Electromagnetic Compatibility Tips for Power Converters

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A power supply design story from Robert A. Pease

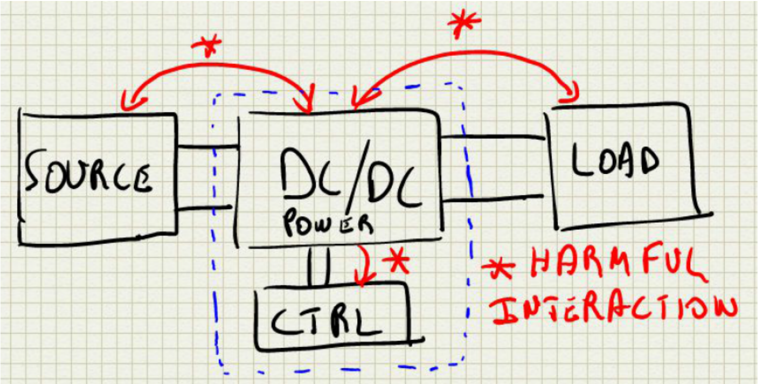
One of the stories that keeps rattling around the industry is about a group of engineers who decide to band together and start a new computer company. The smartest one is assigned to do the main processor board. Another smart engineer does all the interfaces. And the smart but green "kid engineer" is assigned to do the switch-mode power supply because, of course, that's the easiest part to do. (Anybody who has worked on a big switcher will probably speak up right away: The switcher is *not* as easy as it seems.) In the end, the power-supply design takes a lot longer than everybody expects.

One day, the young engineer opens up the compartment where the balky power supply resides, and it blows up in his face. After his co-workers take the poor fellow to the hospital, they ask around and find a consulting engineer who makes a living out of fixing exactly this kind of switcher problem. The switcher design was slightly off-course and needed the hand of an expert before it would work correctly. So remember, designing switchers is no simple task. Don't hesitate to call in an expert. Note, if this story were not substantially true, the consulting engineer would have starved to death, long ago. I rest my case.

Why worrying? (Robert A. Pease)

drawing board—even if we're really good at designing other circuits. After all, a switcher is a complicated system composed of power transistors, transformers, inductors, one or more control ICs, and lots of other passive components. And, the circuit's layout is critical: The layout must guard small signals against electrostatic interference and cross-talk, and, even more importantly, must control and reject the electromagnetic strays. I mean, for a switcher to be efficient, the volts per microsecond and amperes per microsecond get really *large*, so it doesn't take many picofarads or nanohenries to couple a big noise into the rest of the circuit. The paths for high currents are important, and the paths for cooling air are even more critical.

Introduction: what is the "EMC problem"?



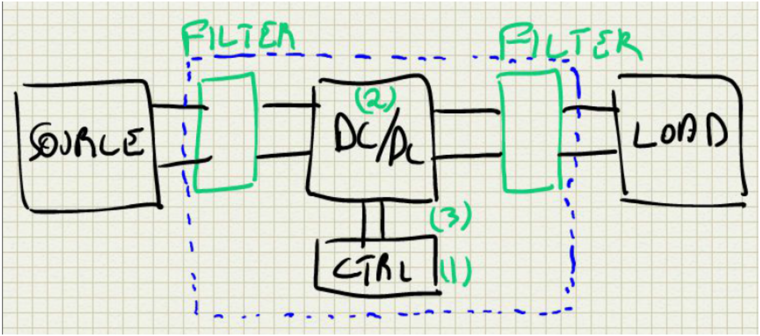
- Harmful and unexpected interactions are present.
- A lot of consequences are possible:
    1. perturbation of the power source/load,
    2. malfunction of the DC/DC controller,
    3. failure...

Introduction: some definitions

- Emission: the device generates electromagnetic noise to the outside world.
- Immunity: the device is perturbed by the outside world.
- Types of interactions:
  1. conducted interferences (U/I),
  2. radiated interferences (EM waves) and,
  3. near field coupling (E/H).

