The Class AB Amplifier

Circuit Based on Motorola Application Note AN-422

explained on a conceptual level

Elaborated By Andreas Chr. Dyhrberg Dec. 2025

Thanks to Clyde S.
(https://www.linkedin.com/in/clyde-s-62b4991/)
for sharing the original schematic with me.

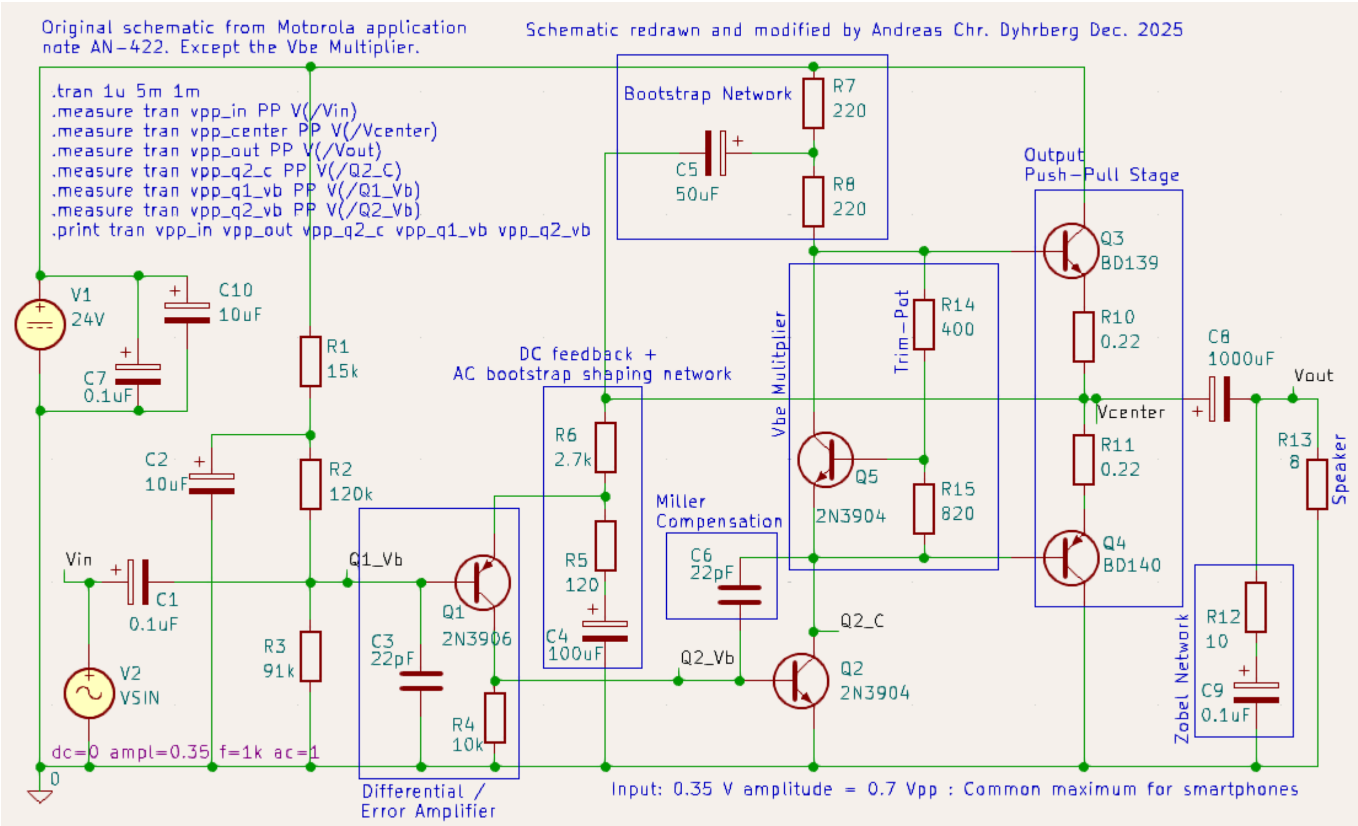
Also thanks to

Eric Habets
(https://www.linkedin.com/in/eric-habets-eupen/)

