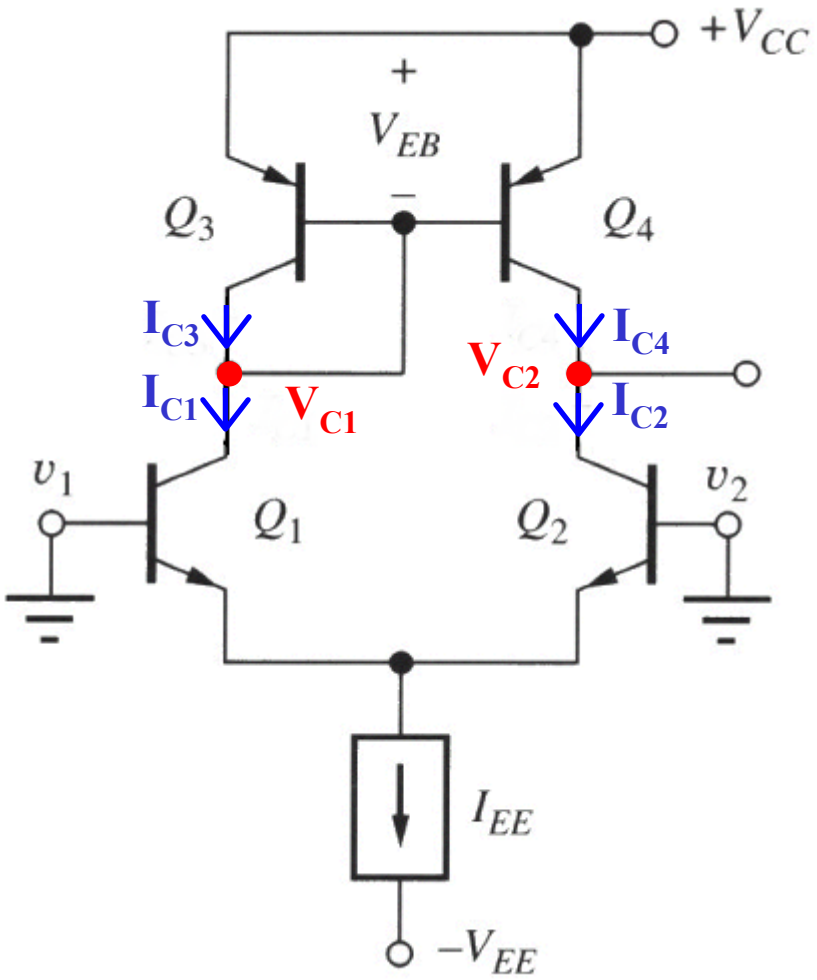
Lecture 31

What makes up an Op-Amp: 741 example

Reading: Jaeger 16.8 and Notes

What Makes up an Op Amp? The "741" Example

Current Mirror Used as an Active Load



DC Analysis

If we can insure that the mirrored currents are equal,

$$I_{C3} = I_{C1} = I_{C4} = I_{C2} = \frac{I_{EE}}{2}$$

$$V_{C1} = V_{C2}$$

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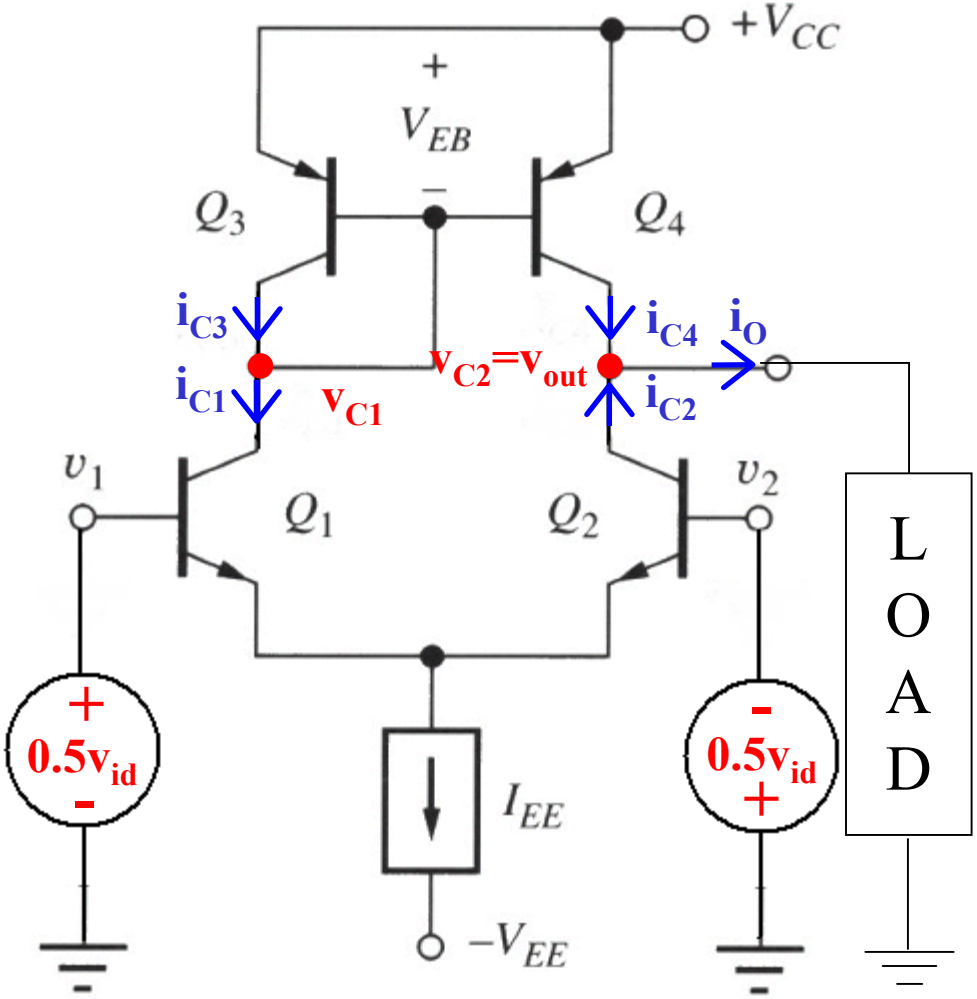


AC Analysis

$$i_{C3} = i_{C1} = i_{C4}$$

$$i_{C1} = i_{C2} = g_m\left(\frac{v_{id}}{2}\right)$$

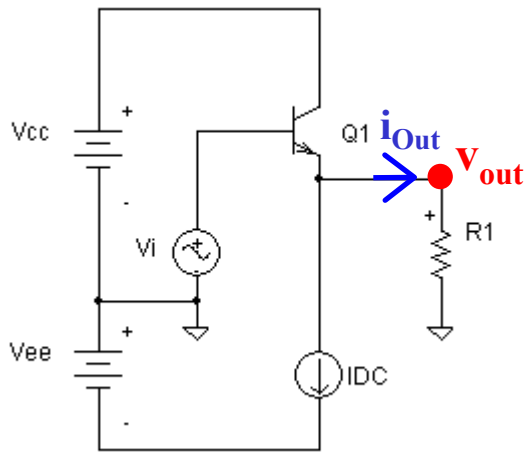
$$i_O = i_{C4} + i_{C2} = g_m\left(\frac{v_{id}}{2}\right) + g_m\left(\frac{v_{id}}{2}\right) = g_m v_{id}$$