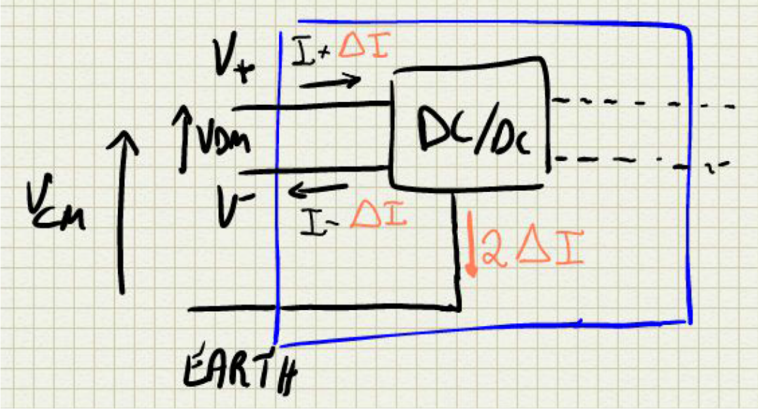
Each discussed topic could take hours but the goal of the course is to provide a minimum toolkit.
Anyway, always use scientific approach to EMC problems, use your brain modeler and simulator and perform measurements to access your understanding.

Introduction: the typical solutions



- A metallic shield prevents radiated interferences.
- Input and output filters prevent conducted/radiated interferences.
- Some design rules have to be followed:
  1. control design has to be robust against HF interferences,
  2. near field emission has to be minimized in the power part and,
  3. unwanted signal coupling has to be minimized by proper layout.

Conducted interferences: common vs. differential mode



- Common mode voltage: $V_{CM} = (V_+ + V_-)/2$
- Differential mode voltage: $V_{DM} = (V_+ - V_-)$
- Common mode current: $I_{CM} = 2\Delta I$
- Differential mode current: $I_{DM} = I$

Conducted interferences: measurements and limits

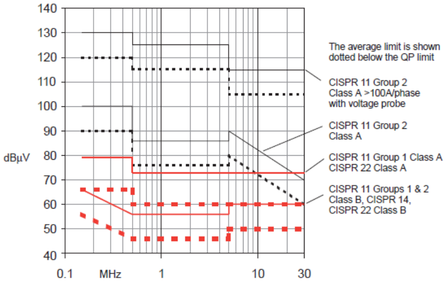
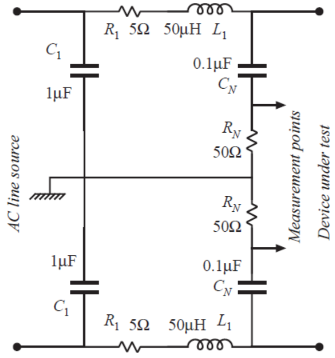


Figure: Excerpt of [1].

Noise is measured with a LISN and a RF receiver or spectrum analyser.

- Noise is measured with a LISN and an RF receiver or spectrum analyser.
- Limits are typically expressed in $dB\mu V$.
- Frequency range is typically from 150kHz range to 30MHz.

Conducted interferences: LISN



LISN example

- **LISN:** "Line Impedance Stabilization Network," or "artificial mains network"
- **Purpose:** to standardize impedance of the power source used to supply the device under test
- Spectrum of conducted emissions is measured across the standard impedance (50Ω above 150kHz)

Figure: Excerpt of [2].

Conducted interferences: filter example

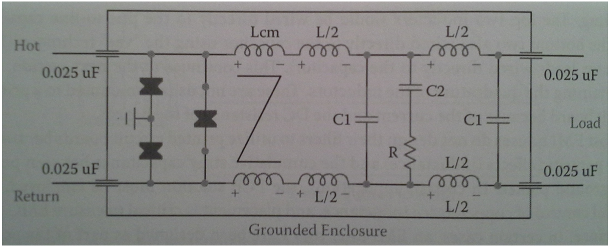


Figure: Excerpt of [3]

The filter includes:

- a common mode part (inductor + capacitor),
- a differential mode part (inductor + capacitor) and,
- some damping.

Conducted noise is reduced on the incoming and outgoing wires, therefore radiated emission is also reduced.

