11

HOW TO MEASURE T

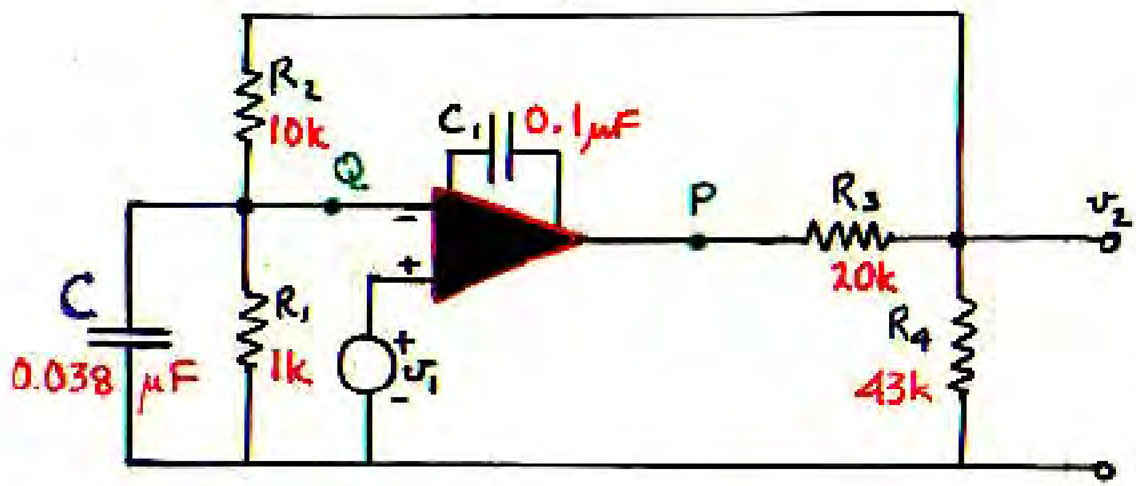
Measurement of Loop Gain

As for the calculation of loop gain, an injection point for the test signal must be found that satisfies two conditions:

1. Must be inside the feedback loop

2. Injected signal must add to the forward signal without affecting the impedance loading.

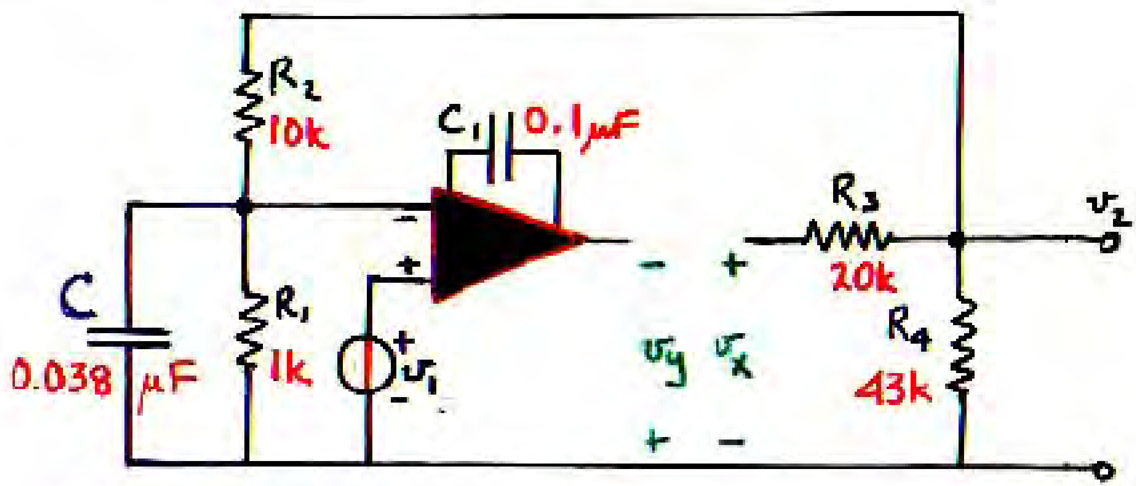
Example



Either point P or point Q could be used for series voltage injection; there is no suitable point for current injection.

Experimentally, P is preferable because the signal levels are higher.

Example

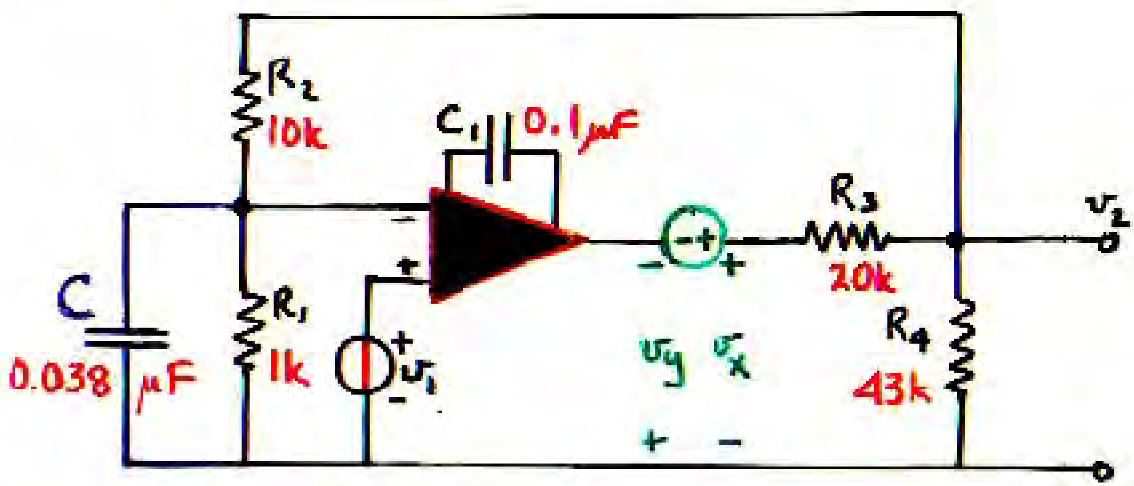


The loop gain $T = \left.\frac{v_y}{v_x}\right|_{v_1 = 0}$ can then be

measured in magnitude and phase by

standard instrumentation.

Example



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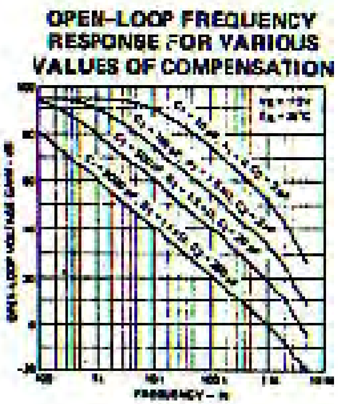
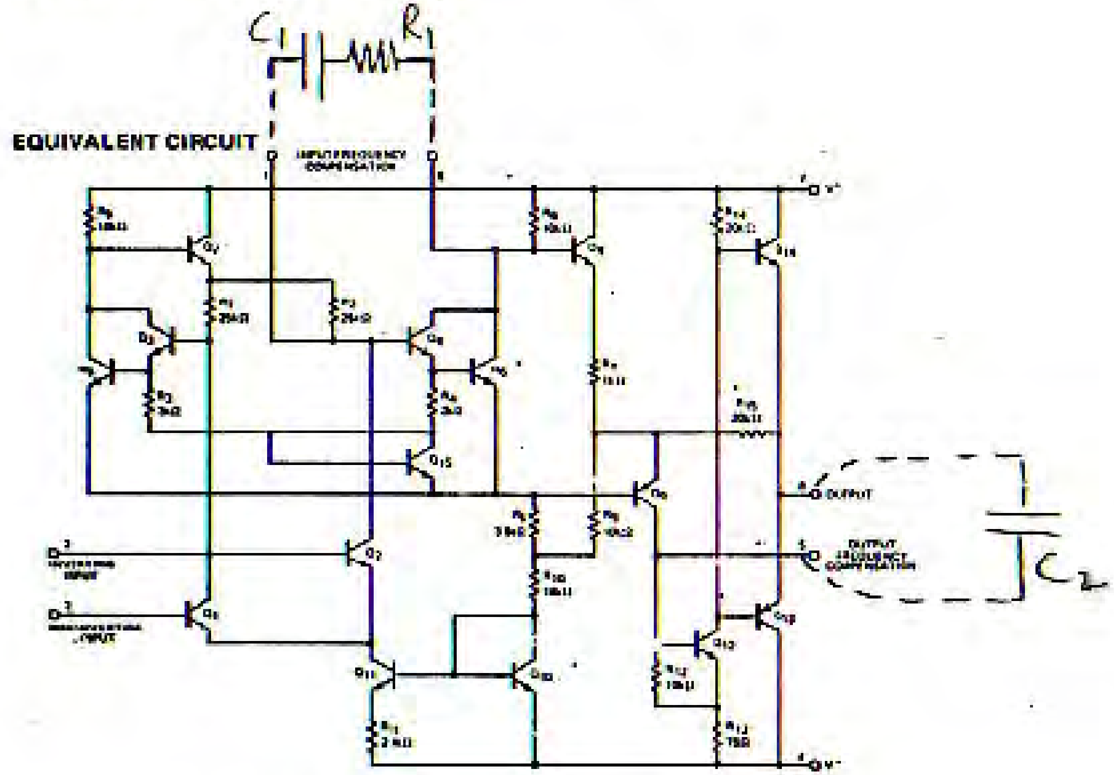
In the normal design-analyze-measure sequence, the loop gain T is first predicted analytically.





