PHYSICS 364, 2010-10-18

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We'll cover a few more bipolar-junction transistor circuits today, mostly linear / amplifier-related.

Next week we'll introduce FETs, and we'll focus on transistor circuits that basically work as switches — ON or OFF — vs. linear behavior.

For next week, read either HH ch. 3 or Bugg FET material in ch 10, §17.7, §18.11. We'll do a quiz that covers only material through this week (BJTs).

One note from last Thursday:

$$\frac{dI_C}{dV_{BE}} = \frac{I_C}{25\,\text{mV}} \implies \frac{dV_{BE}}{d(\log_{10}(I_C))} = 2.3 \times 25\,\text{mV} \simeq \boxed{60\,\text{mV}/\text{decade}}$$

(at room temperature)

(on the lab board, I had forgotten that $\log(10) \simeq 2.3$!)

BJT circuits today

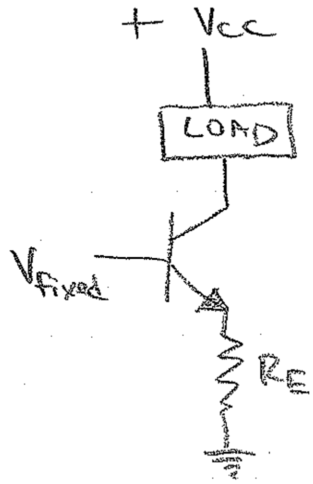
- current source
- switch
- current mirror
- differential amplifier
- simple opamp

Lab #5 is now due on 10-25 (merge w/ #6)

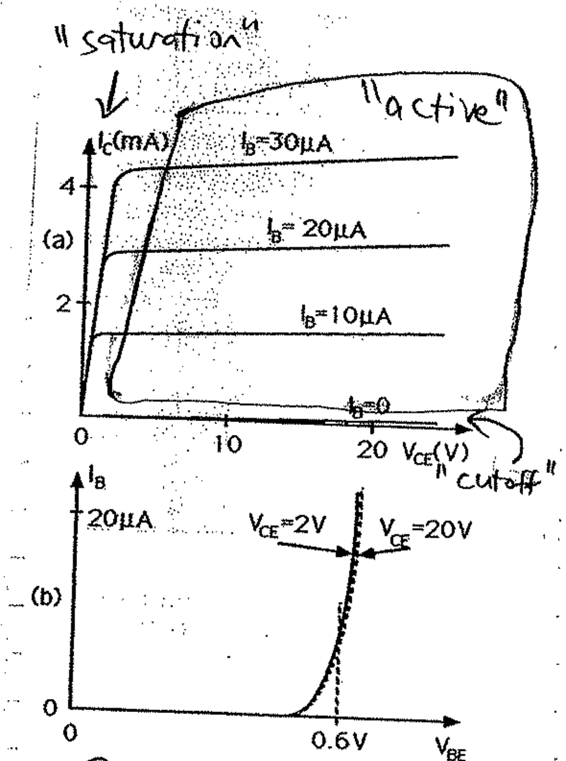
Optional parts are now required.

I will write up differential amplifier, etc., as add-ons to Lab #5/6.

② BJT current source



$$I_C \simeq I_E = \frac{V_{fixed} - V_{BE}}{R_E}$$



Bugg.

Fig. 9.30. Characteristics of the bipolar transistor.

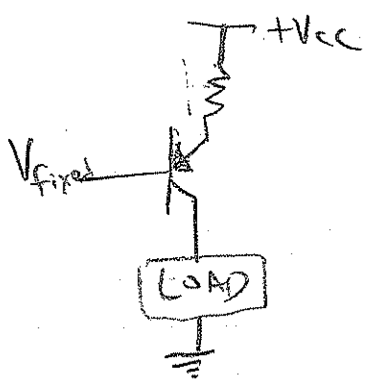
Notes:

- only works as long as V_{CE} stays out of saturation region.
- $\frac{dV_{CE}}{dI_C}$ = source impedance

  is large but not infinite.

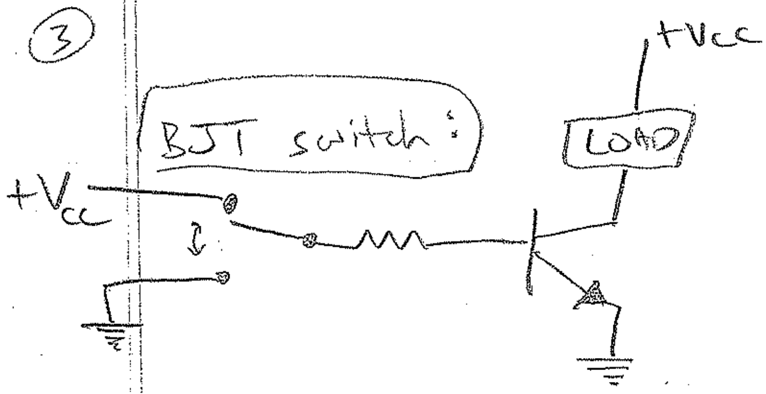
  (Ideal current source has $R_{out} = \infty$.)

Can use PNP for true current source (vs. current "sink" shown above):



③

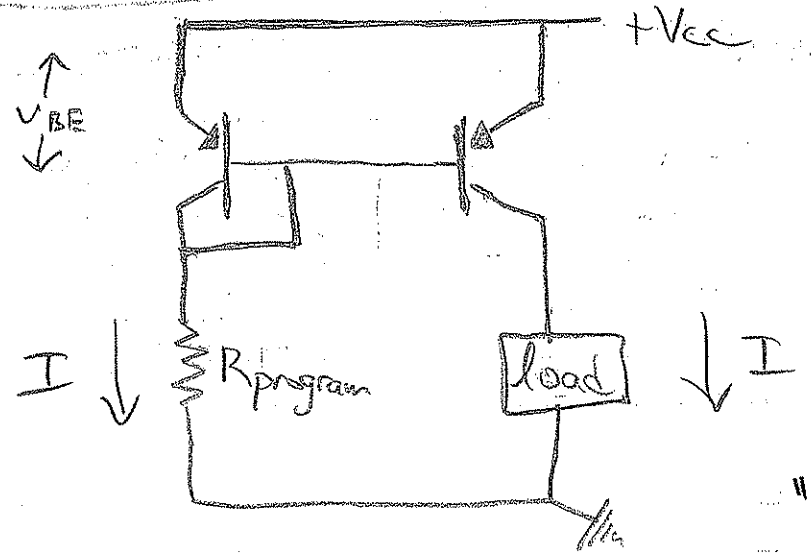
BJT switch:



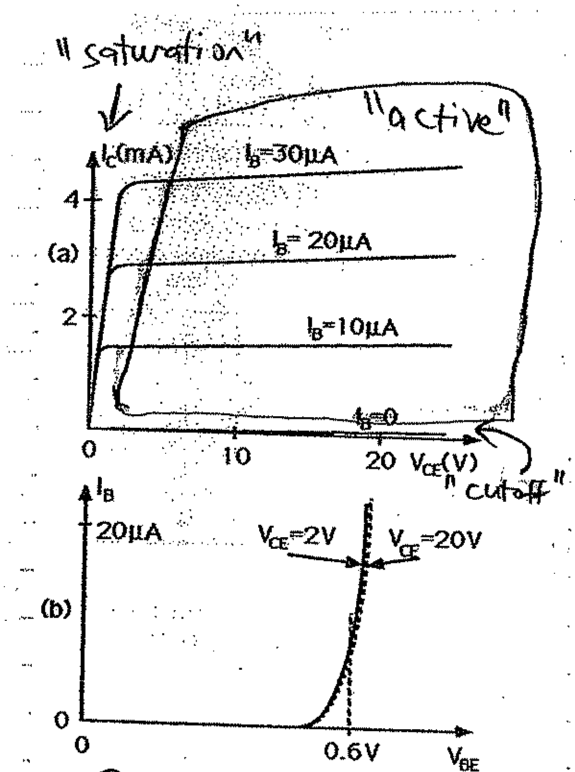
drive base either down to cutoff or up to saturation.

