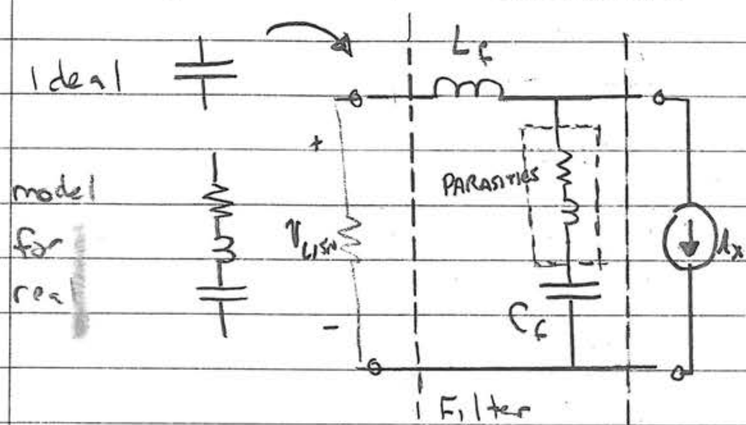
6.334 Lecture Notes

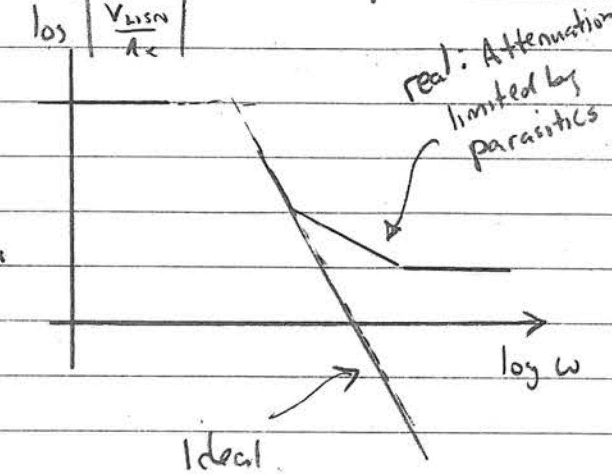
EMI Filters #3 : CM + DM

REVIEW : (VERY SHORT OR SKIP)

From last time, we saw that

① Component + Layout **PARASITICS** often limit filter performance





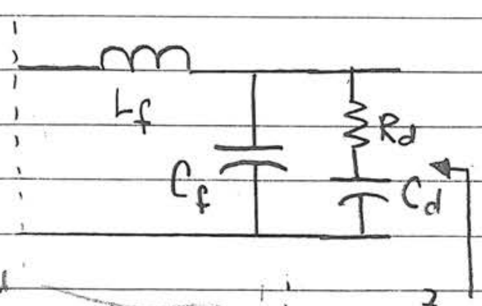
Inductor parasitic capacitance and parasitic L's, C's due to circuit layout can also limit performance

⇒ 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

e.g. damping method:

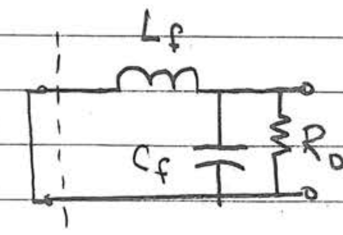


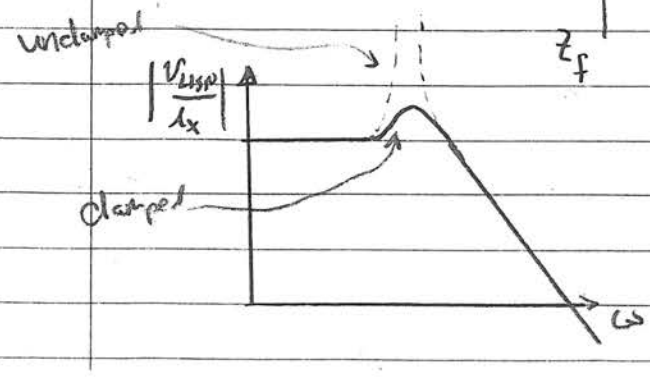
If $C_d >> C_f$

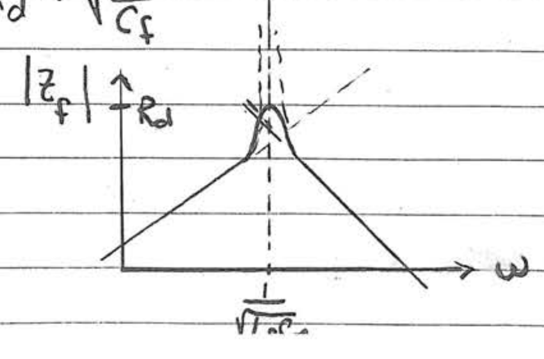
like parallel RLC

$R_d < \sqrt{\frac{L_f}{C_f}}$

≈







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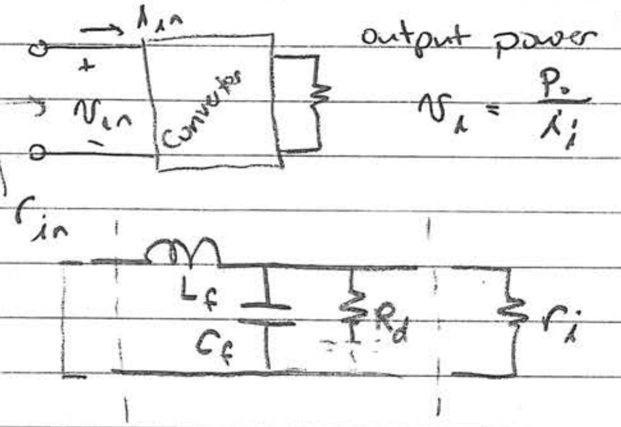
Input filters often need extra damping, because closed-loop converters provide incremental "negative resistance" that tends to destabilize the input filter:



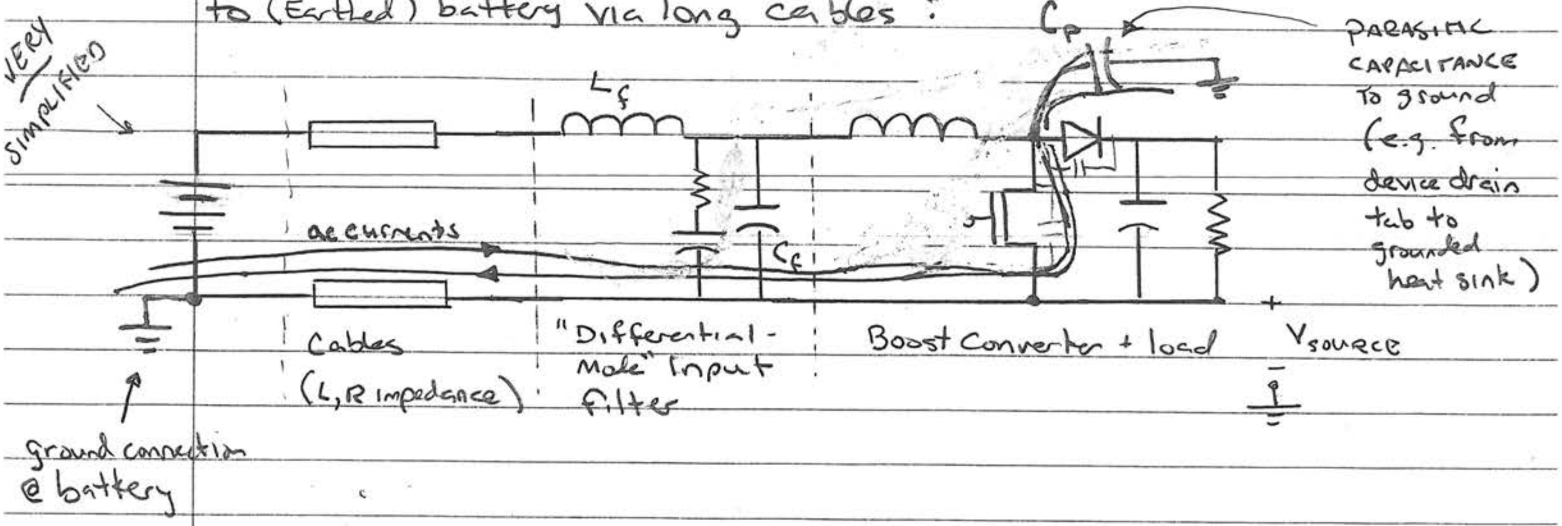
output power P_o ~ constant

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

we need $R_d \ll |r_{in}|$

$$\text{So } R_{eq} \approx \frac{R_d r_{in}}{R_d + r_{in}} > 0$$

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 without parasitic capacitance (well filtered by L_f, C_f) and little high-frequency "bounce" in V_s

