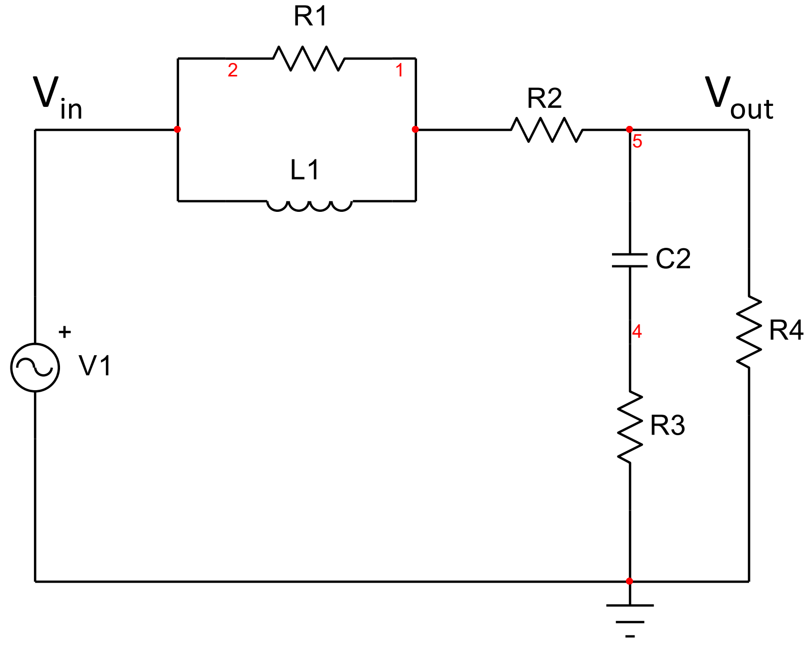
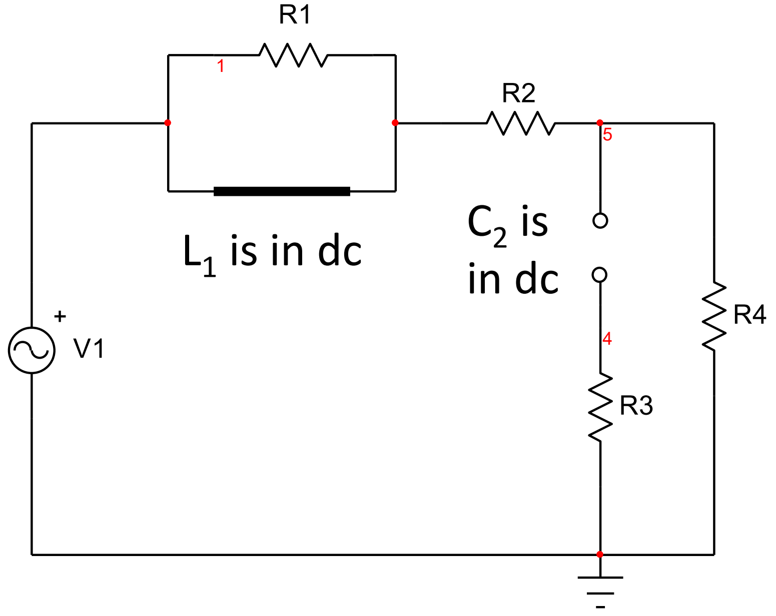
In these examples, I am showing how to solve a circuit with two different reference states in a 2nd-order circuit.



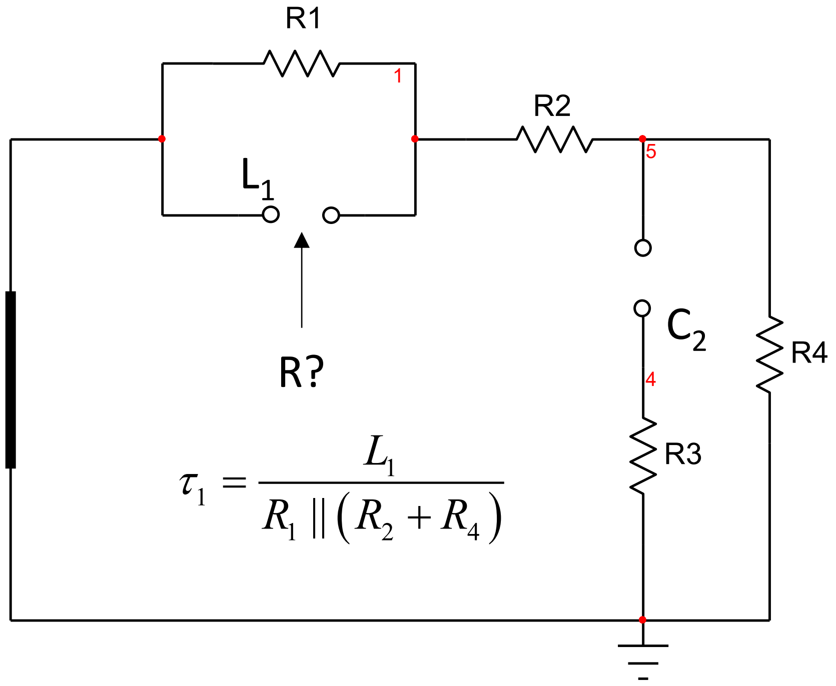
We start by considering s = 0 for the reference state:



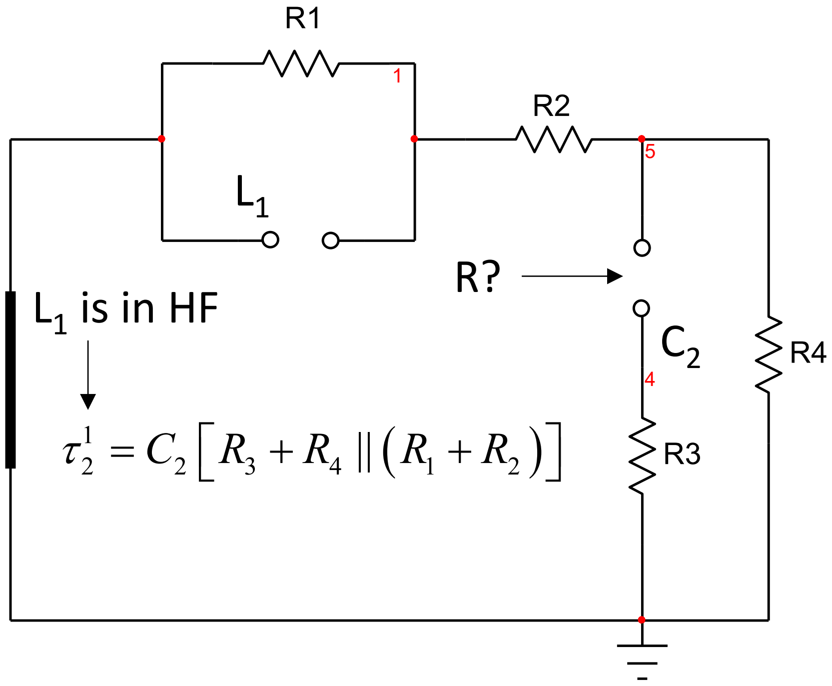
$$H_0 = \frac{R_4}{R_2 + R_4}$$

Brute-force TF

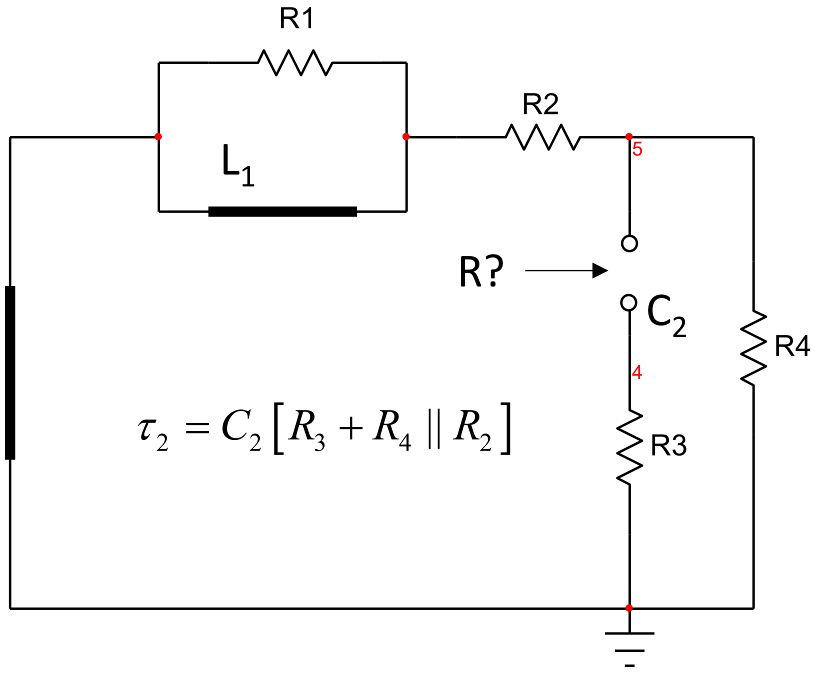
$$H_{BF}(s) := \frac{\left[R_4 \parallel \left(R_3 + \frac{1}{s \cdot C_2}\right)\right]}{\left[R_4 \parallel \left(R_3 + \frac{1}{s \cdot C_2}\right)\right] + \left[R_2 + (s \cdot L_1) \parallel R_1\right]}$$



In this case, C_2 is in its reference state.

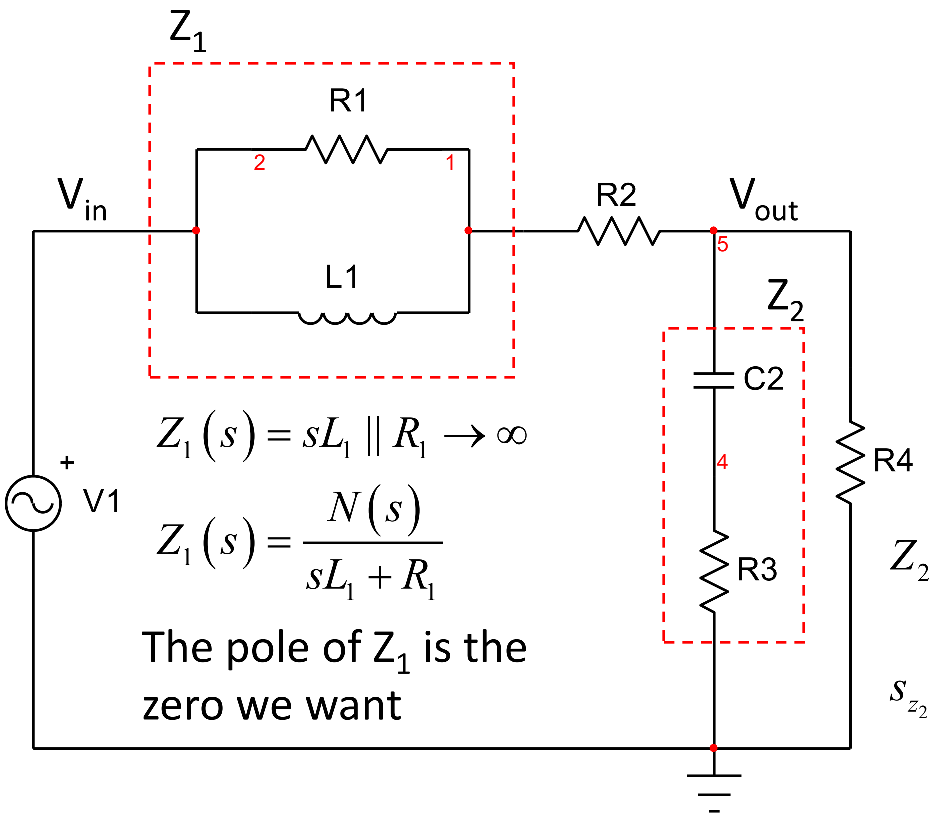


In this mode, L_1 is in the opposite of its reference state (which is high-frequency).