(much more on transistor switches next week)

current mirror



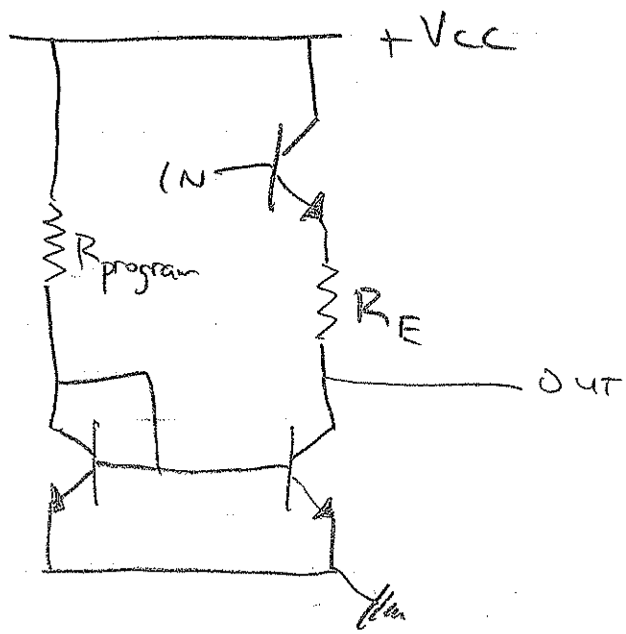
Again, finite (though very large) impedance because I_c vs. V_{CE} is not quite flat ("Early effect")



Bugg.

Fig. 9.30. Characteristics of the bipolar transistor.

(4) Cute current mirror application (from Bugg's book): level shifter



$$I = \frac{V_{CC} - V_{BE}}{R_{program}} \; ; \quad V_{OUT} = V_{IN} - V_{BE} - I \cdot R_E$$

DIGRESSION: corny emitter follower mnemonic from Hayes & Horowitz

Hayes & Horowitz

And here is a corny mnemonic device to describe this impedance-changing effect. Imagine an ill-matched couple gazing at each other in a dimly-lit cocktail lounge—and gazing through a rose-colored lens that happens to be a follower. Each sees what he or she wants to see:

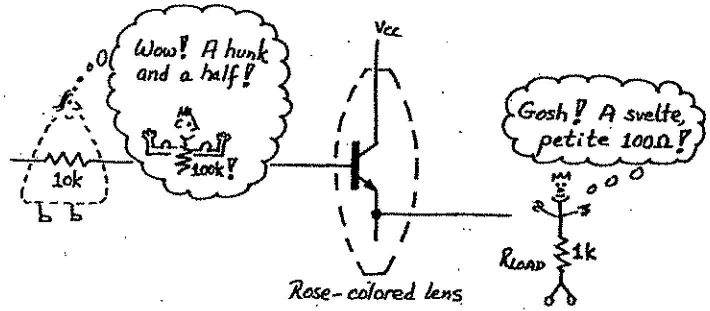
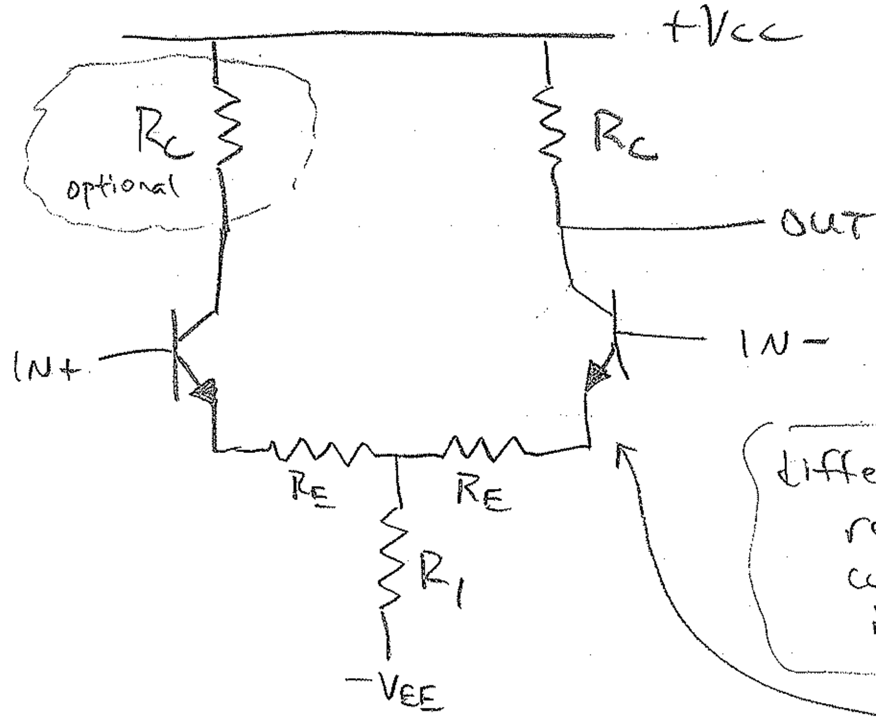


Figure N4.4: Follower as rose-colored lens: it shows what one would *like* to see

(5) Differential amplifier ("long-tailed pair")



differential ⇒ reject interference common to two inputs

include "r_e" from transistor

differential signal: $v \equiv \Delta V_+ - \Delta V_-$

$\Delta V_{IN}^+ = v/2$, $\Delta V_{IN}^- = -v/2$

$$\Delta I_c^- = \Delta V^- / R_E \Rightarrow \Delta V_{OUT} = -\frac{\Delta V^- \cdot R_c}{R_E + r_e} = \frac{v R_c}{2(R_E + r_e)}$$

common-mode signal: $v \equiv \Delta V^+ = \Delta V^-$

$$\Delta I_c^+ = \Delta I_c^- = v/(R_E + r_e + 2R_1) \Rightarrow \frac{v_{OUT}}{v_{cm}} = -\frac{R_c}{2R_1 + R_E + r_e}$$

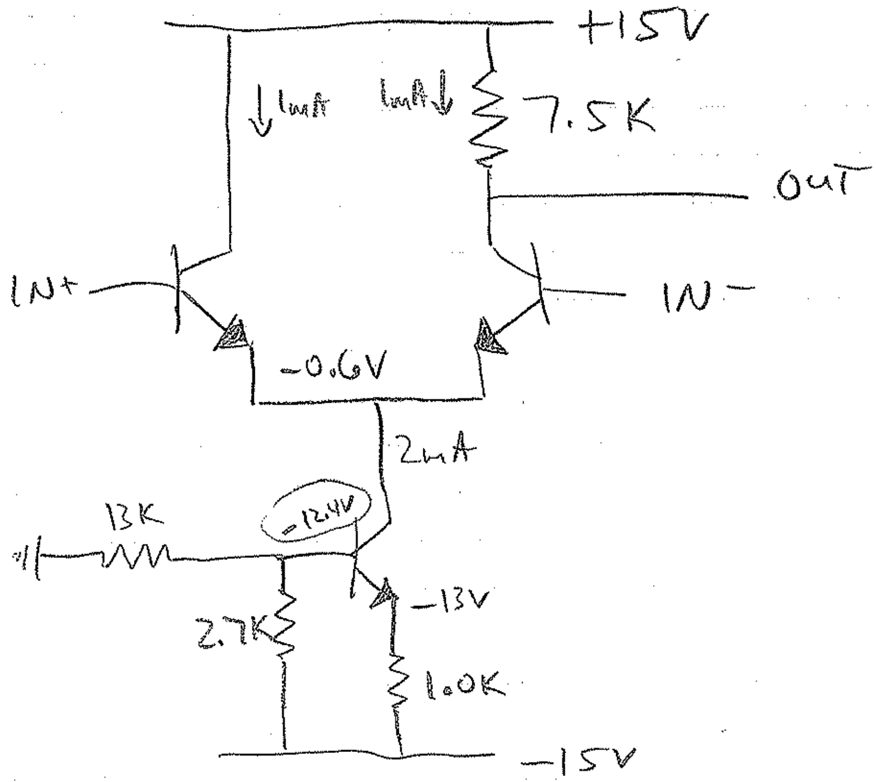
$$CMRR = \frac{2R_1 + R_E + r_e}{2(R_E + r_e)} \rightarrow \frac{R_1}{R_E + r_e} \text{ for } R_1 \gg R_E$$

