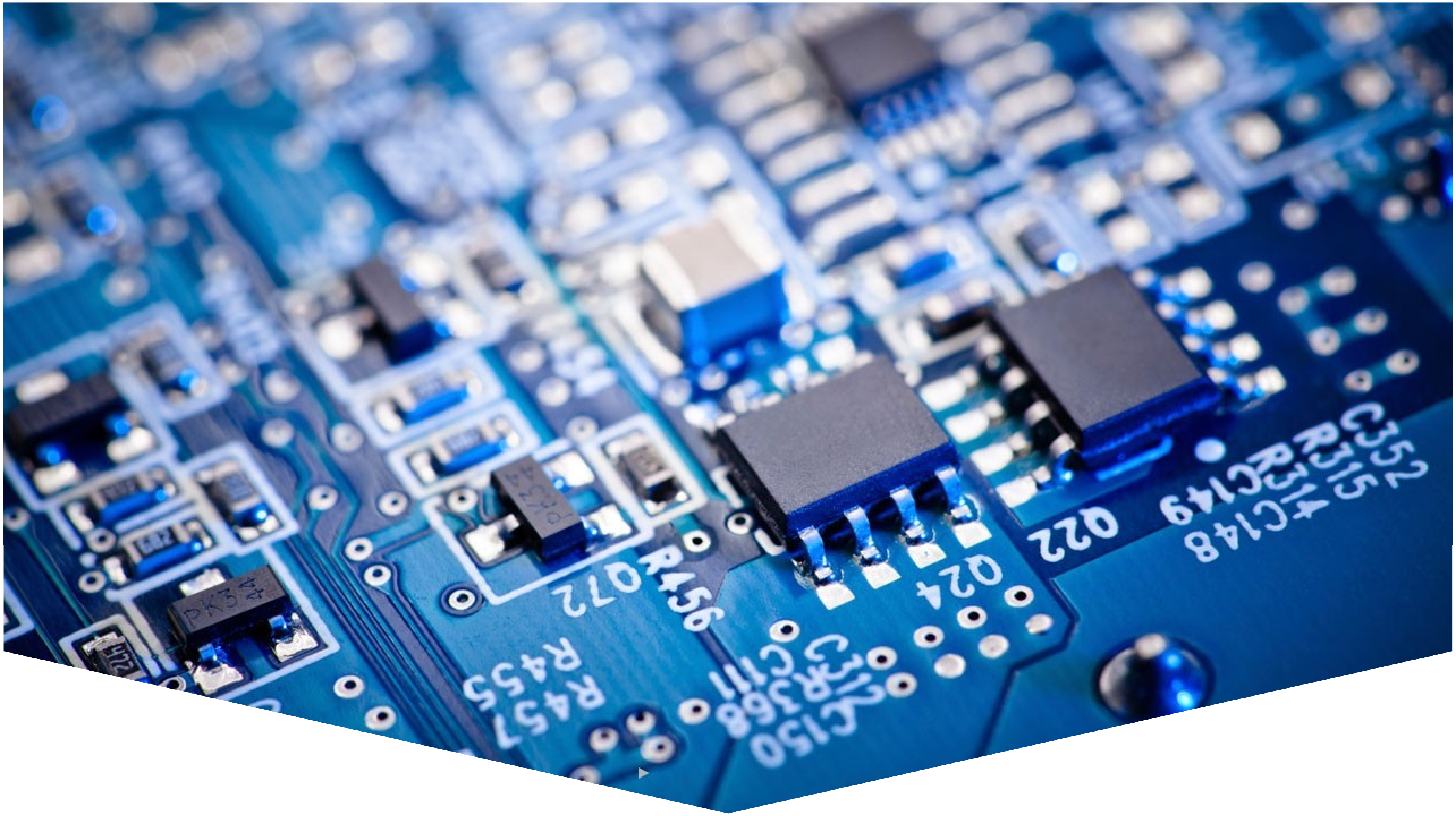


ANALOGE ELEKTRONICA 2

CLASS-AB AMPLIFIERS

overtref jezelf

HOGESCHOOL ROTTERDAM

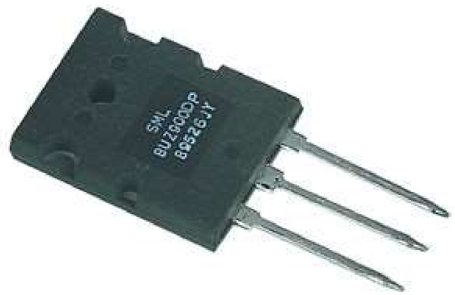
Overzicht

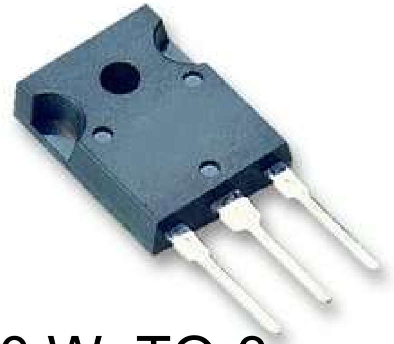
- Power Amplifiers
  - Power Transistors
  - Heat Sinks
- Classes of Amplifiers
  - Class A
  - Class AB
  - Class D
- Class AB amplifiers
  - Input-Filter
  - Input Stage (IPS)
  - Voltage Amplifier Stage (VAS)
    - Current-Mirror
    - Common-Emitter Stage
    - Active-Load
  - Vbe-Multiplier
  - Negative Feedback
  - Output Stage
  - Output Filters

Power Amplifiers

- **Power Amplifiers**:
  - Deliver large amounts of power (> 100 W) to a passive load
  - Typically built with BJT-transistor or MOSFETs
- **Total harmonic distortion (THD)**:
  - RMS value of harmonic components of the output signal
  - Fundamental frequency excluded
  - Expressed as a percentage of the fundamental

Power Transistors





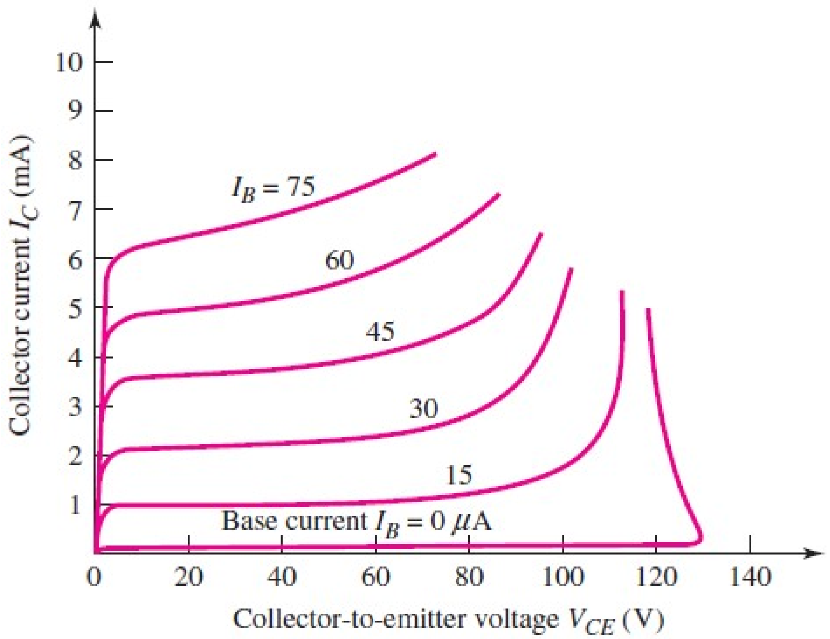
- **Physical Transistor Limitations**:
  - Max. rated current: I_c or I_{ds}
  - Max. rated voltage: U_{ce} or U_{ds}
  - Max. rated power: $P = U_{ce}.I_c$ or $P = U_{ds}.I_{ds}$
- Types of transistor: BJT or MOSFET
- Also to consider: max. temperature
  - Function of rate at which heat is removed
- Examples:
  - **MJ15003** (NPN)/**MJ15004**(PNP): 140 V, 20 A, 250 W, TO-3
  - **TIP142** (NPN)/**TIP147**(PNP): 100 V, 10 A, 125 W, TO-247
  - **MJL21194** (NPN)/**MJL21193**(PNP): 250 V, 16 A, TO-264

