< Linear power Amplifier >

2021 / 4 / 9
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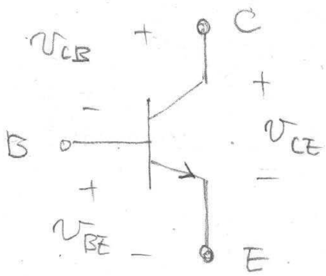
- Objective
  - BJT Emitter Follower
  - Push-pull stage
  - power dissipation.

- Bipolar Junction Transistor (NPN)



As usual, we treat it as an encapsulated objects which interacts with the environment through terminals.

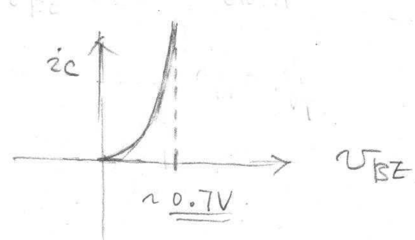
Terminal variables

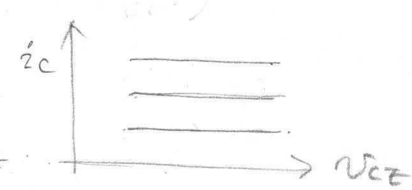
- Currents : i_B, i_C, i_E
- Voltages : v_{BE}, v_{CE}, v_{CB}

Terminal Relations (when "Active" : $v_{BE} > 0$ & $v_{CE} > v_{BE}$)

- $i_C = \beta i_B$
- $i_E = i_C + i_B = i_C \left(1 + \frac{1}{\beta}\right) \simeq i_C$.
-

$$i_C \simeq I_S \exp\left(\frac{v_{BE}}{V_T}\right)$$



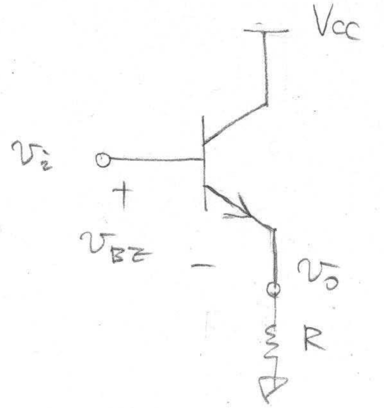


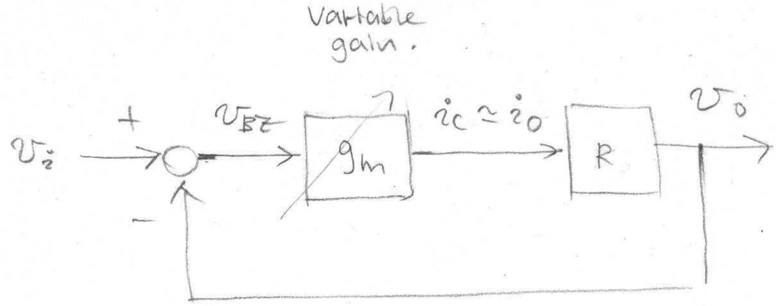
Transconductance

$$g_m \triangleq \frac{di_C}{dv_{BE}} = \frac{I_S}{V_T} \exp\left(\frac{v_{BE}}{V_T}\right) = \frac{i_C}{V_T}$$

- BJT can be used as a voltage-controlled current source.
- Note that i_C is insensitive to v_{CE} when BJT is "Active"

- Emitter follower.





$$\frac{v_o}{v_i} = \frac{g_m R}{1 + g_m R} \simeq 1$$

when $g_m R \gg 1$.

- This circuit provides "power amplication"

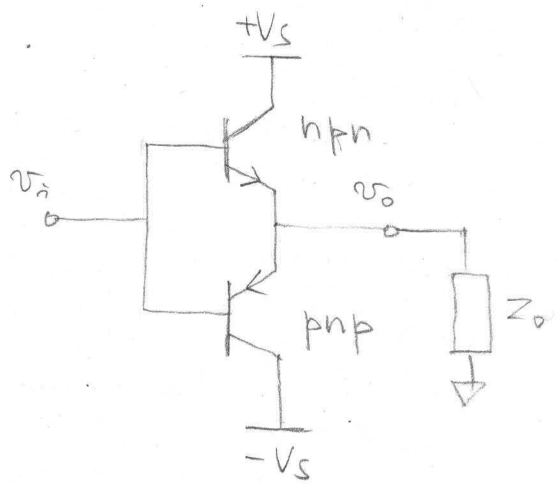
$P_{in} = v_i \cdot i_B$.

$P_{out} = v_o \cdot i_o \simeq v_i \, i_B \cdot \beta$.

$\Rightarrow \frac{P_{out}}{P_{in}} \simeq \beta$.