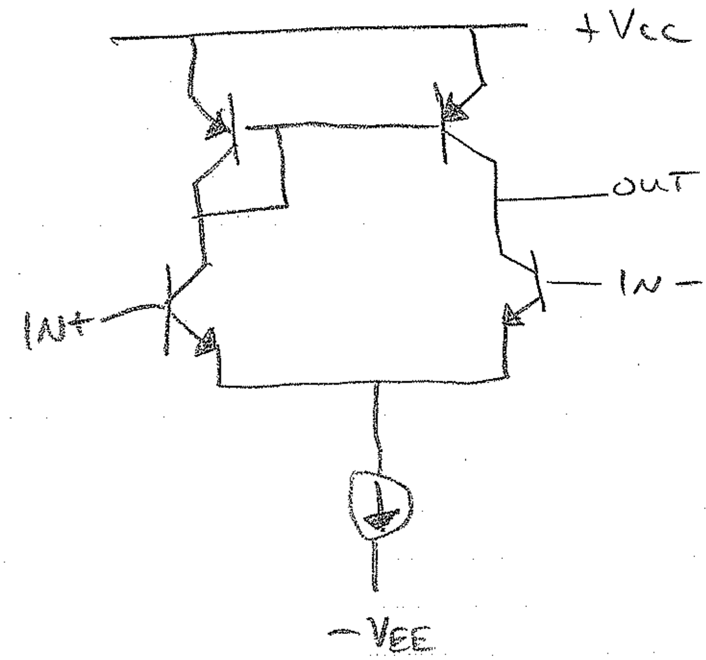
(recall $r_e = \frac{25\,mV}{I_c}$ from diode curve slope)

- Best CMRR ⇒ remove R_E and replace R_1 with current source
- Highest gain ⇒ replace R_c with current mirror

(6)

Differential amp examples

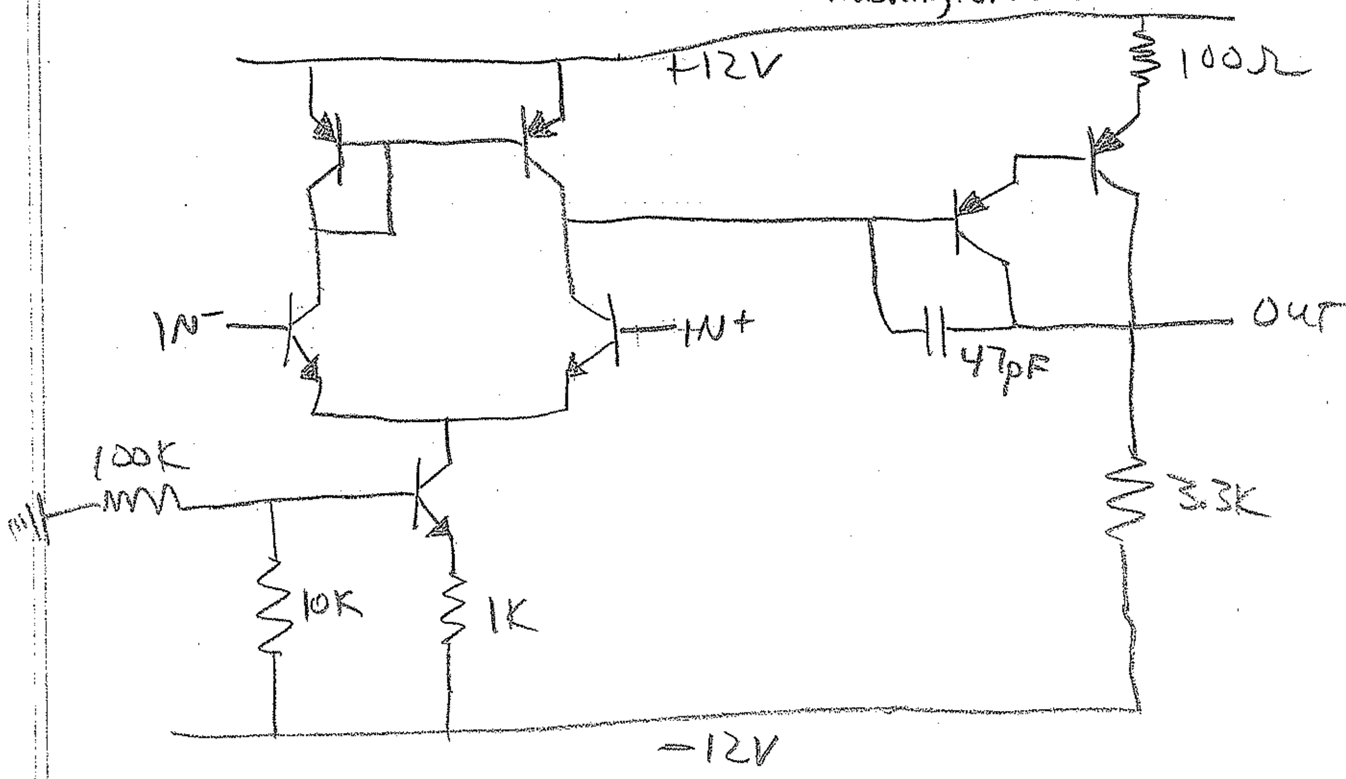




Note: can ground IN− on diff. amp to get single-ended DC amplifier.
⇒ no annoying diode drops; temperature compensation

⑦

I found this relatively simple opamp circuit on web (EE 332, R.B. Darling,) washington.edu



note Darlington ⇒ β^2

note compensation capacitor

⇒ "Miller effect"

capacitance multiplied by voltage gain

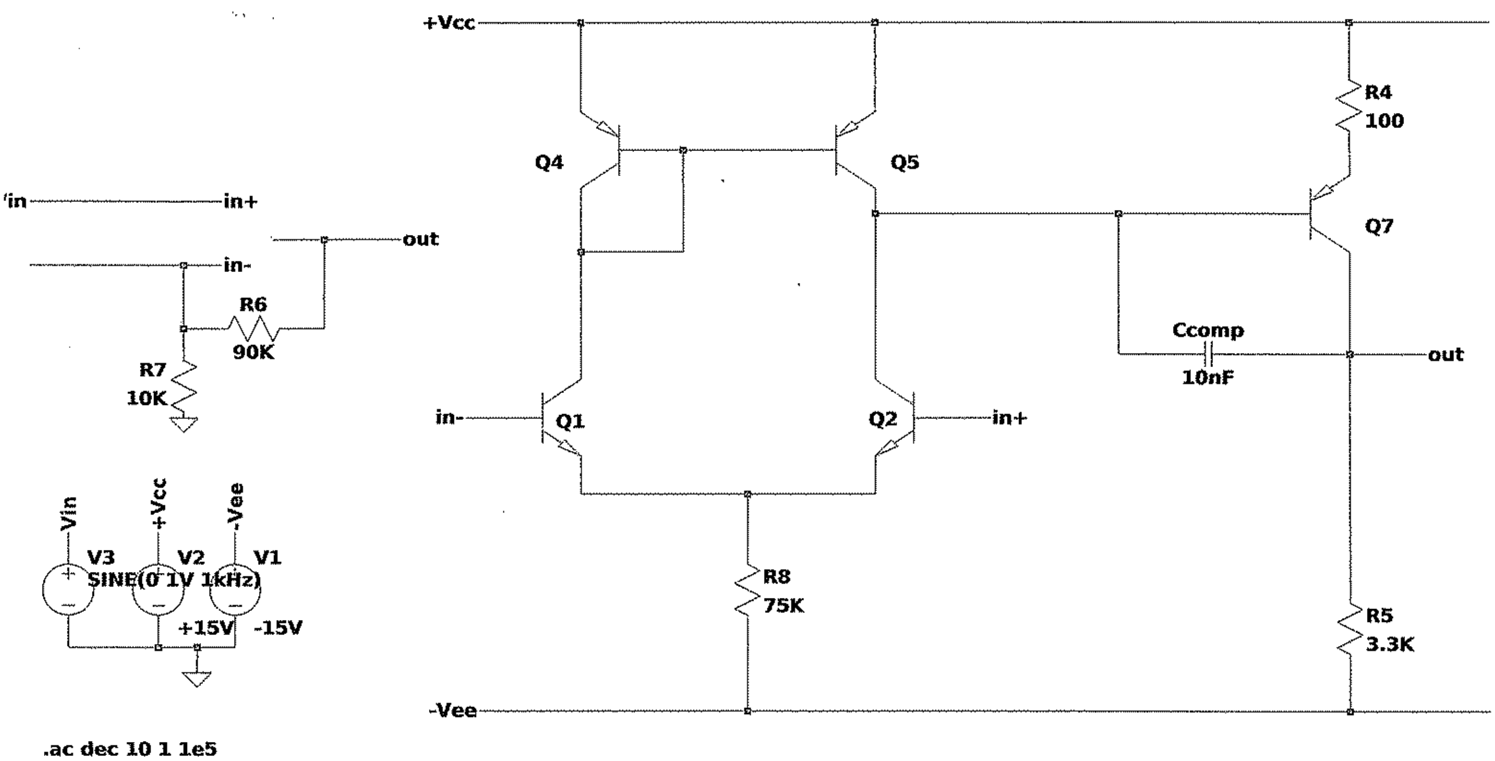
(8) Simplify circuit a bit:

remove current source from tail;

remove Darlington

reduce bandwidth

⇒ works OK in SPICE, as an opamp.



Digression: corny emitter follower mnemonic from Hayes & Horowitz

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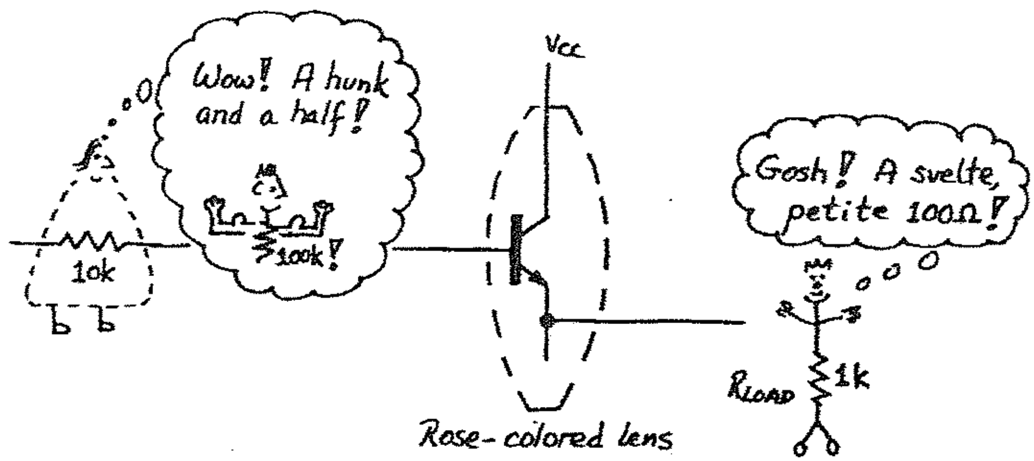

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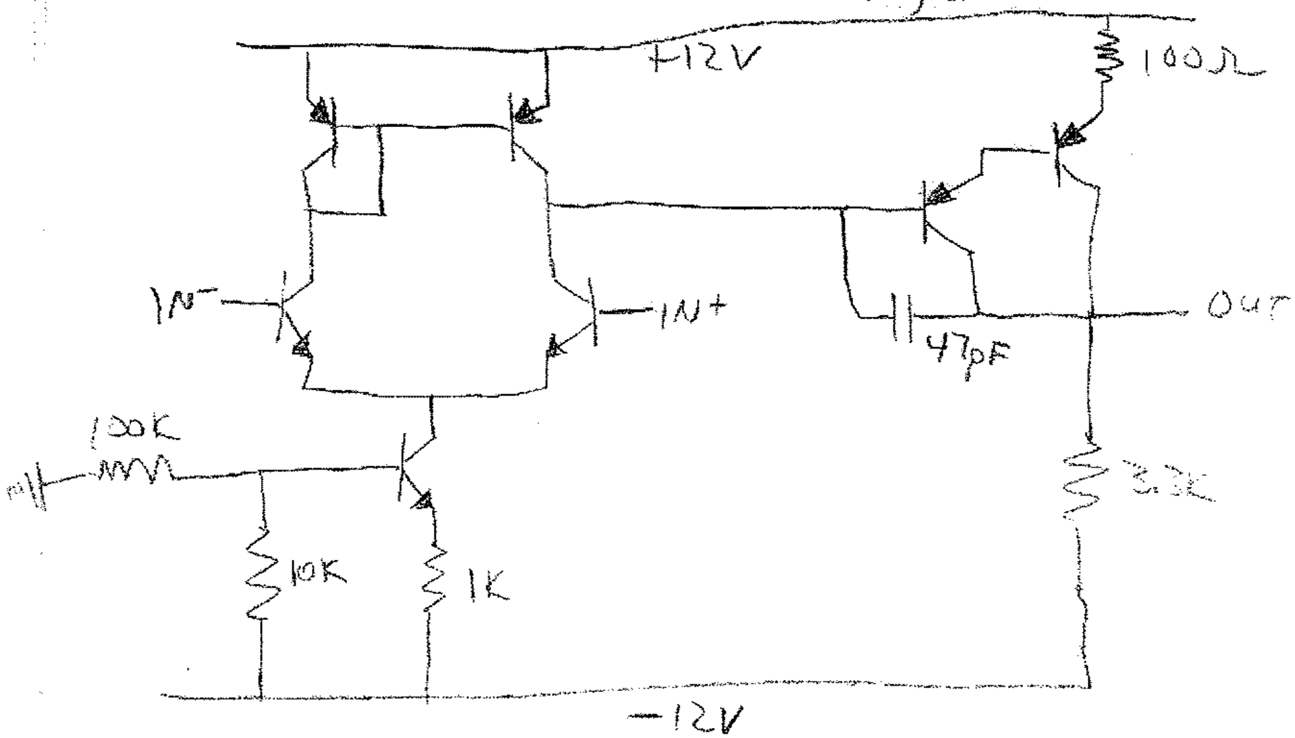

