Lecture 3

Understanding op-amp specifications

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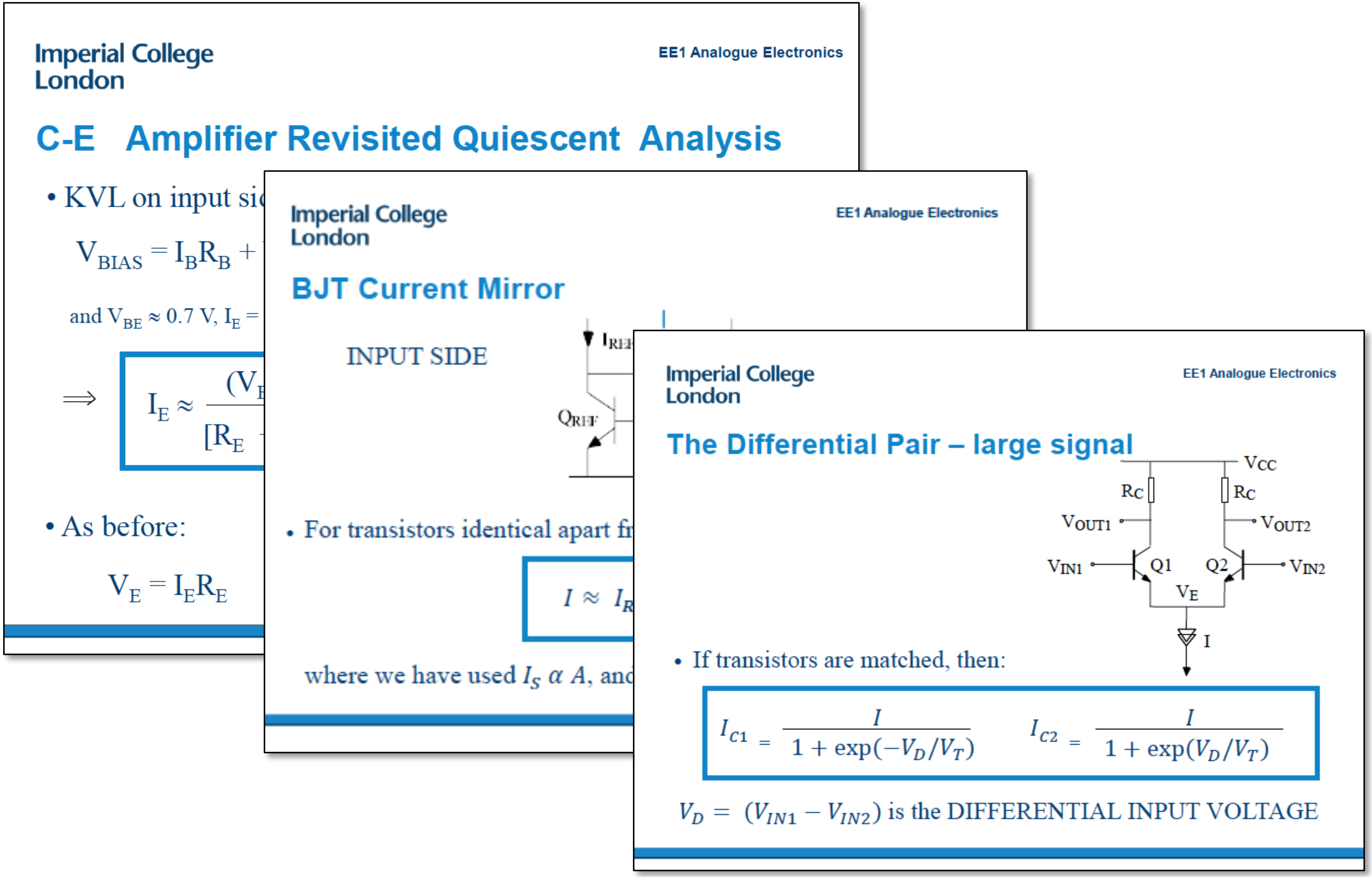
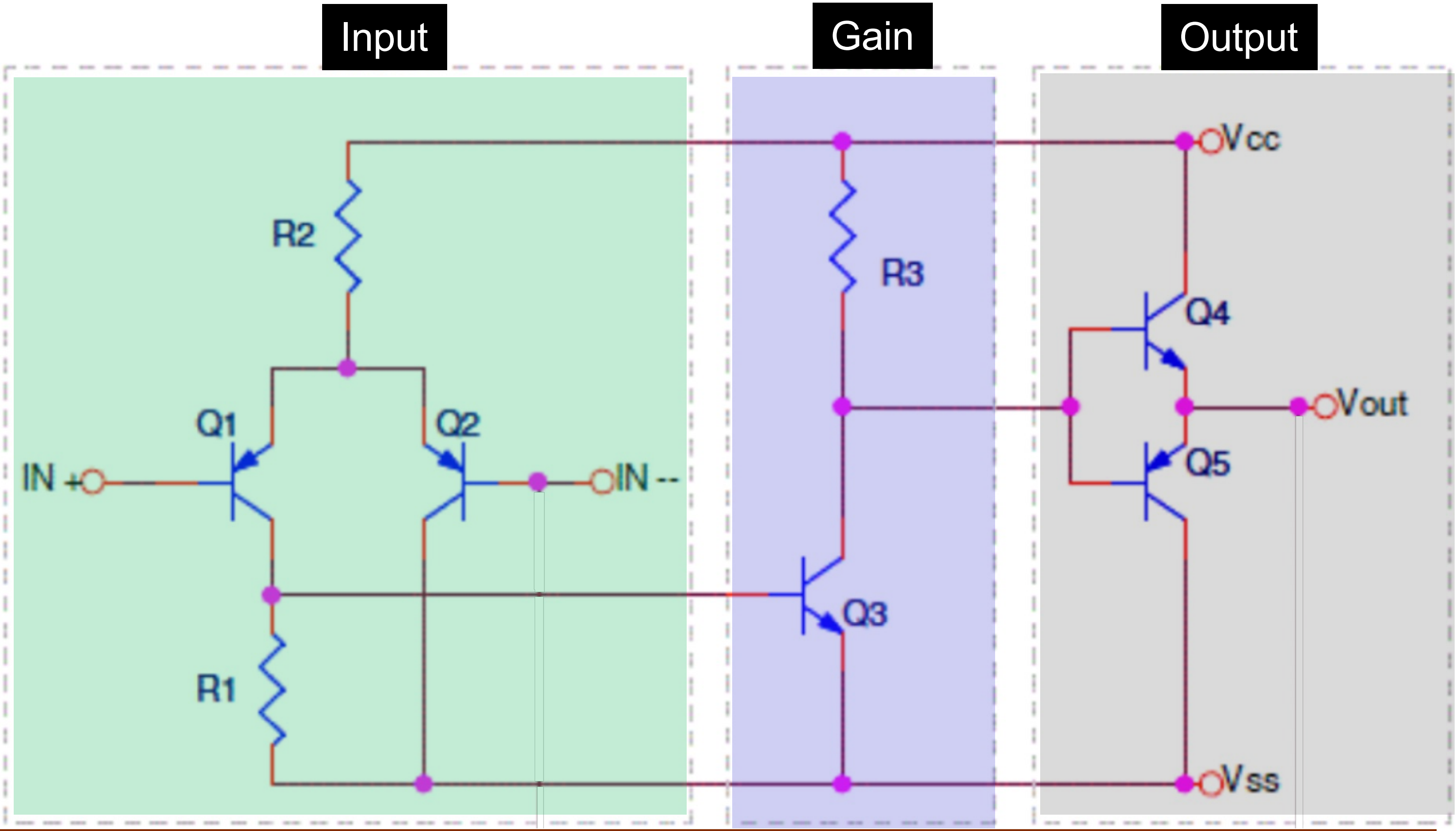
What you should know already?



