E151 Lecture 22 – Output Stages

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Disclaimer

These are notes for Prof. Spencer to give the lecture, they were not intended as a reference for students. Students asked for them anyway, so I'm putting them up as a courtesy. Remember that they are not intended as a substitute for attending lecture.

Loads have Large Signal Implications

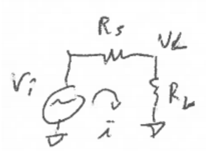
- We've mostly looked at them as small signal dividers
- But pulling a lot of current can "mess up bias point" (see: lab)
- Pulling lots of current is common: speakers, heaters, antennas, etc.
  - Radiation resistance
- Other loads can be tricky/unstable: plasmas, motors, piezos

- In general: want high Pout (to deliver power), efficiency (η), linearity
- Need low zout to get efficiency: Max power xfer thm,
- Linearity comes from large signal analysis, efficiency too

Aside: power gain at low f $A_P = \frac{v_I^2/r_{in}}{v_O^2/R_L} = \frac{r_{in}}{R_L} a_v^2$

Maximum Power Transfer Thm → Low Zout

- Only doing the real valued version here
- Control load → match source, control source → minimize
- Same result for complex loads, but need conjugate match



$i_L = \frac{V_i}{R_s + R_L}$

$V_L = \frac{R_L}{R_s + R_L} V_i$

$\eta = \frac{P_L}{P_s} = \frac{R_L}{R_s + R_L}$

$P_s = \frac{V_i^2}{R_s + R_L}$

$P_L = \frac{R_L}{(R_s + R_L)^2} V_i^2$

– control R_s? (only in denom, so minimize)

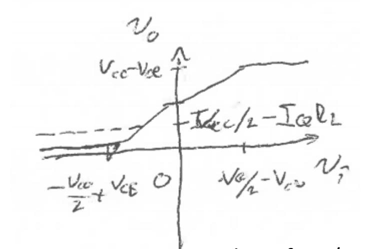
$\frac{\partial}{\partial R_s} (R_s + R_L)^2 = 2(R_s + R_L)$

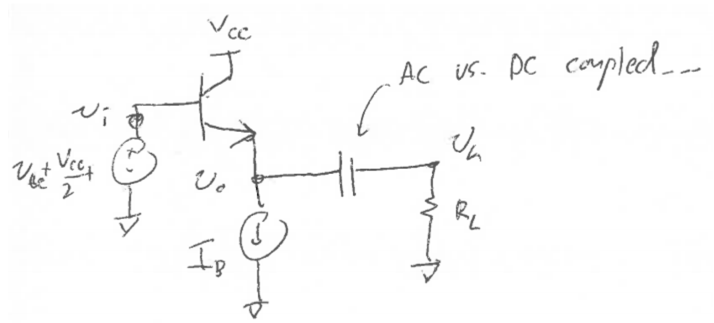
– control R_L

$\frac{\partial}{\partial R_L} \left[R_L (R_s + R_L)^{-2} \right] = (R_s + R_L)^{-2} + \frac{-2R_L}{(R_s + R_L)^3} = \frac{R_s - R_L}{(R_s + R_L)^3}$

Emitter Followers as Output Stages: Linearity

- Pretty linear b/c $v_o = v_i - v_{be}$
- Small output resistance can mess /w linearity $v_{be} = \frac{kT}{q}\ln\left(\frac{I_C}{I_S}\right) = \frac{kT}{q}\ln\left(\frac{I_B + \frac{v_O}{R_L}}{I_S}\right)$
- If vO/Rl is bigger than I_B then you can get clipping b/c all current is in load and Q1 is cutoff
- Alternate minimum cutoff:





Plot is for +/-Vcc

Power Delivered to Load by EF

- Assuming sinusoidal signal for power analysis
- Transistor power is lower b/c it sees Vce*IL → Pt=Vcc*IB/4 on avg.

can save

$$P_L = \frac{(V_{cc} - 2V_{CE})}{2}\cos(\omega t) \cdot I_B \cos(\omega t) = \frac{1}{2} I_B (V_{cc} - 2V_{CE}) \cos^2(\omega t)$$

← $\frac{1}{2}$ on average

$$= \frac{1}{4} I_B (V_{cc} - 2V_{CE})$$

$$P_s = V_{cc} \cdot I_B$$

$$\eta = \frac{P_L}{P_s} = \frac{1}{4}\left(1 - \frac{2V_{CE}}{V_{cc}}\right) \approx 25\%$$