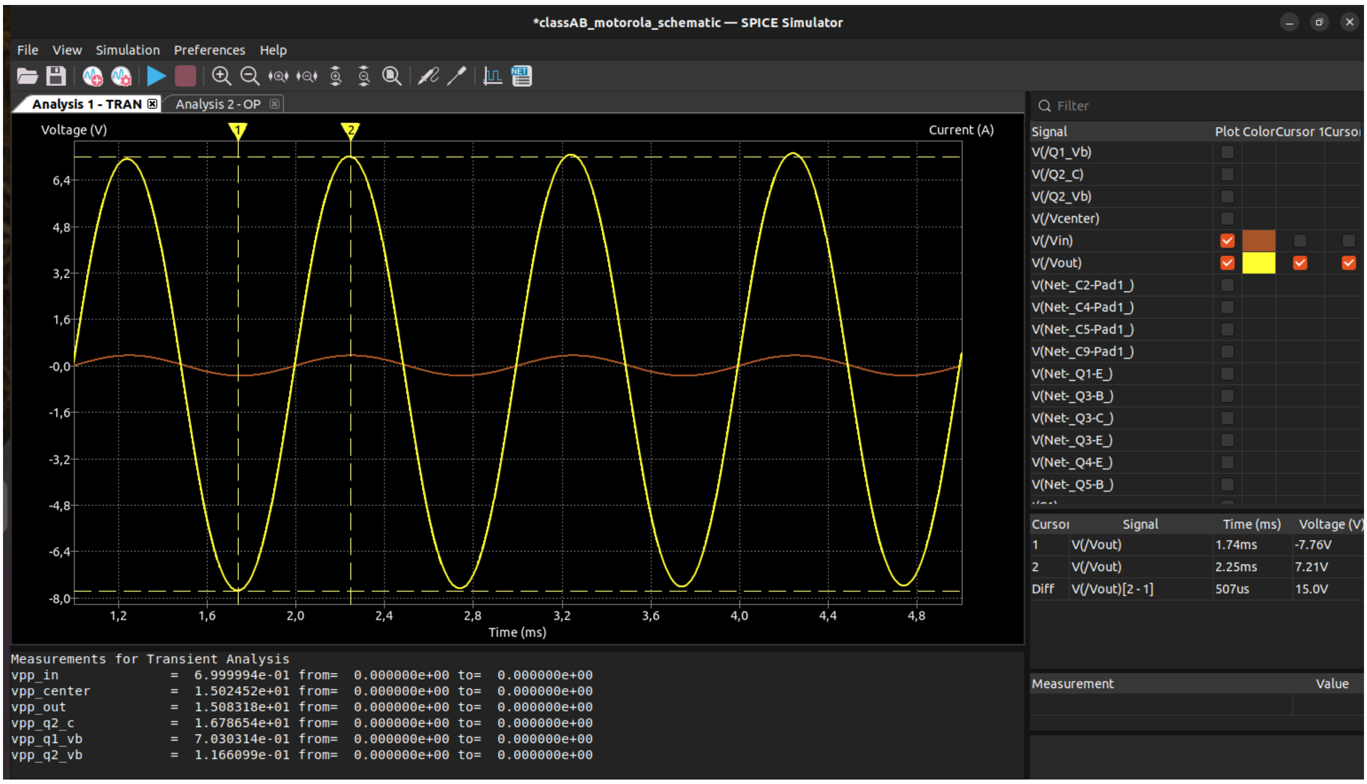
for various explanations.

This is only simulated so far.
No builds and real tests done yet.

0. Schematic



See the last pages for a DC simulation schematic.



1. Input coupling & bias reference

Components

- C1 (0.1 μF) - input coupling - alternatively try out 10 uF
- R1 (15 kΩ)
- R2 (120 kΩ)
- R3 (91 kΩ)

What this part does

- C1 blocks DC from the signal source
- R1, R2, R3 form the **DC reference** for the input stage
- They define:
  - Input impedance
  - DC operating point

Why it's needed

- Prevents DC offsets from the source
- Ensures the amplifier biases correctly even with no input

