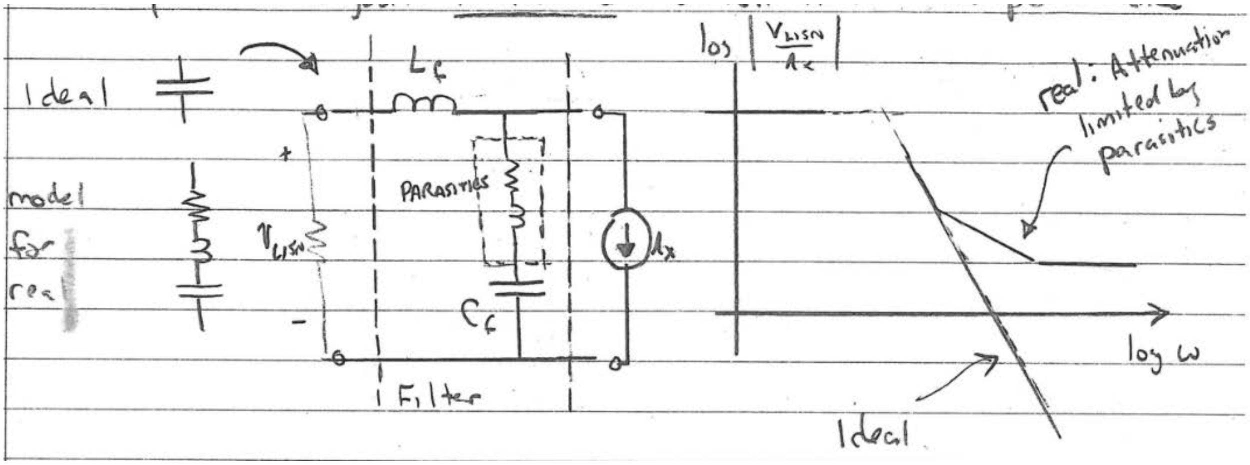
6.622 Power Electronics *Prof. David Perreault*