Power BJT Transistor

Table 8.1 Comparison of the characteristics and maximum ratings of a small-signal and power BJT

Parameter	Small-Signal BJT (2N2222A)	Power BJT (2N3055)	Power BJT (2N6078)
V_{CE}(max) (V)	40	60	250
I_C(max) (A)	0.8	15	7
P_D(max) (W) (at $T = 25\,°C$)	1.2	115	45
β	35–100	5–20	12–70
f_T (MHz)	300	0.8	1

- **DC current gain is not a constant**:
  - Drops at higher current
  - Much lower than a small-signal transistor
- **Watch the breakdown voltage mechanism:**



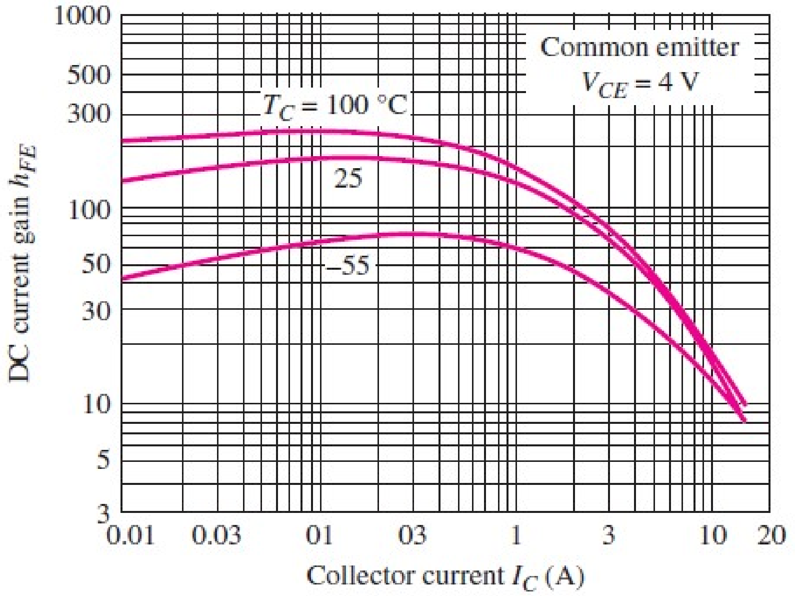


Figure 8.1 Typical dc beta characteristics (h_{FE} versus I_C) for 2N3055

Safe Operating Area (SOA)

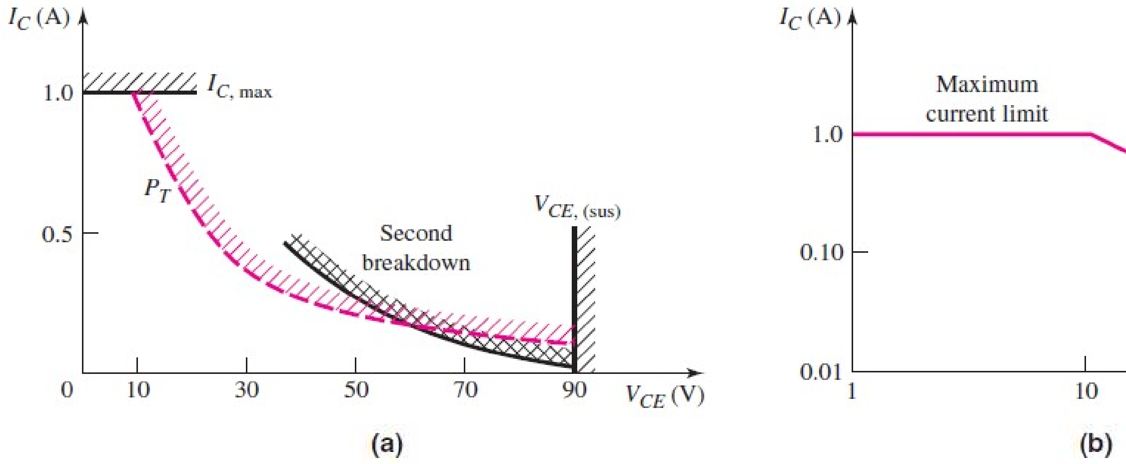


Figure 8.3 The safe operating area of a bipolar transistor plotted on: (a) linear scales and (b) logarithmic scales

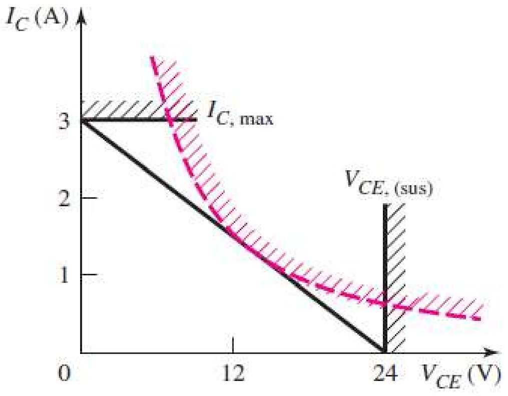


Figure 8.5 DC load line within the safe operating area

- **TIP142 / TIP147**:
  - 30 V: 4 A
  - 40 V: < 3 A

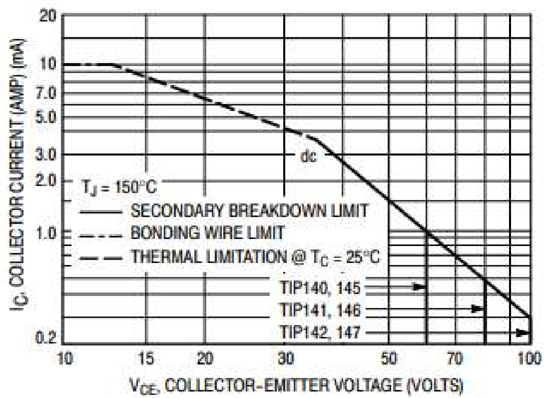


Figure 6. Active–Region Safe Operating Area

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Power MOSFETs

Table 8.2 Characteristics of two power MOSFETs

Parameter	2N6757	2N6792
V_{DS}(max) (V)	150	400
I_D(max) (at $T = 25$ °C)	8	2
P_D (W)	75	20