With a $0.005\,\mu F$ compensating capacitor C_1, the gain-bandwidth product is 1 MHz

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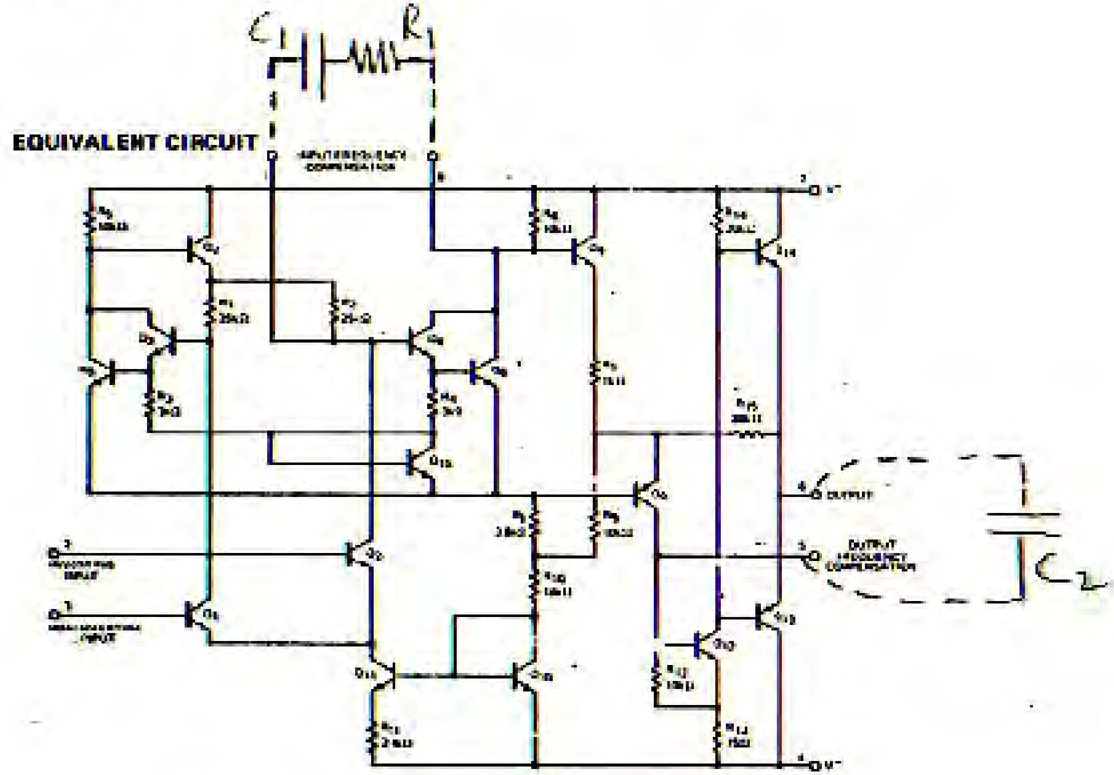
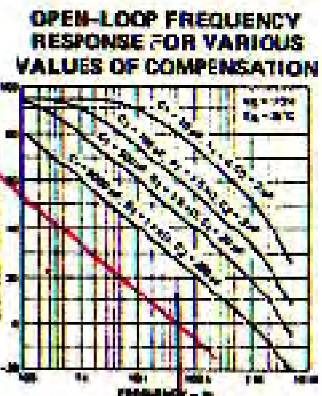


$|A_1|$

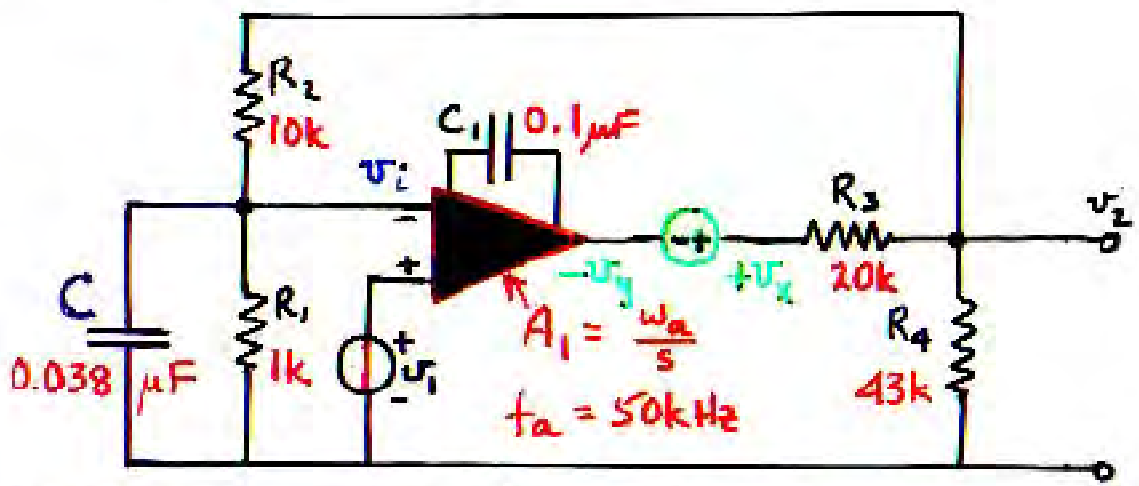


f_a 50kHz

With a $0.005\,\mu F$ compensating capacitor C_1, the gain-bandwidth product is 1 MHz. With $C_1 = 0.1\,\mu F$, the gbw product is $f_a = \frac{0.005}{0.1} \times 1 = 50\,kHz$.

So $\quad A_1 = \frac{\omega_a}{s}$

Example



Without C: $T = \frac{v_y}{v_x} = \frac{v_y}{v_i}\frac{v_2}{v_x}\frac{v_i}{v_2}$

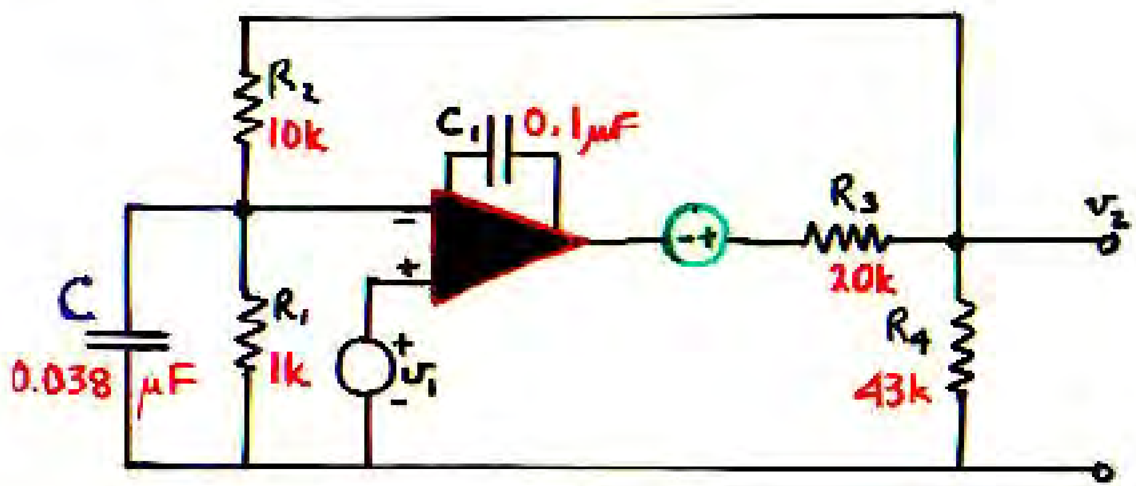
$$= A_1 A_2 K$$

$A_1 = \frac{\omega_a}{s}$ $\qquad A_2 = \frac{R_4 \| (R_1 + R_2)}{R_3 + R_4 \| (R_1 + R_2)}$ $\qquad K = \frac{R_1}{R_1 + R_2}$

$= 0.31$ $\qquad = 0.091$

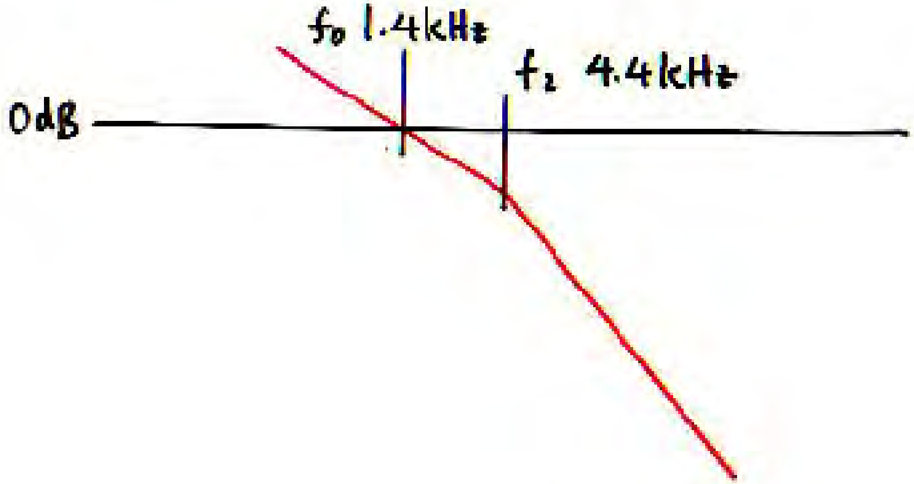
C introduces a pole at: $\omega_2 = \frac{1}{C[R_1 \| (R_2 + R_3 \| R_4)]}$ $\quad f_2 = 4.4$ kHz

