Physics 160
Lecture 14
Fun with Op Amps

R. Johnson

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Ideal Op-Amp

Differential gain, of course. Common-mode gain is ideally zero.

1. Gain--infinite
2. Input impedance--infinite
3. Output impedance--zero
4. Bandwidth--infinite
5. Voltage out--zero (when voltages into each other are equal)
6. Current entering the amp at either terminal--extremely small

The Ideal Amplifier

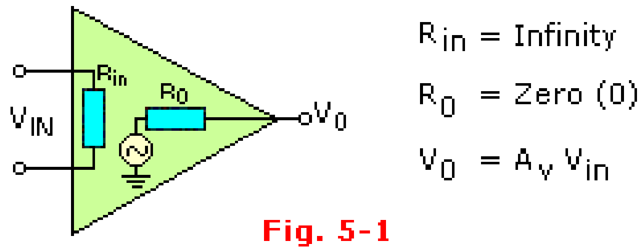
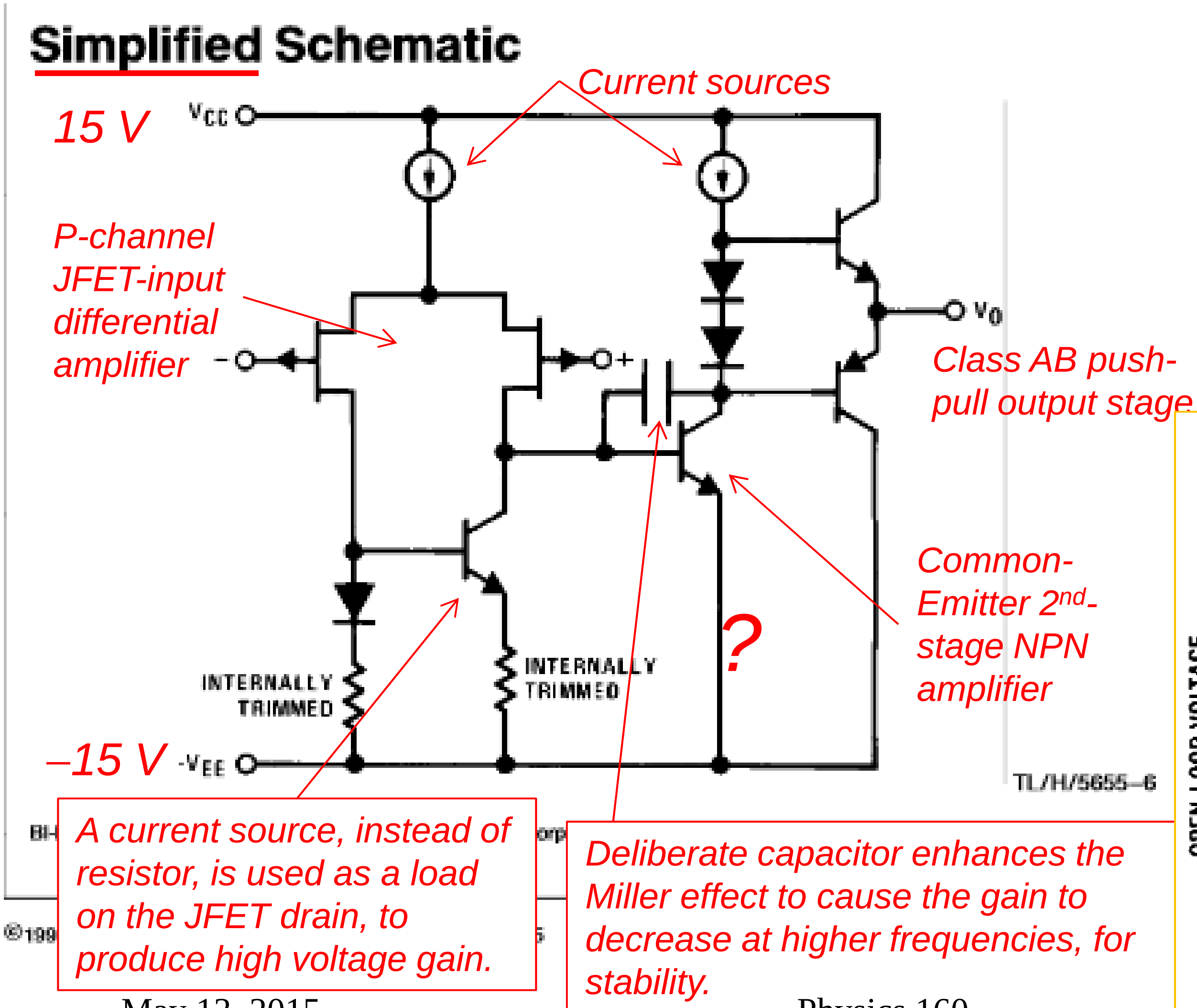


Fig. 5-1

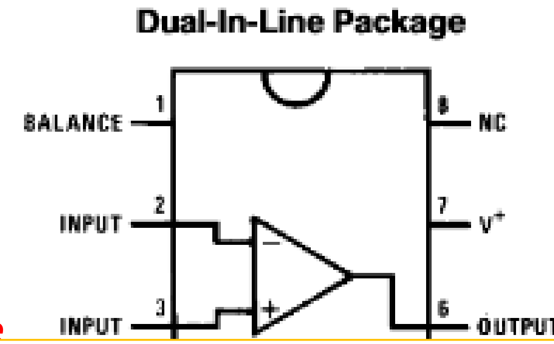
Such an ideal op-amp of course does not exist, but a first analysis of op-amp circuits can be done to a good approximation usually by ignoring the non-ideal behavior.

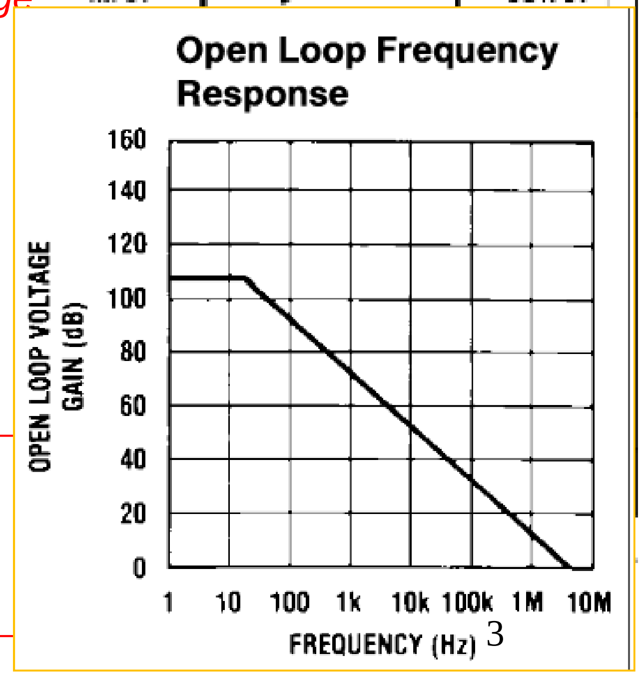
A Real Op-Amp: LF411

Differential voltage gain at low frequency is >100,000!