No thermal runaway

- Transconductance decreases with temperature

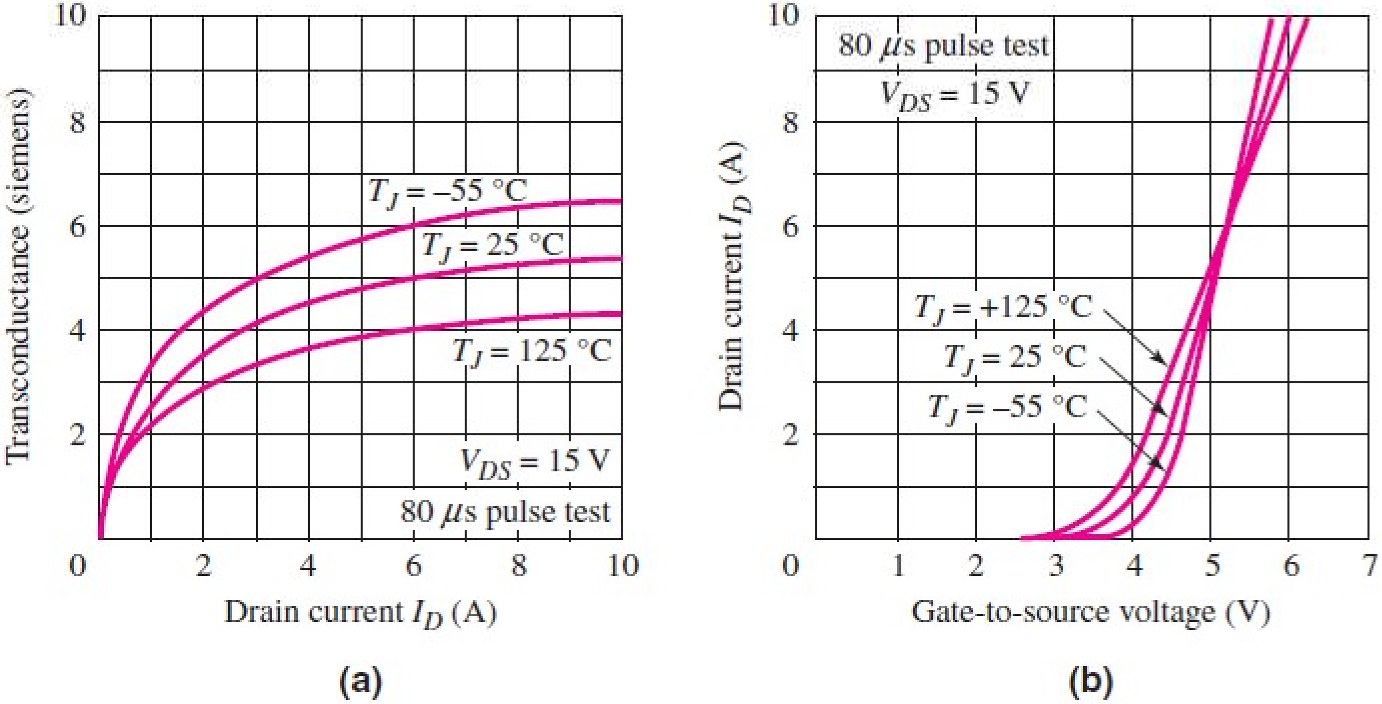
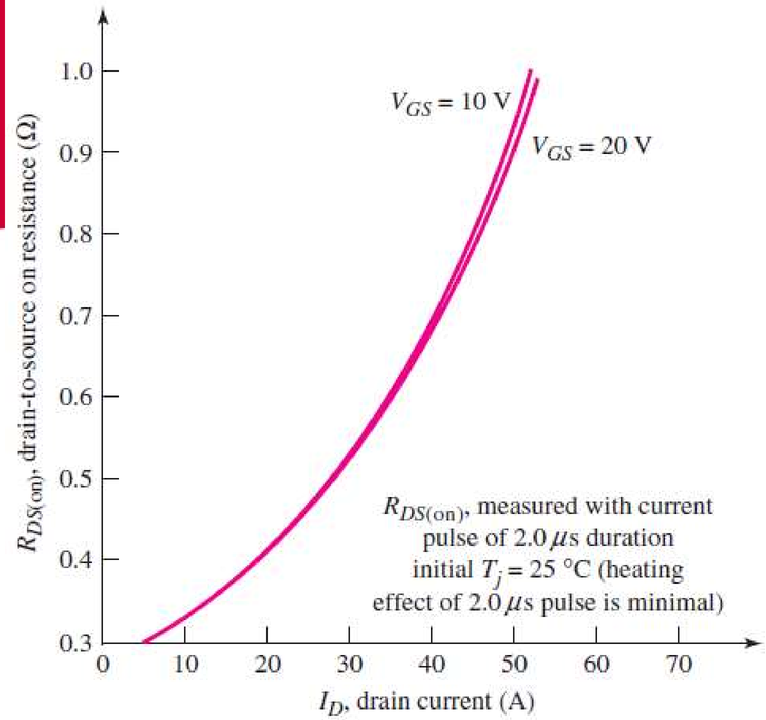


Figure 8.7 Typical characteristics for high-power MOSFETs: (a) transconductance versus drain current; (b) transfer characteristics

Power MOSFETs

Structure of MOSFETs

- HEXFET:
  - N-channel: IRF540
  - P-channel: IRF9540
- Normal FET:
  - N-channel: IRF530
  - P-channel: IRF9530



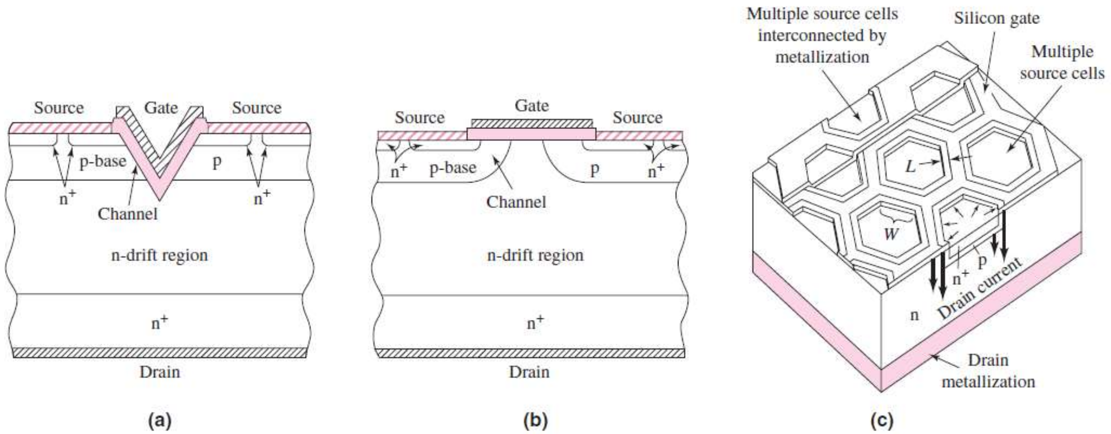
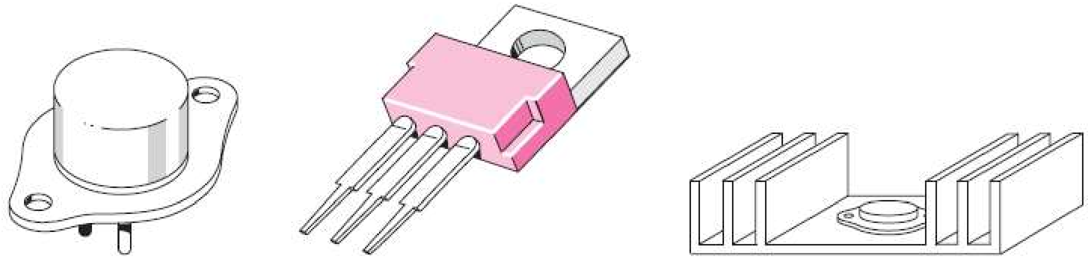


Figure 8.8 (a) Cross section of a VMOS device; (b) cross section of DMOS device; (c) HEXFET structure

Heatsinks



(a) (b) (c)

Figure 8.10 Two packaging schemes: (a) and (b) for power transistors and (c) typical heat sink

Max. Temp. Transistor (Silicium)

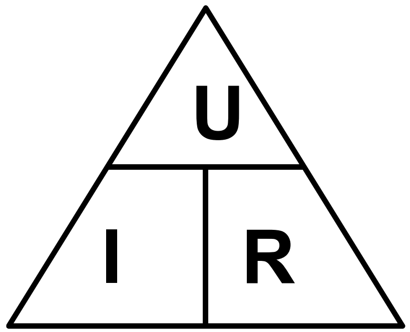
- 150 ^{0}C – 200 ^{0}C

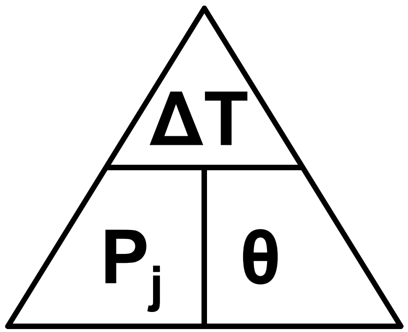
Heatsink needed!

