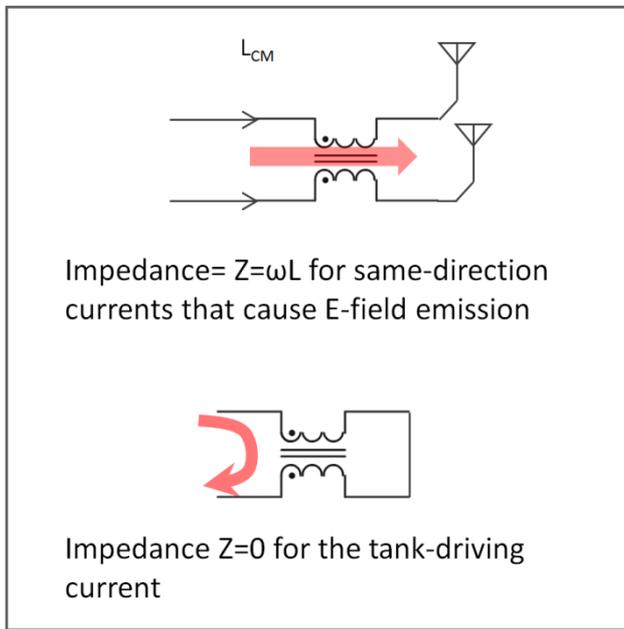
Pi filter reduces PWM pulses

- Attenuates differential-mode noise
- Effective for low frequencies



Common mode filter (choke)

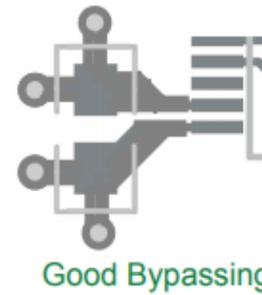
- Attenuates common-mode noise
- Effective for high frequencies



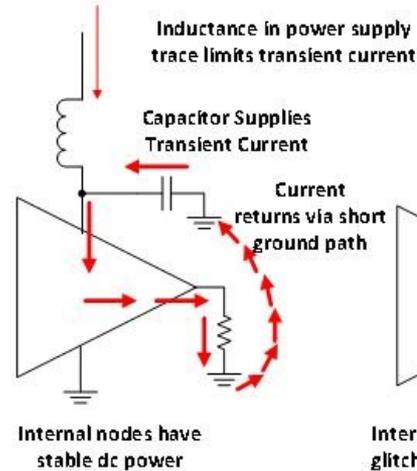
<https://e2e.ti.com/support/sensors/f/1023/t/570116>

Decoupling capacitors

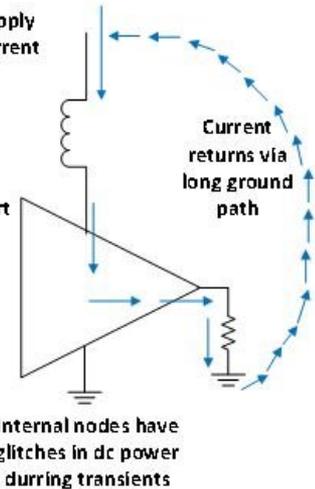
- Decoupling capacitors should be distributed across the entire board to help reduce the board resonances. These board resonances are the main decoupling problem at high frequencies (above about 20 MHz). The actual resonant frequency will change as the number, or location, or value of decoupling capacitors is changed.
- Traditional values of capacitance (for example, .01 uF) make a significant improvement in frequencies below about 200 MHz, but make only a little change at higher frequencies. This is mostly due to the self resonance of the capacitor, and the inductive nature of the capacitor above its natural resonant frequency. Therefore, high frequency capacitors should also be distributed across the board. The value of these capacitors will determine the frequency range over which they are effective.



