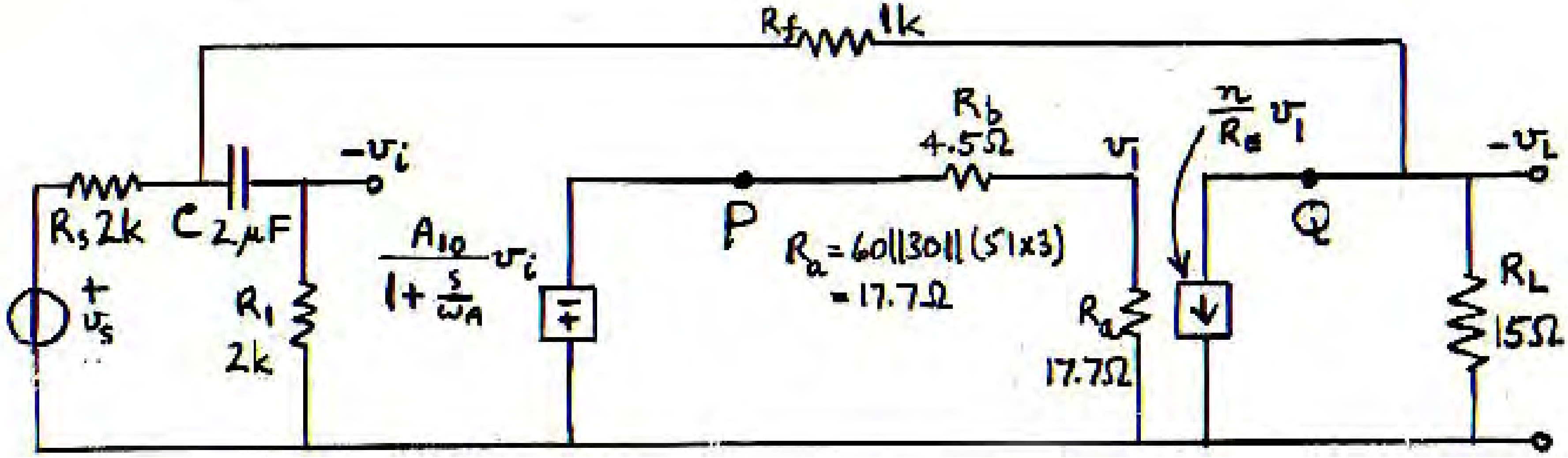
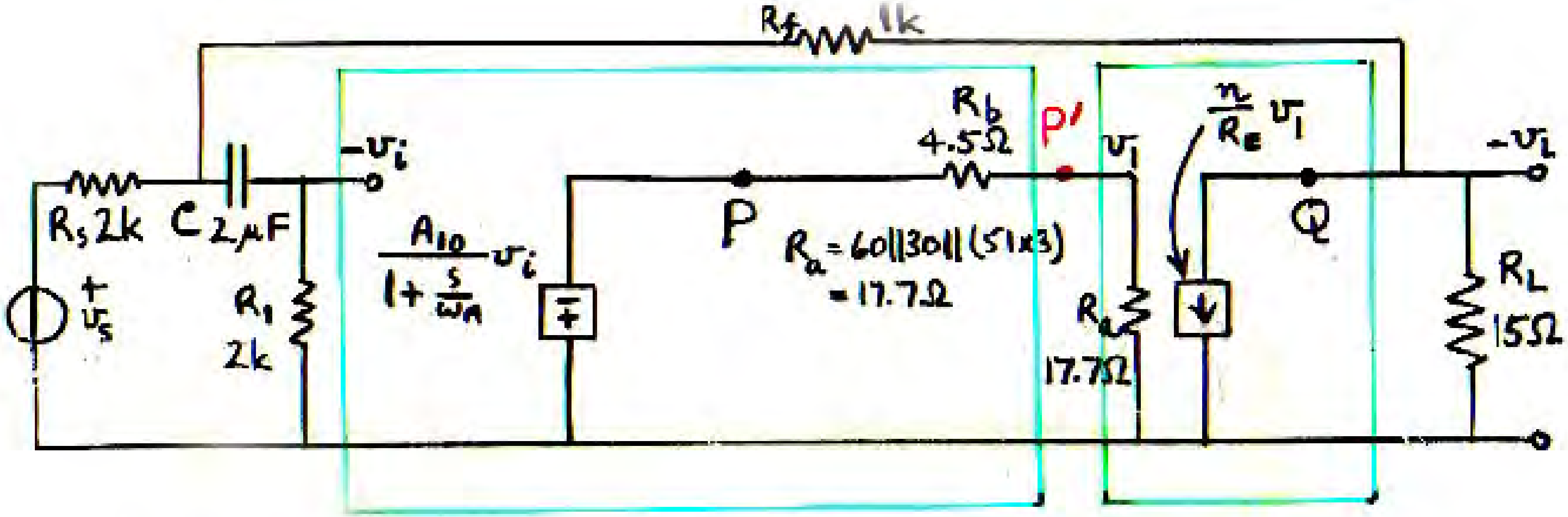
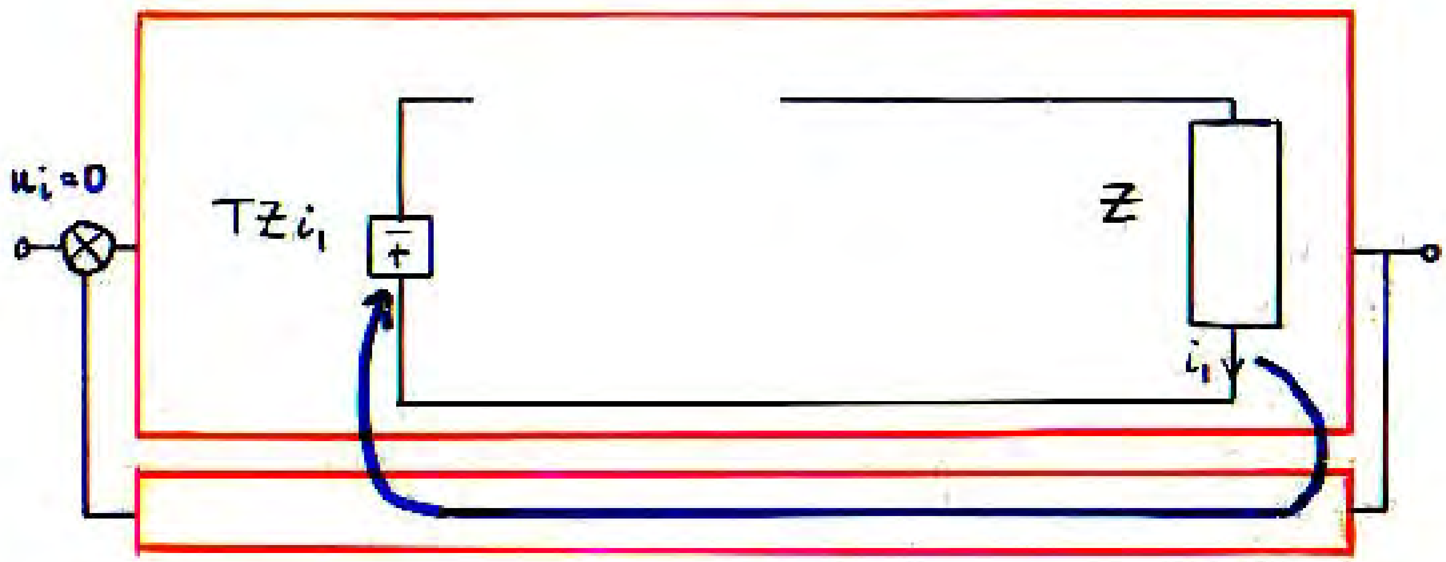