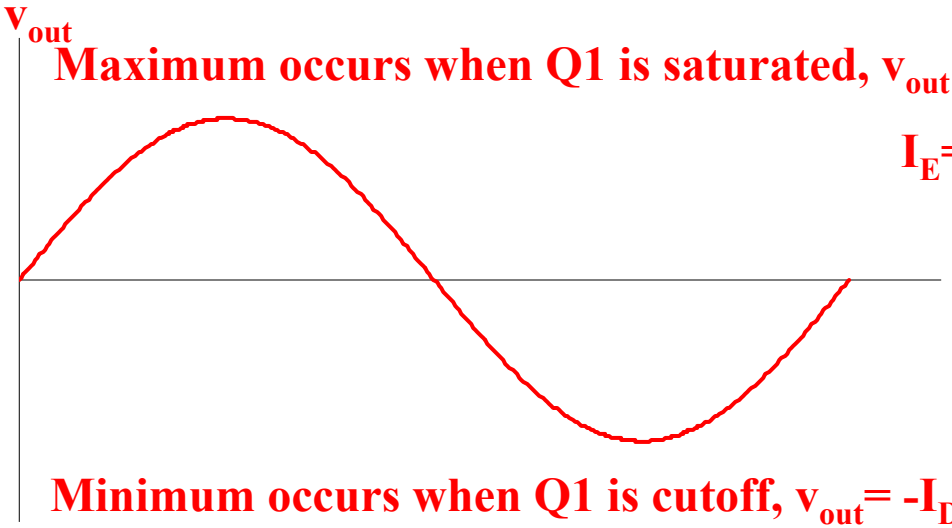
$$v_{out} = g_m v_{id}\left(r_{o2} \| r_{o4} \| R_L\right) \cong g_m v_{id} R_L$$

By using an active load (transistors), we obtain the "Full" gain of a CE stage even though we have a single-ended output. (Remember that for a passive load, resistor, the single ended gain was half the CE gain).

What Makes up an Op Amp? The "741" Example

Output Stages: "Class A" Output Stage





Maximum occurs when Q1 is saturated, $v_{out} <= V_{CC}$

$I_E = I_{DC} + i_{Out}$

Minimum occurs when Q1 is cutoff, $v_{out} = -I_{DC}(R1)$.

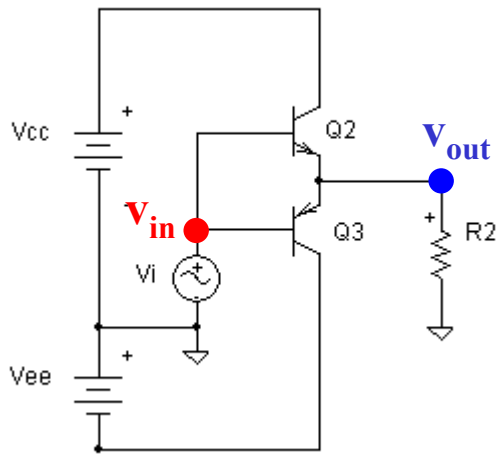
Only at this minimum voltage value would Q1 no longer conduct current

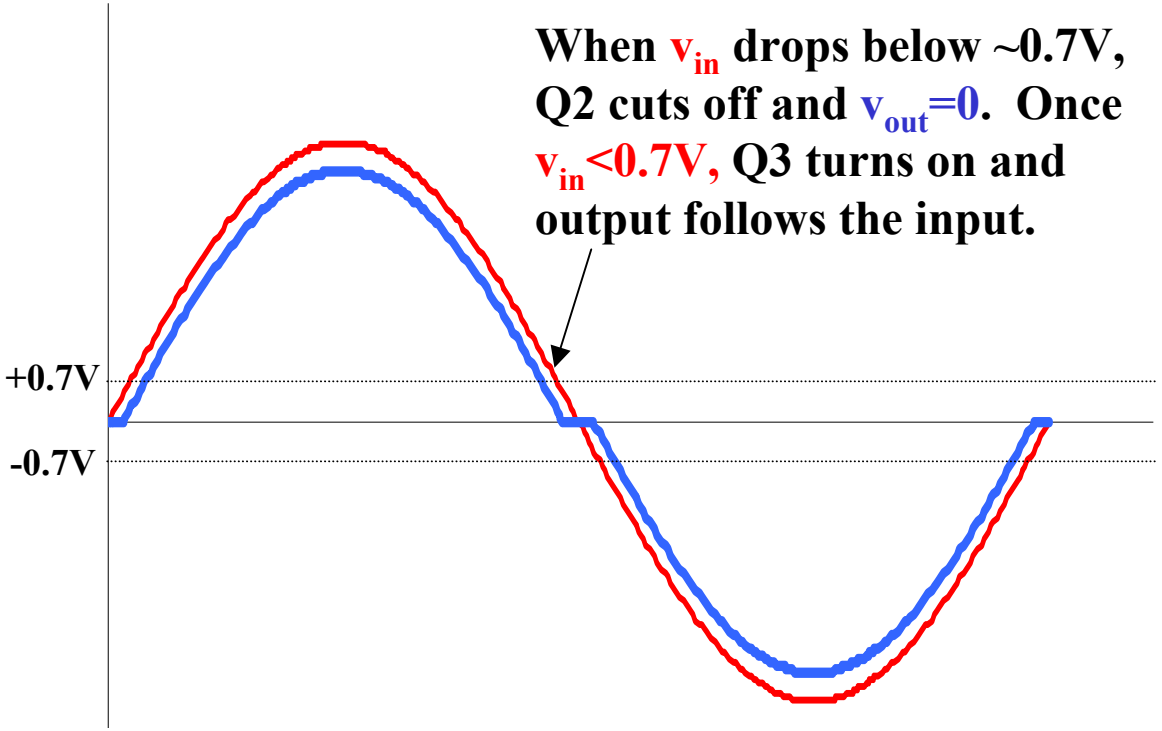
So far, the Common Collector output stages (again chosen for very low output impedance) has consisted of a single transistor.

This transistor must carry the output current (delivered to R1) and the bias current (I_{DC}). This results in wasted power in the output stage and possible overheating.

What Makes up an Op Amp? The "741" Example

Output Stages: "Class B" Output Stage





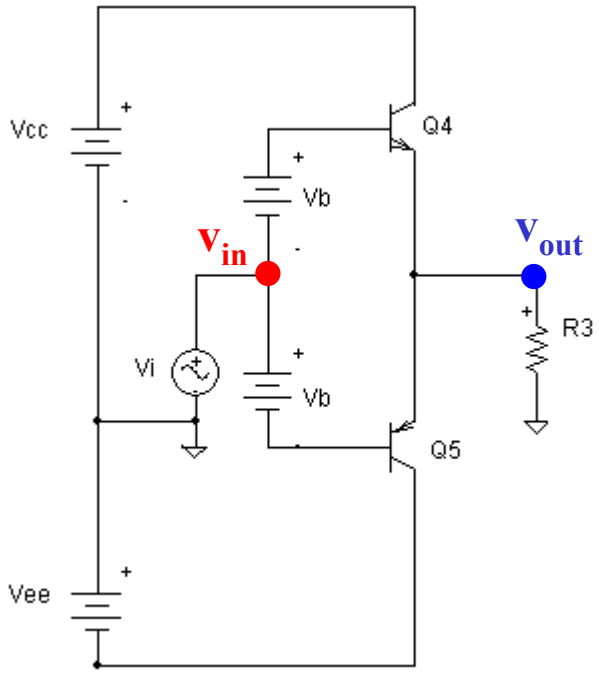
A Common Collector output stage using 2 complementary (1 npn /1pnp) transistors where each transistor conducts only for ~1/2 the cycle is known as a class "B" output stage.