- What heatsink?
- **Θ** [^{0}C/W]: smaller = larger heatsink

Thermodynamics Law:

- Comparable to Ohm's law
- **ΔT**: Temperaturedifference [^{0}C]
- **Pj**: Power dissipation [W]
- **Θ**: Thermal Resistance [^{0}C/W]





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Heatsink calculation

Example:

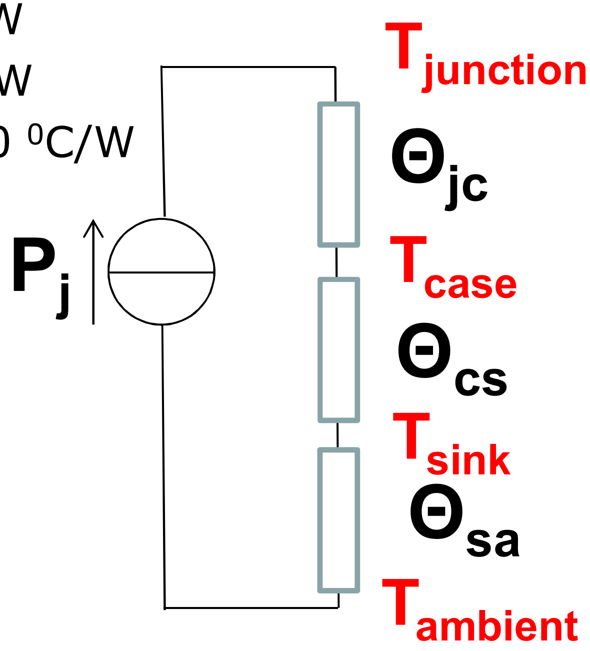
- Transistor Power Rating: 2 W
- Thermal Resistance Junction -> Case: 5 ^{0}C/W
- Thermal Resistance Case -> Heatsink: 2 ^{0}C/W
- Thermal Resistance Heatsink -> Ambient: 10 ^{0}C/W

Hoe groot zijn de temperaturen?

- What heatsink?
- $\mathbf{T}_a$ = 25 ^{0}C (omgevingstemperatuur)

Thermodynamica wet:

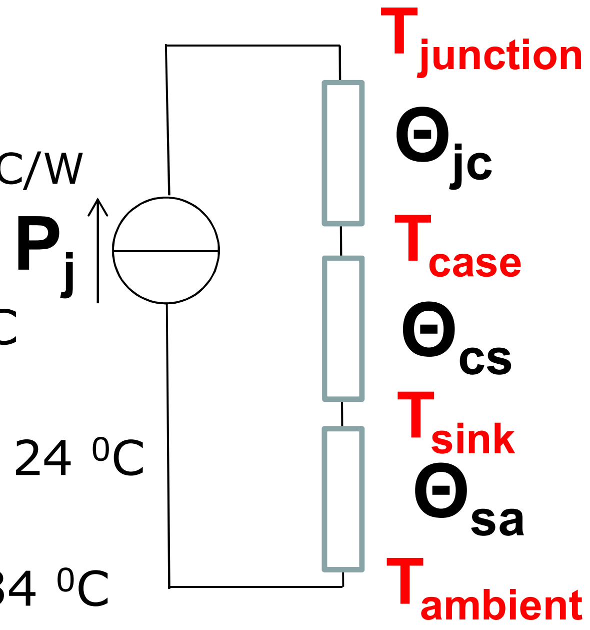
- Vergelijkbaar met wet van Ohm
- **ΔT**: Temperatuurverschil [^{0}C]
- $\mathbf{P_j}$: Power dissipation [W]
- **Θ**: Thermal Resistance [^{0}C/W]



Heatsink calculation

Example:

- Transistor Power Rating: 2 W
- Thermal Resistance Junction -> Case: 5 $^0C/W$
- Thermal Resistance Case -> Heatsink: 2 $^0C/W$
- Thermal Resistance Heatsink -> Ambient: 10 $^0C/W$



Solution:

$\Delta T_{sink,ambient} = T_{sink} - T_{ambient} = 2 \times 10 = 20\ ^0C$

$T_{ambient} = 25\ ^0C \Rightarrow T_{sink} = 45\ ^0C$

$\Delta T_{case,ambient} = T_{case} - T_{ambient} = 2 \times (10+2) = 24\ ^0C$

$T_{ambient} = 25\ ^0C \Rightarrow T_{case} = 49\ ^0C$

$\Delta T_{junction,ambient} = T_j - T_a = 2 \times (10+2+5) = 34\ ^0C$

$T_{ambient} = 25\ ^0C \Rightarrow T_{junction} = 59\ ^0C$

Heatsink calculation

Example MJ15003 power transistor

- Power Transistor: P = 25 W ; Θ_{jc} = 0.7 ^{0}C/W
- Assume Θ_{ca} = 5 ^{0}C/W
- Ambient Temperature T_a = 50 ^{0}C
- Max. Junction Temperature: 150 ^{0}C
- Bepaal Junction-temperatuur zonder heatsink
- Welke heatsink is nodig?
  - Mica-washer: Θ = 0.5 ^{0}C/W

Oplossing:

- $\Delta T_{ja} = T_j - T_a$ = 25 x (0.7+5) = 142.5 ^{0}C
  - T_a = 50 ^{0}C => T_s = 192.5 ^{0}C (zonder heatsink)

- $\Delta T_{ja} = T_j - T_a$ = 25 x (0.7+0.5+ Θ_H)
  - 150 - 50 = 30 + 25. Θ_H
  - Θ_H = 70/25 = 2.8 ^{0}C/W (gewenste heatsink grootte)

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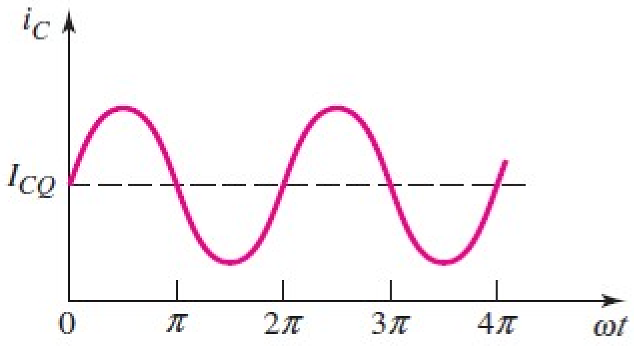
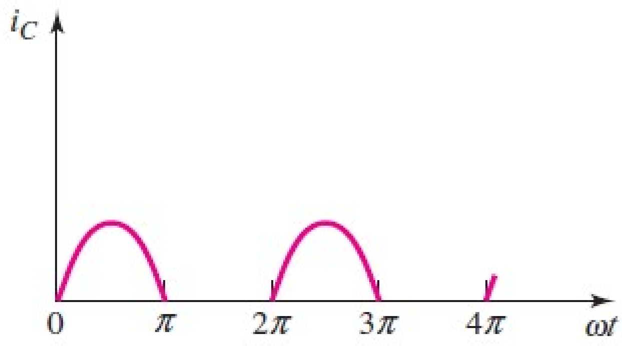
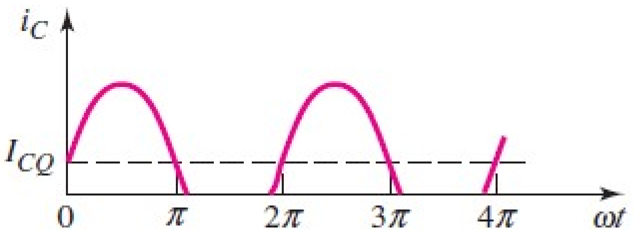
Classes of Amplifiers