- With parasitic capacitance C_p, the lower cable (return) sees high-frequency current, and V_{source} "bounces" substantially from ground at high frequency,

BRING CONVERTER W/FILTER
+ UNPOTTED EMI FILTER FOR "SHOW + TELL"

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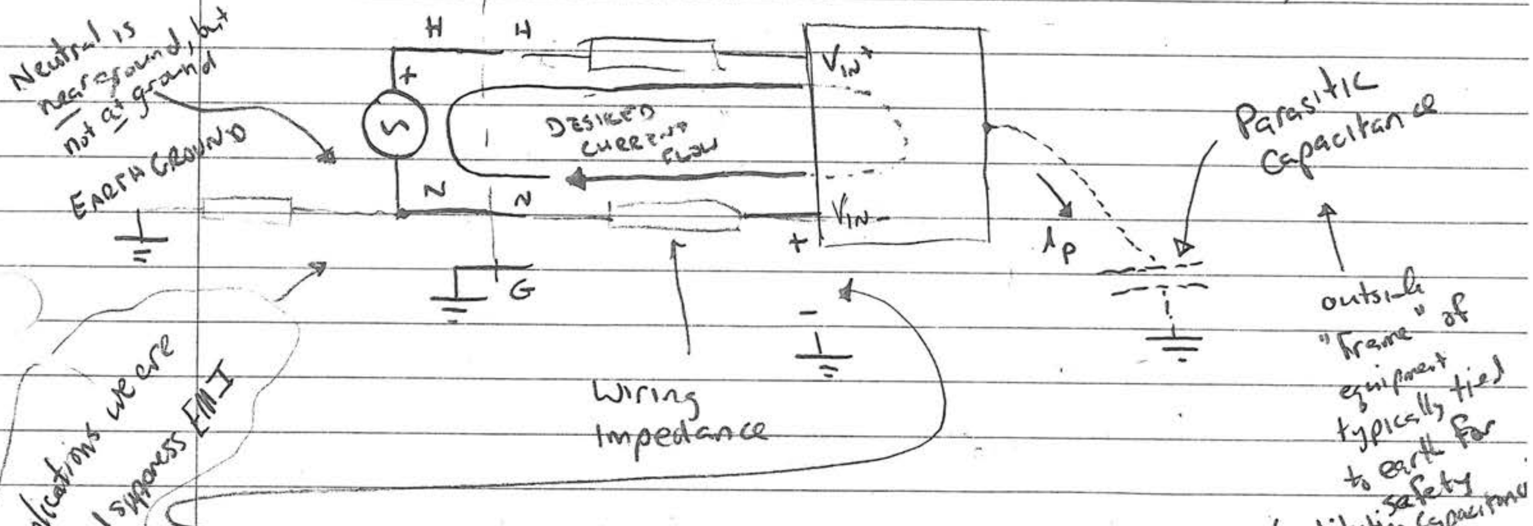
COMMON MODE + DIFFERENTIAL MODE:

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!

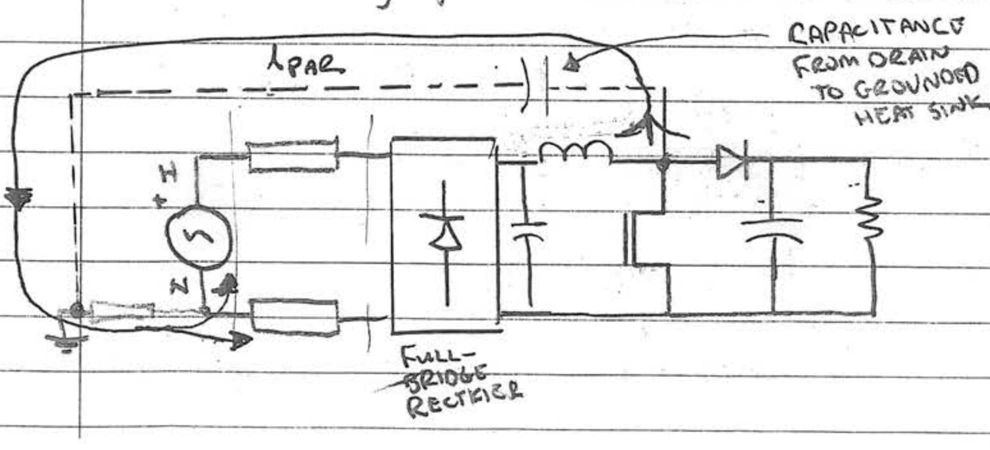
e.g. Systems connected to the ac line: Converter connected to "Hot" H, "Neutral" N



