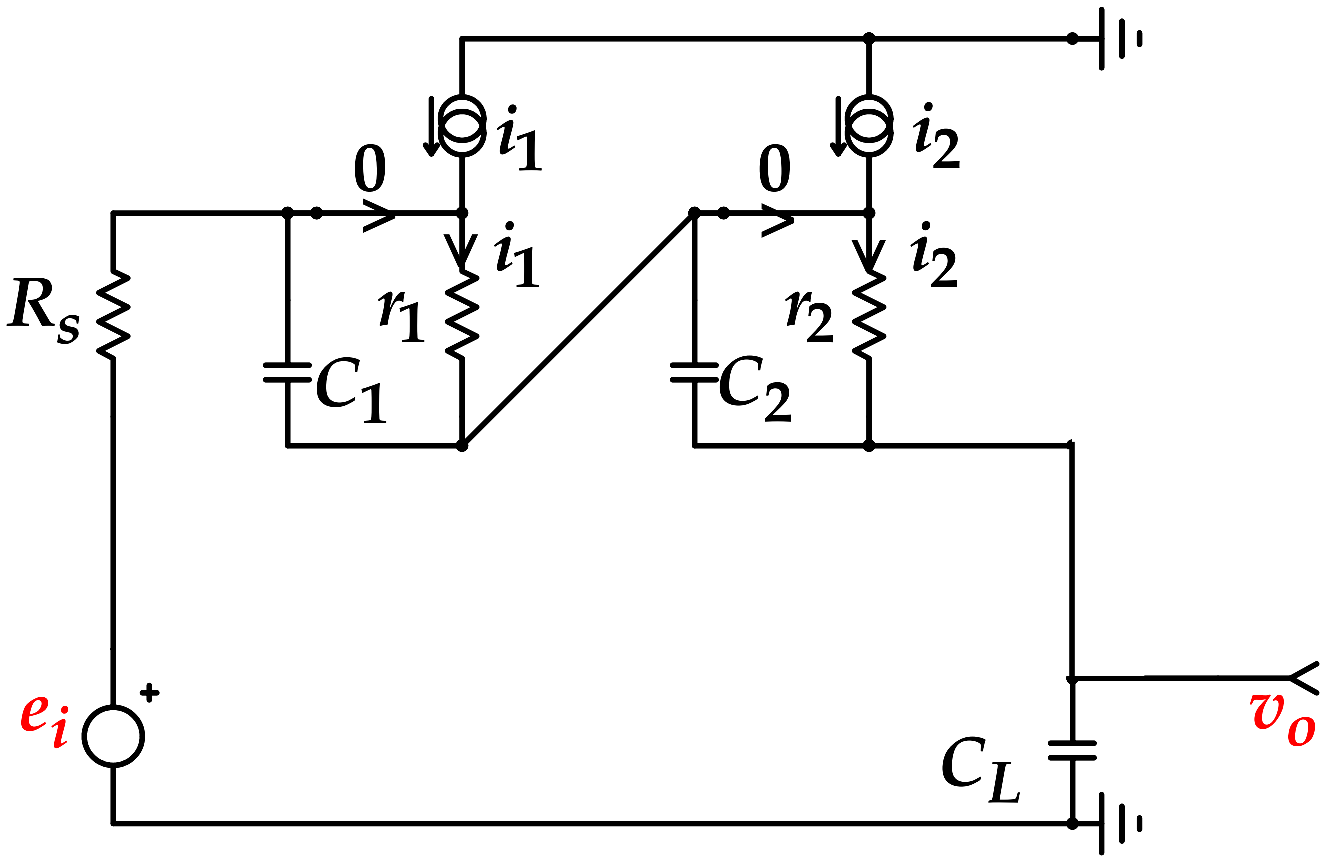
EXAMPLE

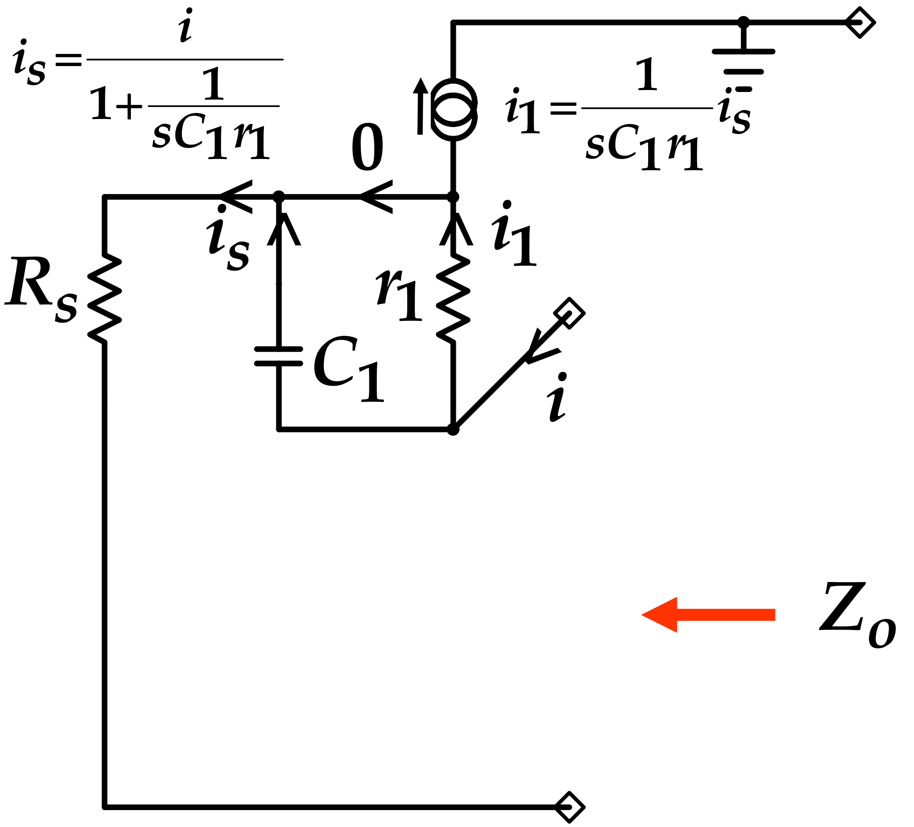
16. A DESIGN SOLUTION TO DARLINGTON FOLLOWER INSTABILITY

Example 3: Darlington Emitter/Source Follower

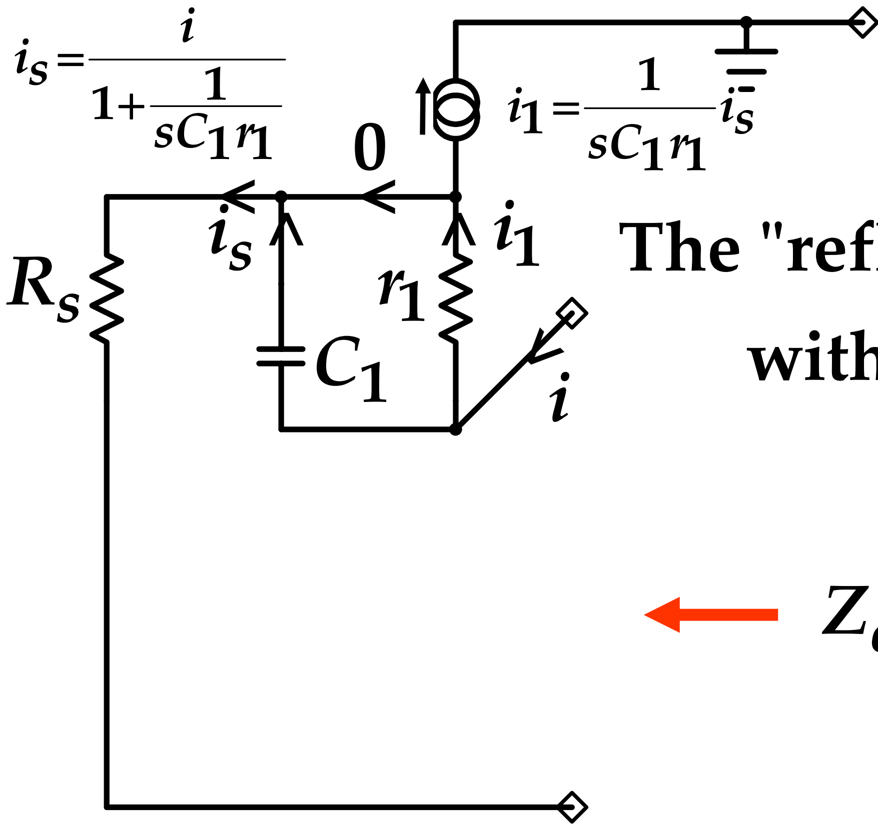
The Darlington Follower is known to be unstable for certain values of load capacitance.

The Design Problem is to select a damping resistance so that the Follower is not only stable, but has a maximum peaking , regardless of the load capacitance.


