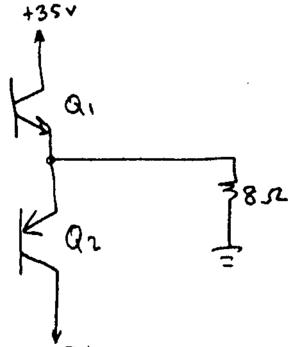
Efficiency in class-B amplifiers

(or.. how hot does it really get).

For class-A amplifiers, we just looked at the quiescent condition — no signal.
It is different with a signal, but not much.

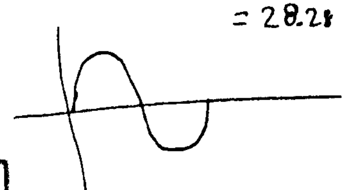
Class-B amplifiers have very low quiescent dissipation, but it goes up a lot with a signal.

Consider the same 50 watt amplifier....



Suppose it is actually delivering 50 watts to the load.

Load voltage = 20 RMS
= 28.28 peak



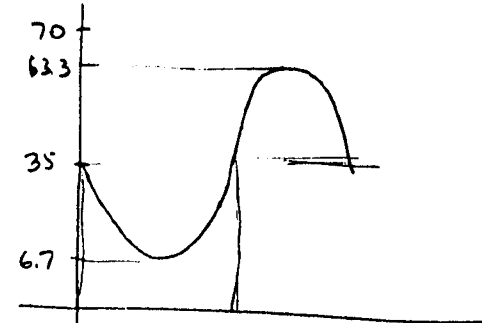
Load current = 2.5 amp.
= 3.536 peak.

Homework —
Chapter 8

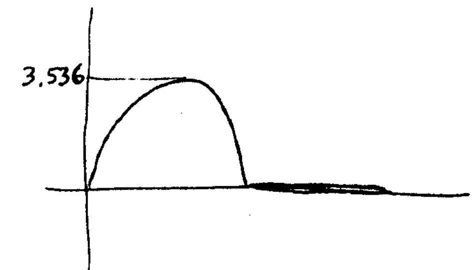
But Voltage across device is $V_{power} - V_{LOAD}$.

Take some points --

V_{OUT}	V_{Q1}
0	35
28.3	6.7
-28.3	63.3

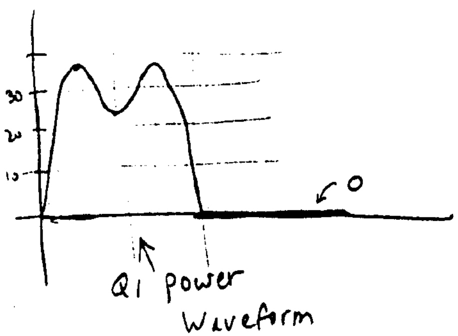


Current is the load current, half wave rectified



Instantaneous power is the product

P_{in}	V_{out}	V_{Q1}	I_{Q1}	P_{LOAD}	P_{Q1}
0	0	35	0	0	0
21.88	5	30	.625	3.125	18.75
43.75	10	25	1.25	12.5	31.25
65.63	15	20	1.875	21.13	37.5
87.50	20	15	2.5	50	37.5
109.4	25	10	3.125	78.13	31.25
131.3	30	5	3.75	112.5	18.75
153.1	35	0	4.375	153.1	0
	28.3	6.7	3.536	100.	23.7
	[illegible]	[illegible]	[illegible]	38.28	38.28



Take average value → ≈ 15 watts.

and ≈ 15 watts in other device.

total ≈ 30 watts

Calculations:

$V_{OUT} = 28.3 \sin(\omega t)$

$V_{Q1} = 35 - V_{OUT}$

$= 35 - 28.3 \sin(\omega t)$

$I_{OUT} = 3.54 \sin(\omega t)$

$I_{Q1} = \begin{cases} 3.54 \sin(\omega t) & V > 0 \\ 0 & V < 0 \end{cases}$ ← $\sin(\omega t)$

$P_{out} = V_{out} I_{out}$

$= (28.3 \sin(\omega t)) * (3.54 \sin(\omega t))$

$= 100 \sin^2(\omega t)$

$P_{Q1} = V_{Q1} I_{Q1}$

$= (35 - 28.3 \sin(\omega t)) * \begin{cases} 3.54 \sin(\omega t) & V > 0 \\ 0 & V < 0 \end{cases}$

