Modeling heat transfer

Heat dissipation $P_D$

- $T_J$: Junction temperature
- $T_C$: Case temperature
- $T_S$: Heat-sink temperature
- $T_A$: Ambient temperature

$\theta_{JC}$, $\theta_{CS}$, $\theta_{SA}$
Modeling heat transfer

Heat dissipation $P_D$

$\theta_{JC}$ Junction-case thermal R

$\theta_{CS}$ Case-heatsink thermal R

$\theta_{SA}$ Heatsink-ambient thermal R

$T_J$, $T_C$, $T_S$, $T_A$
Modeling heat transfer

Heat dissipation $P_D$:

- Junction-case thermal $R_{JC}$: Function of transistor/case design
- Case-heatsink thermal $R_{CS}$: Function of bonding transistor to heatsink
- Heatsink-ambient thermal $R_{SA}$: Function of heatsink cooling, e.g., conduction, convection, radiation, etc.
Multistage amplifiers - rationale

High input Z for minimal loading

(differential input for noise immunity)

High gain (in multiple stages)

High power output

Low output Z for minimal impact from load
Increasing output power

- High power output stage
- Higher operating voltage
- or
- Higher collector current
Increasing output power

High power output stage

Higher operating voltage

or

Higher collector current

Limitation of \( V_{cc} \)

Breakdown voltage

Output impedance may be small
Increasing output power

- High power output stage
- Higher operating voltage
  - or
  - Higher collector current
  - or
  - Darlington configuration for increased $\beta$
    - Limitation of $V_{CC}$
    - Breakdown voltage
    - Output impedance may be small
NPN Darlington Pair

\[ \beta \approx \beta_1 \beta_2 \]
PNP Darlington Pair

\[ i_E \]

\[ i_B \]

\[ i_C \]

\[ \beta = \beta_1 \beta_2 \]
PNP Darlington Pair

NPN used because of limited PNP performance
AB Output Stage with Darlington Pair
AB Output Stage with Darlington Pair

NPN Darlington "push" stage

PNP Darlington "pull" stage

V_{BE} multiplier

V_{CC}

I_{BIAS}

v_I

v_O

R_L
What if the $v_O$ is shorted?
What if the $v_O$ is shorted?
AB amplifier with short circuit protection
Thermal overload protection
Thermal overload protection

Diagram:
- \( +V_{cc} \)
- \( -V_{cc} \)
- Transistor \( Q_1 \)
- Resistor \( R_1 \)
- Zener diode \( Z_1 \)
- Transistor \( Q_2 \)
- Resistor \( R_2 \)

Output transistor

Normally biased off
Thermal overload protection

Thermal coupling
Thermal overload protection

Operation shifts with changing temperature
Thermal overload protection

Turns on, stealing $Q_1$ bias current, shutting off $Q_1$
Normal MOSFET
Normal MOSFET

Thermal conduction path
Power MOSFET
Power MOSFET

Source

Gate

SiO₂

Substrate

Current flow

Drain

Thermal conduction path
AB amplifier with power MOSFETs and BJT drivers
AB amplifier with power MOSFETs and BJT drivers

$V_{BE}$ multiplier

Thermal coupling
AB amplifier with power MOSFETs and BJT drivers

Push-pull darlington pairs
AB amplifier with power MOSFETs and BJT drivers

CMOS power MOSFET output

Thermal coupling
AB amplifier with power MOSFETs and BJT drivers
AB amplifier with power MOSFETs and BJT drivers

Parasitic oscillation suppression

Thermal coupling
AB amplifier with power MOSFETs and BJT drivers