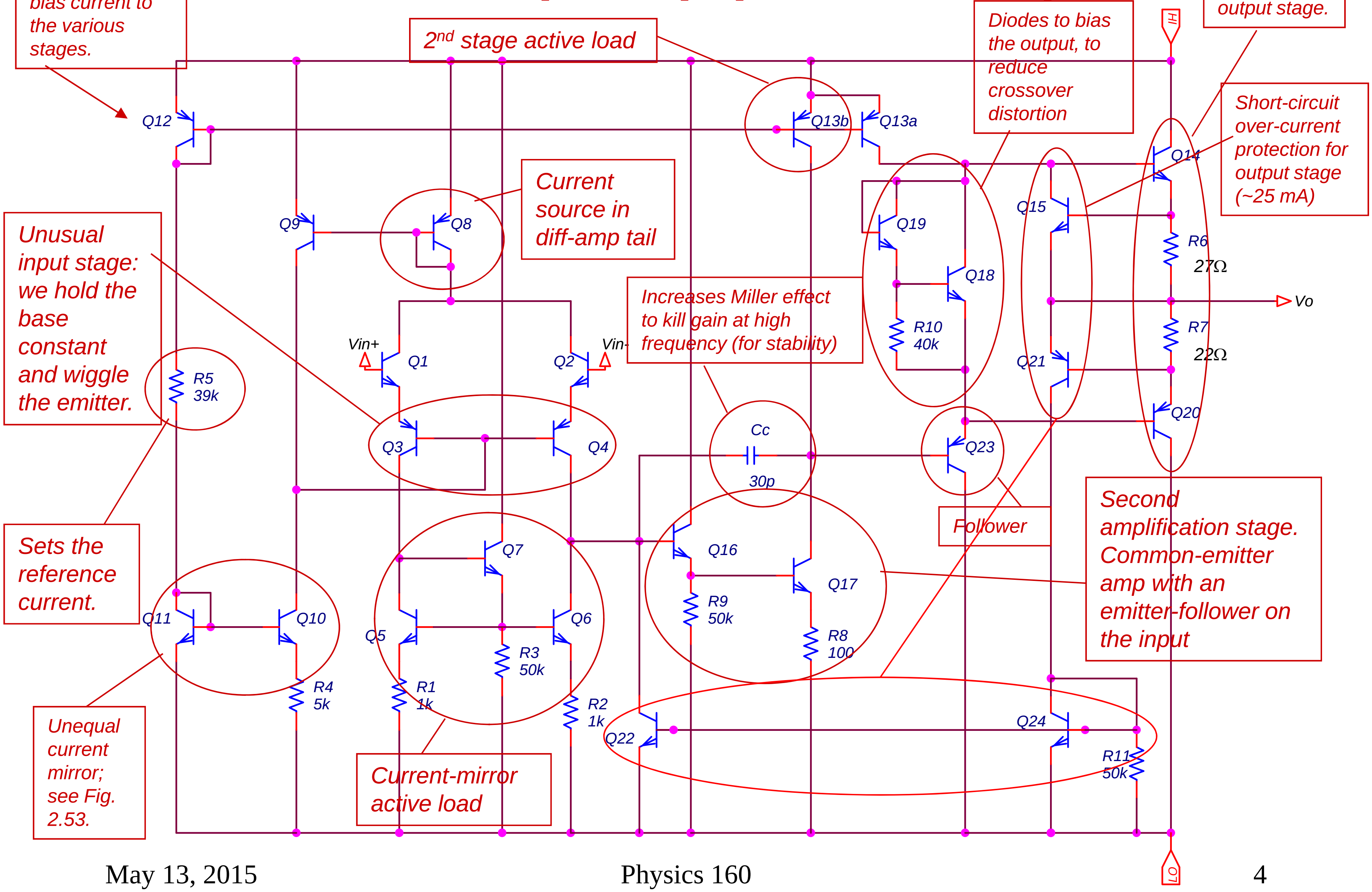
See NS Package Number H08A





(Note: many 741 versions have been made and sold, with varying detailed designs.)

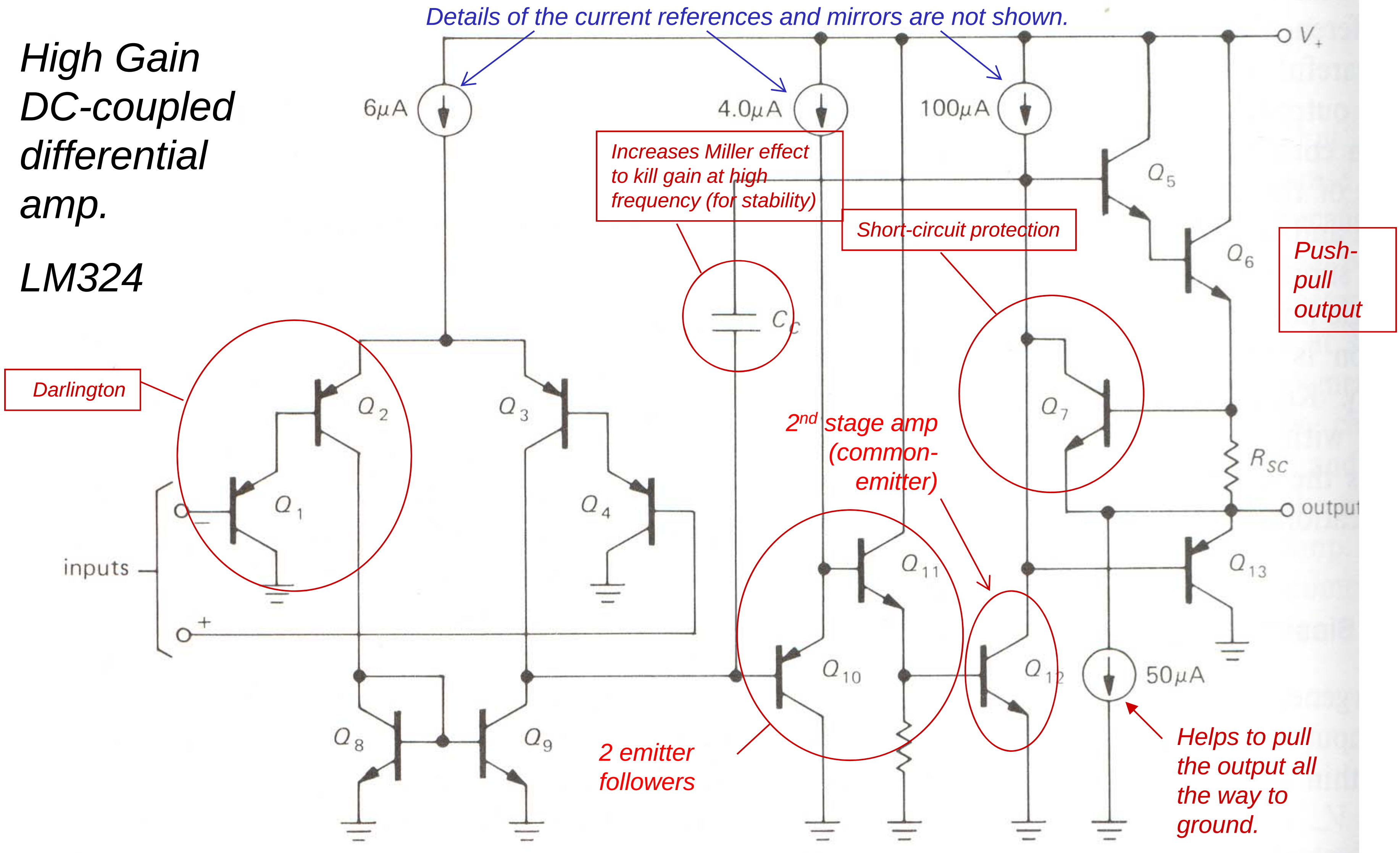
A Real Op-Amp (famous 741)



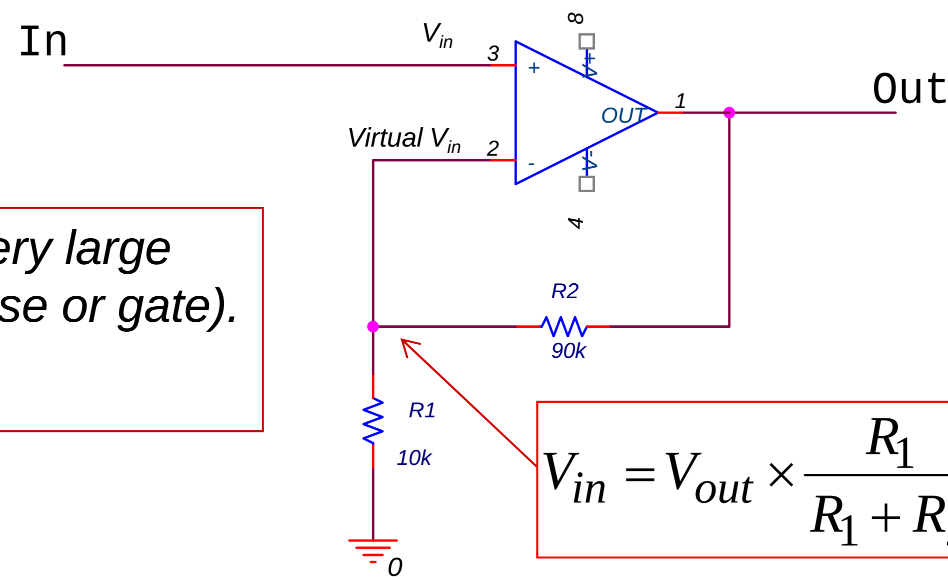
Op-Amp Example (Single Supply)

High Gain DC-coupled differential amp.

LM324



Non-Inverting Amplifier



Note: Z_{in} is very large (transistor base or gate).

This is good!