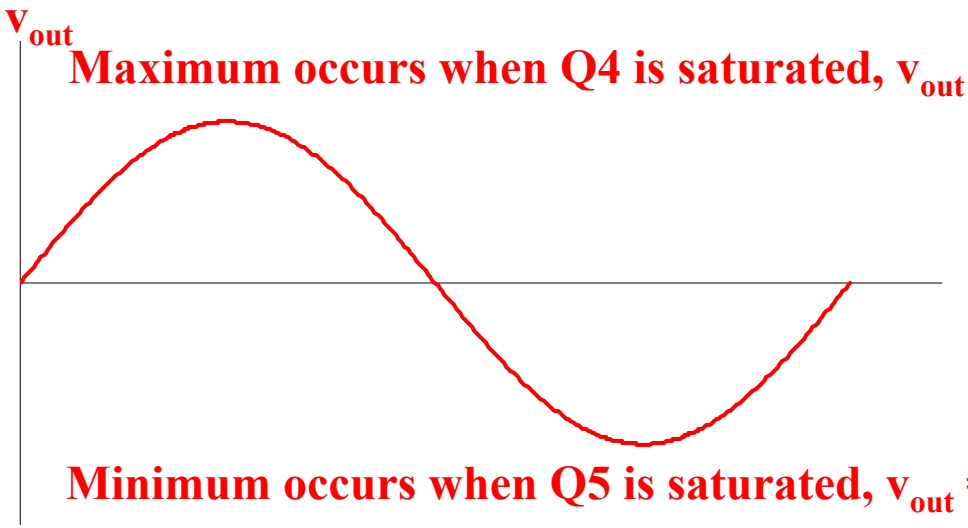
During the positive half cycle, Q2 conducts and Q3 is off. All the current through Q2 is delivered directly to the load.

During the negative half cycle, Q3 conducts and Q2 is off. All the current through Q3 is delivered directly to the load.

What Makes up an Op Amp? The "741" Example

Output Stages: "Class AB" Output Stage



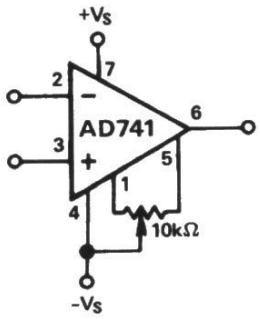


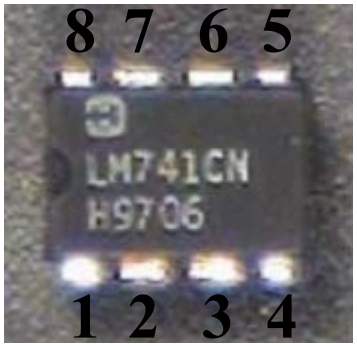
A partially biased Common Collector output stage using 2 complementary (1 npn /1pnp) transistors where each transistor conducts only for ~1/2 the cycle is known as a class "B" output stage.

During the positive half cycle, Q4 conducts and Q5 is weakly on. Almost all the current through Q4 is delivered directly to the load.

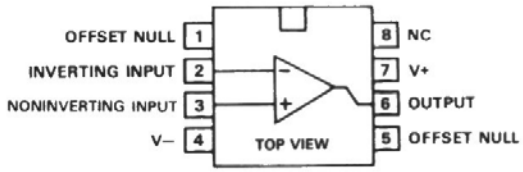
During the negative half cycle, Q5 conducts and Q4 is weakly on. Almost all the current through Q5 is delivered directly to the load.

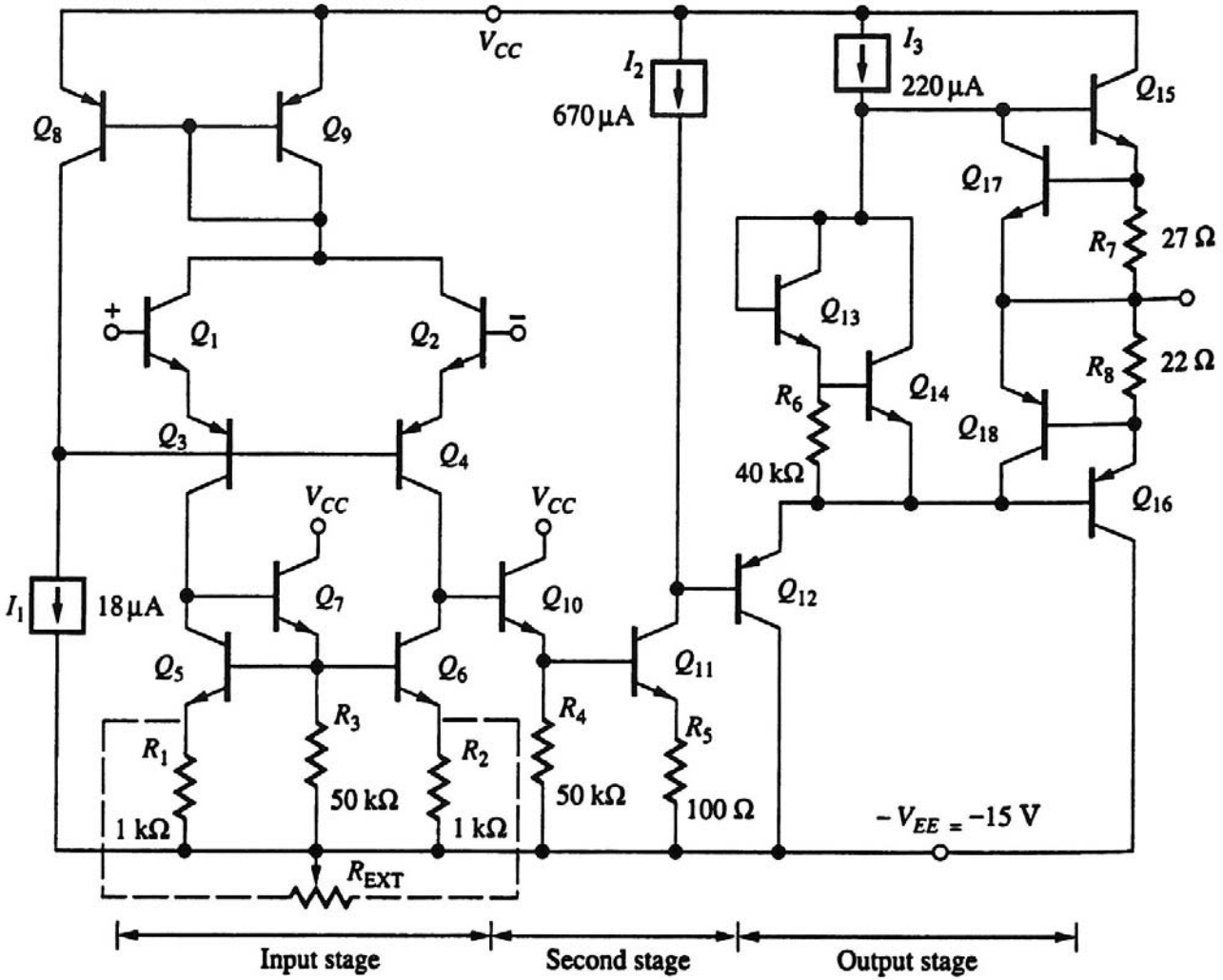
What Makes up an Op Amp? The "741" Example





