1. In order to illustrate that the LISN essentially presents 50 Ω impedances between phase and ground and between neutral and ground, use LTspice to plot the frequency response of the impedance looking into one side of the LISN shown in the figure below over the conducted emission frequency range of 150 kHz – 30 MHz for three cases of impedance seen looking into the power net: (1) short-circuit load, (2) open-circuit load, and (3) 50 Ω load. Determine the values at 150 kHz and 30 MHz.

Short circuit load. At f=150 kHz, Zin=38.31 Ohm. At f=30 MHz, Zin=47.62 Ohm.

Open circuit load. At f=150 kHz, Zin=37.85 Ohm. At f=30 MHz, Zin=47.62 Ohm.
50 Ohm load. At f=150 kHz, Zin=37.84 Ohm. At f=30 MHz, Zin=47.62 Ohm.
2. Determine the equation for the insertion loss of the bandreject filter shown below.

\[
\hat{V}_{L,\omega_0} = \frac{R_L}{R_S + R_L} \hat{V}_0
\]

\[
\hat{V}_{L,W} = \frac{R_L}{R_S + R_L + \frac{1}{j\omega C} + \frac{j\omega L}{R_S + R_L}} = \frac{R_L}{R_S + R_L + \frac{j\omega L}{1 - \omega^2 LC}}
\]

\[
\frac{1}{|\hat{V}_{L,\omega_0}|} = \frac{1}{1 + \frac{j\omega L}{(1 - \omega^2 LC)(R_S + R_L)}} = \frac{1}{1 + \frac{j\omega \tau}{1 - (\omega/\omega_0)^2}}
\]

where \( \tau = \frac{L}{R_S + R_L}, \omega_0 = \frac{1}{\sqrt{LC}} \)

\[
\text{IL} = 20 \log_{10} \left| \frac{\hat{V}_{L,\omega_0}}{\hat{V}_{L,W}} \right| = 10 \log_{10} \left( 1 + \frac{\omega^2 \tau^2}{1 - (\omega/\omega_0)^2} \right)
\]
3. Suppose that a common-mode choke has self-inductances of 28 mH and a coupling coefficient of 0.98.
   a) Determine the leakage inductance presented to differential-mode currents.
   b) Repeat this for a coupling coefficient of 0.95.

\[ k = \frac{M}{L} \Rightarrow M = 0.98 \times 28 \text{ mH} = 27.44 \text{ mH}. \]

\[ \text{Leakage} = L - M = 0.56 \text{ mH}. \]

\[ M = 0.95 \times 28 \text{ mH} = 26.6 \text{ mH} \]

\[ \text{Leakage} = L - M = 1.4 \text{ mH}. \]
4. The effect of a power supply filter on common-mode currents is sometimes characterized by the common-mode impedance as \( \hat{Z}_C = \frac{\hat{V}_C}{\hat{I}_C} \) with reference to figure (a) below. For \( L_{GW} = 1mH \), \( L = 28mH \), \( k = 0.98 \), and \( C_{CL} = C_{CR} = 3300pF \),

a) Use LTspice to plot \( \hat{Z}_C \) from 150 kHz to 30 MHz. What are the \( \hat{Z}_C \) values at 150 kHz and 30 MHz?

b) Repeat this for the differential-mode impedance \( \hat{Z}_D = \frac{\hat{V}_D}{\hat{I}_D} \) with respect to figure (b) below with \( C_{DR} = C_{DL} = 0.1\mu F \).

c) Suppose that the common-mode and differential-mode currents at the input to the power supply filter at 150 kHz are equal to 1 mA. Determine the total received voltage across the LISN 50 Ω resister. Which component is dominant?

\[
\hat{Z}_C \approx kL = 0.98 \times 28 \text{mH} = 27.44 \text{mH}.
\]

\[
\hat{Z}_C(150\text{kHz}) = -23.86 \text{dBΩ} \quad \hat{Z}_C(30\text{MHz}) = -209.7 \text{dBΩ}
\]

\[
\hat{Z}_C = 64.1 \text{mΩ} \quad \hat{Z}_C = 32.8 \mu\Omega
\]
b) 

\[ Z_D(150\,\text{kHz}) = -25.62\,\text{dB}\Omega \]
\[ = 52.36\,\text{m}\Omega \]

\[ Z_D(30\,\text{MHz}) = -163.8\,\text{dB}\Omega \]
\[ = 6.45\,\text{n}\Omega \]

C). \[ \hat{V}_c(150\,\text{kHz}) = \hat{Z}_c(150\,\text{kHz}) \cdot 1\text{mA} \]
\[ = 64.1 \times 10^{-3} \times 10^{-3} \]
\[ = 64.1\mu\text{V} \]

\[ \hat{V}_D(150\,\text{kHz}) = \hat{Z}_D(150\,\text{kHz}) \cdot 1\text{mA} \]
\[ = 52.36 \times 10^{-3} \times 10^{-3} \]
\[ = 52.36\,\mu\text{V} \]

\[ \hat{V}_{\text{total}}(150\,\text{kHz}) = \hat{V}_c(150\,\text{kHz}) + \hat{V}_D(150\,\text{kHz}) \]
\[ = 116.46\,\mu\text{V} = 41.3\,\text{dBmV} \]

Since \[ \hat{V}_c(150\,\text{kHz}) > \hat{V}_D(150\,\text{kHz}) \], common mode component dominates.
5. (Bonus) The buck regulator in the Switched-Mode Power Supply (SMPS) is to be operated at a switching frequency of 50 kHz, an input voltage of 100 V, and an output voltage of 5 V.

a) Determine the required duty cycle.

b) Calculate the level of the 25th harmonic (1.25 MHz) of the ideal chopped voltage $V_{in}$. (Use the asymptotic approximations developed in Chapter 3 and the exact formula.)

c) Why is the SMPS better than linear power supply?

A simple “buck regulator” switching power supply.

\[ V_{out} = D V_{in} \Rightarrow D = \frac{V_{out}}{V_{in}} = 5\% \]

\[ 2AD = 2 \cdot 100 \cdot 0.05 = 10 \]

\[ f_0 = 50 \text{ kHz} \]

\[ f_1 = \frac{f_0}{\pi D} = \frac{50 \times 10^3}{\pi \times 0.05} = 318.3 \text{ kHz} \]

\[ |\hat{V}_{in}(f_{25})| = 20 \log_{10} \left( \frac{10}{10^{-6}} \right) \]

\[ - 20 \log_{10} \left( \frac{f_{25}}{f_1} \right) \text{ dBuV} \]

\[ = 140 \text{ dBuV} - 11.88 \text{ dBuV} \]

\[ = 128.12 \text{ dBuV}, \text{ approximate} \]

\[ |\hat{V}_{in}(f_{25})|_{\text{exact}} = 2AD \left| \frac{\sin(n\pi D)}{n\pi D} \right| = 10 \left| \frac{\sin \left( \frac{25\pi}{25} \cdot 0.05 \right)}{25\pi \cdot 0.05} \right| = 1.8 \text{ V} \]

\[ = 125.1 \text{ dBuV}, \text{ exact} \]

C) SMPS has much larger efficiencies of order 60-90%, while linear power supply typically has much lower efficiencies of order 20-40%.

SMPS usually are lighter in weight compared with linear power supply.

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