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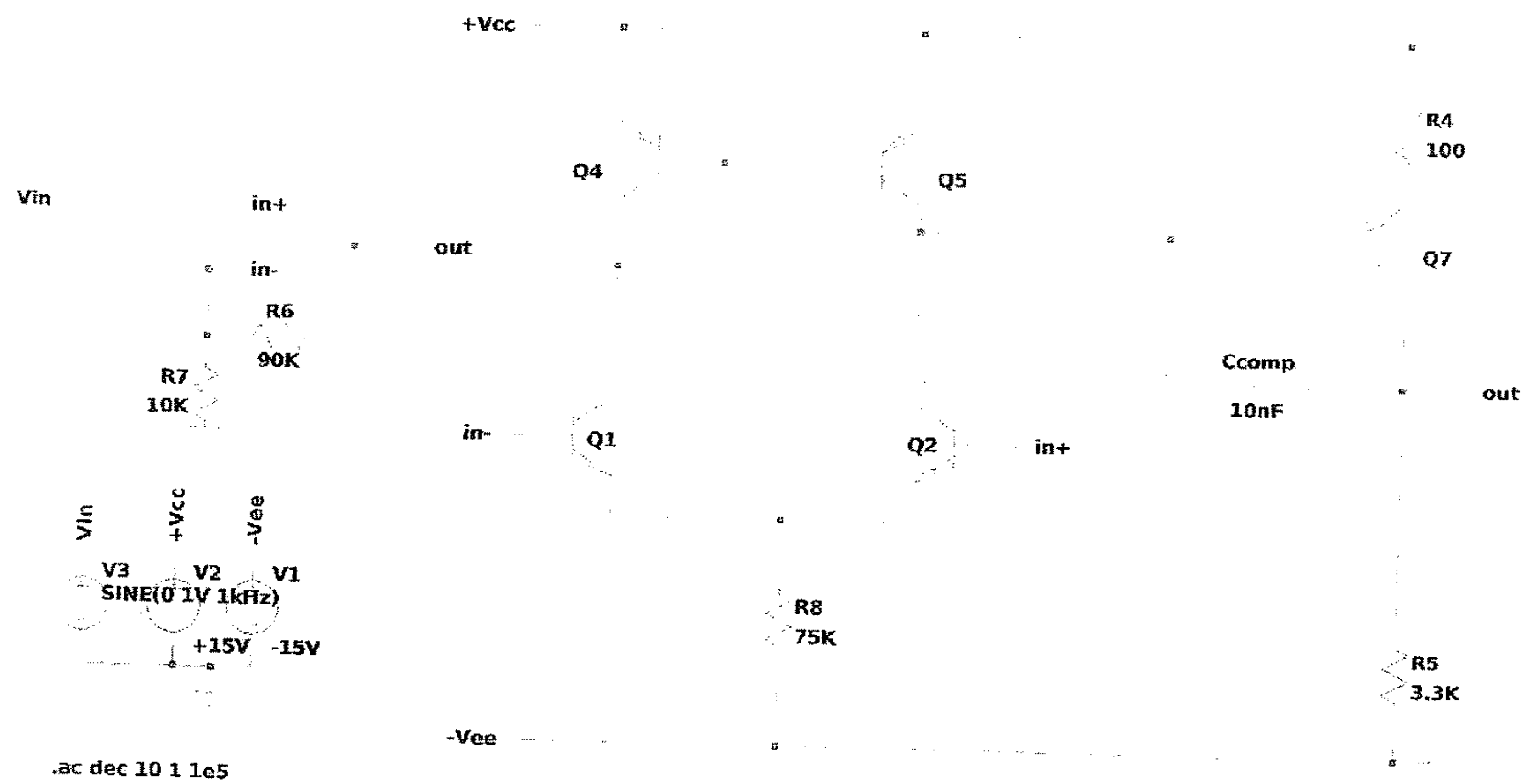