Mini-DIP (N) Package

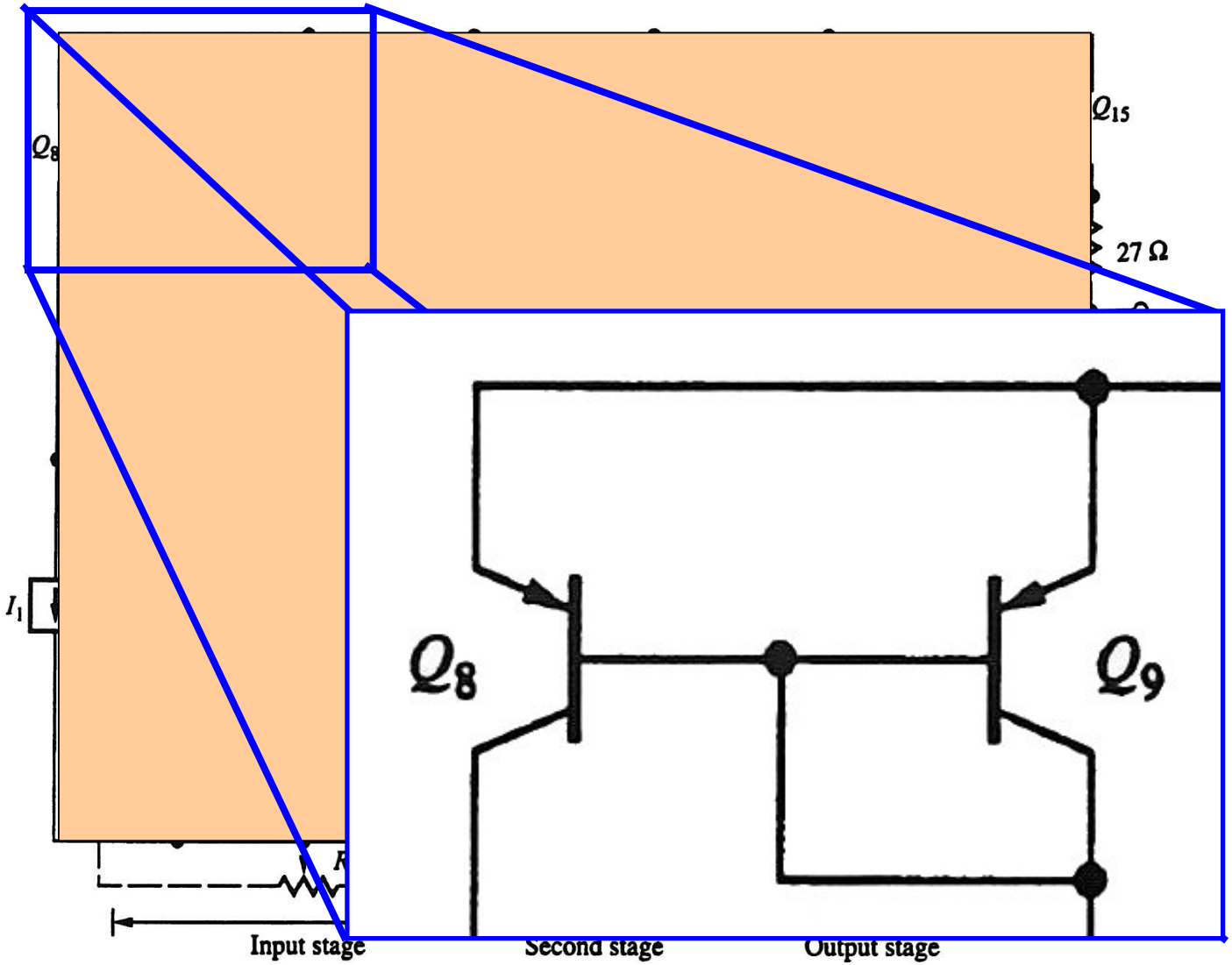




Reading: Jaeger 15.5, 16.5, 16.7

What Makes up an Op Amp? The "741" Example

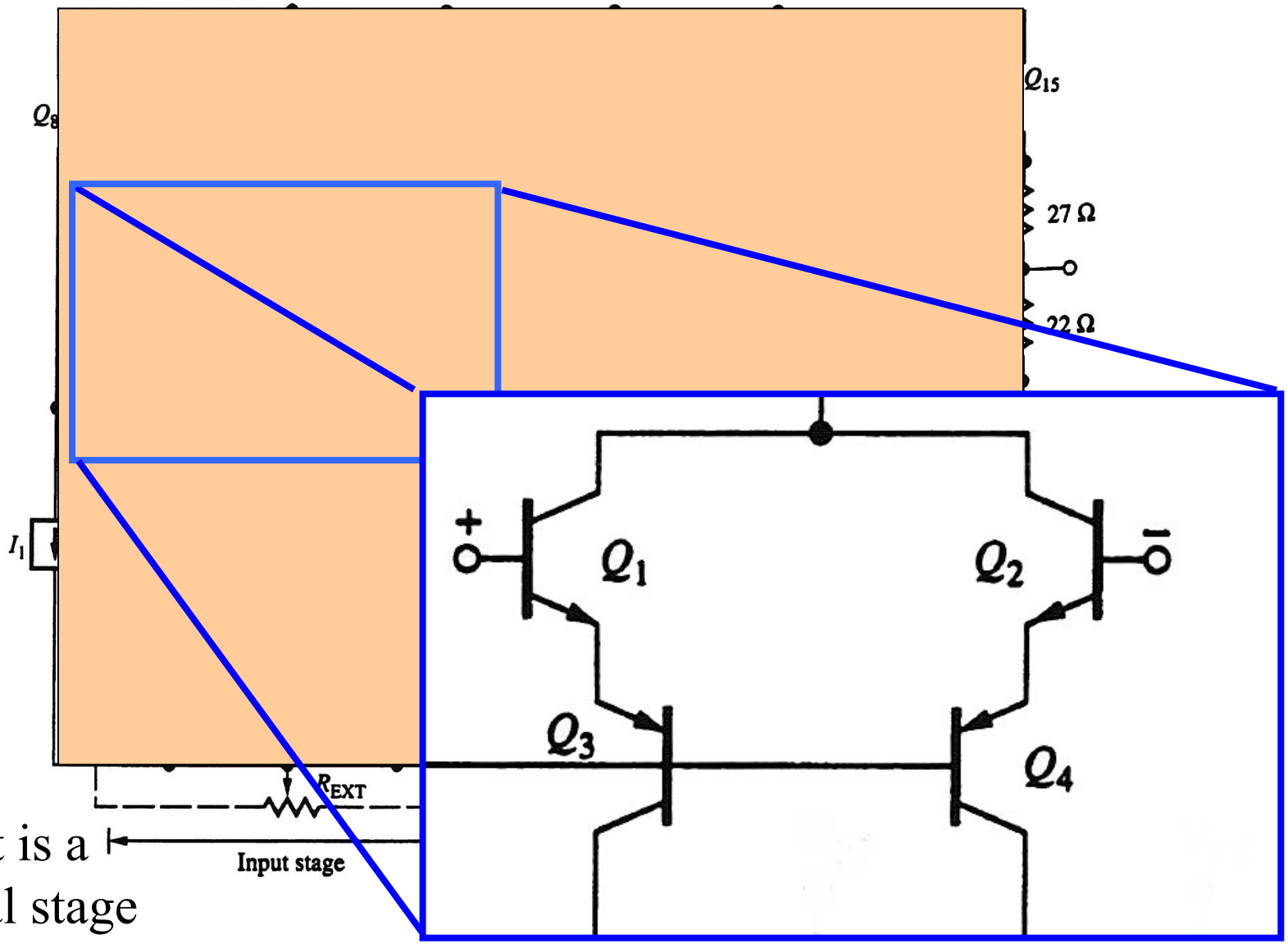
Bias Stage



Differential stage is biased by a current mirror

What Makes up an Op Amp? The "741" Example

Input Stage



Main input is a Differential stage

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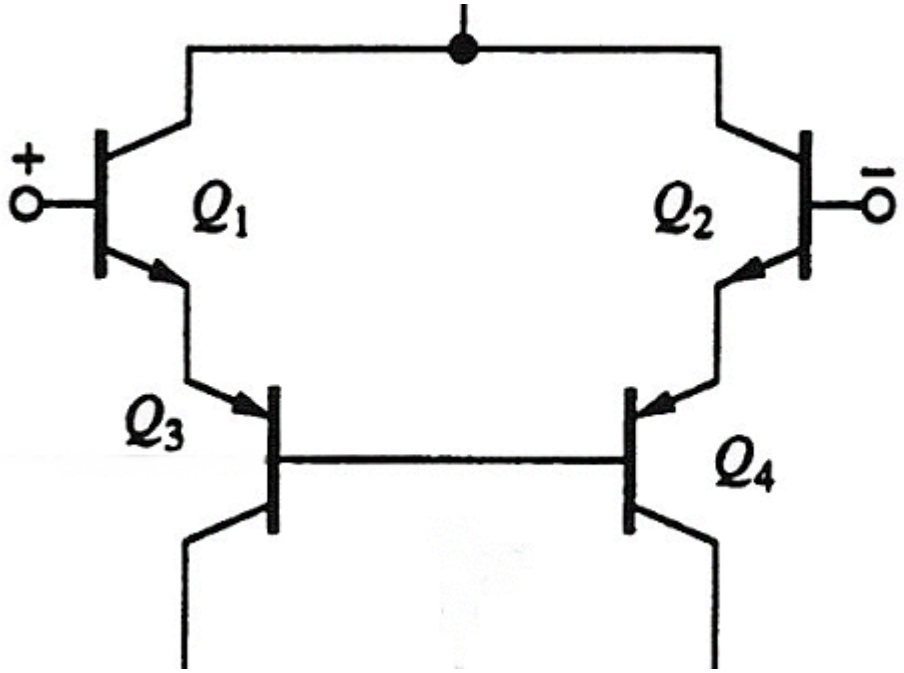
Input Stage



Q1 and Q2 form a Common collector difference amp (CC used for it's high input impedance). Q3 and Q4 form a Common base stage that only increases the input's resilience to over-voltage damage. The worst case situation would be V+ = $+V_{CC}$ and V- = $-V_{EE}$ (or