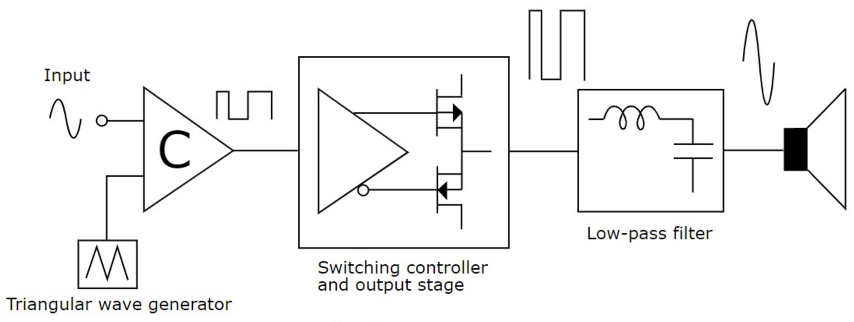
(a)



(b)



(c)



(a) Class A

(b) Class B

(c) Class AB

(d) Class D

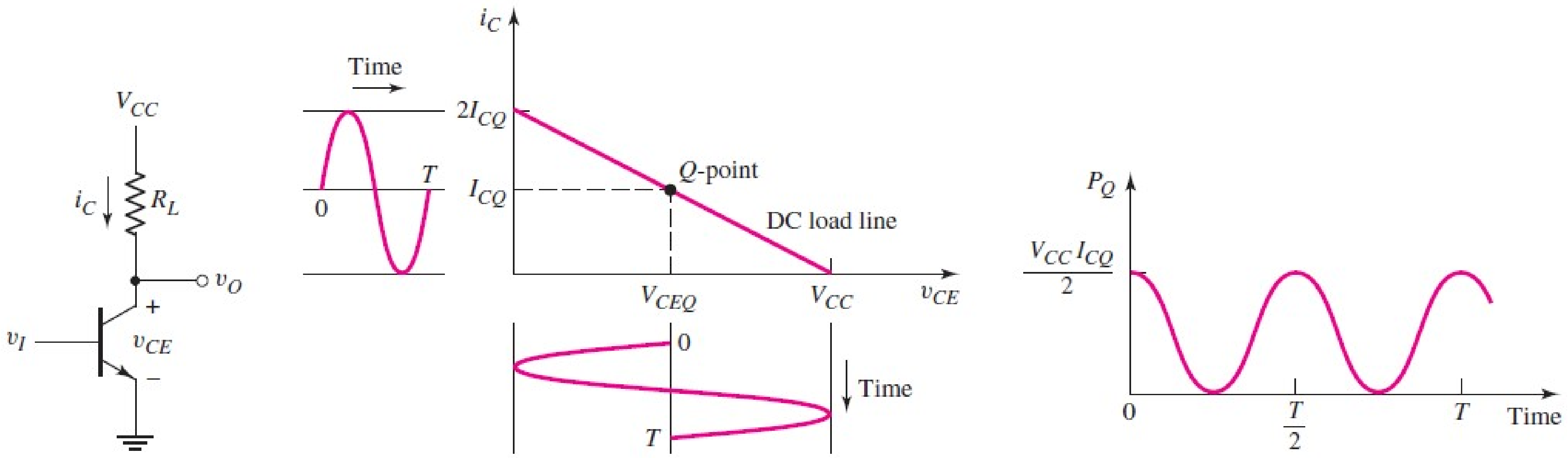
Class A amplifier

Advantage:

- Lowest distortion => high-quality amplifier

Disadvantage:

- Always on => low-efficiency (10-15 % max.)
- Large heatsinks



(a) (b) (c)

Class B amplifier

- Class B not a practical amplifer
  - Because of BJT imperfections
  - Crossover distortion as a result

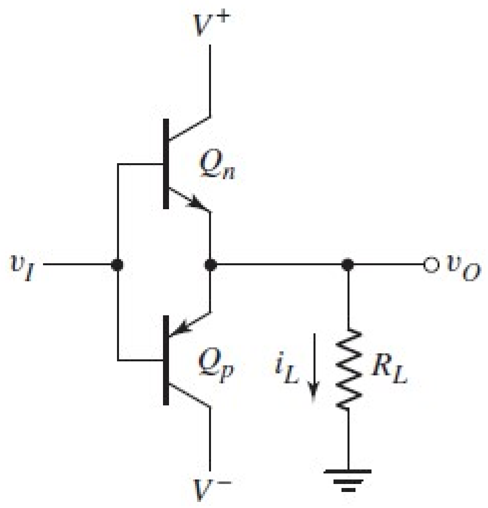


Figure 8.19 Basic complementary push–pull output stage

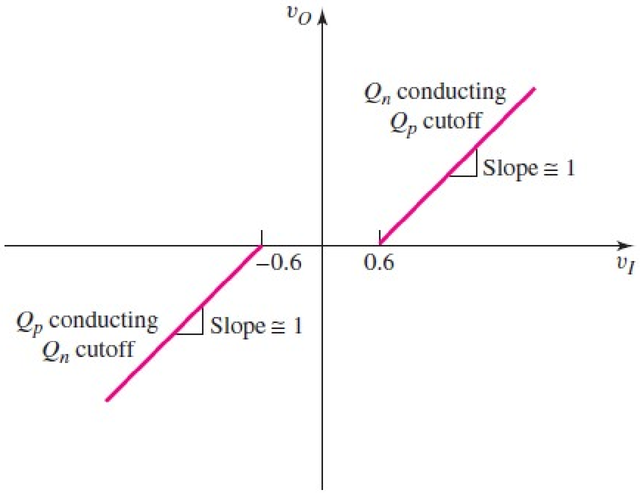


Figure 8.20 Voltage transfer characteristics of basic complementary push–pull output stage

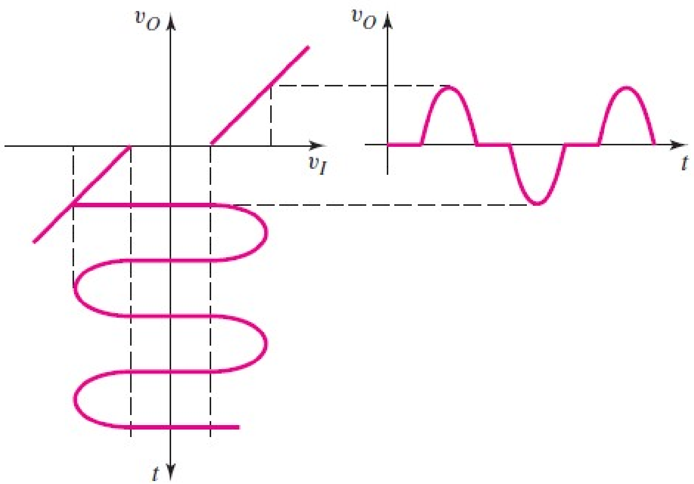


Figure 8.21 Crossover distortion of basic complementary push–pull output stage

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Class AB amplifier

Difference with Class B:

- Small bias current set
- Most practical amplifiers use this
- V_{be} multiplier (bias voltage) needed