0
i_1
i_1
r_1
C_1
0
i_2
i_2
r_2
C_2
R_s
e_i
+
C_L
v_o

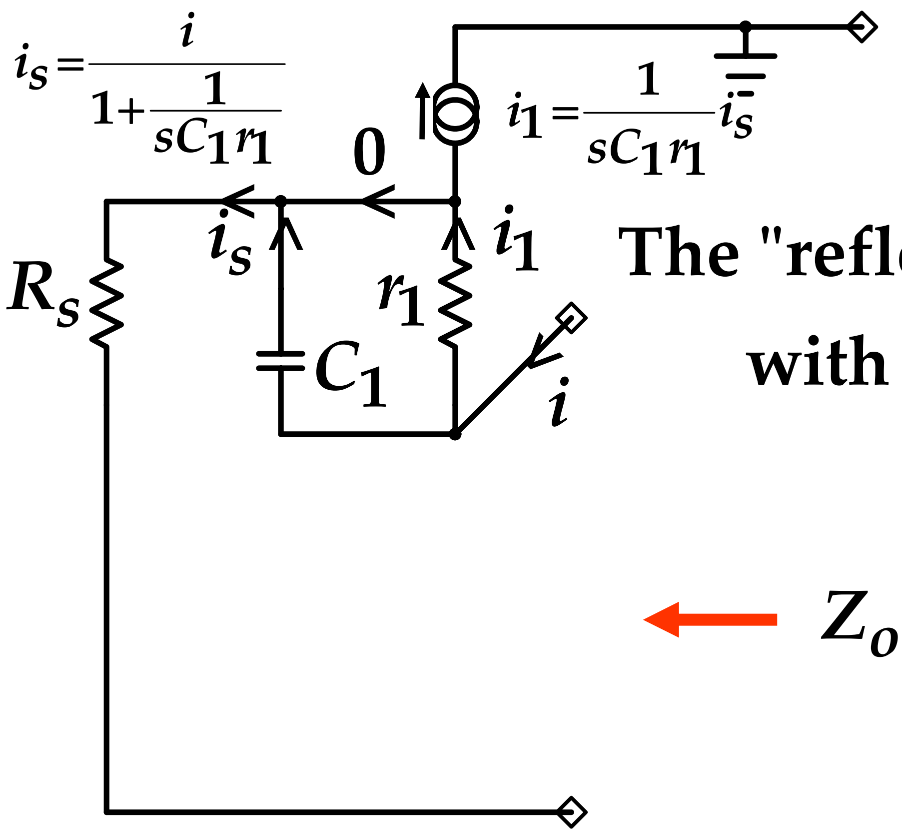


$i_s = \frac{i}{1+\frac{1}{sC_1 r_1}}$
$i_1 = \frac{1}{sC_1 r_1} i_s$
0
i_s
i_1
R_s
r_1
C_1
i
Z_o



The "reflection" process works with effective $\beta_1 = \frac{1}{sC_1 r_1}$:

$$Z_o = \frac{R_s}{1+\beta_1} + r_1 \left\| \frac{1}{sC_1} \right.$$

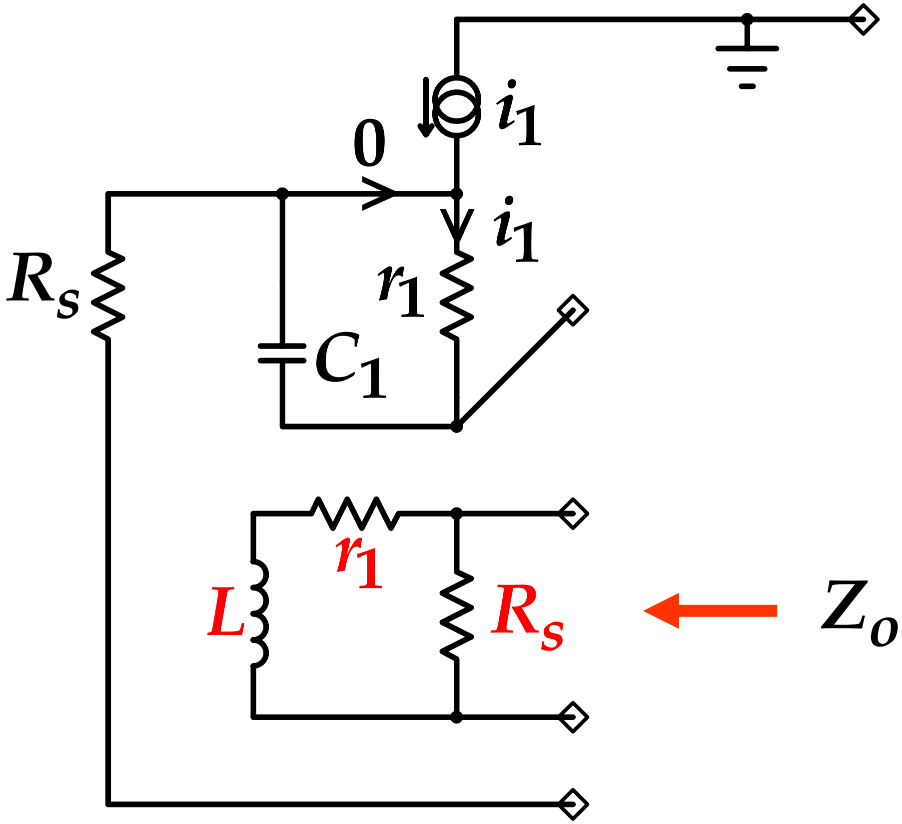


The "reflection" process works with effective $\beta_1 = \frac{1}{sC_1 r_1}$:

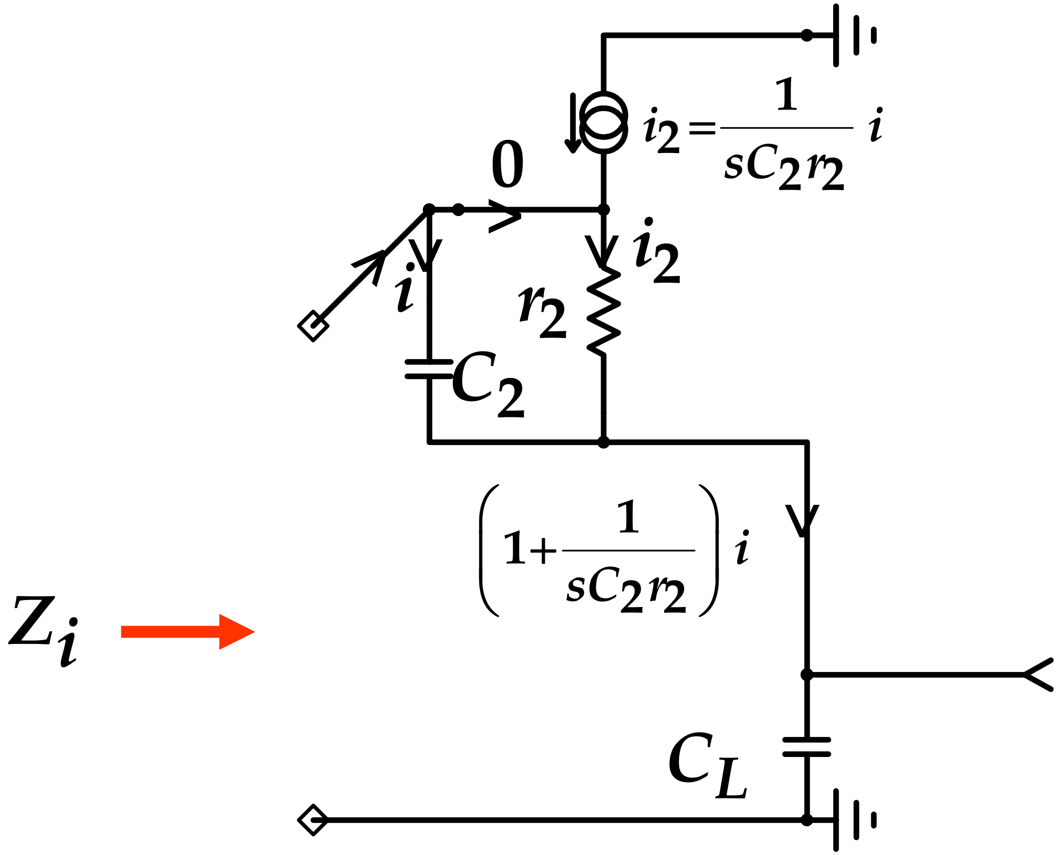
$$Z_o = \frac{R_s}{1+\beta_1} + r_1 \left\| \frac{1}{sC_1} \right.$$

$$Z_o = \frac{R_s + \frac{1}{sC_1}}{1 + \frac{1}{sC_1 r_1}} = \frac{R_s\left(r_1 + sC_1 R_s r_1\right)}{R_s + sC_1 R_s r_1} = \frac{R_s\left(r_1 + sL\right)}{R_s + sL}$$

where $L \equiv C_1 R_s r_1$. **If** $R_s >> r_1$, $Z_o \approx R_s \left\| \left(r_1 + sL\right)\right.$

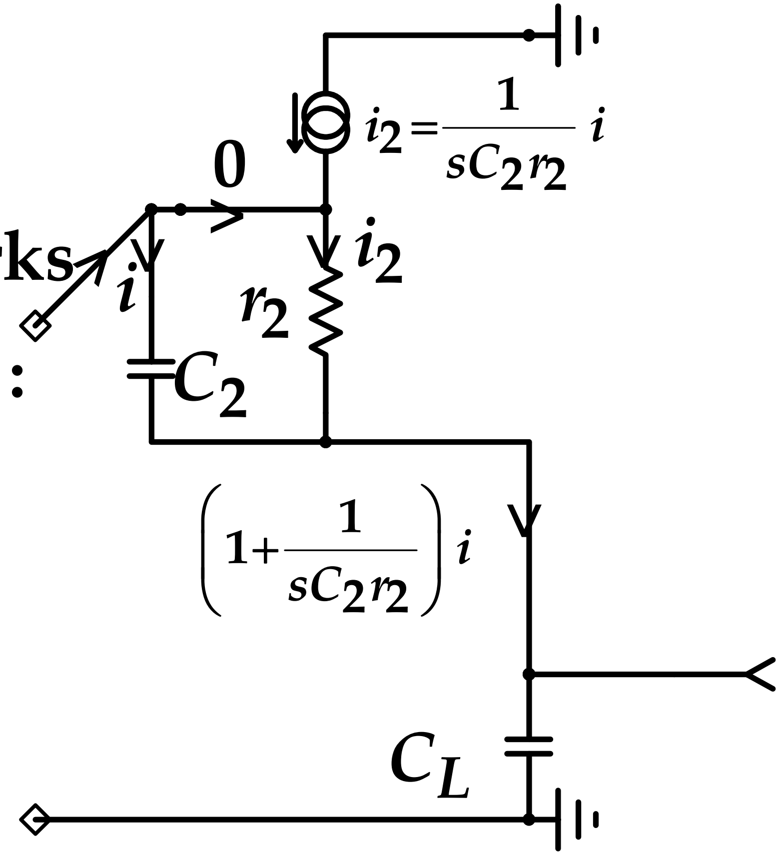


$$Z_o \approx R_s \| (r_1 + sL)$$


Z_i
0
$i_2 = \frac{1}{sC_2 r_2} i$
i
i_2
r_2
C_2
$\left(1+\frac{1}{sC_2 r_2}\right) i$
C_L