vice-versa). This would result in 2 reverse biased junctions (V_{BE4} and V_{BE2}) instead of just one as is found in the standard differential amplifier input circuit. This extra junction provides an extra amount of safety to insure that large break down currents do not flow and damage the input stage.

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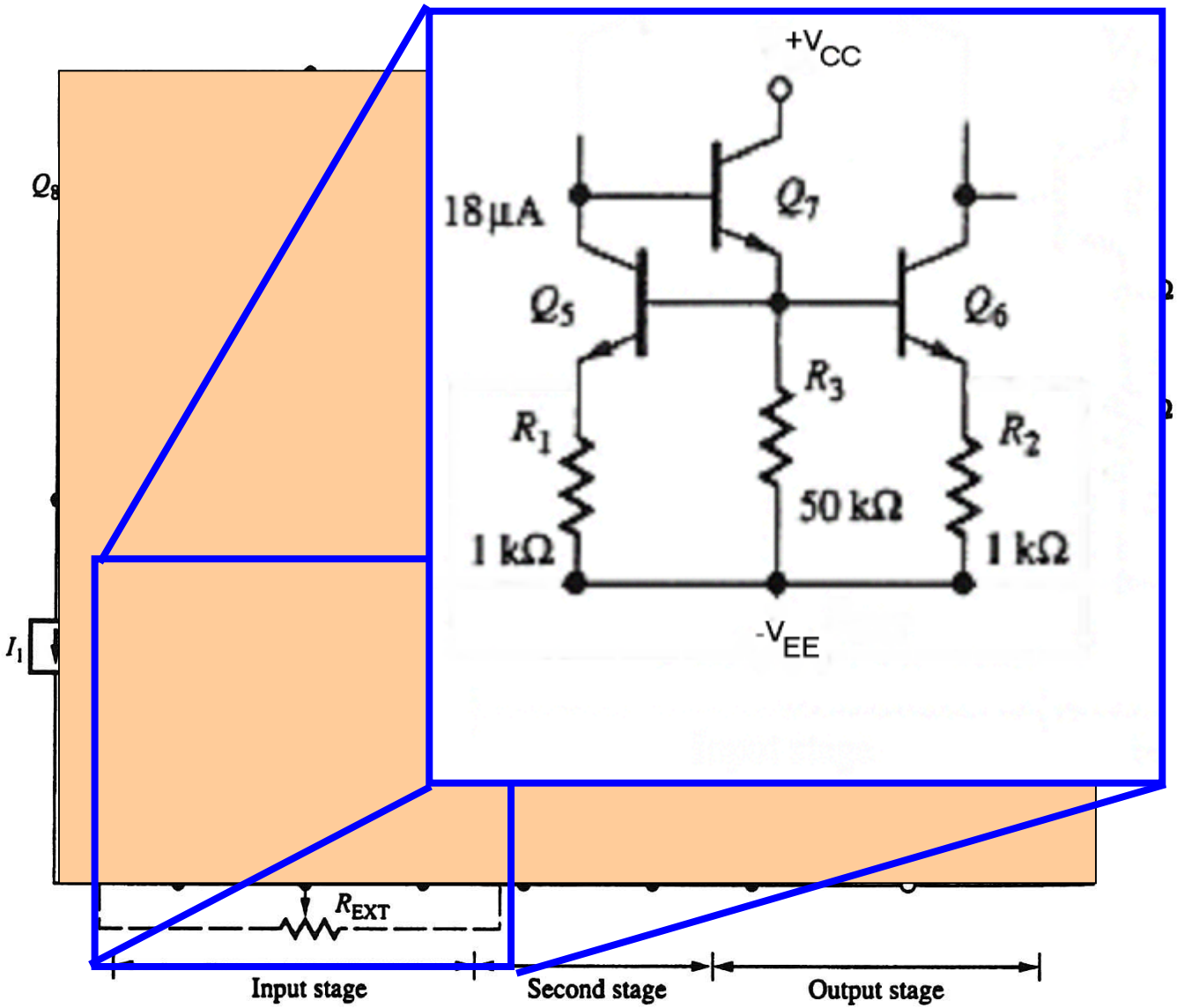
Differential Input Load Stage uses an Active Load in the form of a current mirror



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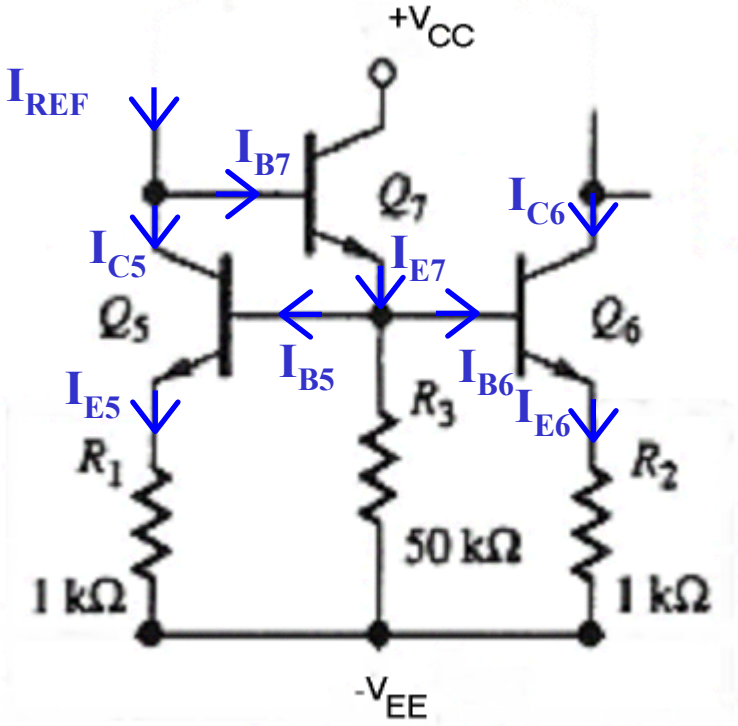

$$I_{E7} = I_{B5} + I_{B6} + \frac{V_B}{50K}$$

$$I_{B7} = \frac{I_{B5}}{(\beta+1)} + \frac{I_{B6}}{(\beta+1)} + \frac{V_B}{(\beta+1)50K} << I_{C5}$$