With Decoupling



Without Decoupling

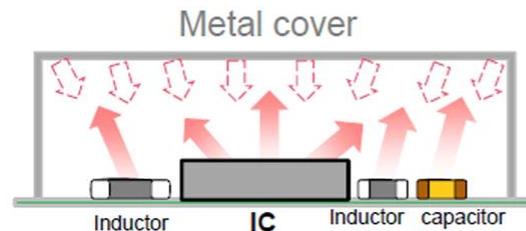
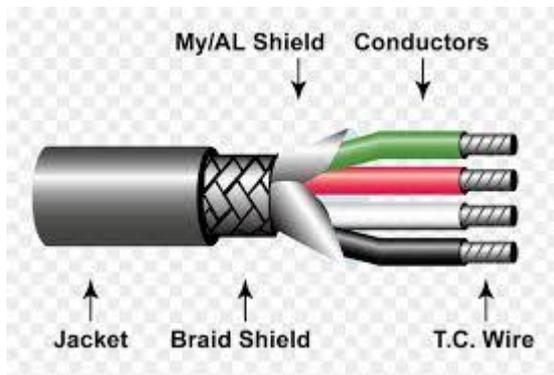


https://e2e.ti.com/blogs_/archives/b/precisionhub/archive/2013/08/13/the-decoupling-capacitor-is-it-really-necessary

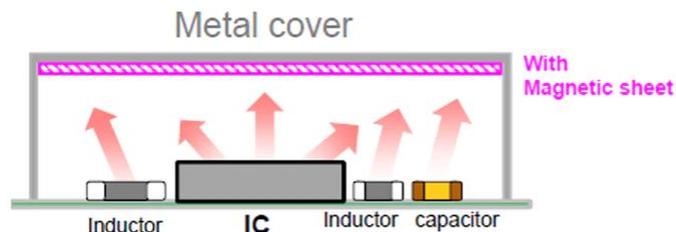
SHIELDING

Shielding

- Shielded components
- Shielded board
- Shielded cables



(a)

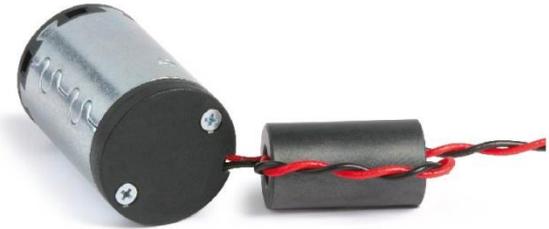
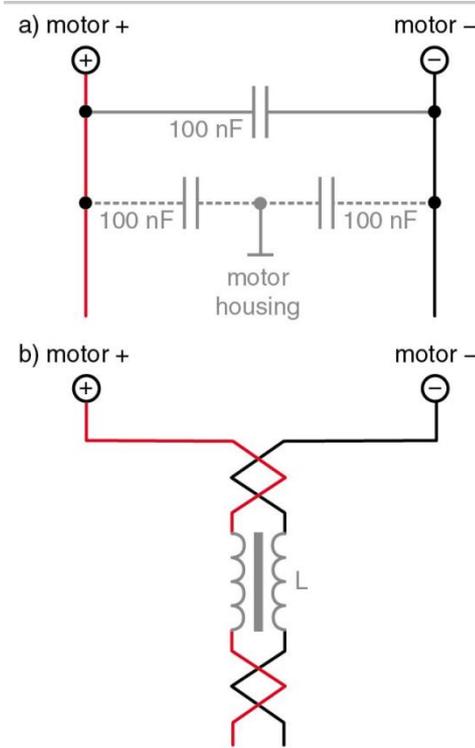


(b)

