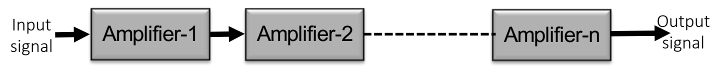
L10 multistage amplifier, skipped for now

12 lectures in total

Power Amplifiers: Basic Idea

Multistage amplifiers deliver a large amount of power to the load



- For large current, load resistance is low (such as audio speaker)
- For large voltage, load resistance is high (such as switching power supply)

1

Power Transistors

for power amplifiers:

- Larger area
- Different geometry
- Different doping concentration

Limiting factors

- Current
- Voltage
- Power
- Temperature

- have fans
- have heatsinks

Thermal runaway

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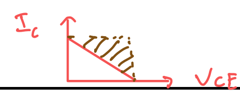
Comparison Between Small-Signal and Power Transistors

Parameter	Small-signal 2N2222A	Power 2N3055	Power 2N6078
$I_{C(max)}$ in A	0.8	15	7
$V_{CE(max)}$ in V	40	60	250
$P_{D(max)}$ in W	1.2	115	45
β	35-100	5-20	12-70

- Current gain (β) is generally low → compared to small-signal
- Notice that $\boxed{I_{C(max)} \times V_{CE(max)} \neq P_{D(max)}}$

not simple multiplication

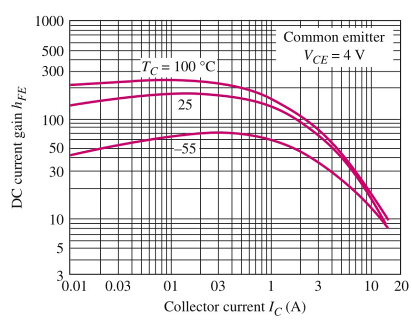
** come in exam



3

Variation of β With Current and Temperature

- inc in current or temp decreases gain



- The current gain (β) decreases for higher currents
- The current gain (β) decreases with the increase of temperature

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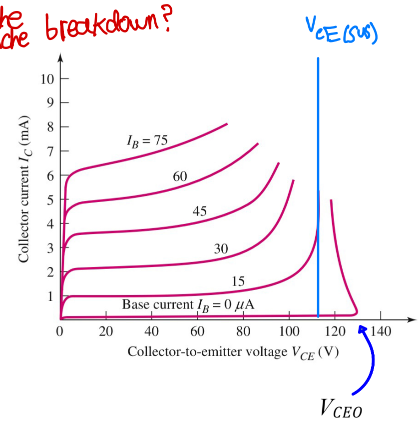
Safe Operating Area (SOA)

what is the avalanche breakdown?

- Maximum voltage is generally related to the avalanche breakdown in the reverse biased base-collector junction
- All the curves tend to merge to the same V_{CE} upon reaching breakdown voltage. This voltage is called sustainable voltage $V_{CE(sus)}$.



min voltage necessary to sustain transistor in breakdown

- $V_{CE(sus)}$ is the minimum voltage necessary to sustain the transistor in breakdown
- Example: V_{CEO} = 130 V and $V_{CE(sus)}$ = 115 V

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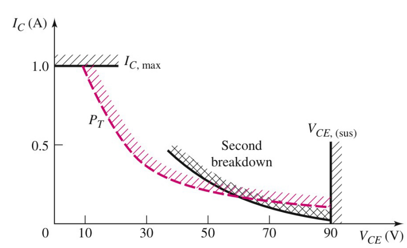
Second Breakdown



Second breakdown occurs in a BJT operating at high voltage and at a fairly high current.

- Higher current increases heat
- Higher temperature reduces resistance, more current
- Increased current increases the current further
- This is a positive feedback
- This is called thermal runaway
- This is also known as second breakdown

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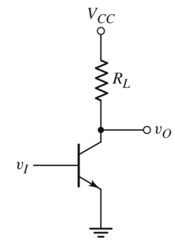
Power Dissipation Example



Example: Assume $V_{CC} = 24$ V and $R_L = 8\ \Omega$

top of load line

$$I_{C(max)} \cong \frac{V_{CC}}{R_L} = \frac{24}{8} = 3A$$

$$V_{CE(max)} \cong V_{CC} = 24V$$

bot of load line

Power dissipation

$$P_T = V_{CE} I_C = (V_{CC} - I_C R_L) I_C$$

$$P_T = V_{CC} I_C - I_C^2 R_L$$

take derivative

The current at maximum power is found by using the equation

$$\frac{dP_T}{dI_{C(p,max)}} = 0$$

This leads to

$$V_{CC} - 2I_{C(p,max)} R_L = 0$$

$$\boxed{I_{C(p,max)} = \frac{V_{CC}}{2R_L} = \frac{24}{2\times 8} = 1.5A}$$

Thus,

$$V_{CE(p,max)} = V_{CC} - \underbrace{1.5\times 8}_{I_C R_L}$$

$$\boxed{V_{CE(p,max)} = 12\ V}$$

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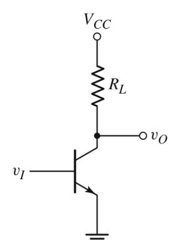
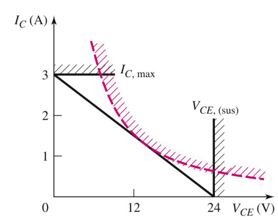
$$\boxed{V_{CE(p,max)} = V_{CC} - I_C R_L}$$

$$\boxed{I_{C(p,max)} = \frac{V_{CC}}{2R_L}}$$

Power Dissipation Example (Continued)





Thus, maximum power dissipates at the center of the load-line and

$$\boxed{P_T = 12\times 1.5 = 18W}$$

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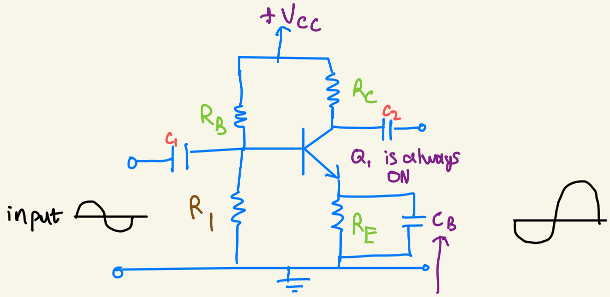
Class A Amplifier

Function: increase power level of AC input by transferring power from DC power supply to input signal

- R_B and R_1 form voltage divider



output (inverted and larger)

allows AC signal to bypass emitter resistor, increasing voltage gain

- C_1 and C_2 are coupling capacitors

$V_{be} = 0.7$

$\beta = \frac{I_C}{I_B}$

$A_V = \frac{V_o}{V_{in}}$

$\eta\% = \frac{P_L}{P_{DC}} \times 100$

efficiency

ac load power

power delivered by DC power source

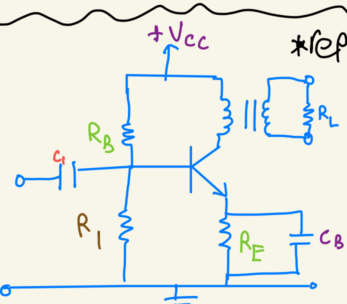
max theoretical efficiency $= 25\%$

to get as close as possible to max set $V_{CE} = \frac{1}{2} V_{CC}$

- low efficiency
- not good as power amplifier, usually used as small signal
- conducts for entire 360° of input cycle
- very little to low distortion

To increase efficiency

*replace R_c with a transformer coupled



output here

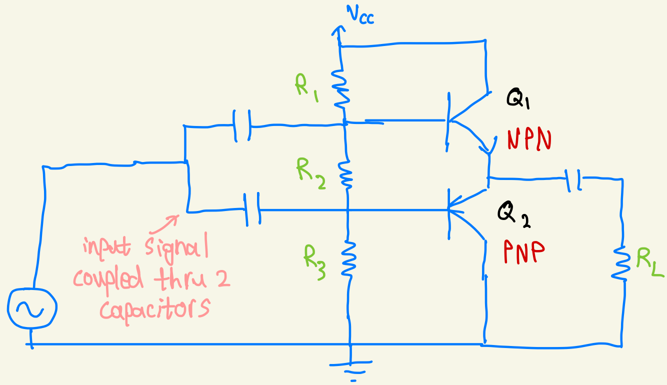
max theoretical $\eta\% = 50\%$

- Due to transformer absorbing and releasing stored energy using magnetic fields

Class B amplifier

- uses 2 complementary transistors npn and pnp

$n\% = 78.5\%$

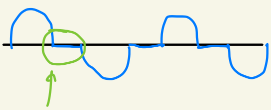


- 2 transistors must be at cut off
- for each half cycles only one transistor should be conducting, other should be off

∴ conducting angle = 180

disadvantage:

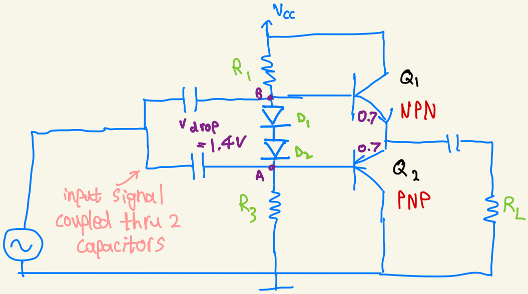
- presence of crossover distortion



due to $V_{BE} = 0.7$
so until input sine wave reaches +ve or -ve 0.7 the 2 transistors will be off and $V_{out} = 0$

improved by creating class AB amplififier

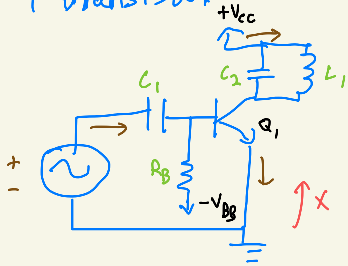
Class AB → replace R_2 with 2 diodes



- removes crossover distortion

Class C

- only uses 1 transistor

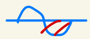


Tuned amplifier, has inductor and capacitor in parallel with each other

$n\% = 99\%$

disadvantage
- distortion
- conducts for $< 180°$ of input cycle

- for +ve half cycle, > 0.7 V
- activate npn transistor
- current flows from DC supply charging C_2 and L_1, oscillations begin
- energy is transferred back and forth between C_2 and L_1



- for -ve half cycle Q_1 is off
- current won't flow since BE is not biased

- there is another way of implementing class C amplifier, using voltage gain

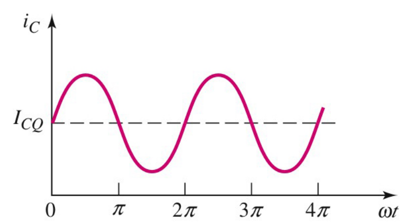
Classes of Amplifier Operations

- Class-A operation
- Class-B operation
- Class-AB operation
- Class-C operation

textbooks will have more definitions

Class-A Operation

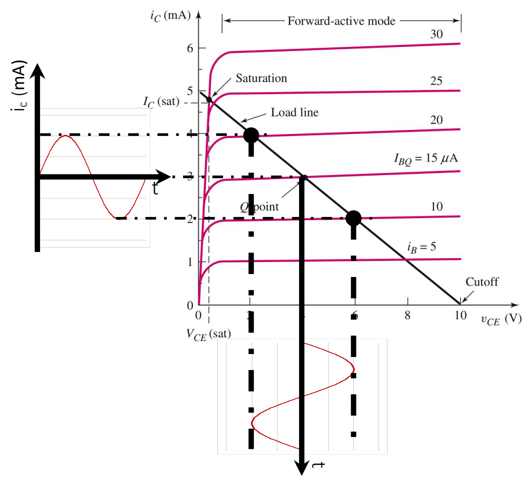
Output



- Conducting angle is 360°
- No clipping
- Output is a sinusoidal for a sinusoidal input
- Operating point is not necessarily in the middle of the load-line

clipped means it doesn't appear in output

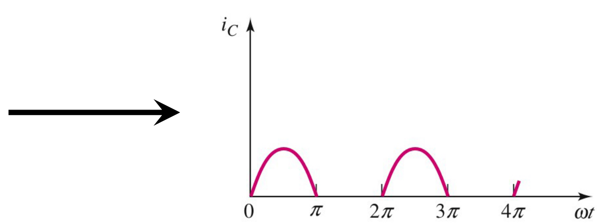
Graphical Illustration of Class-A Amplifier



you can see that output is inverted

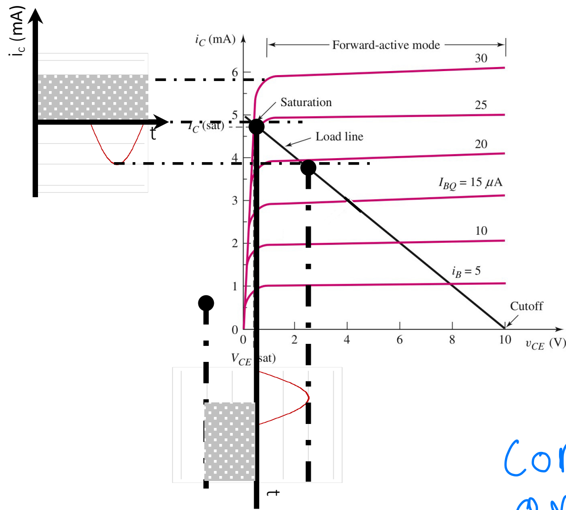
Class-B Operation

Output



- Conducting angle is 180°
- Either half of the input signal is clipped
- Output is a half-sinusoidal for a sinusoidal input
- Operating point is either at the boundary between saturation and active region, or at the cutoff

Graphical Illustration of Class-B Amplifier



Conducting angle = 180°

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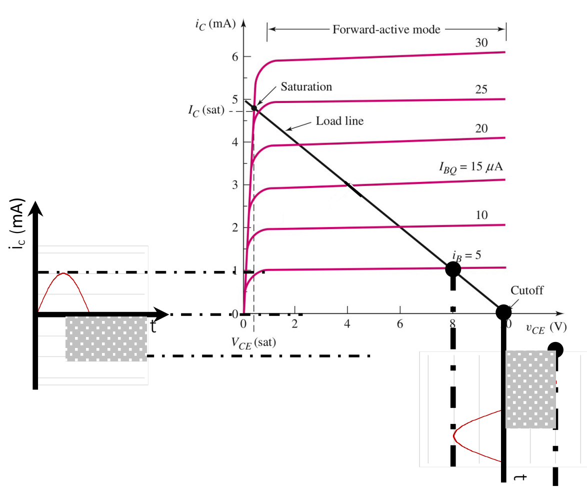
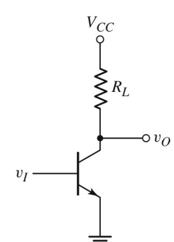
Graphical Illustration of Class-B Amplifier





* Cutoff condition is more reliable than saturation

for switching purposes

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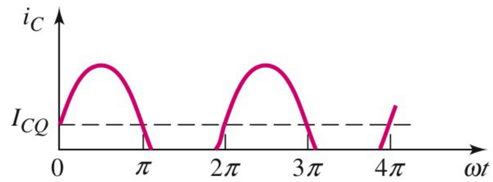
Class-AB Operation

Output →



- Conducting angle is more than 180° but less than 360°
- Less than one half-cycle of the input signal is clipped
- Output is more than half cycle but not a complete sinusoidal
- Operating point is either closer to saturation or closer to cutoff

changed by adjusting operating point

done by changing DC biasing

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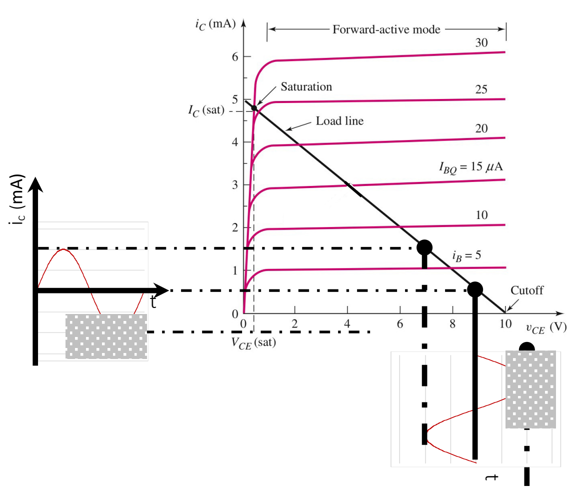
Graphical Illustration of Class-AB Amplifier



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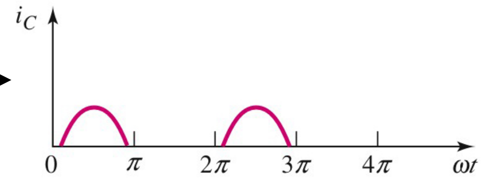
Class-C Operation

Output



- Conducting angle is more than 0° but less than 180°
- More than one half-cycle of the input signal is clipped
- Output is less than half cycle but not zero
- Operating point is either deep in saturation or deep in cutoff

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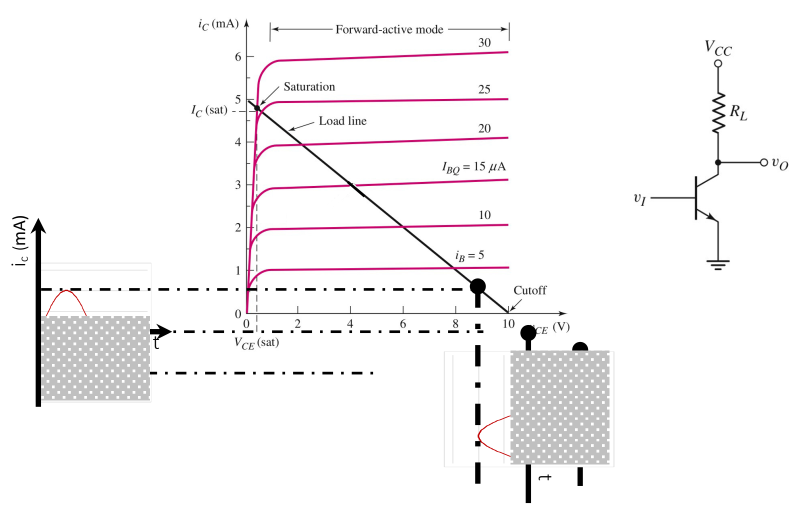
Graphical Illustration of Class-C Amplifier



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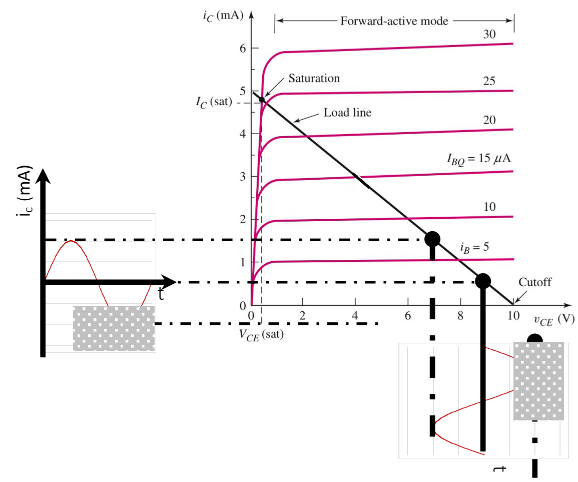
Graphical Illustration of Class-AB Amplifier



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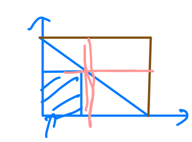
Efficiency of Class-A Amplifiers

DC to AC conversion

$$efficiency = \eta = \frac{Load\ power}{Supply\ power}$$

- For resistive load, maximum efficiency of a class-A amplifier is 25%
- For a transformer coupled class-A amplifier, maximum efficiency is 50%



25%

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Schematic of a Push-Pull Amplifier

A and B are two switches and given that when

$V_I > 0$, A is ON and B is OFF

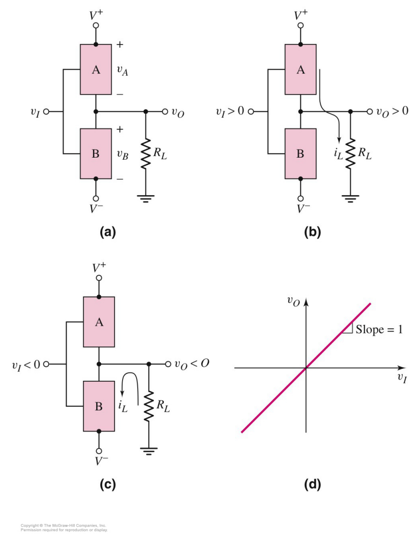
$V_I < 0$, A is OFF and B is ON

When $V_I > 0$

- Voltage drop across A (V_A) is zero
- Voltage drop across B (V_B) is $|V^-|$
- The current flows downwards in the load

When $V_I < 0$

- Voltage drop across A (V_A) is $|V^+|$
- Voltage drop across B (V_B) is zero
- The current flows upwards in the load



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Class B Push-Pull Amplifier

Qn and Qp are two CC amplifiers. When

$V_I > 0$, Qn is ON and Qp is OFF

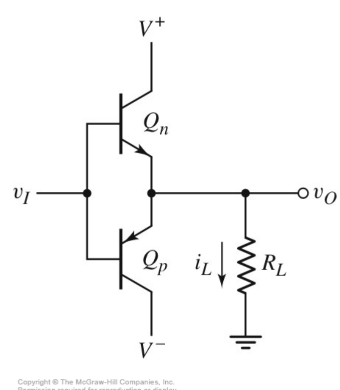
$V_I < 0$, Qn is OFF and Qp is ON

When $V_I > 0$

- $V_{CE,n} = V_{CE(sat)} \approx 0$
- $V_{CE,n} = |V^+|$
- $V_o \approx V_I$ and i_L is positive (downwards)

When $V_I < 0$

- $V_{CE,p} = V_{CE(sat)} \approx 0$
- $V_{CE,n} = |V^-|$
- $V_o \approx -V_I$ and i_L is negative (upwards)



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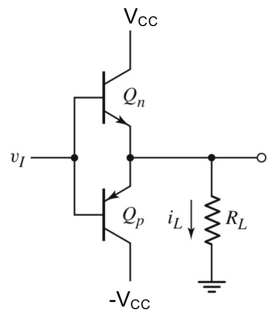
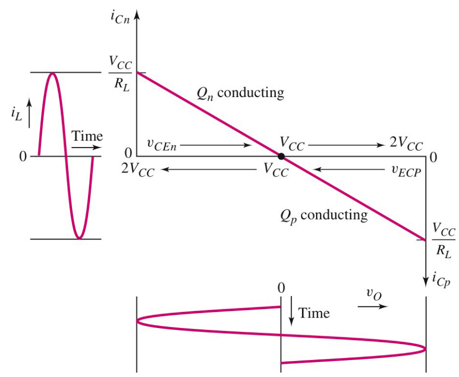
The Load-Line of Class B Push-Pull Amplifier





When the input satisfies $0 \leq \omega t \leq \pi$

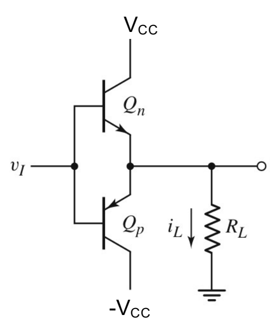
then $v_o = V_{CC} - v_{CEn}$

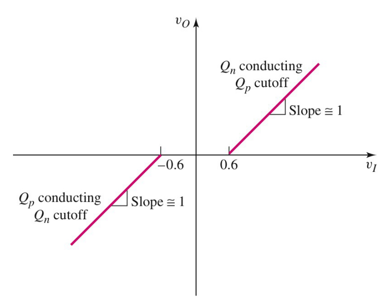
Maximum conversion efficiency is 78.5%

When the input satisfies $\pi \leq \omega t \leq 2\pi$

then $v_o = -V_{CC} + v_{ECp}$

Crossover Distortion

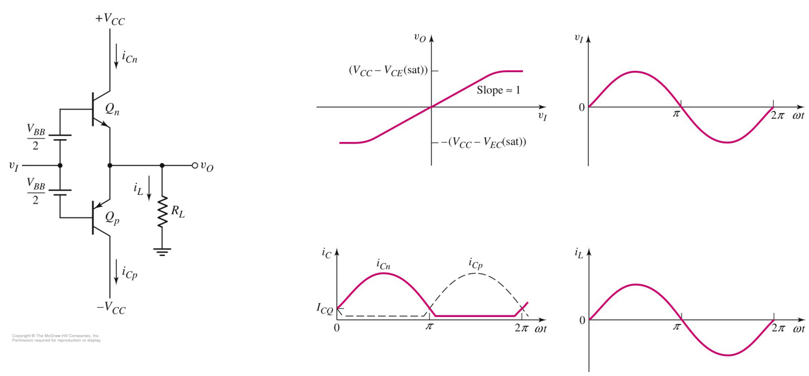




- Transistors need 0.7V at the base-emitter junction in order the junction to be properly forward biased
- Thus, the input signal doesn't amplify until its value exceed 0.7V in either direction
- This gives a distorted output signal

quiz 4
until here

Elimination of Crossover Distortion: Class AB Operation



- A voltage of V_{BB} has been applied between the two bases
- Here, VBB = 0.7 x 2 = 1.4 V
- This eliminates the crossover distortion

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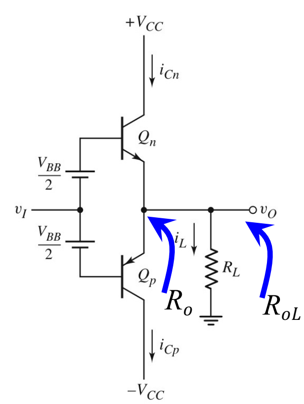
Output Resistance

- $R_o = (r_{en}) || (r_{ep})$
- $r_{en} = (V_T) | (i_{en})$
- $R_o = \frac{V_T}{i_p + i_n}$
- If $|i_p| = |i_n| = 0.5$ A,
  Ro = $V_T/1$= 25 mΩ
- Even for small current such as
  $|i_p| = |i_n| = 1$ mA,
  Ro = V_T = 12.5 Ω



- $R_{oL} = (R_o) || (R_L)$
- Thus, $R_{oL} < R_o$

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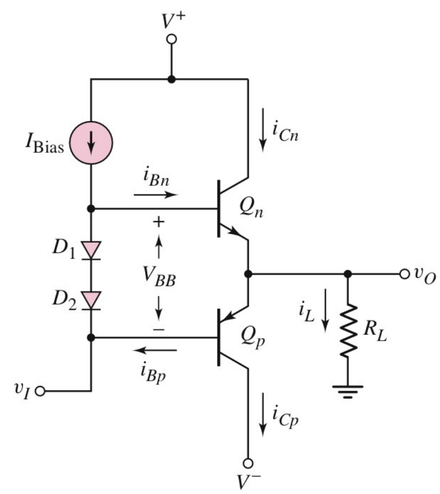
Fri Nov 10
ends here

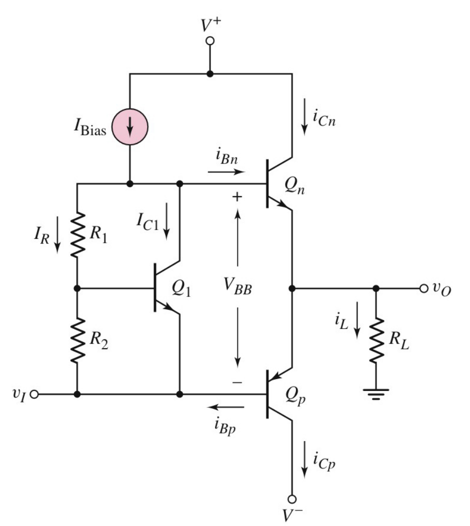
Class AB Output Stage With Diode Biasing

- D1 and D2 are biased by I_{Bias}
- V_{BB} provides the quiescent bias

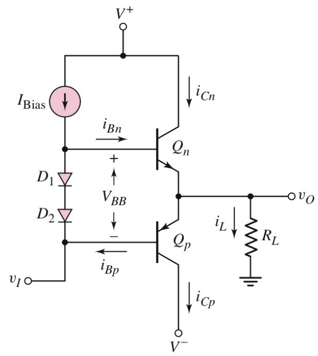


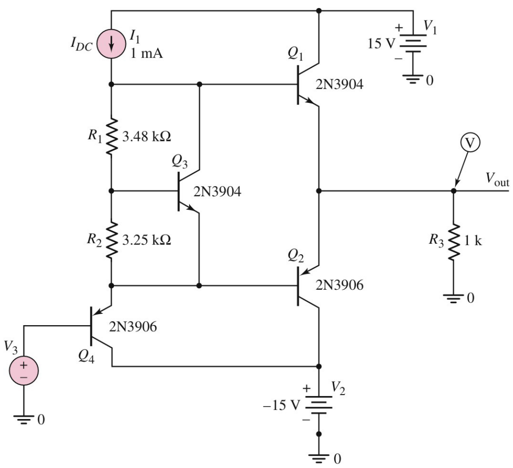
Class AB Operation Using V_{BE} Multiplier

- Assume, $I_{B1} = 0$
- $I_R = (V_{BE1})/(R_2)$
- $V_{BB} = I_R\,(R_1 + R_2)$
- $V_{BB} = V_{BE1}\left(1 + \frac{R_1}{R_2}\right)$
- V_{BE1} is multiplied by the factor $(1 + R_1/R_2)$
- One can control this factor to set the V_{BB}
- A potentiometer can be used in a discreate circuit



An Example Circuit



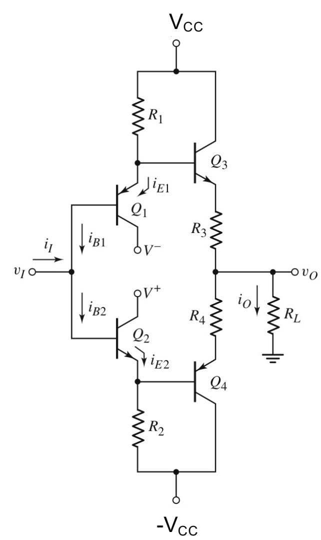


Class AB with Input Buffer

- Q_1 and Q_2 are emitter followers
- High input resistance
- R_3 and R_4 provide thermal stability
- R_3 and R_4 are very small
- The overall voltage gain is approximately unity

When v_I increases, the following happens

- i_{B1} decreases and i_{B2} increases
- i_{B3} increases because of reduced i_{E1}
- Q3 conducts
- Q2 also conducts because of increased i_{B2}
- High input resistance
- Q4 doesn't conduct because of increased i_{E2}
- i_L flows through Q3, R3, and RL (downwards)



Class AB with Input Buffer

Let's consider the positive half cycle of the input signal is applied

- i_{B2} and i_{E2} increase
- Thus, $i_I = i_{B2} - i_{B1}$

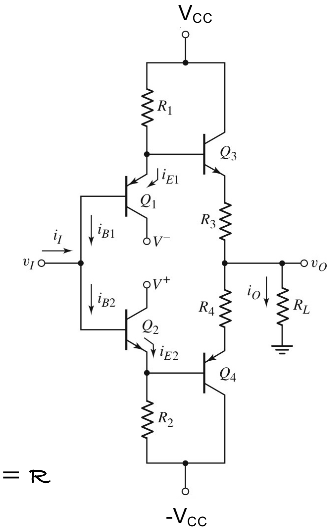
Neglecting the voltage drops across R_3 and R_4, we can write

$$i_{B2} = \frac{(v_I - v_{BE2}) - (-V_{CC})}{(1+\beta_n)R_2}$$

and $$i_{B1} = \frac{V_{CC} - (v_I + v_{EB1})}{(1+\beta_p)R_1}$$

If $|V_{BE}| = |V_{EB}|$, $\beta_p = \beta_n = \beta$, and $R_1 = R_2 = R$

$$i_I = i_{B2} - i_{B1} = \frac{2v_I}{(1+\beta)R}$$



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Class AB with Input Buffer

Here,

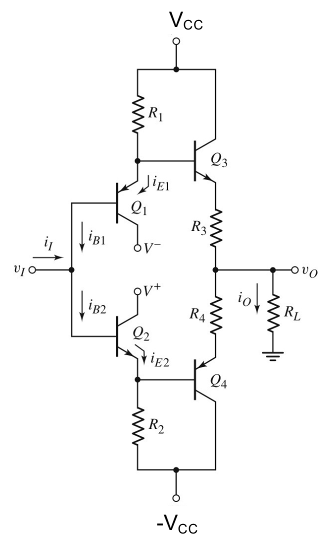
$$i_L = \frac{v_O}{R_L} \cong \frac{v_I}{R_L} = \frac{i_I(1+\beta)R}{2R_L}$$

Thus, Current gain $= A_i = \frac{i_L}{i_I}$

or, $$\boxed{A_i = \frac{R}{2R_L}(1+\beta)}$$

Example: If $R = 580\Omega$, $RL = 8\ \Omega$, and $\beta = 30$, determine the current gain.

Current gain = 1123.8



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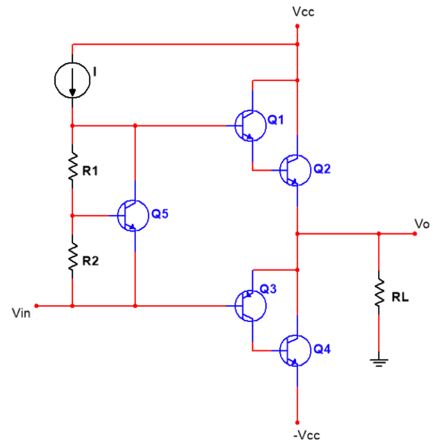
Class AB with Compound Devices

- The signal voltage gain is approximately unity
- If Q1, Q2, Q3, and Q4 are identical, the current gain for the Darlington (Q1 & Q2) is β^2 and
- The current gain for the composite pnp (Q3 & Q4) is also β^2.
- $V_{BB} = 0.7x3 = 2.1$ V



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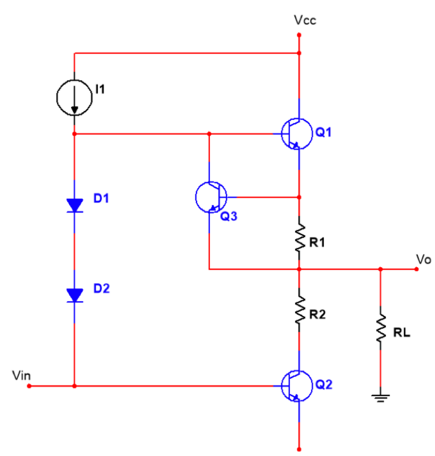
Class AB with Short Circuit Protection

- If Q1 is short-circuited because of overflow of current
- The voltage across R1 increases
- Increased V_{R1} turn Q3 on
- I_{C3} will decrease I_{B1} to a safe level
- Thus, Q3 protects overflow/short-circuit in Q1



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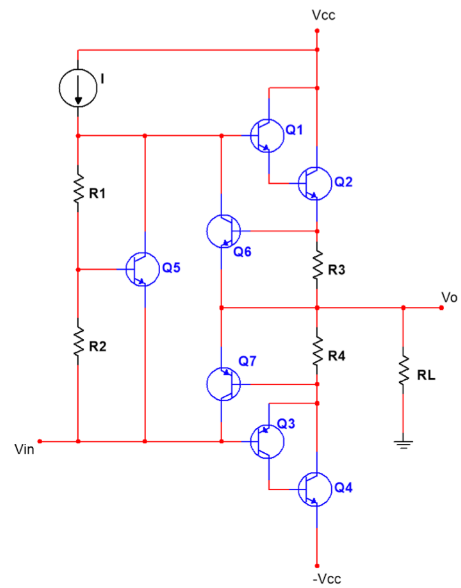
What Does This Circuit Do?



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General Structure of an Op-amp (+ Current Booster)

High power can be obtained from a power amplifier consisting of an op-amp followed by a class AB buffer.

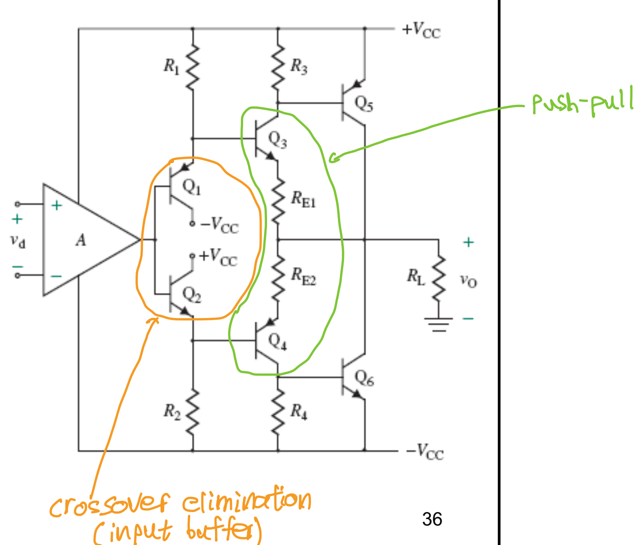
Q3 supplies load current until the voltage across R3 is sufficiently high to turn on Q5

Q5 supplies additional load current

Q4 and Q6 do the same but supply a negative current to the load

The stage formed by Q5 and Q6 supplies the additional load current and acts as a current booster

RE1 and RE2 are used for biasing stability



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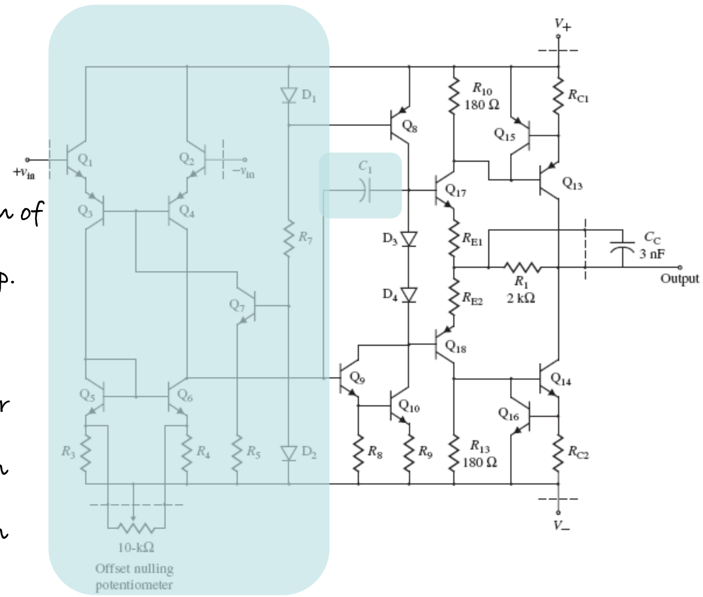
Power Op-Amp LH0021

Explain the operation of
- Q17 and Q18
  - Push-pull amp.
- RE1 and RE2
  - stabilizer
- Q13 and Q14
  - current booster
- Q15 and Q16
  - S.C. protection
- RC1 and RC2
  - S.C. protection



Output Stage of LM741 Op-Amp Circuit