In this case, L_1 is in its reference state.

For the zeroes, there are two and can be obtained by inspection immediately:



$$Z_1(s) = sL_1 \parallel R_1 \to \infty$$

$$Z_1(s) = \frac{N(s)}{sL_1 + R_1}$$

The pole of Z_1 is the zero we want

$$Z_2(s) = R_3 + \frac{1}{sC_2} = 0$$

$$s_{z_2} = -\frac{1}{R_3 C_2}$$

$$\omega_{z_1} = \frac{R_1}{L_1} \qquad \omega_{z_2} = \frac{1}{R_3 C_2}$$

$$N(s) = \left(1 + \frac{s}{\omega_{z_1}}\right)\left(1 + \frac{s}{\omega_{z_2}}\right)$$

$$D(s) = 1 + b_1 s + b_2 s^2$$

$$b_1 = \tau_1 + \tau_2 = \frac{L_1}{R_1 \parallel (R_2 + R_4)} + C_2 (R_3 + R_4 \parallel R_2)$$

$$b_2 = \tau_1 \tau_2^1 = \frac{L_1}{R_1 \parallel (R_2 + R_4)} C_2 \left[R_3 + R_4 \parallel (R_1 + R_2)\right]$$

$$H(s) = H_0 \frac{\left(1 + \frac{s}{\omega_{z_1}}\right)\left(1 + \frac{s}{\omega_{z_2}}\right)}{1 + \frac{s}{\omega_0 Q} + \left(\frac{s}{\omega_0}\right)^2}$$

$$H_0 = \frac{R_4}{R_1 + R_2 + R_4}$$

$$\omega_{z_1} = \frac{R_1}{L_1} \qquad \omega_{z_2} = \frac{1}{R_3 C_2}$$

$\|(x,y) := \dfrac{x \cdot y}{x + y}$

$R_1 := 10k\Omega$ $\quad R_2 := 1k\Omega$ $\quad R_3 := 10\Omega$ $\quad R_4 := 500\Omega$ $\quad C_2 := 0.1\mu F$ $\quad L_1 := 100\mu H$

$\tau_1 := \dfrac{L_1}{R_1 \| (R_2 + R_4)} = 0.077 \cdot \mu s$ $\qquad H_0 := \dfrac{R_4}{R_2 + R_4}$

$\tau_2 := C_2 \cdot (R_3 + R_4 \| R_2) = 34.333 \cdot \mu s$

$\tau_{12} := C_2 \cdot [R_3 + R_4 \| (R_2 + R_1)] = 48.826 \cdot \mu s$ $\qquad \omega_{z1} := \dfrac{R_1}{L_1}$ $\qquad \omega_{z2} := \dfrac{1}{R_3 \cdot C_2}$

$b_1 := \tau_1 + \tau_2$ $\qquad b_2 := \tau_1 \cdot \tau_{12}$

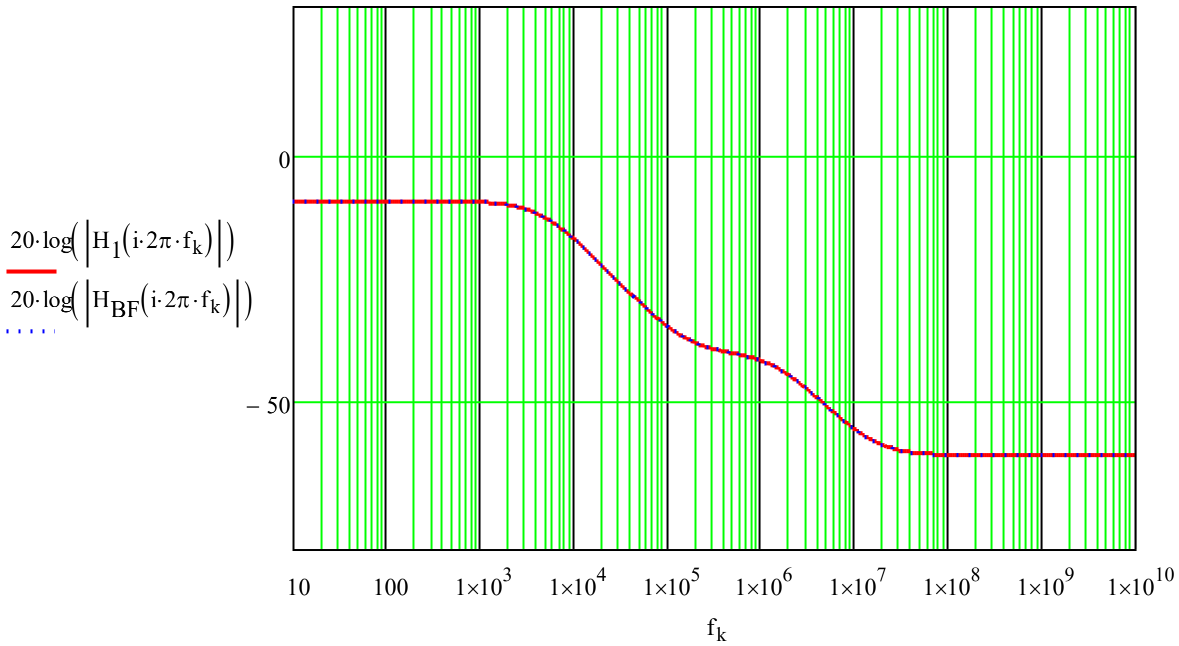
$D_1(s) := 1 + s \cdot (\tau_1 + \tau_2) + s^2 \cdot (\tau_1 \cdot \tau_{12})$ $\qquad N_1(s) := \left(1 + \dfrac{s}{\omega_{z1}}\right) \cdot \left(1 + \dfrac{s}{\omega_{z2}}\right)$

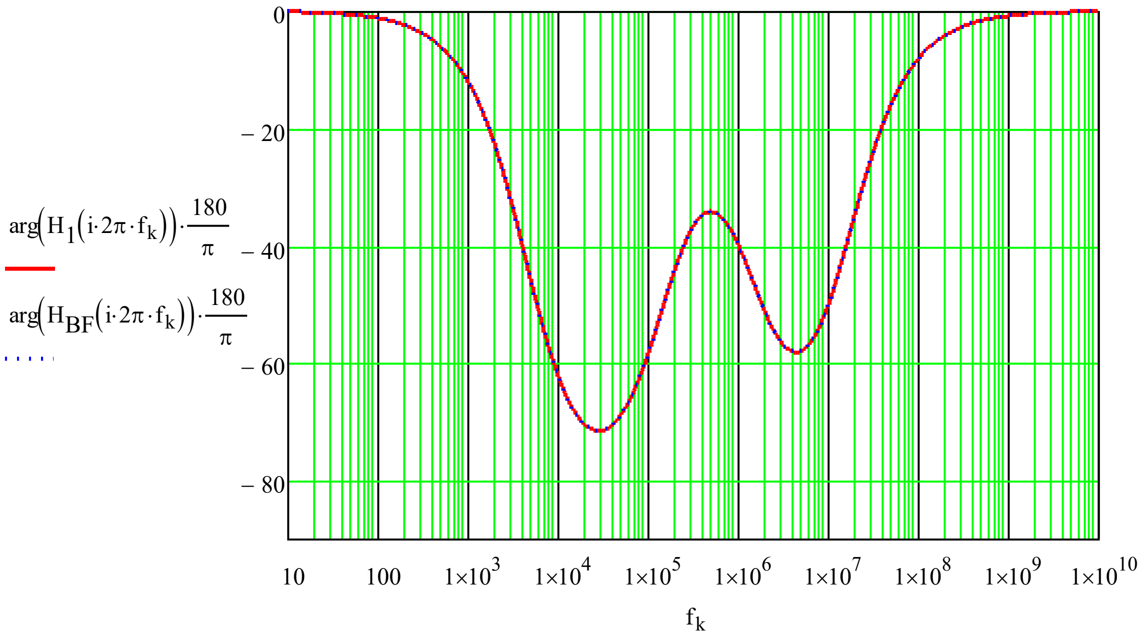
$Q := \dfrac{\sqrt{b_2}}{b_1} = 0.056$ $\qquad \omega_0 := \dfrac{1}{\sqrt{b_2}}$ $\qquad f_0 := \dfrac{\omega_0}{2 \cdot \pi} = 82.26 \cdot kHz$

$D_2(s) := 1 + \dfrac{s}{\omega_0 \cdot Q} + \left(\dfrac{s}{\omega_0}\right)^2$

$H_1(s) := H_0 \cdot \dfrac{N_1(s)}{D_1(s)}$

$$H_{BF}(s) := \frac{\left[R_4 \| \left(R_3 + \frac{1}{s \cdot C_2}\right)\right]}{\left[R_4 \| \left(R_3 + \frac{1}{s \cdot C_2}\right)\right] + \left[R_2 + (s \cdot L_1) \| R_1\right]}$$





The factorization of the 2nd-order polynomial form changes depending on the adopted leading term:

2nd-order expression

$$H(s)=\frac{a_0+a_1s+a_2s^2}{b_0+b_1s+b_2s^2}$$

dc mid-freq high-freq

$$H(s)=\frac{a_0}{b_0}\,\frac{1+\frac{a_1}{a_0}s+\frac{a_2}{a_0}s^2}{1+\frac{b_1}{b_0}s+\frac{b_2}{b_0}s^2}$$

dc

$$H(s)=\frac{a_1}{b_1}\,\frac{a_0+s+\frac{a_2}{a_1}s^2}{b_0+s+\frac{b_2}{b_1}s^2}$$

Mid-band
Ok for a bandpass filter

$$H(s)=\frac{a_2}{b_2}\,\frac{\frac{a_0}{a_2}+\frac{a_1}{a_2}s+s^2}{\frac{b_0}{b_2}+\frac{b_1}{b_2}s+s^2}$$

HF

Factor s^2

$$H(s)=\frac{a_2}{b_2}\frac{s^2}{s^2}\,\frac{\frac{a_0}{a_2s^2}+\frac{a_1}{a_2s^2}s+1}{\frac{b_0}{b_2s^2}+\frac{b_1}{b_2s^2}s+1}$$

$$H(s)=\frac{a_2}{b_2}\,\frac{1+\frac{a_1}{a_2s}+\frac{a_0}{a_2s^2}}{1+\frac{b_1}{b_2s}+\frac{b_0}{b_2s^2}}$$

$$H_{11}(s):=\frac{R_4+\left(\frac{L_1\cdot R_4}{R_1}+C_2\cdot R_3\cdot R_4\right)\cdot s+\frac{C_2\cdot L_1\cdot R_3\cdot R_4\cdot s^2}{R_1}}{R_2+R_4+s\cdot(R_2+R_4)\cdot\left[\frac{L_1}{R_1\parallel(R_2+R_4)}+C_2\cdot(R_3+R_4\parallel R_2)\right]+s^2\cdot(R_2+R_4)\cdot\left[\frac{L_1}{R_1\parallel(R_2+R_4)}\cdot\left[C_2\cdot\left[R_3+R_4\parallel(R_2+R_1)\right]\right]\right]}$$

$$a_0:=R_4\qquad a_1:=\frac{L_1\cdot R_4}{R_1}+C_2\cdot R_3\cdot R_4\qquad a_2:=\frac{C_2\cdot L_1\cdot R_3\cdot R_4}{R_1}$$

$$b_0:=R_2+R_4\qquad b_1:=(R_2+R_4)\cdot\left[\frac{L_1}{R_1\parallel(R_2+R_4)}+C_2\cdot(R_3+R_4\parallel R_2)\right]\qquad b_2:=(R_2+R_4)\cdot\left[\frac{L_1}{R_1\parallel(R_2+R_4)}\cdot\left[C_2\cdot\left[R_3+R_4\parallel(R_2+R_1)\right]\right]\right]$$

