Purdue University Department of Physics

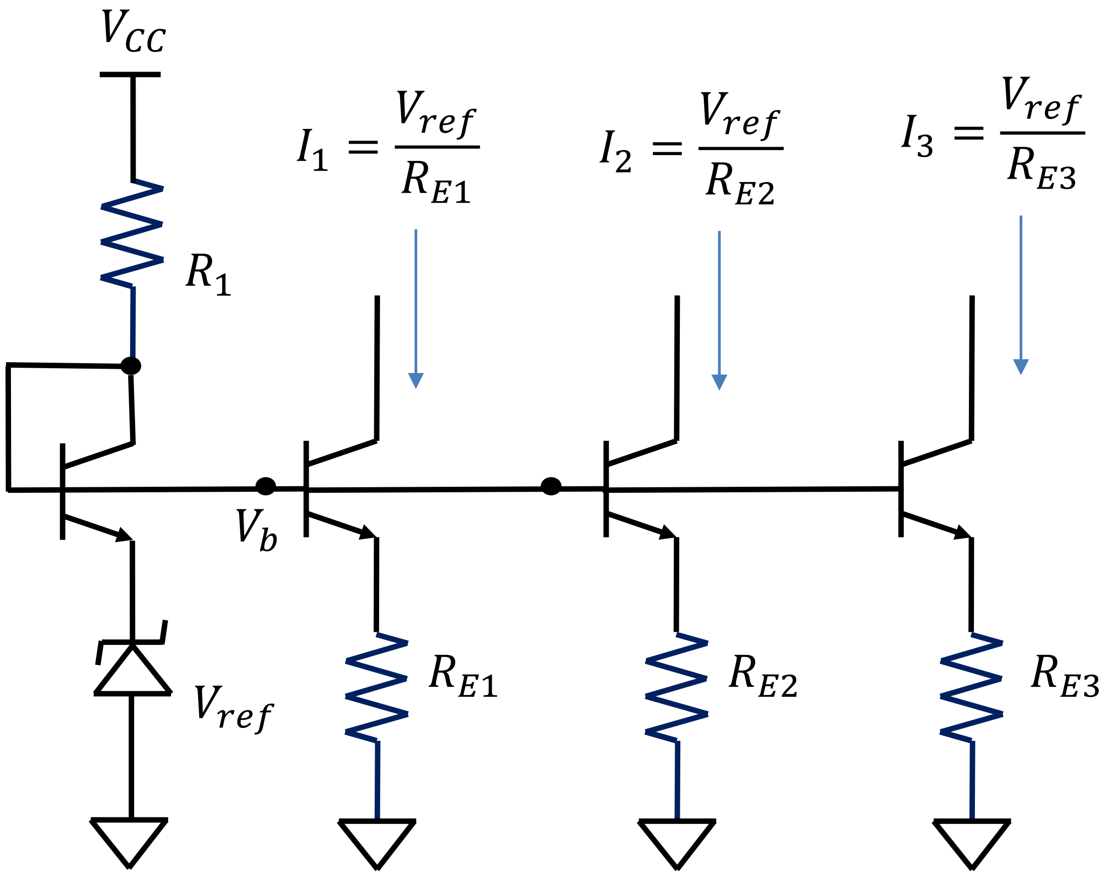
Physics 53600
Electronics Techniques for Research

Now in PowerPoint!