$$V_{in} = V_{out} \times \frac{R_1}{R_1 + R_2}$$

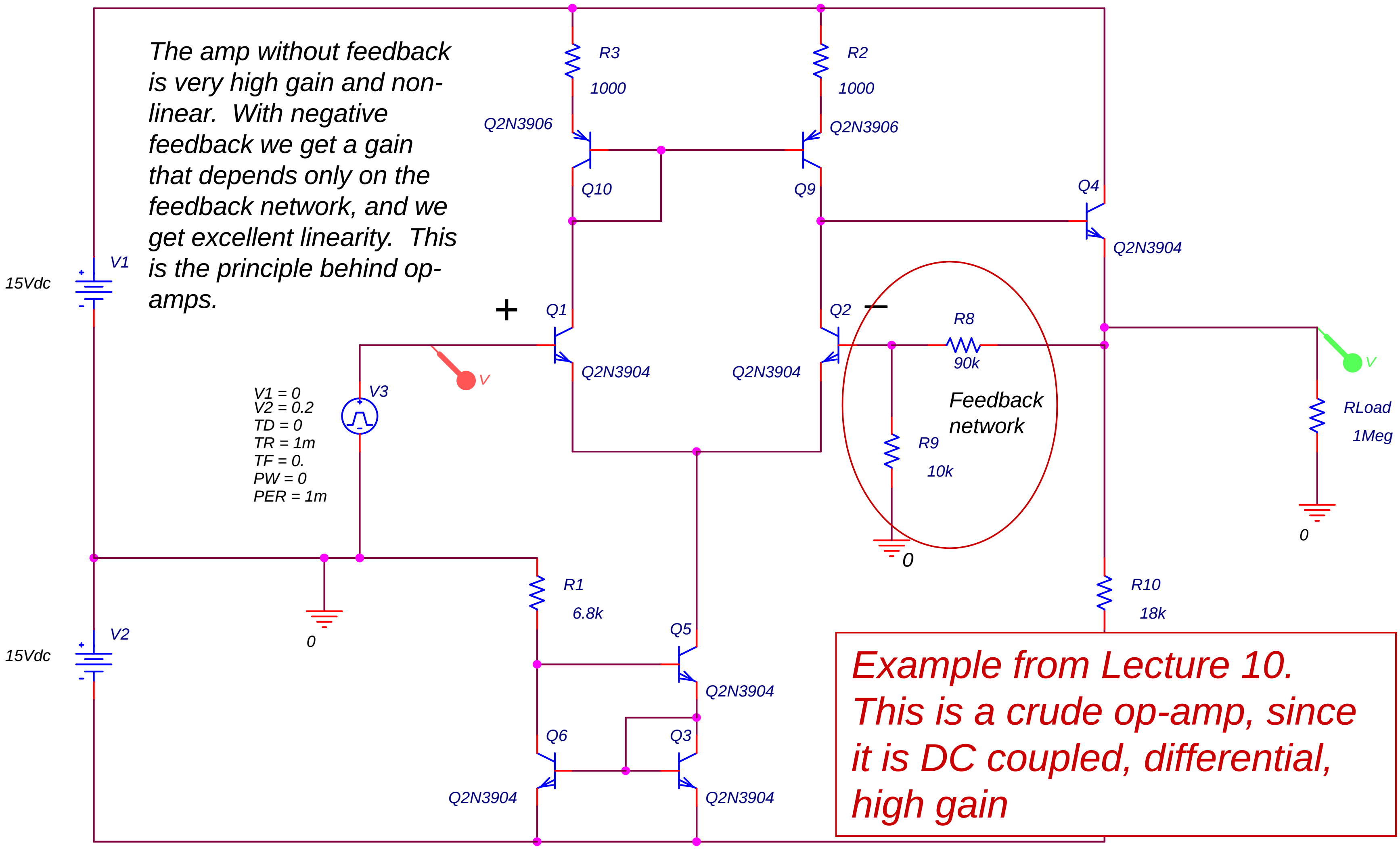
Simplified analysis of an op-amp with negative feedback:

- *Assume infinite gain, so the negative feedback always has to* ***keep the two inputs equal*** *in order to have a finite output.*
- *Assume zero current flow into the op-amp inputs.*
- *Then calculate the relationship between input and output from the feedback network.*

$$G = \frac{V_{out}}{V_{in}} = 1 + \frac{R2}{R1} = 1 + 9 = 10$$

Linear Amp using Negative Feedback

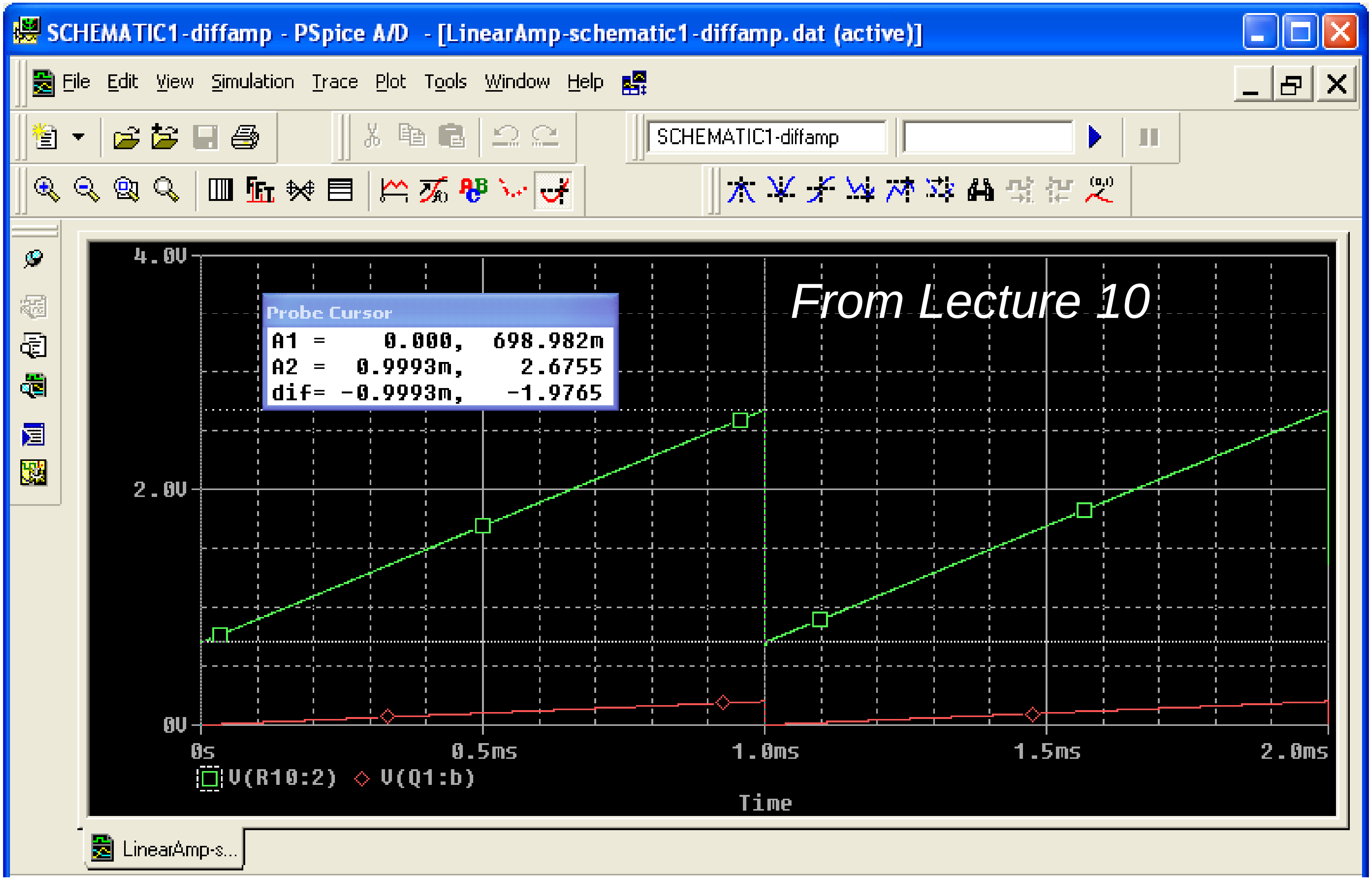
The amp without feedback is very high gain and non-linear. With negative feedback we get a gain that depends only on the feedback network, and we get excellent linearity. This is the principle behind op-amps.



Example from Lecture 10. This is a crude op-amp, since it is DC coupled, differential, high gain

Gain is (10k+90k)/10k=10

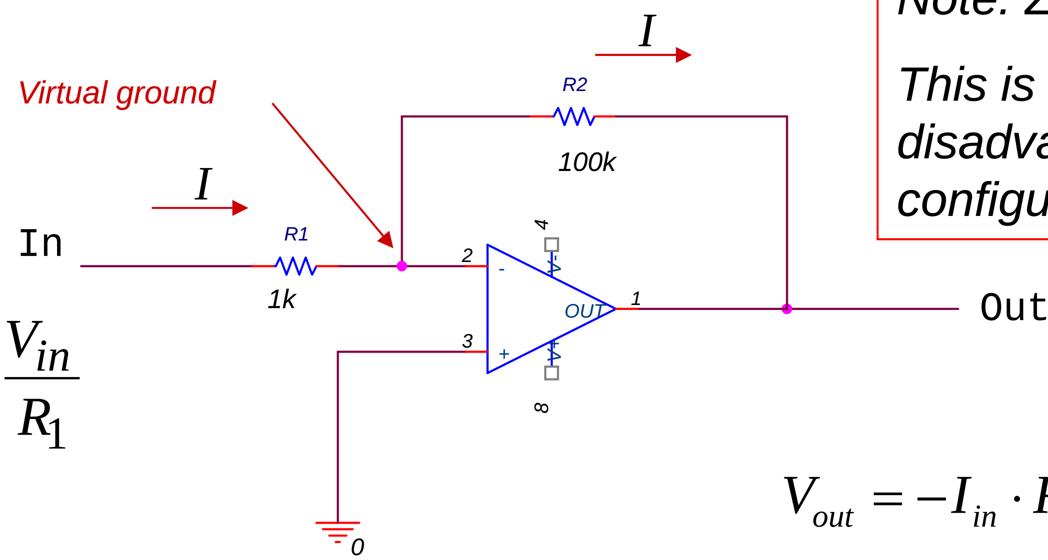
Gain=10 with excellent linearity!