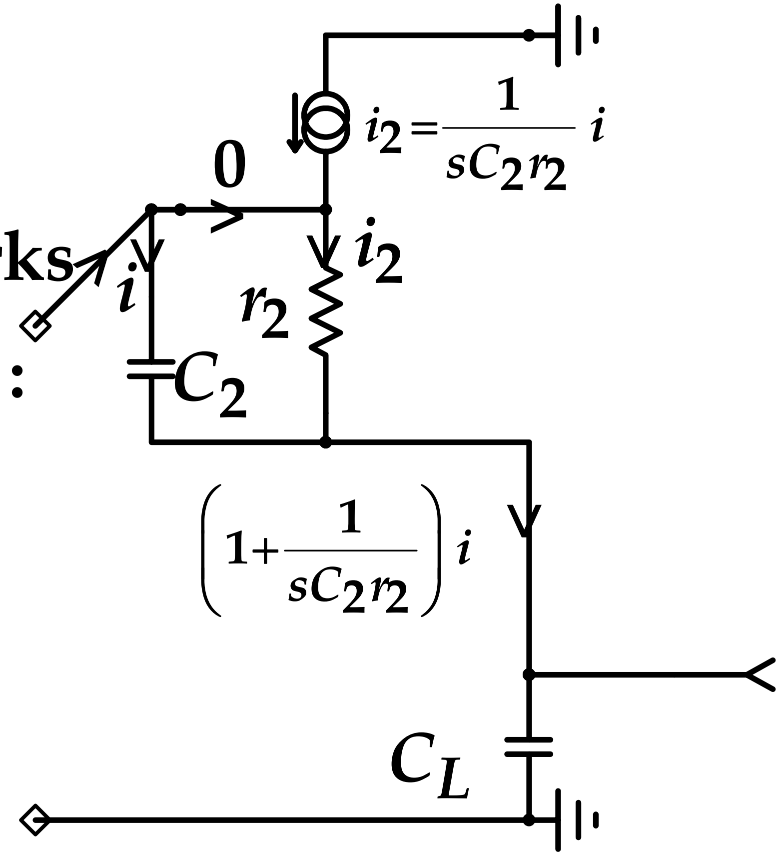
The "reflection" process works with effective $\beta_2 = \frac{1}{sC_2 r_2}$:

$$Z_i = \frac{1}{sC_2} + \frac{1+\beta_2}{sC_L}$$



The "reflection" process works

with effective $\beta_2 = \frac{1}{sC_2 r_2}$ **:**

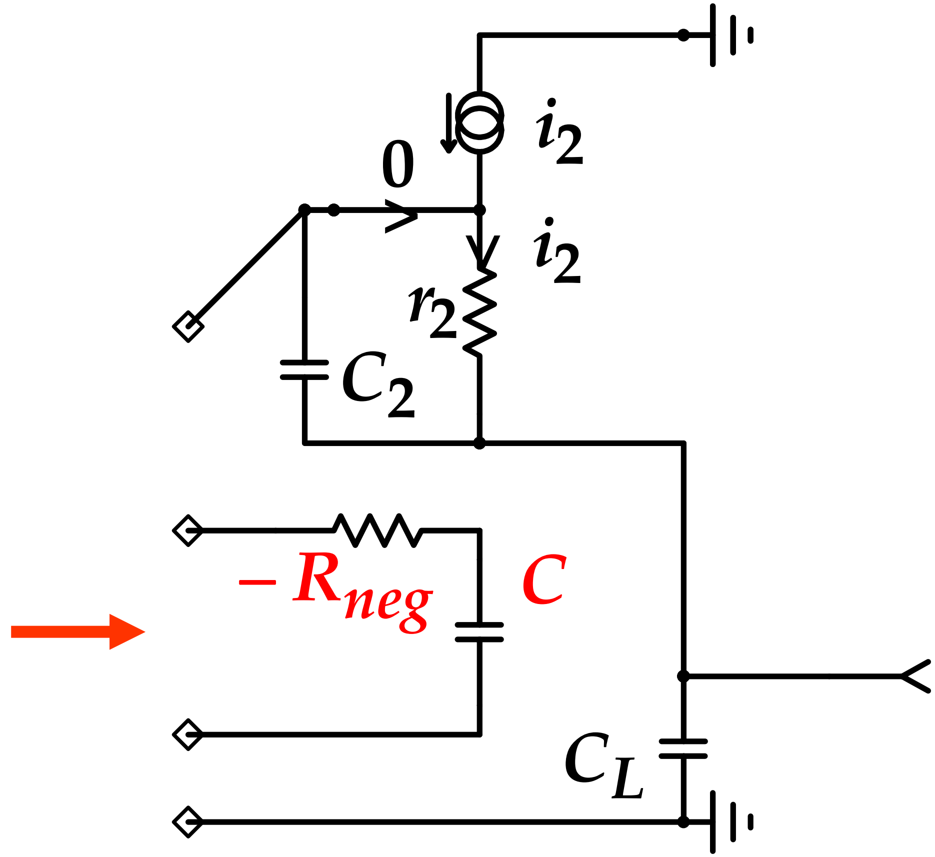


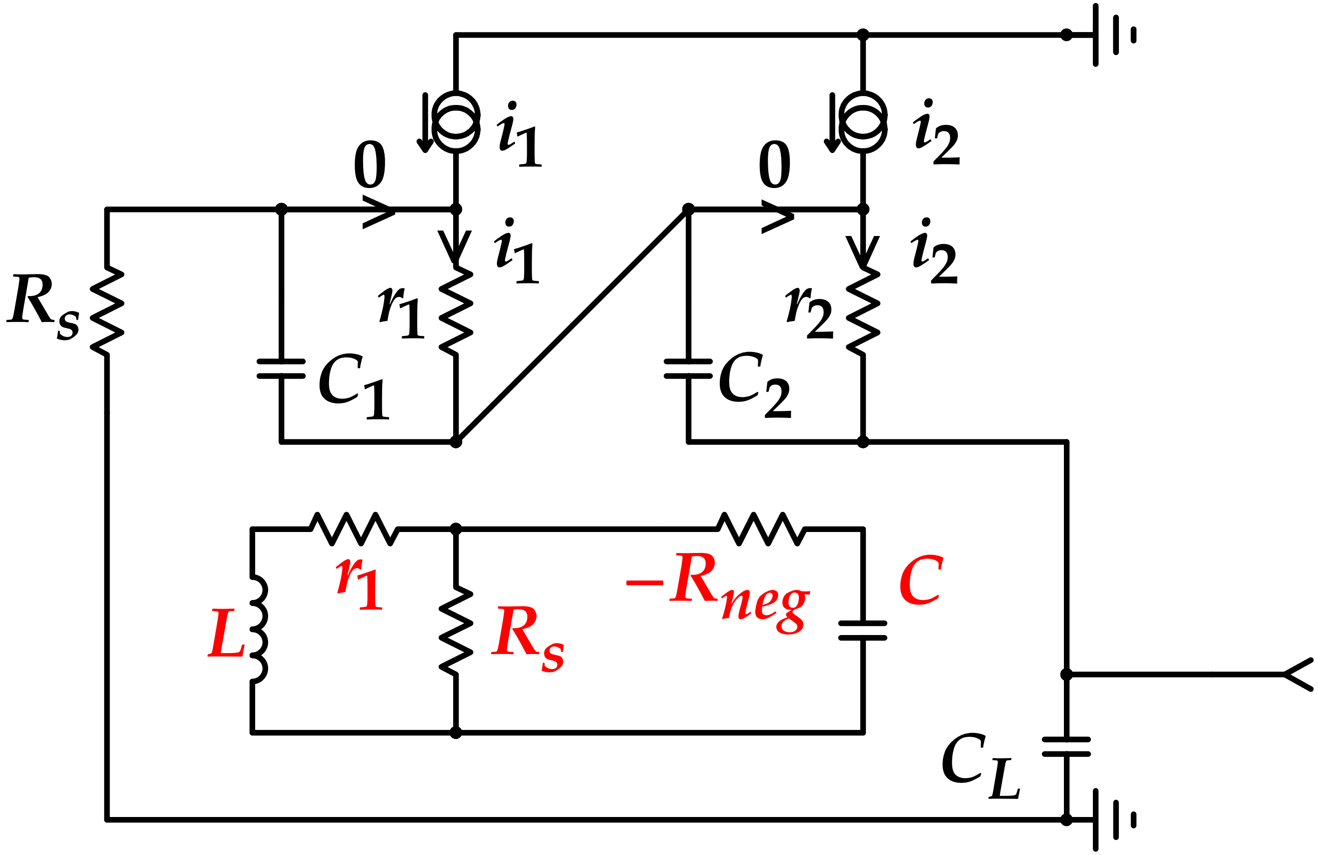
$$Z_i = \frac{1}{sC_2} + \frac{1+\beta_2}{sC_L} \rightarrow$$

$$Z_i = \frac{1}{sC_2} + \frac{1}{sC_L}\left(1 + \frac{1}{sC_2 r_2}\right) = \frac{1}{sC} - R_{neg}$$

where $\frac{1}{C} \equiv \frac{1}{C_2} + \frac{1}{C_L}$ **and** $R_{neg} \equiv \frac{1}{\omega^2 C_2 r_2 C_L}$