Spring 2020 Semester

Prof. Matthew Jones

Current Mirror

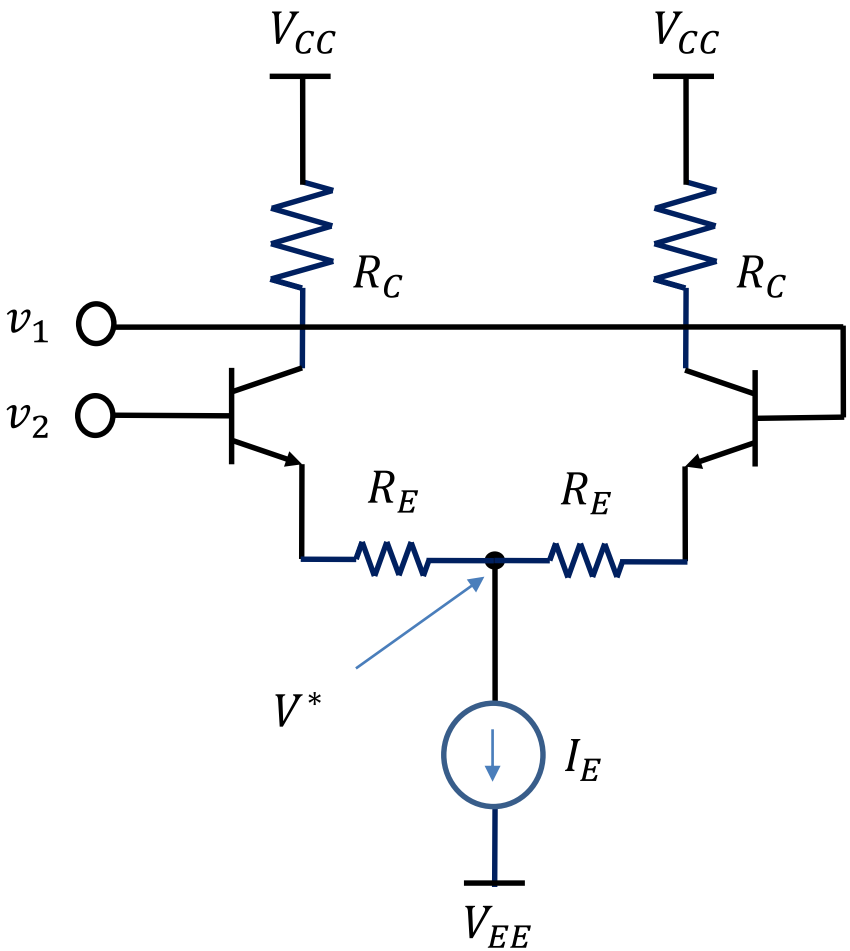


Current Mirror

- What good are all these current sources?
- They can provide the quiescent current through other transistors
- This is the default current when no other signal is present

Differential Pair

- Consider this circuit:



1. Ignore currents flowing into bases
2. $I_1 + I_2 = I_E$ (always!)
3. $V_{E1} = v_1 - V_{be}$
   $V_{E2} = v_2 - V_{be}$
4. $I_1 = \frac{V_{E1} - V^*}{R_E}$
   $I_2 = \frac{V_{E2} - V^*}{R_E} = I_E - I_1$

$\rightarrow I_1 = \frac{1}{2}\left(I_E - \frac{v_2 - v_1}{R_E}\right)$

$\rightarrow I_2 = \frac{1}{2}\left(I_E + \frac{v_2 - v_1}{R_E}\right)$

Differential Pair

- The output can be taken from the collector of one of the resistors

$$v_{out} = V_{CC} - I_1 R_C$$
$$\delta v_{out} = -\delta I_1 R_C$$
$$= -\delta(v_1 - v_2)\frac{R_C}{2R_E}$$

- v_{out} does not depend on V_{be}
  - No temperature dependence
- v_{out} depends only on Δv, not on v_1 or v_2 explicitly