Thus, Q_7 insures that we can neglect I_{B7}

But $I_{E5} \approx I_{REF}$ *and* $R_1 = R_2$, *so,*

Since,

$$V_B = I_{E6}(R_2) + V_{BE6} = I_{E5}(R_1) + V_{BE5}$$

and Q_5 is matched with Q_6,

$$I_{REF} = I_{E6} \approx I_{C6}$$

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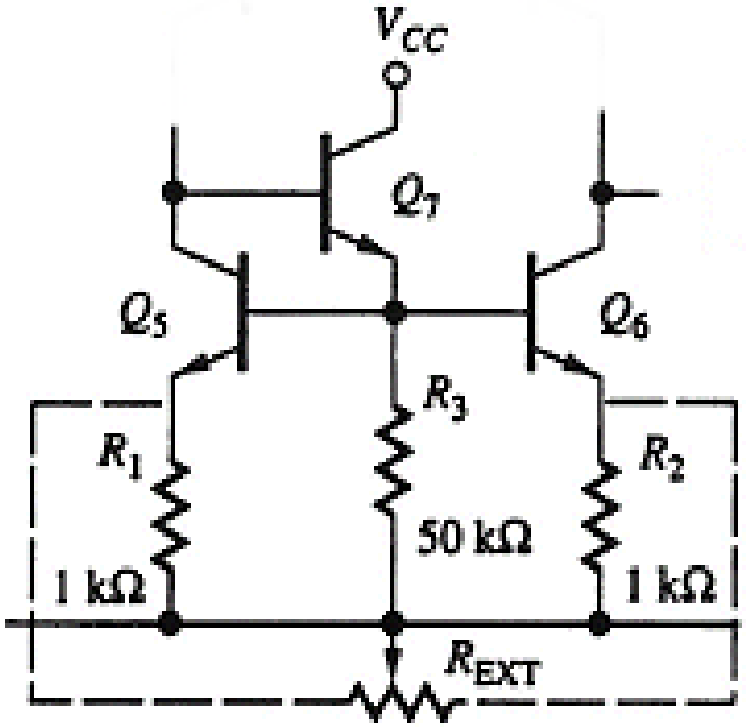

The 741 allows the user to adjust the current in the active load to insure proper current balance, insuring zero offset voltage at the output. Current balance is achieved by an external "potentiometer" which acts to replace R_1 and R_2 with,

$$R_1 \rightarrow R_1 \,||\, \left(xR_{Potentiometer}\right) \quad and \quad R_2 \rightarrow R_2 \,||\, \left((1-x)R_{Potentiometer}\right)$$

$$where \quad 0 \le x \le 1$$

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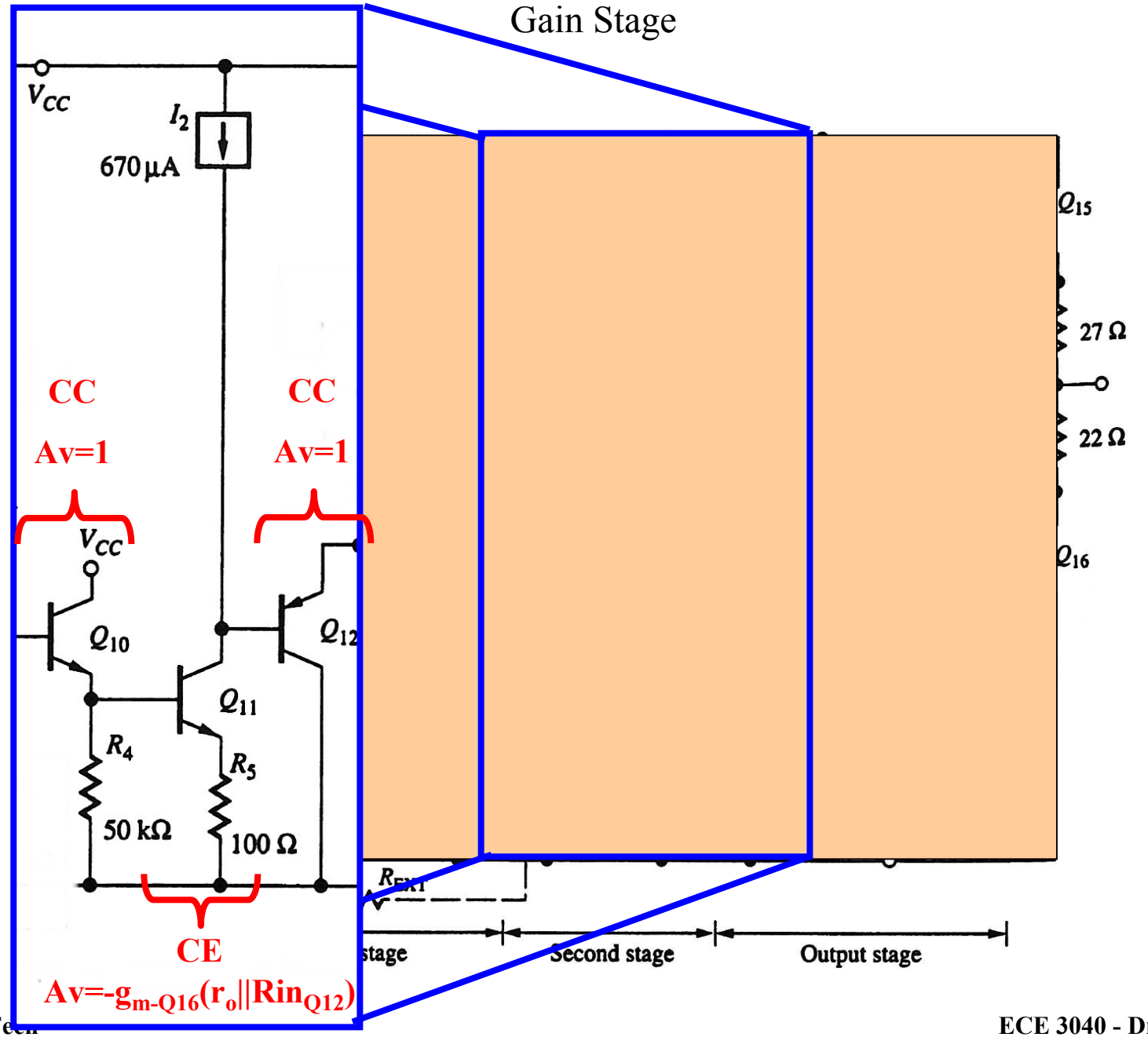
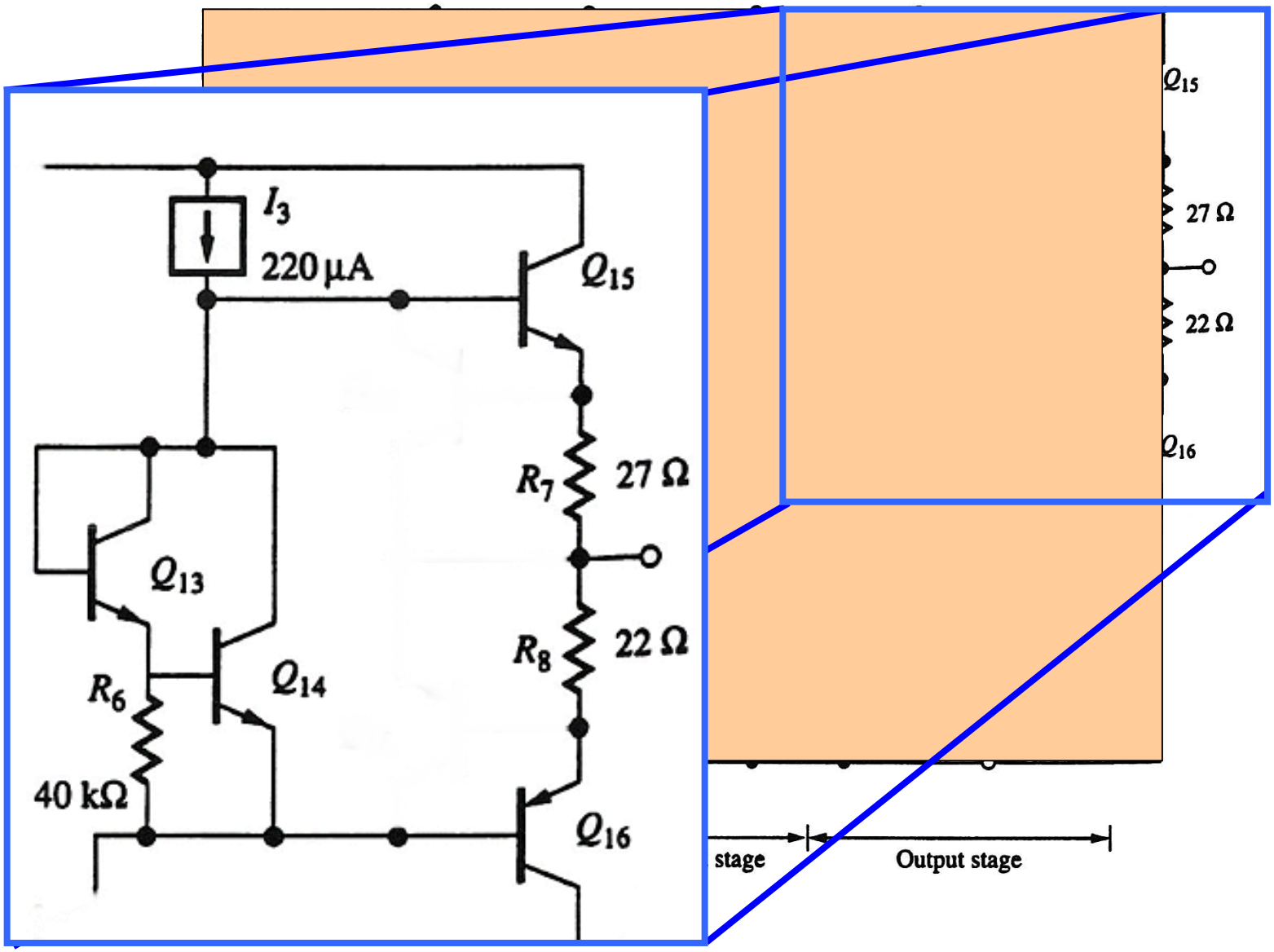