Rf 1k
Rb
4.5Ω
$-v_i$
v_1
$\frac{n}{R_E} v_1$
$-v_L$
R_s 2k
C 2μF
P
Q
$\frac{A_{10}}{1+\frac{s}{\omega_A}} v_i$
$R_a = 60\|30\|(51 \times 3)$
$= 17.7\Omega$
v_s
R_1
2k
R_a
17.7Ω
R_L
15Ω



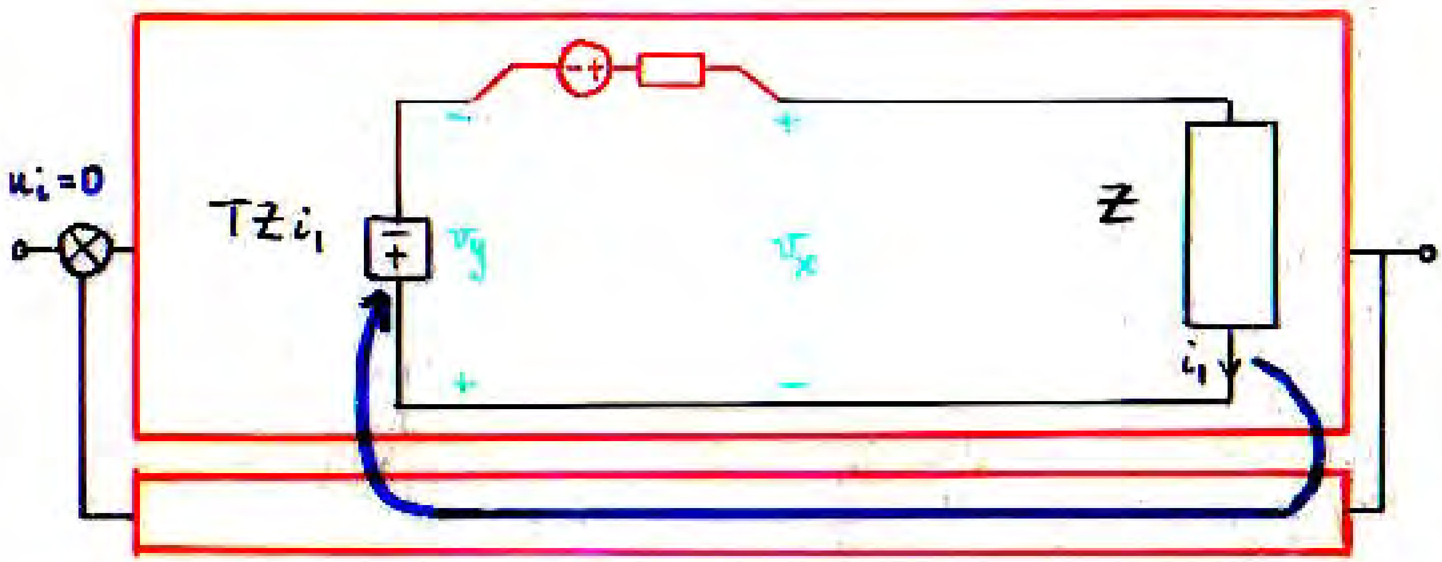
The voltage injection point P is not accessible.

The nearest accessible point is P.′

Consider, in general, voltage injection at a nonideal point. Also, take into account nonzero impedance of the injecting source.

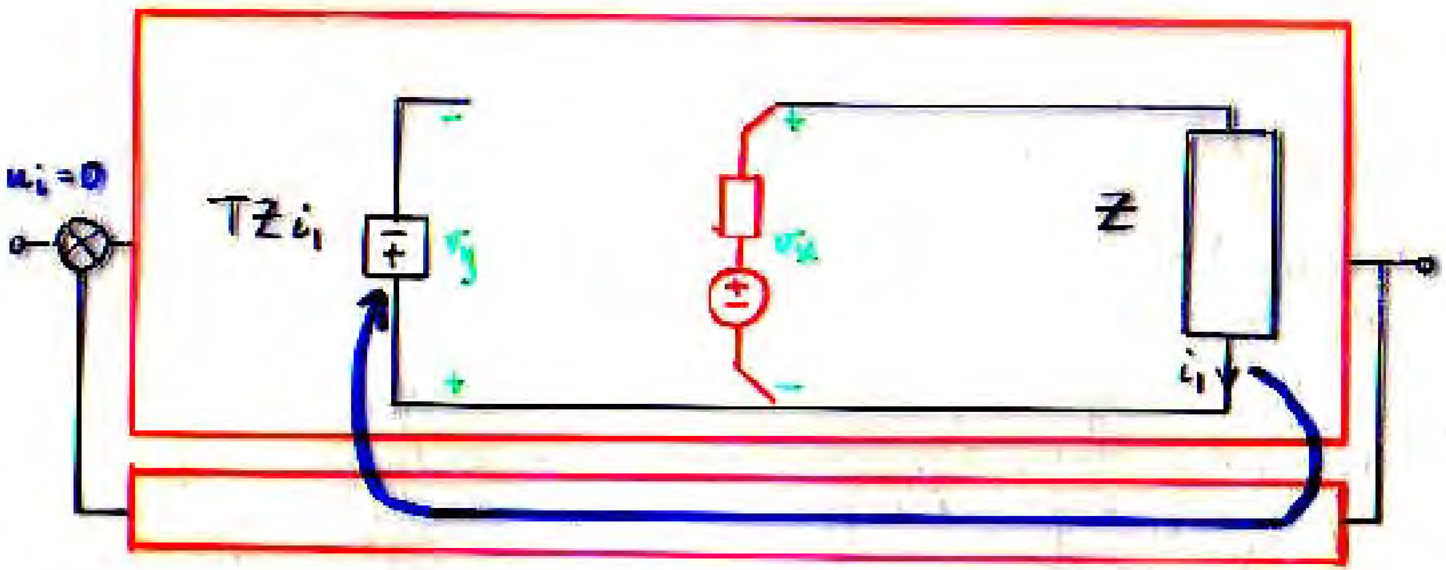


u_i=0
TZi_1
Z
i_1



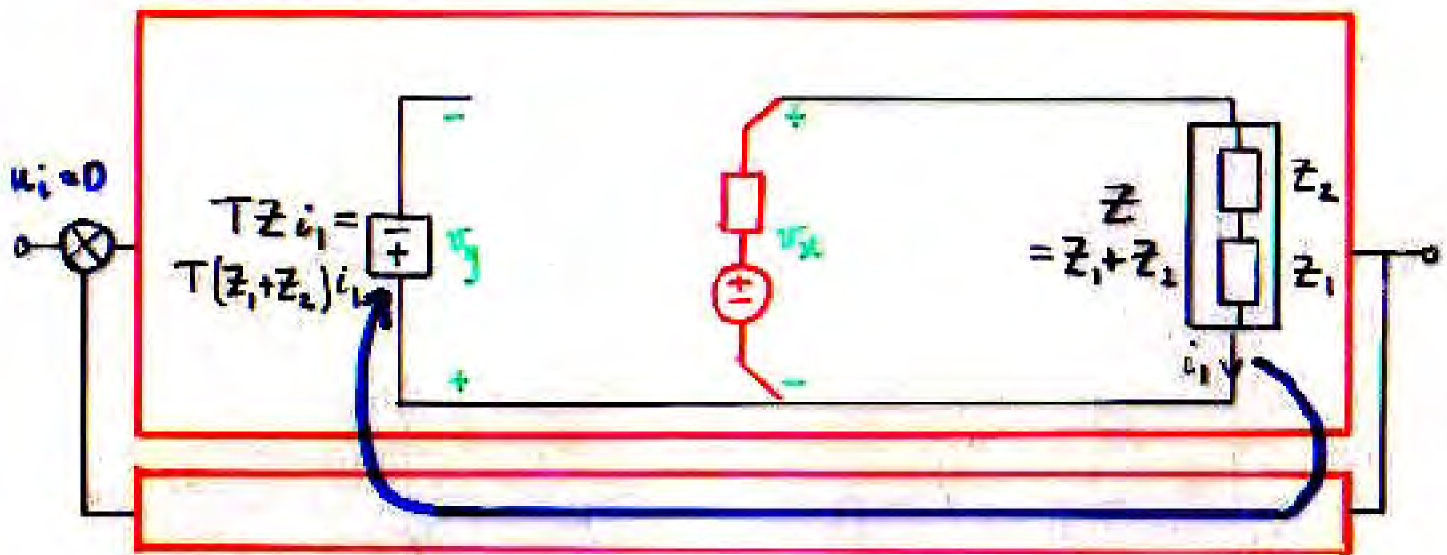
Loop gain by injection of a test signal at an "ideal" point:

$$T_v \equiv \frac{v_y}{v_x} = T \quad \leftarrow \quad \begin{cases} v_y = TZi_1 \\ i_1 = \dfrac{v_x}{Z} \end{cases}$$