Differential Pair

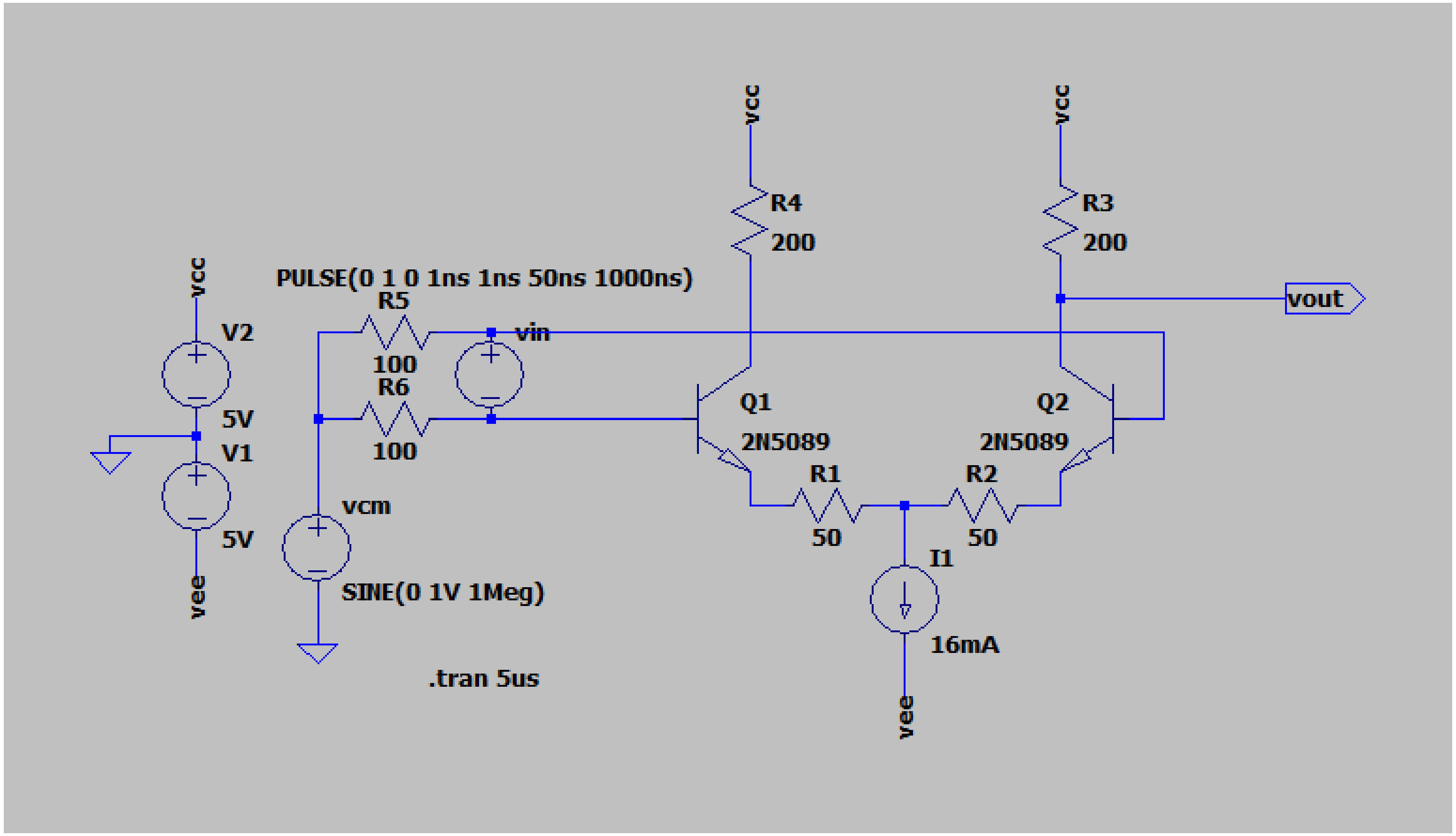
- v_{out} measures the differential voltage between v_1 and v_2
- The common mode voltage is cancelled