What Makes up an Op Amp? The "741" Example

Output Stage: Complementary (npn/pnp) Common Collector



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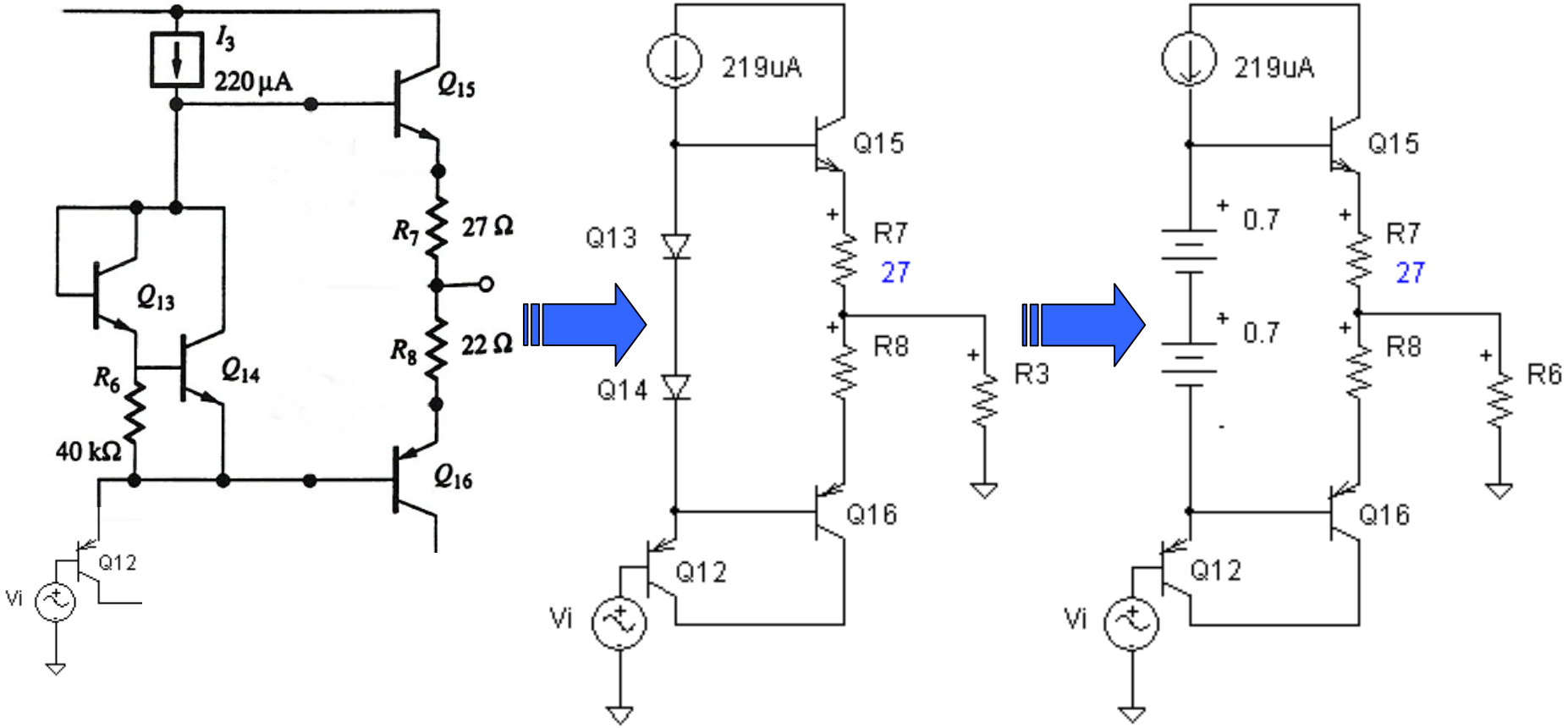
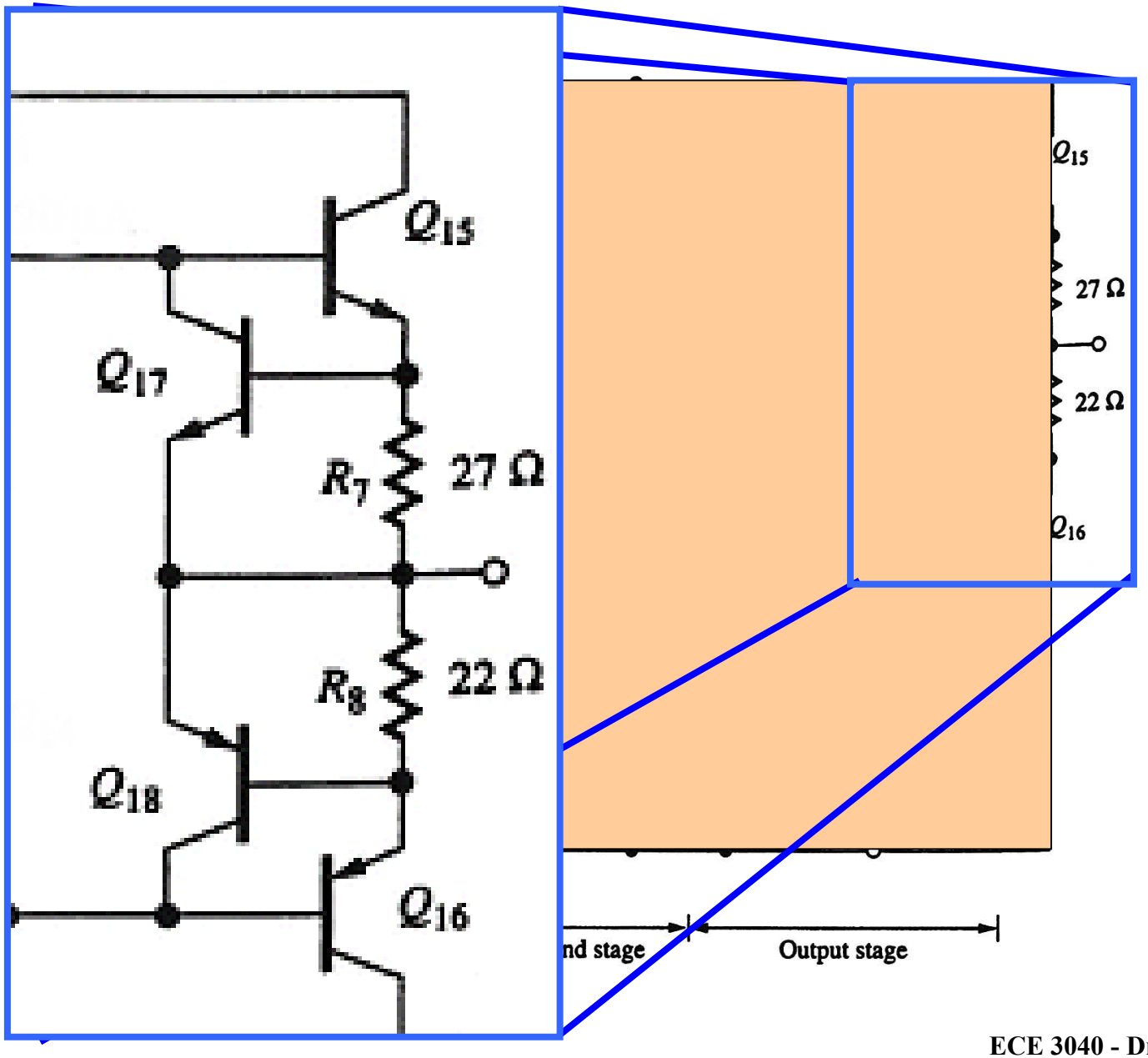


