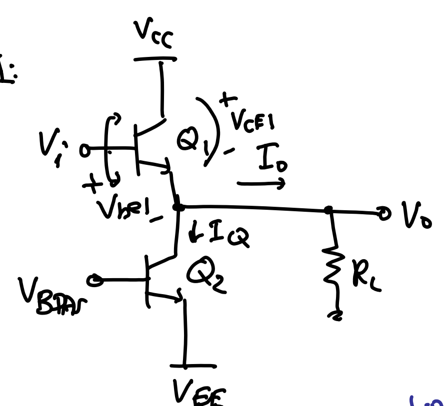
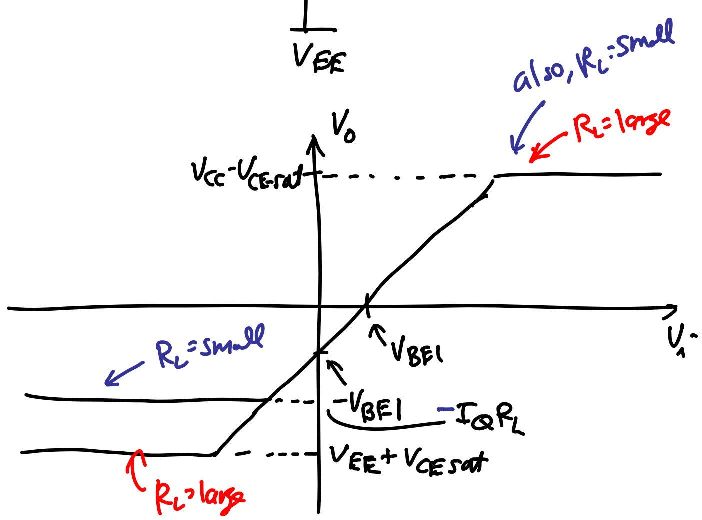
- **Announcements**:
  - As has been mentioned numerous times in lecture, your Lab#2 reports are individual reports; not group reports
  - Evening lecture next week, Tuesday, 7 p.m., in TBD
- **Today**:
  - Finish Output Stages
  - Start Stability & Compensation

Last Time –
⇒ Class A:





Two Cases:

Case ①: R_L = large → $I_o < I_Q$

⇒ I_o not Δ'ing much → I_{C1} not Δ'ing much

For V_i = large and (+): Q_1 must source $I_o + I_Q$

$V_o = V_i - V_{BE1}$

at some point Q_1 will saturate as V_o ↑
↳ get V_{omax}

$V_{omax} = V_{CC} - V_{CE(sat)}$
↳ and $V_i = V_{CC} - V_{CE(sat)} + V_{BE1}$

For V_i = large and (−): V_o follows V_i until Q_2 saturates

$V_{omin} = V_{EE} + V_{CE(sat)}$
↳ $V_i = V_o + V_{BE1} = V_{EE} + V_{CE2(sat)} + V_{BE1}$

Case ②: R_L = small → then, I_o can be large!

For V_i = (+) and large: Q_1 can source as much current as needed until it saturates (or until it fries)

For V_i = (−) and large: $V_o = +I_o R_L$ → min $V_o = -I_Q R_L$

⇒ Q_1 cut off ($I_{C1} = 0$)
⇒ V_o clamps @ $-I_Q R_L$
⇒ further decrease in V_i → no Δ in V_o!

Need I_Q = large to avoid this problem!

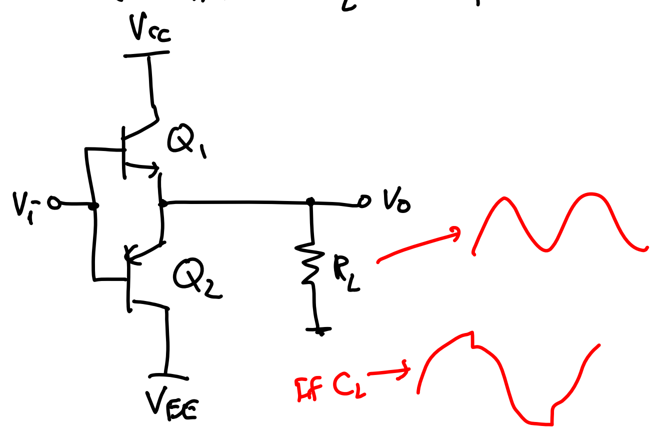
Problem: too much power consumption

$P_Q = (V_{CC} - V_{EE}) I_Q$ ⇐ DC power consumption
↳ if want large output swings, must consume power!

V_{EE} = (−)

Solution: $\boxed{\text{Class B Output Stage}}$ ← DC

↳ can attain zero quiescent power

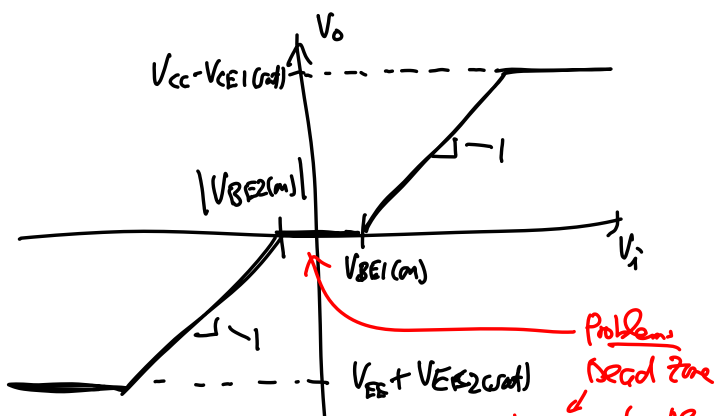


Operation:

$|V_i| < V_{BE(on)} \rightarrow I_{E1} = I_{E2} = 0 \rightarrow V_o = 0V$

$V_{CC} > |V_i| > V_{BE(on)} \rightarrow V_o \cong V_i - V_{BE(on)}$

$V_{omax} = V_{CC} - V_{CE1(sat)}$, $V_{omin} = V_{EE} + V_{CE2(sat)}$

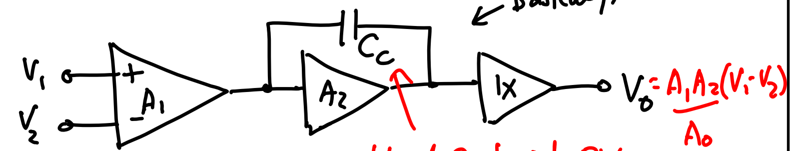


Problem: Dead Zone

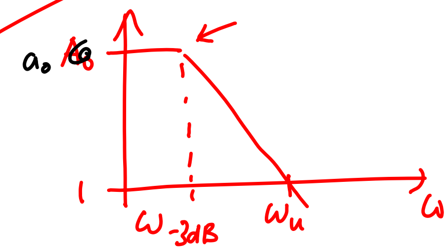
To solve, use class AB.

Stability & Compensation

← Basically, Lab#2.



Used C_c to set BW:



Why is C_c needed?

Stability & Compensation in Op Amps

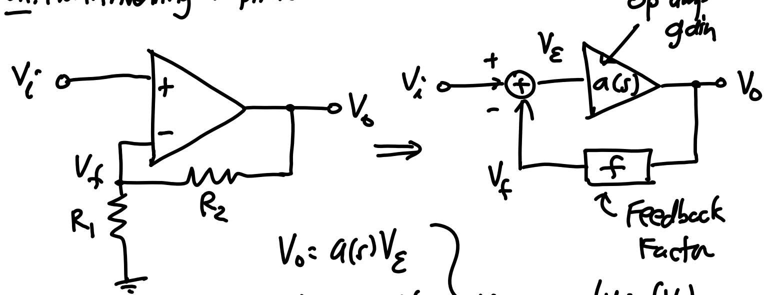
In general, op amps are used in neg FB loops. ← These cause instability.

Reasons:

1. Feedback sets the biasing → no large coupling or bypass caps needed.
2. FB increases BW.
3. FB increases linearity or input range. (eg., emitter degeneration is a type of FB)
4. Gain determined by external FB components → more accurate than op amp gain.
5. FB sets R_i and R_o.
6. FB can improve temperature stability.

⇒ Problem: any FB loop can become unstable under certain conditions → ∴ must compensate to suppress instability!

Ex. Non-inverting Amplifier



$$\left.\begin{aligned} V_o &= a(s)V_\varepsilon \\ V_\varepsilon &= V_i - V_f \\ V_f &= fV_o \end{aligned}\right\} V_o = a(s)(V_i - fV_o)$$

$$A(s) = \frac{V_o}{V_i}(s) = \frac{a(s)}{1+a(s)f} = \frac{a(s)}{1+T(s)}$$

$A(s)$: closed loop voltage gain

Loop Transmission $T(s) = a(s)f$

Instability occurs when $A(s) \to \infty$.

$$\Rightarrow A(s) = \frac{a(s)}{1+a(s)f} \to A(s) = \frac{a(s)}{1-1} \Leftarrow \text{will also go unstable if denominator} \to (-)$$

$a(s)f = -1$

In General:

$$\boxed{\text{If } |a(s)f| \geq 1 \text{ when } \measuredangle a(s)f = -180^\circ \Big\} \Rightarrow \text{Instability}}$$

This is a simplified form of the Nyquist Criterion.

Stability of FB Ckt. Using a Single Pole Op Amp

For a single pole op amp: $a(s) = \dfrac{a_o}{1-\frac{s}{p_1}} \equiv$ op amp transfer function

Thus: closed loop Xfer Fcn

$$A(s) = \frac{a(s)}{1+a(s)f} = \frac{a_o}{1+a_of} \cdot \frac{1}{1-\frac{s}{p_1(1+a_of)}}$$

$p_1(1+a_of)$: much high 3dB freq.

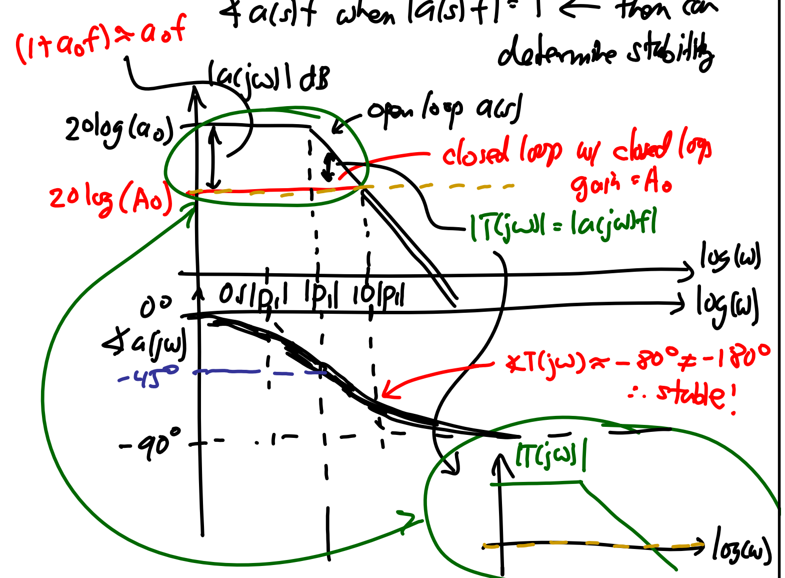
A_o = closed loop dc gain → $(1+a_of) \approx a_of$ X smaller than a_o

$\approx \frac{1}{f}$

$T_o = a_of$ = loop gain (defined at dc)

$T(s) = a(s)f$ = loop transmission (defined for general frequencies)

Bode Plot: → use to determine $\measuredangle a(s)f$ when $|a(s)f| = 1$ ← then can determine stability



Remarks:

① For the case of a single pole op amp, FB can never reach $\measuredangle T(j\omega) = -180°$!

② Thus, an op amp FB ckt. w/ f = const. and using a single-pole op amp is always stable!

↓

But add a few non-dominant poles → then instability is possible!

since now, $\measuredangle T(j\omega)$ can reach $-180°$!