$$\Delta v = v_1 - v_2$$

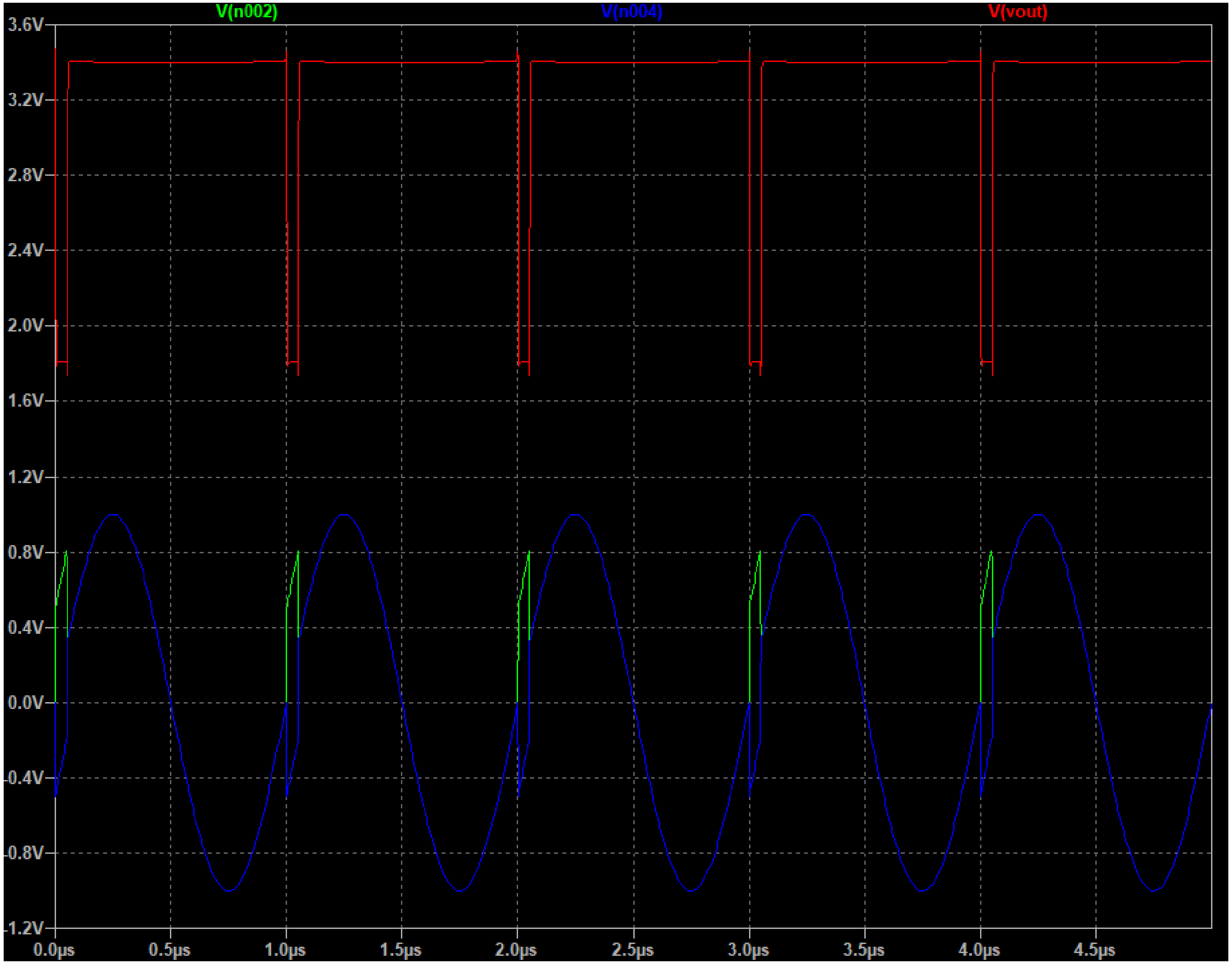
$$v_{cm} = \frac{1}{2}(v_1 + v_2)$$

- Any electronic noise picked up on both v_1 and v_2 will be cancelled.
- The total current draw is constant; it is just switched between the two transistors.