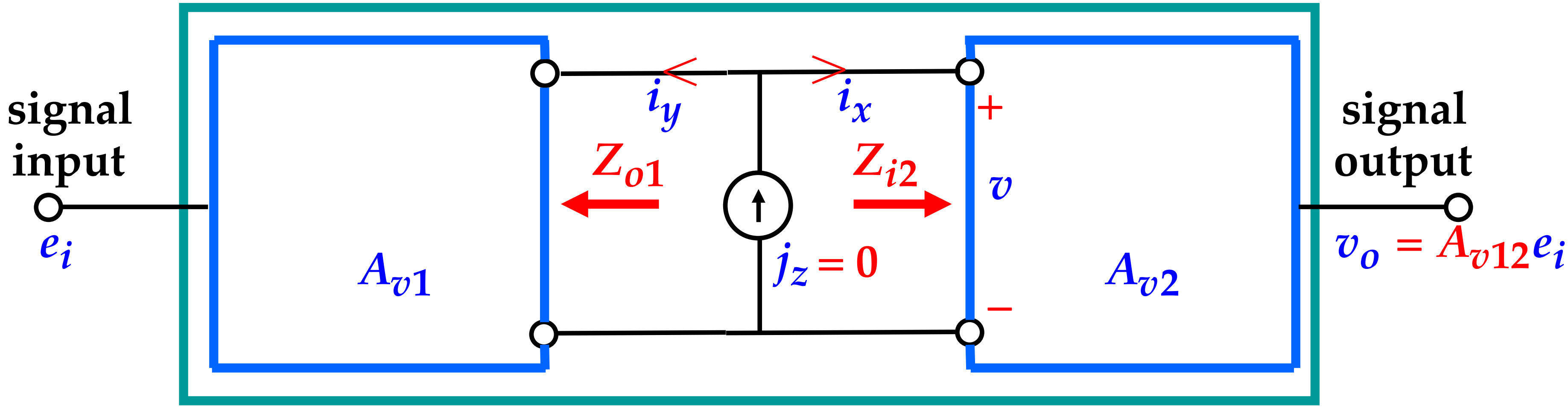
$$Z_i = \frac{1}{sC} - R_{neg}$$





i1
0
i1
r1
Rs
C1
i2
0
i2
r2
C2
r1
L
Rs
−Rneg
C
CL

A detailed analysis can be done with the DT/CT

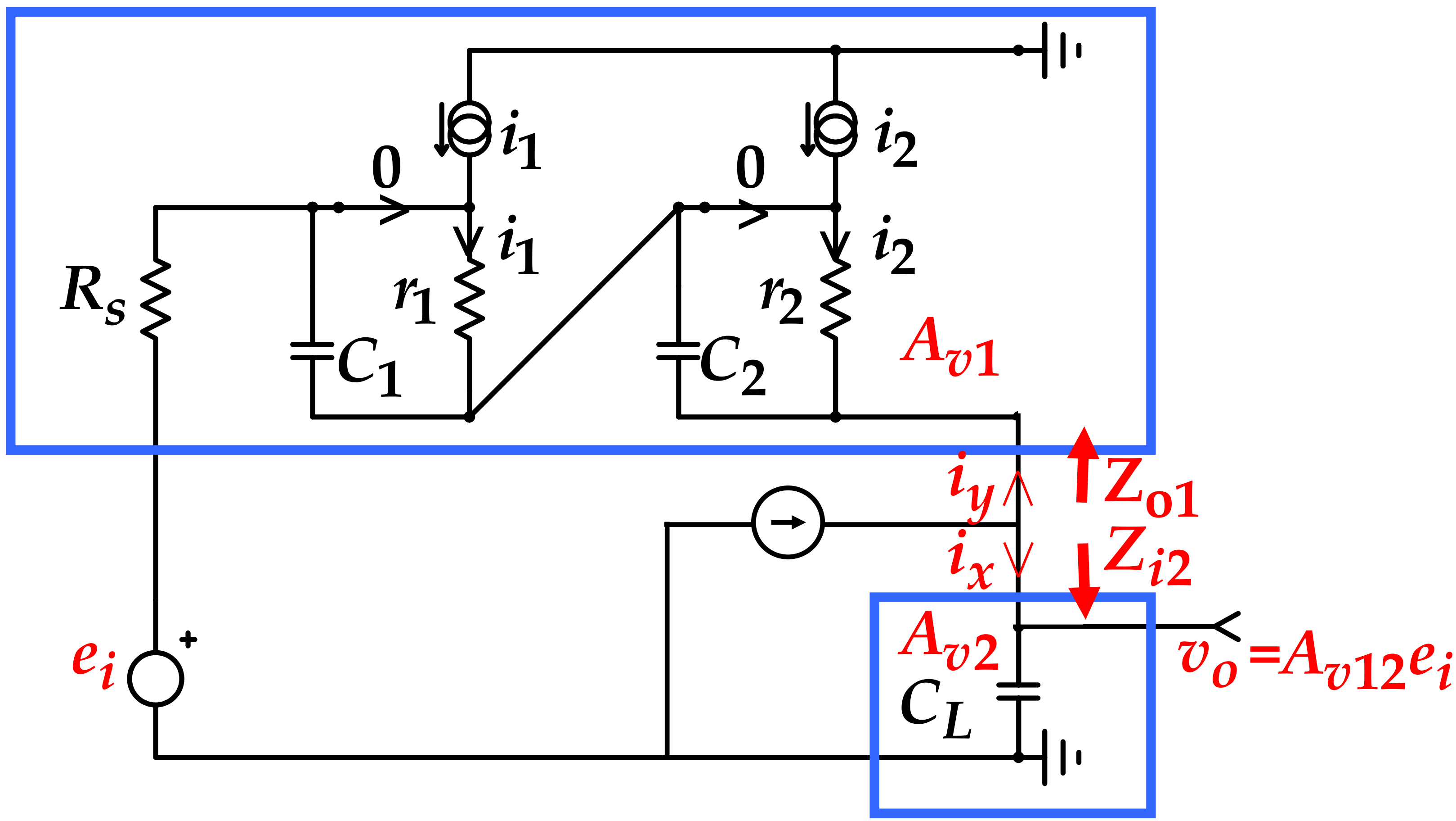


The gain $A_{v12} \equiv \frac{v_o}{e_i}$ is given by the DT:

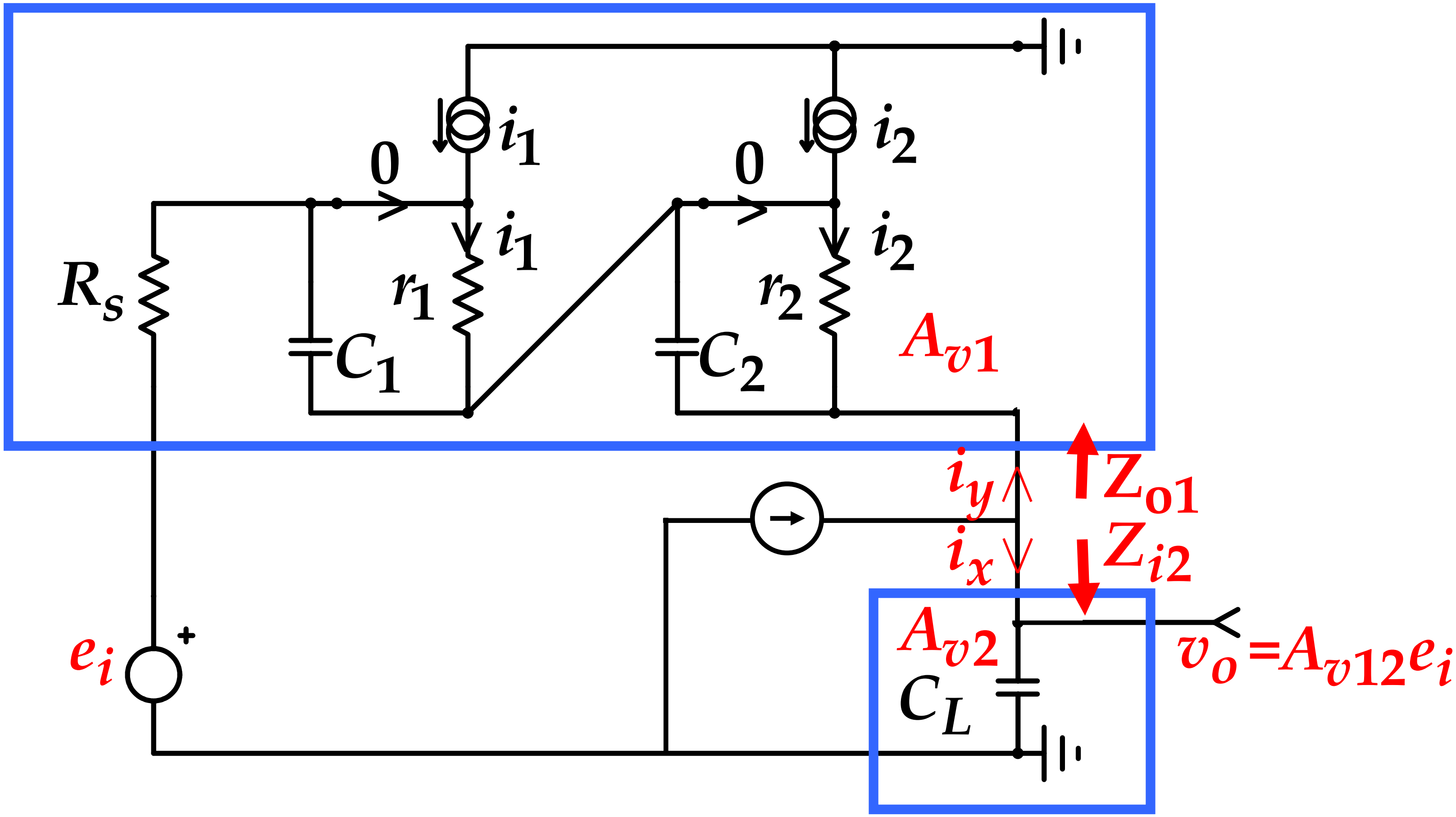
$$A_{v12} = A_{v12}^{i_y} \frac{1 + \frac{1}{T_{ni}}}{1 + \frac{1}{T_i}}$$

The null return ratio $T_{ni} \equiv i_y / i_x \big|_{v_o = 0}$ is an ndi calculation with the output v_o nulled. If v_o is nulled, so is i_x, so $T_{ni} = \infty$.