Loop gain by application of a test signal to the loop broken at an "ideal" point:

$$T_v \equiv \frac{v_y}{v_x} = T$$

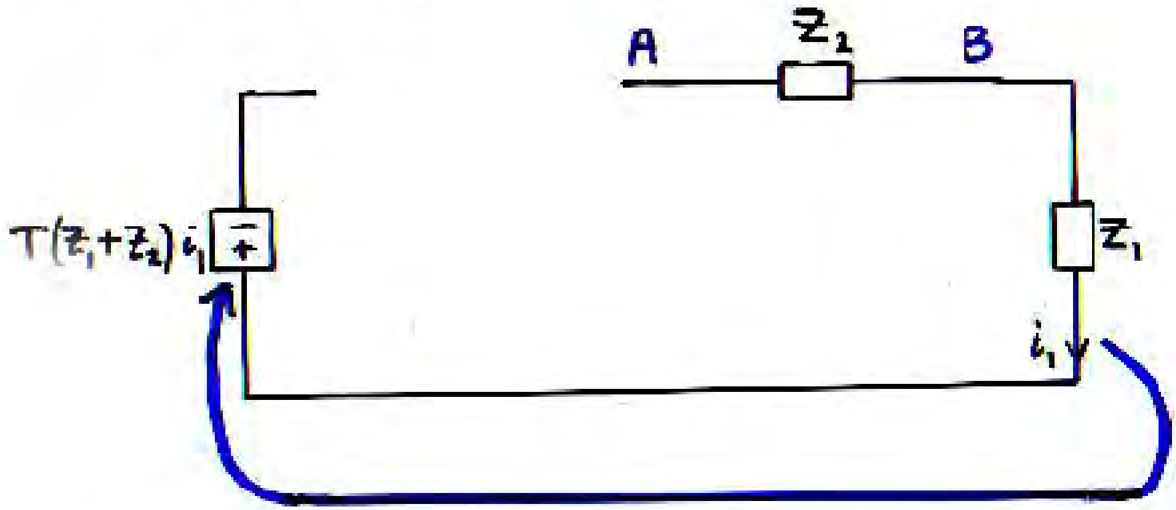


Same results

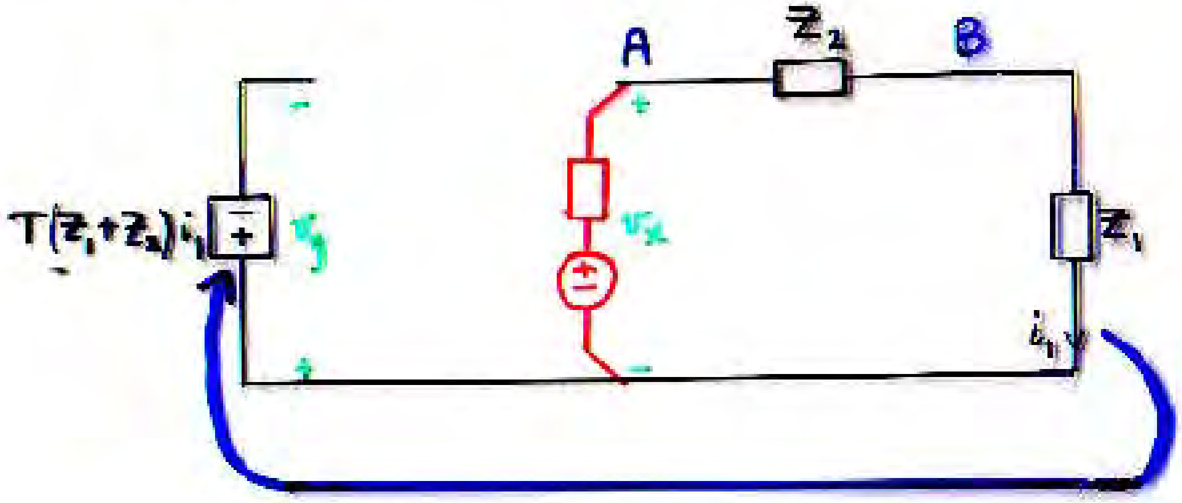
Loop gain by application of a test signal to the loop broken at an "ideal" point:

$$T_v \equiv \frac{v_y}{v_x} = T$$

Redraw the model:



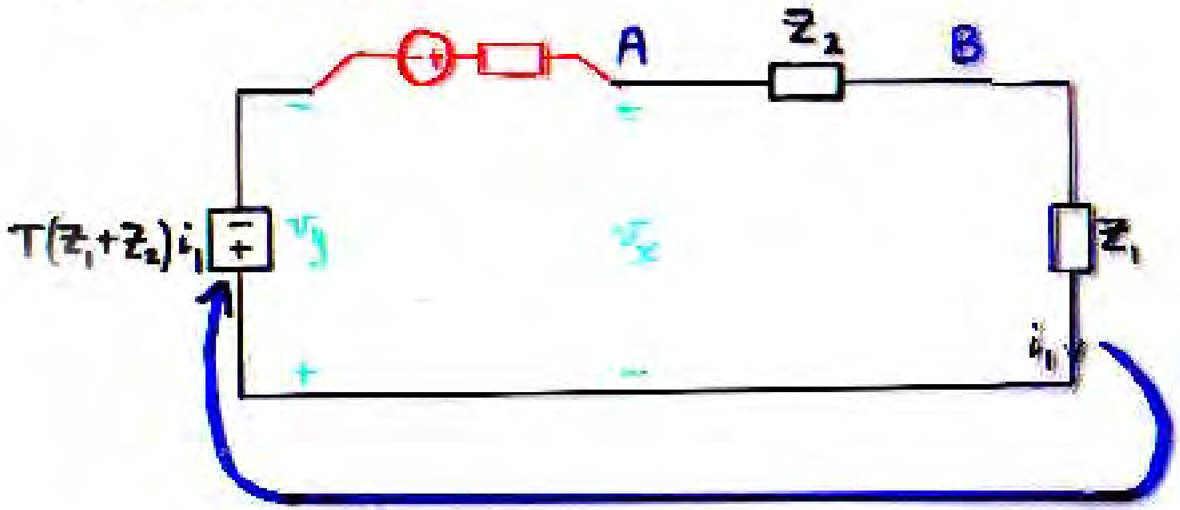
Redraw the model:



Loop gain by application of a test signal to the loop broken at an "ideal" point:

$$T_v \equiv \frac{v_y}{v_x} = T$$

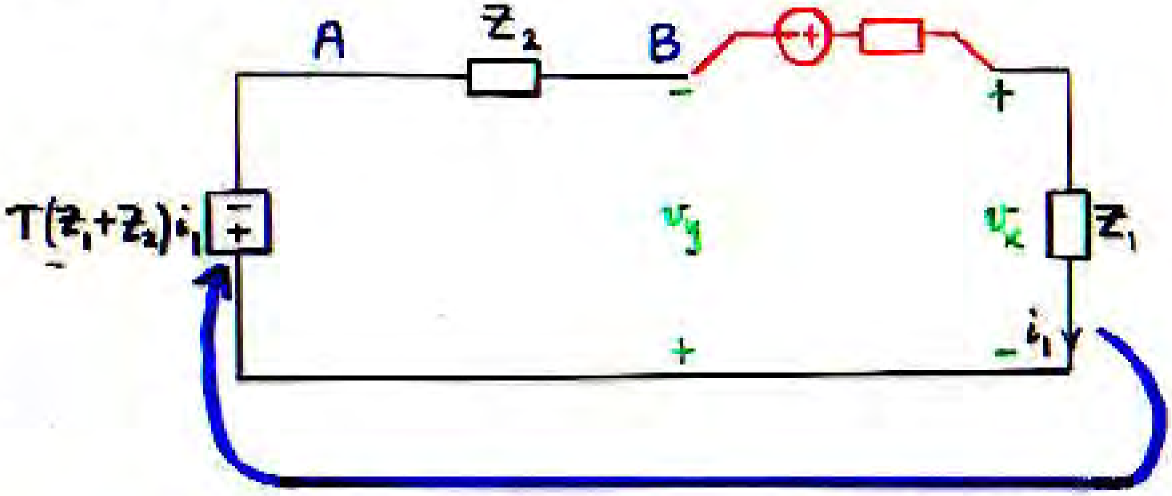
Redraw the model:



Loop gain by injection of a test signal at an "ideal" point:

$$T_v \equiv \frac{v_y}{v_x} = T \quad \leftarrow \quad \begin{cases} v_y = TZi_1 \\ i_1 = \dfrac{v_x}{Z} \end{cases}$$

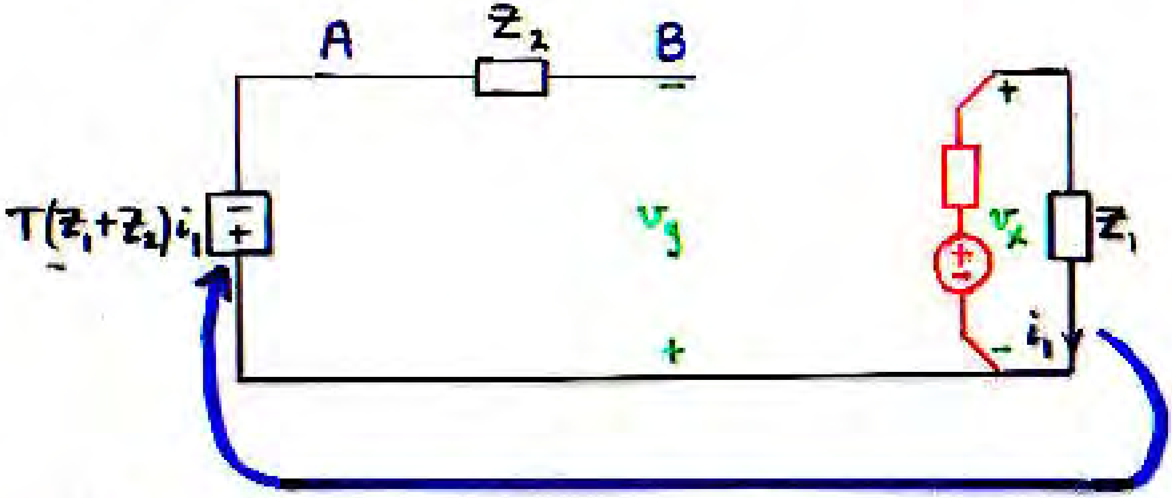
Redraw the model:



However, results are different if test signal is injected at "nonideal" point B:

$$T_v = \frac{v_y}{v_x} = \left(1+\frac{Z_2}{Z_1}\right)T + \frac{Z_2}{Z_1} \quad \leftarrow \quad \begin{cases} v_y = T(Z_1+Z_2)i_1 + Z_2 i_1 \\ i_1 = \dfrac{v_x}{Z_1} \end{cases}$$

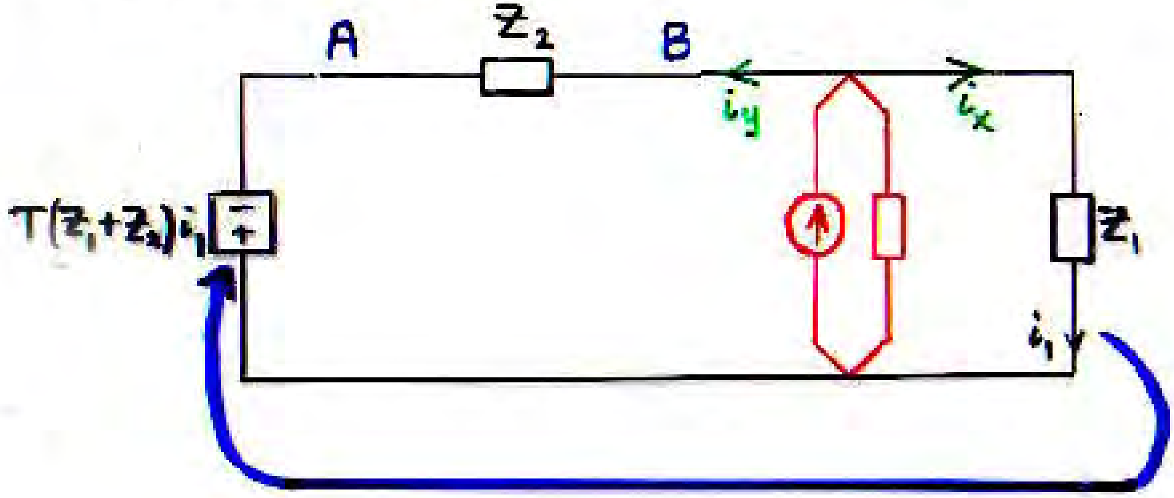
Redraw the model:



Results are different again if test signal is applied to loop broken at "non ideal" point B:

$$T_v \equiv \frac{v_y}{v_x} = \left(1+\frac{Z_2}{Z_1}\right)T \quad \longleftarrow \quad \begin{cases} v_y = T(Z_1+Z_2)i_1 \\ i_1 = \dfrac{v_x}{Z_1} \end{cases}$$

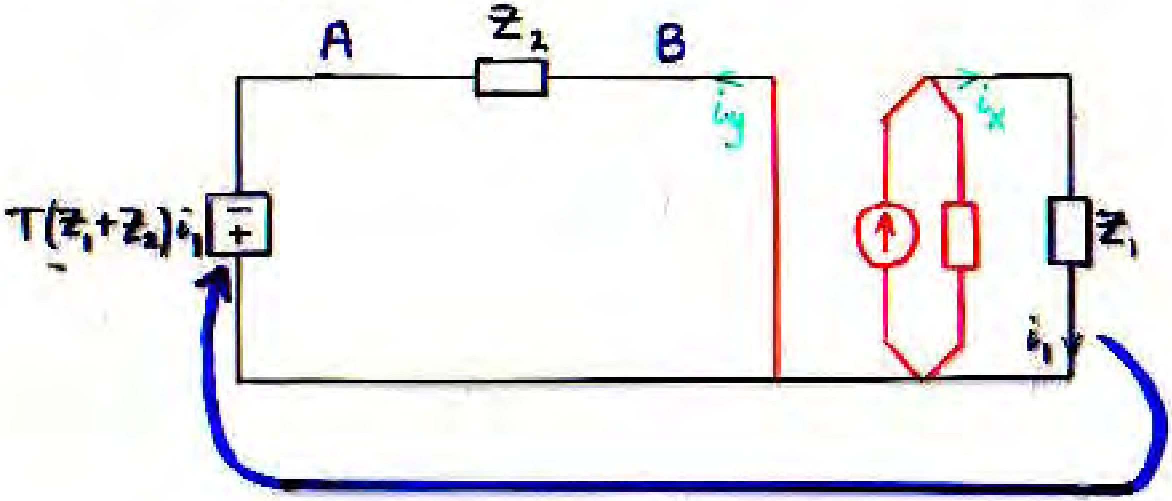
Redraw the model:



If current test signal is injected at the "nonideal" point B:

$$T_i \equiv \frac{i_y}{i_x} = \left(1+\frac{Z_1}{Z_2}\right)T + \frac{Z_1}{Z_2} \leftarrow \begin{cases} i_y = \dfrac{T(Z_1+Z_2)i_1 + Z_1 i_1}{Z_2} \\ i_1 = i_x \end{cases}$$

Redraw the model:



If a current test signal is applied to loop broken (shorted) at the "nonideal" point B:

$$T_i \equiv \frac{i_y}{i_x} = \left(1 + \frac{Z_1}{Z_2}\right) T \quad \leftarrow \quad \begin{cases} i_y = \dfrac{T(Z_1+Z_2)}{Z_2} \\ i_1 = i_x \end{cases}$$

Loop gain T can be calculated or measured by

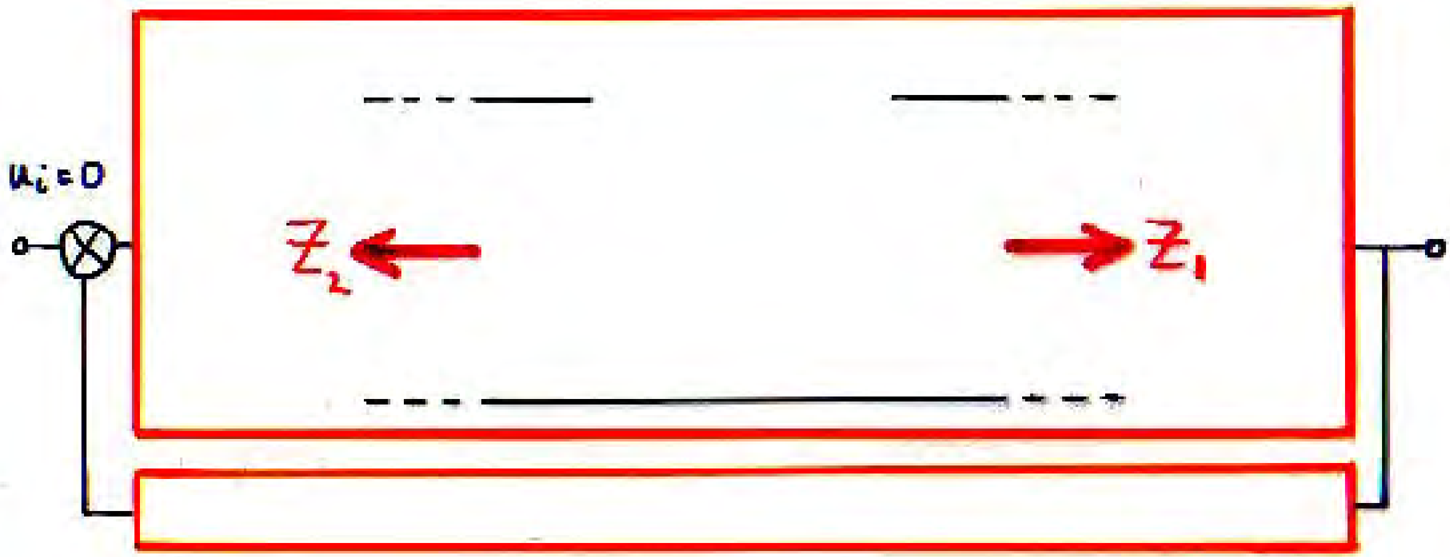
1. Test signal applied to broken loop

2. Test signal injected into the closed loop.

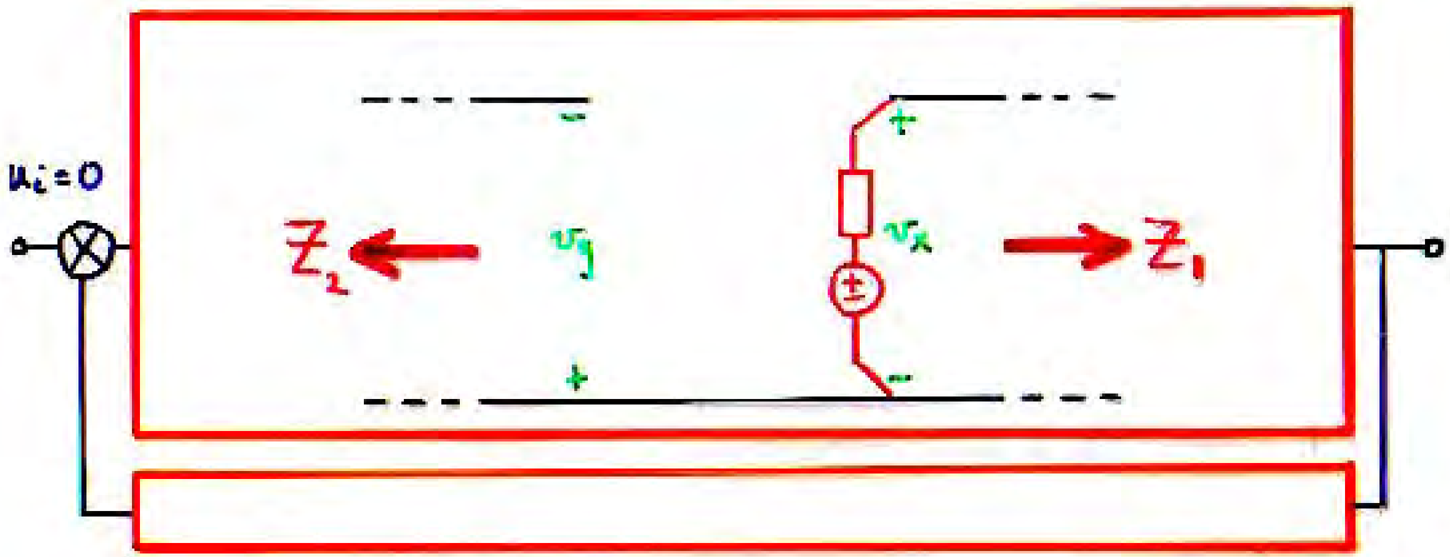
Method 2 is preferable for measurement, since the loop remains closed and the dc operating points remain undisturbed. If method 1 is used for measurement, a dc bias must be applied to re-establish the proper operating point before the ac test signal can be applied.