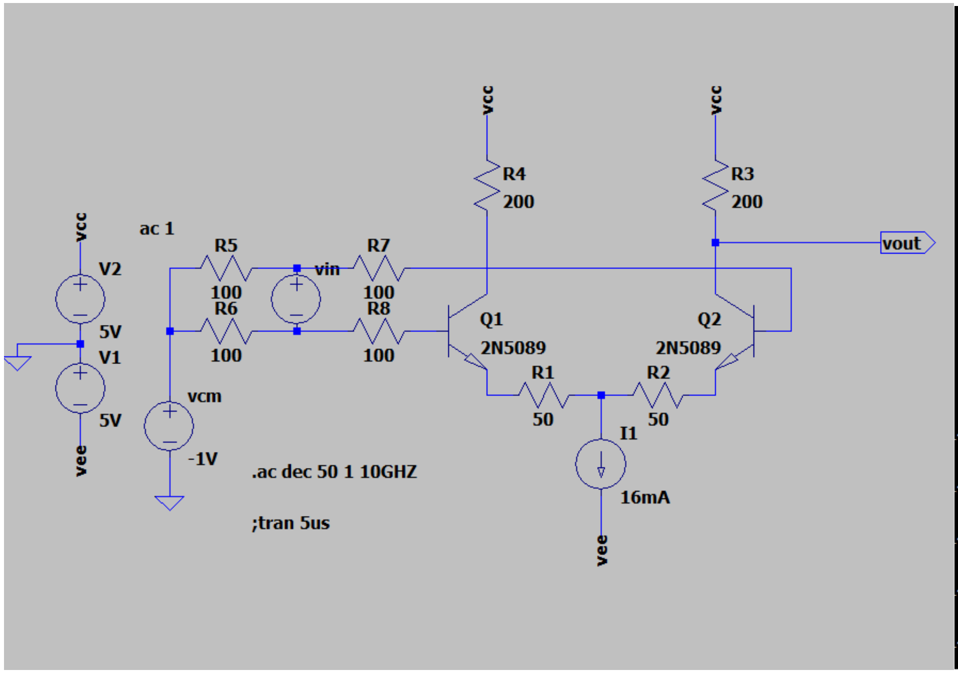
Differential Pair

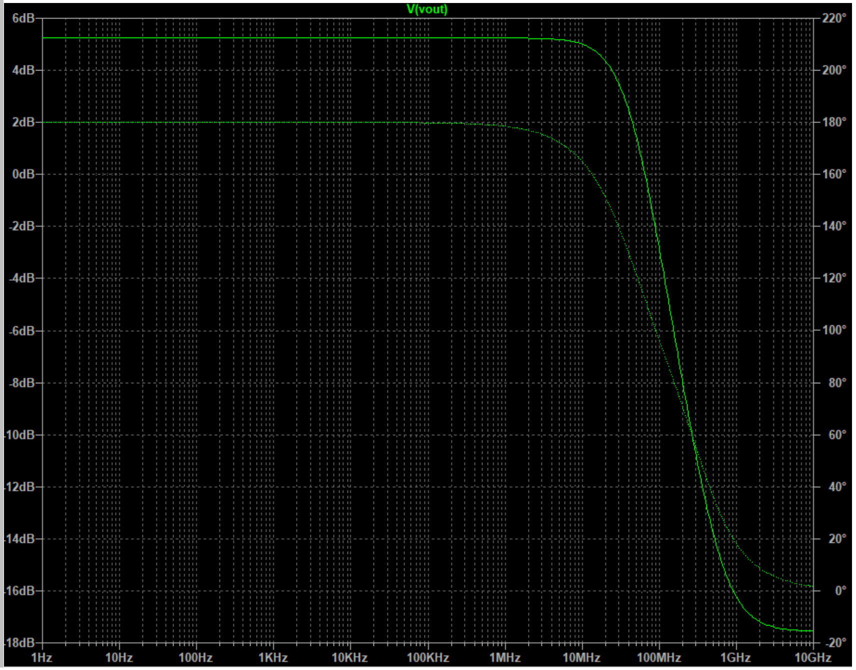


Differential Pair



Differential Pair



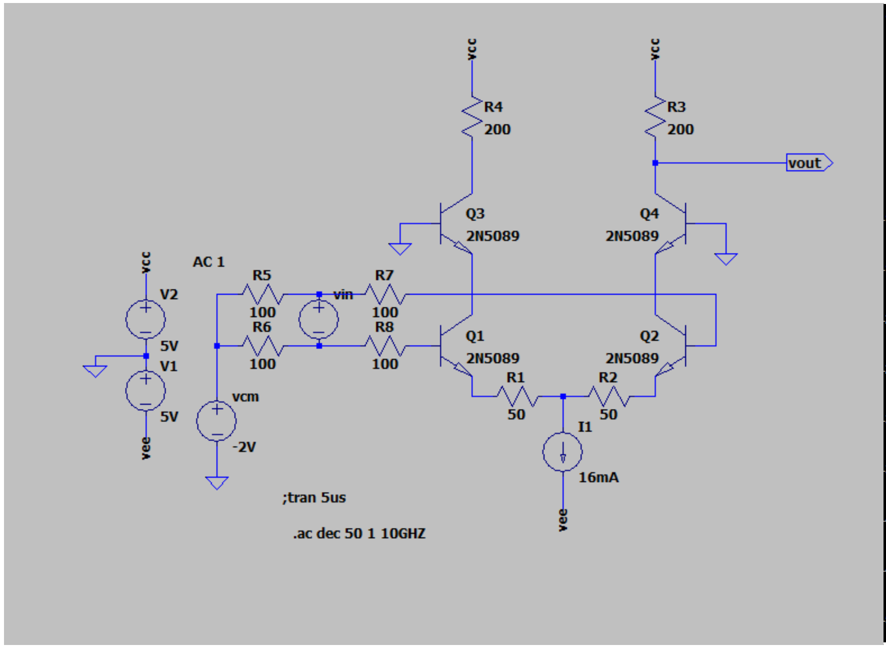


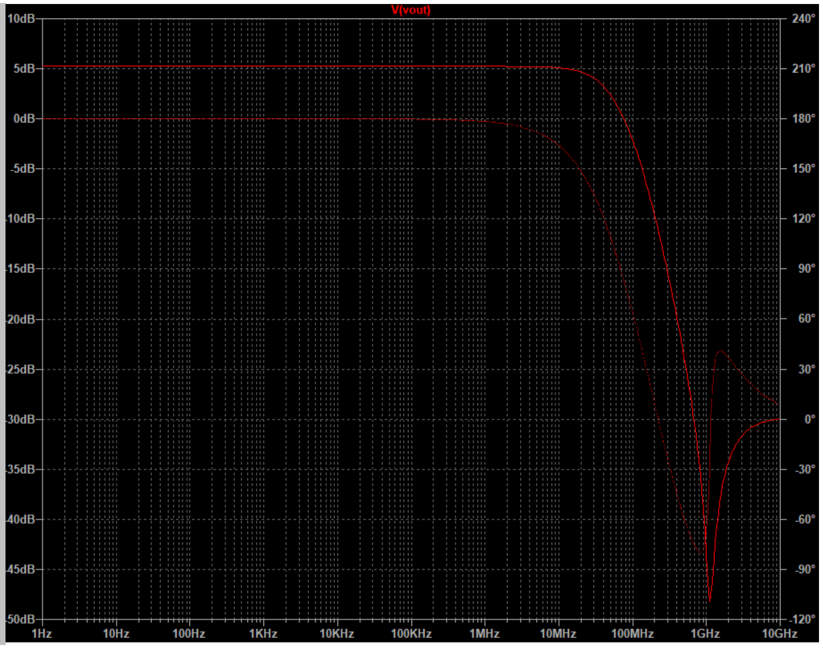
Gain reduced by -3 dB at about 40 MHz

What limits the frequency response?