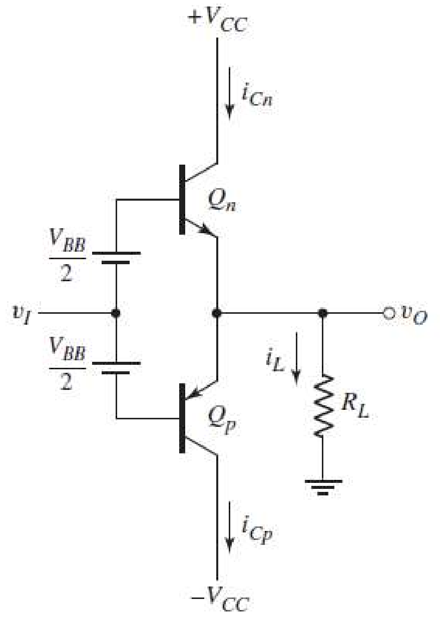


Figure 8.24 Bipolar class-AB output stage

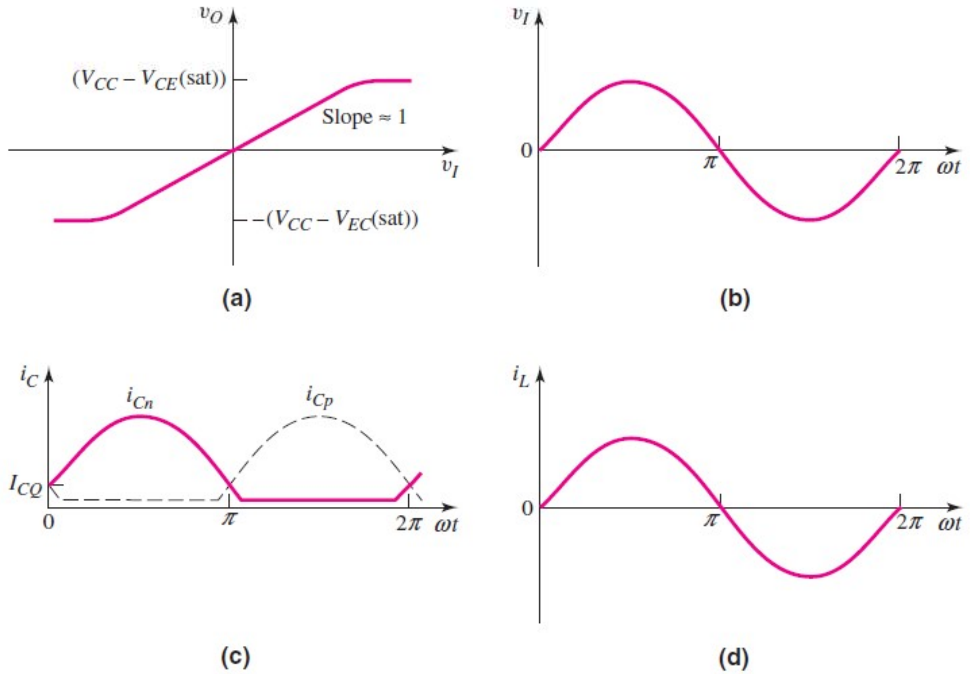


Figure 8.25 Characteristics of a class-AB output stage: (a) voltage transfer curve, (b) sinusoidal input signal, (c) collector currents, and (d) output current

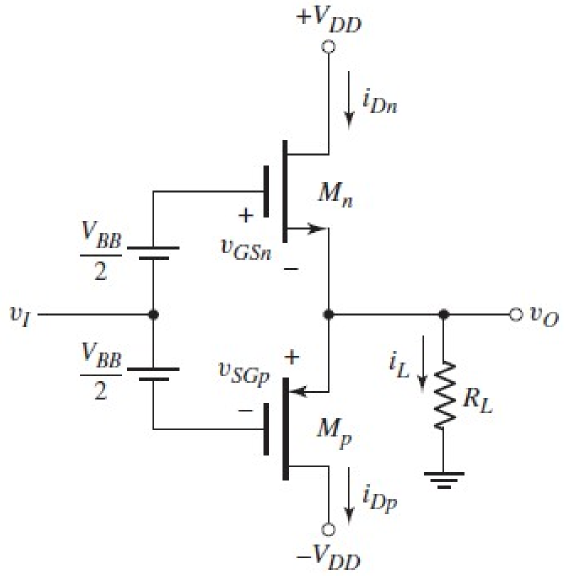
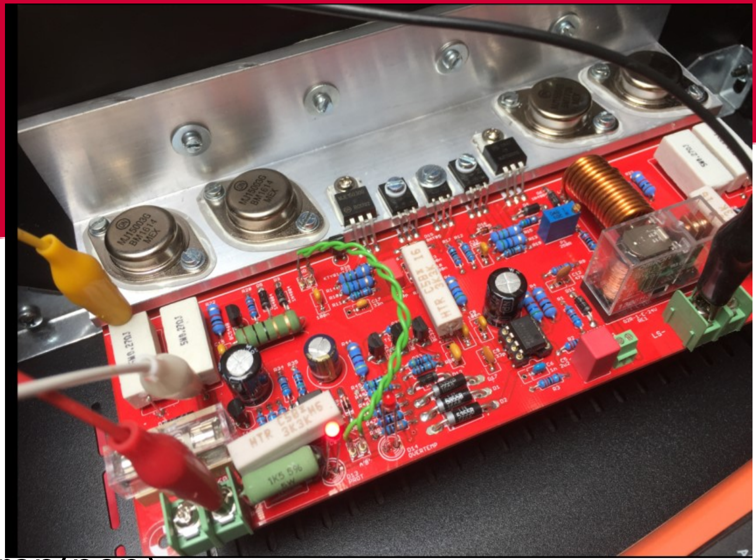


Figure 8.26 MOSFET class-AB output stage

Class AB amplifier



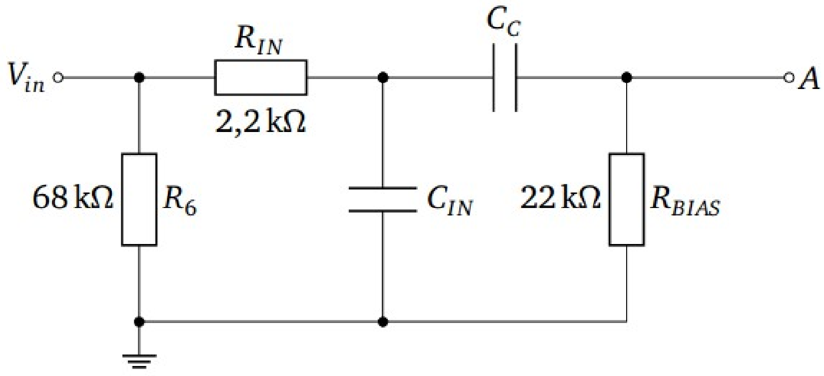
Typical Components:

- **Input-Filter**: 1ᵉ orde RC-filters
- **Input Stage** (IPS): verschilversterker met stroombron(nen)
- **Voltage Amplifier Stage** (VAS): common-emitter versterker
- **Vbe-multiplier**: instellen spanningsverschil / ruststroom
- **Output Stage** (OPS): NPN / PNP eindtransistoren
- **Negative feedback** (NFB): terugkoppeling naar IPS, bepaalt A_v
- **Output-Filters**: RC (Zobel) en RL netwerk

Beveiligingen:

- Kortsluitbeveiliging eindtransistoren
- Temperatuur beveiliging
- DC-offset beveiliging
- Over- en onderspanning voedingsspanning