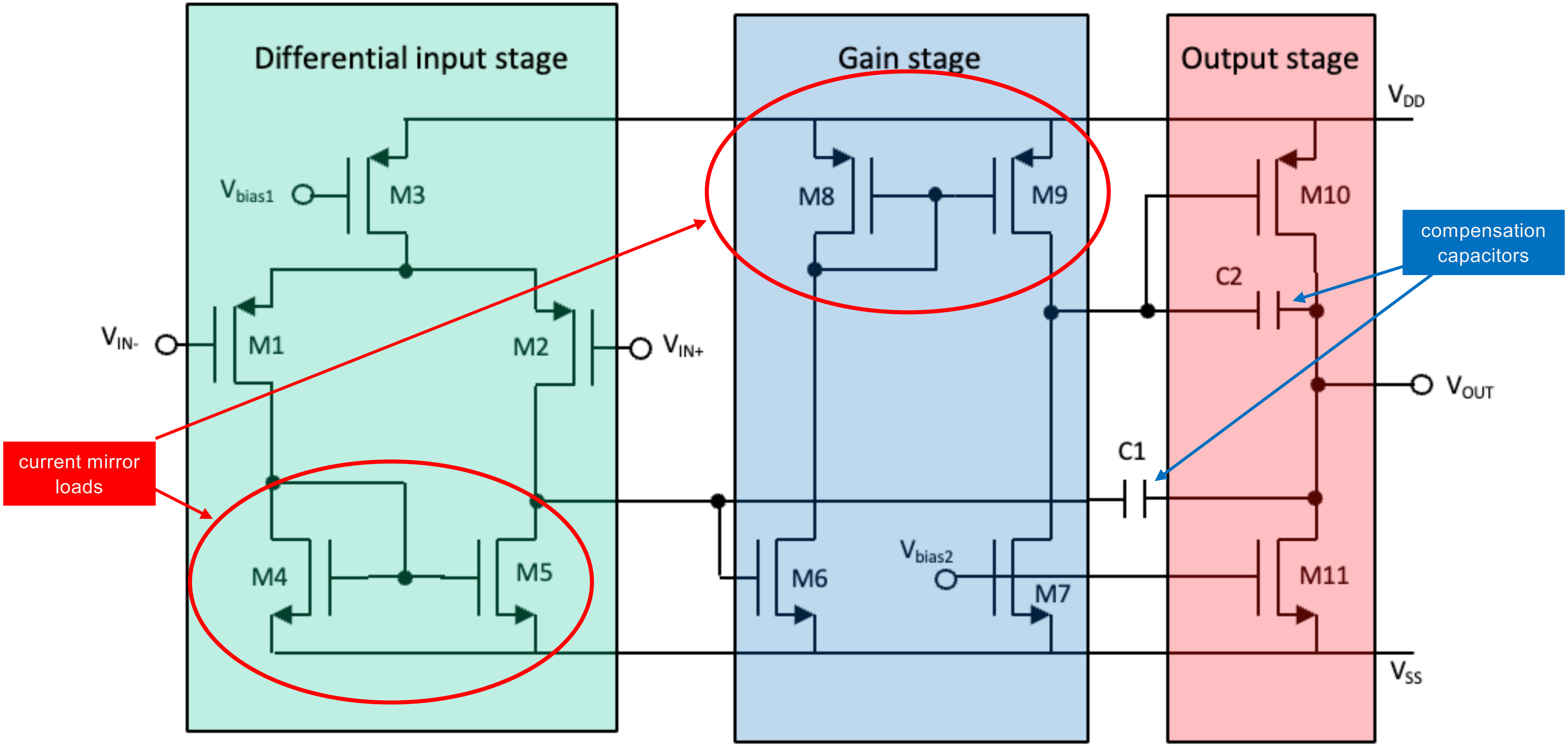
Inside a typical BJT op-amp

- Three stages architecture:
  1. **Differential input stage** – long-tail pair (Yr 1 Circuits part 2, adc_9, slides 8-14)
  2. **Voltage gain stage** – common emitter amp (adc_6, slides 3-7)
  3. **Output drive stage** – push-pull circuit