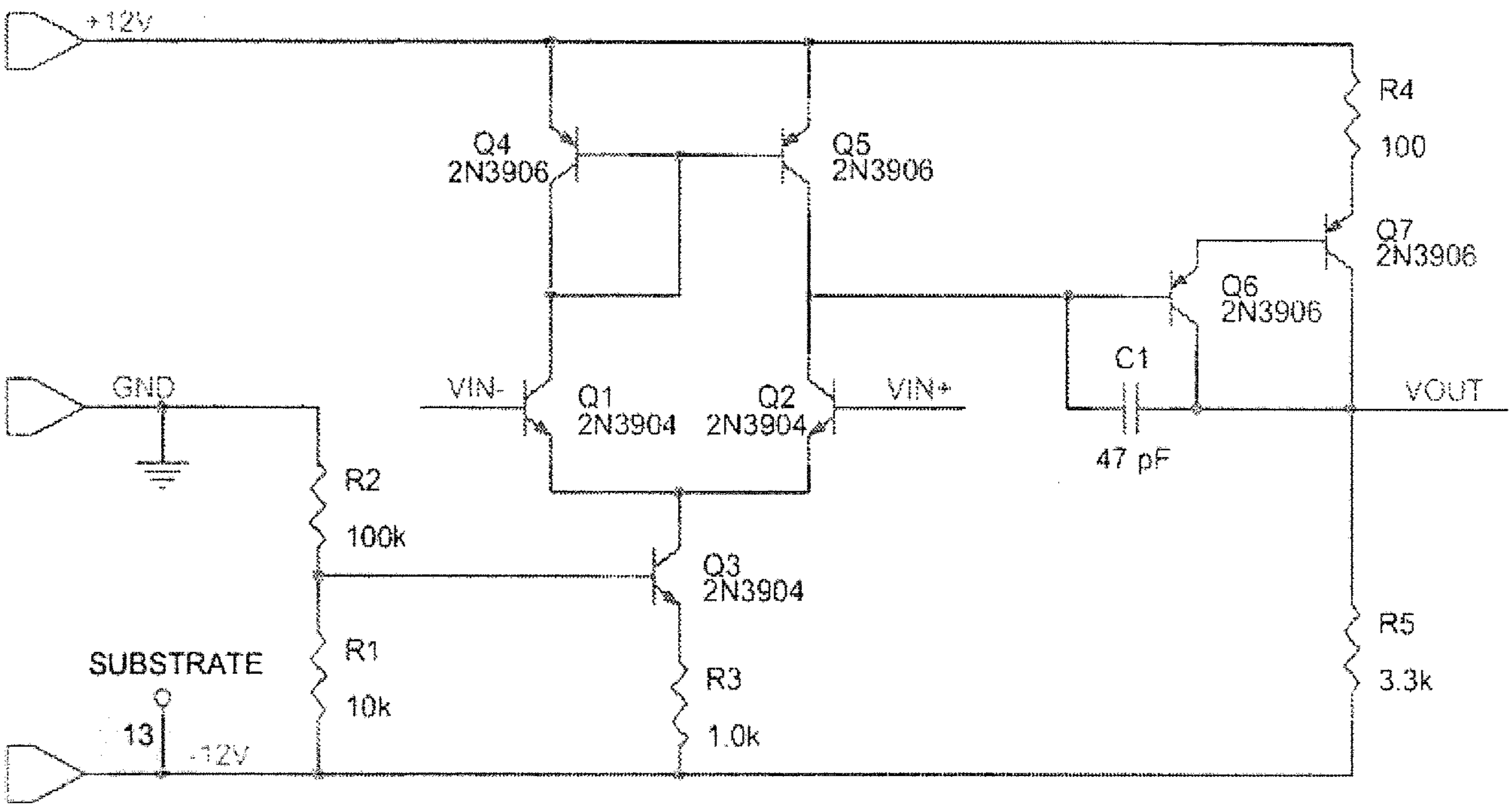
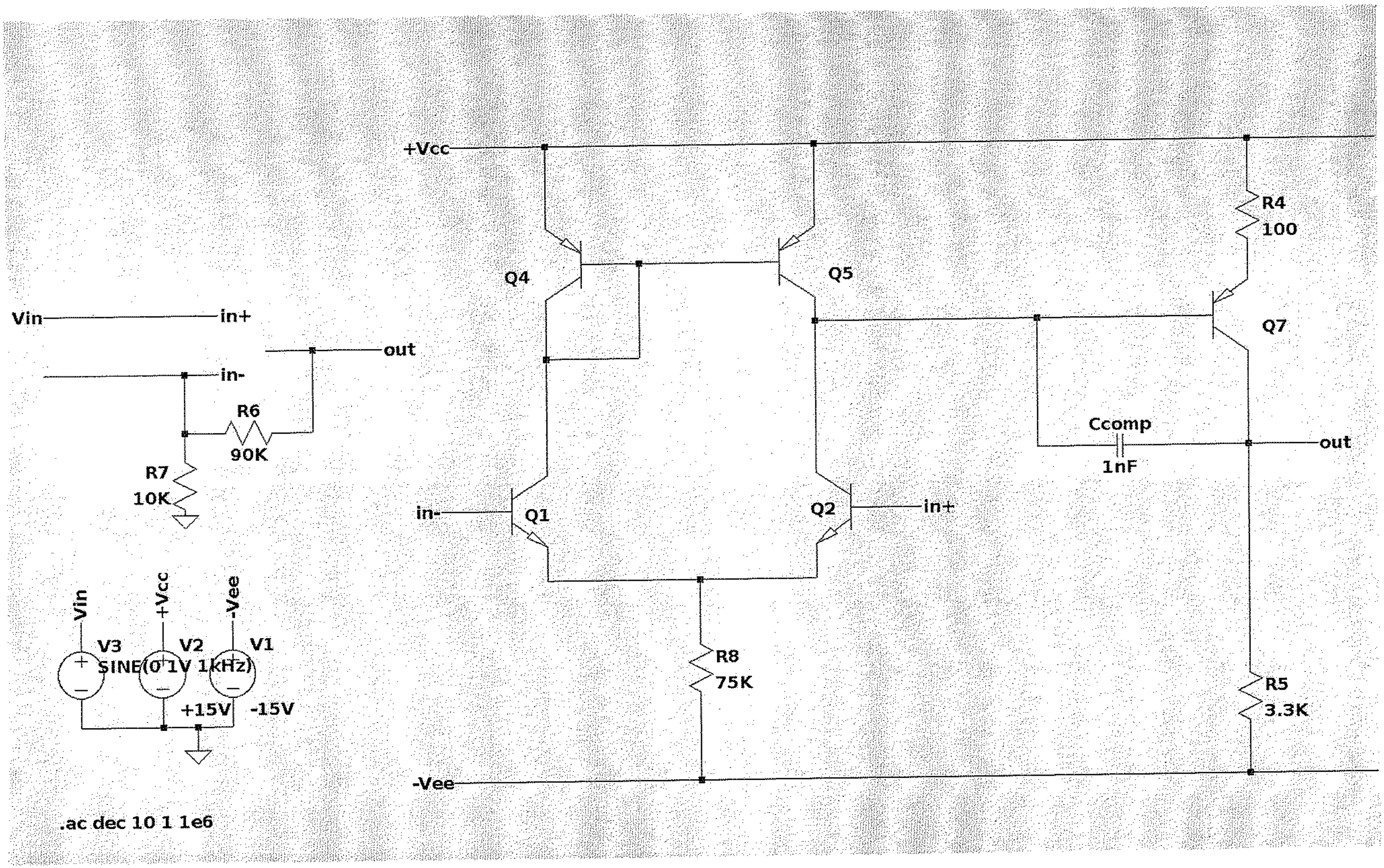
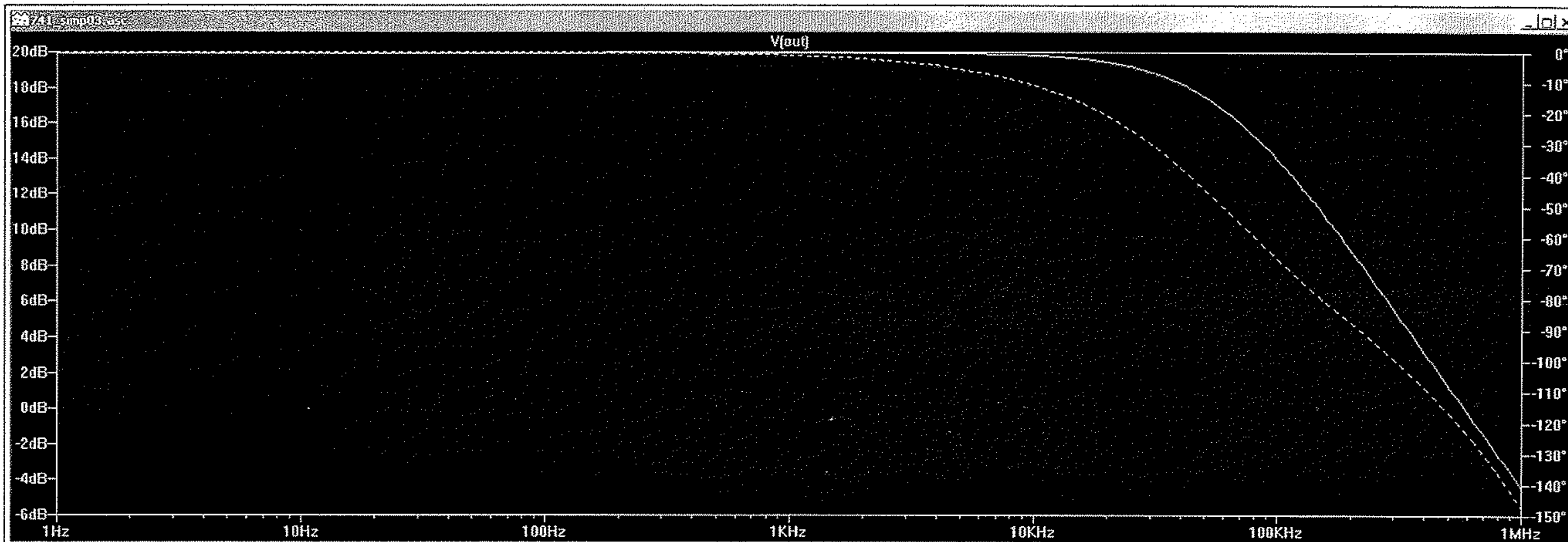