Example

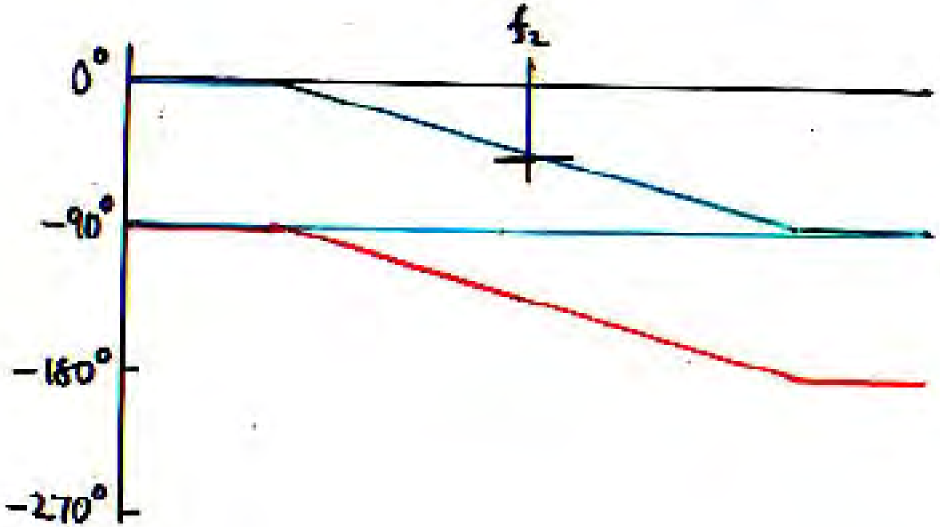


Hence
$$T = \frac{\omega_a}{s} A_2 K \frac{1}{1+\frac{s}{\omega_2}}$$
$$= \frac{1}{\frac{s}{\omega_0}\left(1+\frac{s}{\omega_2}\right)} \qquad \text{where } \omega_0 \equiv A_2 K \omega_a$$
$f_0 = 1.4\,\text{kHz}$

The Q of the closed-loop quadratic $D = T/(1+T)$ is
$$Q = \sqrt{\omega_0/\omega_2} = 0.56 \Rightarrow -5\,\text{dB}$$
and the phase margin is $\phi_M = 73°$

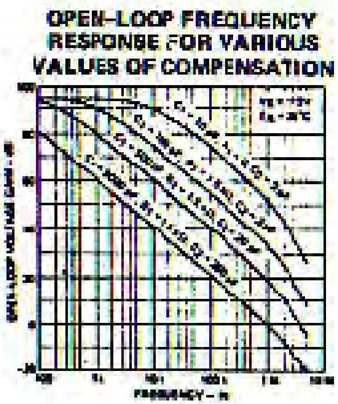


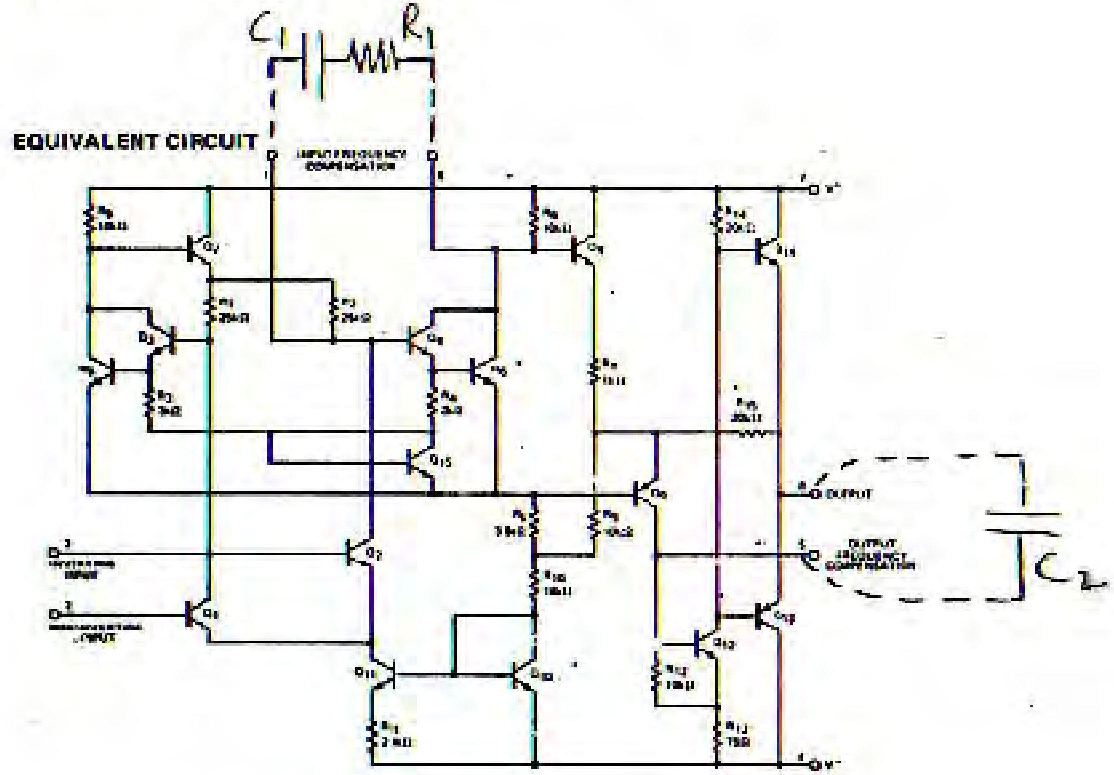
f0 1.4kHz
f2 4.4kHz
0dB



f2
0°
-90°
-180°
-270°

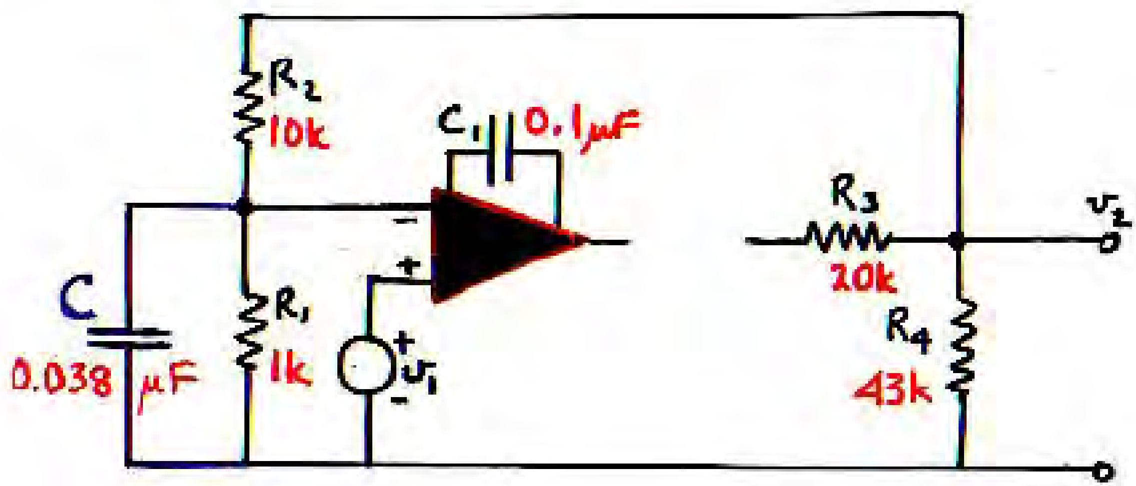
In the normal design-analyze-measure sequence, the loop gain T is first predicted analytically.