Inside a typical MOSFET op-amp

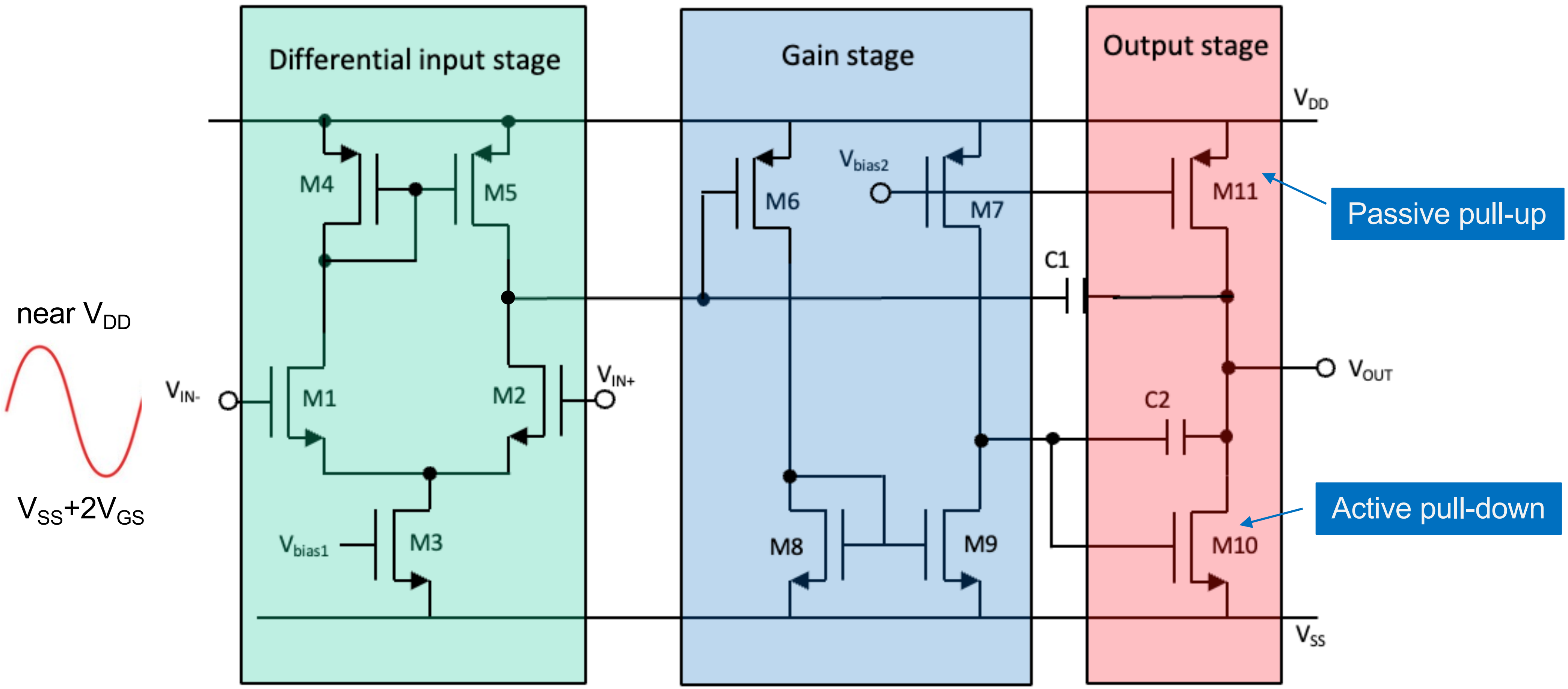
- Early MOSFET op-amp follows similar architecture to the BJT version.