Concepts involved

- AC coupling
- DC biasing

2. A. Input differential / error amplifier (single-ended)

Components

- Q1 – 2N3906 (PNP)
- R4 – 10 kΩ
- C3 – 22 pF

What this part does

- `Q1` compares:
  - Input signal (via `C1`)
  - Feedback signal (via `R5/R6`)
- Converts the **error voltage** into a current
- `R4` is the collector load → voltage gain

Why it's needed

- This is where **error correction starts**
- The amplifier amplifies *difference*, not absolute input

Concepts involved

- Error amplification
- Common-emitter voltage gain
- Signal inversion

Comment from Eric Habets in this part:

> *Q1 acts like an Op Amp. Emitter is the -IN, base the +IN and collector OUT.*
>
> *Through R6 is a DC path that maintains the output at Vcc/2 (set by R1/R2/R3), C4 blocks this DC.*
>
> *For AC, the output signal is divided by R6/R5, as in an Op Amp circuit. Thus the ratio of R6/R5 determines the AC amplification factor.*
>
> *Both DC and AC are negative feedback.*
>
> *For the negative half wave Q2 provides enough drive, no bootstrap trick necessary.*

2. B. The R5 – R6 – C4 network

Components

- `R5` – 120 Ω
- `R6` – 2.7 kΩ
- `C4` – 100 µF

Connected between:

- The **VAS / bootstrap node**
- The **output node**

What this block actually is

This is a **slow DC feedback + AC bootstrap shaping network**. - It performs **three roles at once**, which is why it's easy to miss.

1. DC feedback path (low-frequency / DC stabilisation)

At **DC**:

- C4 is open
- The feedback path is mainly through **R6 (2.7 kΩ)**

Effect

- Provides a **DC return path** from output to the VAS bias point
- Stabilises the **output DC offset**
- Prevents long-term drift due to transistor Vbe mismatch

Without this path:

- The output offset would wander
- Thermal drift would accumulate

Concept

- *DC servo without an op-amp*
- Very typical in older single-supply and quasi-complementary designs

2. AC bootstrap enhancement (midband & low-frequency gain)

At **audio frequencies**:

- C4 has low impedance
- The output signal is coupled into the VAS load via **R5**

Effect

- Increases effective VAS load impedance
- Improves voltage swing
- Reduces low-frequency distortion

This works **together with C5/R7/R8**, but it is **frequency-shaped**, not full-range.

Concept

- Frequency-selective bootstrapping
- Prevents over-bootstrapping at very low frequencies

3. Controlled LF roll-off of the bootstrap loop

The **R5–R6–C4 time constant** sets:

- How much of the **output signal is fed back into the VAS**
- At which frequency the bootstrap “lets go”

This prevents:

- Motorboating
- Low-frequency instability
- Excessive LF phase shift inside the global feedback loop

In other words

> This network deliberately *weakens* bootstrapping at very low frequencies while keeping it effective in the audio band.

3. Dominant pole / Miller compensation

What C6 is

Components

- `C6` – 22 pF (collector → base of Q2)

What this part does

- Introduces a **dominant pole**
- Forces open-loop gain to roll off early
- Ensures global feedback remains stable

Why it’s needed

Without this:

- The amplifier will oscillate
- Especially with real speakers (inductive + capacitive loads)

Concepts involved

- Miller compensation
- Phase margin control
- Stability engineering

What C3 is

C3 is a **base-to-ground shunt capacitor** on the **input/error amplifier transistor**.

Its function is:

1. Input-stage dominant pole (HF roll-off)

- It forms an **RC low-pass filter** with:
  - The source impedance
  - The feedback network impedance seen at Q1’s base
- This limits the **closed-loop bandwidth** early

This is sometimes called:

- *Input pole compensation*
- *Shunt compensation*
- *Lag compensation*

Why this stabilises the global feedback loop

Although C3 is not Miller-multiplied:

- Q1 is the **first high-gain node**
- Limiting bandwidth *here*:
  - Reduces loop gain at HF
  - Improves phase margin
  - Prevents oscillation caused by later stages

This is a **perfectly valid dominant-pole strategy**, just a different one.