Inverting Amp

Note: $Z_{in}=R_1=1$ kohm

This is a distinct disadvantage of this configuration.



$$I_{in} = \frac{V_{in}}{R_1}$$

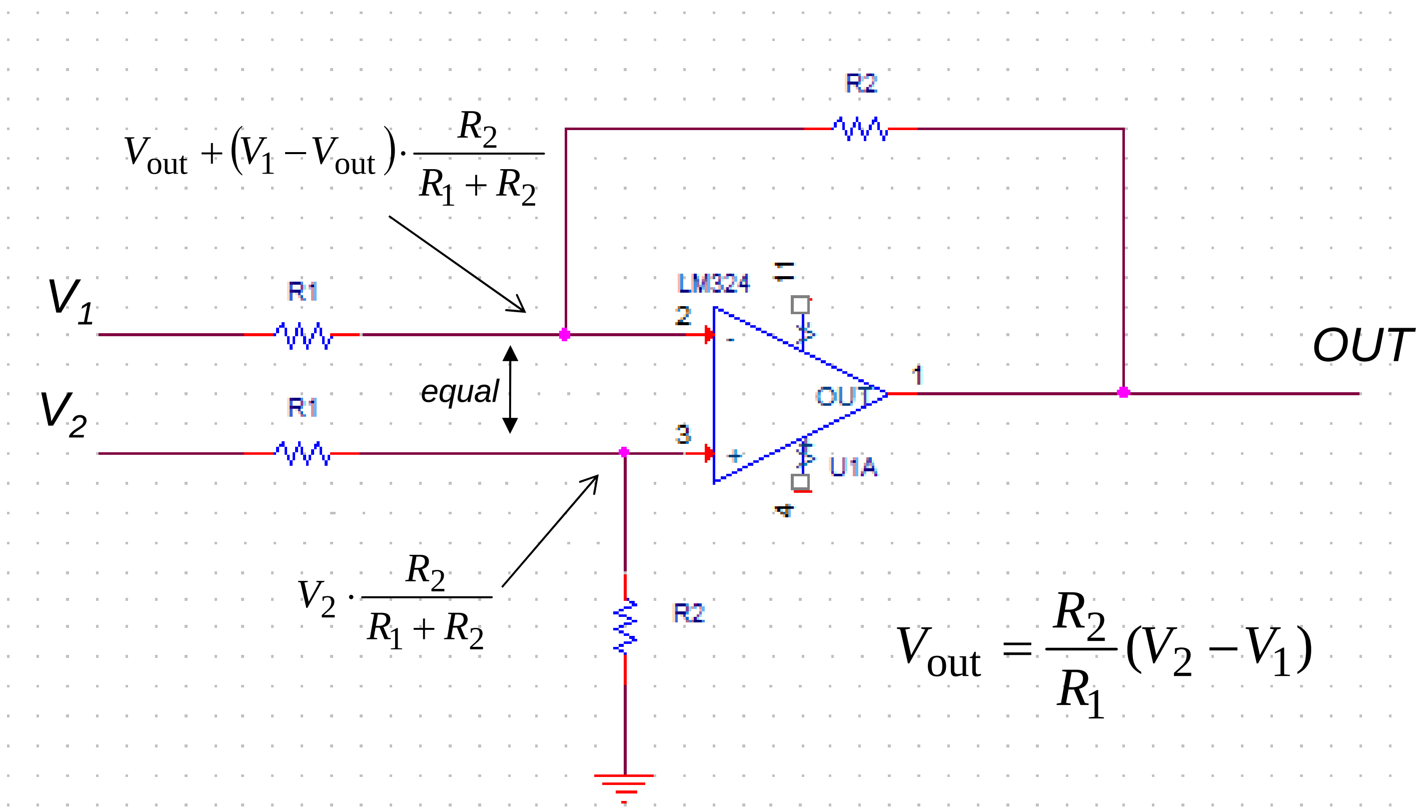
$$V_{out} = -I_{in} \cdot R_2 = -\frac{V_{in}}{R_1} \cdot R_2$$

Simplified analysis of an op-amp with negative feedback:

- *Assume infinite gain, so the negative feedback always has to* ***keep the two inputs equal*** *in order to have a finite output.*
- *Assume zero current flow into the op-amp inputs.*
- *Then calculate the relationship between input and output from the feedback network.*

$$G = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} = -100$$

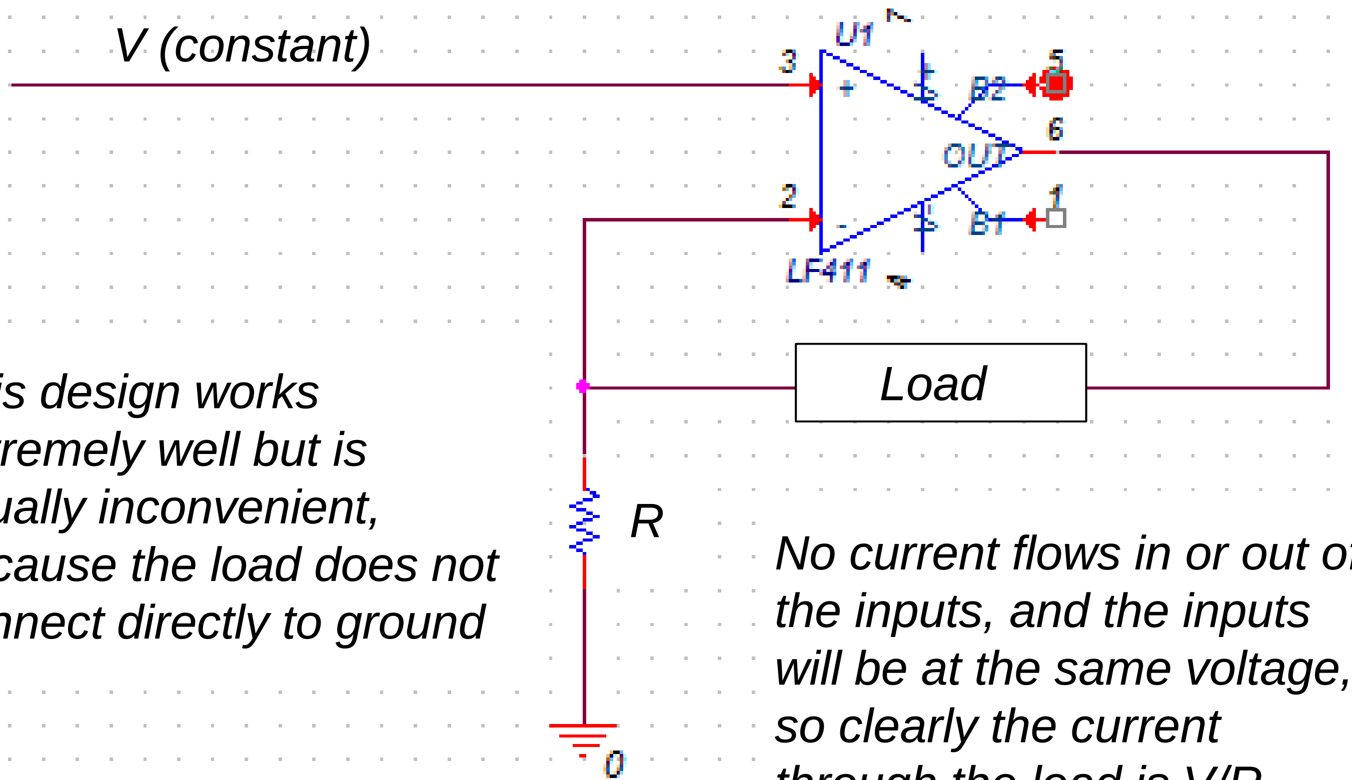
Differential Amplifier



$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

Beware that the CMRR depends almost entirely on the matching of the resistors, so high precision resistors are essential in order to make this work well.

Simple Current Source



This design works extremely well but is usually inconvenient, because the load does not connect directly to ground

No current flows in or out of the inputs, and the inputs will be at the same voltage, so clearly the current through the load is V/R.

(As long as the op-amp output doesn't try to exceed the supply voltage!)

Current Sources

$$I_{out} = \frac{V_{CC} - V_{in}}{R}$$

$$I_{out} = \frac{V_{in}}{R_1} \cdot \frac{R_2}{R_3}$$

No base current error if MOSFET is used.