n-type input MOSFETs but not rail-to-rail

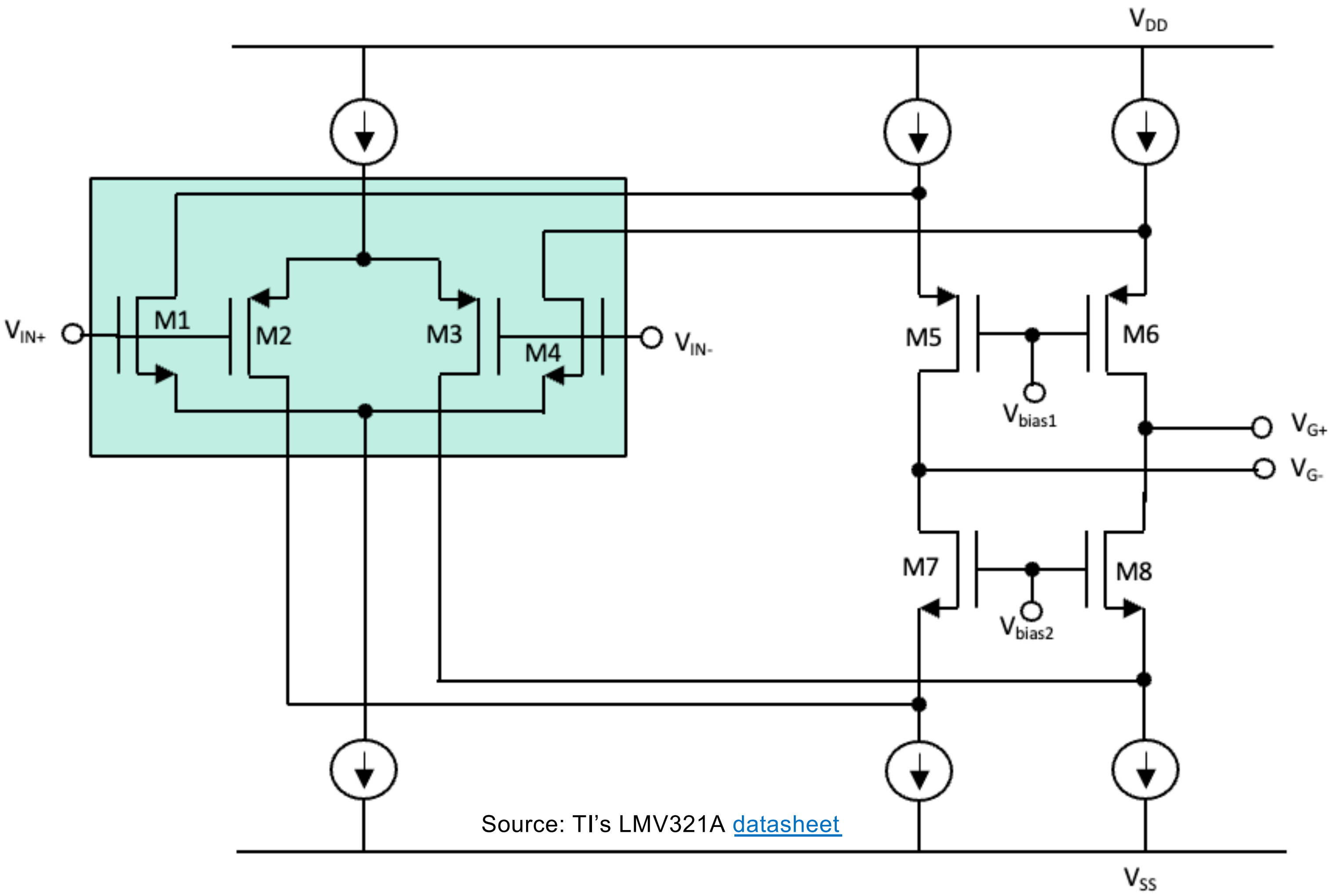
- Similar op-amp is obtained by:
  - Flip circuit up-side-down.
  - Replace all n-type with p-type and vice versa.

- Not rail-to-rail input or output.
- Asymmetrical output drive.
- Bad for low-voltage, single supply.



Complementary differential input

- Use complementary differential input to solve input rail-to-rail issue.



Source: TI's LMV321A datasheet

Common-Mode Input Range	V_{CMR}	$V_{SS} - 0.3$	—	$V_{DD} + 0.3$	V

Source: MCP6001 datasheet

Op-amp Input Specifications

❖ These are the input specifications for the MCP6001 op-amp.

Input Offset						
Input Offset Voltage	V_{OS}	-4.5	—	+4.5	mV	$V_{CM} = V_{SS}$ **(Note 1)**
Input Offset Drift with Temperature	$\Delta V_{OS}/\Delta T_A$	—	±2.0	—	µV/°C	T_A= -40°C to +125°C, $V_{CM} = V_{SS}$
Power Supply Rejection Ratio	PSRR	—	86	—	dB	$V_{CM} = V_{SS}$