$P_{Q1} = \begin{cases} 124 \sin(\omega t) - 100 \sin^2(\omega t) & V > 0 \\ 0 & V < 0 \end{cases}$

↑ Input power ($124 \sin(\omega t)$); ↑ Power delivered to load ($100 \sin^2(\omega t)$)

Avg power dissipated =

$\frac{1}{2\pi}\left(\int_0^{\pi}(124 \sin(\omega t) - 100 \sin^2(\omega t))\, d(\omega t) + \int_{-\pi}^{0} 0 \, d(\omega t)\right)$

$= \frac{1}{2\pi}\left(124(-\cos(\pi) + \cos(0)) - 100\left(\left(\frac{\pi}{2} - \frac{1}{4}\sin(2\pi)\right) - \left(\frac{0}{2} - \frac{1}{4}(\sin(0))\right)\right)\right)$

$= \frac{1}{2\pi}\left(124(2) - 100\left(\frac{\pi}{2}\right)\right)$

$= 14.47$ watts → each device

or 28.9 watts total

$\int \sin^2 dx = \frac{x}{2} - \frac{1}{4}\sin 2x$ (+c)

Power in

$= \underbrace{\frac{1}{2\pi}\int_0^{\pi} 124 \sin(\omega t)\, d\omega t}_{NPN} + \underbrace{\frac{1}{2\pi}\int_{-\pi}^{0} -124 \sin(\omega t)\, d\omega t}_{PNP}$

$= \frac{1}{2\pi}(124(1+1)) + \frac{1}{2\pi}(-124(-1-1))$

$= 39.5 + 39.5 = 79$ watts.

Efficiency $= \frac{50}{79} = .63$ → 63% (at 50 watts)

Thermal considerations

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Usually, you will find a spec for thermal resistance.

$$\Theta = \frac{°C}{watts}$$ ← temperature difference.

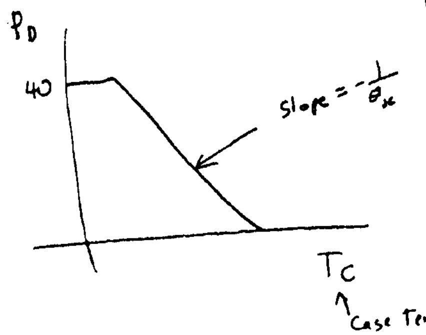
It's covered in detail in Thermodynamics.

For here, think of it like a circuit –

Heat sources are like currents.

Temperatures are like voltages.

You will also find a "derating curve".



Example –

A 2N2219 is dissipating .5 watt, with ambient temp = 30°C.

What is the case temp?

What is junction temp?

From data sheet..

$\Theta_{JA} = 219 \frac{°C}{W}$

$\Theta_{JC} = 58 \frac{°C}{W}$

→ Implies $\Theta_{CA} = 161 \frac{°C}{W}$

Example – continued

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$\Theta_{JA} = 219 \frac{°C}{W}$ → $219 \frac{°C}{W} * .5W = 109.5°C \approx 110°C$

↑ Junction temp rise.

Junction temp $= T_A + T_{rise} = 30 + 110 = \underline{140°C}$

$\Theta_{CA} = 161 \frac{°C}{W}$ → $161 \frac{°C}{W} * .5W = 80.5 \approx 81$

Case temp $= T_A + T_{CA} = 30 + 81 = \underline{111°C}$.

If max junction temp is 200°C, ambient temp = 40°C

What thermal resistance is required for our 50 watt amp?

Power dissipation ≈ 15 watts per device

$T_{Diff} = 200 - 40 = 160$

$$\Theta_{required\ JA} = \frac{160°C}{15\ watts} = 10.67 \frac{°C}{Watt}$$

↑ junction to ambient

MJ802 has $\Theta_{jc} = .875 \frac{°C}{W}$

need heat sink $10.67 - .875 = 9.8 \frac{°C}{Watt}$

TIP31 is cheaper and rated 40 watts. Will it work?

Max jct temp = 150°C, $\Theta_{jc} = 3.125 \frac{°C}{W}$

$\Theta_{req} = \frac{150-40}{15} = \frac{110}{15} = 7.33 \frac{°C}{Watt}$ – Yes – need heatsink –

$7.33 - 3.125 = 4.2 \frac{°C}{W}$

↑ More than twice the heat sink as MJ802