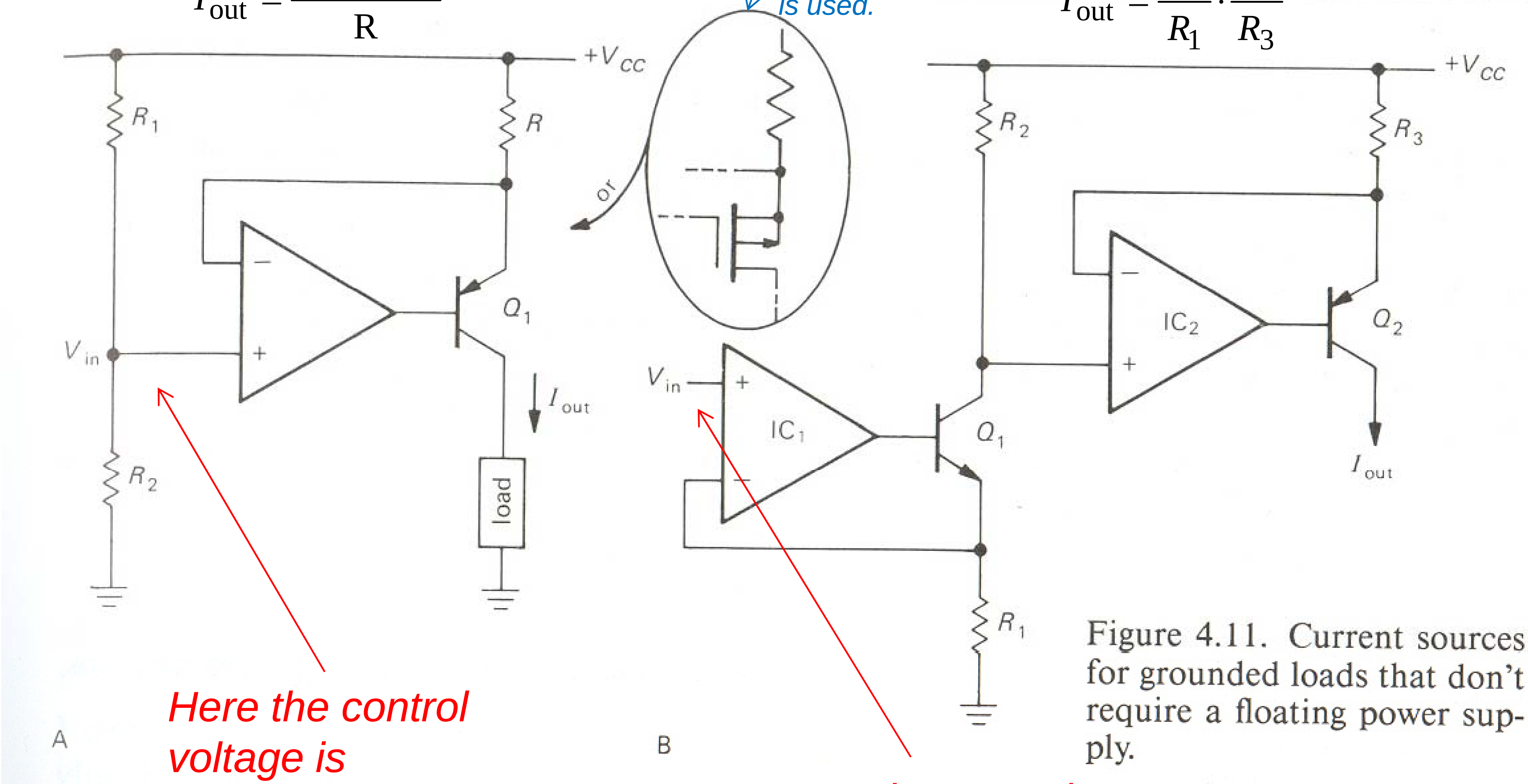
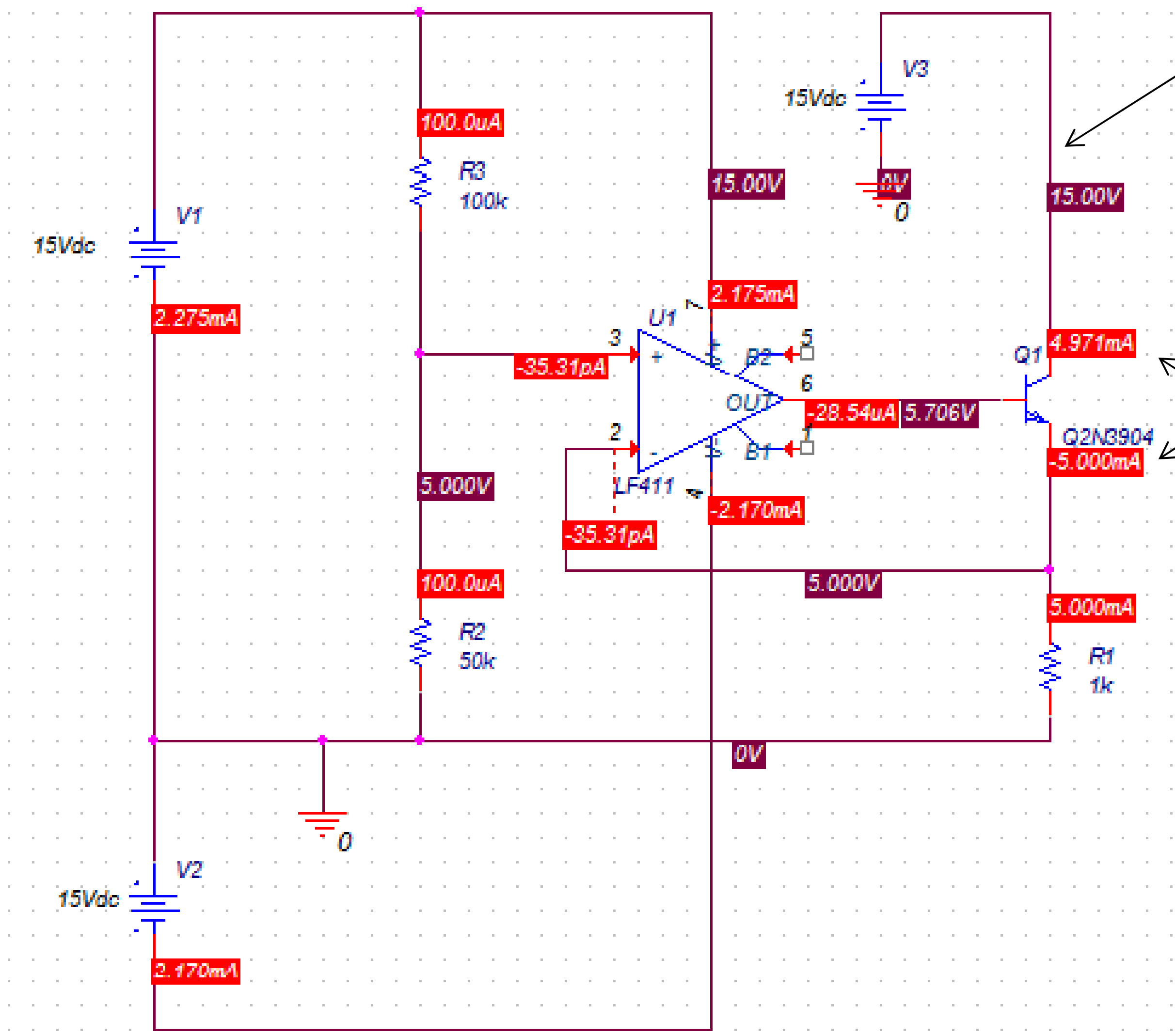


Figure 4.11. Current sources for grounded loads that don't require a floating power supply.

Here the control voltage is relative to VCC.

Here the control voltage is relative to ground.

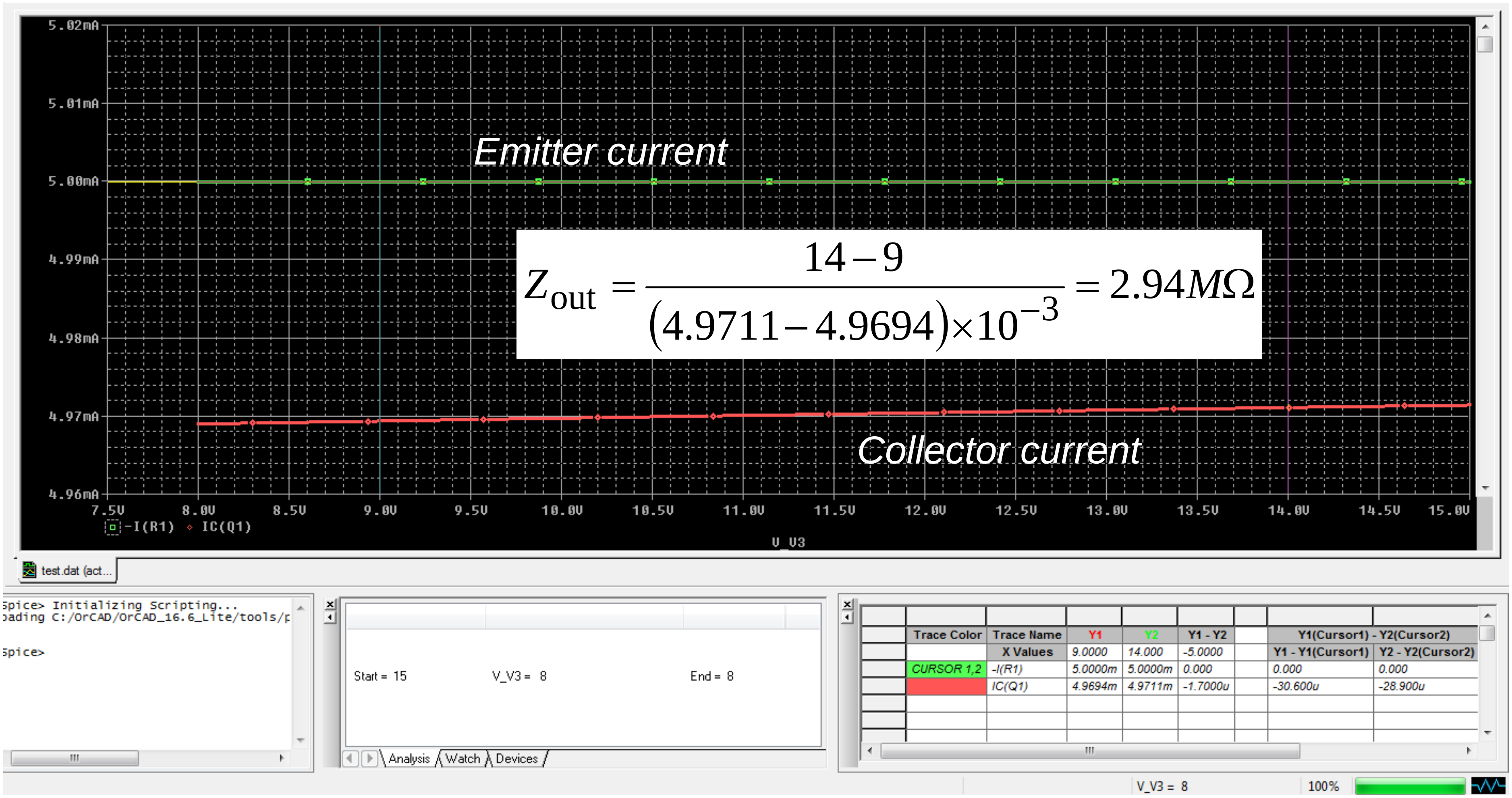
Example Current Sink



Load would go here

"Base current error"