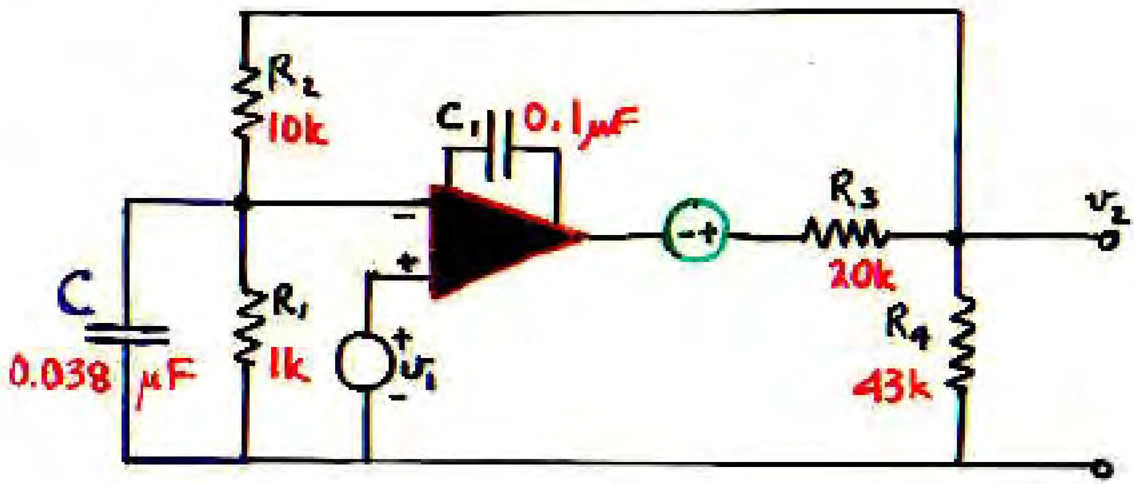


With a 0.005 uF compensating capacitor C_1, the gain-bandwidth product is 1 MHz

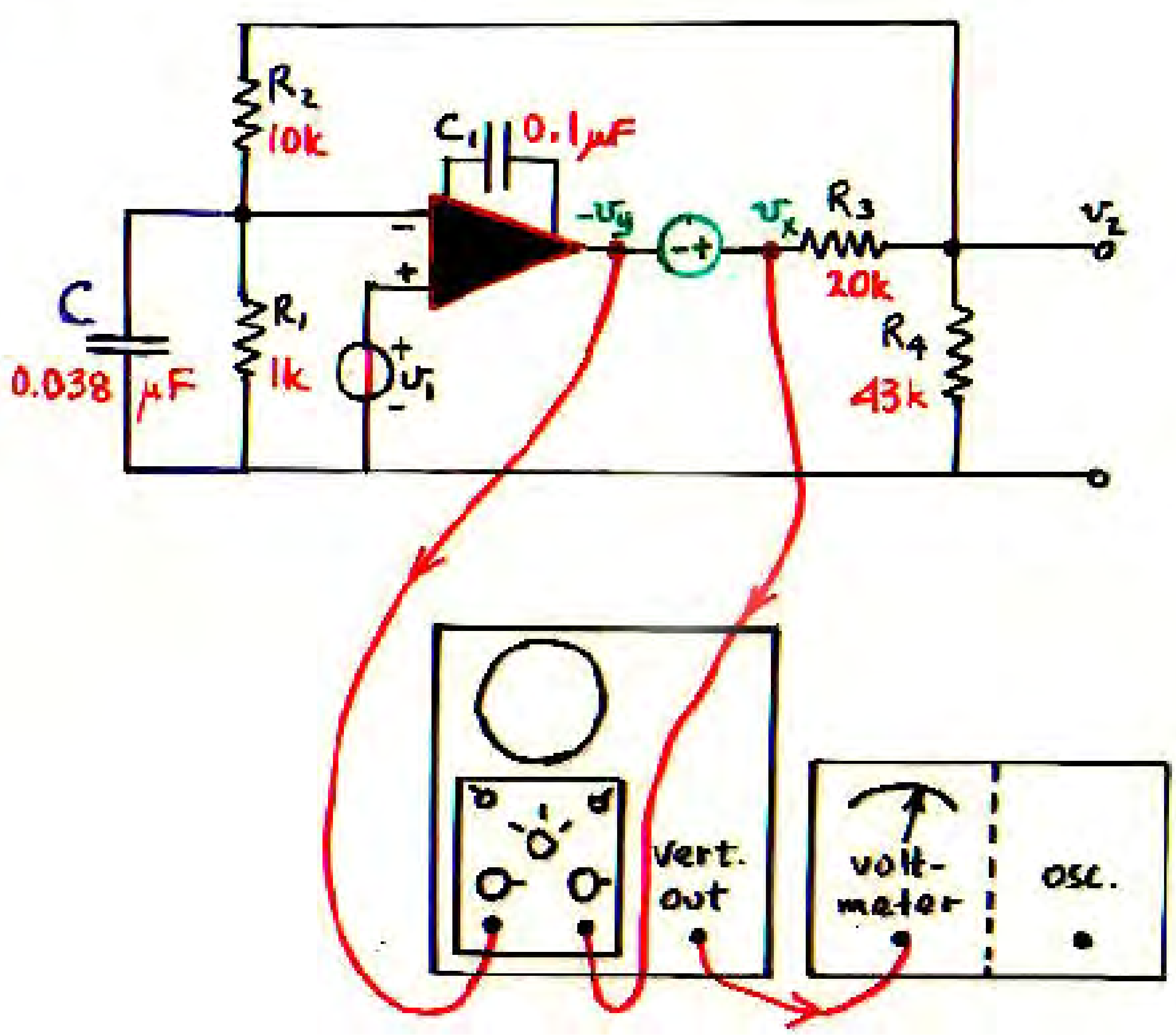
Example



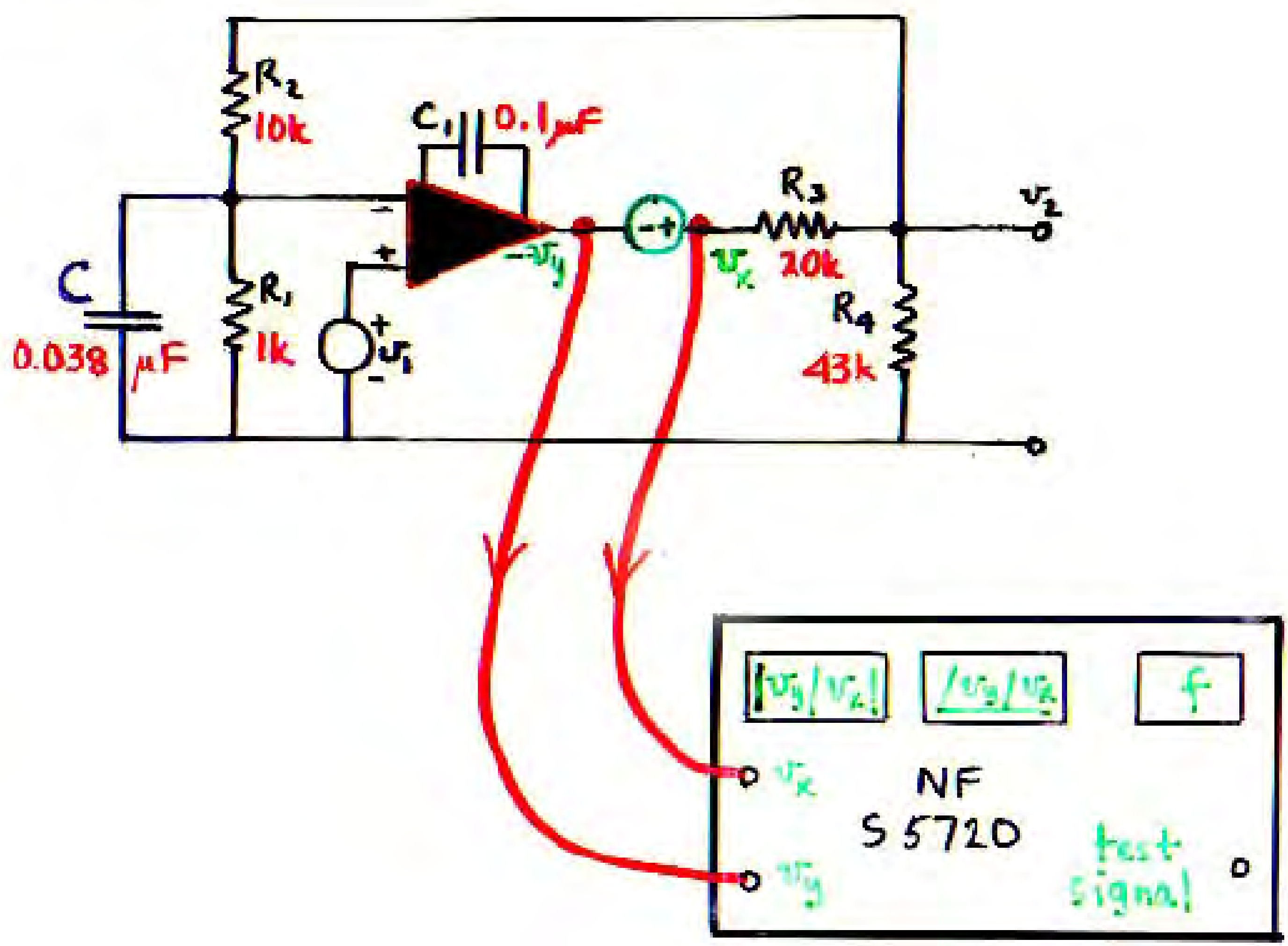
Example



Example Measurement instrumentation:

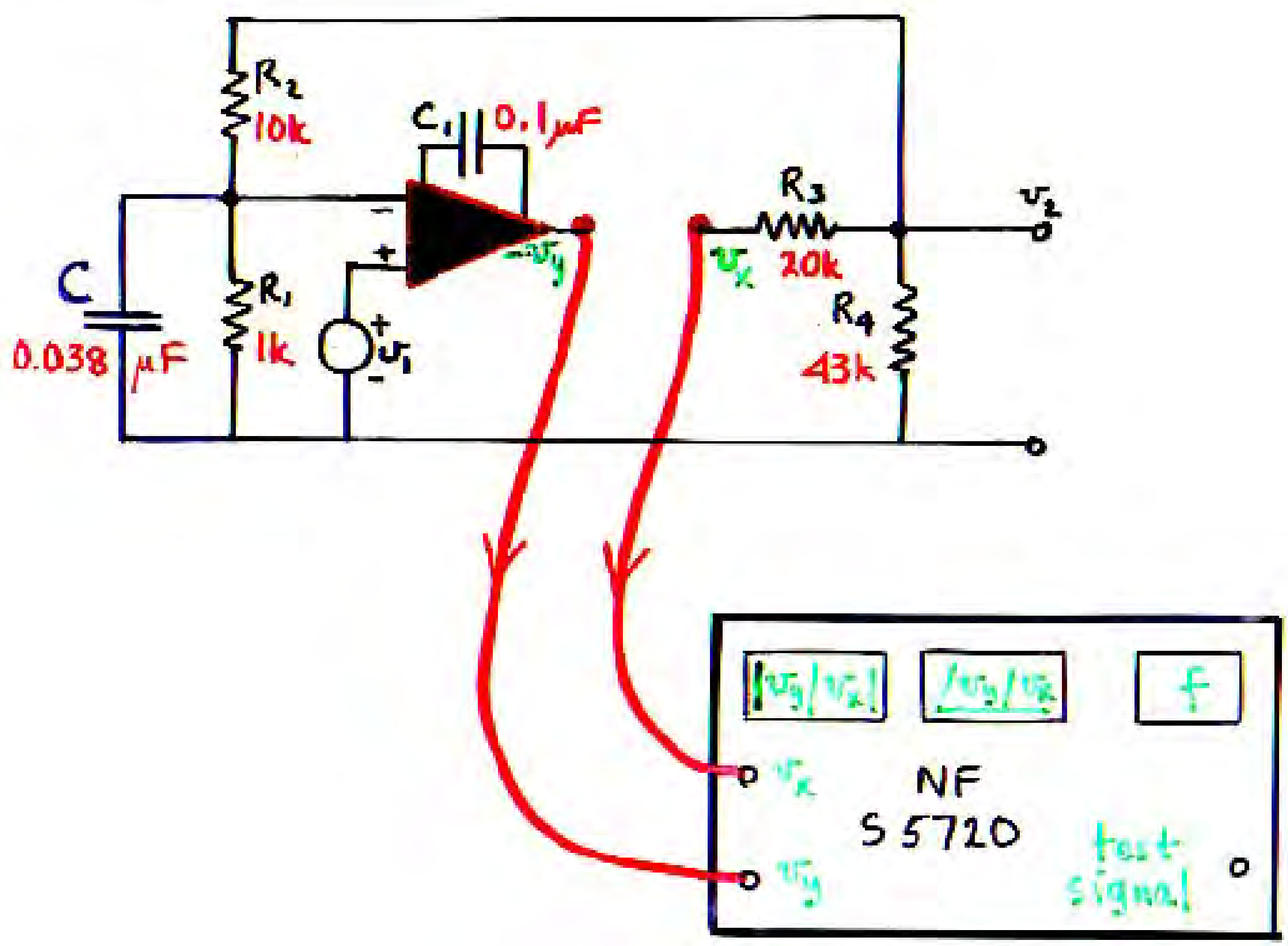


Example



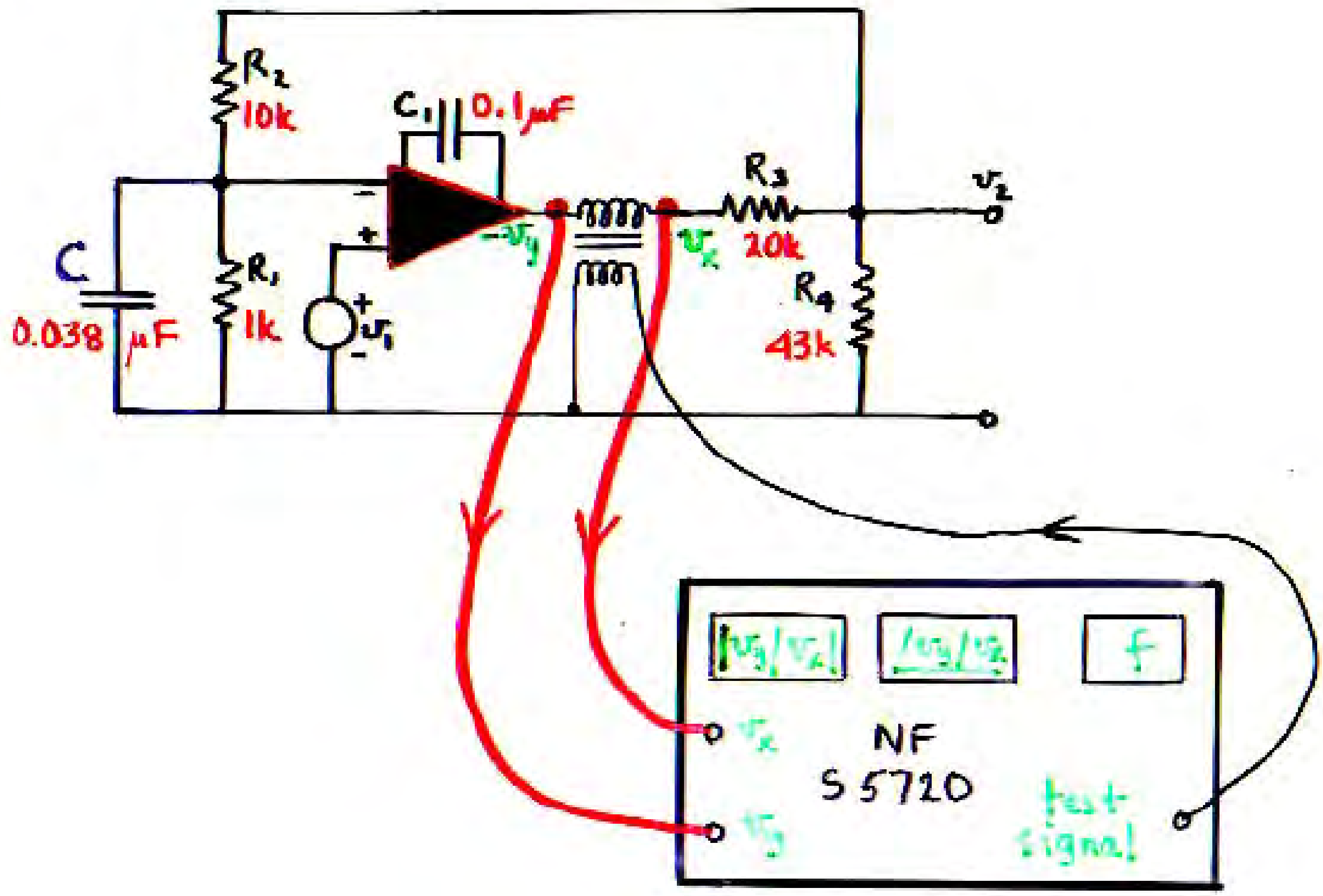
R2
10k
C1
0.1μF
R3
20k
v2
C
0.038 μF
R1
1k
v1
-vy
vx
R4
43k
|vy/vx|
∠vy/vx
f
vx
vy
NF
S 5720
test signal

Example



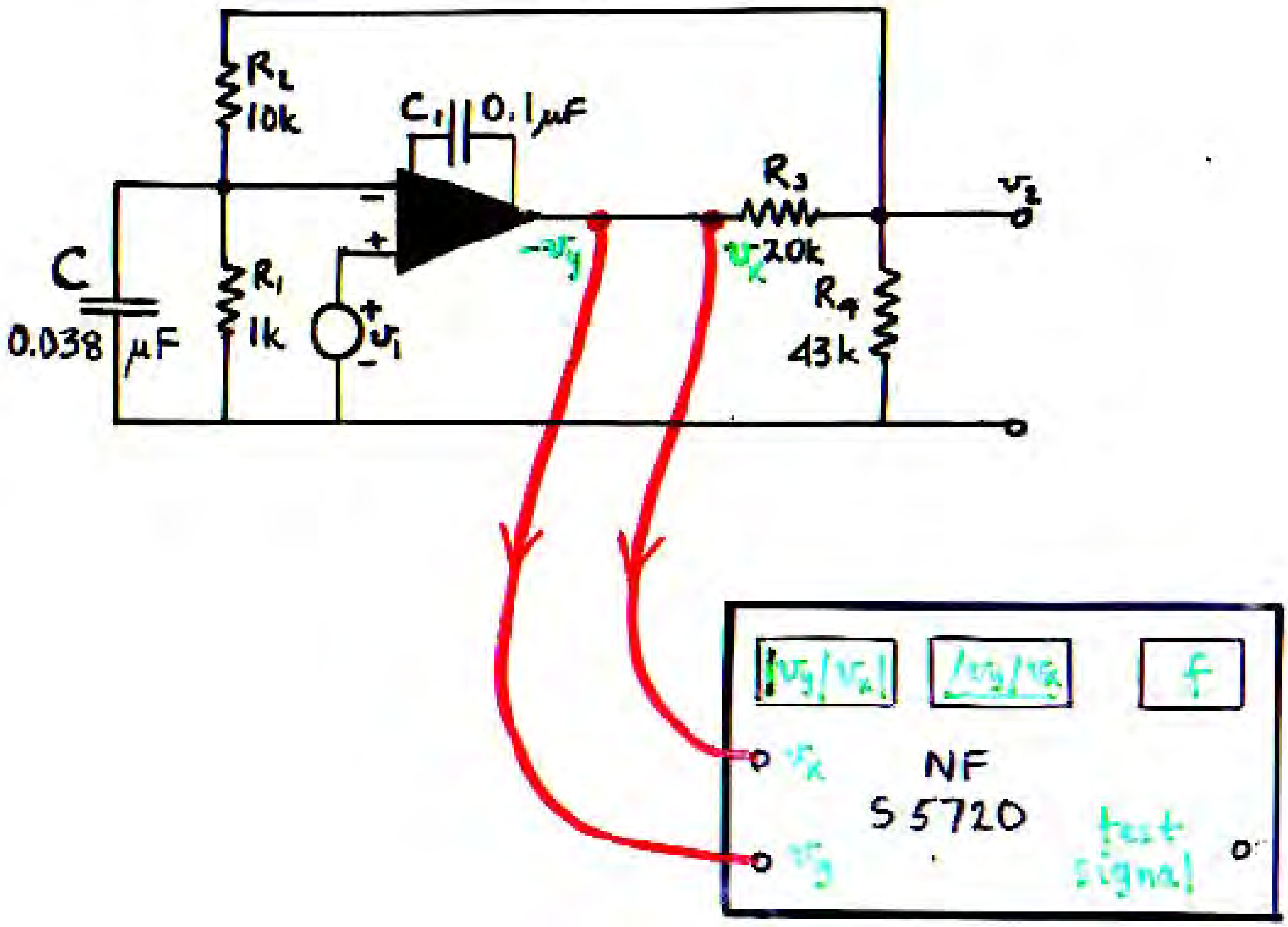
R_2
10k
C_1
0.1 μF
R_3
20k
v_2
v_y
v_x
C
0.038 μF
R_1
1k
v_1
R_4
43k
$|v_y/v_x|$
$\angle v_y/v_x$
f
v_x
v_y
NF
S 5720
test
signal