This implies that T_{ni} is infinite unless the signal can bypass the injection point.



0
0
i1
i2
i1
i2
Rs
r1
r2
C1
C2
Av1
iy
Zo1
ix
Zi2
Av2
CL
ei
+
vo=Av12ei

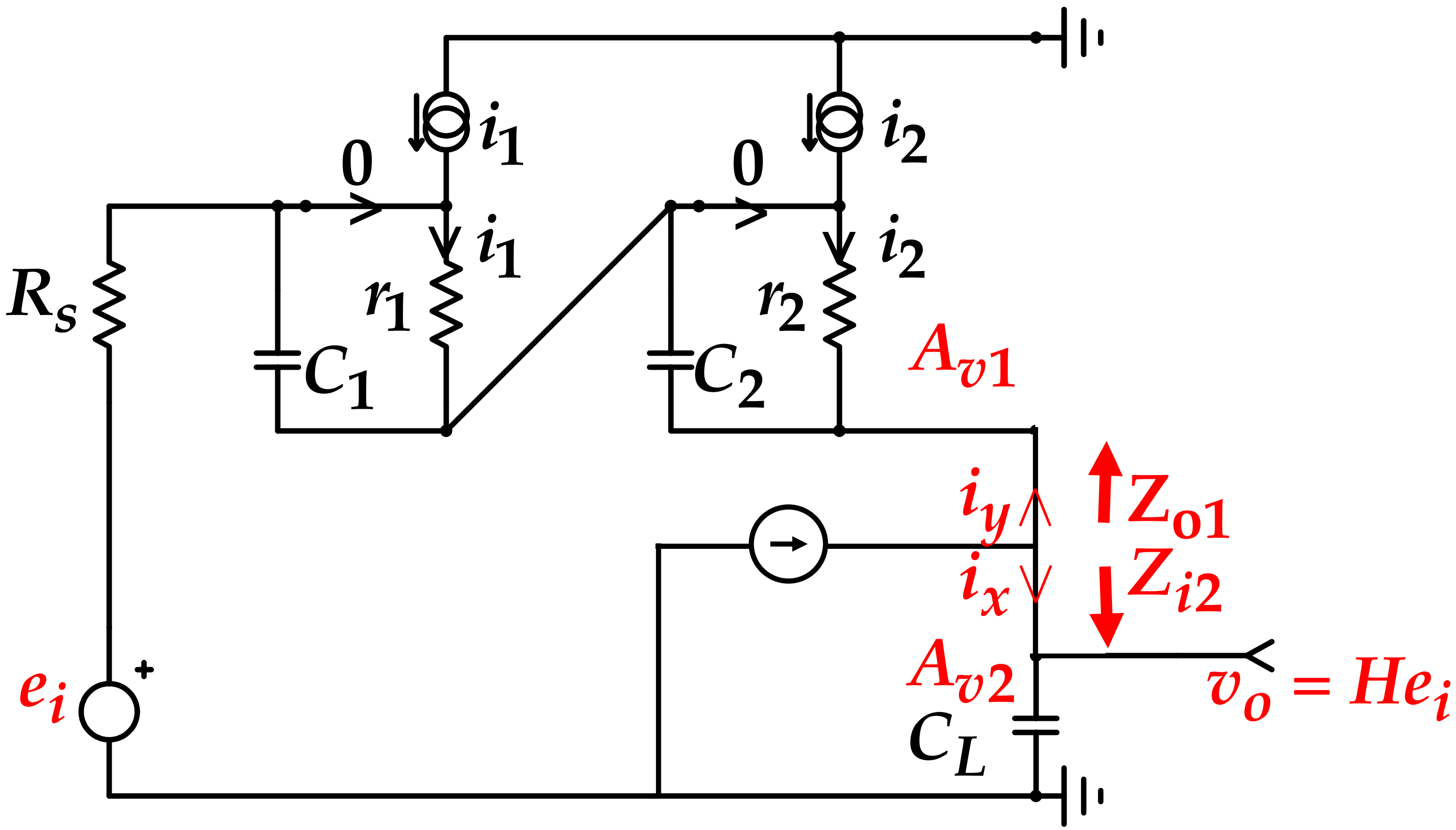


Nulled i_y means that the A_{v1} box is unloaded, so the input voltage to the A_{v2} box is the open-circuit (oc) output voltage of the A_{v1} box. Thus

$$A_{v12}^{i_y} = A_{v1}^{oc} A_{v2}$$

Also, $T_i = Z_{i2} / Z_{o1}$,

so the DT becomes $A_{v12} = A_{v1}^{oc} A_{v2} \dfrac{1}{1 + \dfrac{Z_{o1}}{Z_{i2}}}$



$$A_{v1}^{oc} = 1, \quad A_{v2} = 1, \quad \text{so}$$

$$H = A_{v12} = \frac{1}{1+\frac{1}{T}} = D \quad \text{where} \quad T = T_i = \frac{Z_{i2}}{Z_{o1}}$$

We can figure out a lot about T before doing a simulation.

Z_{o1} has two poles, because it has two capacitances.

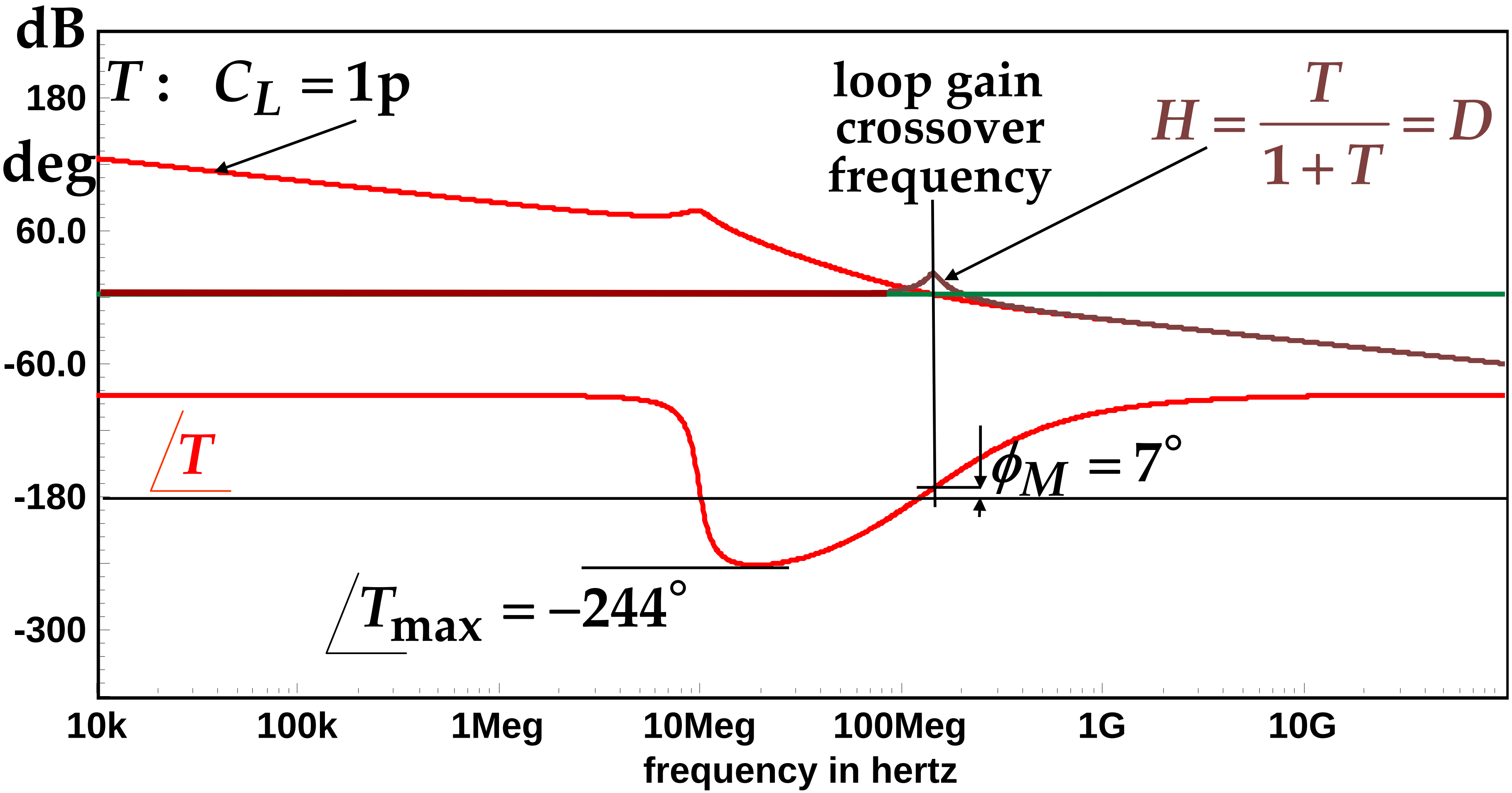
By "mental frequency sweep,"

$$Z_{o1}(0) = r_2, \qquad Z_{o1}(\infty) = R_s$$

Since Z_{o1} is flat at zero and infinite frequency, Z_{o1} must have two zeros as well as two poles.