Conducted interferences: filter and negative resistance

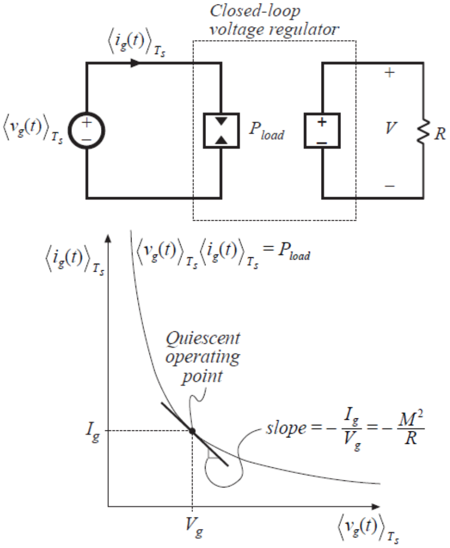


Figure: Excerpt of [2]

Conducted interferences: filter design rules

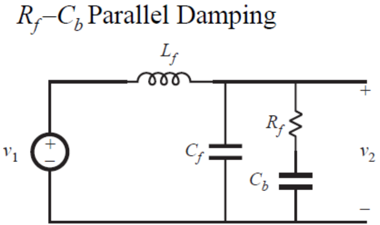


Figure: Excerpt of [2].

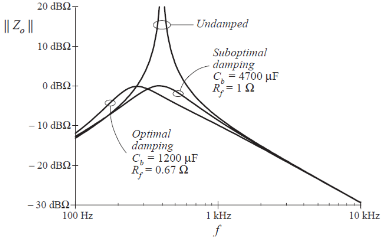
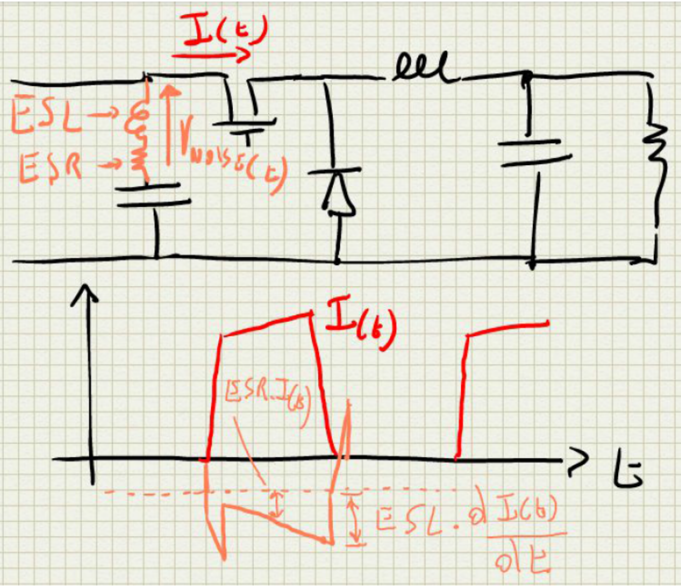


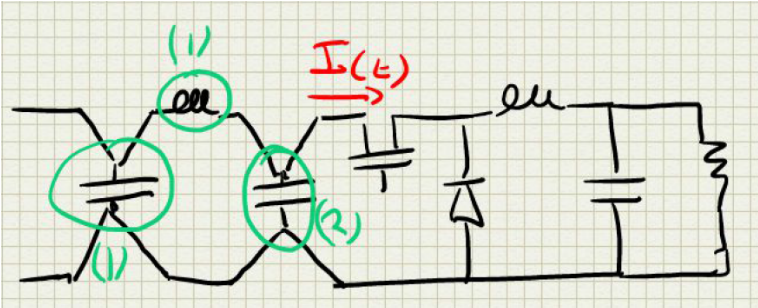
Figure: Excerpt of [2].

- Pole placement gives the required attenuation.
- Use a characteristic impedance far lower than the converter negative resistance.
- Correctly damp the filter (see [2] chapter 10, paragraph 10.4.1).

Noise sources: current pulses

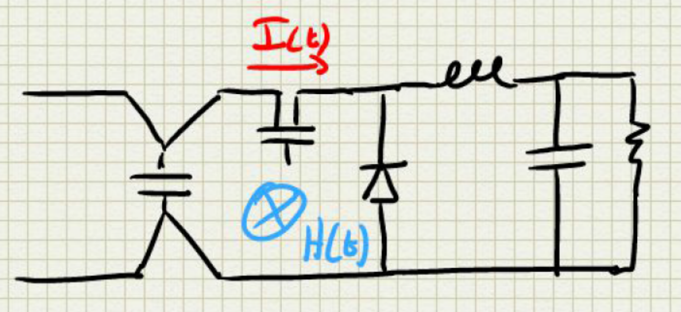


Noise sources: solution to current pulses



- Add a differential mode filter.
- Connect capacitors using VEEING to reduce ESL.
- Use low ESR capacitors (film, ceramic).
- The problem is far less critical on the output of the buck converter because...

Noise sources: current pulses are back



$I(t)$ has high $\frac{dI(t)}{dt} \Rightarrow H(t)$ has high $\frac{dH(t)}{dt}$.
Therefore, a large $\frac{d\Phi(t)}{dt}$ exists and creates emf in surrounding circuit loops.

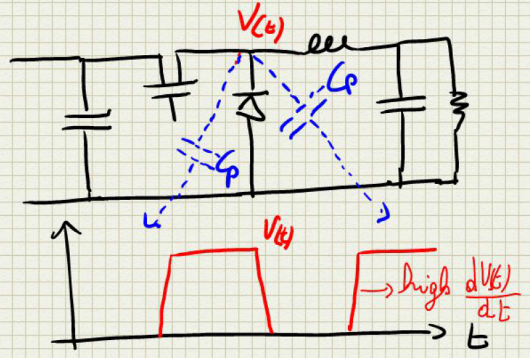
Noise sources: solution for current pulses

Rule: minimize the surface of loops with high $\frac{dI(t)}{dt}$.

Possible solutions are:

- minimize loops with clever layout,
- add an extra wire to improve an existing circuit or,
- use a ground plane.

Noise sources: voltage pulses



$V(t)$ has high $\frac{dV(t)}{dt} \Rightarrow I_{Cp} = Cp\frac{dV(t)}{dt}$ is high.
Example: V(t) switches in 25 ns from 0 to 24 V. A parasitic capacitor as low as 1 pF creates a path for a current:
$I_{Cp} = Cp\frac{dV(t)}{dt} = 1pF\frac{24V}{25ns} = 1mA.$

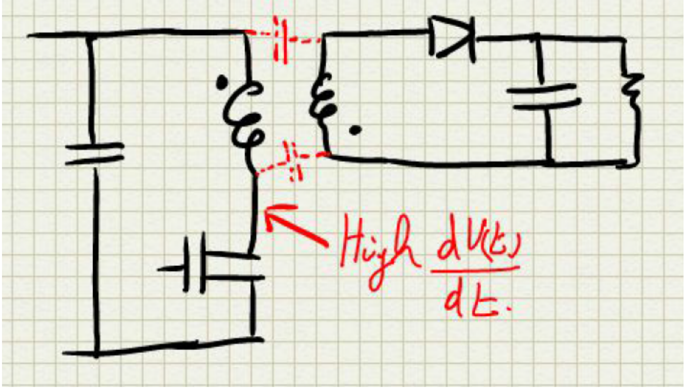
Noise sources: solution for voltage pulses

Rule: reduce the surface of copper tracks with high $\frac{dV(t)}{dt}$.

Possible solutions are:

- use a good layout,
- put sensitive circuits apart from high $\frac{dV(t)}{dt}$ tracks,
- use the last layer of an inductor winding as a shield,
- add an electric insulation between the switches and the heatsink.

Noise sources: voltage pulses are back



Parasitic currents create common mode noise.

Noise sources: solution for voltage pulses

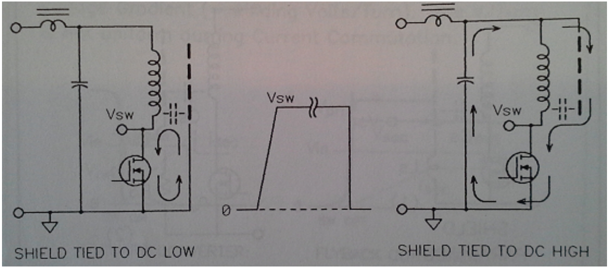
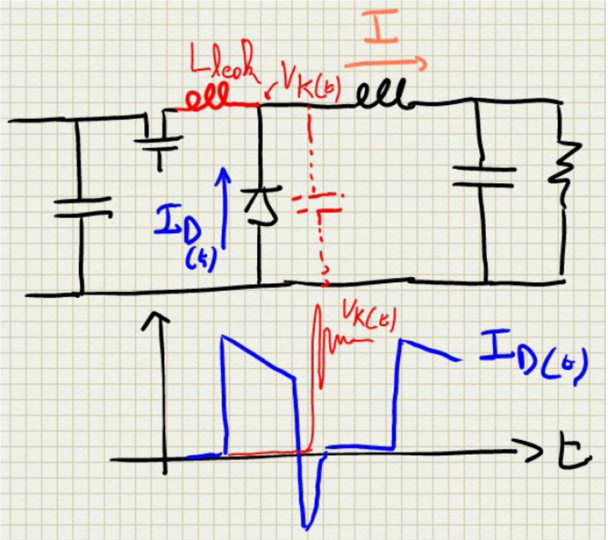


Figure: Excerpt of [4].