Lecture 30 - EMI Filtering 3: CM+DM

1 Review

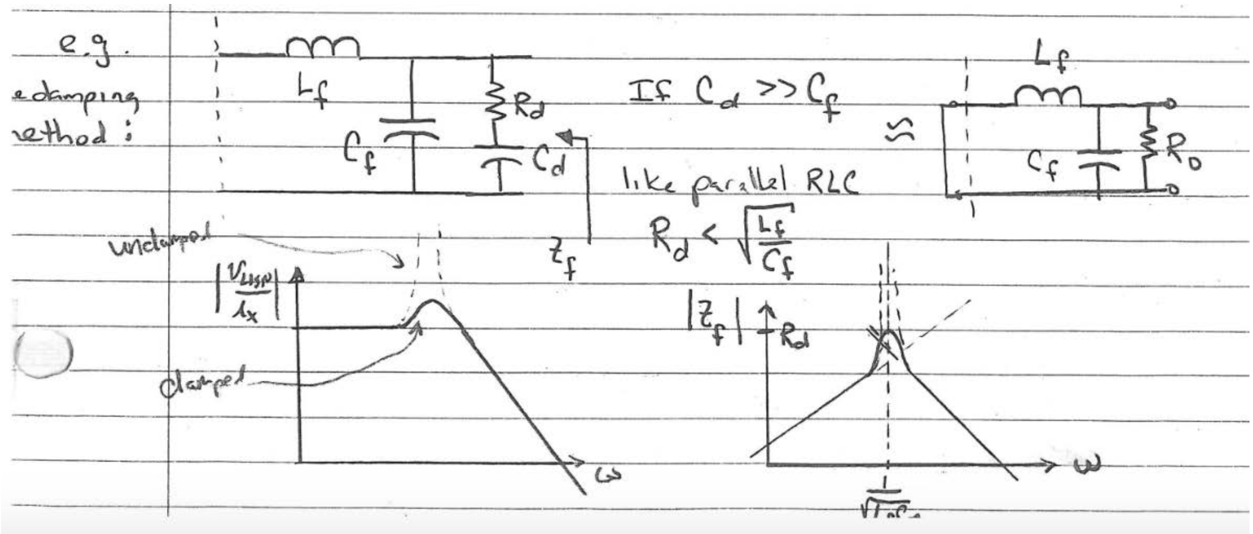
From last time, we saw that

1. Component + layout parasitics often limit filter performance

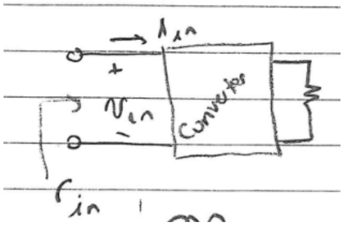


Inductor paraisitic capacitance and parasitic L's, C's due to circuit layout can also limit performance
⇒ example of how layout capacitance across L_f was a major issue in one consulting design

2. Filter damping is important
⇒ damp corner frequency of LC

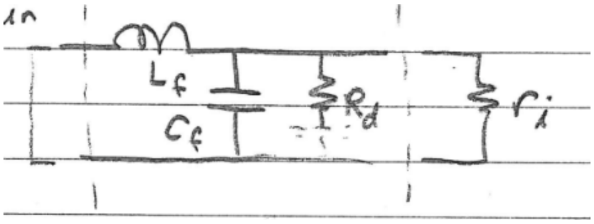


Input filters often need extra damping, because closed-loop converters provide incremental "negative resistance" that tends to destabilize the input filter:



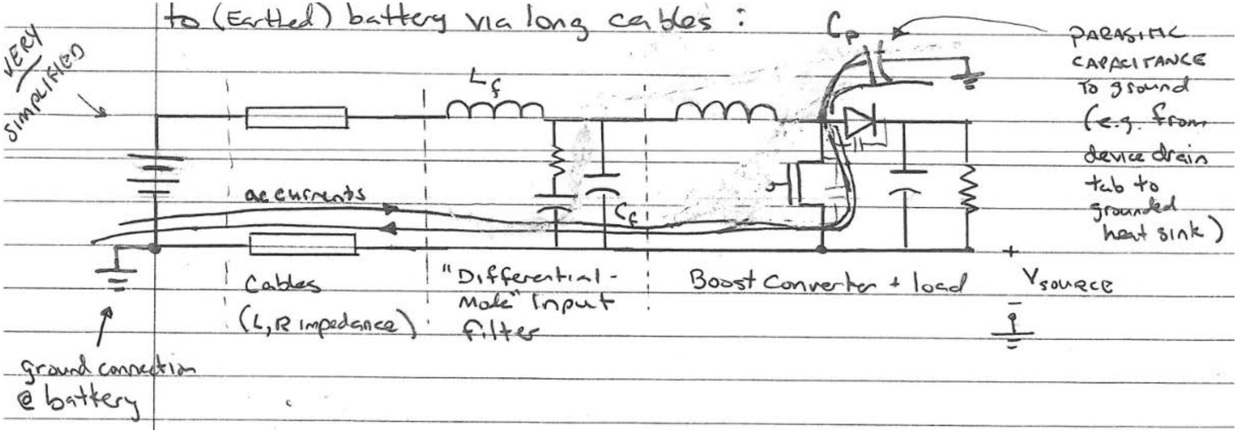
Output power P_0 constant

$$v_i = \frac{P_0}{i_i} \Rightarrow r_{in} = \frac{\partial v_{in}}{\partial i_{in}}|_{I_{in}} = -\frac{P_0}{I_{in}^2}$$



We need $R_d << |R_{in}|$
So R_{eq} $\frac{R_d r_{in}}{R_d \cdot r_{in}} >$ ①

Simple example to introduce notion of common mode + differential mode noise: filtered boost converter connected to (earthed) battery via long cables