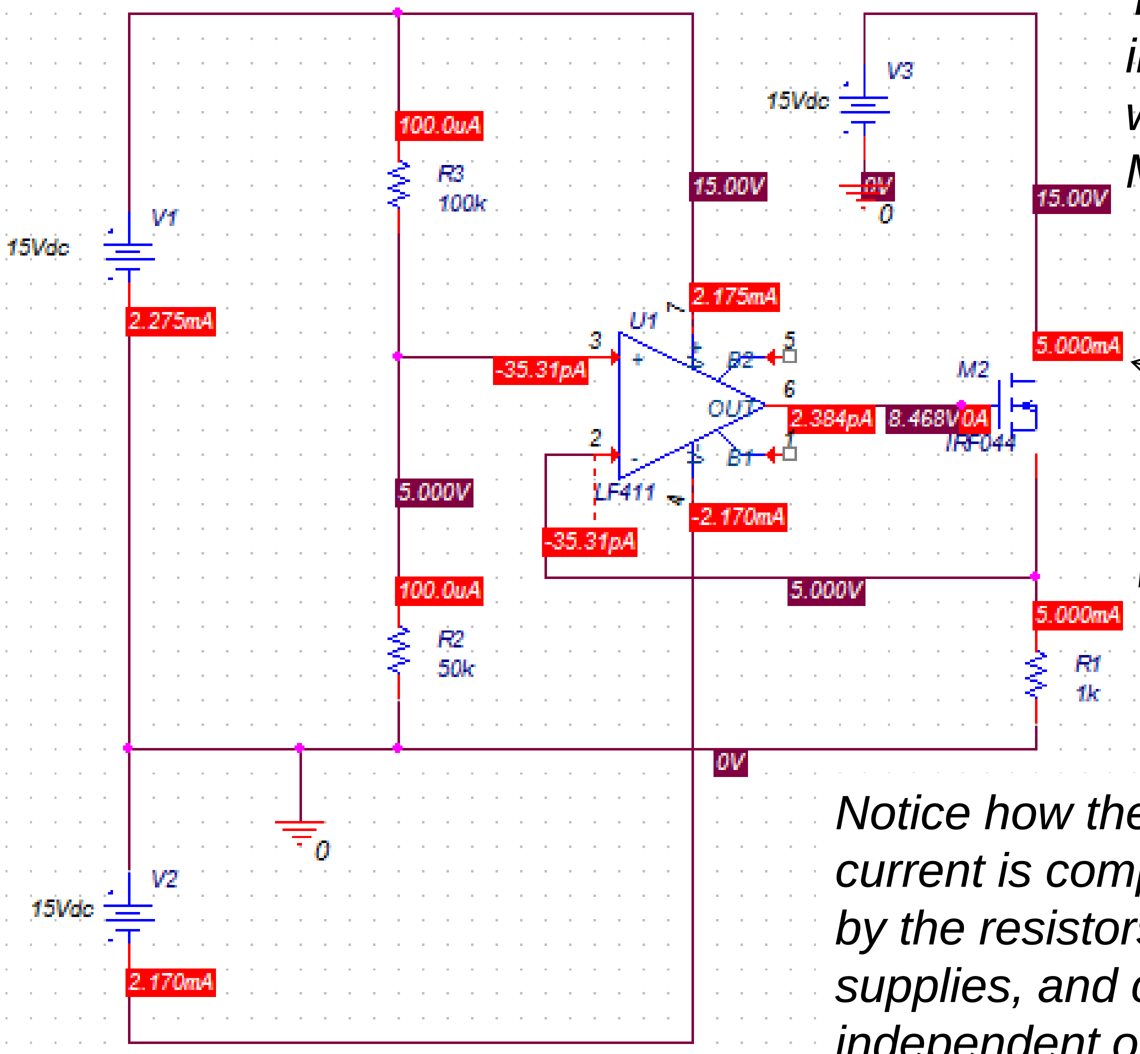
Current Sink Performance



$$Z_{\text{out}} = \frac{14-9}{(4.9711-4.9694)\times 10^{-3}} = 2.94 M\Omega$$

The output impedance is completely dominated by the base current error and the Early effect.

Substitute a MOSFET for the BJT



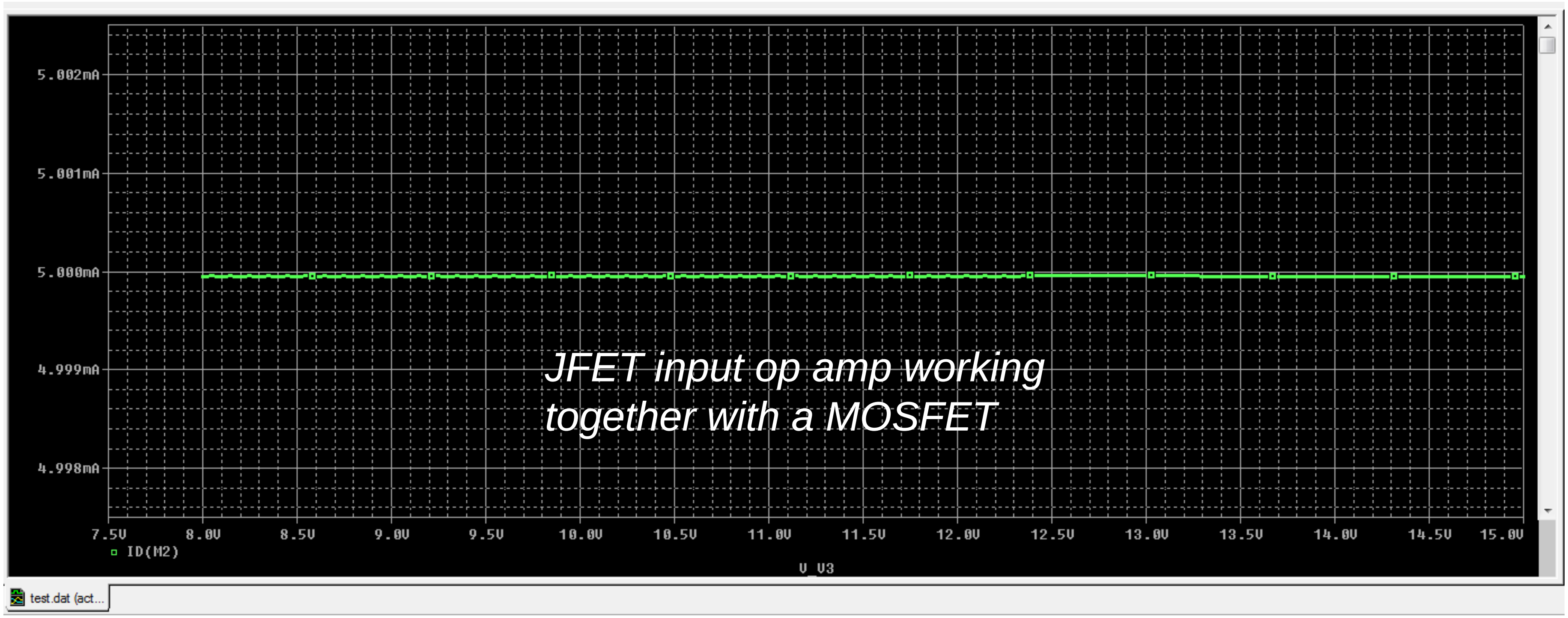
This is the only place in your lab course where you will use a MOSFET (IRL510).

No Base current error

Notice how the programmed current is completely determined by the resistors and voltage supplies, and completely independent of any transistor characteristics!