Also, $Z_{i2} = \dfrac{1}{sC_L}$

Therefore, $T = \dfrac{Z_{i2}}{Z_{o1}}$ **has three poles and two zeros.**



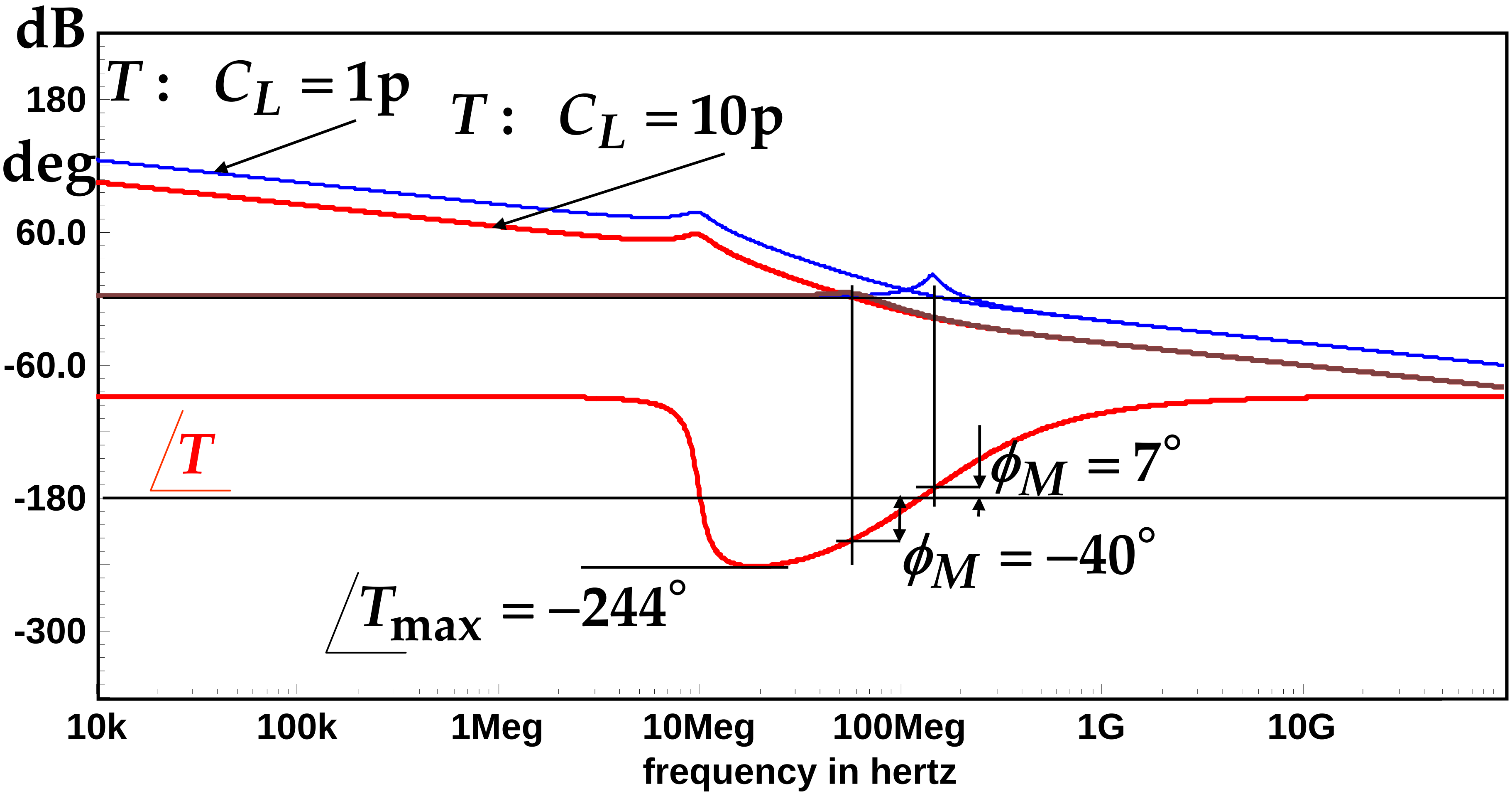
The phase margin ϕ_M is positive, so the Follower is stable. However, ϕ_M is small, so H has a large peak.

For design, C_L is to be considered a variable.

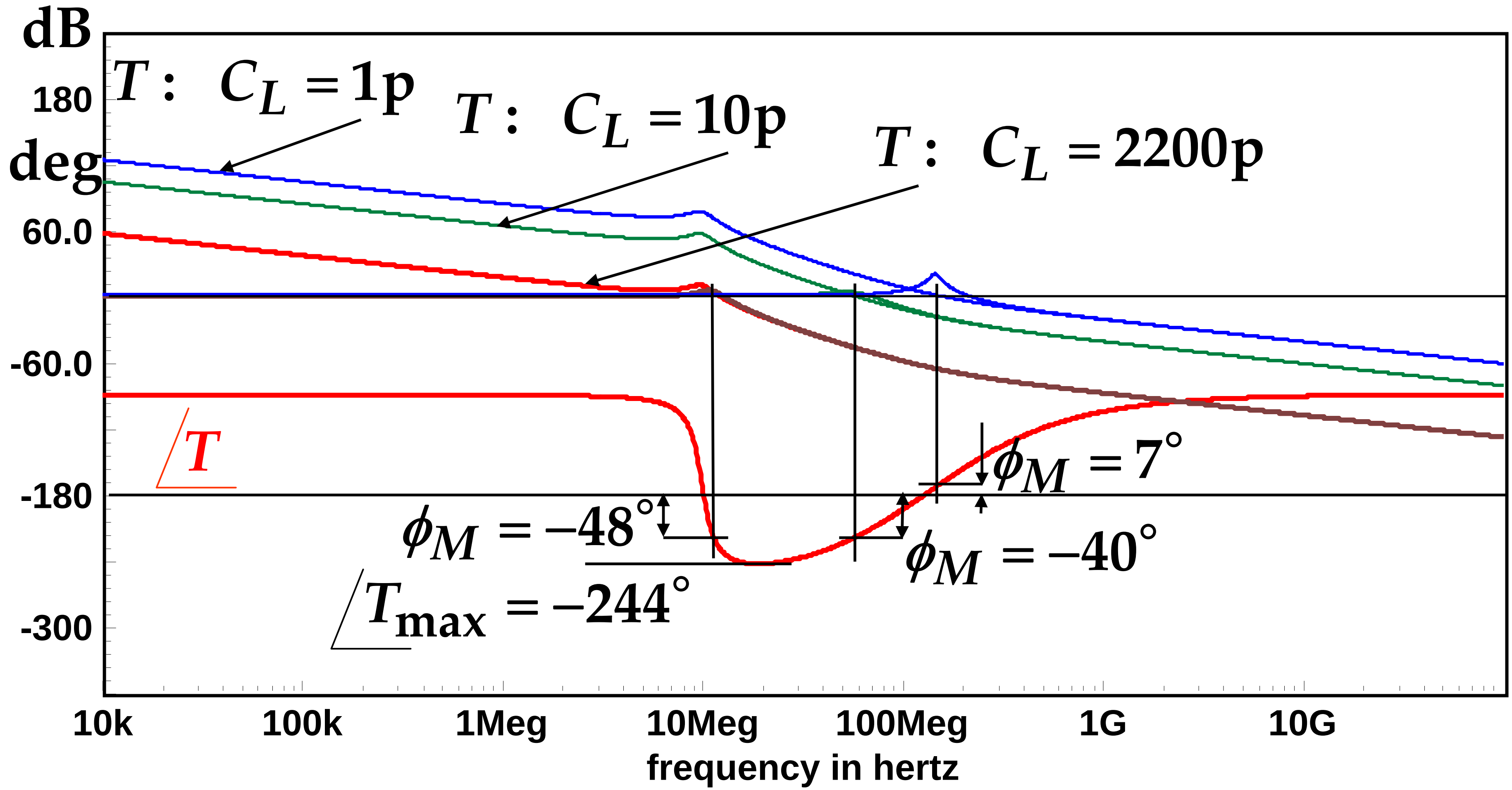
Examine the effect of C_L upon $T = 1/sC_L Z_{o1}$.

Since C_L is not inside Z_{o1}, increasing C_L does not change the shape of either $|T|$ or $\angle T$; $|T|$ decreases in inverse proportion to C_L, but $\angle T$ does not change at all.