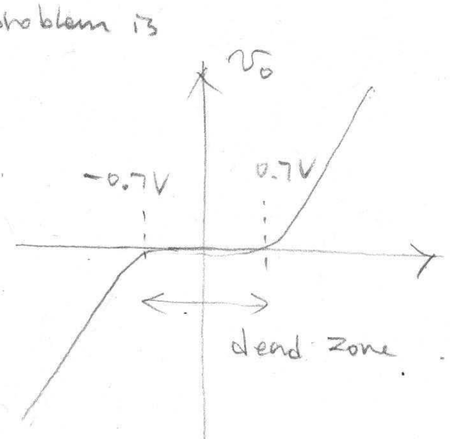
- However, cannot "sink" current.

- Push-pull stage (Class B)

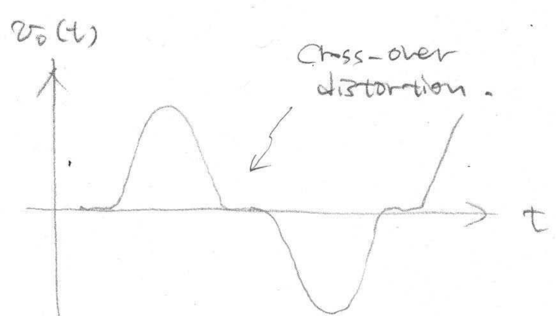


- Note the "Complementary" architecture.
- Now, it can not only source but also sink the current.
- $$\frac{v_o}{v_i} = \frac{g_m Z_o}{1 + g_m Z_o} \simeq 1.$$

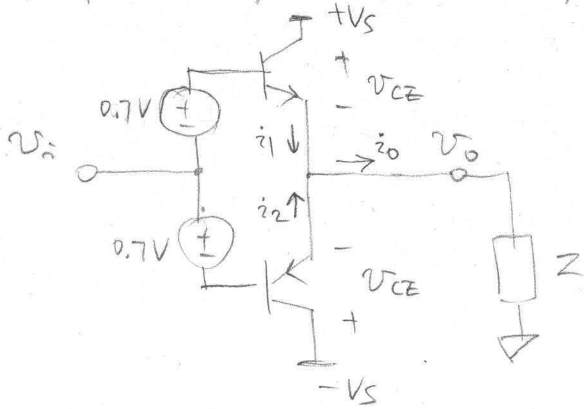
But, problem is

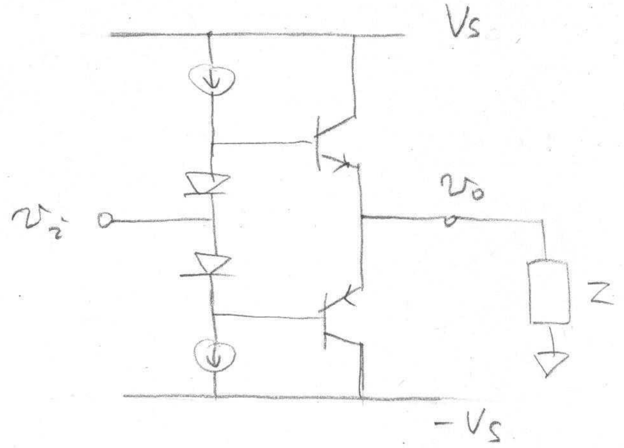


$\Rightarrow$



- Improved push-pull stage (Class AB)





- Inserting offset voltages can eliminate the crossover distort. and dead zone issues.

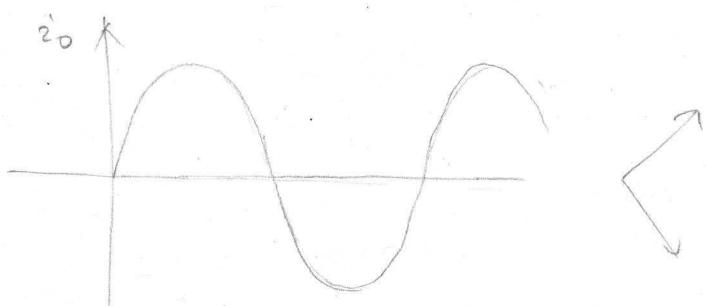
- Too much offsets will turn on both Q_1 and Q_2

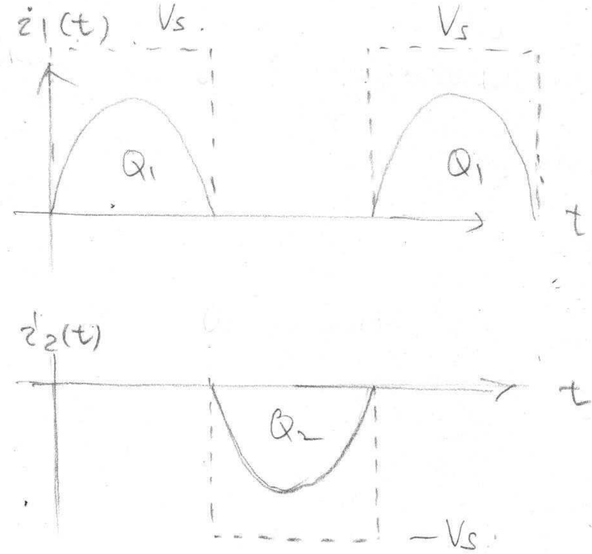
  $\Rightarrow$ shoot through current.

- The output stage of power op-Amp (e.g. pA 13) is based on BJT push-pull stage.

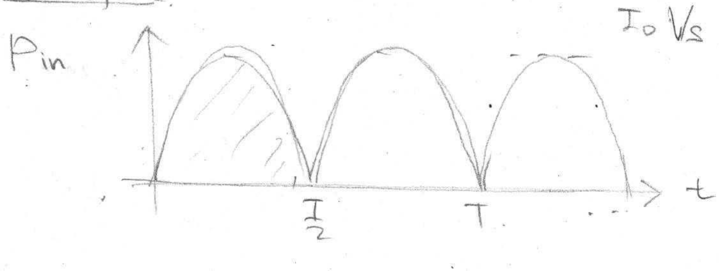
- power dissipation.

  Suppose $\begin{cases} \text{the load is inductive.} \\ i_o = I_o \cdot \sin\omega t. \end{cases}$





Therefore:



$$\overline{P_{in}} = \frac{2}{T}\int_0^{\frac{T}{2}} I_o V_o \sin\omega t \, dt$$

$$= \frac{2}{T} \cdot I_o V_o \cdot \frac{2}{\omega} = \frac{2}{\pi} \cdot I_o V_s$$

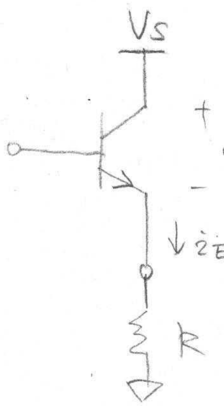
$$\overline{P_{in}} = \frac{2}{T}\int_0^{T/2} I_o V_s \sin\omega t \, dt$$

$$= \frac{2}{T} I_o V_s \frac{1}{\omega} 2 = \frac{4 I_o V_s}{T\omega} = \frac{2}{\pi} I_o V_s$$

$\overline{P_{out}} = 0$ for pure inductor. $\therefore \overline{P_{diss}} = \frac{2}{\pi} I_o V_s$.

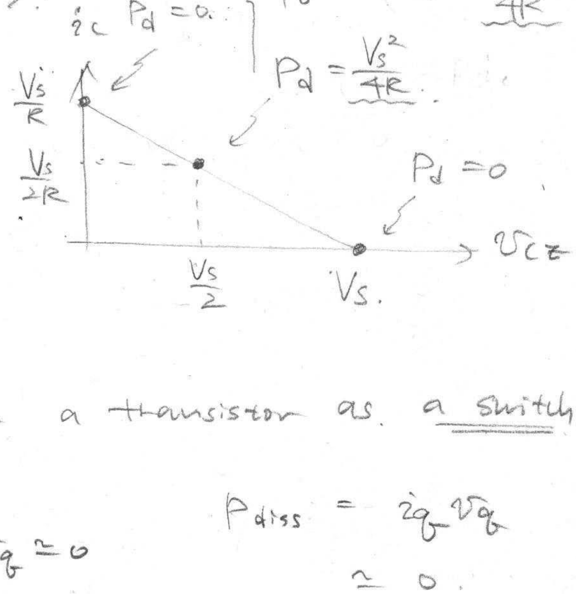
- Note that $\overline{P}_{diss}$ increases with supply voltage V_s.
  - For efficiency, we want low V_s.
  - For control, we want high V_s because it increases the current slope: $\max\left(\frac{di}{dt}\right) = \frac{V_s}{L}$.
- Large P_{diss} limits device downsizing.
  - Power semiconductor size $\uparrow$.
  - Additional components for cooling (Heat sinks, fans).
- Popular option for precision applications, audio amplifiers, etc.

○ Switched-mode Amplifiers. (Class D).

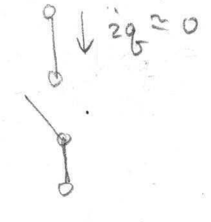


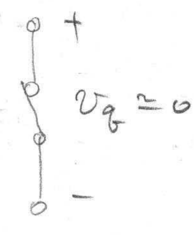
$P_{diss} = v_{CE} \cdot i_C$

$v_{CE} = V_s - R i_C$



This motivates to use a transistor as a switch





$P_{diss} = i_q v_q \simeq 0$.