Note: in ac-line applications we are required to measure and suppress EMI in both Hot + neutral!

- We can have voltage differences between V_{in-} (Connected to N) and gnd (and $V_{in,+}$ and gnd)

- Thus 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

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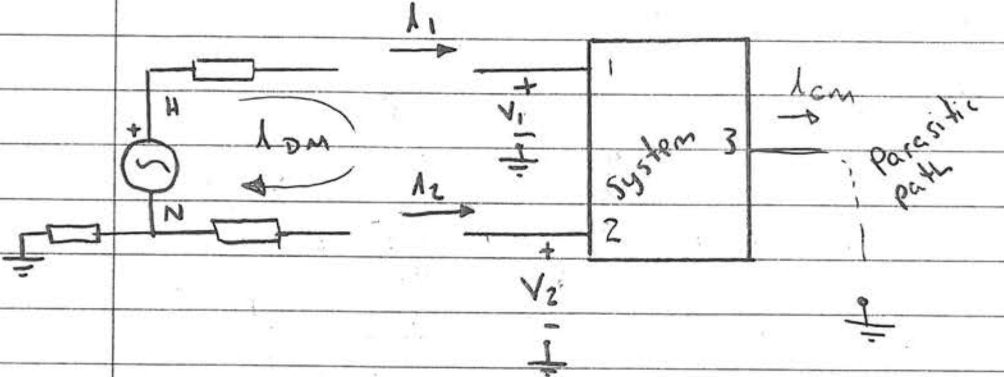
CM Example #2: MOTOR DRIVES often have a high capacitance from the windings (driven by converter) to the grounded frame.

How can we describe the different voltages and currents?



$$\left\{\begin{array}{ll}\text{differential-mode current} & i_{DM} = \dfrac{i_1 - i_2}{2} \\ \text{common-mode current} & i_{CM} = i_1 + i_2\end{array}\right\} \therefore \begin{array}{l} i_1 = i_{DM} + \frac{1}{2} i_{cm} \\ i_2 = -i_{DM} + \frac{1}{2} i_{cm}\end{array}$$

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 + differential-mode voltages

$$\left\{\begin{array}{ll}\text{differential-mode voltage} & v_{dm} = v_1 - v_2 \\ \text{common-mode voltage} & v_{cm} = \dfrac{v_1 + v_2}{2}\end{array}\right\} \begin{array}{l} v_1 = v_{cm} + \frac{1}{2} v_{dm} \\ v_2 = v_{cm} - \frac{1}{2} v_{dm}\end{array}$$

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

⇒ Why? e.g. placing a capacitor from 1-2 ("differentially") will <u>not</u> suppress common-mode current or voltage ripple at all! Other methods prevail.

