6.334 Lecture Notes EMI Filtering #1

Need for input + Output filters (start w/ Diff. Mode):
Input + output ripple /EMI Filtering is important to prevent interference with other circuitry (eg. a power supply with an improperly designed EMI filter can easily interfere with radios, televisions, etc., in the vicinity)

Requirements are often imposed to prevent this:
AC-line interfaced systems : FCC, VDE
DC systems : MIL-STD-461, SAE J1113, CISPR

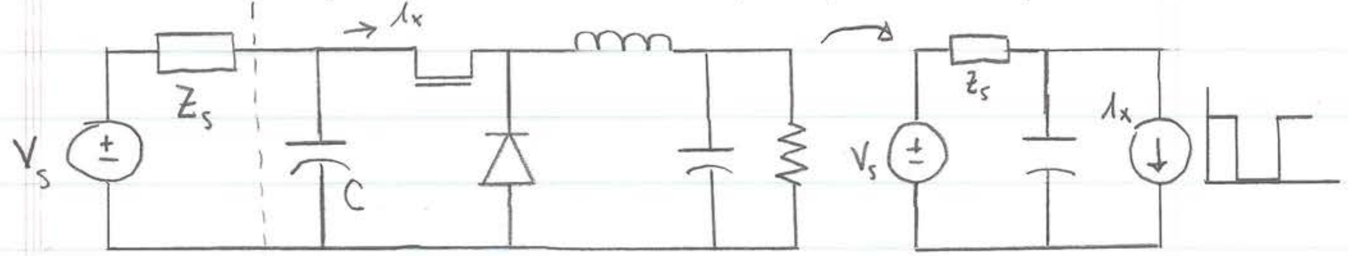
Ripple or EMI limits generally come in 2 flavors:

1. Time-domain voltage or current ripple limits
2. Frequency domain limitations
   - (i.e. amount of ripple energy detected within specified bandwidths over specified frequency ranges.)
   - e.g. FCC conducted limits use 9kHz "resolution bandwidth" from 450kHz - 30MHz.

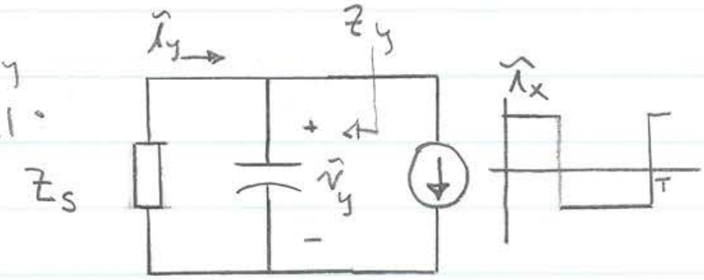
We will consider "conducted" EMI as a first step, as one will likely fail "radiated" EMI tests if conducted emissions are not controlled.

Start by considering "input filters" which prevent switching ripple being conducted back into the input line:

Consider a simple buck converter w/ capacitive input filter:



ac-only model:

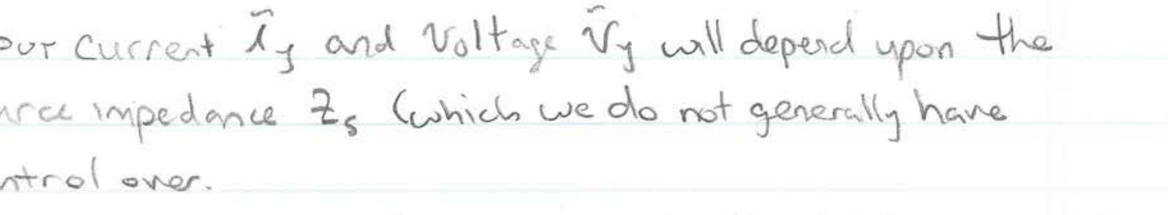


Input current $\hat{i}_y$ and voltage $\tilde{v}_y$ will depend upon the source impedance Z_s (which we do not generally have control over.