What Makes up an Op Amp? The "741" Example

Output Stage: Current Limiting the output



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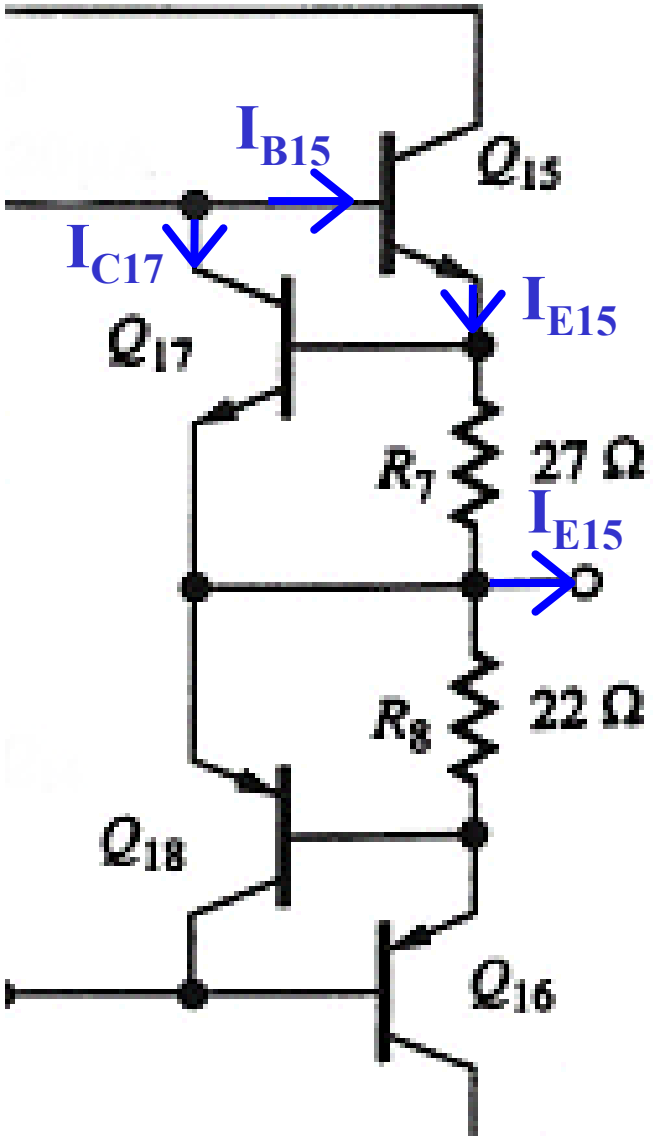


During the "positive voltage half-cycle":

Once the voltage across R_7 builds up due to large output current, I_{E15}, Q_{17} turns on and begins to suck current away from the base of Q_{15}. This prevents further increases in the output current, I_{E15}.

During the "positive voltage half-cycle":

Q_{18} operates in an analogous fashion with Q_{16}.

As promised on the first day of class, we have completed our journey from "Atoms to Op- Amps"

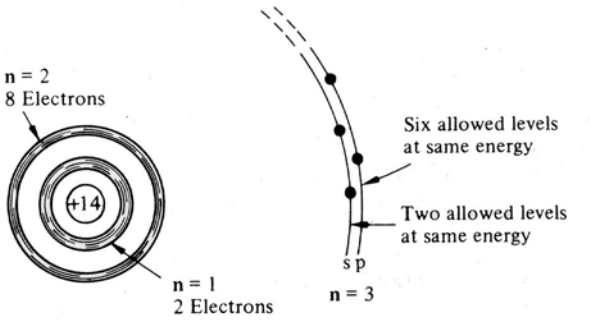
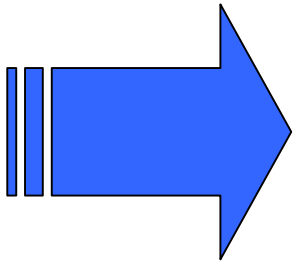
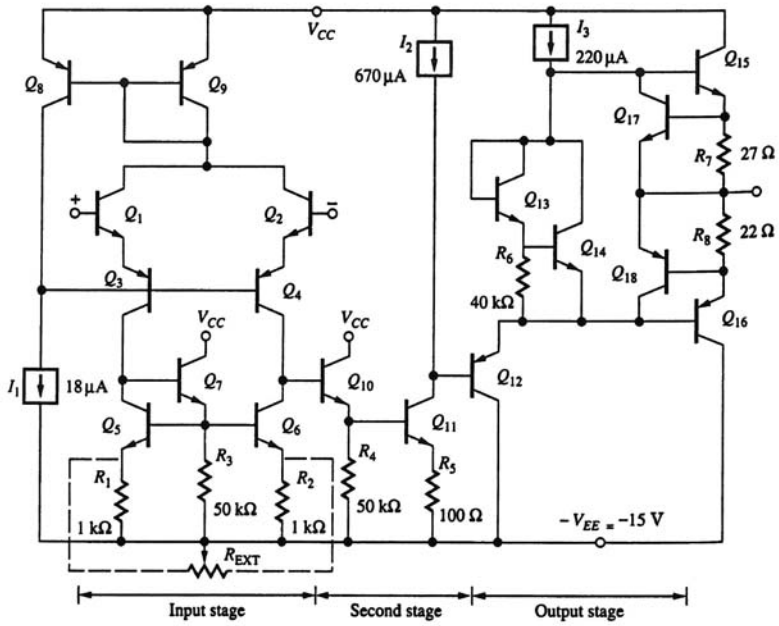


Figure 2.2 Schematic representation of an isolated Si atom.





Next: On to computer chips….