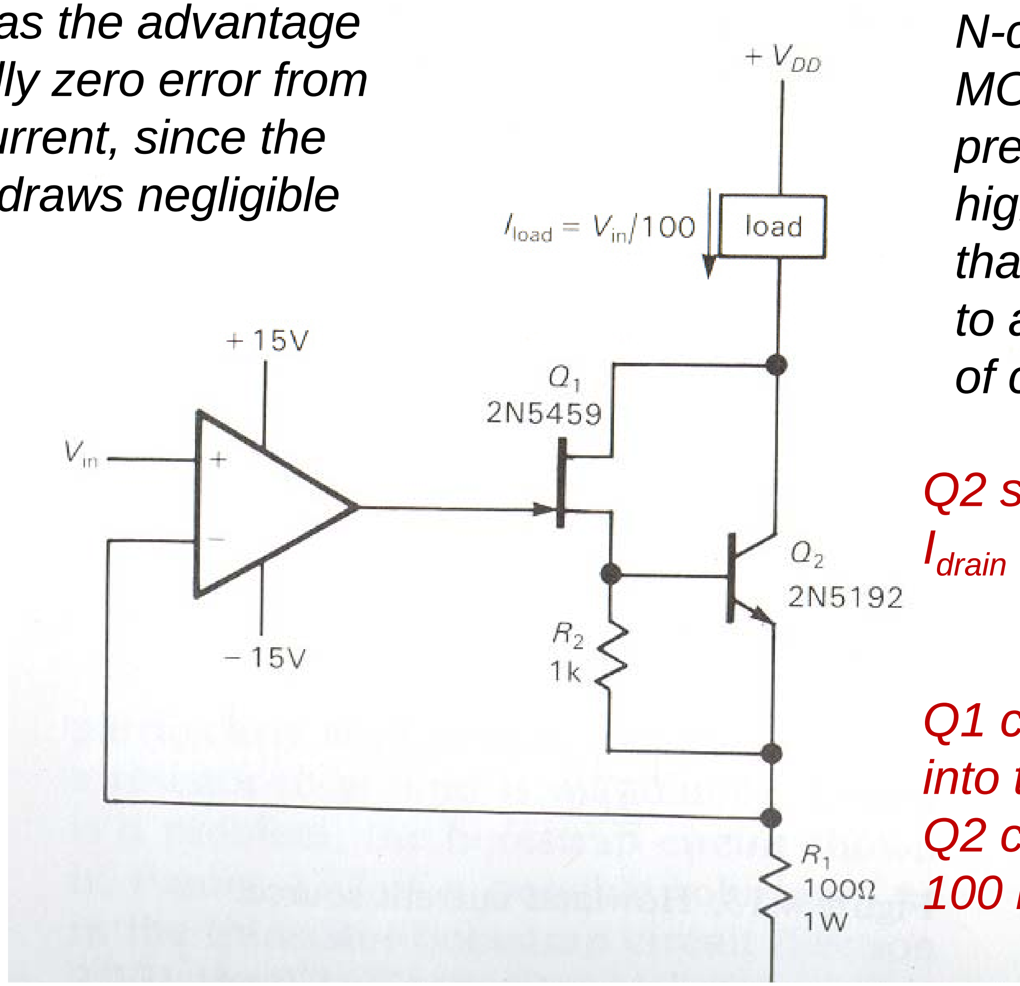
Current Sink Performance

The output impedance is so high now that I cannot see any difference in the simulated current over this 7 volt range! Practically a perfect current source, as long as the compliance range is not exceeded.



High-Current Sink

This also has the advantage of essentially zero error from the base current, since the JFET gate draws negligible current.



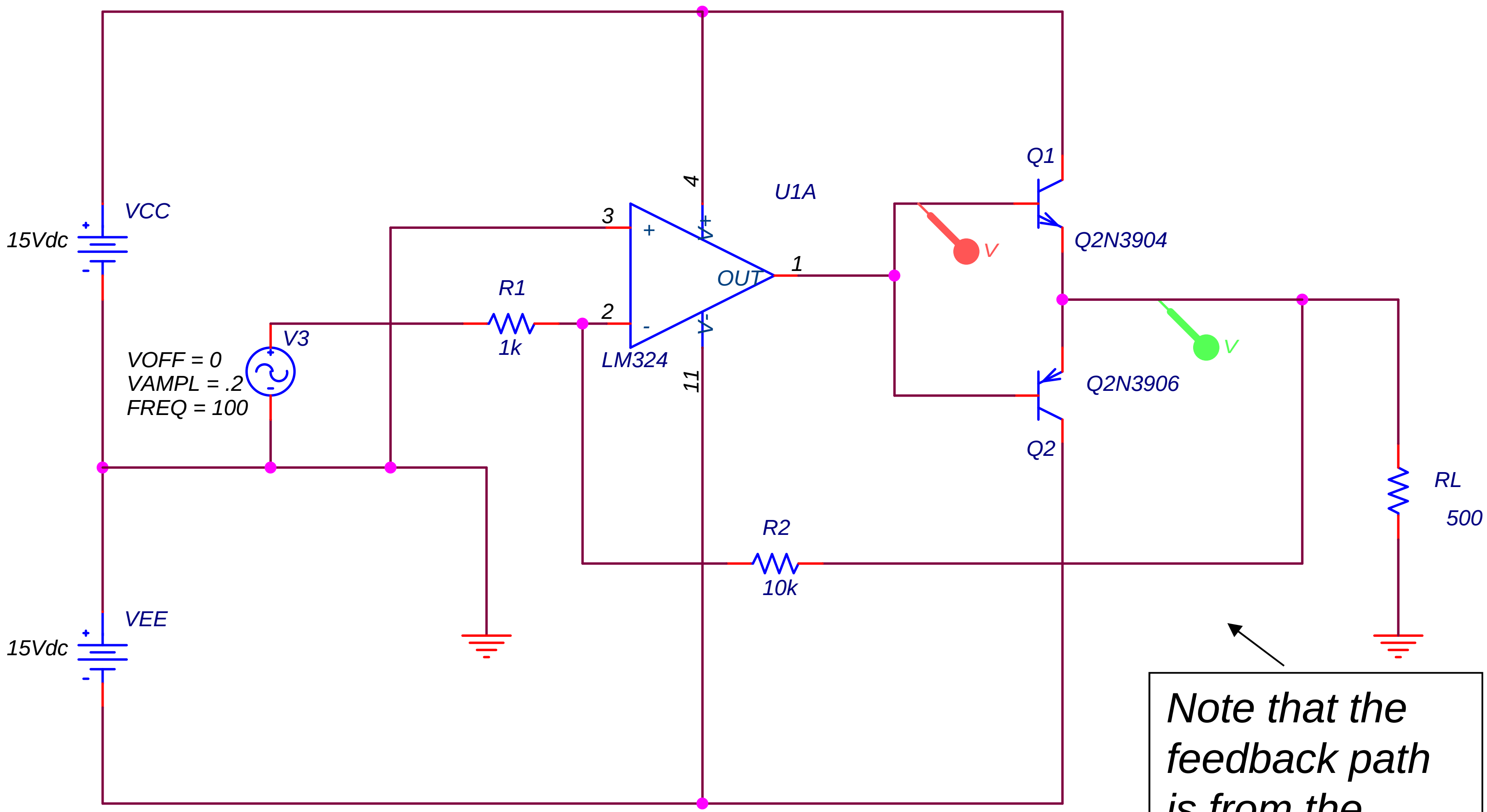
GND

Note, using the IRL510 N-channel power MOSFET as in the previous slide is also a high-current option, as that device is rated up to about 4 to 5 amperes of current.

Q2 starts to turn on when I_{drain} is about 0.6 mA.

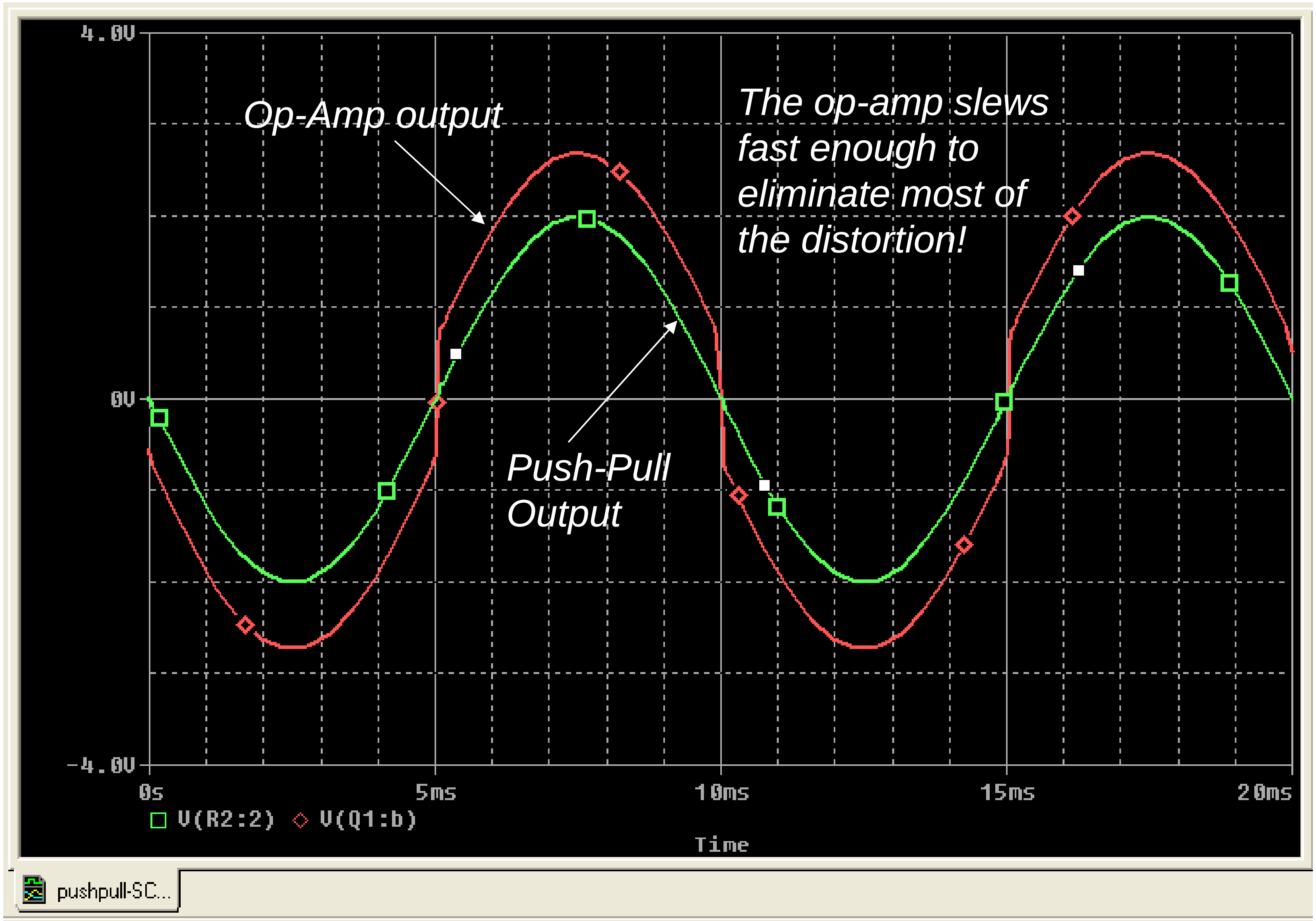
Q1 can put at least 4 mA into the base of Q2, so Q2 can sink at least 100 mA.