- Parasitic capacitance within the transistors between the collector and the base
- What if we could shield the base by keeping the collector at a constant potential?

Cascode Configuration

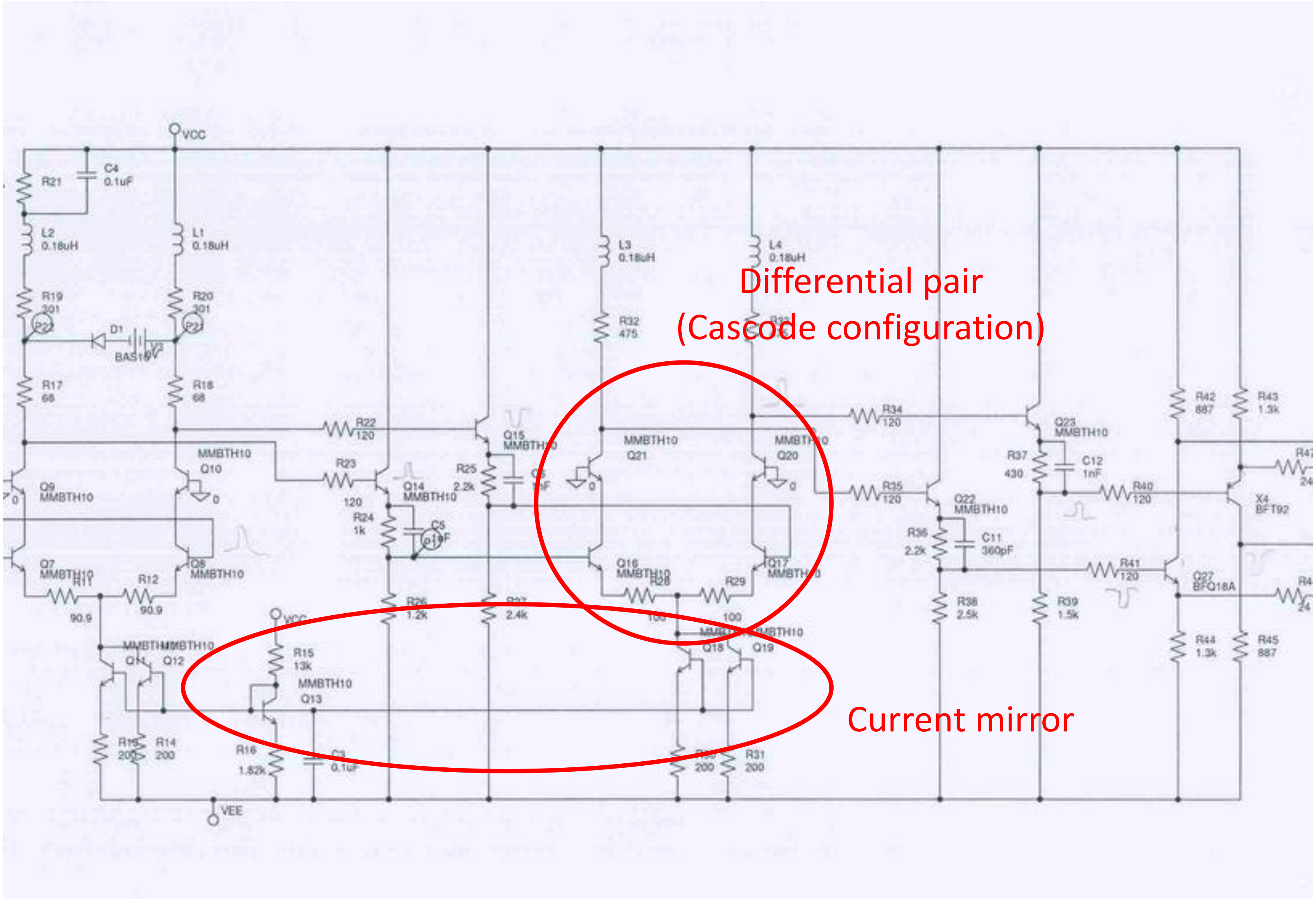




- Now the gain is reduced by -3 dB at about 60 MHz
- More important for higher speed transistors

(it’s a good design practice but your mileage may vary)

