\[ |H(s = \sigma + j\omega)| \]
Zero at the origin

\[ z = \frac{v}{l} = \angle s \]
\[ y = \frac{v}{l} = \angle c \leq \]

\[ \angle z(s) = \angle s \]
\[ |z(jw)| = \angle 1 \omega \]
\[ \log_{10} |z(jw)| = \log_{10} |w| + \log_{10} \frac{1}{z(jw)} \]
\[ \angle z(jw) = \left\{ \begin{array}{ll}
-90^\circ & \text{for } \omega < 0 \\
+90^\circ & \text{for } \omega > 0
\end{array} \right. \]
Pole at origin

\[ Y = \frac{1}{V} = \frac{1}{c_5} \]
\[ Z = \frac{Y}{X} = \frac{1}{c_5} \]

Let \( Z(s) = \frac{1}{c_5} \)

\[ |Z(j\omega)| = \frac{1}{c\omega} \]

\[ \log |Z(j\omega)| = -\log|\omega| - \log c \]

\[ \angle Z(j\omega) = \begin{cases} +90^\circ & \text{for } \omega < 0 \\ -90^\circ & \text{for } \omega > 0 \end{cases} \]

20 \log \frac{|Z(j\omega)|}{c}
Displaced Zero

\[ Z = \frac{V}{I} = L(s + \frac{R}{L}) \]
\[ Y = \frac{I}{V} = C(s + \frac{1}{RC}) \]

\[ Z(j\omega) = L(s + j\omega) \]
\[ s = \frac{R}{L} \]

\[ \log_{10} \left| \frac{Z(j\omega)}{R} \right| \]

-20 dB/decade slope

-2 \log_{10} \omega

100 \log_{10} \omega

-20 \log_{10} \omega

100 \log_{10} \omega

-145 \degree/decade slope
Displaced P&c

\[ Z = \frac{1}{C} \left( \frac{1}{s + \frac{1}{RC}} \right) \quad \frac{V_2}{V_1} = \frac{1}{RC} \left( \frac{1}{s + \frac{1}{RC}} \right) \]

\[ Y = \frac{1}{L} \left( \frac{1}{s + \frac{1}{LC}} \right) \quad \frac{V_2}{V_1} = \frac{R}{L} \left( \frac{1}{s + \frac{1}{LC}} \right) \]

\[ Z(j\omega) = \frac{1}{C} \frac{1}{j\omega + \frac{1}{RC}} \quad \\]

\[ V_x = \frac{1}{RC} \]

\[ 20 \log \left| \frac{Z(j\omega)}{R} \right| \]

\[ -20 \text{ dB/decade slope} \]

\[ XZ(j\omega) \]

\[ -45 \text{°/decade slope} \]
Displaced pole at zero $s$:

\[
Z = R \frac{S}{S + \omega L} \quad V_i = \frac{S}{S + \omega L} \quad V_o = \frac{S}{S + \omega L}
\]

\[
Z(\omega) = R \frac{j\omega}{\omega \omega + \omega L}
\]

\[
\alpha = \frac{\omega}{\omega}
\]
**CASCADE PLAN**

\[
\begin{align*}
H_1 &= \frac{V_2}{V_1} \\
H_2 &= \frac{V_3}{V_2} \\
H_3 &= \frac{V_3}{V_1} = H_1 \cdot H_2
\end{align*}
\]

When multiplying complex numbers:
- multiply magnitudes (add logarithms)
- add angles

So when you're looking at Bode plots...

*Note: Loading Bug*
Parallel-in, Series-Out Plan

\[ H_1 = \frac{V_3}{V_1}, \quad H_2 = \frac{V_4}{V_1} \]

\[ V_2 = V_3 + V_4 \]

So \[ \frac{V_3 + V_4}{V_1} = H_1 + H_2 \]

So \[ H_3 = \frac{V_2}{V_1} = H_1 + H_2 \]

Note: Common ground bug.
In general, an impedance or an admittance can be transformed into a voltage-transfer ratio with an op-amp. Even better -- we can form ratios of impedances!

\[ \frac{V_2}{V_1} = -\frac{Z_2}{Z_1} \]
Problem: To make a filter with the following characteristic:

\[ 20 \log \left| \frac{V_2}{V_1} \right| \]

Note:
\[ \omega = 2\pi f \]
Problem Solving By Debugging Almost-Right Plans

Given a problem to solve

Plan:

Do I know the answer?

if so, done.

Can I split the problem into subproblems by a known decomposition?

if so

Solve each subproblem.

Construct a putative solution to the whole from the solutions of the parts.

test the composite result:
    does it actually solve the problem?

if so, done.

if not

Describe the difference between the behavior obtained and the behavior desired.

Solve a new subproblem:
    Make a modification to our putative solution that eliminates the difference.

Can I change the representation of the problem?

if so

Solve the problem in the new representation.
Ideas from programming

Recursion

Subproblems are problems to be solved. Solutions to subproblems are combined to construct solution to the whole.

Search process

Alternative paths must be considered. Organization required to prevent considering the same alternative multiple times.

Analysis and Debugging

Must be able to evaluate the consequences of a choice.

Dependencies must be maintained to help with diagnosis of failed paths.

Rule system

Pattern match of rule antecedent to the specification of the problem:

To determine rule applicability.
To determine relevant problem-specific values.

Substitution of problem-specific values for variables in rule consequent.
From: Edgar Allen Poe,
The Philosophy of Composition,
1846

... 

I select "The Raven" as most generally known. It is my design to render it manifest that no one point in its composition is referable either to accident or intuition--that the work proceeded step by step, to its completion, with the precision and rigid consequence of a mathematical problem.