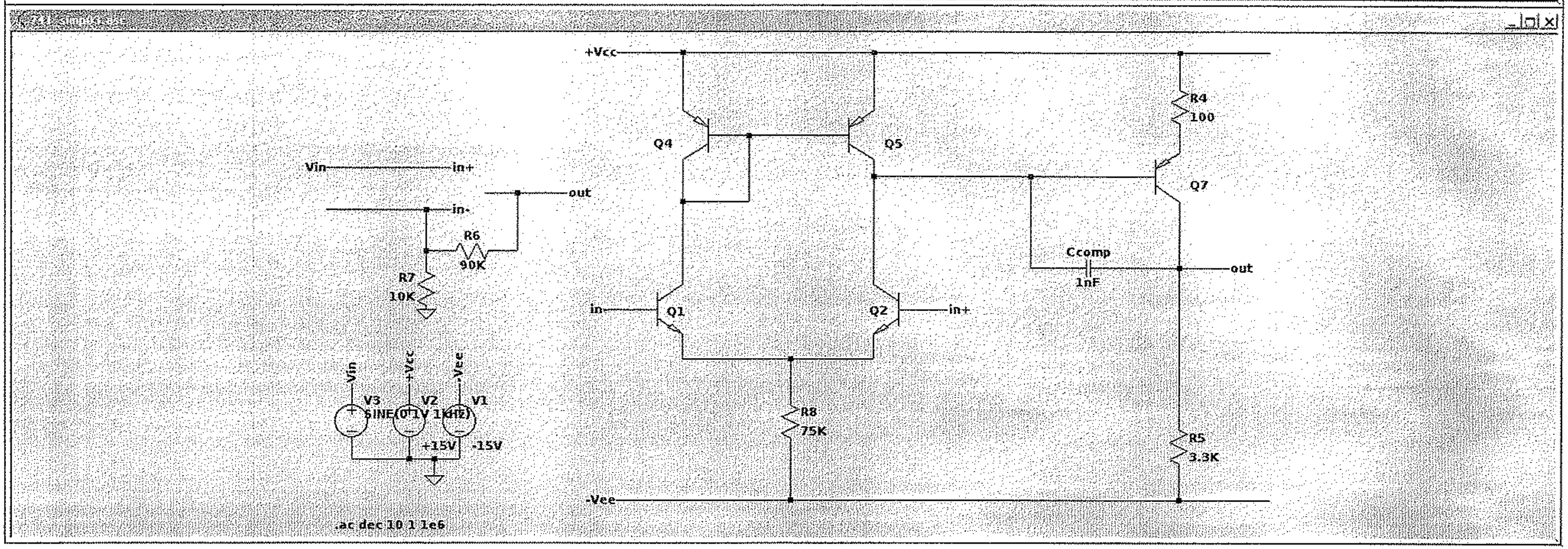


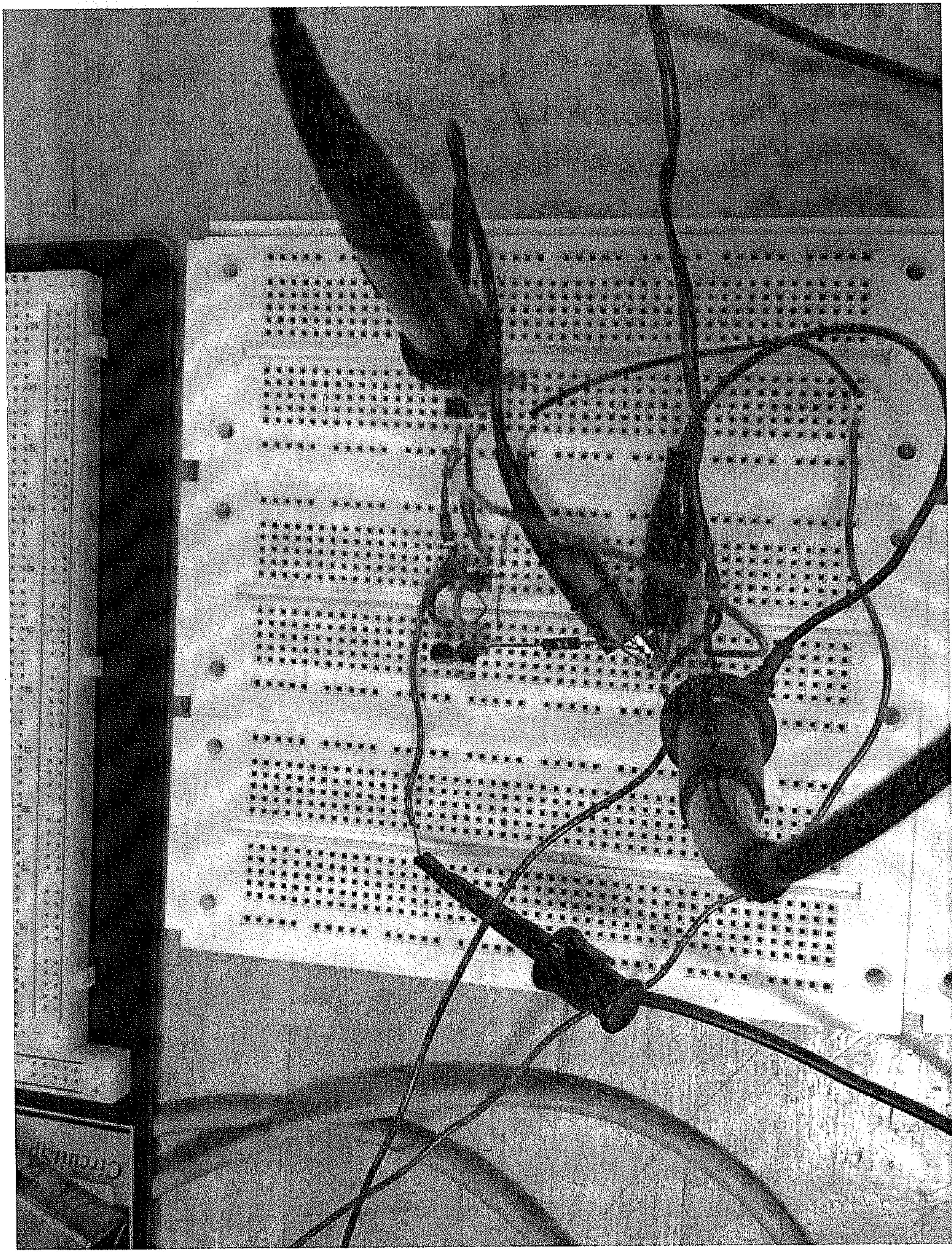
+12V
R4
100
Q4
2N3906
Q5
2N3906
Q7
2N3906
Q6
2N3906
C1
47 pF
GND
VIN-
Q1
2N3904
Q2
2N3904
VIN+
VOUT
R2
100k
Q3
2N3904
R5
3.3k
SUBSTRATE
R1
10k
R3
1.0k
13
-12V