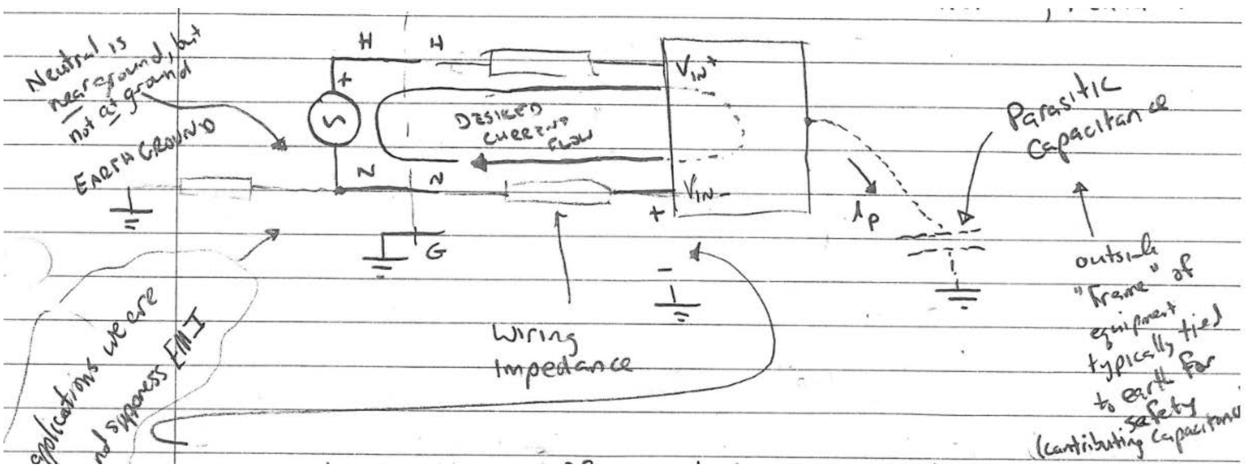


- First describe input currents <u>without</u> parasitic capacitance (well filtered by L_f, C_f) and little high-frequency "bounce" in V_s
- <u>with</u> parasitic capacitance C_p, the lower cable (return) sees high-frequency current, and V_{source} "bounces" substantially from ground at high frequency

2 Common mode + differential mode

The filter strategies shown thus far are appropriate when all circuits are well-connected to earth ground and supplied from a ground referenced input. However, this is not exactly the case in many applications!

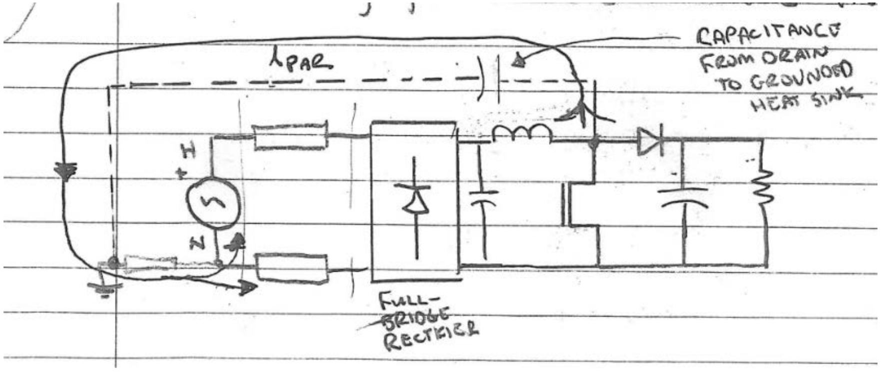
Eg systems connected to the ac line: converter connected to "hot" H, "neutral" N



Note: in ac-line applications we are required to measure and suppress EMI in <u>both</u> hot and neutral!

