

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.

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Loads have Large Signal Implications

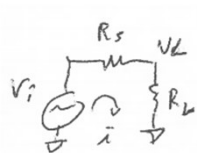
- We've mostly looked at them as small signal dividers
- But pulling a lot of current can "mess up bias point" (see: lab)
- Pulling lots of current is common: speakers, heaters, antennas, etc.
 - Radiation resistance of antennas, wire resistance of speakers + wild dynamics
- Other loads can be tricky/unstable: 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 $A_p = \frac{v_i^2/r_{in}}{v_o^2/R_L} = \frac{r_{in}}{R_L} a_v^2$

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Maximum Power Transfer Thm \rightarrow Low Zout

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



$$\eta = \frac{P_L}{P_S} = \frac{R_L}{R_S + R_L}$$

$$P_S = \frac{V_i^2}{R_S + R_L}$$

$$i = \frac{V_i}{R_S + R_L}$$

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

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

- control R_S^2 (only in denom, so minimize)

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

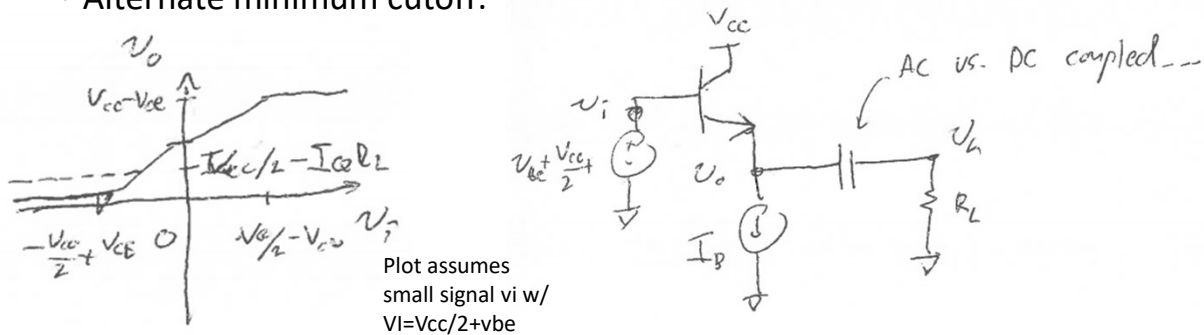
- control R_L

$$\frac{\partial}{\partial R_L} \left[\frac{R_L}{(R_S + R_L)^2} \right] = \frac{1}{(R_S + R_L)^2} - \frac{2R_L}{(R_S + R_L)^3} = \frac{R_S - R_L}{(R_S + R_L)^3}$$

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Emitter Followers as Output Stages: Linearity

- Pretty linear b/c $v_b = v_i - v_{be}$
- 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 v_o/R_L approaches I_B then you get clipping b/c $v_{be} \rightarrow -ve$ infinity
- Alternate minimum cutoff:



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Power Delivered to Load by EF

- Assuming sinusoidal signal for power analysis
- Transistor power is lower b/c it sees $V_{ce} * I_L \rightarrow P_t = V_{cc} * I_B / 4$ on avg.

$$P_L = \frac{(V_{cc} - 2V_{ce}) \cos(\omega t) \cdot I_B \cos(\omega t)}{2} = \frac{1}{2} I_B (V_{cc} - 2V_{ce}) \cos^2(\omega t) \xrightarrow{\frac{1}{2} \text{ on average}} = \frac{1}{4} I_B (V_{cc} - 2V_{ce})$$

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

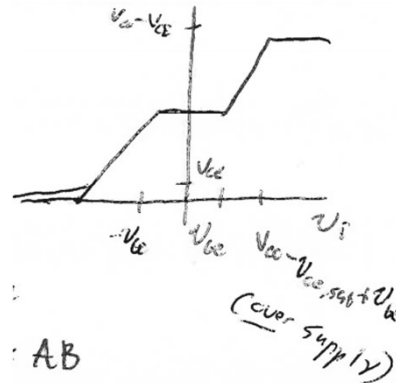
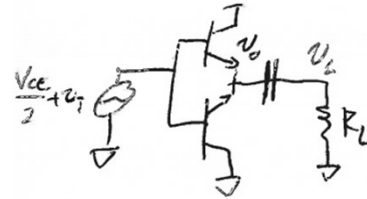
$$\eta = \frac{P_L}{P_s} = \frac{1}{4} \left(1 - \frac{2V_{ce}}{V_{cc}}\right) \approx 25\% \quad \text{at best}$$

\hookrightarrow back to 6 hurts b/c I_B stays
 \hookrightarrow non-optimal load hurts

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Class B amplifiers

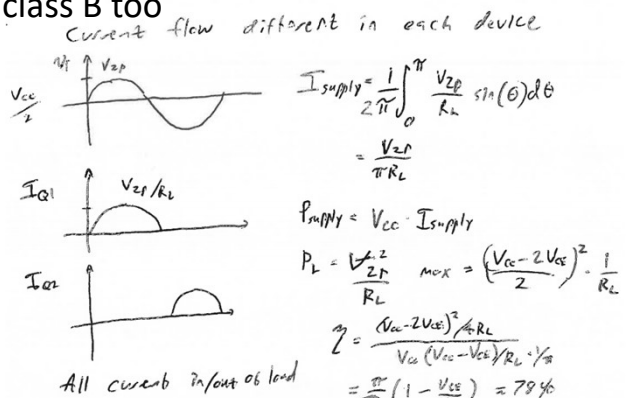
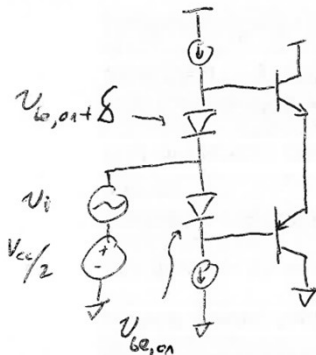
- EF called "Class A" b/c output device is "on" for the whole cycle
- Very linear b/c it doesn't flirt w/ cutoff or sat, but current inefficient
- Fix w/ class B – each device on for 50% of cycle
- linearity hurt by crossover disto, but eff better. Also called push-pull
- Only one on at a time, find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



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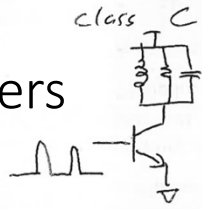
Class AB Amplifier, Thermal Runaway, η

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



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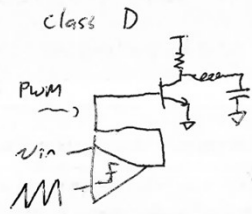
Other Amplifiers



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

Diamond Buffer

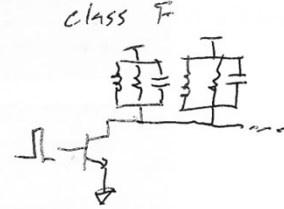
- ↳ easily powerful & high bandwidth
- ↳ Anecdote



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



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



- switch mode
- no harmonic filter
- often use LEDs as constant current source