Transistor Configurations



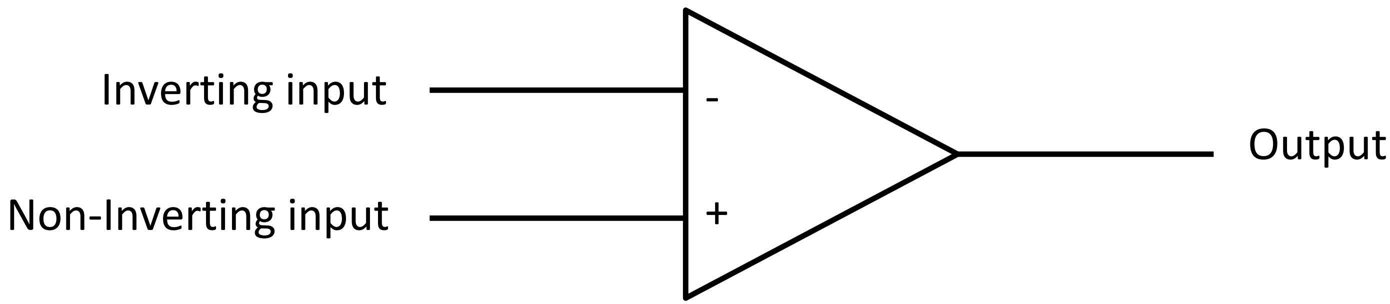
Discrete Component Amplifiers

- Advantages:
  - Relatively simple
  - Specific to a given application
  - Can be quite fast / high frequency
- Disadvantages:
  - Limited dynamic range
  - Possibly non-linear
  - Complexity of design needed to counteract non-ideal characteristics

Operational Amplifiers

- An operational amplifier is a multi-stage amplifier that provides:
  - Very large intrinsic gain
  - Very high input impedance
  - Very low output impedance
- Easily configured into a wide range of analog circuits using discrete components

Operational Amplifiers



- Connections to the power supply are often not shown.
- Open loop gain:

$$v_{out} = A_0(v_+ - v_-)$$

- The parameter A_0 is usually very large (10^5-10^6)

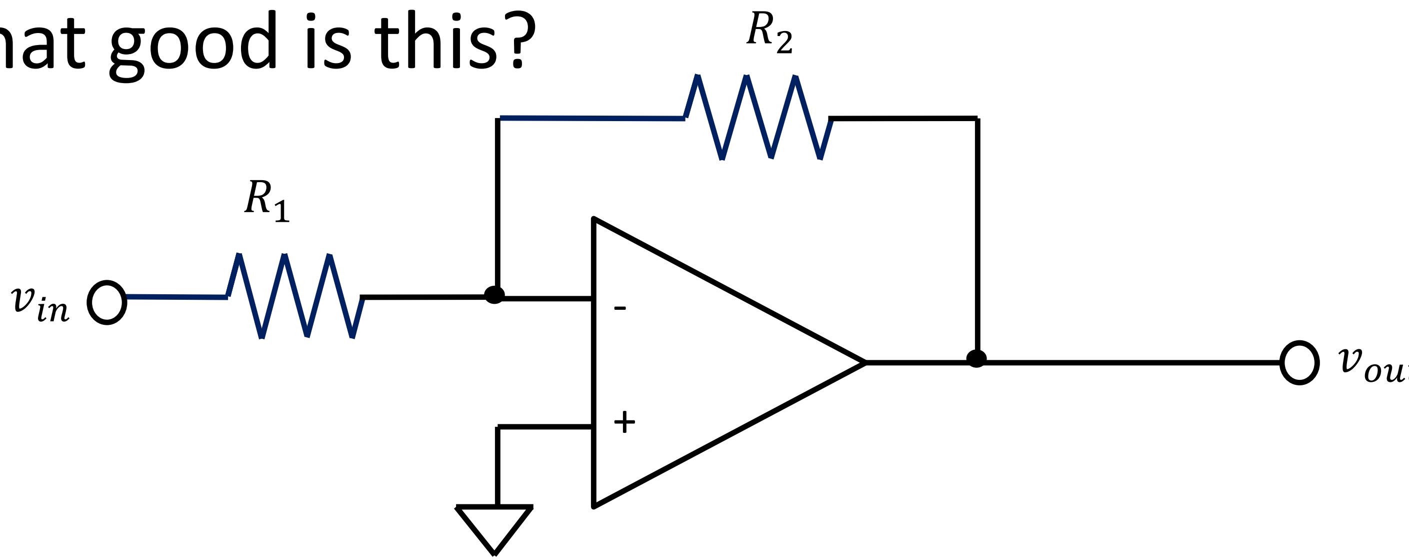
Operational Amplifiers

- In practice, A_0 depends on frequency:

- Typically, the product of the intrinsic gain and the bandwidth is a constant.
  - And it's called the Gain-Bandwidth product

Operational Amplifiers

- So what good is this?



$$v_+ = 0\ V \text{ (connected to ground)}$$

$$v_- = \frac{v_{in}R_2 + v_{out}R_1}{R_1 + R_2}$$

$$v_{out} = A_0(v_+ - v_-) = -A_0 v_-$$

Operational Amplifiers

- After a little bit of algebra…

$$v_{out}\left(\frac{1}{A_0}+\frac{R_1}{R_1+R_2}\right)=-\frac{v_{in}R_2}{R_1+R_2}$$

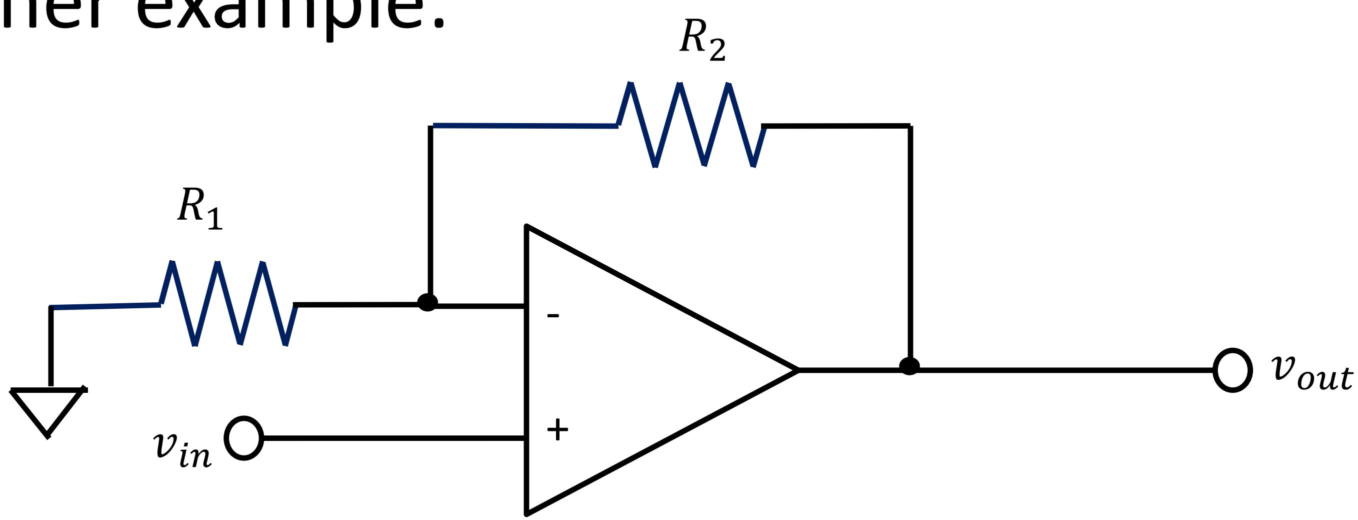
- But $A_0 \gg 1$ so this becomes

$$v_{out}=-v_{in}\frac{R_2}{R_1}$$

- This configuration is called an inverting amplifier

Operational Amplifiers

- Another example:



$$v_+ = v_{in}$$

$$v_- = \frac{v_{out} R_1}{R_1 + R_2}$$

$$v_{out} = A_0 (v_+ - v_-)$$

Operational Amplifiers

$$v_{out} = \left(v_{in} - \frac{v_{out}R_1}{R_1 + R_2}\right)$$

$$v_{out}\left(\frac{1}{A_0} + \frac{R_1}{R_1 + R_2}\right) = v_{in}$$

- But yet again, $A_0 \gg 1$…

$$v_{out} = v_{in}\left(1 + \frac{R_2}{R_1}\right)$$

- This is called a non-inverting amplifier.

Operational Amplifiers

- There are some simple rules for designing circuits using operational amplifiers:

1. The inputs draw negligible current
2. The output will produce whatever voltage is needed to equalize v_+ and v_- (op-amp magic)

- Example: inverting amplifier

$$v_+ = 0$$

$$v_- = \frac{v_{in}R_2 + v_{out}R_1}{R_1 + R_2} = 0$$

$$v_{out} = -\frac{v_{in}R_2}{R_1}$$

Operational Amplifiers

- Another example: non-inverting amplifier

$$v_+ = v_{in}$$

$$v_- = \frac{R_1 v_{out}}{R_1 + R_2} = v_{in}$$

$$v_{out} = v_{in}\left(\frac{R_1 + R_2}{R_1}\right) = v_{in}\left(1 + \frac{R_2}{R_1}\right)$$