Input Filter

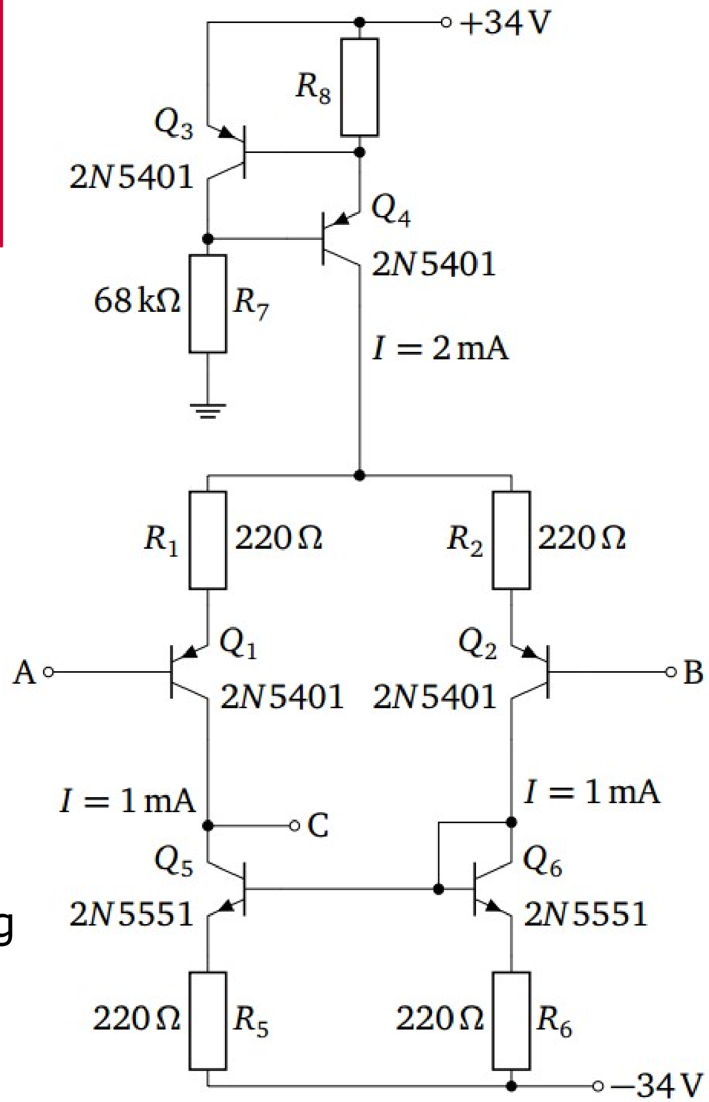


Schakeling 2: Input-netwerk

- Eerste orde LPF
  - f_c = 70 kHz of hoger
- Eerste orde HPF
  - f_c = 4 Hz of lager
- R_6: voorkomt radio-storingen
- R_{bias}: zorgt voor retourstroom van IPS
- Opdracht: bereken C_c en C_{in} en simuleer in LT-Spice

Input Stage (IPS)

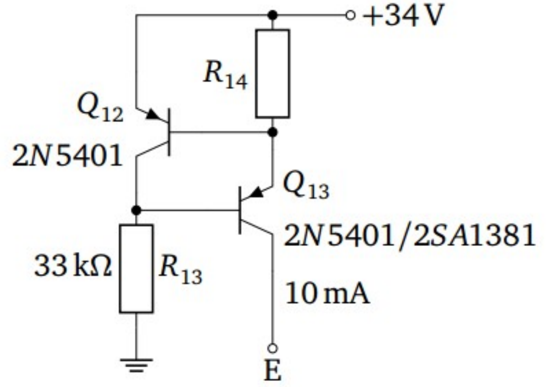
- Drie onderdelen
  - Stroombron
  - Verschilversterker
  - Active-Load (current-mirror)
- Stroombron
  - Lab AB.2 en Lab AB.3 kennisclip voor details!
- Verschilversterker
  - Lab AB.4 kennisclip voor details!
  - Single-ended spanningsversterking zo hoog mogelijk!
  - Daarom R_c zo groot mogelijk
  - Active-load i.p.v. R_c is enorme verbetering
- Active-Load
  - Uitgangsimpedantie wordt bepaald door r_o
  - $r_0 = V_A / I_c$ met V_A = Early-Voltage



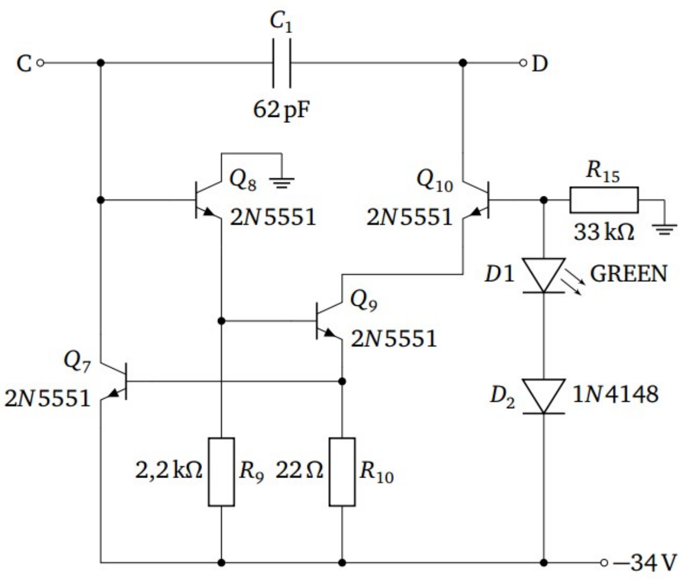
Schakeling 3: Schema van de Input-Stage (IPS)

Voltage Amplifier Stage (VAS)

- Drie onderdelen
  - Stroombron
  - Common-emitter schakeling
  - V_{be} multiplier
- Stroombron
  - Lab AB.2 en Lab AB.3 kennisclip voor details!
  - In LT-Spice:
    - koppel spanningsbron aan punt E
    - Stel 2 spanningen in, bijv. +10 V en -25 V
    - Bepaal de geleverde stromen
    - $R_{out} = \Delta V / \Delta I$
- Common-Emitter versterker
  - $Q_8 + Q_9$: de CE-transistor (Darlington)
  - Q_{10}: cascodeschakeling (common-base)
  - Q_7: stroombeveiliging voor Q_9
  - Bepaal spanningsversterking m.b.v. $R_c = R_{out}$



Schakeling 6: Schema van de VAS: Stroombron deelschakeling



Schakeling 4: Schema van de VAS: common-emitter deelschakeling

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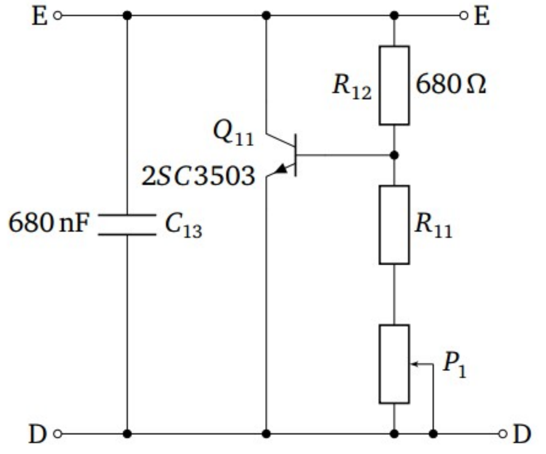
Voltage Amplifier Stage (VAS): V_{be}-Multiplier

- Vbe Multiplier
  - Lab AB.6 en AB.7 kennisclip voor details
  - Instellen van aantal V_{be} overgangen
  - Bepaalt de ruststroom van de eindtransistoren
  - Instellen tussen 3.0 x V_{be} en 5.5 x V_{be}
  - $V_{DE} = V_{be} * (1 + R_{12}/(R_{11}+P_1)$
  - Draai P_1 naar kleinste spanning!
    - Bij inbedrijfstellen.