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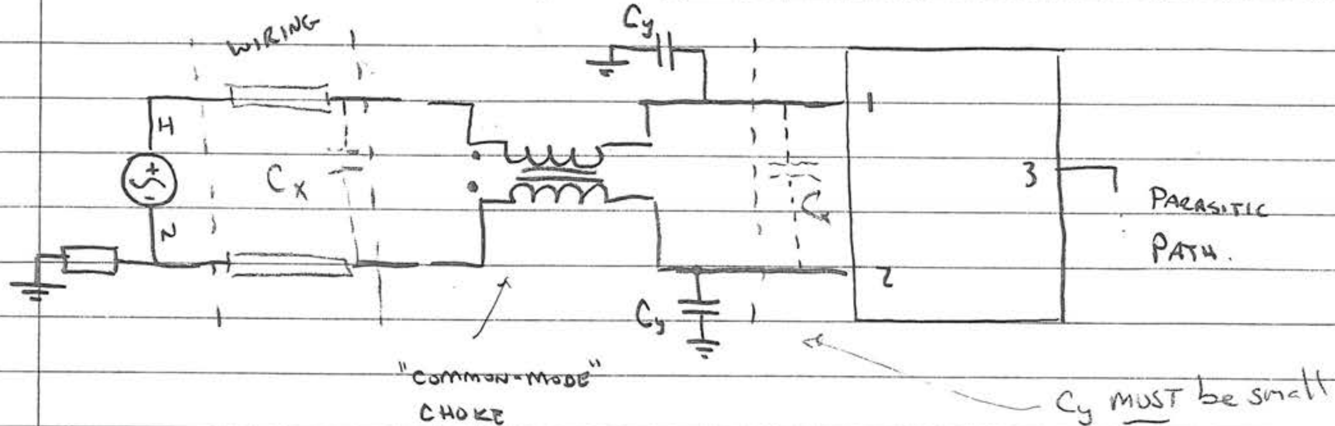
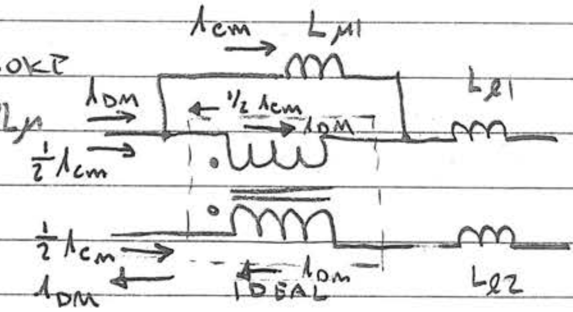
WE ARE REQUIRED TO NOT INJECT COMMON OR DIFFERENTIAL-MODE current back into the line.

CONSIDER A MEANS TO SUPPRESS COMMON-MODE CURRENT (from line wiring)

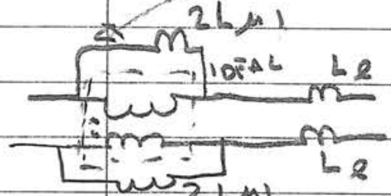


Common-mode choke is a transformer that tries to suppress common-mode currents (current "into one dot must flow out the other")

MODEL CM CHOKE



- Split L_μ into $2L_\mu \| 2L_\mu$



- Differential-mode current flows through ideal xformer, 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!

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- So a common mode choke presents a very high impedance to common mode current flow. We get large inductance to CM from a <u>small</u> core, since CM currents are small.

- This is important, since we are only allowed to add <u>tiny</u> (< 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

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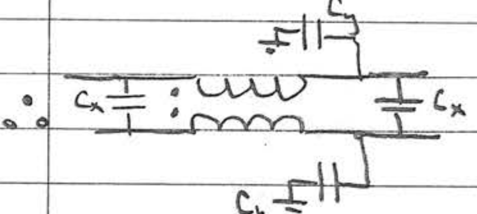
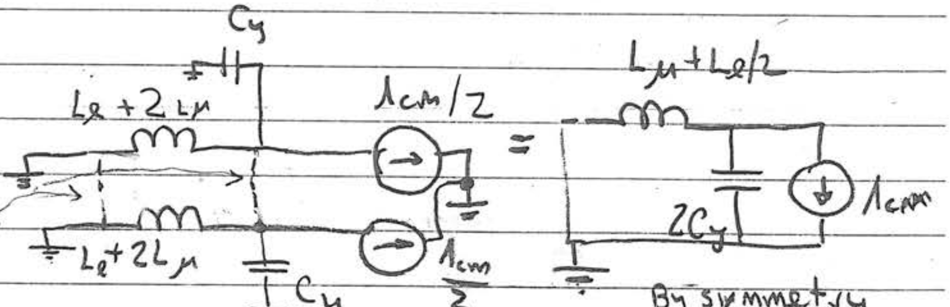
To suppress Differential-mode currents, we can add <u>large</u> differential mode capacitors as described previously. (use "x" capacitors for ac-line applications)

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





Common-mode:
- C_x is open
- Ideal xformer is open
- "virtual" short by symmetry

DIFFERENTIAL MODE
- Ideal xformer shorts out magnetizing
- C_y currents symmetric → ground is virtual open