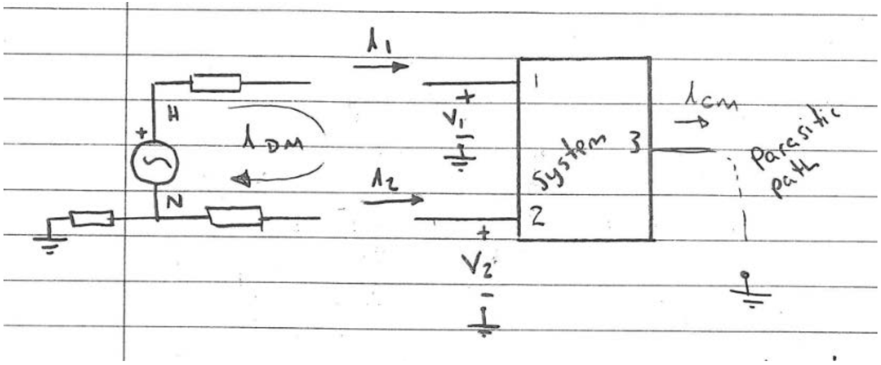
- We can have voltage differences between $v_{in,-}$ (connected to N) and gnd (and $v_{in,+}$ and ground)
- Thurs current can flow through parasitic impedances (e.g. capacitance) back through earth ground, and return along paths we don't desire (not via H, N)

Example 1. Boost rectifier



CM Example 2: Motor drives often have a high capacitance from the windings (driven by converter) to the grounded frame.

How can we describe the different voltages and currents?



$$\left\{ \begin{array}{c} \text{differential-mode current } i_{dm} = \frac{i_1 - i_2}{2} \\ \text{common-mode current } i_{cm} = i_1 + i_2 \end{array} \right\}. \qquad \therefore \qquad \begin{array}{c} i_1 = i_{dm} + \frac{1}{2} i_{cm} \\ i_2 = -i_{dm} + \frac{1}{2} i_{cm} \end{array}$$

The differential-mode current flows into terminal 1 and back out terminal 2 (as expected). The common-mode current flows equally into terminals 1,2 and returns through the parasitic path (via "terminal 3")

We can also specify common and differential-mode voltages

$$\left\{ \begin{array}{c} \text{differential-mode voltage } v_{DM} = v_1 - v_2 \\ \text{common-mode voltage } v_{cm} = \frac{v_1+v_2}{2} \end{array} \right\}.$$

$$v_1 = v_{cm} + \frac{1}{2} v_{dm}$$

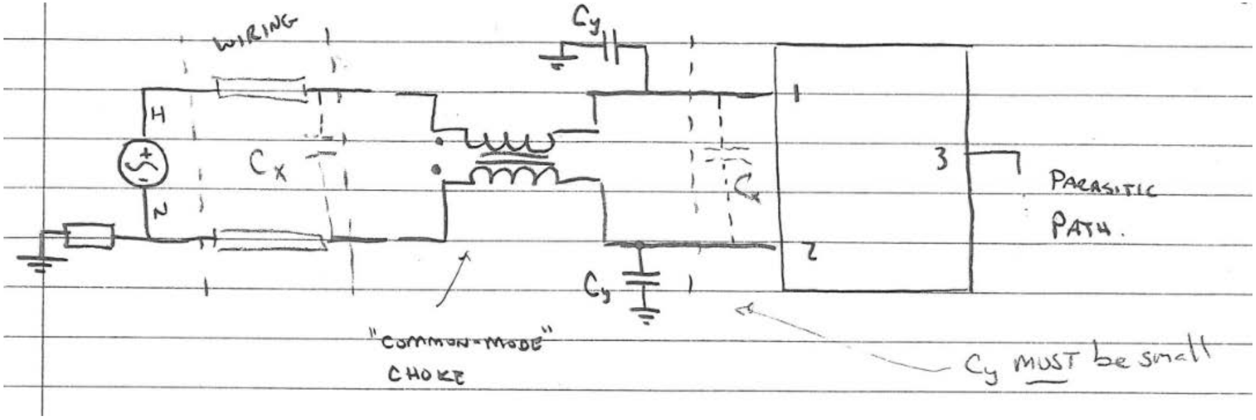
$$v_2 = v_{cm} - \frac{1}{2} v_{dm}$$

These definitions are useful, since we use different techniques to solve common-mode and differential mode noise problems.