$$H_{12}(s):=\frac{a_0+a_1\cdot s+a_2\cdot s^2}{b_0+b_1\cdot s+b_2\cdot s^2}$$

$$H_{00}:=20\cdot\log\left(\frac{a_0}{b_0}\right)=-9.542$$

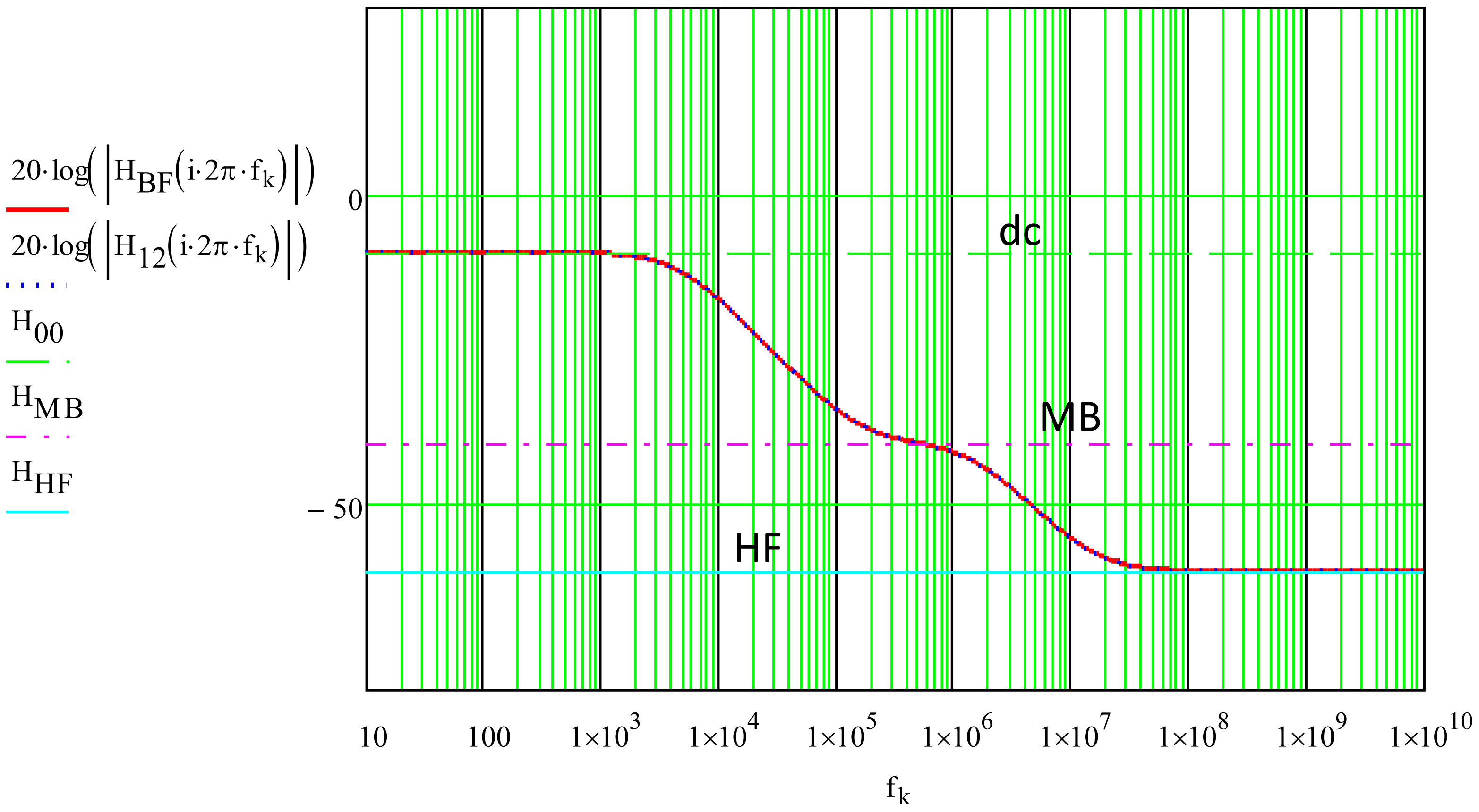
dc gain

$$H_{MB}:=20\cdot\log\left(\frac{a_1}{b_1}\right)=-40.19$$

mid-band gain

$$H_{HF}:=20\cdot\log\left(\frac{a_2}{b_2}\right)=-61.008$$

high-frequency gain



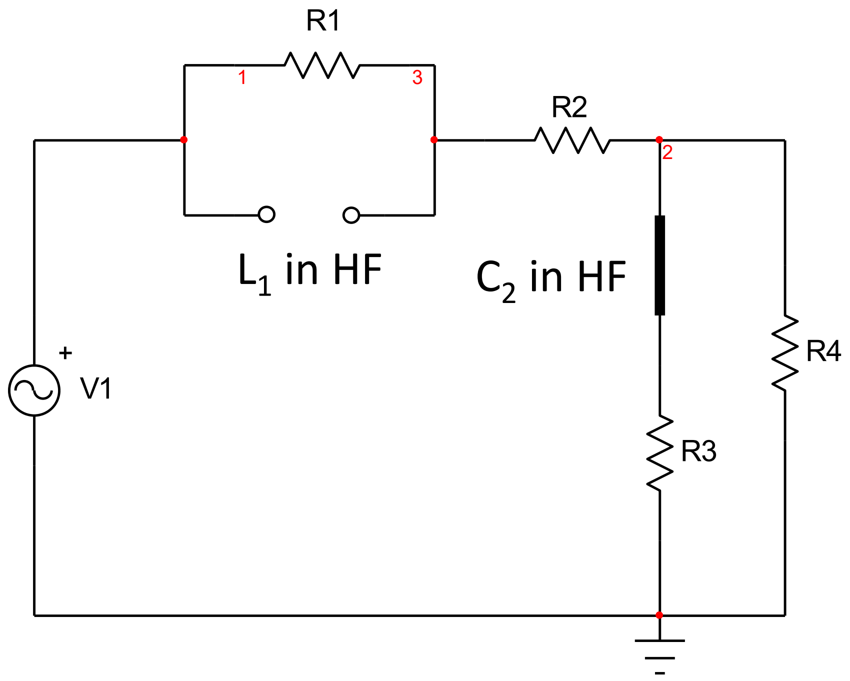
Depending on the adopted leading term, it is possible to highlight any of the three possible gains: the dc gain when $s = 0$, the midband gain for moderate frequencies and the high-frequency gain when s approaches infinity.

If the dc gain is nonzero, we can use the classical approach with H_0 as a leading term. If the dc gain is zero (or not) but there exists a high-frequency gain, then use the adapted expression with H_{INF} as a leading term. And if there are no dc or HF gains, like in a selective filter or bandpass, use the expression with H_{MB} as the leading term.

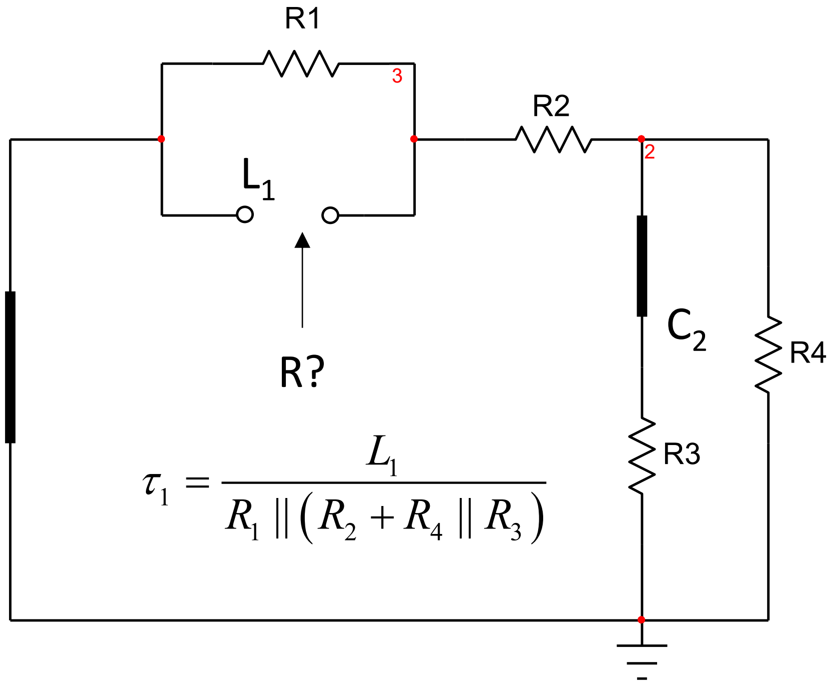
Now we change the reference state to *s* approaches infinity:

inductance L_1 is open
C_2 is a short.

This is the new reference state

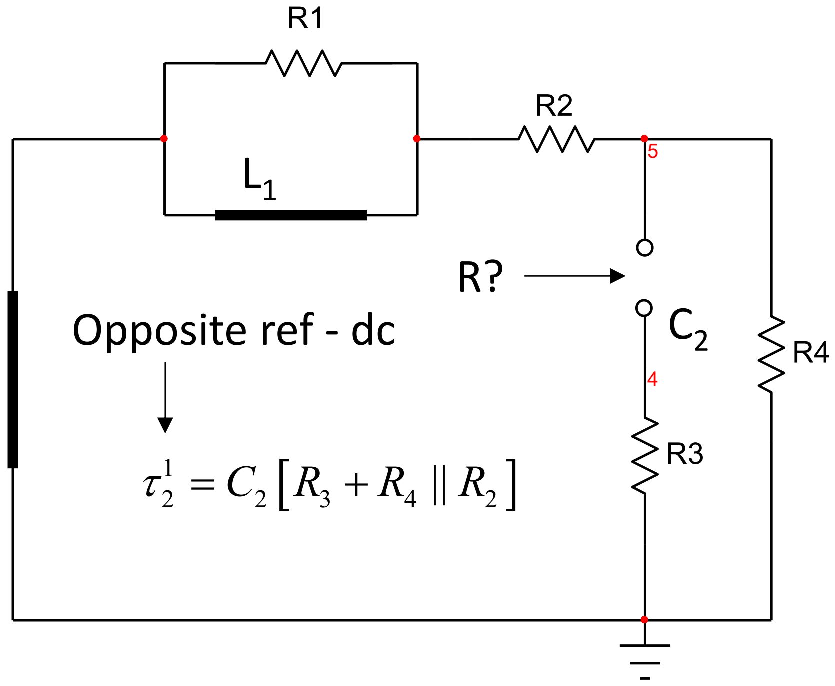


$$H_{INF} = \frac{R_3 \parallel R_4}{R_3 \parallel R_4 + R_1 + R_2}$$



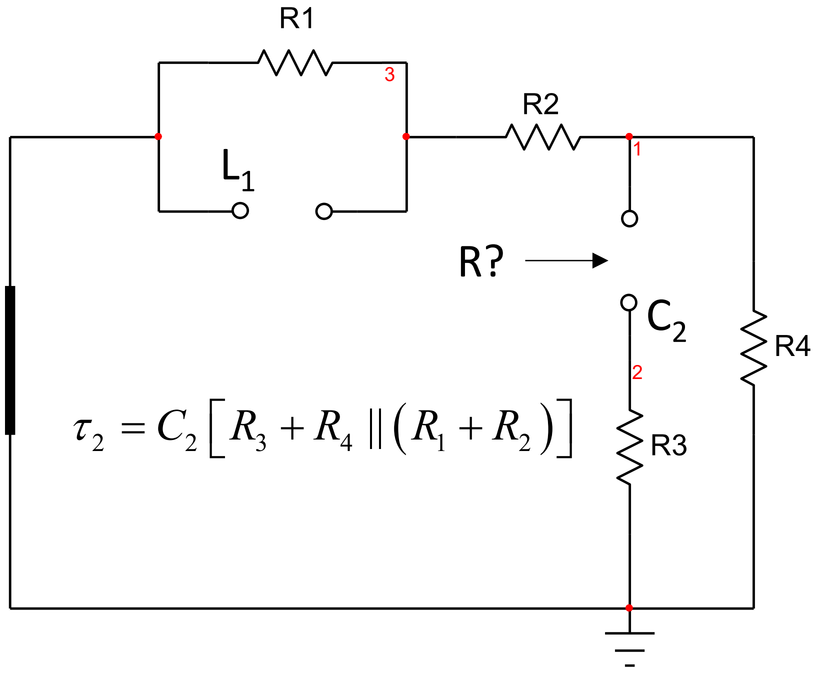
$$\tau_1 = \frac{L_1}{R_1 \| \left(R_2 + R_4 \| R_3\right)}$$

