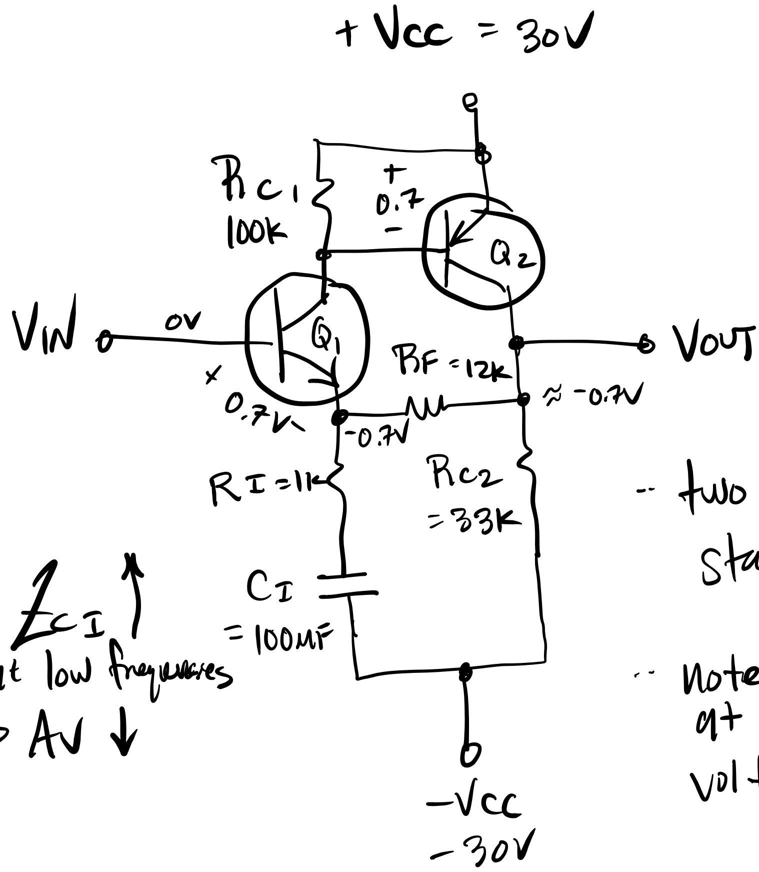
Multistage Feedback Amplifiers

- we know from the feedback equation that if βA_{vo} is a sufficiently high value, then the closed-loop gain of a feedback amplifier becomes $\frac{1}{\beta}$; strictly determined by the feedback network!

- thus, we would like higher open-loop gain A_{vo}.
- one way to do this is to use two or more stages of amplification
- we need more than one stage anyway if we want a non-inverting amplifier with gain.
- this configuration was very popular in the 60s, which uses an NPN CE direct-coupled to a PNP CE, with direct-coupled negative feedback:



$Z_{CI} \uparrow$ at low frequencies $\rightarrow A_V \downarrow$

∴ two inverting gain stages (net non-inverting)

∴ note that V_{OUT} rests at a DC collector voltage of $\approx -0.7V$

∴ ∴ V_{OUT} can swing close to $\pm V_{CC}$

∴ also note that C_I introduces a high-pass filter into the circuit; more importantly, $Z_{CI}\big|_{DC} = \infty$;

∴ there is 100% D.C. negative feedback, which stabilizes the operating point

∴ another important point: note the use of a PNP transistor for Q_2 with negative V_{CE2} intentionally shifts V_{C2} ($= V_{OUT}$) back towards 0V.

∴ thus, Q_2 is both a CE amplifier and level shifter

·· moving towards an all-DC-coupled amplifier!

·· this is a <u>shunt-derived</u>, <u>series-applied</u> feedback network whose β value is a <u>voltage division</u> of V_{OUT} caused by R_F and R_I

$$\underbrace{\beta = \frac{R_I}{R_F + R_I}}$$

-· plugging this into our feedback equation:

$$A_V = \frac{A_{VO}}{1 + \beta A_{VO}}$$

$$= \frac{A_{VO}}{1 + \frac{R_I}{R_F + R_I} A_{VO}}$$

·· and if the loop gain βA_{VO} is high, then

$$A_V \approx \frac{\cancel{A_{VO}}}{\frac{R_I}{R_F + R_I} \cancel{A_{VO}}} = \frac{R_F + R_I}{R_I}$$

$$\boxed{A_V \approx 1 + \frac{R_F}{R_I}}$$

look familiar???

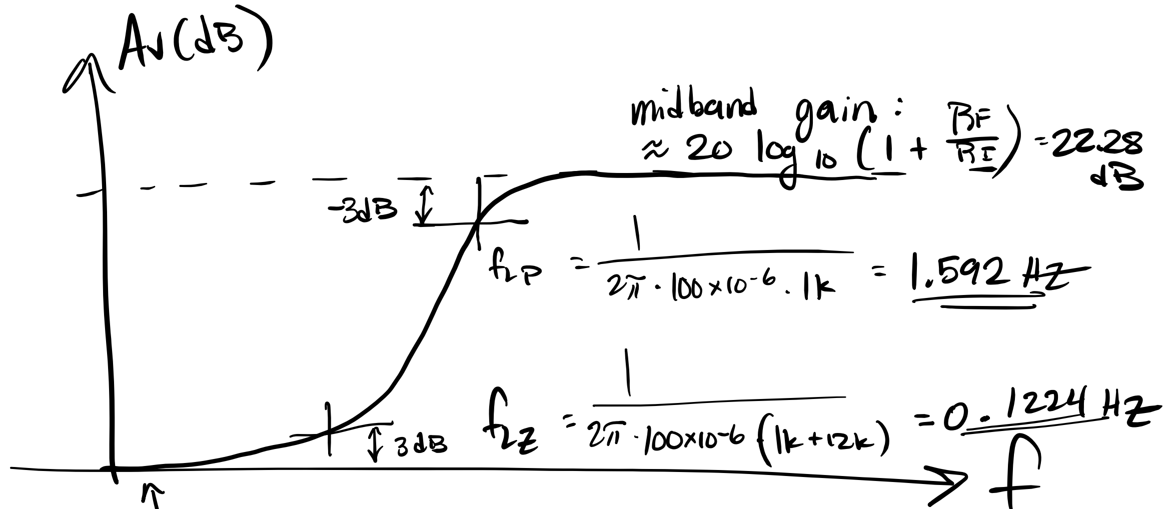
.. there is only one low-frequency pole, located at

$$f_{LP} = \frac{1}{2\pi \cdot C_I \cdot R_I} \quad \text{(user-selected)}$$

... and one <u>zero</u> located at

$$f_{LZ} = \frac{1}{2\pi \cdot C_I \, (R_I + R_F)}$$

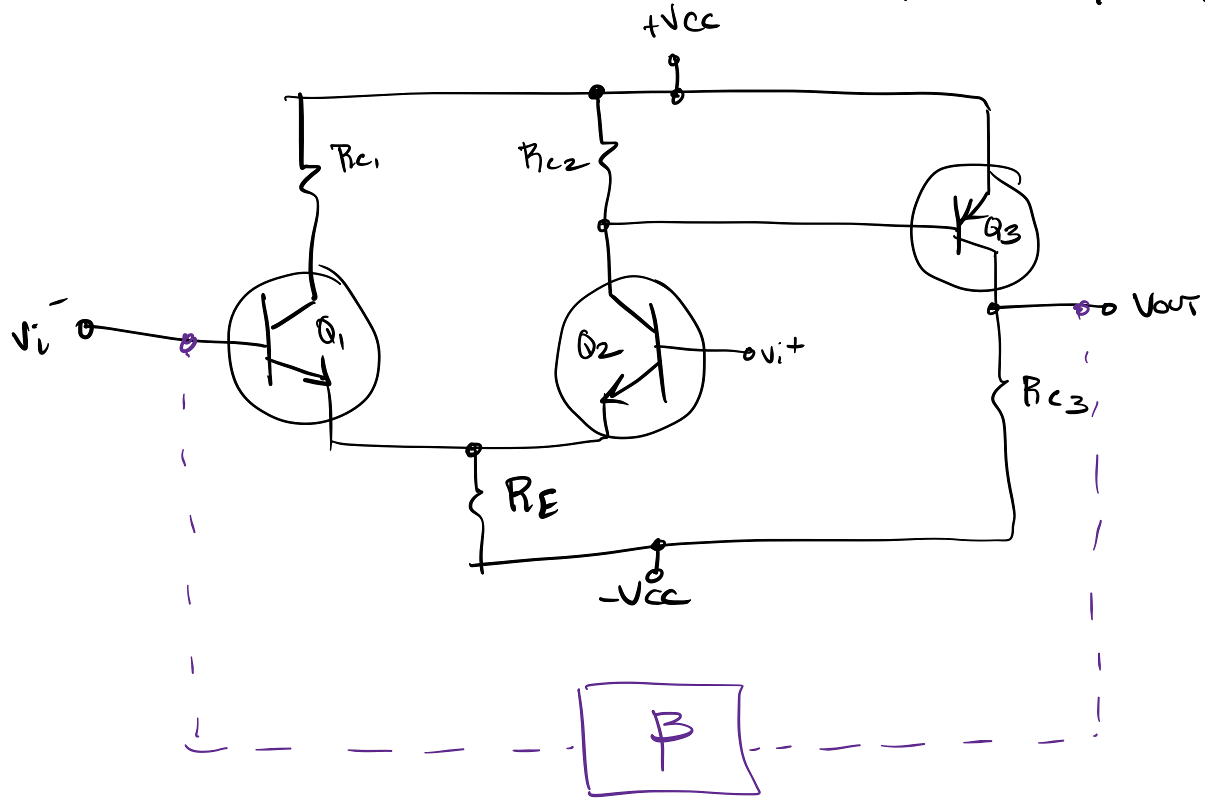
.. thus, the low-frequency response is:



tapers off to 0 dB (unity) at D.C.
due to 100% negative feedback

Three-Transistor Op-Amp

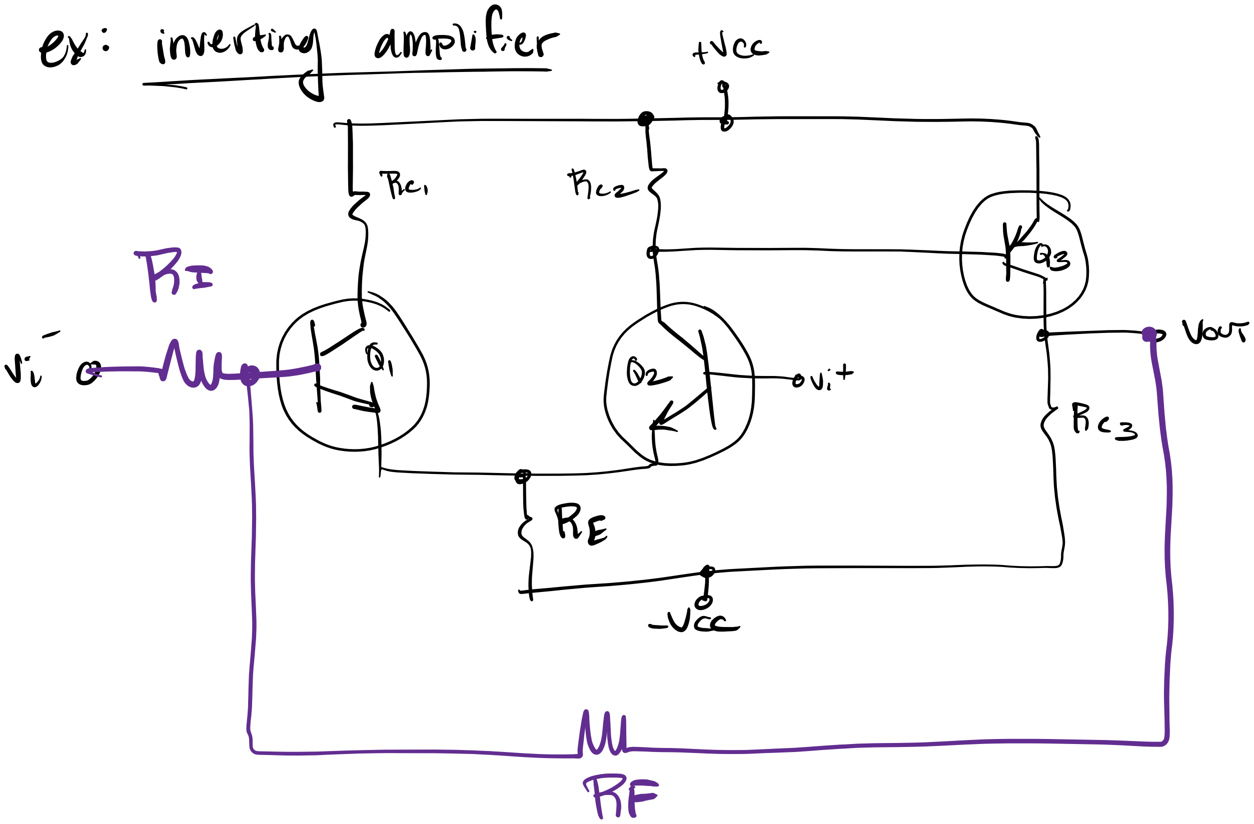
- this is truly the missing link between discrete one- or two-transistor amplifiers and I.C. op-amps!



- a differential pair direct-coupled to a complimentary CE/level shifter

  - diff pair provides gain, differential input for negative feedback, and common-mode rejection.
  - second stage provides gain and level-shifts Vout so we can have an all D.C. coupled amplifier.

ex: inverting amplifier



∴ assuming high A_{vo}, $A_v \approx \frac{-R_F}{R_I}$

∴ no capacitors @ LF; works at D.C. !!!

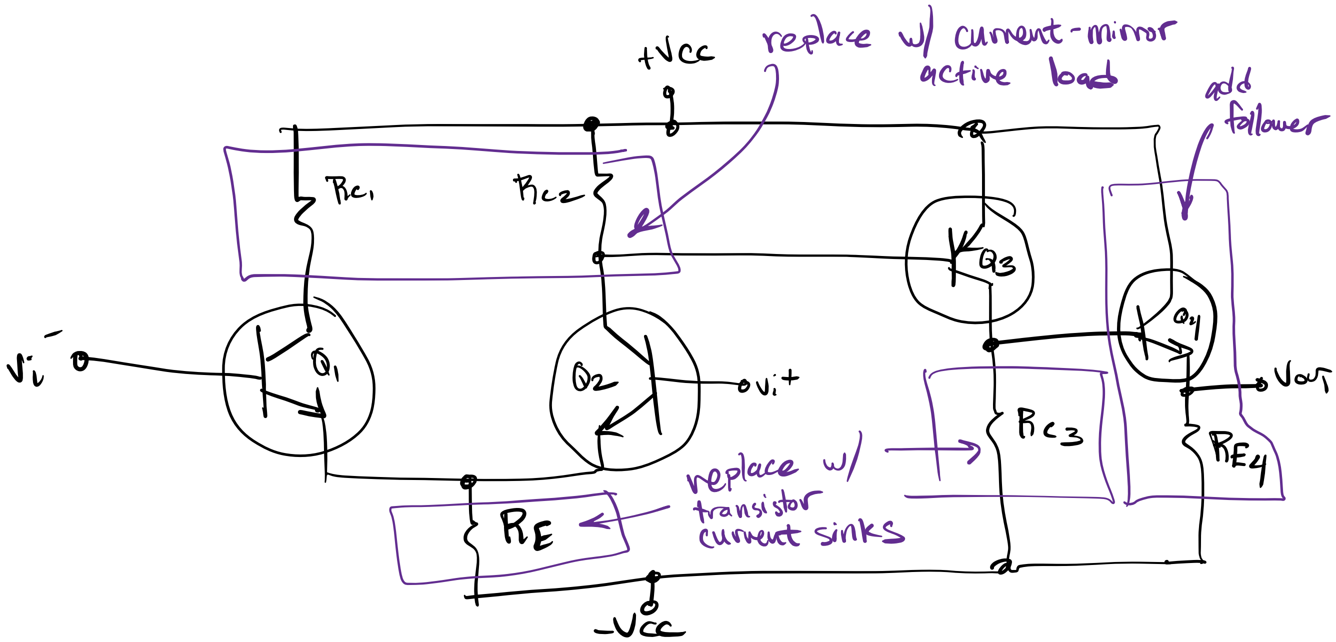
∴ with three amplifying stages inside the feedback loop, there is potential for high-frequency instability due to multiple HF poles ∴ but we can adress this!

∴ how do we improve on the three-transistor op-amp?

∴ replace resistors with active loads / current sinks

∴ more gain, better CMRR, advantages in I.C. fabrication

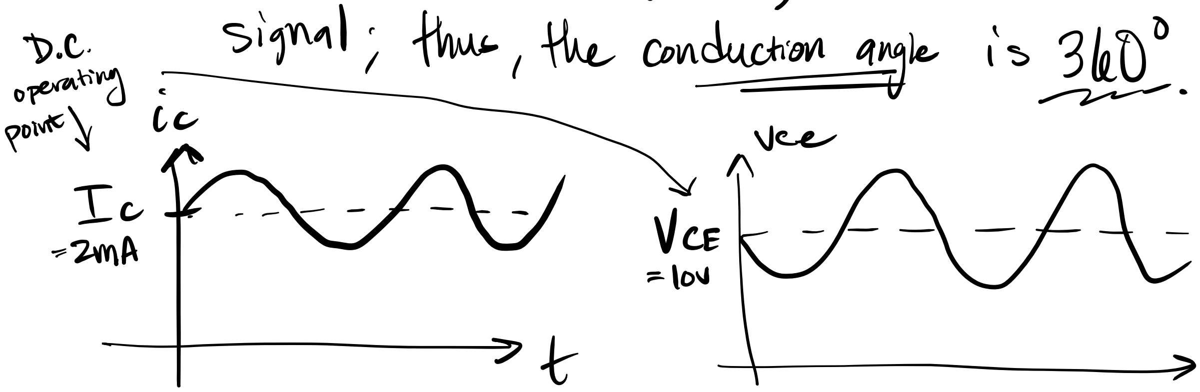
.. add output emitter follower in order to drive a variety of loads



.. so far, all of our amplifiers have been Class-A;

that is, we bias the transistor such that current and voltage "wiggle" above and below some carefully-chosen mid value

.. the transistor is always ON, even when there's no signal; thus, the conduction angle is 360°.

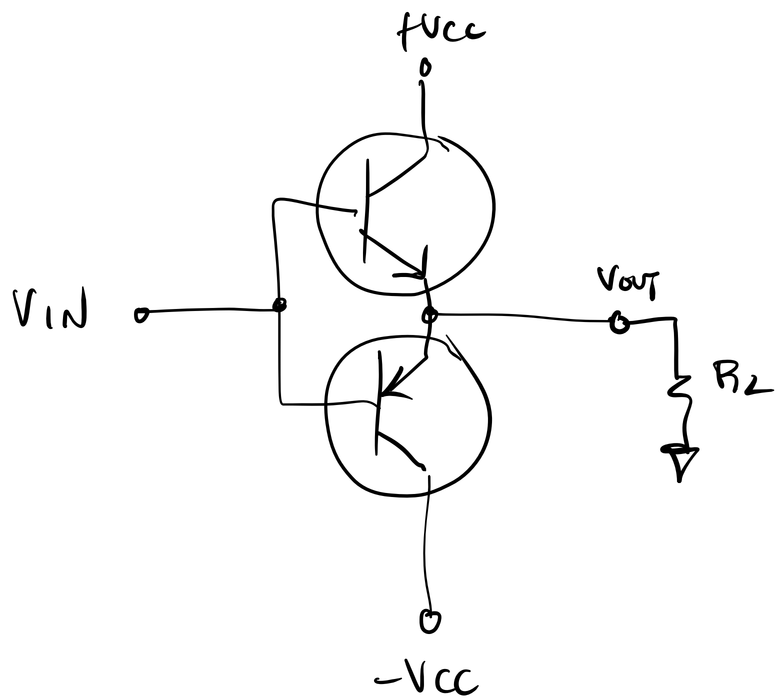


.. the transistor dissipates power continuously even when there's no signal present ; thus, it is <u>inefficient</u>.

→ max. Class-A efficiency is 25%

.. we can do better!

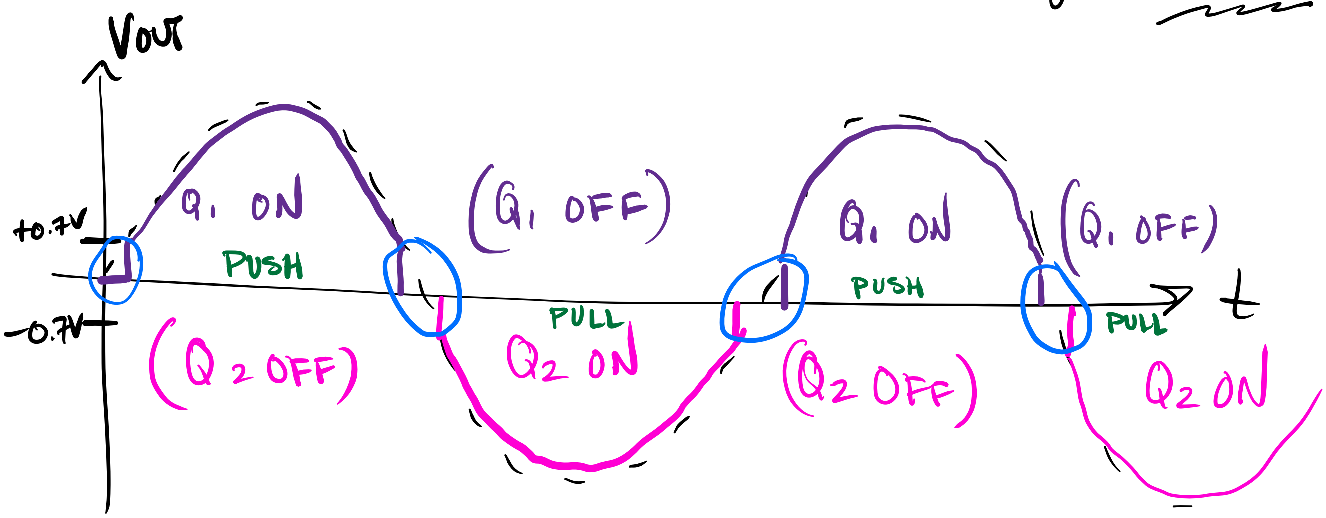
Class-B Push/Pull Power Amplifier



.. when $V_{IN} = 0$ (zero signal), both transistors are OFF

.. when $V_{IN} > +0.7V$, Q_1 turns ON and becomes a NPN emitter follower with $V_{OUT} \approx V_{IN}$

- When $V_{IN} < -0.7V$, Q_2 turns ON and becomes a PNP emitter follower with $V_{OUT} \approx V_{IN}$
- thus, each transistor has a conduction angle of 180°



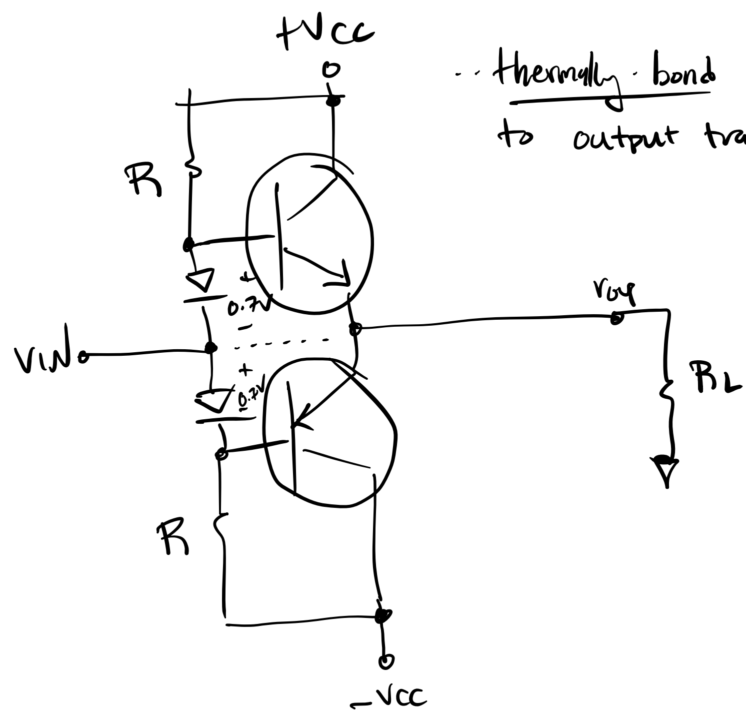
- max. efficiency is 78.5 % (much better)
- there is, naturally, a problem: crossover distortion caused by dead zones when $|V_{IN}| < 0.7V$
- how do we fix this?

1) include the Class-B push/pull amplifier inside negative feedback loop

  - regions where V_{OUT} starts to turn off are equivalent to lower open-loop gain; thus, closed-loop gain will change less, but will eventually run out!

2) bias the stage such that Q_1 and Q_2 are barely turned ON all the time; this is called

Class AB operation



∴ thermally bond bias diodes to output transistors

∴ next lecture: we tie this all together into a true operational amplifier