Possible solutions are:

- use a shielded transformer (primary, secondary or both),
- use a shunt capacitor between primary and secondary,
- select the winding direction that minimizes the parasitic capacitance.

Noise sources: leakage inductances/reverse recovery



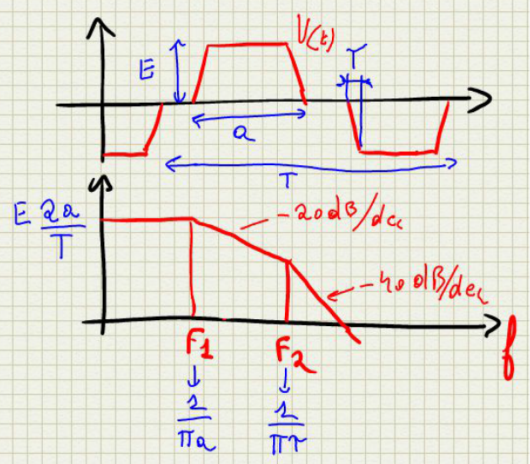
Noise sources: leakage inductances

Possible solutions are:

- reduce the loop of high $\frac{dI(t)}{dt}$,
- as a rule of thumb estimate L_{leak} between 5 and $10nH/cm$,
- refine your model using EM tools or formulae.

Soft switching converters do not undergo this problem.

Noise sources: bandwidth envelope

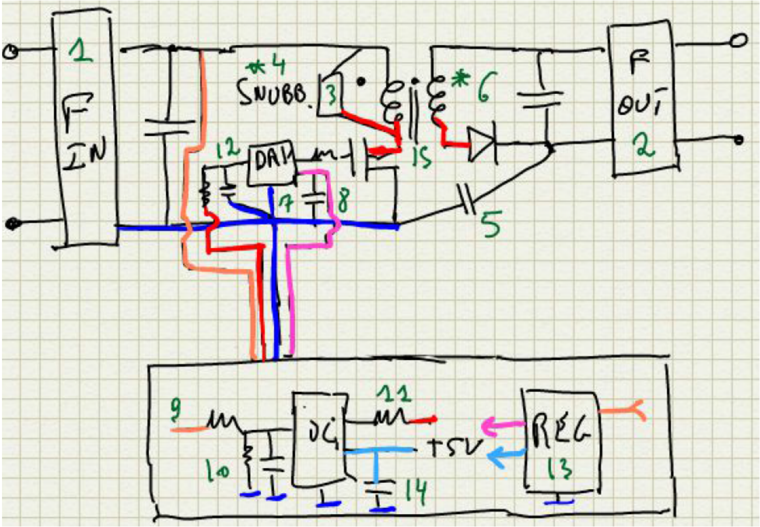


τ is higher in soft switching converters. This reduces HF signal energy.

Controller: increase its robustness

- Minimize signal loops that can pick-up $\Phi(t)$ variation.
- "Correctly" decouple all IC's.
- Filters all ADC inputs locally (Nyquist criterion).
- Use as low as possible impedance to control MOSFET drivers.
- Use high impedance at the input of your controller (measurements).
- Define your grounding strategy (1000 pages about grounding in [5]) to reduce galvanic coupling. Any current with high $\frac{dI(t)}{dt}$ creates voltage differences in ground conductors.
- Generate low voltage locally or use filter locally.

An example with 15 precautions



References

See also http://www.montefiore.ulg.ac.be/~geuzaine/ELEC0017/

[1] Schaffner, "Rf emission testing, a handy guide."

[2] R. W. Erickson and D. Maksimović, *Fundamentals of Power Electronics*.
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[3] R. L. Ozenbaugh, *EMI Filter Design*.
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[4] B. Carsten, "Magnetics design for high-frequency applications," in *Modern Power Conversion Design Techniques, E.J.Bloom course*, 2000.

[5] E. B. Joffe and K.-S. Lock, *Grounds for Grounding*.
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