The decrease of $|T|$ results in lowered loop gain crossover frequency:

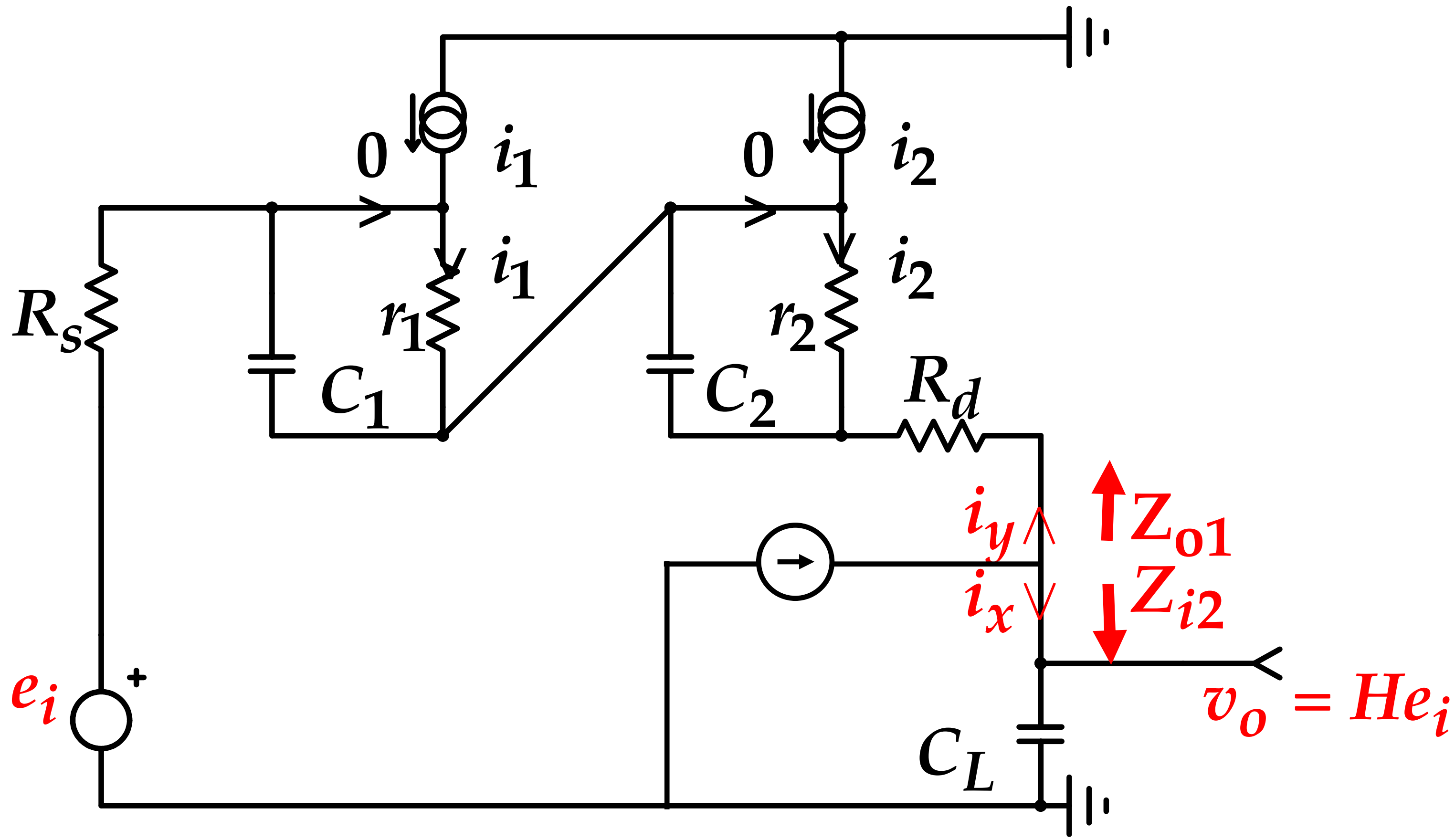


dB
deg
180
60.0
-60.0
-180
-300
T : C_L = 1p
T : C_L = 10p
∠T
∠T_max = −244°
φ_M = 7°
φ_M = −40°
10k
100k
1Meg
10Meg
100Meg
1G
10G
frequency in hertz

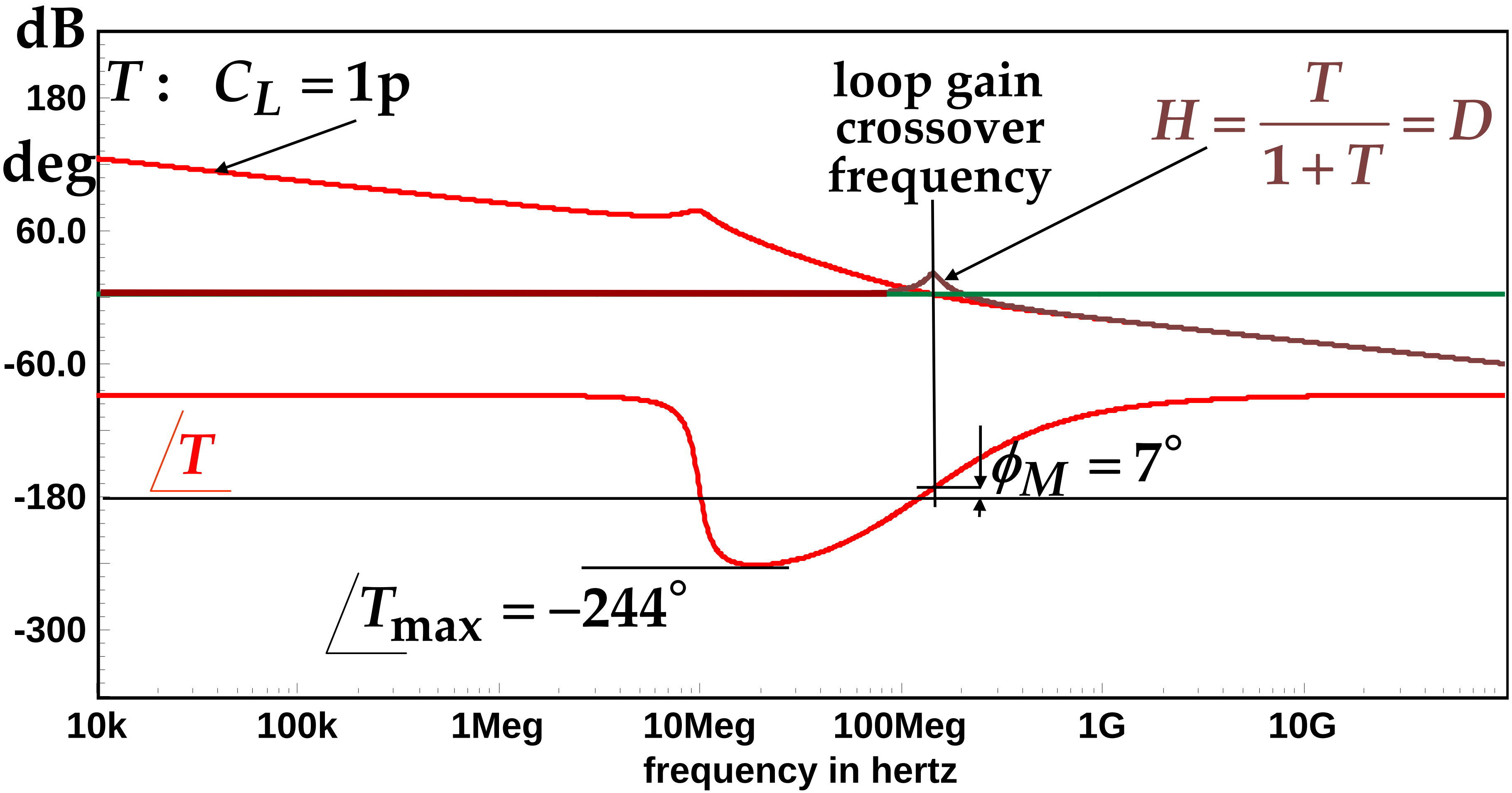


There is a range of C_L for which the phase margin ϕ_M is negative, and the Follower is unstable.

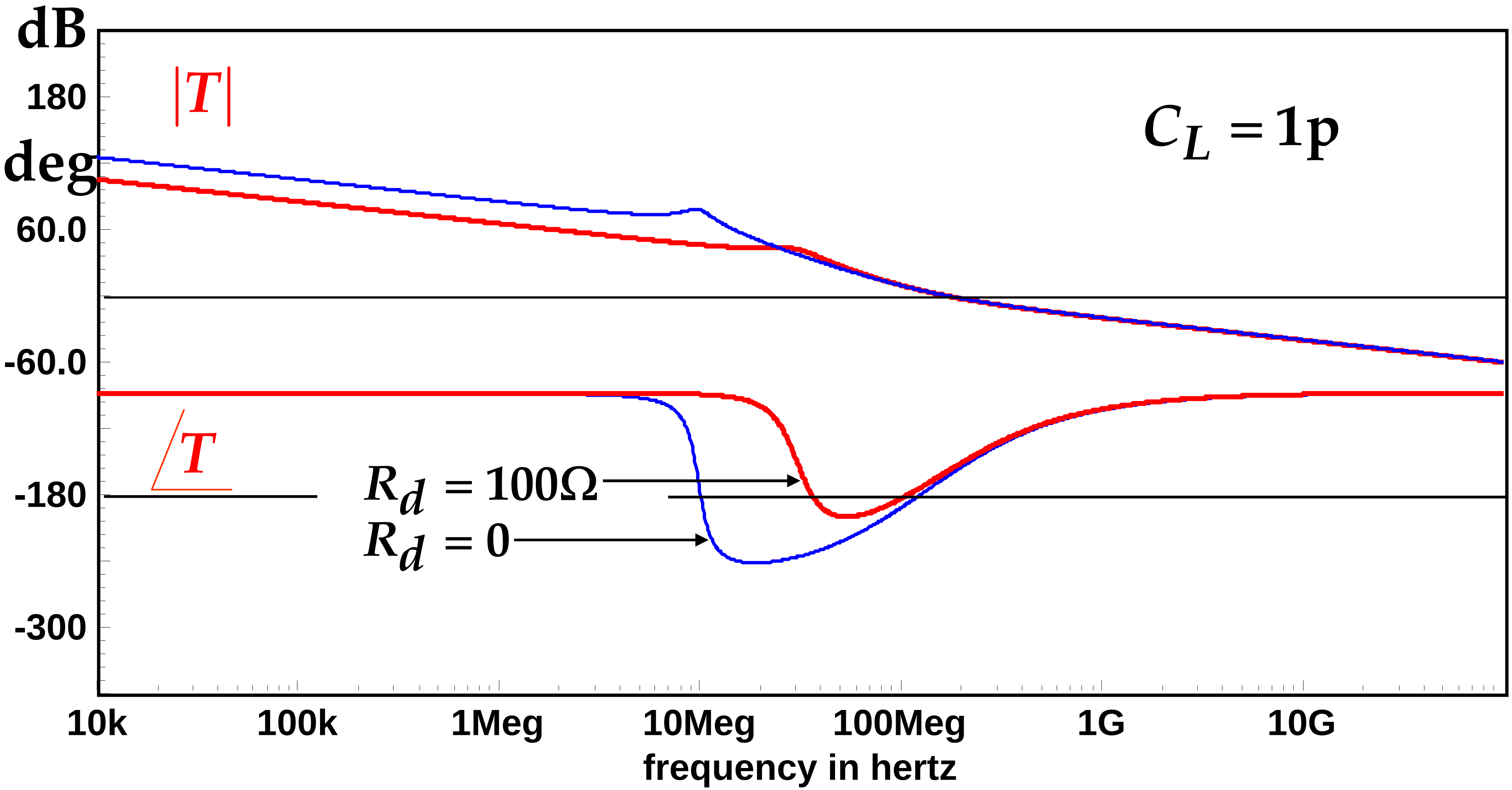
A design strategy is to add sufficient damping resistance R_d to Z_{o1} so that the maximum phase lag is less than 180° by some desired phase margin.