→ we won't get the same results for different conditions!

$$|Z_s| \to 0 \Rightarrow \hat{i}_y \to \hat{i}_x \,,\ \tilde{v}_y \to 0$$
$$|Z_s| \to \infty \Rightarrow \hat{i}_y \to 0 \,,\ |\tilde{v}_y(\omega)| \to \left| \frac{\tilde{I}_x(\omega)}{j\omega C} \right|$$

To get repeatable results, we often do our measurements with a Line Impedance Stabilization Network (LISN) to get a repeatable, known condition for measurement:

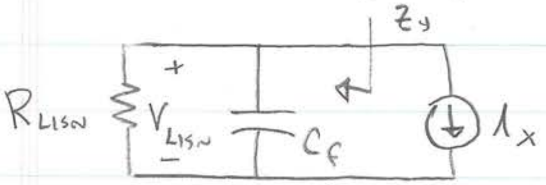


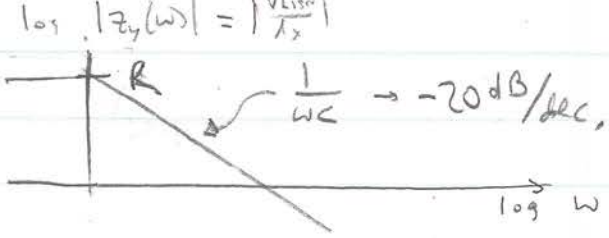
Typ: $C_{LISN} = 1\mu F$, $L_{LISN} = 5\mu H$, $R_{LISN} = 50\Omega$

The LISN is Used for EMI testing ONLY!

- The LISN provides a known ripple-frequency source impedance
  - → It is a short @ dc (+ low frequency) + passes power signals to the source
  - → @ high frequency $Z_{LISN} \rightarrow 50\Omega$
- OFTEN, the EMI specification is given in terms of frequency domain limits on V_{LISN} (across the 50Ω resistor), measured by a spectrum analyzer with a 50Ω input
  - → This corresponds to a limit of ripple content into the Known LISN impedance!

EMI Filter Design : (simplifying assuming source impedance @ high frequency is 50Ω). For our buck converter:





$$V_{LISN}(\omega) \approx \frac{I_x(\omega)}{j\omega C}$$

The capacitor to achieve typical ripple specifications may be impractically large! (e.g. for a typical automotive application $|i_x| \sim 10A$, $|i_{R_{LISN}}| < 100\mu A$ is required!

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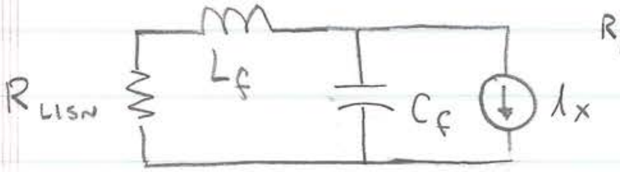
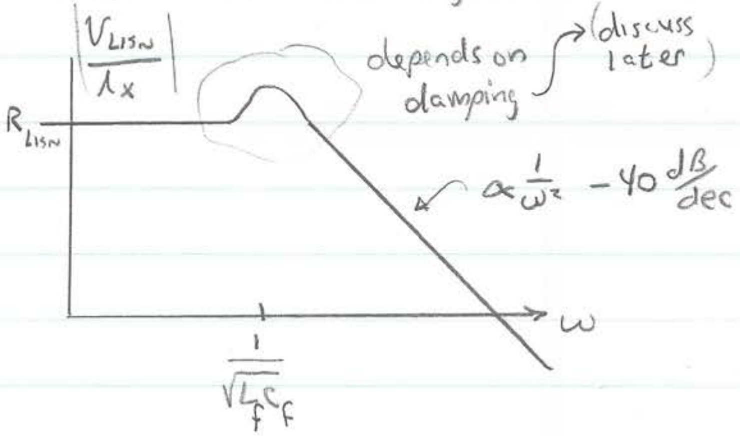
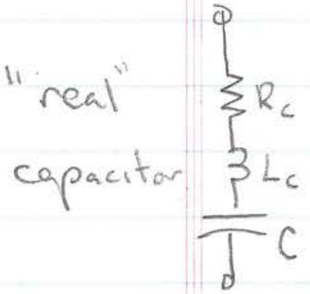
We can design a low-loss second-order filter by adding an inductor:

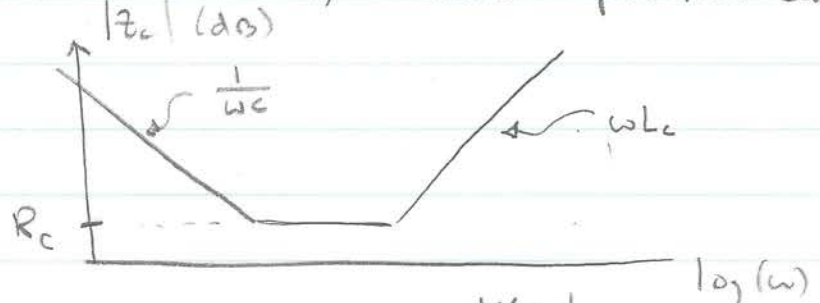


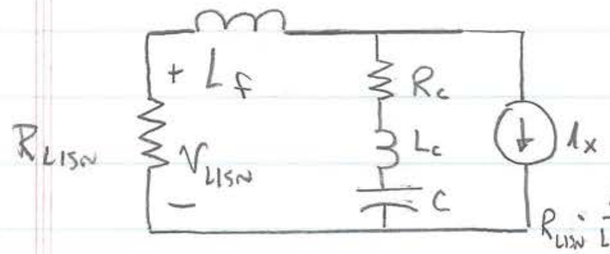


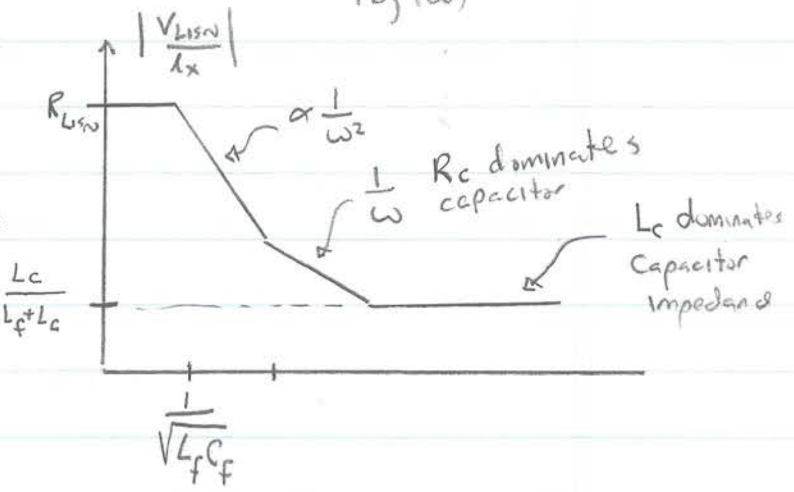
The mismatch between the growing impedance $j\omega L_f$ + the shrinking impedance $\frac{1}{j\omega C_f}$ gives attenuation $\propto \omega^2$!

Note: we must carefully consider component parasitics: e.g. consider a practical capacitor









⇒ we need good components + careful layout, + still we must compensate for practical limits!

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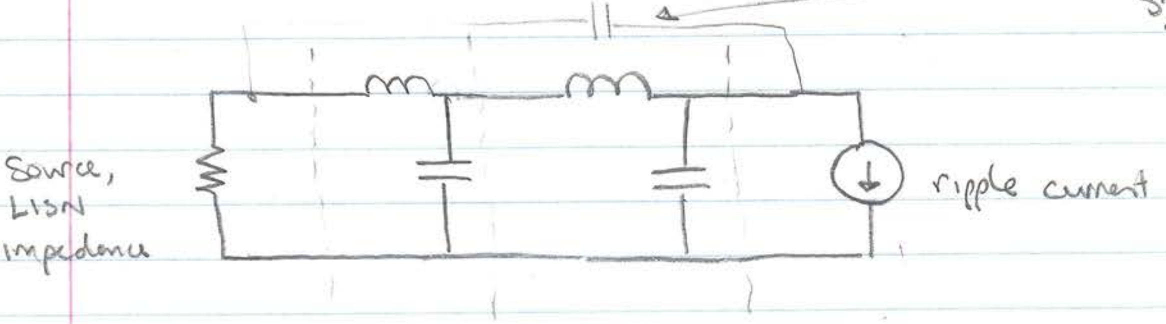
NOTE THAT IN SOME CASES IT IS THE PARASITICS THAT DETERMINE COMPONENT + FILTER SPECIFICATIONS

e.g. Electrolytic capacitor in an input filter
→ "low-frequency" ripple attenuation determined by R_{ESR}, not C
→ Amount of capacitance (size) may be determined by RMS current ripple rating!
→ we often parallel capacitors of different sizes & types

In addition to component parasitics, filter layout parasitics can be important.

Consider a high-attenuation filter



Even a very small parasitic capacitance can bypass the effect of the filter!

Such parasitic effects are often the source of seemingly anomolous behavior.

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Spring 2023