Example



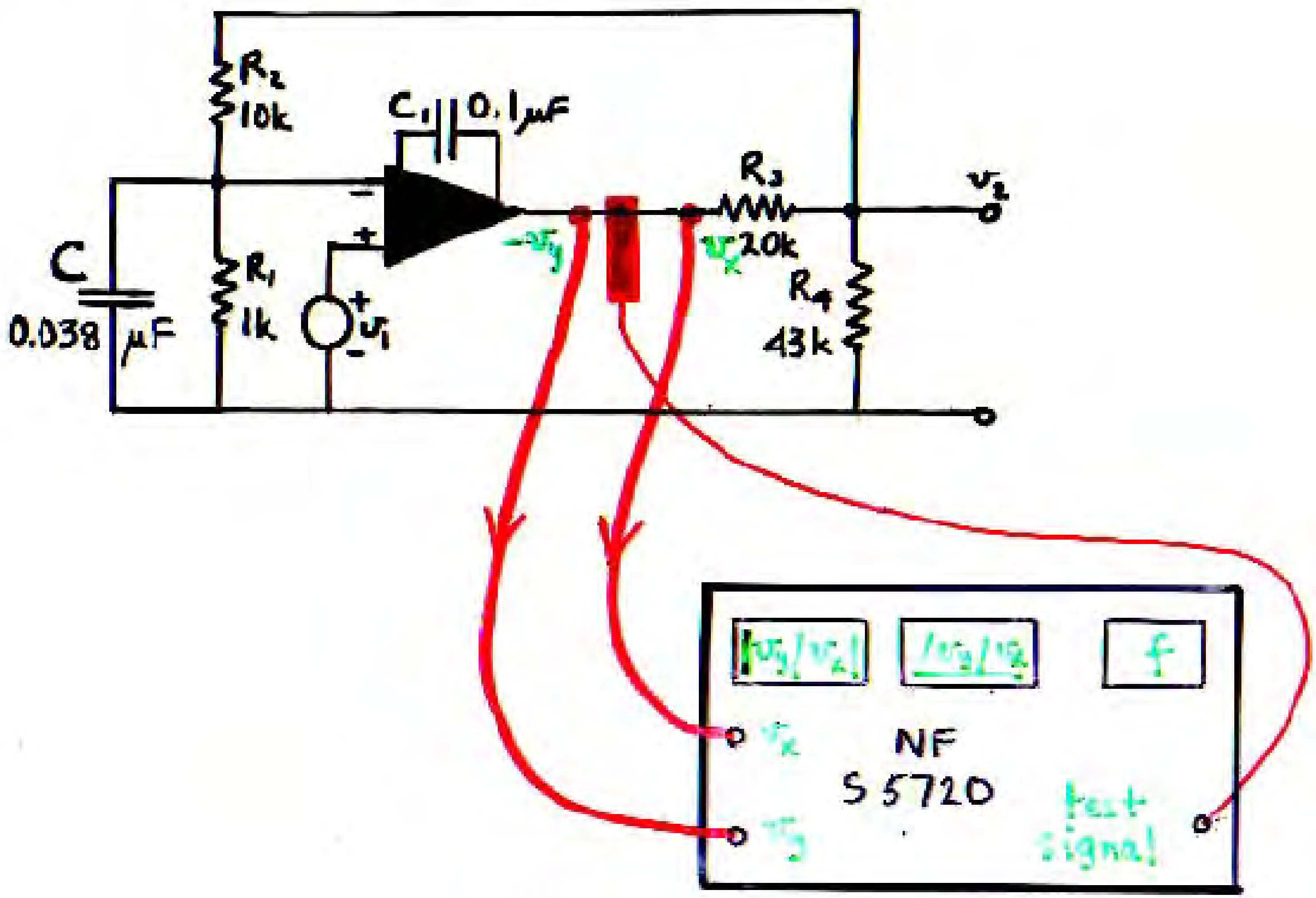
An isolation transformer is needed to couple in the injected signal.

Example



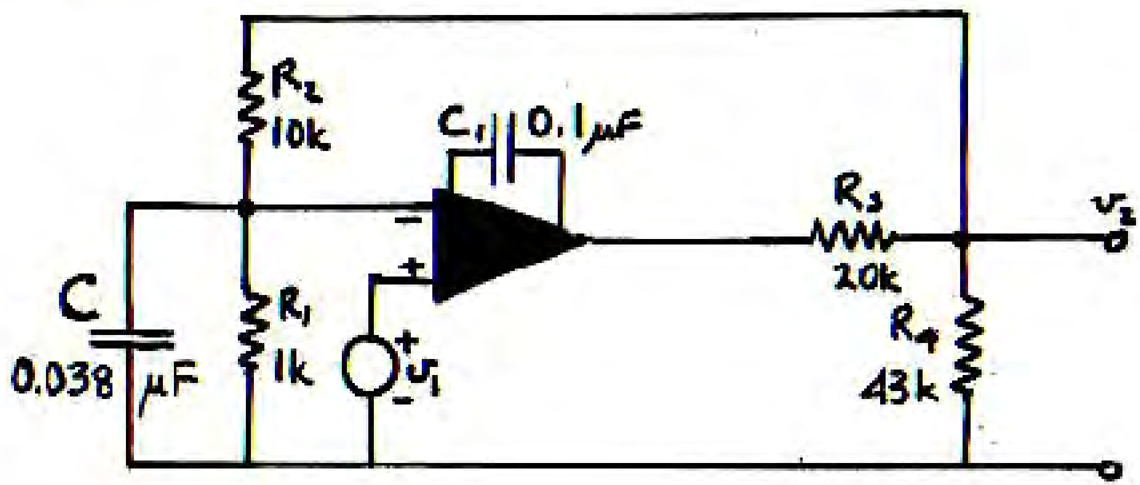
C_1 0.1μF
R_2 10k
R_3
20k
R_4 43k
R_1 1k
C
0.038 μF
v_1
v_2
$-v_y$
v_x
$|v_y/v_x|$
$\angle v_y/v_x$
f
v_x
v_y
NF
S 5720
test signal