Why designers sometimes prefer this over Miller caps

Advantages:

- Simple
- Predictable
- Less interaction with large-signal swing
- No charge storage during clipping

Disadvantages:

- Requires higher capacitance than Miller
- Adds input-referred noise filtering
- Bandwidth depends on source impedance

Motorola used this a lot when:

- The input stage had **plenty of gain**
- They wanted **robust real-world stability**

4. Voltage Amplifier Stage (VAS)

Components

- Q2 – 2N3904 (including the $\mathbf{r_e}$ inside, substituting the R_E in other, primitive circuits)
- R7 + R8 – 440 Ω

What this part does

- Takes the small-signal output of Q1
- Produces **large voltage swing**
- Drives the driver/output stage bases

Why it's needed

- Output transistors need **volts**, not just millivolts
- This stage provides almost all open-loop voltage gain

Concepts involved

- VAS
- High-voltage swing amplification
- Gain staging

5. Bootstrap network

Components

- C5 – 50 µF
- R7 – 220 Ω (2 W)
- R8 – 220 Ω (2 W)

What this part does

- Bootstraps the VAS load
- Makes the effective load impedance appear much higher
- Allows the VAS collector voltage to "ride" with the output

Why it's needed

- Increases voltage swing
- Reduces distortion at high output levels
- Avoids early clipping

Concepts involved

- Bootstrapping
- Dynamic load impedance
- Voltage swing enhancement

This is **textbook Motorola design philosophy**.

6. Vbe Multiplier (Bias spreader)

Components

- Q5 (part of the bias loop for Q3 and Q4)
- R13, R14, R15

What this part does

- Generates a controlled voltage drop between driver bases (Q3+Q4)
- Sets **idle current** through the output stage
- Allows trimming of crossover distortion

Why it's needed

Without it:

- Class-B crossover distortion
- Or thermal runaway if overbiased

Concepts involved

- Vbe multiplier
- Thermal bias tracking
- Class-AB operation

7. Output stage (Class-AB push-pull)

Components

- `Q4` – BD140 (PNP outputs)
- `Q3` – BD139 (NPN side)
- `R10`, `R11` – 0.22 Ω

What this part does

- Push-pull emitter followers
- Source and sink load current
- Provide low output impedance

Why it's needed

- Speakers require **current**
- Voltage gain stages cannot deliver power

Concepts involved

- Class-AB push-pull
- Emitter degeneration
- Thermal current sharing

8. Emitter resistors (local negative feedback)

Components

- `R10`, `R11` – All 0.22 Ω resistors

What this part does

- Introduces **local current feedback**
- Forces current sharing (if several of them are coupled in parallel)
- Limits thermal runaway

Why it's needed

Without these:

- Output devices will not share current (if several of them are coupled in parallel)
- One transistor may destroy itself

Concepts involved

- Local negative feedback
- Thermal stabilization (Need even with only one power transistor, not in parallel)
- Current balancing

9. Global negative feedback loop

Components

- Output node → `R5` / `R6` → input stage

What this part does

- Feeds a portion of output back to input
- Forces linear behavior
- Sets closed-loop gain

Why it's needed

- Reduces distortion by orders of magnitude
- Stabilizes DC offset
- Makes the amplifier predictable

Concepts involved

- Voltage-series negative feedback
- Gain control

- Distortion reduction

10. Output Zobel & HF stabilization

Components

- `R12` – 10 Ω
- `C9` – 100 nF

What this part does

- Provides a resistive load at high frequencies
- Prevents oscillation with inductive speakers

Why it's needed

Real speakers are **not resistors**.

Concepts involved

- Zobel (Boucherot) network
- Load stabilization

11. Supply decoupling

Components

- `C7` – 100 nF
- `C10` – 1 µF
- `C8` – 1000 µF

What this part does

- Local energy storage
- Prevents supply rail modulation
- Improves transient response

Why it's needed

Without proper decoupling:

- Feedback loop becomes unstable
- Signal leaks into supply rails

12. Recap - Big-picture functional map

Functional "part"	Why it exists
Input coupling	Block DC
Input error amp	Compare input vs output
Miller compensation	Stability
VAS	Voltage swing
Bootstrap	More swing, less distortion
Bias spreader	Class-AB operation
Driver stage	Current buffering
Output stage	Power delivery
Emitter resistors	Thermal safety
Global feedback	Linearity
Zobel network	Load stability
Supply decou pling	Noise & oscillation control

13. DC Simulation Schematic