Correcting Cross-Over Distortion



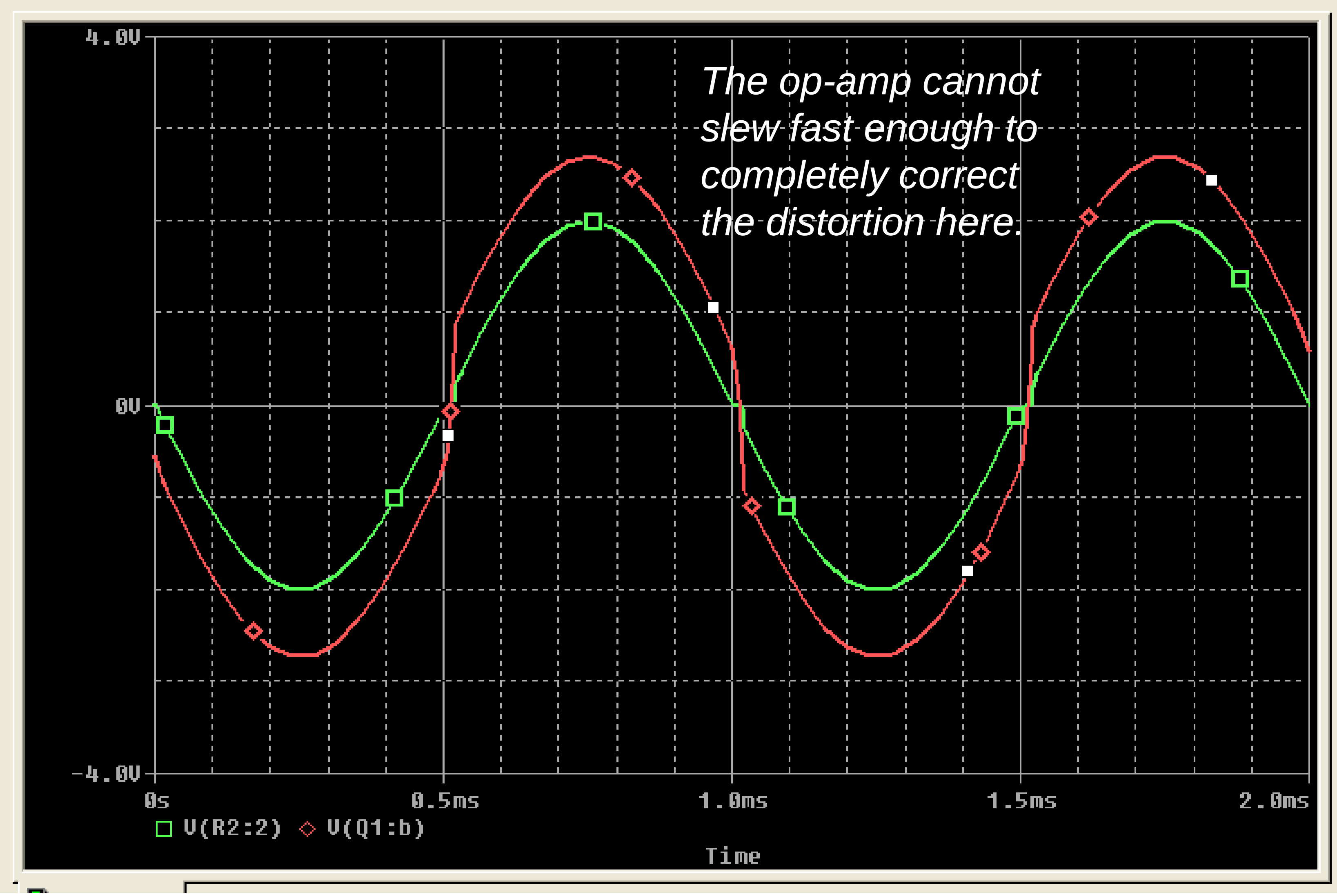
Note that the feedback path is from the output of the push-pull stage!

f = 100 Hz



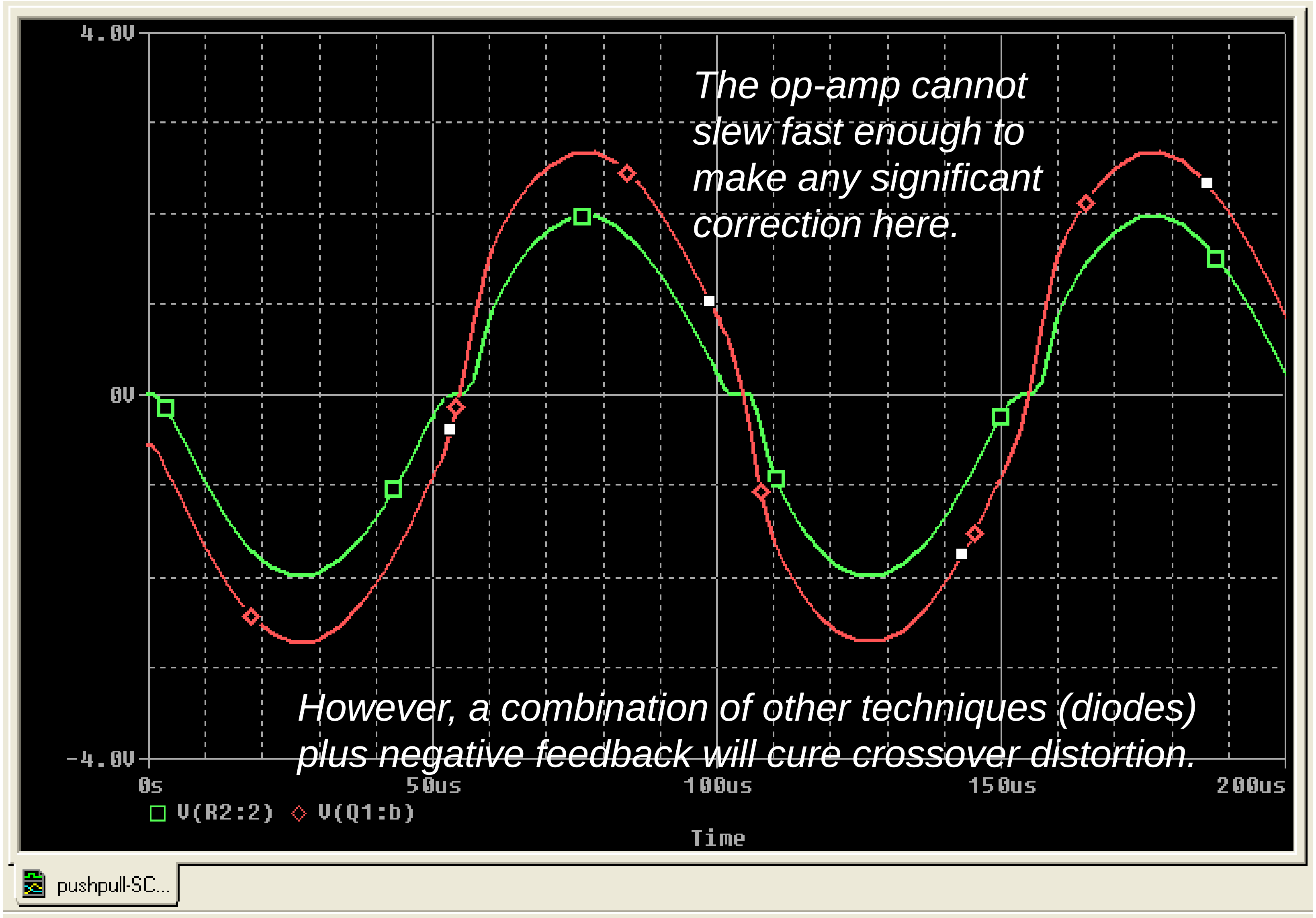
4.0V
0V
-4.0V
0s
5ms
10ms
15ms
20ms
V(R2:2)
V(Q1:b)
Time
Op-Amp output
The op-amp slews fast enough to eliminate most of the distortion!
Push-Pull Output
pushpull-SC...

f = 1000 Hz



4.0V
0V
-4.0V
0s
0.5ms
1.0ms
1.5ms
2.0ms
V(R2:2)
V(Q1:b)
Time
The op-amp cannot slew fast enough to completely correct the distortion here.

f = 10,000 Hz


4.0V
0V
-4.0V
0s
50us
100us
150us
200us
V(R2:2)
V(Q1:b)
Time
pushpull-SC...
The op-amp cannot slew fast enough to make any significant correction here.
However, a combination of other techniques (diodes) plus negative feedback will cure crossover distortion.