In this case, C_2 is in its reference state which is a short.



$$\tau_2^1 = C_2\left[R_3 + R_4 \| R_2\right]$$

In this mode, L_1 is in <u>the opposite</u> of its reference state (which is a short).



$$\tau_2 = C_2\left[R_3 + R_4 \| \left(R_1 + R_2\right)\right]$$

In this case, L_1 is in its reference state which is open.

$$b_1 = \frac{1}{\tau_1} + \frac{1}{\tau_2} \quad b_2 = \frac{1}{\tau_1 \tau_2^1}$$

$$D(s) = 1 + \frac{b_1}{s} + \frac{b_2}{s^2} = 1 + s\left(\frac{1}{\tau_1} + \frac{1}{\tau_2}\right) + \frac{1}{\tau_1 \tau_2^1 s^2} = 1 + \frac{\omega_0}{sQ} + \left(\frac{\omega_0}{s}\right)^2$$

$$Q = \frac{\sqrt{b_2}}{b_1} \quad \omega_0 = \sqrt{b_2}$$

The definitions for b_i and a_i supersede the ones given in the starting 2nd-order expression.

The zeroes are the same than the ones found by inspection but they factor differently to account for the new format. They are identical in position but the numerator is now factored with inverted zeroes:

$$N(s) = \left(1 + \frac{\omega_{z_1}}{s}\right)\left(1 + \frac{\omega_{z_2}}{s}\right)$$

The final 2nd-order transfer function with a high-frequency leading term is expressed as:

$$H(s) = H_{INF} \frac{\left(1 + \frac{\omega_{z_1}}{s}\right)\left(1 + \frac{\omega_{z_2}}{s}\right)}{1 + \frac{\omega_0}{sQ} + \left(\frac{\omega_0}{s}\right)^2}$$

In this expression, Q and ω_0 are those determined above and differ from the ones we have found earlier.

$$H_{inf} := \frac{R_3 \parallel R_4}{R_3 \parallel R_4 + R_1 + R_2} \qquad 20\cdot\log\left(H_{inf}\right) = -61.008 \quad \text{dB}$$

$$\tau_{1a} := \frac{L_1}{R_1 \parallel \left(R_2 + R_4 \parallel R_3\right)} = 0.109\cdot\mu s$$

$$\tau_{2a} := C_2\cdot\left[R_3 + R_4 \parallel \left(R_2 + R_1\right)\right] = 48.826\cdot\mu s$$

$$\tau_{12a} := C_2\cdot\left(R_3 + R_4 \parallel R_2\right) = 34.333\cdot\mu s$$

$$D_{1a}(s) := 1 + \left(\frac{1}{\tau_{1a}} + \frac{1}{\tau_{2a}}\right)\cdot\frac{1}{s} + \left(\frac{1}{\tau_{1a}\cdot\tau_{12a}}\right)\cdot\frac{1}{s^2} \qquad N_{1a}(s) := \left(1 + \frac{\omega_{z1}}{s}\right)\cdot\left(1 + \frac{\omega_{z2}}{s}\right)$$

$$b_{1a} := \frac{1}{\tau_{1a}} + \frac{1}{\tau_{2a}} \qquad b_{2a} := \frac{1}{\tau_{1a}\cdot\tau_{12a}}$$

$$Q_a := \frac{\sqrt{b_{2a}}}{b_{1a}} = 0.056 \qquad \omega_{0a} := \sqrt{b_{2a}} \qquad f_{0a} := \frac{\omega_{0a}}{2\cdot\pi} = 82.26\cdot\text{kHz}$$

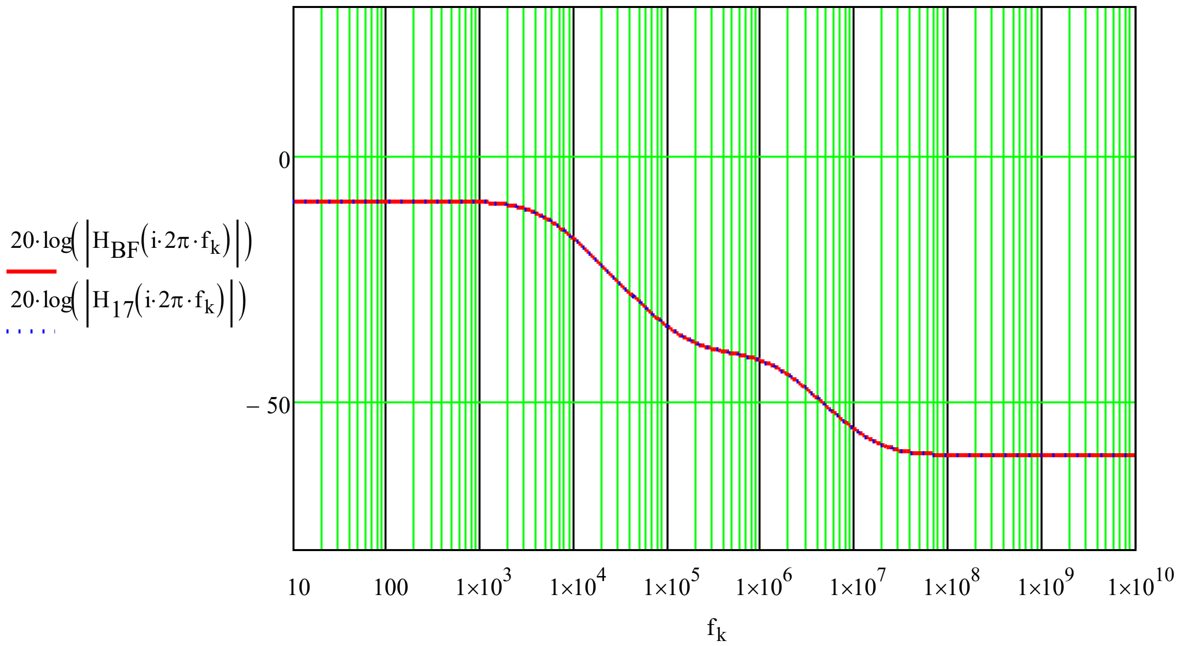
$$D_{2a}(s) := 1 + \frac{\omega_{0a}}{s\cdot Q_a} + \left(\frac{\omega_{0a}}{s}\right)^2$$

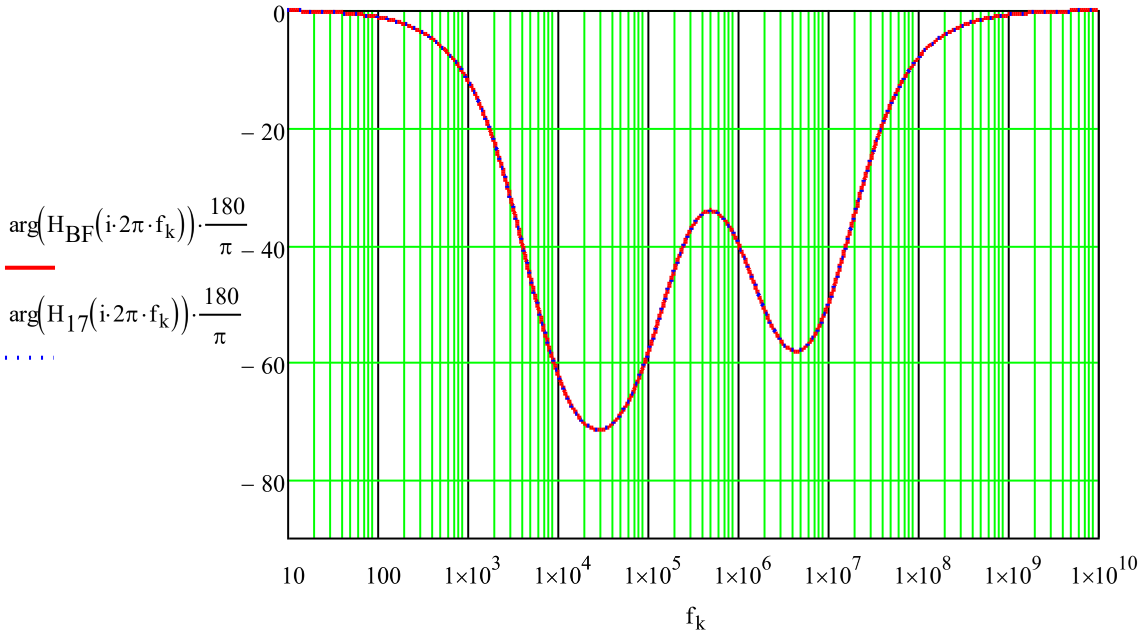
$$H_{16}(s) := H_{inf}\cdot\frac{\left(1 + \frac{\omega_{z1}}{s}\right)\cdot\left(1 + \frac{\omega_{z2}}{s}\right)}{1 + \frac{b_{1a}}{s} + \frac{b_{2a}}{s^2}}$$

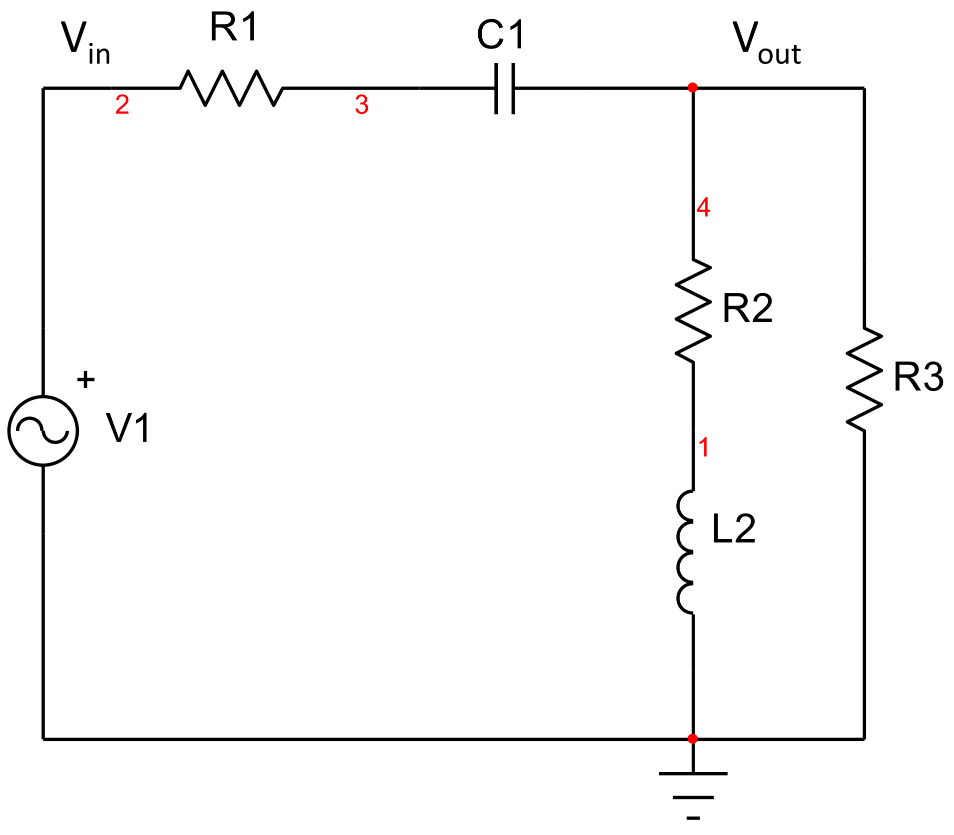
$$H_{18}(s) := H_{inf}\cdot\frac{N_{1a}(s)}{D_{1a}(s)}$$

$$H_{15}(s) := H_{inf}\cdot\frac{\left(1 + \frac{\omega_{z1}}{s}\right)\cdot\left(1 + \frac{\omega_{z2}}{s}\right)}{1 + \left(\frac{1}{\tau_{1a}} + \frac{1}{\tau_{2a}}\right)\cdot\frac{1}{s} + \left(\frac{1}{\tau_{1a}}\cdot\frac{1}{\tau_{12a}}\right)\cdot\frac{1}{s^2}}$$

$$H_{17}(s) := H_{inf}\cdot\frac{\left(1 + \frac{\omega_{z1}}{s}\right)\cdot\left(1 + \frac{\omega_{z2}}{s}\right)}{1 + \frac{\omega_{0a}}{s\cdot Q_a} + \left(\frac{\omega_{0a}}{s}\right)^2}$$