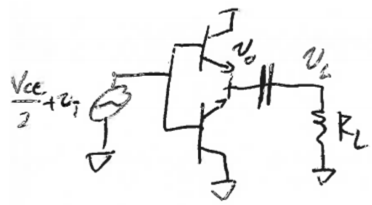
at best

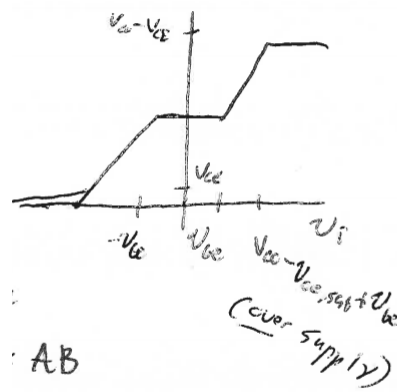
↳ backoff hurts b/c I_B stays

↳ non-optimal load hurts

Class B amplifiers

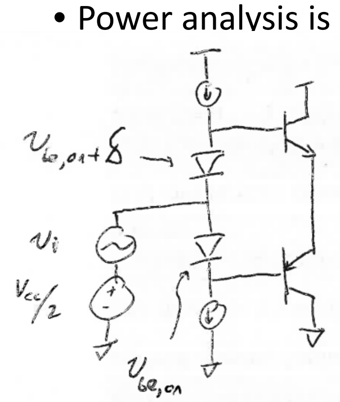
- EF called “Class A” b/c output device is “on” for the whole cycle
- Very linear b/c it doesn’t flirt w/ cutoff or sat, but current inefficient
- Fix w/ class B – each device on for 50% of cycle
- linearity hurt by crossover disto, but eff better. Also called push-pull
- Only one on at a time, find zout as EF

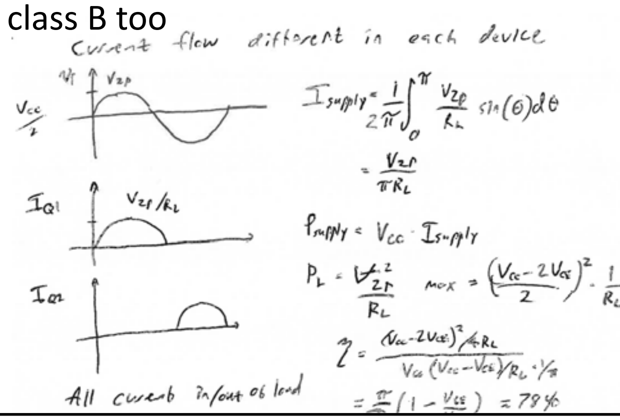




Class AB Amplifier, Thermal Runaway, η

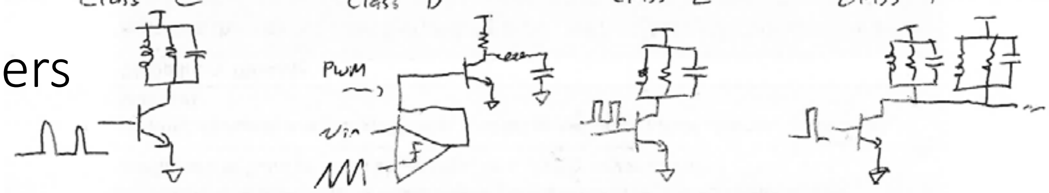
- Use diodes to cancel crossover distortion.
- Thermal runaway if delta not 0 → DC current in Q1 heats, +ve feedback
- Power analysis is about correct for class B too





Other Amplifiers

class C | class D | class E | class F



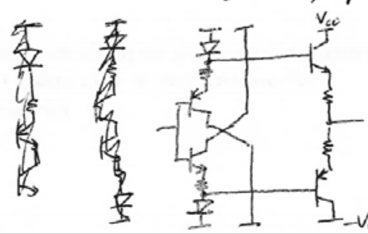
class C
- conducts for $< \pi$ but does enter linear region
- used in RF where filters smaller harmonics widely spaced

class D
- switch mode
- input is PWM
- big output filter
- slow, only good for audio

class E
- Like class C but in switch mode
- Zero voltage switching
- common, esp. in MOS

class F
- switch mode
- Do harmonic filter

Diamond Buffer
↳ really powerful & high bandwidth
↳ Anecdote



- often use LEDs as constant current source