In *either* method, certain inequalities must be satisfied by the impedance ratio Z_2/Z_1, where

$$\frac{Z_2}{Z_1} = \frac{\text{impedance looking back}}{\text{impedance looking forward}} \left.\vphantom{\frac{A}{B}}\right\} \begin{array}{l}\text{into the loop from}\\ \text{the injection point}\end{array}$$



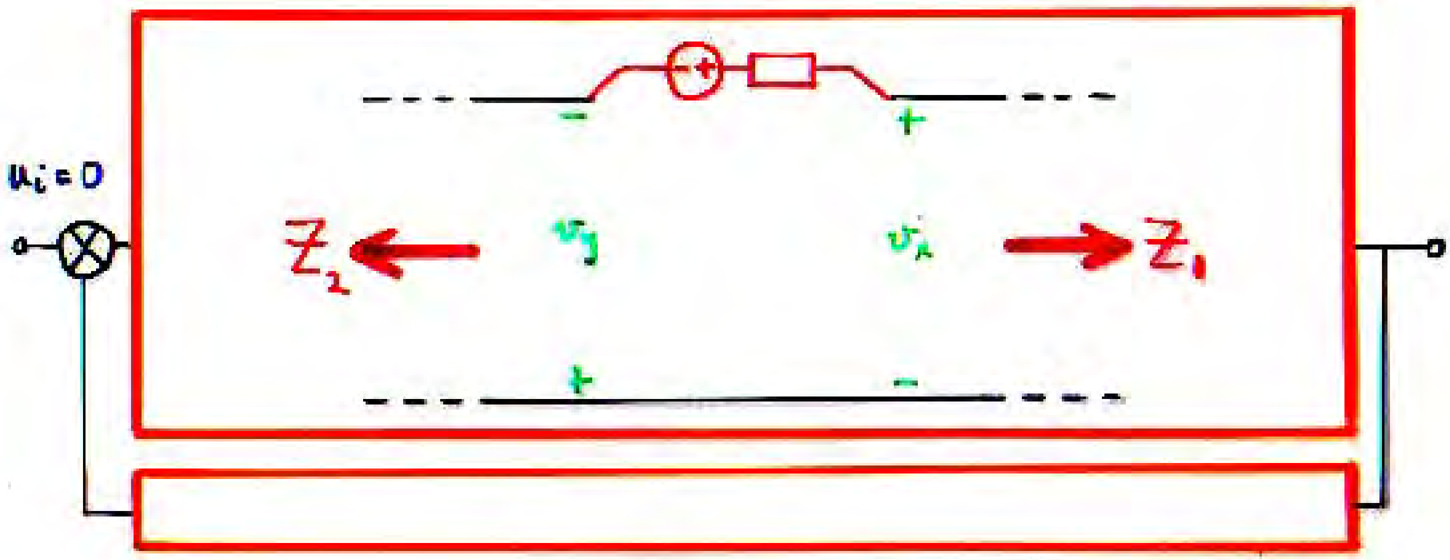
$u_i = 0$
Z_2
Z_1



Voltage test signal applied to broken loop:

$$T_v = \frac{v_y}{v_x} = \left(1 + \frac{Z_2}{Z_1}\right) T$$

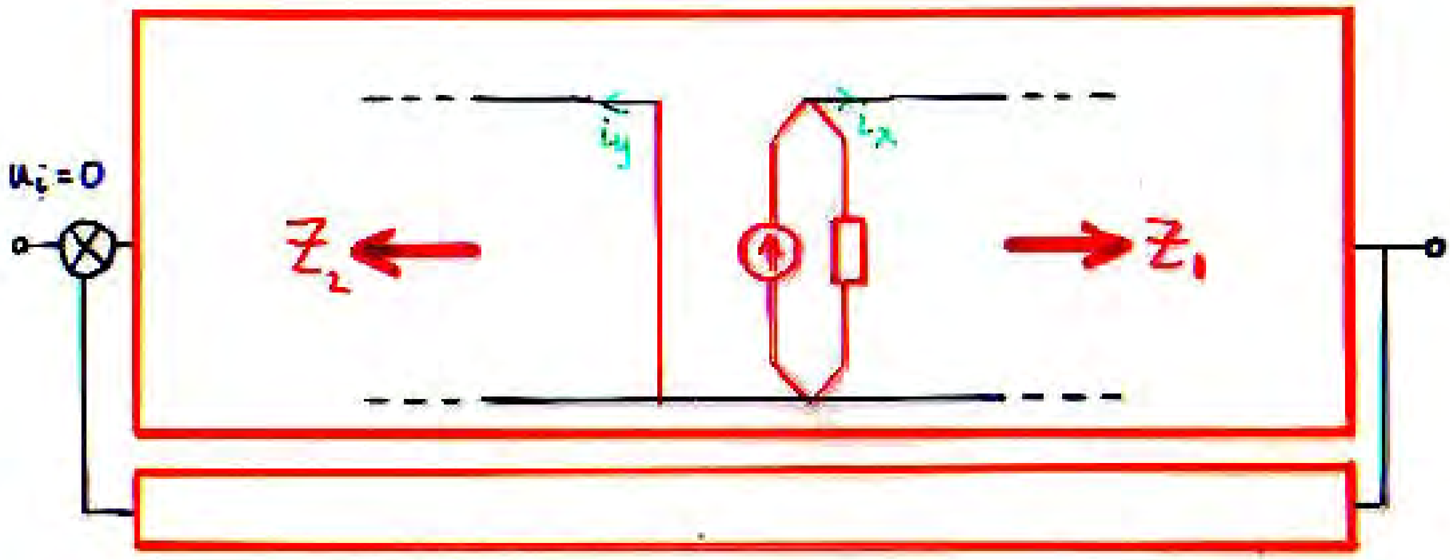
$$\rightarrow T \quad \text{if} \quad \frac{Z_2}{Z_1} \ll 1$$



Voltage test signal injected into closed loop:

$$T_v \equiv \frac{v_y}{v_x} = \left(1 + \frac{Z_2}{Z_1}\right) T + \frac{Z_2}{Z_1}$$

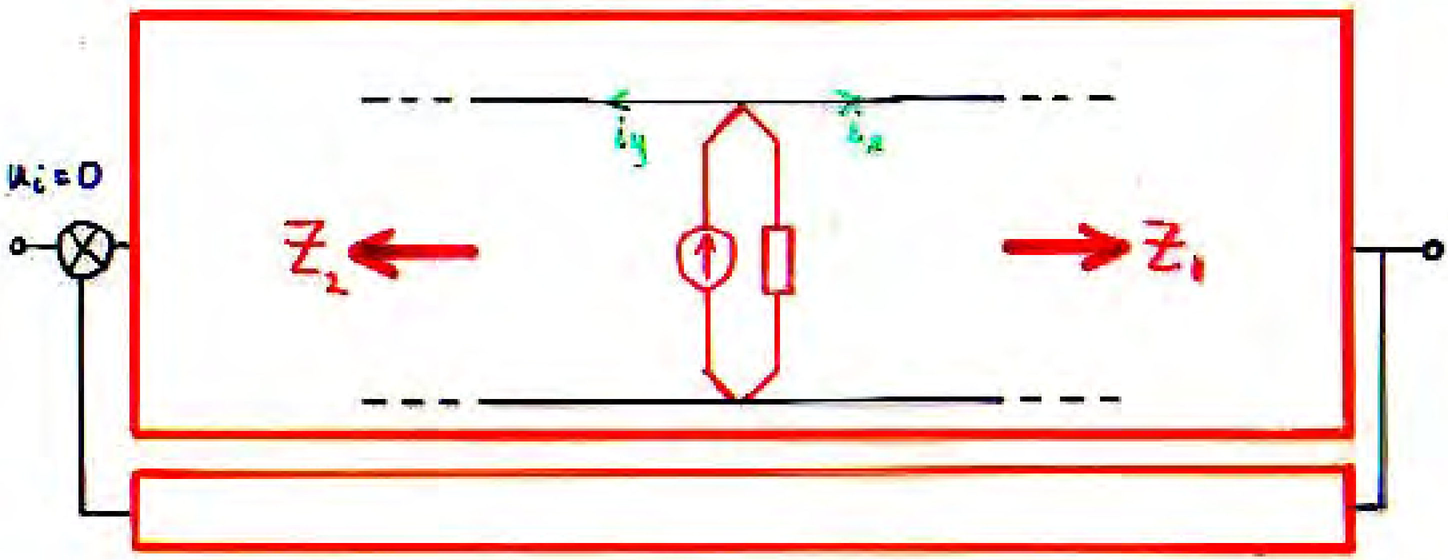
$$\rightarrow T \quad \text{if} \quad \frac{Z_2}{Z_1} \ll 1 \ \underline{\text{and}} \ \frac{Z_2}{Z_1} \ll T$$



Current test signal applied to broken loop:

$$T_i \equiv \frac{i_y}{i_x} = \left(1 + \frac{Z_1}{Z_2}\right) T$$

$$\rightarrow T \quad \text{if} \quad \frac{Z_1}{Z_2} \ll 1$$



Current test signal injected into closed loop:

$$T_i \equiv \frac{i_y}{i_x} = \left(1 + \frac{Z_1}{Z_2}\right) T + \frac{Z_1}{Z_2}$$

$$\rightarrow T \quad \text{if} \quad \frac{Z_1}{Z_2} \ll 1 \quad \text{and} \quad \frac{Z_1}{Z_2} \ll T$$

Generalization: Determination of loop gain by voltage/current application/injection at an ideal/nonideal point

$$\text{Z-ratio} \equiv \begin{cases} \dfrac{Z_2}{Z_1} & \text{for voltage application/injection} \\[2ex] \dfrac{Z_1}{Z_2} & \text{for current application/injection} \end{cases}$$

where

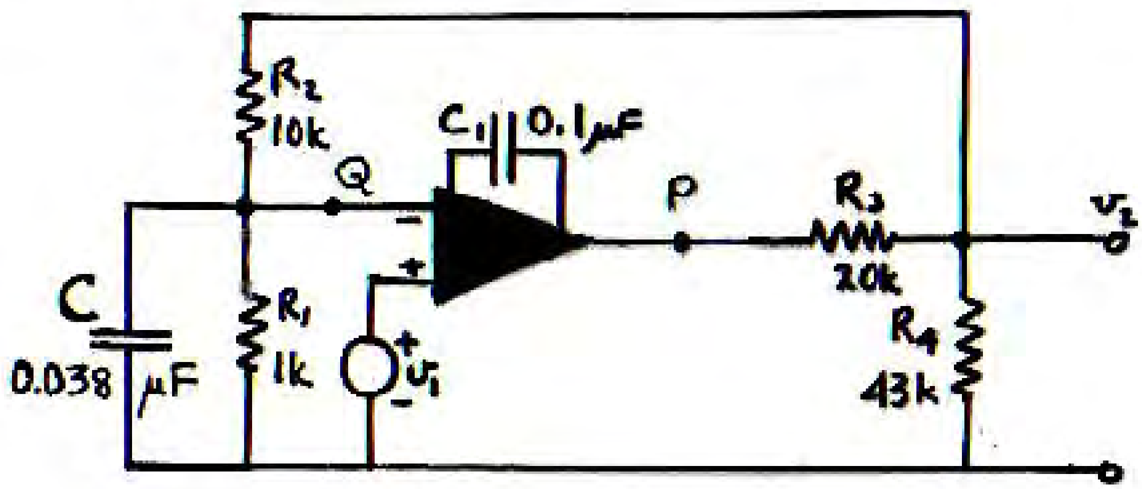
$Z_1 \equiv$ impedance looking forward from application/injection point
$Z_2 \equiv$ " " backward " " " "

To determine loop gain, both by signal application to a broken loop and by signal injection into a closed loop, the Z-ratio must be sufficiently small; the necessary inequalities are different:

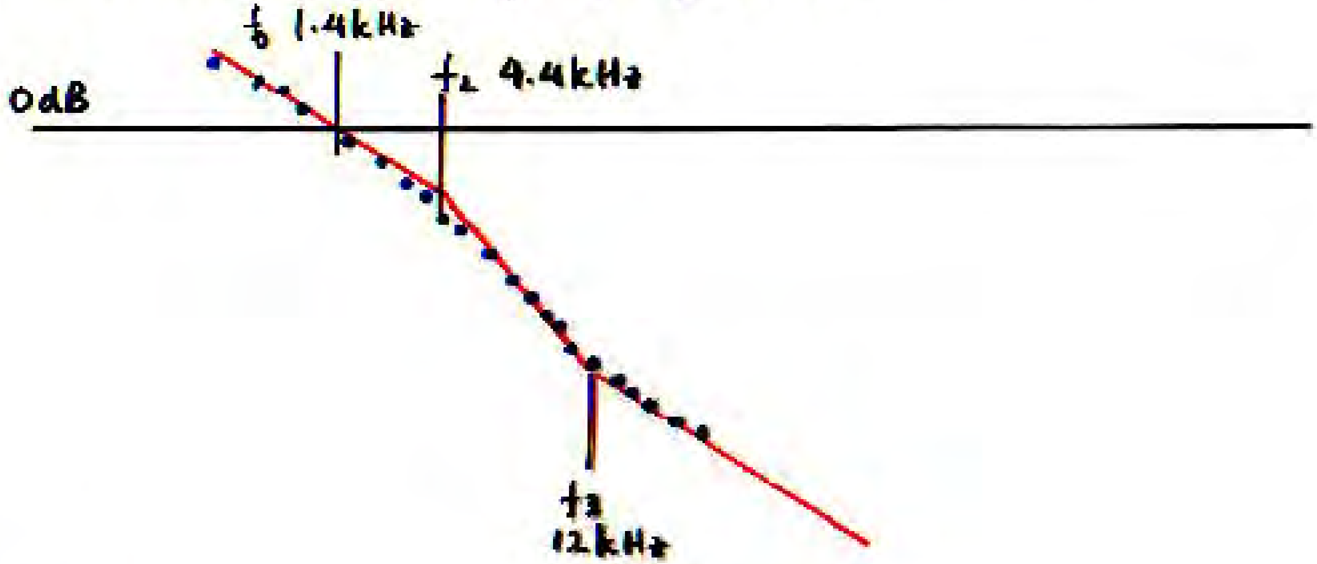
For signal application to a broken loop: Z-ratio $\ll 1$
For signal injection into a closed loop: Z-ratio $\ll 1$ and $\ll T$

The impedance of the signal source is irrelevant in all cases.

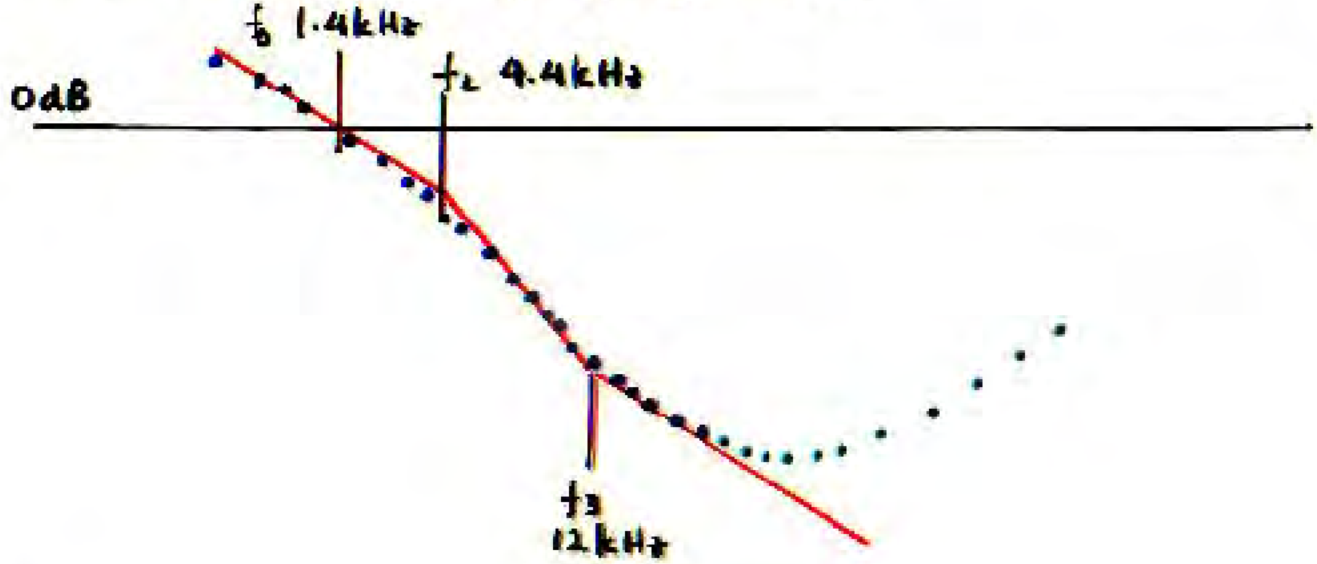
Example



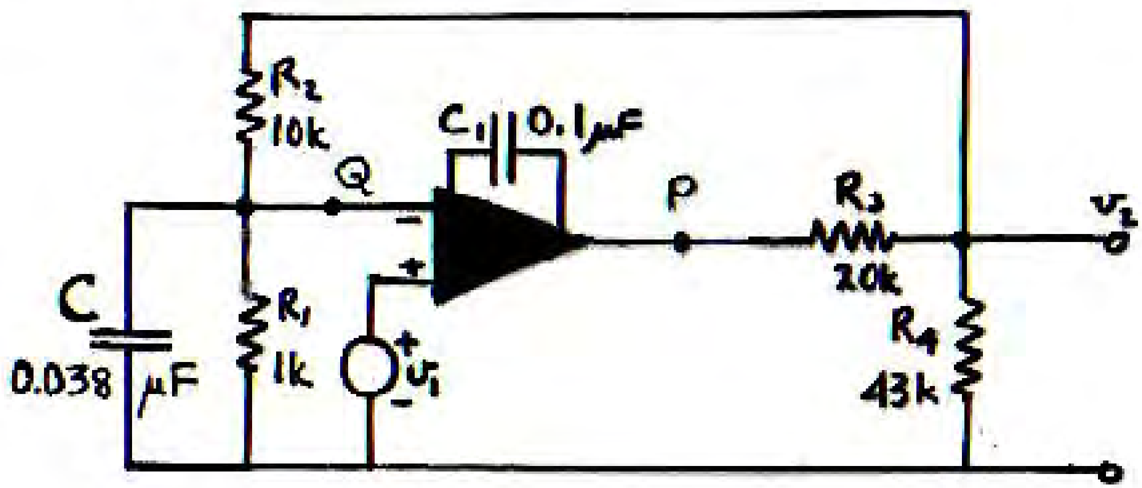
Example of T_v not being equal to T: the previous opamp circuit at high frequencies.

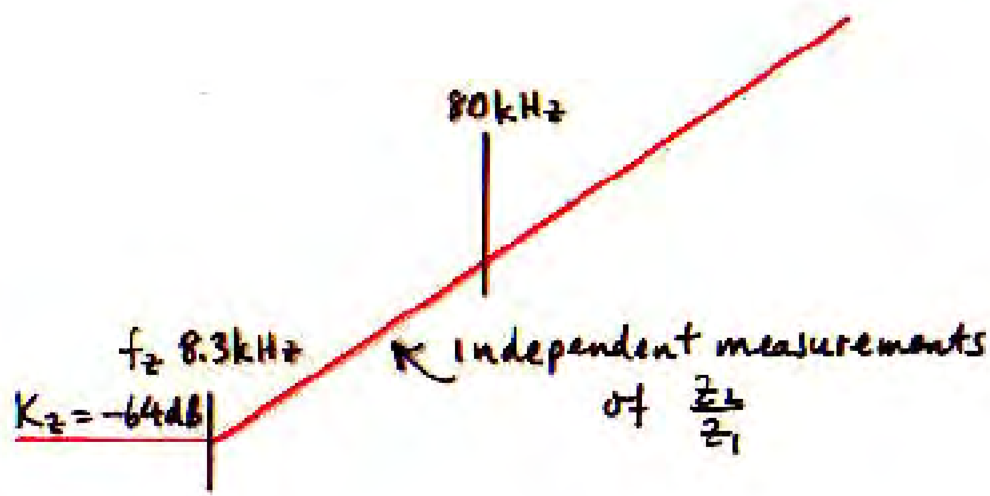


Example of T_v not being equal to T: the previous opamp circuit at high frequencies.



Example





80kHz
fz 8.3kHz
Kz = -64dB
independent measurements
of Z2/Z1

Analytically:

$$T_v = \left(1+\frac{Z_2}{Z_1}\right)T + \frac{Z_2}{Z_1} \approx T + \frac{Z_2}{Z_1}$$

$$= \frac{1-\frac{s}{\omega_3}}{\frac{s}{\omega_0}\left(1+\frac{s}{\omega_2}\right)} + K_z\left(1+\frac{s}{\omega_z}\right)$$

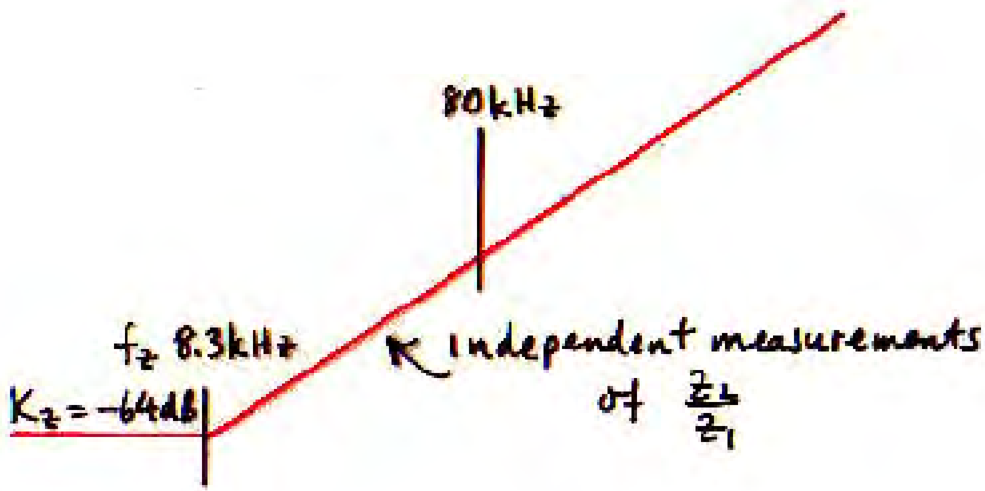
In the neighborhood of the crossover:

$$T_v = \frac{-\frac{s}{\omega_3}}{\frac{s}{\omega_0}\cdot\frac{s}{\omega_2}} + K_z\frac{s}{\omega_z}$$

$$= \frac{-\frac{s}{\omega_3}\left[1-\left(\frac{s}{\omega_c}\right)^2\right]}{\frac{s}{\omega_0}\cdot\frac{s}{\omega_2}}$$

where

$$\omega_c \equiv \sqrt{\frac{\omega_0\,\omega_2\,\omega_z}{K_z\,\omega_3}} \qquad f_c = 81\text{ kHz}$$



80kHz
f_z 8.3kHz
$K_z = -64$dB
independent measurements
of $\frac{Z_2}{Z_1}$

Analytically:

$$T_v = \left(1+\frac{Z_2}{Z_1}\right)T + \frac{Z_2}{Z_1} \approx T + \frac{Z_2}{Z_1}$$

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where

$$\omega_c \equiv \sqrt{\frac{\omega_0\,\omega_2\,\omega_z}{K_z\,\omega_3}}$$ $f_c = 81\text{ kHz}$

Example of T_v not being equal to T: the previous opamp circuit at high frequencies.