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

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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

![Brushed DC motor radiated emissions graph](chart.png)

- Original
- Added caps, ferrite, etc.
EMI test circuit model

**LISN**

- C1 1u
- L1 5u
- C2 100n
- R1 1k
- T1 2N6755
- R2 1m
- CurrentProbe+
- VG1
- C3 100n
- R4 1m
- R5 1m
- R6 6
- C4 100p
- V1 12
- ILoad
- VResistor+
- CurrentProbe-
- Ctest 10u
- R3 1m

**ECU**

- C5 1u
- C6 100n
- R7 1k
- VResistor-

**Texas Instruments**
SIGNAL SHAPING
Frequency spectra of waveforms – wave shape

20KHz Sine

20KHz 50% duty cycle Square

20dB/decade
Frequency spectra of waveforms – duty cycle
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

- $I_{GATE} = 250 \text{ mA}$
  $t_{rise} = 18 \text{ ns}$

- $I_{GATE} = 70 \text{ mA}$
  $t_{rise} = 92 \text{ ns}$

- $I_{GATE} = 10 \text{ mA}$
  $t_{rise} = 560 \text{ ns}$
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

- 250/500
- 10/20
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
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

Impedance = $Z = \omega L$ for same-direction currents that cause E-field emission

Impedance $Z = 0$ for the tank-driving current

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.

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

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

• 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

9. Printed Circuit Board Decoupling Capacitor Performance For Optimum EMC Design - Bruce Archambeaut,, Doug White, Electromagnetic Compatibility Center of Competency, January 1999, [https://studfile.net/preview/429206](https://studfile.net/preview/429206/)
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