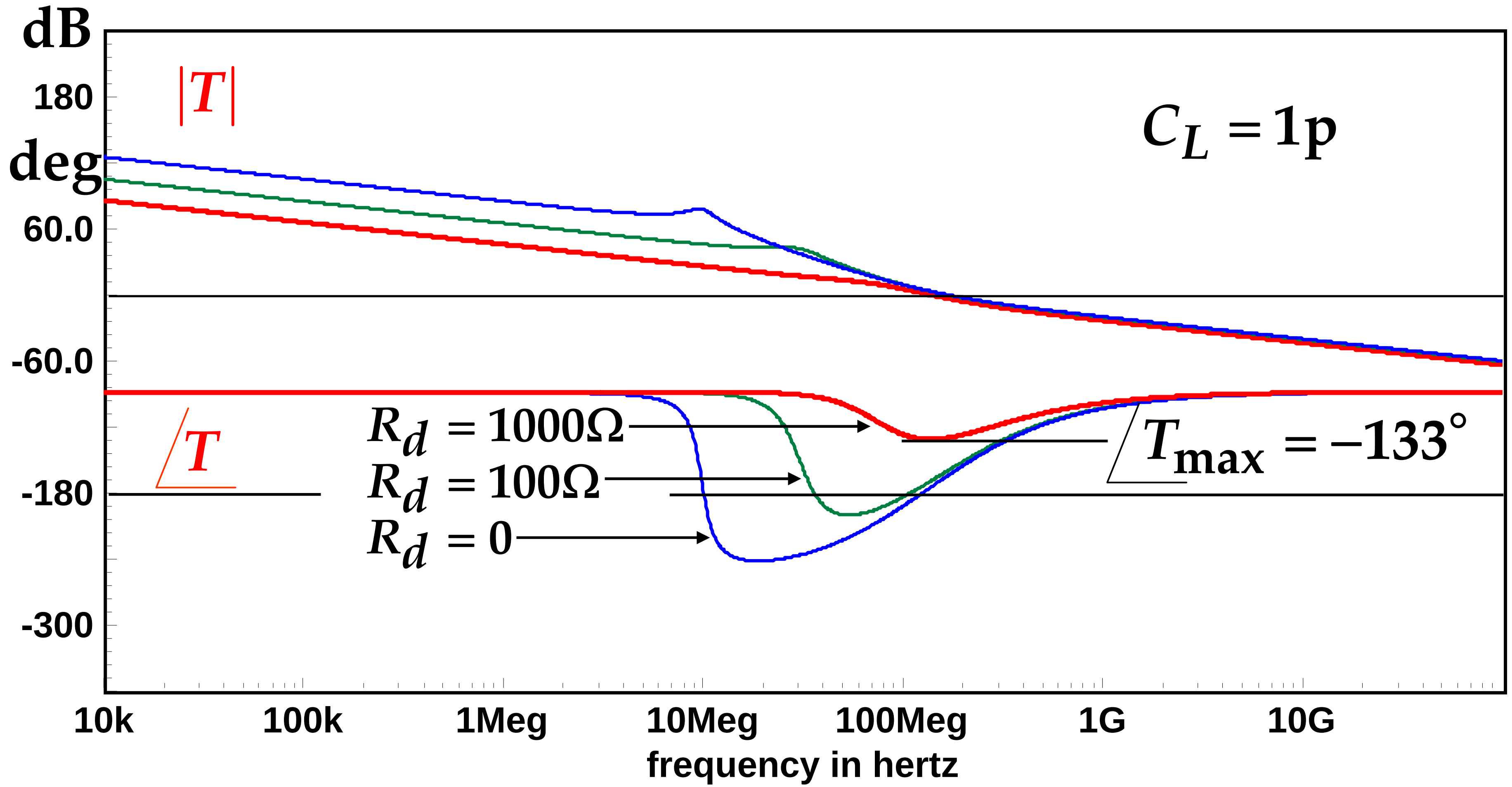


Damping resistance R_d added

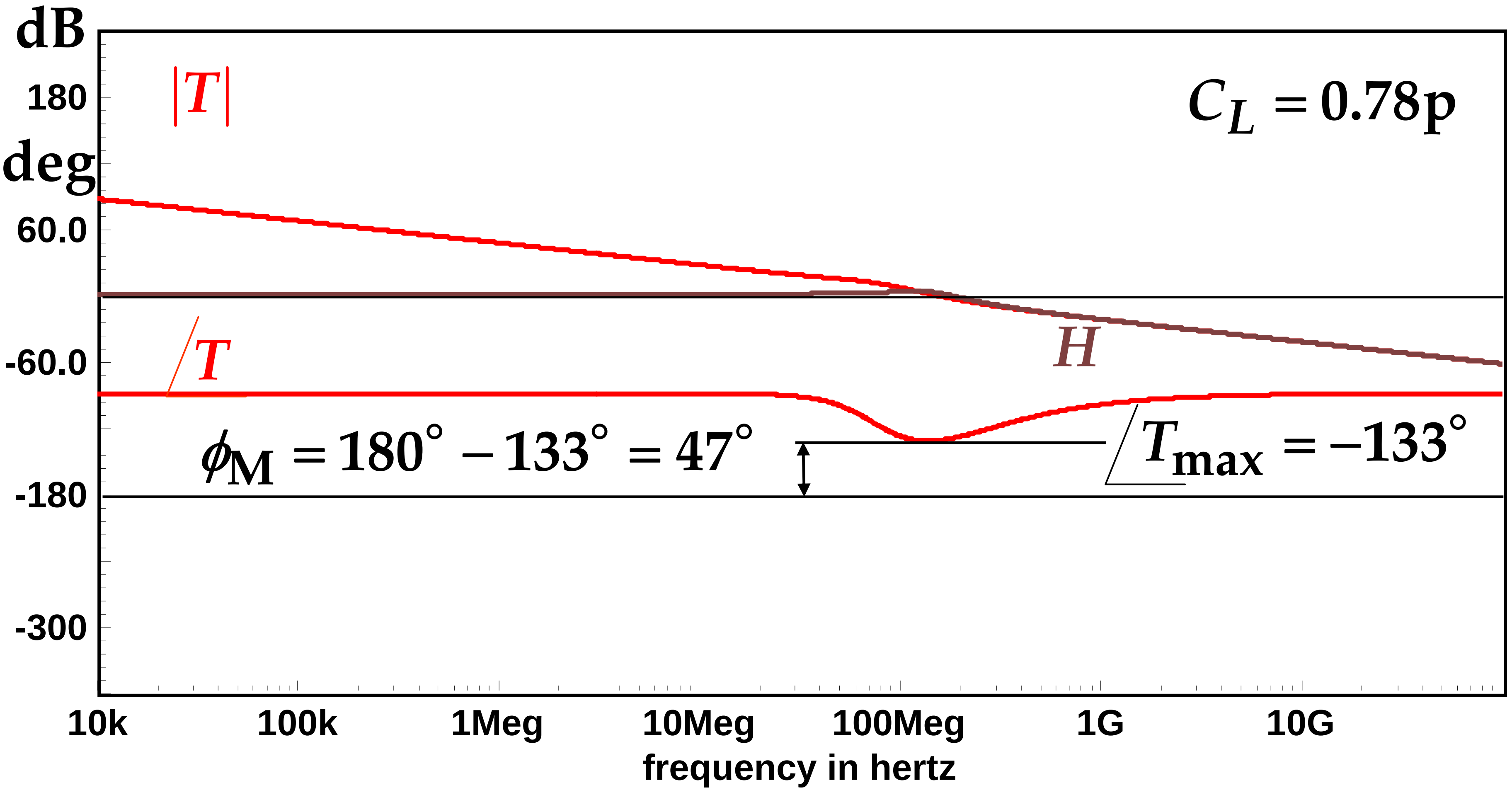


The phase margin ϕ_M is positive, so the Follower is stable. However, ϕ_M is small, so H has a large peak.


dB
deg
180
60.0
-60.0
-180
-300
|T|
∠T
$C_L = 1\text{p}$
$R_d = 100\Omega$
$R_d = 0$
10k
100k
1Meg
10Meg
100Meg
1G
10G
frequency in hertz



The worst-case phase margin thus occurs when C_L is such that the $|T|$ crossover frequency f_c is at the frequency where $\angle T$ is maximum:



Worst-case $\phi_M = 47^\circ$, and consequent greatest peaking in H, occurs for $C_L = 0.78\text{p}$.

Expanded scale: