ELEC 3106
Study Notes

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Semester 1 2013 – Electrical Engineering
The University of New South Wales

NOTES: Week 9 - Power Amplifiers

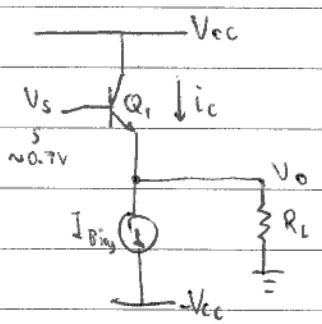
Power Amplifiers

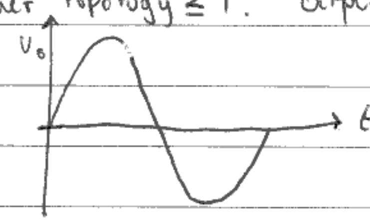
- Class A : usual voltage gain
- Class B : deliver higher output current
- Class C : low output impedance
- Class D : power gain
- Class E : distortion...

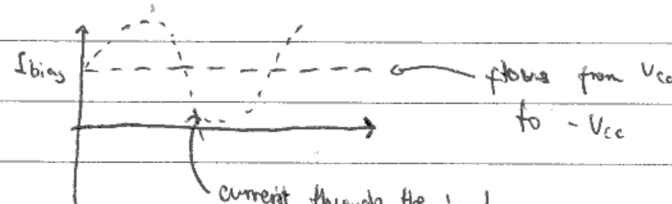
Classed according to the collector current waveform that results when an input signal is applied.

Class A amplifier

Transistor conducts over the entire period. One of the most inefficient amplifier classes - uses emitter-follower topology ≤ 1. Output impedance is low.

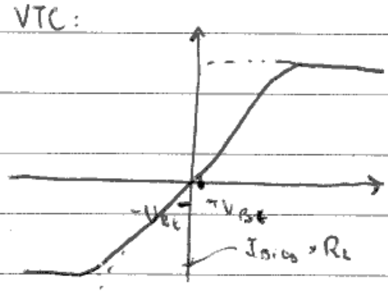






$\therefore$ Conduction angle = 360°.

VTC:



Efficience

$P_{R_L} = \frac{1}{2} V_{op}^2 / R_L$

Power drawn from negative supply rail

$I_{Bias} \times V_{cc}$

Power dissipation in Q_1 depends on R_L. With an open circuit load, average power dissipation is $V_{cc} \times I$. When there is a short circuit load, however, a positive input voltage = infinite load current - raising its junction temperature and causing a fire.

$$\text{Efficiency } \eta = \frac{P_{LOAD}}{P_{SUPPLY}} = \frac{\frac{1}{2}\frac{V_o^2}{R_L}}{2V_{cc} I}$$

max eff for class A = 25%.

DO NOT USE for applications greater than 1 Watt.

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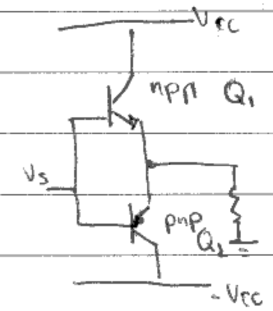
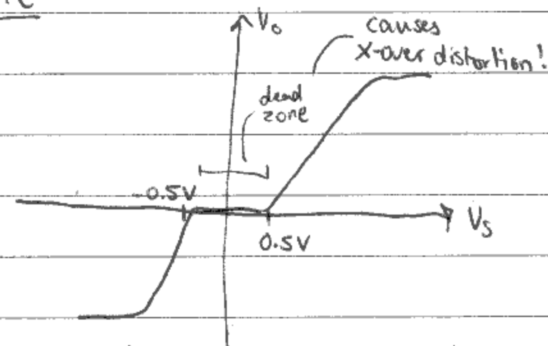
Class B amplifier

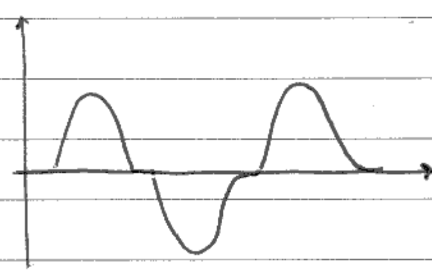


VTC



Transistors cannot be conducted simultaneously. When $v_s = 0$, both transistors are cut off. As it goes positive & exceeds about 0.5 V, Q_N conducts and operates as an emitter follower. At this stage, $V_o = V_S - V_{BE1}$ and Q_1 supplies the load current. Meanwhile the emitter base junction of Q_2 is reverse biased by $V_{BE1} \sim 0.7$ V, cutting it off. When V_S goes negative past -0.5V, Q_2 acts as emitter follower. It is a PUSH-PULL circuit, Q_N pushes current into the load when v_s is positive and Q_2 sinks current from the load when v_s is negative.

Output:



Efficiency

Average load power is $P_L = \dfrac{V_o^2}{2R_L}$

Average power drawn from Vcc rail:

$$P_{CC} = V_{CC} \int_0^T i_c(t)\, dI$$

$$= V_{CC} \left[\int_0^{T/2} \frac{V_{op} \sin(\omega t)}{R_L} \right] = \frac{V_{CC} V_{op}}{\pi R_L}$$

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Since the same power is drawn for the negative case, total supply power is:

$$P_S = \frac{2}{\pi} \times \frac{V_o}{R_L} \times V_{CC}$$

Total efficiency for Class B: $\eta = \frac{\pi}{4} \frac{V_o}{V_{CC}}$

Maximum (theoretical) efficiency is 78.5%, much superior to Class A.

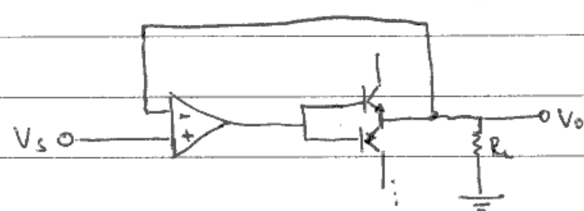
Dissipation

Class A amplifiers dissipate maximum power under quiescent conditions ($v_o = 0$), but Class B is zero! Upon application of an input signal, average power dissipated in a Class B is:

$$P_D = P_S - P_L.$$

Maximum power dissipation: $P_{max} = \frac{V_{CC}^2}{\pi^2 R_L}$

Crossover distortion quick fix (dodgy):



Dodgy because slew rate limited op-amp will make switching noticeable.

Summary

We consider class A amplifiers to have a 360° conduction angle because it is biased at a current equal to or greater than the amplitude, so it amplifies the full wave. A class B amp changes this bias point to 0 so it only conducts half the wave, giving a conduction angle of 180°. So, what about the class C...

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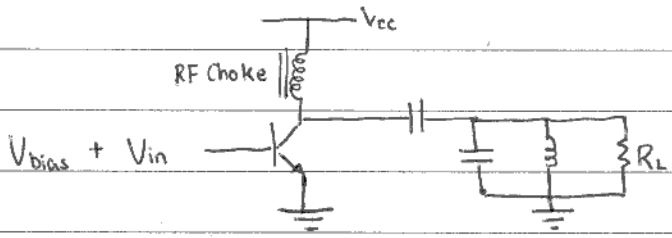
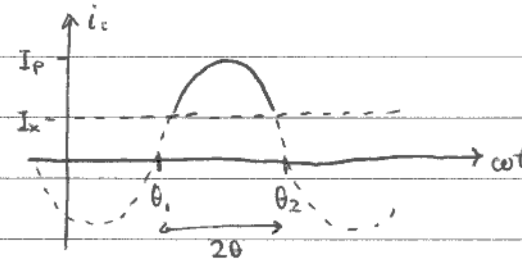
Class C Amplifier

Conducts less than 50% of the input signal with high output distortion (conduction angle < 180°), but high efficiency (> 90%) is now possible. It seems we have a theme here.





Usually used in RF transmitters operating at a single frequency where distortion is controlled by a tuned load.

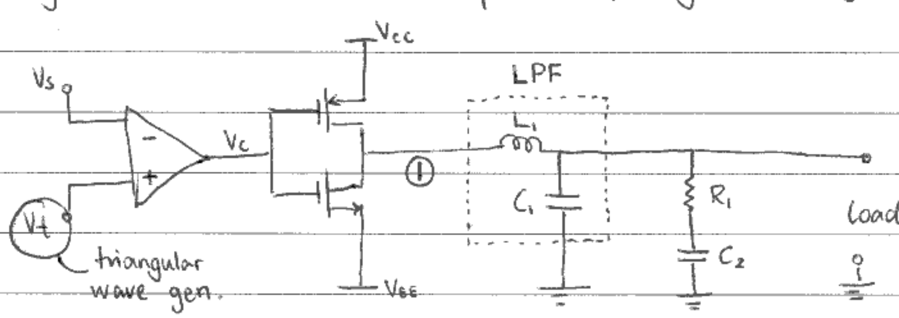
$$i_c \text{ (collector current)} = \begin{cases} I_p \sin(\omega t) - I_x & \theta_1 < \omega < \theta_2 \\ 0 & \text{elsewhere} \end{cases}$$

$$I_x = I_p \sin\theta_1$$

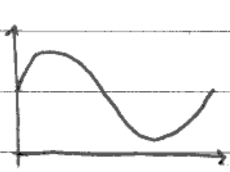
Fundamental harmonic current component: $I_1 = \frac{I_p}{2\pi}(2\theta - \sin 2\theta)$

Class D (D for Digital) Amplifier

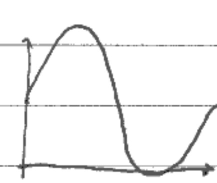
Input signal is converted to a sequence of higher voltage output pulses.



in

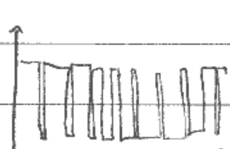


out ②



Gain: $A = \frac{V_o}{V_t}$

out ①



The low-pass filtered signal is an amplified replica of the input.

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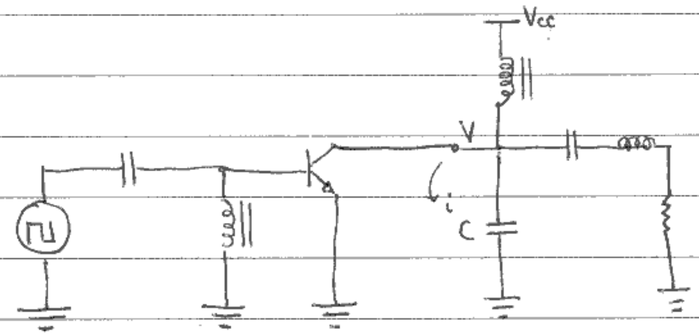
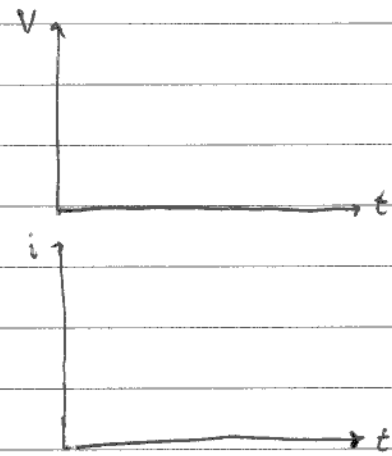
Class E Amplifier

A specialised, tuned amplifier for RF. Very high efficiency. Uses an on-off state of switching and corresponding current flow is that high current & high voltage do not overlap. It consists (key components) of a switching transistor, a shunt capacitance, a series inductance and a tuned series filter. It will suppress higher order harmonics.

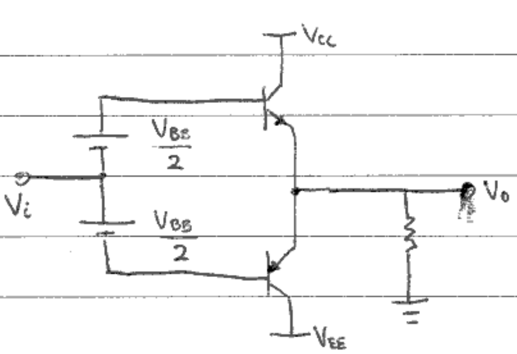
SCH:



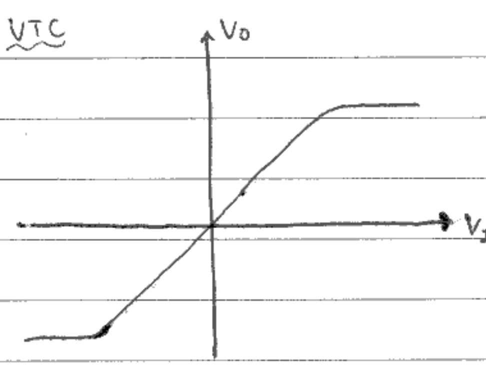


Class AB Power Amplifier

Class B would be a great amplifier if not for that cross-over distortion! Fortunately, the class AB amplifier has come to save the day. It will be rid of the cross-over distortion and provide a conduction angle greater than 180° and less than 360°. It works by biasing the output transistors with a small nonzero current.



VTC



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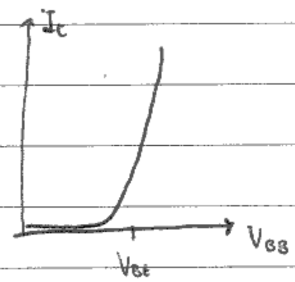
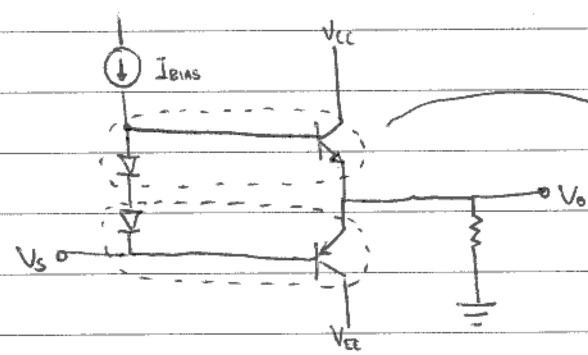
Thermal Runaway

Caused by positive feedback. The V_{BE} (base-emitter voltage) of a transistor has a negative thermal coefficient.



$$\frac{dV_{BE}}{dt} \simeq -2mV/°C.$$

We also need to find some way to bias this circuit. So why not kill two birds with one stone and use the magical powers of DIODES?

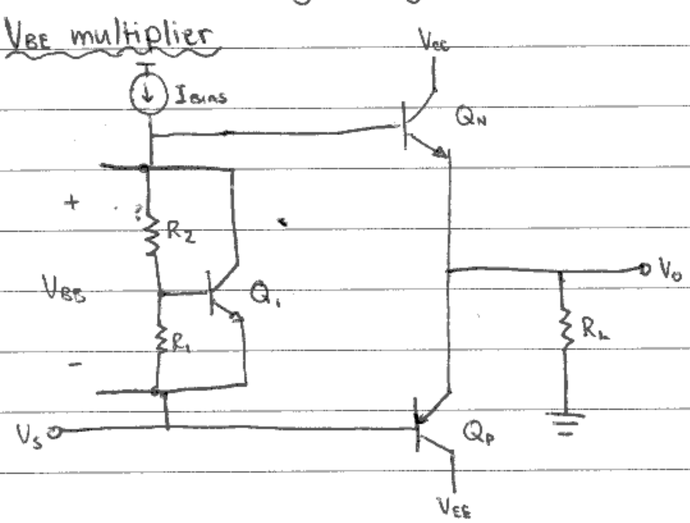


diodes will bias the transistors AND offer thermal coupling.

how? remember power is dissipated under quiescent conditions. increases in temperature mean increased collector current. the diodes increase in temperature with the transistors, so both diode & transistor V_{BE} increases, leaving I_Q constant and the transistor safe from destruction.

Other class AB biasing arrangements

V_{BE} multiplier



Current through R_1 & R_2:

$$I_R = \frac{V_{BE1}}{R_1}$$

bias network voltage:

$$V_{BB} = V_{BE1}\left(1 + \frac{R_2}{R_1}\right)$$

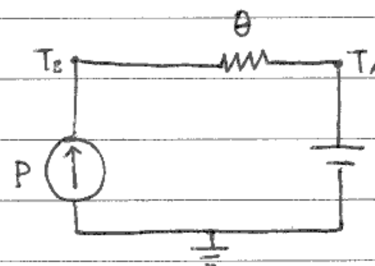
Also consider the Darlington pair and Emitter-Follower driver.

NOTES: Week 9 - Thermal Management

We can model thermal parameters of circuits as equivalent "heat circuits". This allows us to use circuit theory on thermal problems.

Thermal	Electrical
Temperature T (K)	Voltage V
Heat Flow P (W or J/s)	Current I
Heat capacity C (J/K)	Capacitance C
Thermal resistance θ (K/W)	Resistance R

E.g.

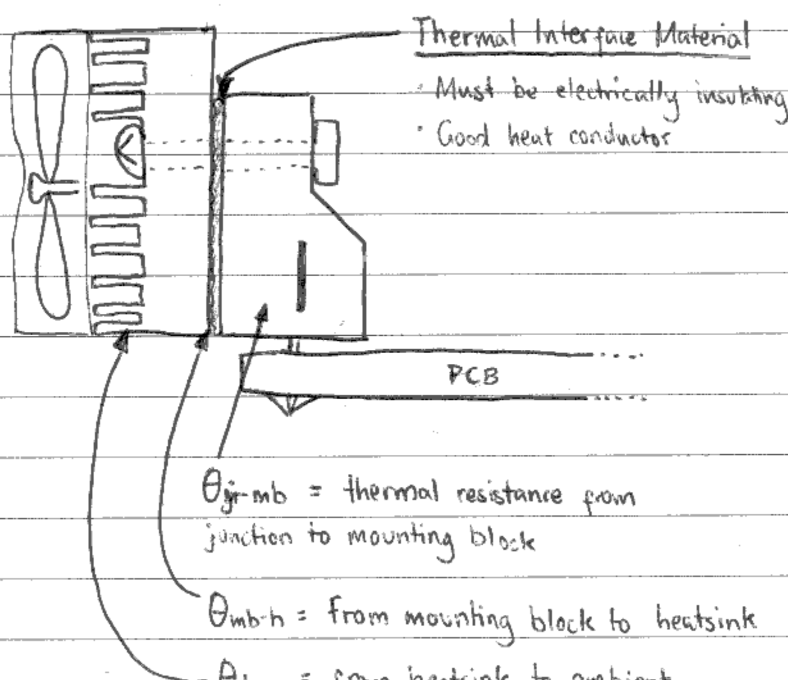


as $V_B - V_A = IR$,

$$T_B - T_A = P\theta$$

Deeper:
- T_A = 'ambient temperature' - has infinite heat capacity.
- Objective is always to achieve the path of least thermal resistance to the ambient.

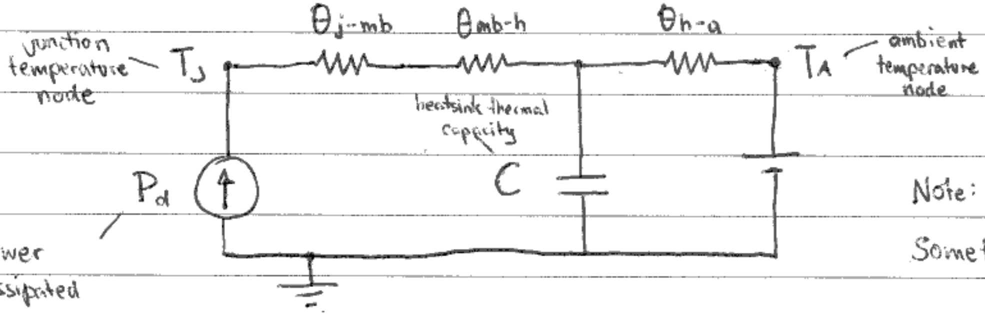
Analysing a package mount on PCB & heat-sink, for a power MOSFET.



Heat sinks also have a large thermal capacity, modelled by C.

NOTES: Week 9 - Thermal Management

The diagram of the heatsink package on the previous page can now be modelled by the following circuit:



Note: C is very large.

Sometimes we can ignore it.