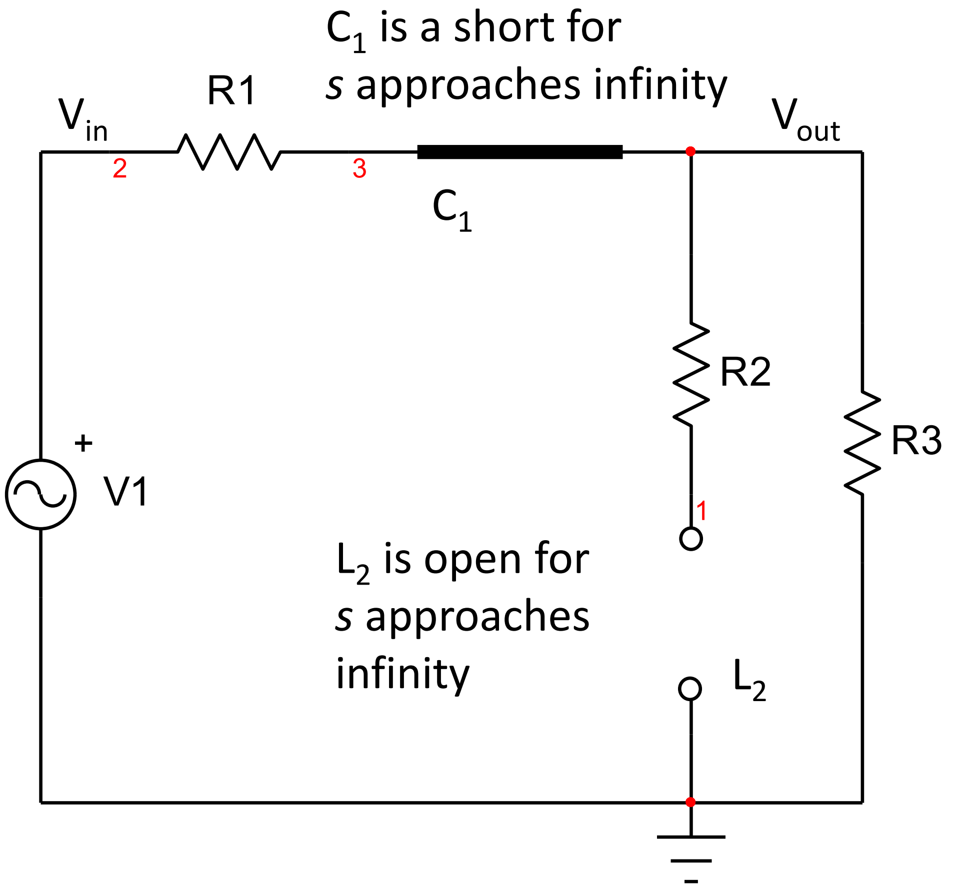




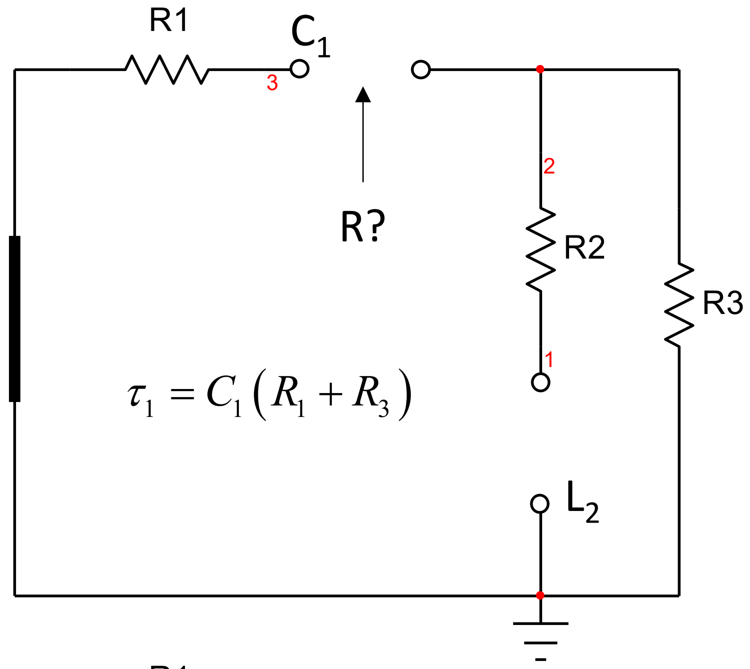
Reference state:
C_1 is a short.
Inductance L_2 is open

In this circuit, we can see that the dc gain is equal to zero. However, the gain when *s* approaches infinity exists:

$$H_{INF} = \frac{R_3}{R_1 + R_3}$$

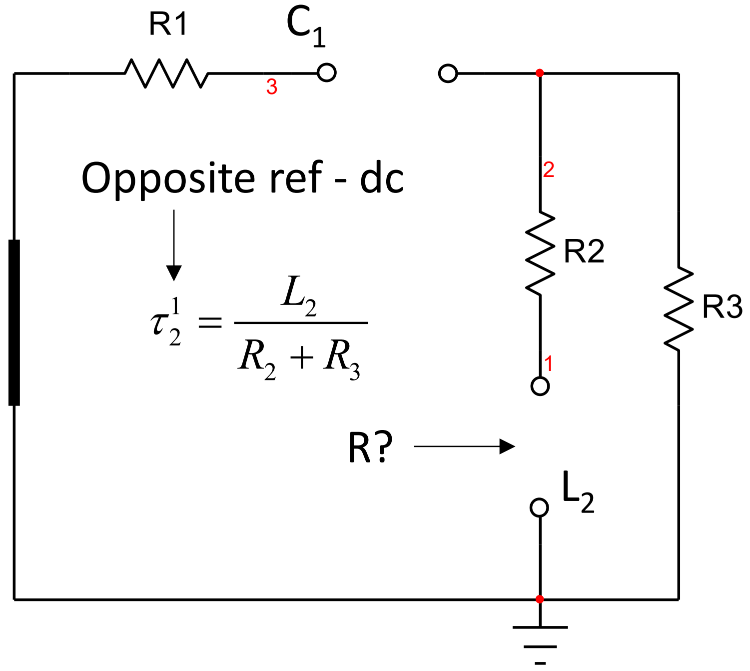


Determine tau1:



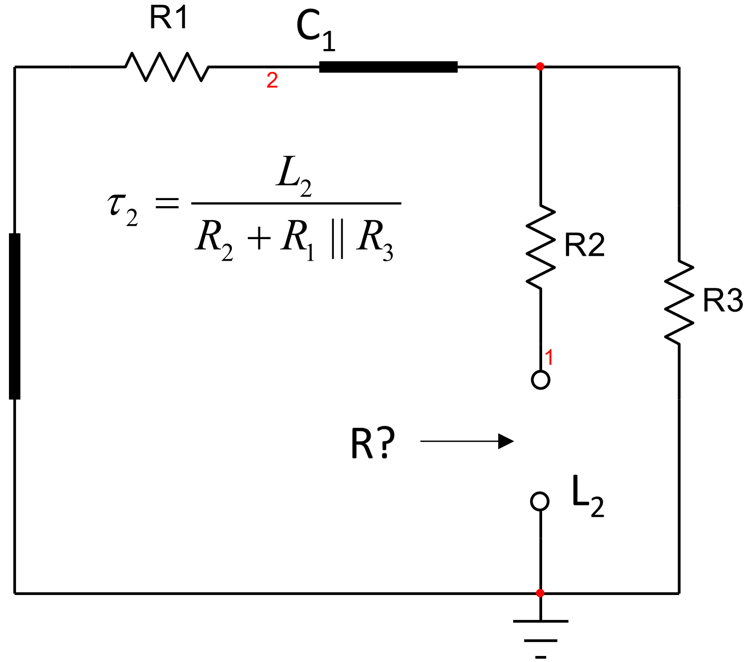
$$\tau_1 = C_1\left(R_1 + R_3\right)$$

In this case, L_2 is in its reference state which is an open circuit.



$$\tau_2^1 = \frac{L_2}{R_2 + R_3}$$

Determine tau2:



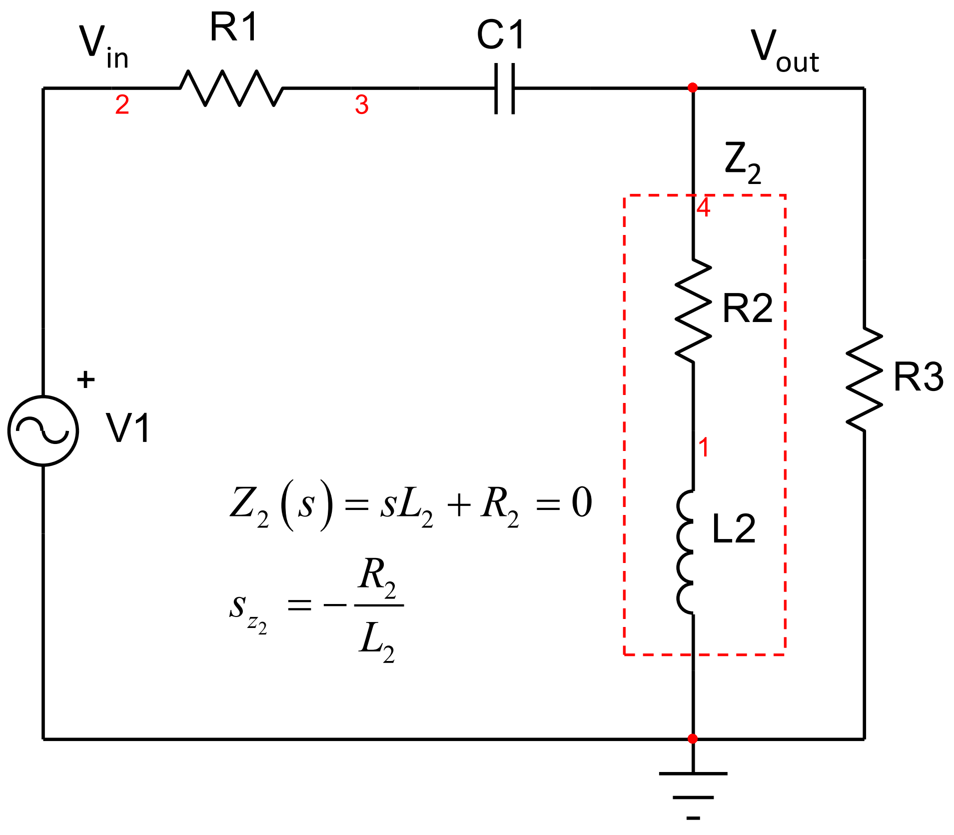
$$\tau_2 = \frac{L_2}{R_2 + R_1 \| R_3}$$

In this case, C_1 is in its reference state which is a short.

In this mode, C_1 is in <u>the opposite</u> of its reference state (which is an open circuit).

$$b_1 = \frac{1}{\tau_1} + \frac{1}{\tau_2} = \frac{1}{C_1\left(R_1 + R_3\right)} + \frac{R_2 + R_1 \| R_3}{L_2}$$

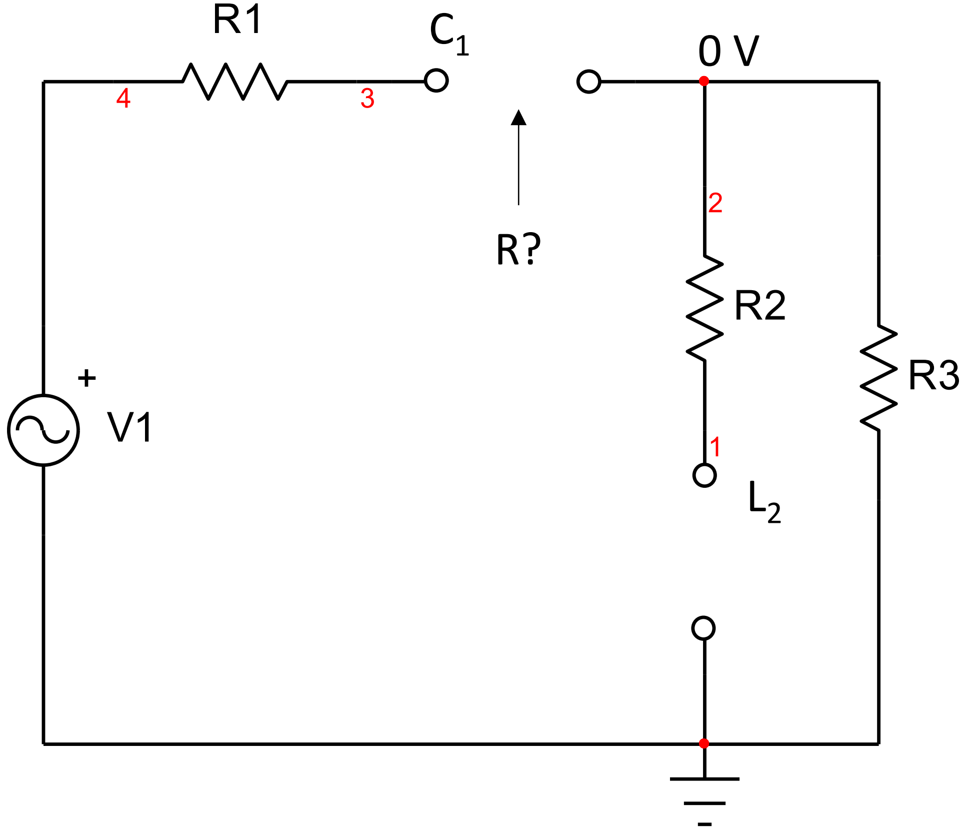
$$b_2 = \frac{1}{\tau_1 \tau_2^1} = \frac{1}{C_1\left(R_1 + R_3\right)\dfrac{L_2}{R_2 + R_3}} = \frac{1}{C_1 L_2}\frac{R_2 + R_3}{R_1 + R_3}$$



$$Z_2(s) = sL_2 + R_2 = 0$$

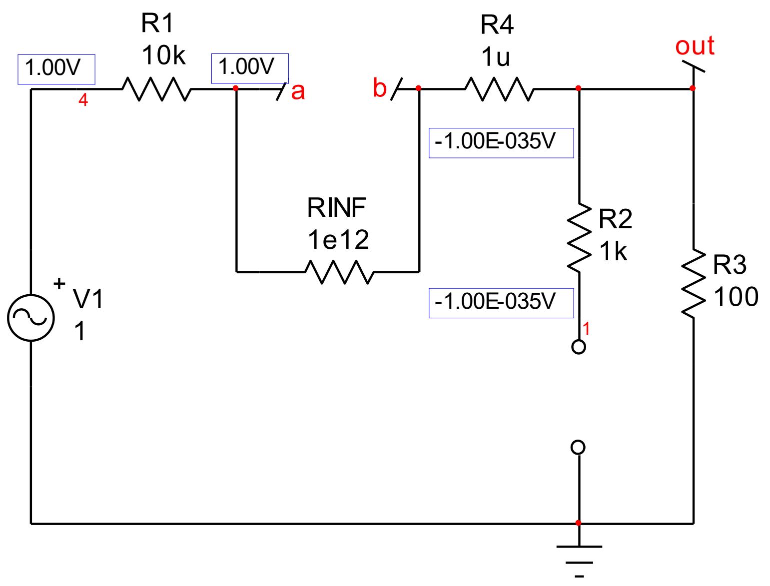
$$s_{z_2} = -\frac{R_2}{L_2}$$

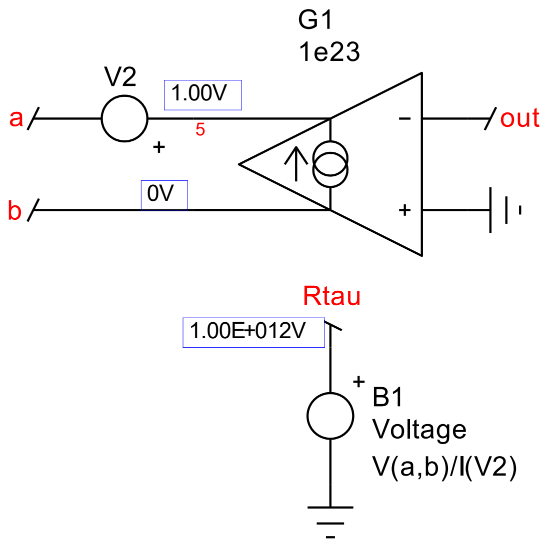
Apply NDI to C_1, keeping V_{out} to 0 V ac.



In this case, there is just one zero which is determined by inspection. The zero at the origin is merged with the inverted poles and zeroes. But we can perform the NDI to confirm this point.

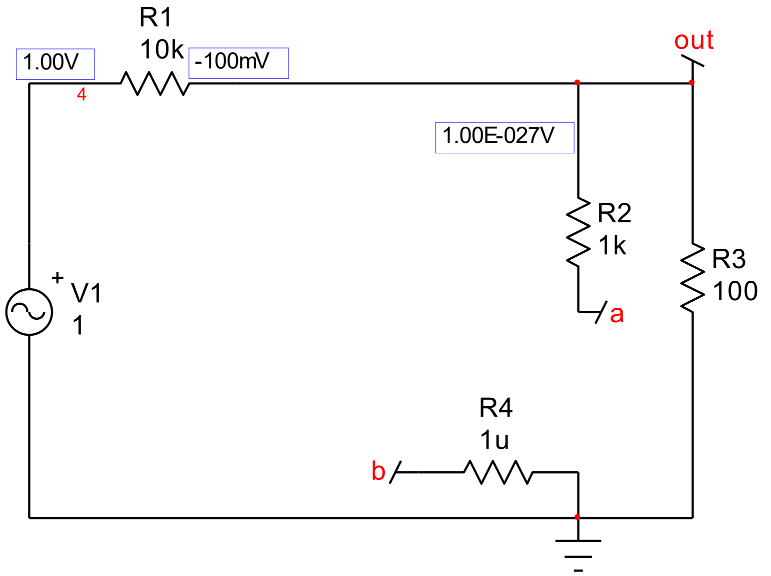
In this case, the resistance offered by the connecting terminals is infinite.

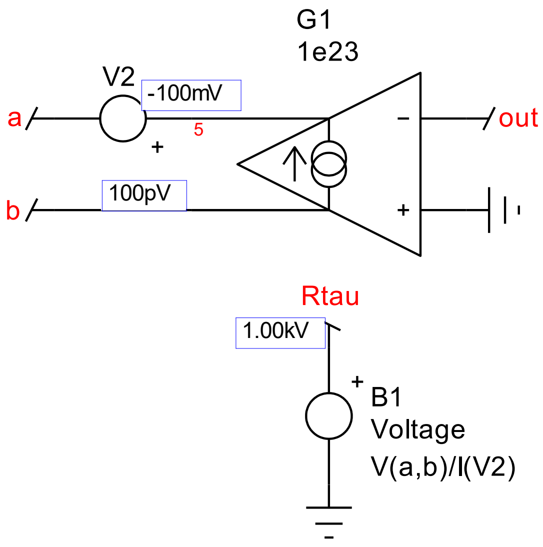


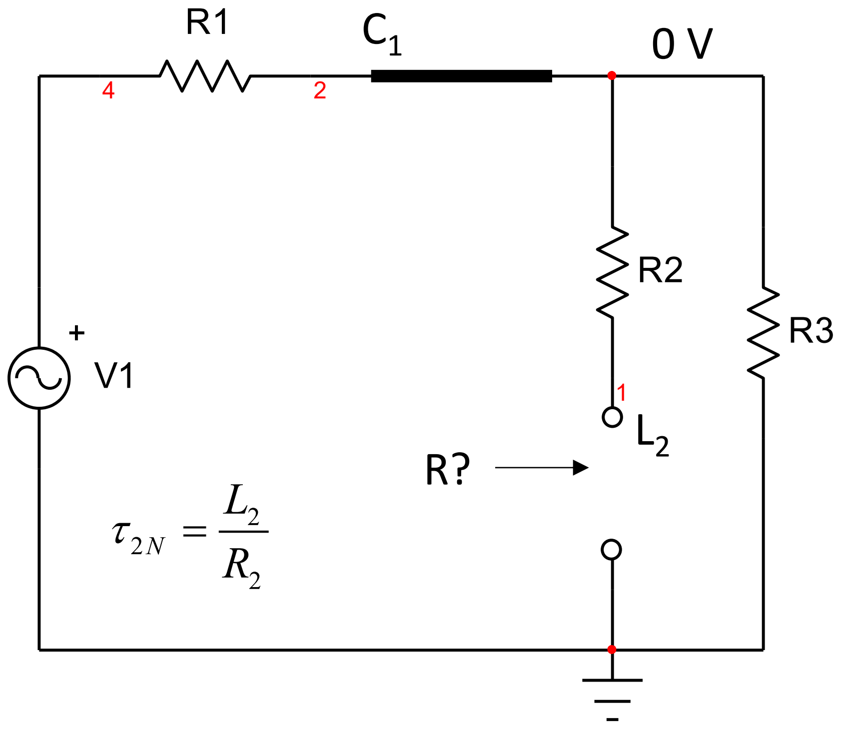


SPICE NDI confirms an infinite time constant that I make finite with resistance R_{INF}.

$$\tau_{1N} = C_1 R_{INF}$$

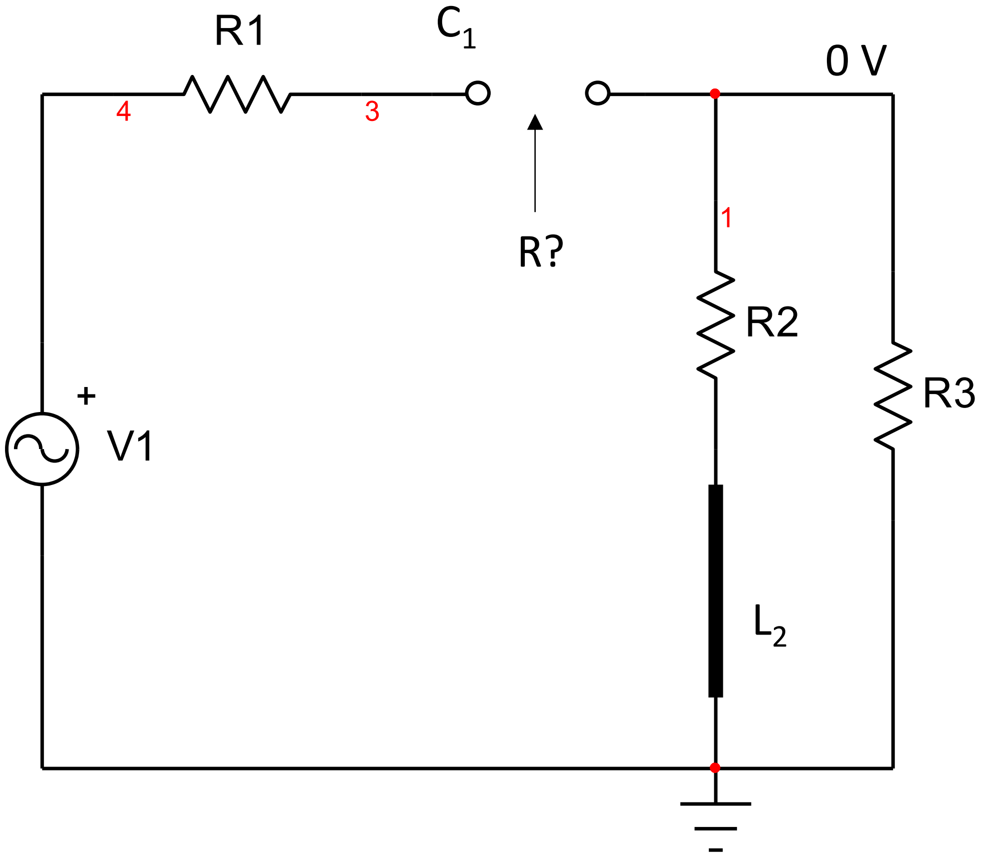


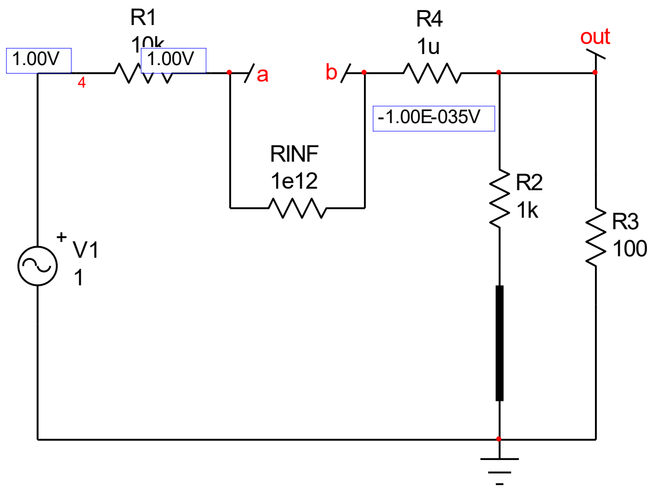


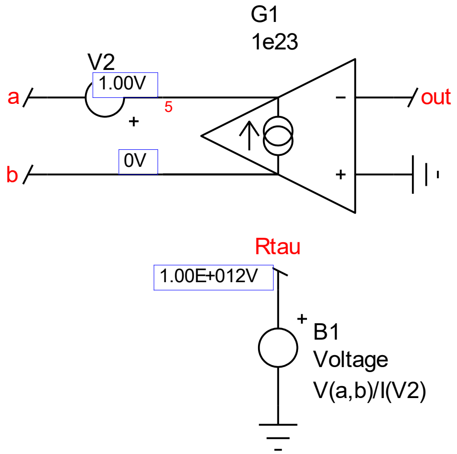


Confirmed by operating point

$$a_1 = \frac{1}{\tau_{1N}} + \frac{1}{\tau_{2N}} = \frac{1}{C_1 R_{INF}} + \frac{R_2}{L_2} = \frac{R_2}{L_2}$$







Opposite ref – short for L_2

$$\tau_{1N}^{2} = C_1 R_{INF}$$

$$a_2 = \frac{1}{\tau_{2N}\tau_{1N}^{2}} = \frac{1}{\frac{L_2}{R_2} C_1 R_{INF}} = 0$$

$$N(s) = 1 + \frac{a_1}{s} + \cancel{\frac{a_2}{s}} = 1 + \frac{R_2}{L_2 s} = 1 + \frac{\omega_z}{s}$$

$$b_1 = \frac{1}{\tau_1} + \frac{1}{\tau_2} = \frac{1}{C_1\left(R_1 + R_3\right)} + \frac{R_2 + R_1 \parallel R_3}{L_2}$$

$$b_2 = \frac{1}{\tau_1 \tau_2^1} = \frac{1}{C_1\left(R_1 + R_3\right)\frac{L_2}{R_2 + R_3}} = \frac{1}{C_1 L_2}\frac{R_2 + R_3}{R_1 + R_3}$$

$$D(s) = 1 + \frac{b_1}{s} + \frac{b_2}{s^2} = 1 + s\left(\frac{1}{\tau_1} + \frac{1}{\tau_2}\right) + \frac{1}{\tau_1 \tau_2^1 s^2} = 1 + \frac{\omega_0}{sQ} + \left(\frac{\omega_0}{s}\right)^2$$

$$Q = \frac{\sqrt{b_2}}{b_1} \quad \omega_0 = \sqrt{b_2}$$

$$N(s) = 1 + \frac{a_1}{s} + \frac{a_2}{s^2} = 1 + s\left(\frac{1}{\tau_{1N}} + \frac{1}{\tau_{2N}}\right) + \frac{1}{\tau_{1N}\tau_{2N}^1 s^2}$$

$$H(s) = H_{INF}\frac{N(s)}{D(s)} = H_{INF}\frac{1 + \frac{s}{\omega_z}}{1 + \frac{\omega_0}{sQ} + \left(\frac{\omega_0}{s}\right)^2}$$

$$H_{22}(s) := \frac{R_3}{R_1 + R_3} \cdot \frac{1 + \frac{R_2}{s \cdot L_2}}{1 + \left[\frac{1}{C_1 \cdot (R_1 + R_3)} + \frac{1}{\frac{L_2}{R_2 + R_1 \parallel R_3}}\right] \cdot \frac{1}{s} + \left[\frac{R_2 + R_3}{C_1 \cdot (R_1 + R_3) \cdot L_2}\right] \cdot \frac{1}{s^2}}$$

$\|(x,y) := \frac{x \cdot y}{x+y}$ $\quad R_{INF} := 10^{23}\Omega$

$R_1 := 10k\Omega \quad R_2 := 1k\Omega \quad R_3 := 22k\Omega \quad C_1 := 0.1\mu F \quad L_2 := 10\mu H$

$\tau_1 := C_1 \cdot (R_1 + R_3) = 3.2 \cdot ms$

$H_{INF} := \frac{R_3}{R_1 + R_3} \quad 20 \cdot \log(H_{INF}) = -3.255$

$\tau_2 := \frac{L_2}{R_2 + R_1 \| R_3} = 1.27 \times 10^{-3} \cdot \mu s$

$\tau_{12} := \frac{L_2}{R_2 + R_3} = 4.348 \times 10^{-4} \cdot \mu s \quad \omega_z := \frac{R_2}{L_2}$

$\tau_{1N} := C_1 \cdot R_{INF} \quad \tau_{2N} := \frac{L_2}{R_2} \quad \tau_{21N} := C_1 \cdot R_{INF}$

$D_1(s) := 1 + \left(\frac{1}{\tau_1} + \frac{1}{\tau_2}\right) \cdot \frac{1}{s} + \left(\frac{1}{\tau_1 \cdot \tau_{12}}\right) \cdot \frac{1}{s^2}$

$N_1(s) := 1 + \left(\frac{1}{\tau_{1N}} + \frac{1}{\tau_{2N}}\right) \cdot \frac{1}{s} + \left(\frac{1}{\tau_{2N} \cdot \tau_{21N}}\right) \cdot \frac{1}{s^2}$

$b_1 := \frac{1}{\tau_1} + \frac{1}{\tau_2} \quad b_2 := \frac{1}{\tau_1 \cdot \tau_{12}} = 7.188 \times 10^{11} \frac{1}{s^2}$

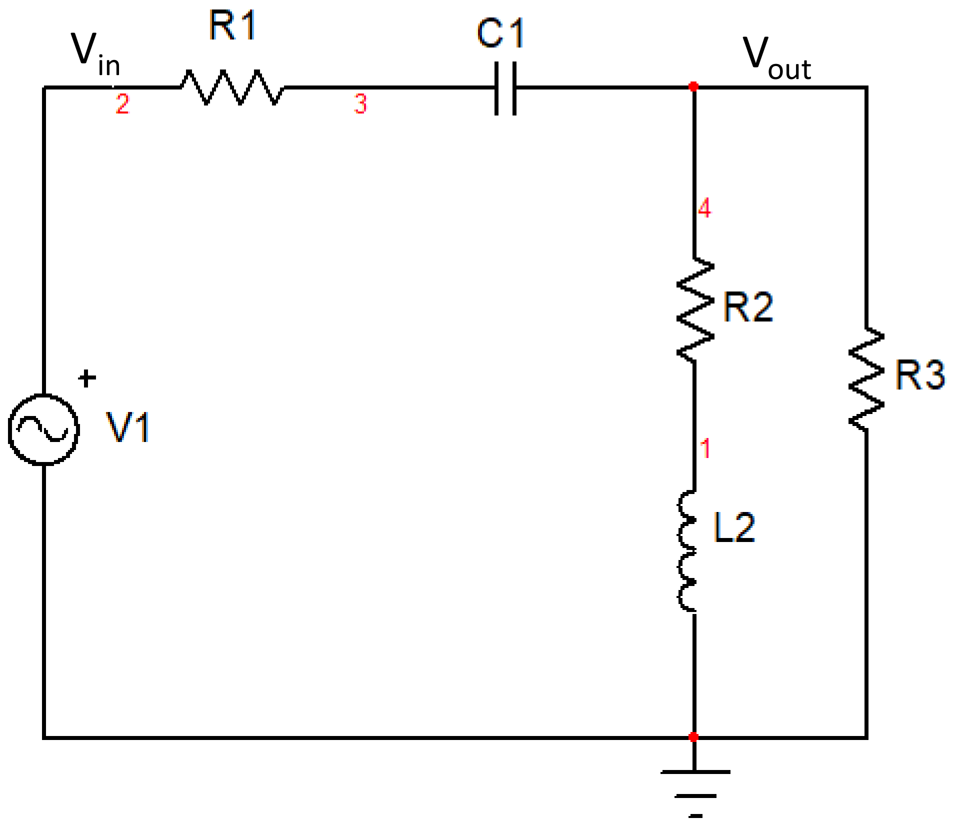
$a_1 := \frac{1}{\tau_{1N}} + \frac{1}{\tau_{2N}} \quad a_2 := \frac{1}{\tau_{2N} \cdot \tau_{21N}}$

$N_3(s) := 1 + \frac{a_1}{s} + \frac{a_2}{s^2} \quad D_3(s) := 1 + \frac{b_1}{s} + \frac{b_2}{s^2}$

$Q := \frac{\sqrt{b_2}}{b_1} = 1.077 \times 10^{-3} \quad \omega_0 := \sqrt{b_2} \quad f_0 := \frac{\omega_0}{2 \cdot \pi} = 134.93 \cdot kHz$

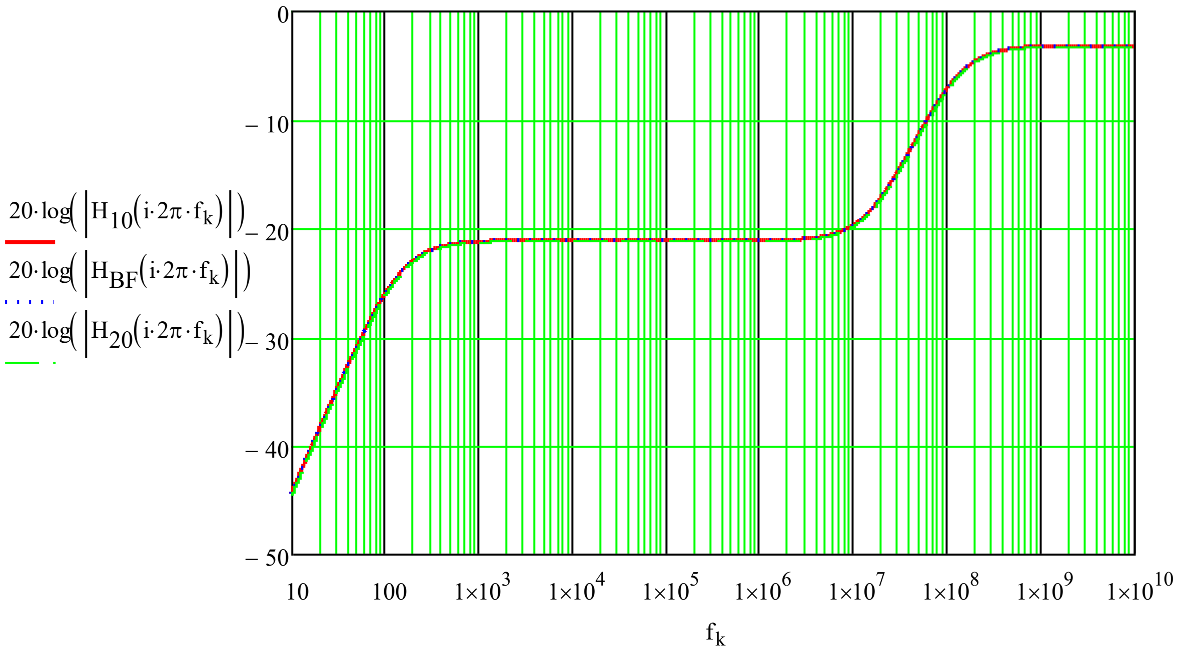
$D_4(s) := 1 + \frac{\omega_0}{s \cdot Q} + \left(\frac{\omega_0}{s}\right)^2 \quad H_{10}(s) := H_{INF} \cdot \frac{N_1(s)}{D_1(s)}$

$$H_{20}(s) := H_{INF} \cdot \frac{1 + \frac{\omega_z}{s}}{1 + \frac{\omega_0}{s \cdot Q} + \left(\frac{\omega_0}{s}\right)^2}$$

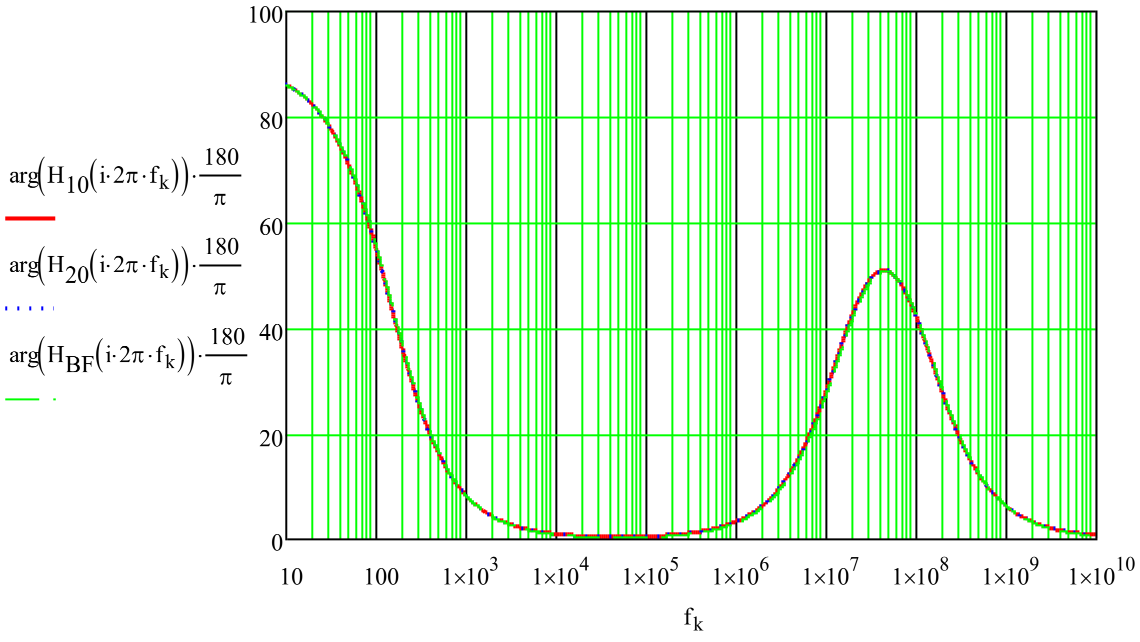


Raw brute-force TF:

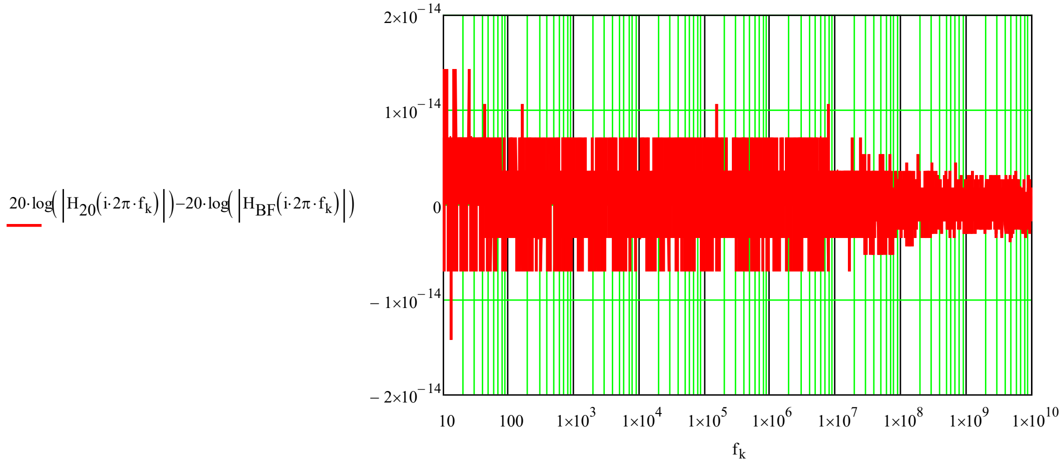
$$H_{BF}(s) := \frac{\left[R_3 \| (R_2 + s \cdot L_2)\right]}{R_1 + \frac{1}{s \cdot C_1} + \left[R_3 \| (R_2 + s \cdot L_2)\right]}$$



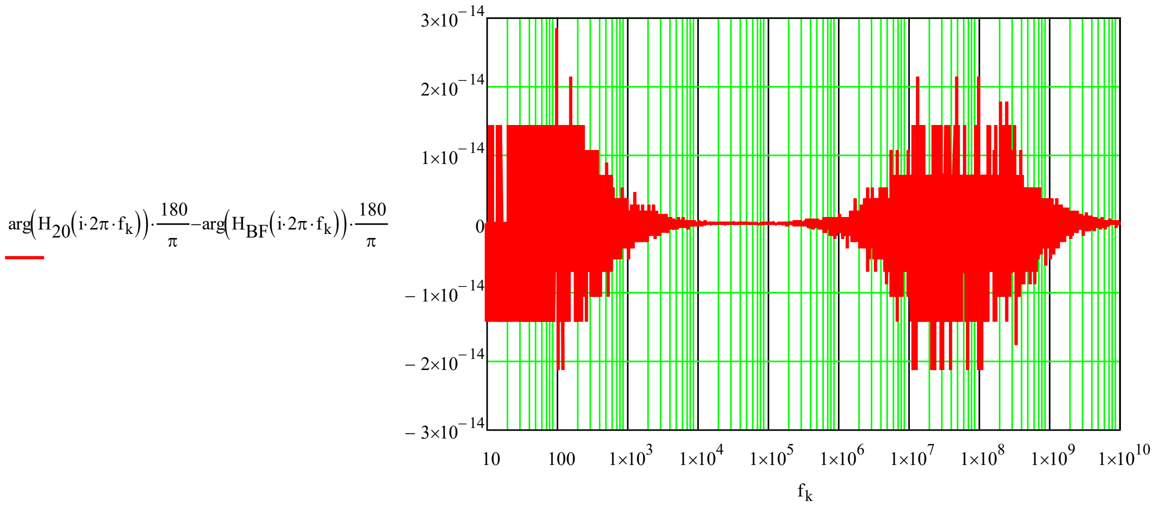
20·log(|H10(i·2π·fk)|)
20·log(|HBF(i·2π·fk)|)
20·log(|H20(i·2π·fk)|)
0
−10
−20
−30
−40
−50
10
100
1×10^3
1×10^4
1×10^5
1×10^6
1×10^7
1×10^8
1×10^9
1×10^10
fk



arg(H10(i·2π·fk))·180/π
arg(H20(i·2π·fk))·180/π
arg(HBF(i·2π·fk))·180/π
100
80
60
40
20
0
10
100
1×10^3
1×10^4
1×10^5
1×10^6
1×10^7
1×10^8
1×10^9
1×10^10
fk



20·log(|H20(i·2π·fk)|)−20·log(|HBF(i·2π·fk)|)
2×10^−14
1×10^−14
0
−1×10^−14
−2×10^−14
10
100
1×10^3
1×10^4
1×10^5
1×10^6
1×10^7
1×10^8
1×10^9
1×10^10
fk



arg(H20(i·2π·fk))·180/π−arg(HBF(i·2π·fk))·180/π
3×10^−14
2×10^−14
1×10^−14
0
−1×10^−14
−2×10^−14
−3×10^−14
10
100
1×10^3
1×10^4
1×10^5
1×10^6
1×10^7
1×10^8
1×10^9
1×10^10
fk

In my 2016 book, I have illustrated how a 2^{nd}-order circuit transfer function could be expressed in four different transfer functions, depending on the various states adopted for the reference state H_{ref}:

Z_1 and Z_2 are both considered for $s = 0$
Z_1 and Z_2 are both considered for $s \to$ infinity
Z_1 is considered for $s = 0$ and Z_2 for $s \to$ infinity
Z_1 is considered for $s \to$ infinity and Z_2 for $s = 0$

For practical reasons, I realized that the first case (all impedances considered for $s = 0$) was the most intuitive and practical for engineers as it represents a natural state in the lab for a dc-biased circuit or when determining an operating bias point in simulation (all caps open and inductors shorted).

In some cases – especially when one or several zeroes at the origin exist (no dc path) – the leading term determined at $s = 0$ is zero. It is therefore possible to factor the original second-order transfer function and have a leading term determined for s approaches infinity instead, using inverted poles and zeroes in this case. These are the examples I have documented in this PPT.

After all, the goal of the FACTs is to swiftly determine transfer functions by breaking down a complicated circuit in smaller and simpler schematic diagrams. To that respect, considering s approaches infinity for all the elements, is a possible option. But if the process remains reasonably simple for a 2^{nd}-order system (you juggle with two energy-storing elements), it seriously complicates with more elements, especially if you mix a combination of reference states for the energy-storing elements.