Source: MWFR.com

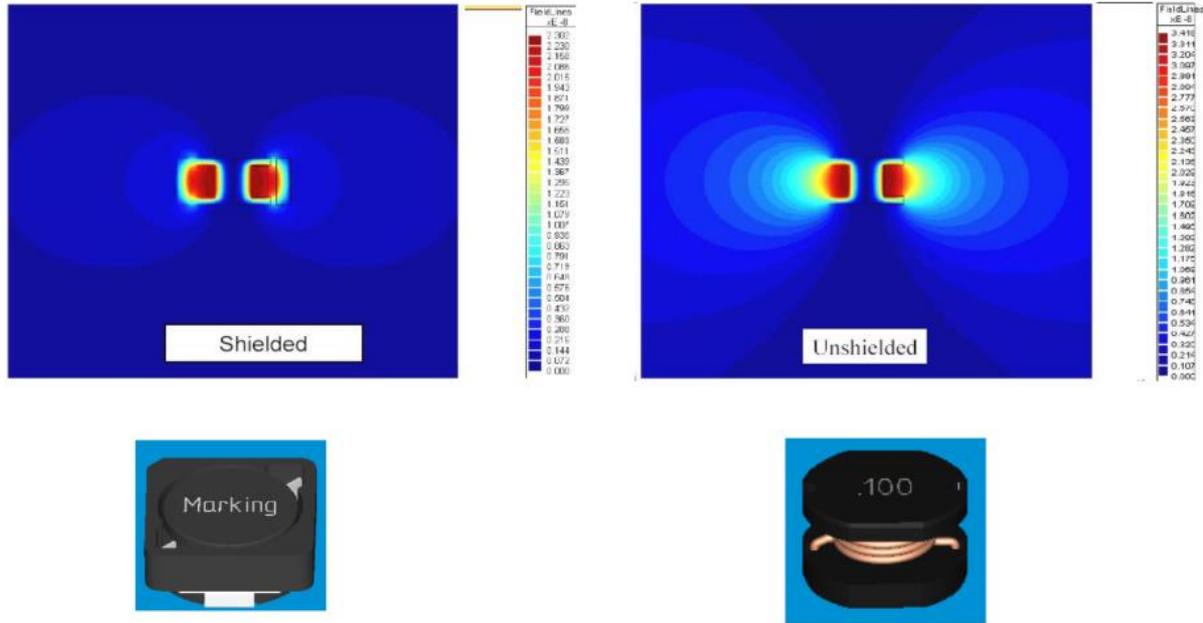
Emission reduction at the motor

- Use a brushless motor.
- Install suppression capacitors between the terminals and the ground shield.
- Install a toroidal ferrite core on the motor leads.
- Pair motor leads and shield, if possible.
- Controllers with a linear power stage produce less emissions on the motor lines than controllers with PWM actuation of the motor.
- Encapsulate the motor in a grounded housing (the principle of a Faraday cage).



Source: Maxon Group

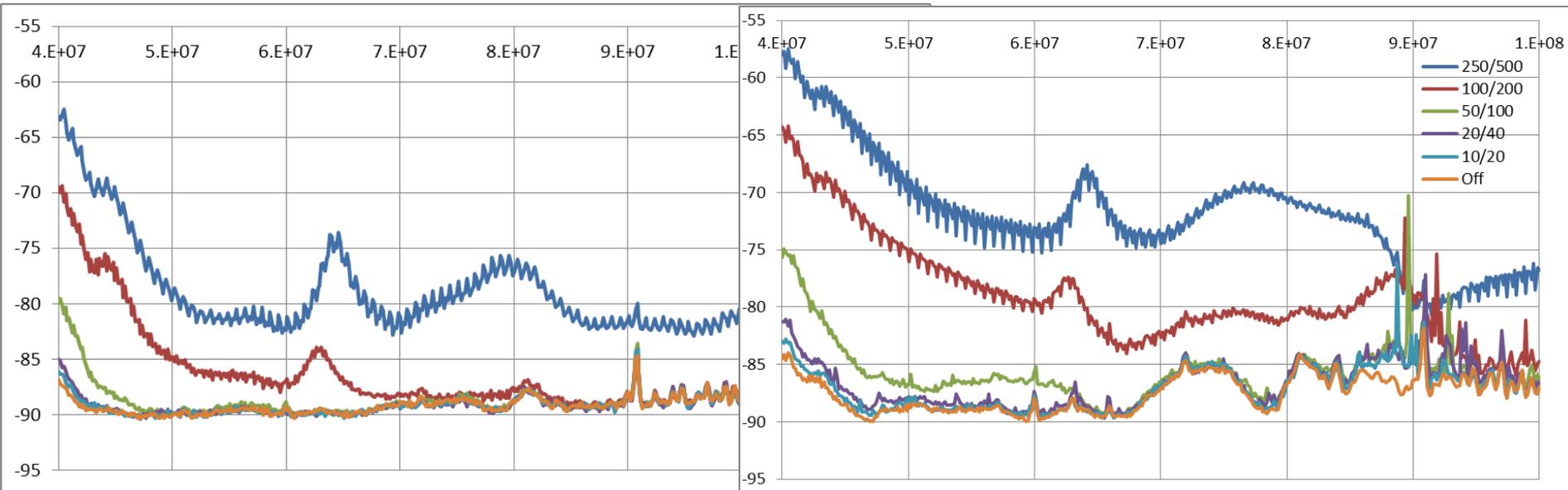
Shielded and unshielded inductors



Source: [Wurth Elektronik](#)

Twisted pair and untwisted motor wires

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



Quiz question 2:

A paper published by the American Institute of Physics this year documented how Chinese scientists used Maxwell's equations and finite element analysis to determine:

- A. Whether a kettle or microwave is the best way to heat water to make tea
- B. Optimal charging rates for 5G smart phones in sub-ocean caves
- C. How 14-year olds send such a high number of texts per minute
- D. Which is better for coding, using spaces or tabs

Polling question 2:

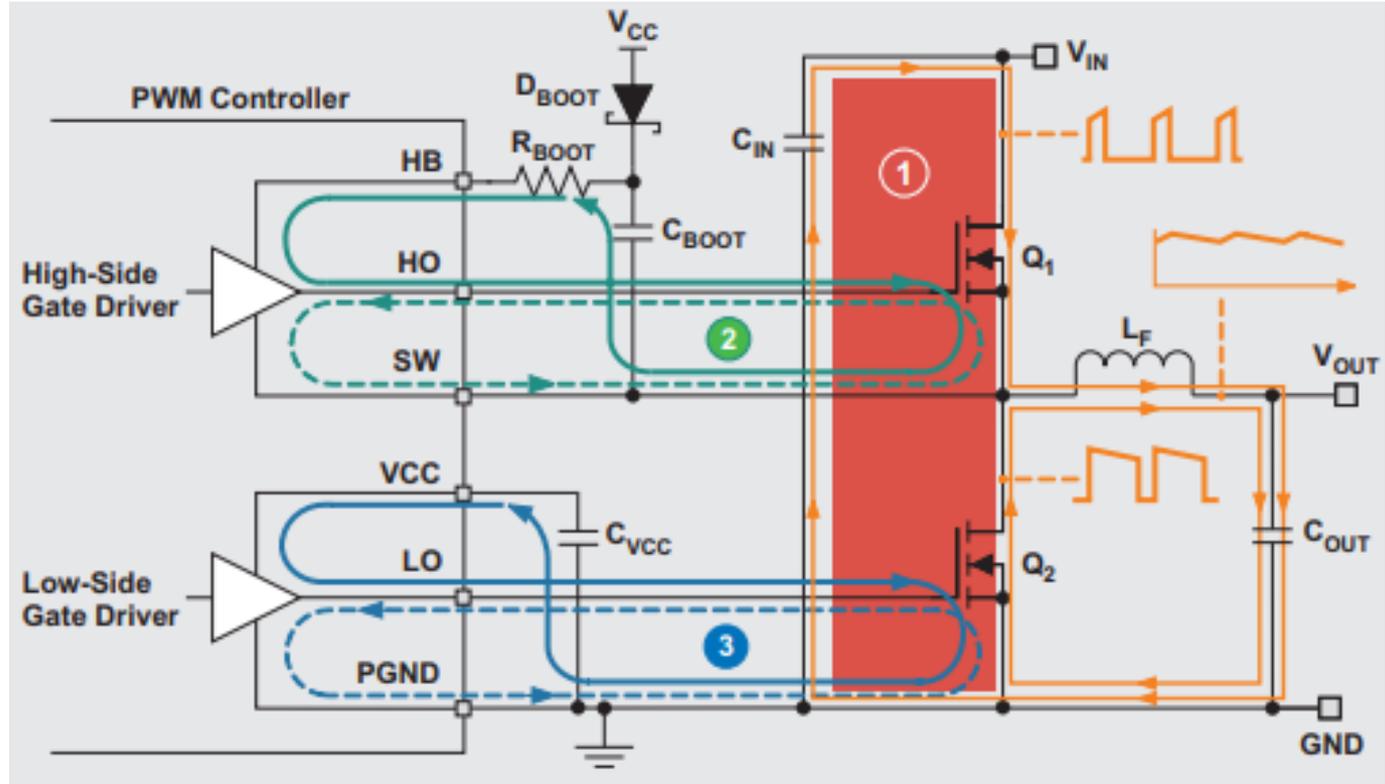
Which sport do you most enjoy watching?

- Soccer/football
- Cricket
- Tennis
- Wrestling
- Badminton
- Auto racing
- Kabaddi
- Hockey
- Cycling

BOARD LAYOUT

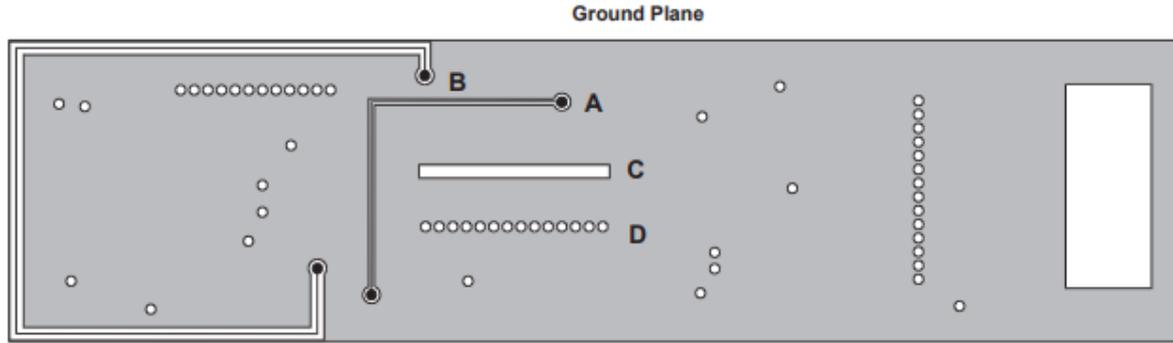
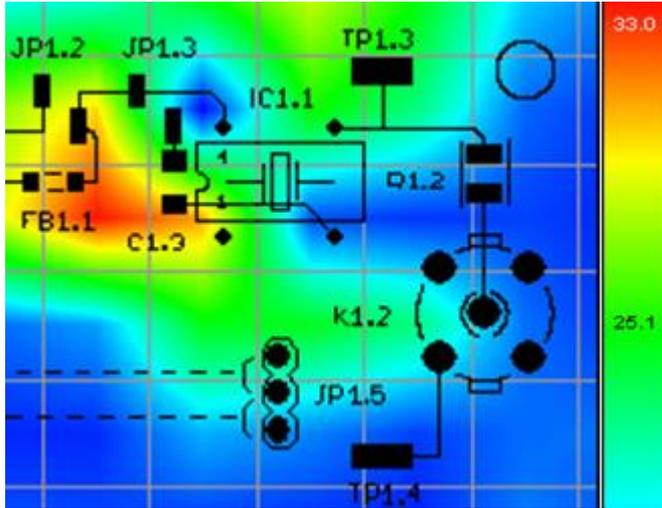
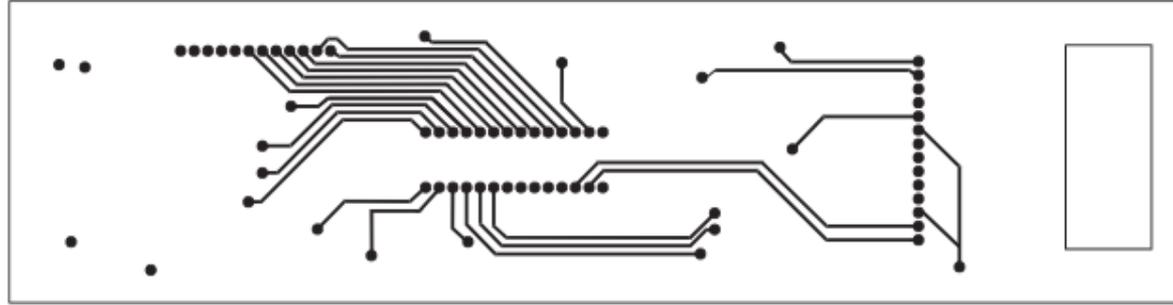
Board layout – critical loops

- Small loop size
- Separate from other signals



Board layout

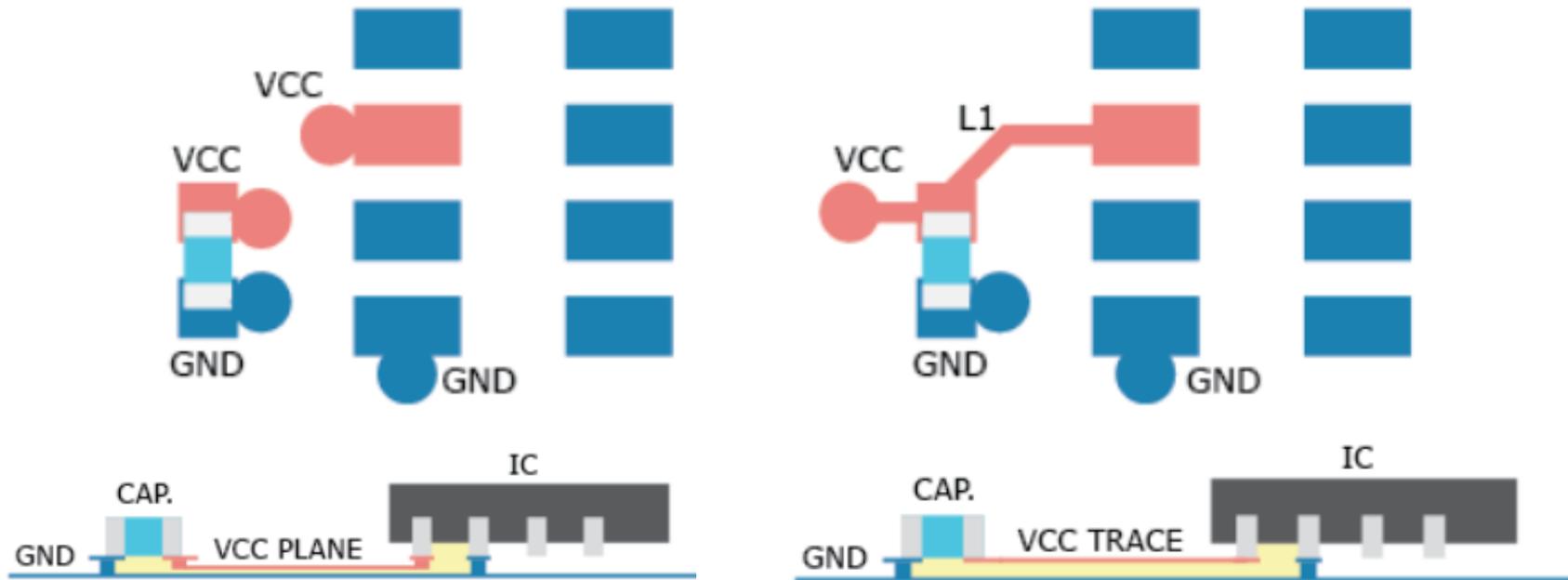
- Grounding
- Board layers



Layout suggestions

- Minimize crosstalk due to capacitive coupling by increasing the separation between tracks.
- Place the power and ground in parallel to maximize the PCB capacitance.
- Place sensitive and high frequency traces away from high noise power traces.
- Widen ground and power traces to reduce the impedance.
- Divide the circuit into functional sub-circuits to keep return currents as close as possible to the sources.
- Connect decoupling capacitors between power and ground at each chip, as close as possible to the pins. This helps to filter out switching transients.
- Avoid right-angle corners in traces; make to 45 degree angles instead.
- Keep trace widths constant and avoids stubs in the traces.

Connection of decoupling capacitors



CONCLUSIONS

Conclusions

- Each application presents different requirements and may require different combinations of individual EMI mitigation techniques
- Reducing the source of emissions can be accomplished with wave shaping, dithering and spread spectrum techniques.
- Filtering primarily reduces conducted emissions
- Shielding primarily reduces radiated emissions
- Board layout is important to reduce both conducted and radiated emissions
- Best practices are documented in numerous TI application notes

Sources and further reading

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