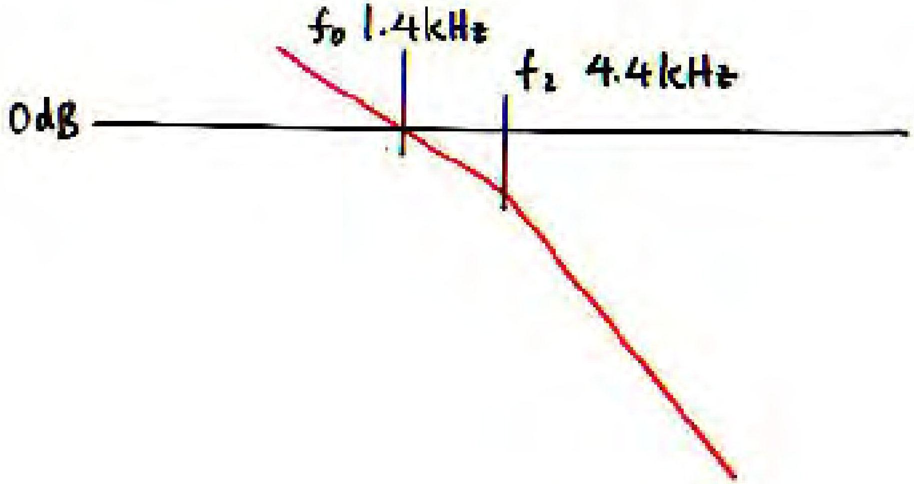
Example

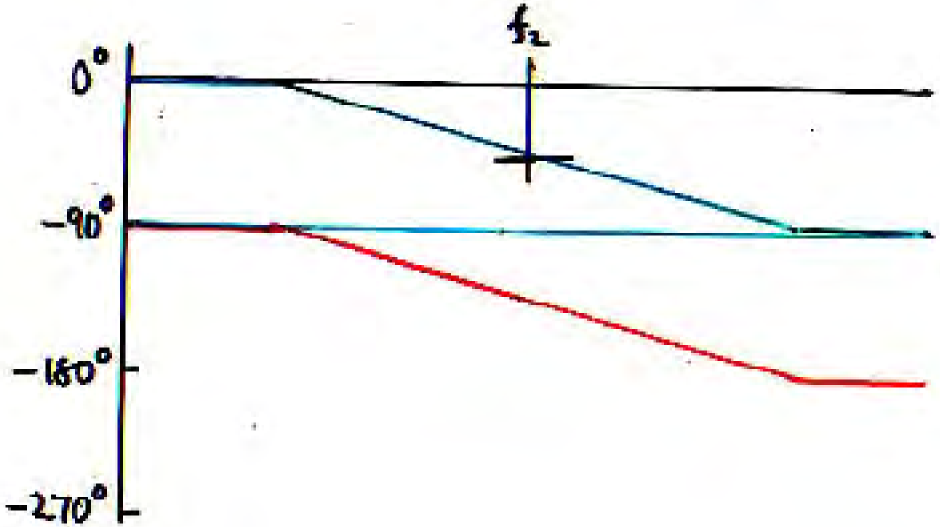


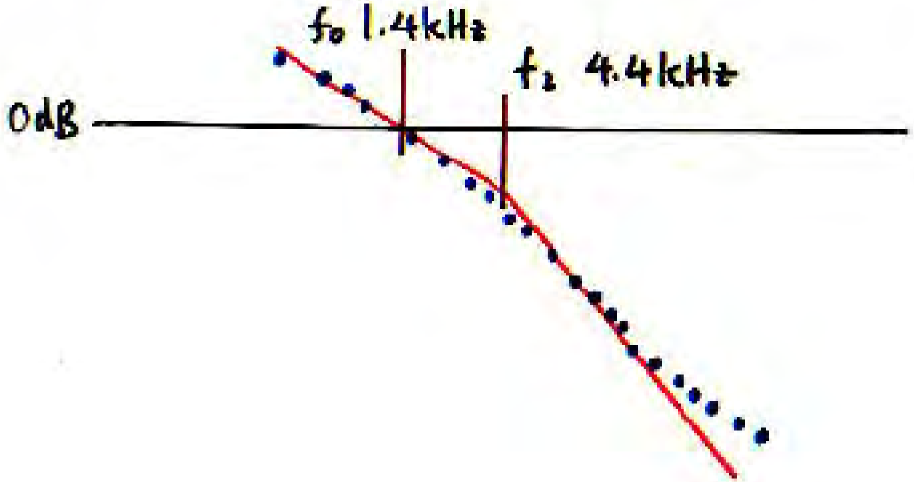
R_2
10k
C_1
0.1μF
R_3
20k
v_2
C
0.038 μF
R_1
1k
v_1
$-v_y$
v_x
R_4
43k
$|v_y/v_x|$
$\angle v_y/v_x$
f
v_x
v_y
NF
S 5720
test signal

Example

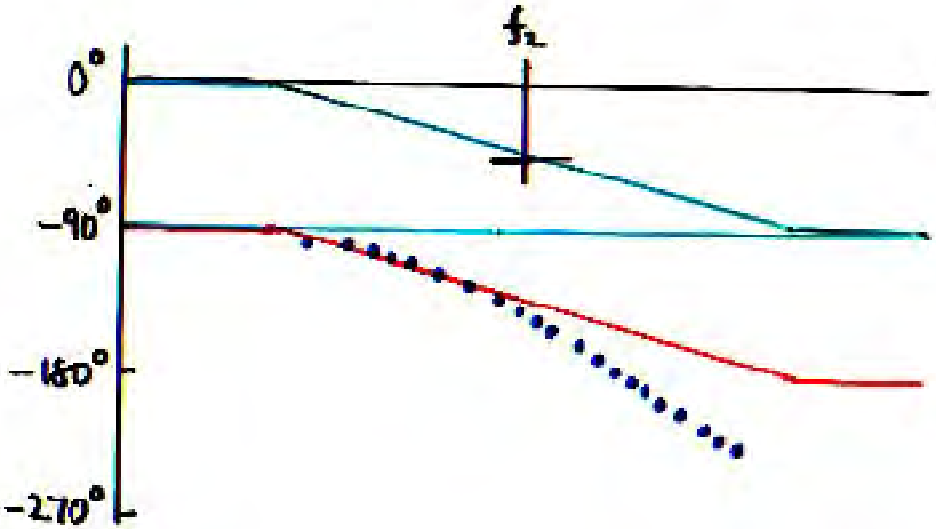



f0 1.4kHz
f2 4.4kHz
0dB

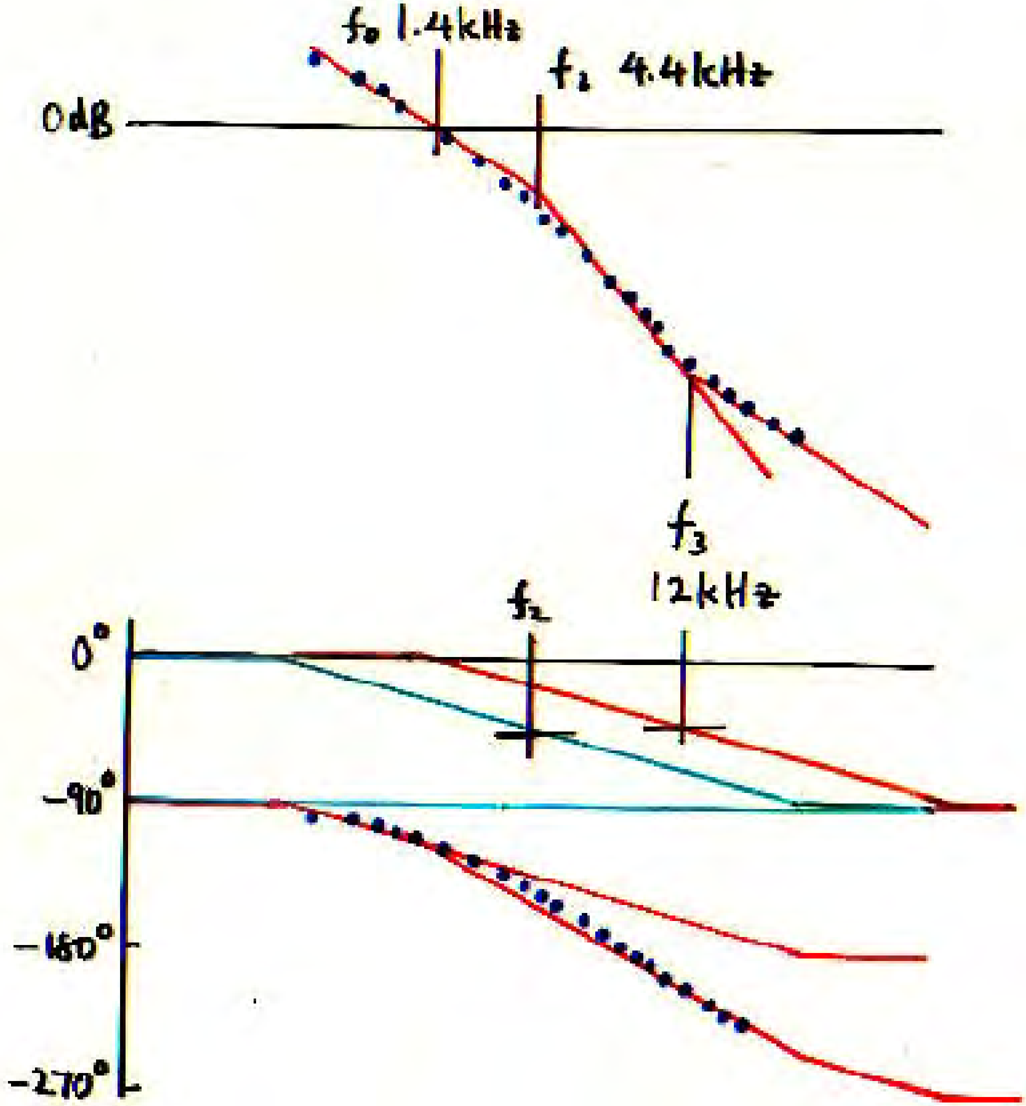

f2
0°
-90°
-180°
-270°



f0 1.4kHz
f2 4.4kHz
0dB



f2
0°
-90°
-180°
-270°



f0 1.4kHz
f1 4.4kHz
0dB
f3
12kHz
f2
0°
-90°
-180°
-270°

Measurements indicate a right half-plane zero at $f_3 = 12\ \text{kHz}$.