Schakeling 5: Schema van de VAS: V_{BE}-multiplier deelschakeling

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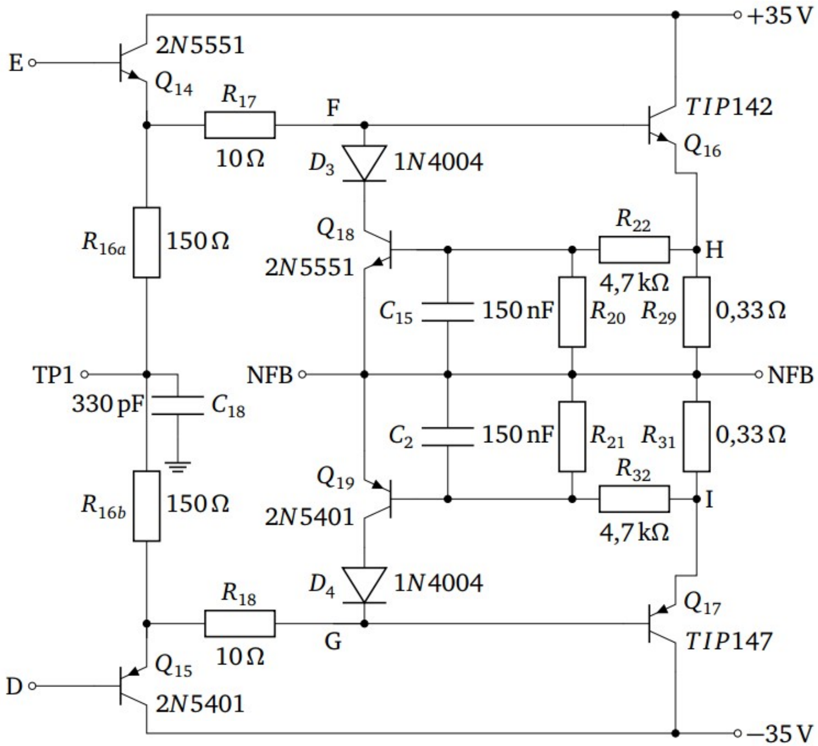
Output Stage (OPS)

- Klasse AB eindtrap
  - Kennisclip AB-5 voor details
- Wat is wat?
  - Q_{14} en Q_{15}: pre-drivers
    - Welke stroom loopt hier door?
    - Waar wordt die door bepaald?
  - Kortsluitbeveiliging voor Q_{16}
    - D_3, Q_{18}, C_{15}, R_{20}, R_{22}
  - Kortsluitbeveiliging voor Q_{17}
    - D_4, Q_{19}, C_2, R_{21}, R_{32}
  - R_{29} en R_{31}: stabilisatieweerstanden
  - Spanningsmeting over punten H en I
  - NFB punt: naar IPS en naar luidspreker



Schakeling 7: Output-stage

Negatieve Feedback (NFB)

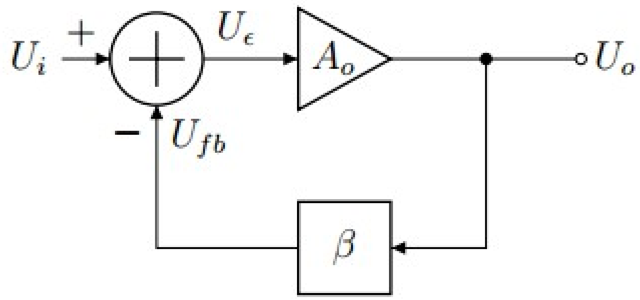
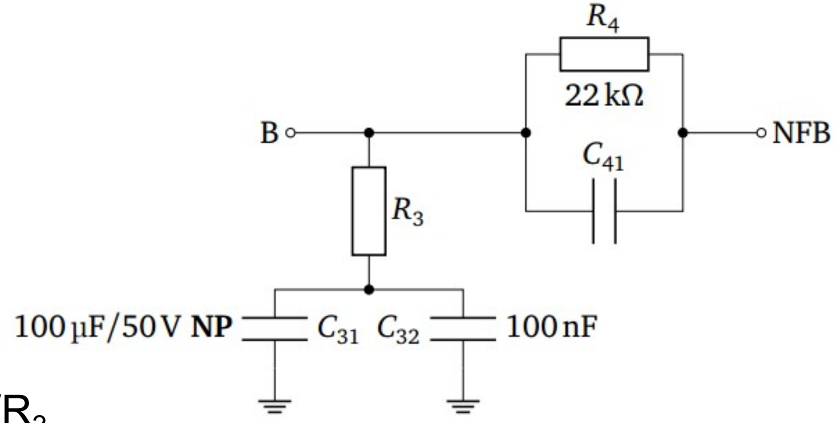


Figure 1.1: An amplifier with negative feedback

- Negatieve feedback
  - Closed-loop gain: $\boxed{A_f = \dfrac{U_o}{U_i} = \dfrac{A_o}{1+\beta \cdot A_o}}$
  - Open-loop gain A_0 zo groot mogelijk

$$A_f = \lim_{A_o \to \infty} \frac{A_o}{1+\beta \cdot A_o} = \lim_{x \to \infty} \frac{1}{\frac{1}{A_o}+\beta} \approx \frac{1}{\beta}$$



Schakeling 9: Negative-feedback

  - In schakeling 9: $\beta = R_3 / (R_3 + R_4)$
  - Closed-loop gain wordt dan $1/\beta = 1 + R_4/R_3$
  - C_{31}/C_{32}: voor DC/lage frequenties wordt $\beta = 1$
    - Vormt met R_3 een RC paar, bereken kantelfrequentie
  - C_{41}: voor hoge frequenties wordt $\beta = 1$
    - R_4 en C_{41} vormen RC paar
    - Kantelfrequentie op ongeveer 150 kHz

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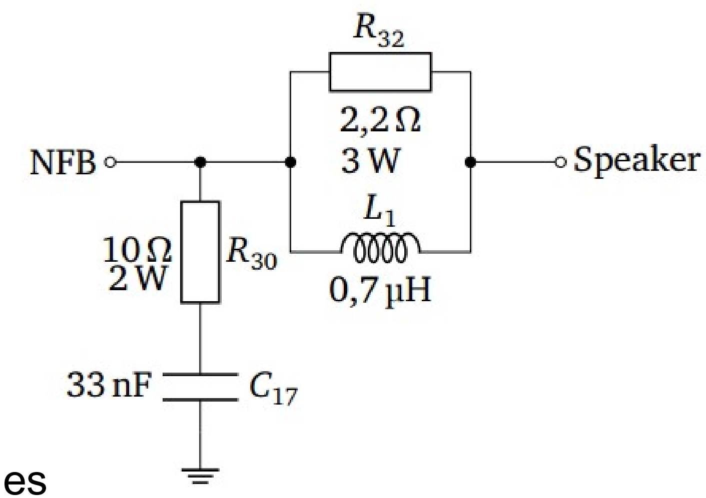
Output filters

- Zobel netwerk
  - R_{30} en C_{17}
  - Ook wel Boucherot cell genoemd
  - Zorgt voor voldoende belasting bij hoge frequenties
    - Luidspreker is in feite een spoel
- Spoel L_1 en weerstand R_{32}
  - Voorkomt problemen bij capacitieve belastingen
  - R_{32} mag geen draadgewonden type zijn, bij voorkeur Metal-Oxide-Film
  - L_1 zelf wikkelen: ongeveer 15 wikkelingen
  - Monteer L_1 over R_{32} en zorg voor aansluiting op print



Schakeling 8: Output-stage

Class AB amplifiers