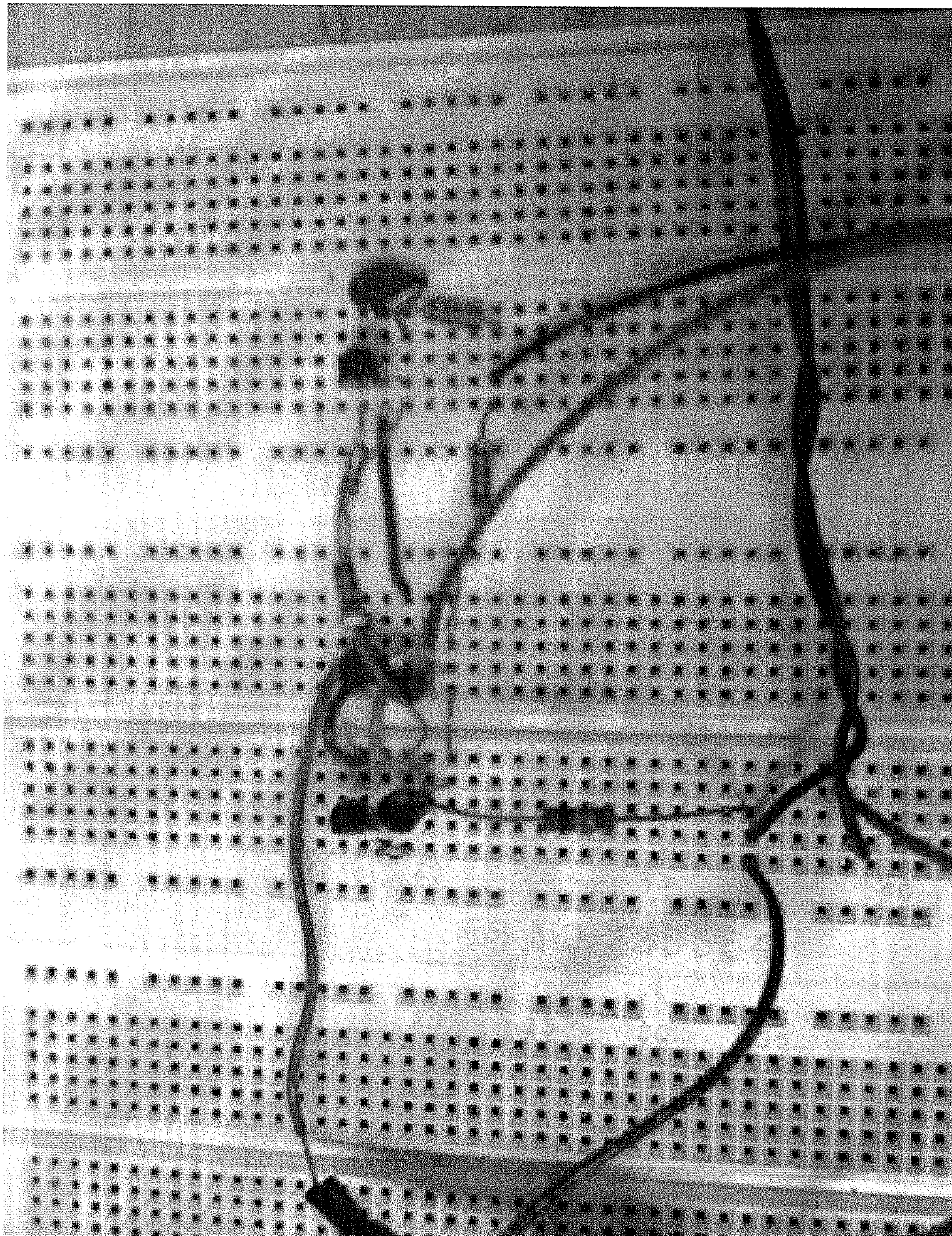


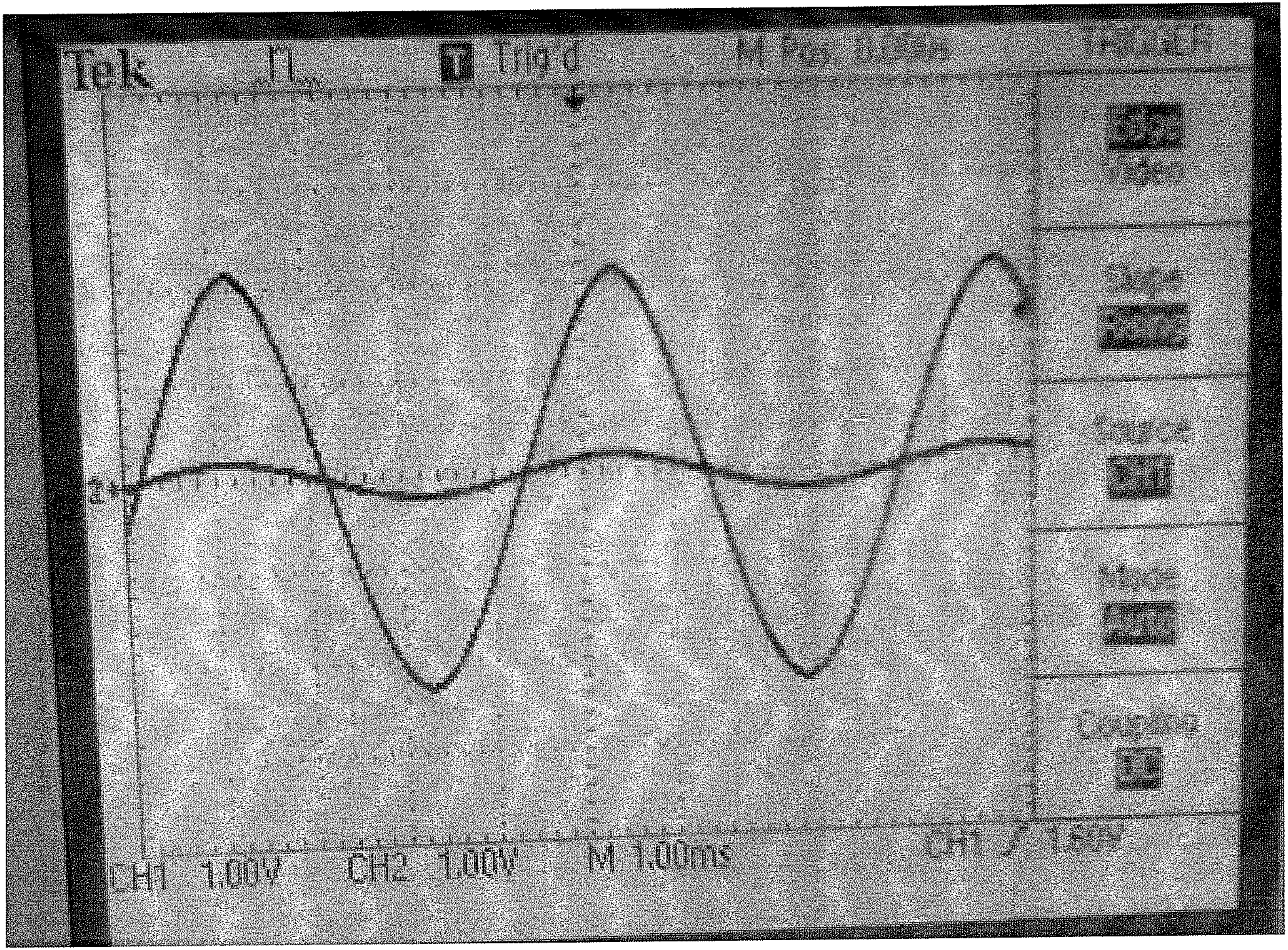
+Vcc
R4
100
Q4
Q5
Q7
Vin
in+
out
in-
R6
90K
R7
10K
Ccomp
1nF
out
in-
Q1
Q2
in+
Vin
+Vcc
-Vee
V3
V2
V1
SINE(0 1V 1kHz)
+15V
-15V
R8
75K
R5
3.3K
-Vee
.ac dec 10 1 1e6

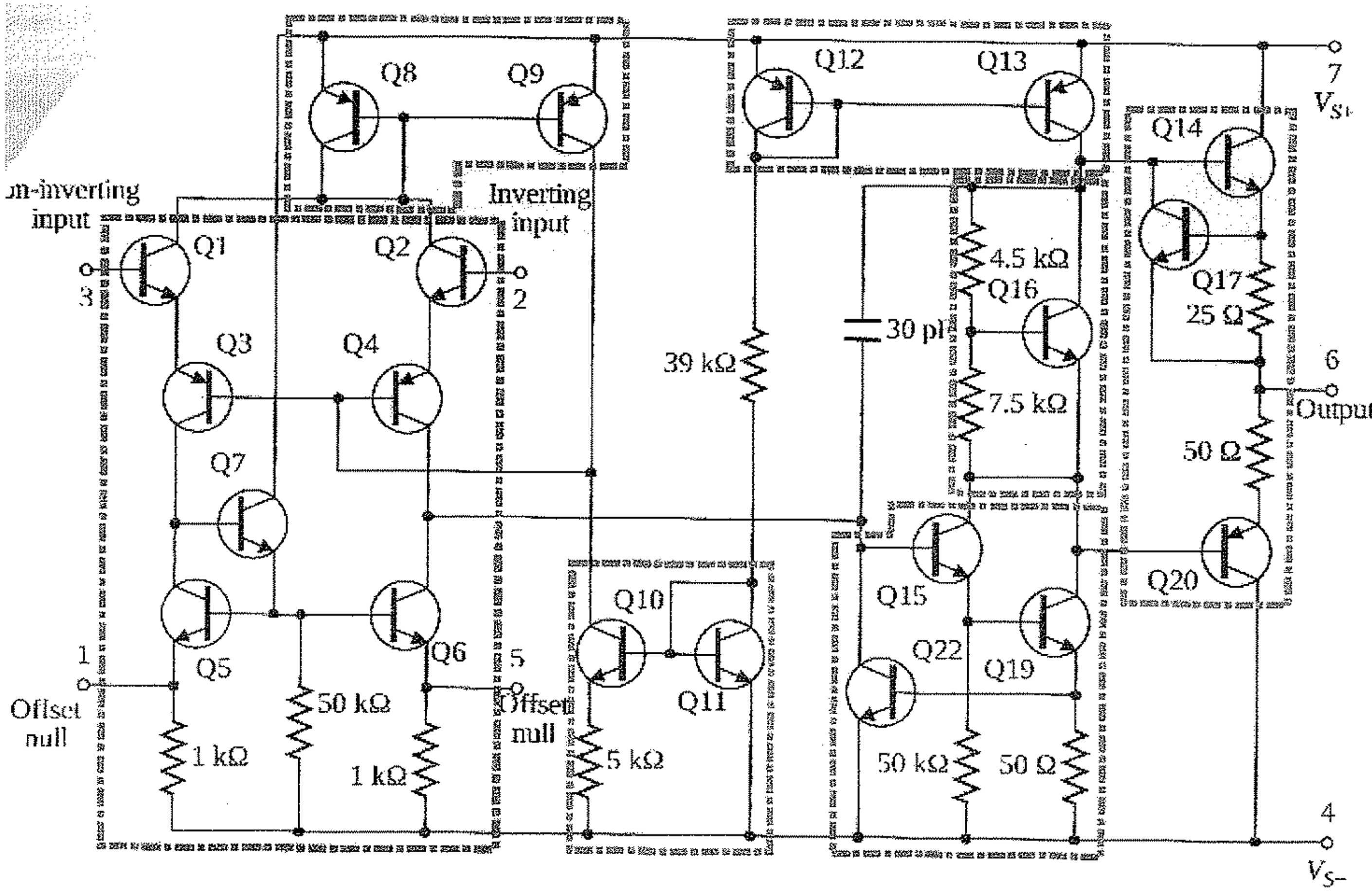

741_simp03.asc
V(out)
20dB
18dB
16dB
14dB
12dB
10dB
8dB
6dB
4dB
2dB
0dB
-2dB
-4dB
-6dB
0°
-10°
-20°
-30°
-40°
-50°
-60°
-70°
-80°
-90°
-100°
-110°
-120°
-130°
-140°
-150°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz


741_simp03.asc
+Vcc
Q4
Q5
R4
100
Q7
Vin
in+
in-
out
R6
90K
R7
10K
Ccomp
1nF
out
in-
Q1
Q2
in+
Vin
+Vcc
-Vee
V3
V2
V1
SINE(0 1V 1KHz)
+15V
-15V
R8
75K
R5
3.3K
-Vee
.ac dec 10 1 1e6






Tek
Trig'd
CH1 1.00V
CH2 1.00V
M 1.00ms



You should now recognize more pieces of the 741 schematic (In this case, from Wikipedia "opamp" entry.)