Hence the actual loop gain is

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

and the actual phase margin is

$$\phi_M = 73^\circ - \tan^{-1}\frac{\omega_0}{\omega_3} = 73^\circ - 7^\circ = 66^\circ$$

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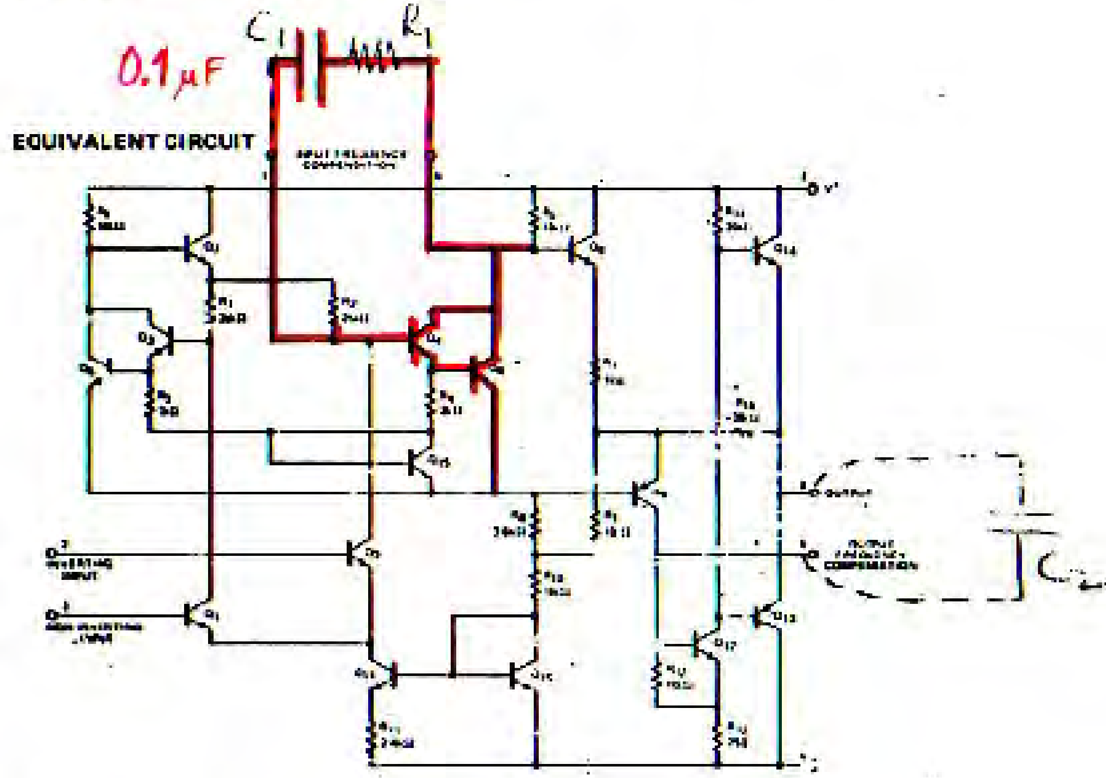
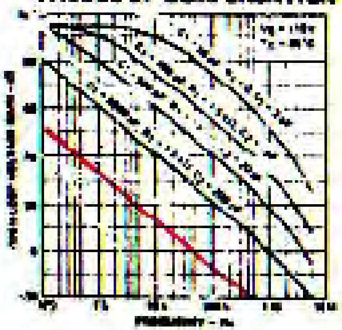




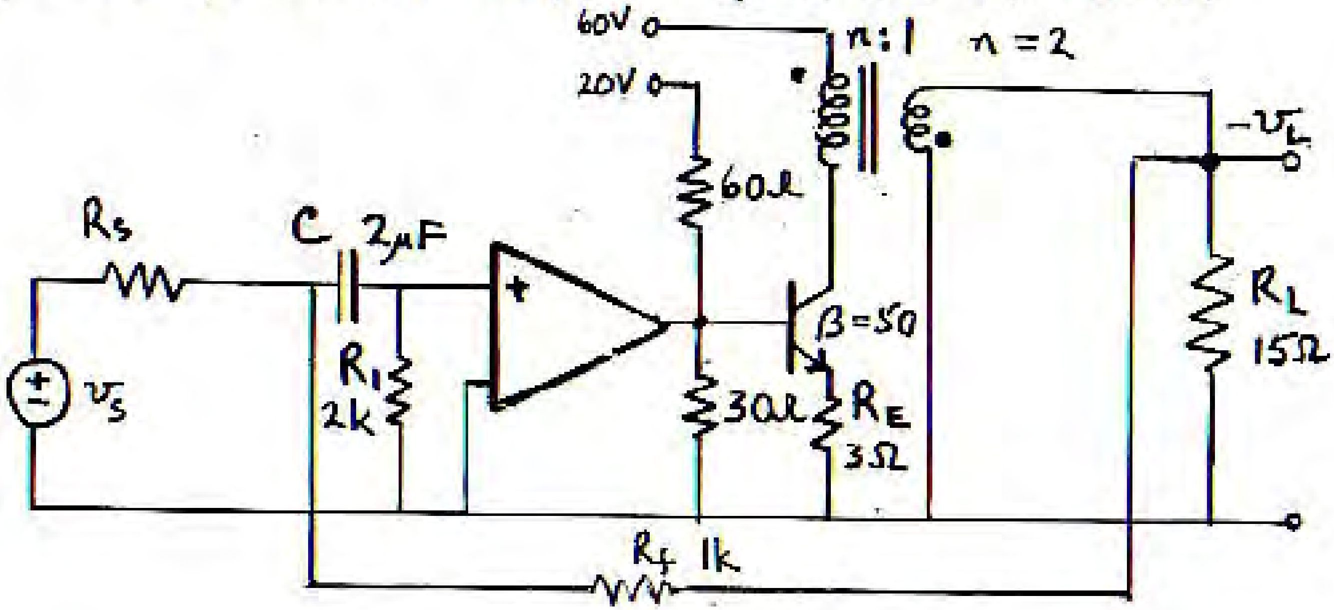
With ~ 0.005 μF compensating capacitor C_1, the gain-bandwidth product is 1 MHz

Generalization: Implementation of Series Voltage Injection of Loop Gain Test Signal

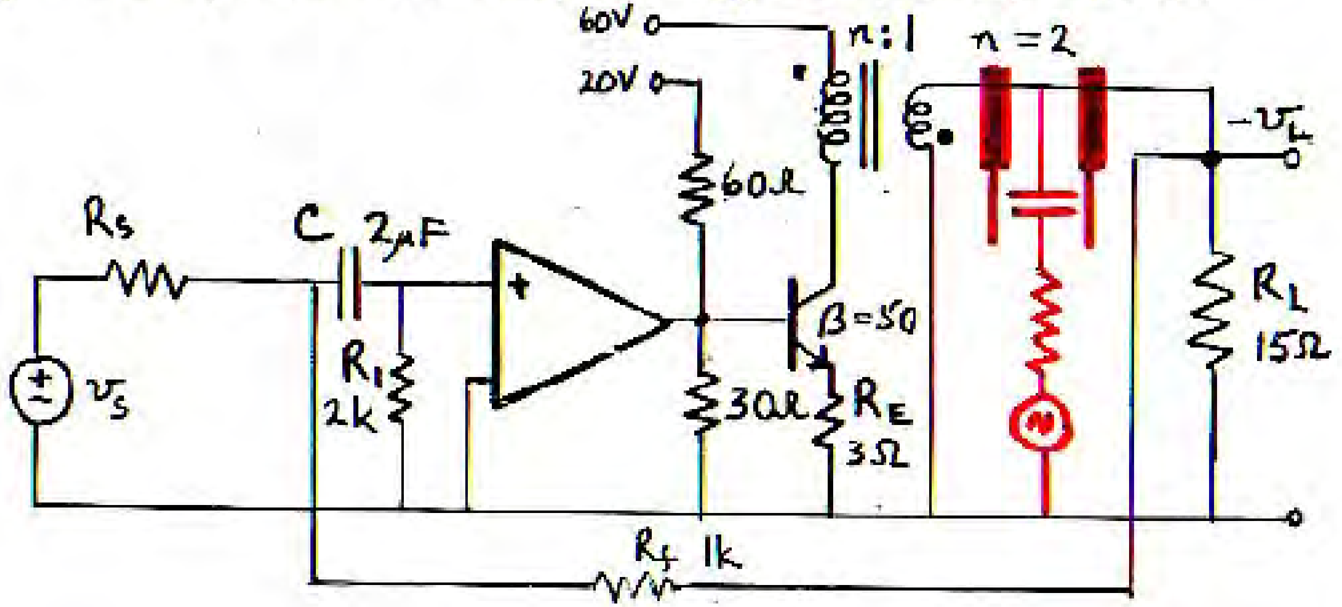
The necessary floating injection signal can be obtained from a grounded source by "backwards" use of an ac current probe as a "one-turn secondary isolation transformer."

Higher signal injection can be obtained by wrapping more than one secondary turn around the probe.

Single-ended Class A audio feedback power amplifier, based on the same power stage previously discussed. The driver opamp has a gain $A_1 = A_{10}/((1+s/\omega_A)$, where $A_{10} = 8dB$ and $f_A = 2kHz$, and an output impedance of 4.5Ω



Single-ended Class A audio feedback power amplifier, based on the same power stage previously discussed. The driver opamp has a gain $A_1 = A_{10}/(1+s/\omega_A)$, where $A_{10} = 8\,dB$ and $f_A = 2\,kHz$, and an output impedance of $4.5\,\Omega$.



Injection at a non-ideal point:

There are two conditions upon the choice of injection point:

1. Must be inside the feedback loop
2. Injected signal must add to the forward signal without affecting the impedance loading.

What happens if #2 is not satisfied?

Single-ended Class A audio feedback power amplifier, based on the same power stage previously discussed. The driver opamp has a gain $A_1 = A_{10}/((1+s/\omega_A)$, where $A_{10} = 8dB$ and $f_A = 2kHz$, and an output impedance of 4.5Ω