⇒ why? e.g. placing a capacitor from 1-2 ("diferentially") will not suppress common-mode current or voltage ripple at all! Other methods prevail.

We are required to not inject common or differential-mode current back into the line

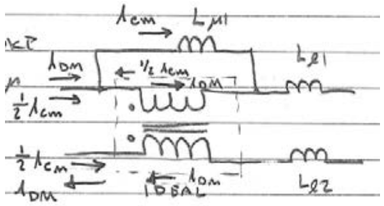
Consider a means to suppress common-mode current (from line wiring)



Common-mode choke is a transformer that tries to suppress common-mode currents (current "into one dot must flow out the other")

Model CM choke

- Split L_μ into $2L_\mu \| 2L_\mu$



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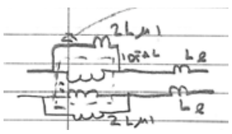
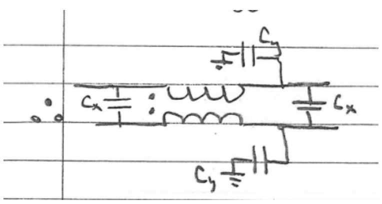


- Differential-mode current flows through ideal transformer, small leakage inductances
- common-mode current must flow through BIG magnetizing inductance L_μ. Core size/energy storage does not depend on i_{dm} (big @ high power), only on i_{cm}, which we always want to be small!
- So a common mode choke presents a very high impedance to common mode current flow. We get large inductance to CM from a small core, since CM currents are small.
- This is important since we are only allowed to add tiny (<10nF) common-mode capacitors C_y to ground (to keep I_{cm} from flowing out to the line). This is due to safety "leakage" current limits.

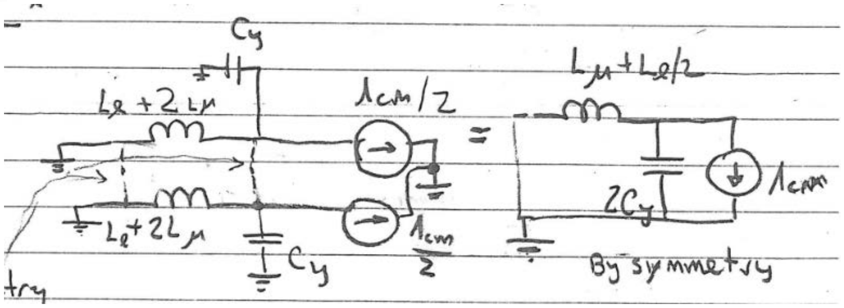
To suppress differential-mode currents we can add large differential mode capacitors as described previously (use "X" capacitors for ac-line applications).

The leakage inductances from the common-mode choke can form some or all of the differential-mode filter inductances.



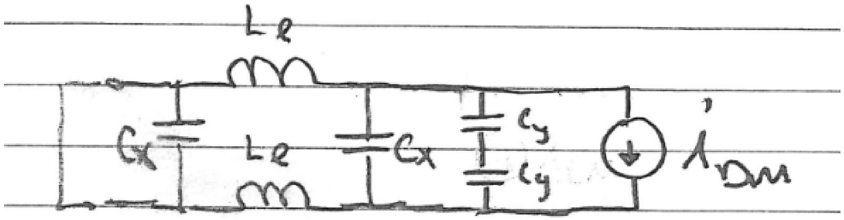
Common mode:

- C_x is open
- ideal transformer is open
- "virtual" short by symmetry



Differntial mode:

- ideal transformer shorts out magnetizing
- C_y currents symmetric → ground is virtual open



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