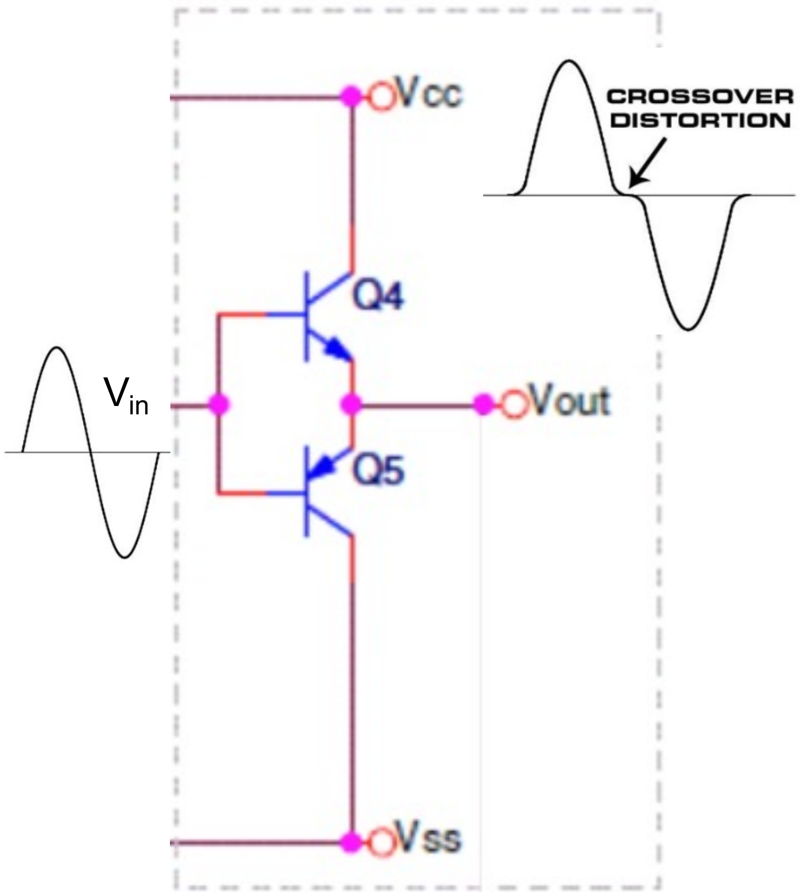
Input Bias Current and Impedance						
Input Bias Current:	I_B	—	±1.0	—	pA	
Industrial Temperature	I_B	—	19	—	pA	T_A = +85°C
Input Offset Current	I_{OS}	—	±1.0	—	pA	
Common-Mode Input Impedance	Z_{CM}	—	$10^{13}\|\|6$	—	Ω||pF	
Differential Input Impedance	Z_{DIFF}	—	$10^{13}\|\|3$	—	Ω||pF	

Common-Mode						
Common-Mode Input Range	V_{CMR}	V_{SS} – 0.3	—	V_{DD} + 0.3	V	
Common-Mode Rejection Ratio	CMRR	60	76	—	dB	V_{CM} = -0.3V to 5.3V, V_{DD} = 5V

Highlighted entries are implemented in the MCP6001 LTSpice model.

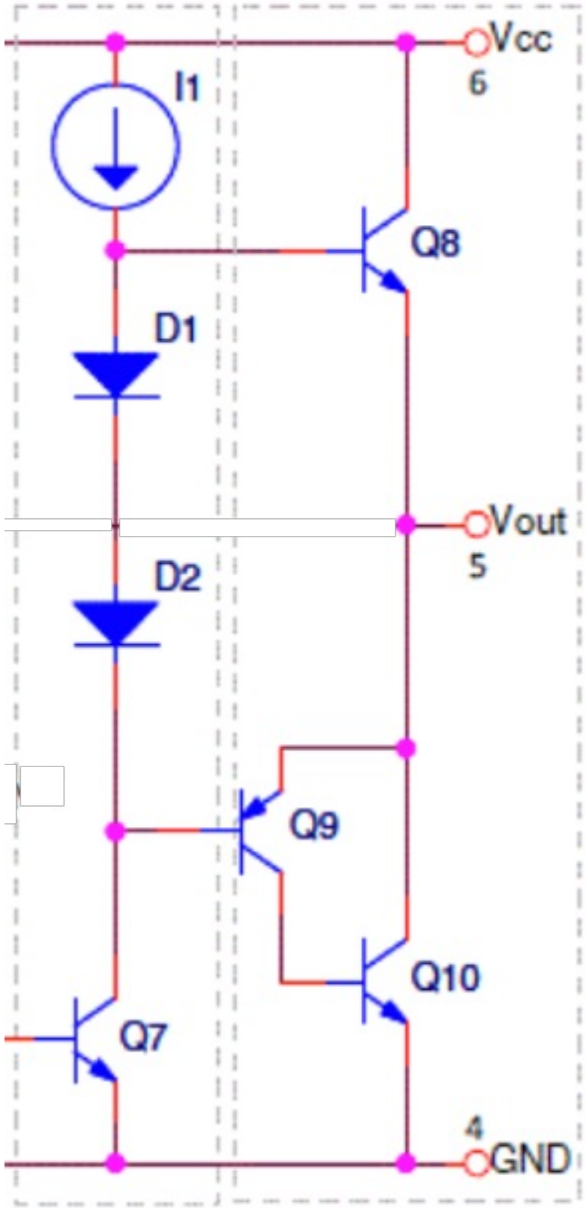
Source: MCP6001 datasheet

Output Stage – Class B



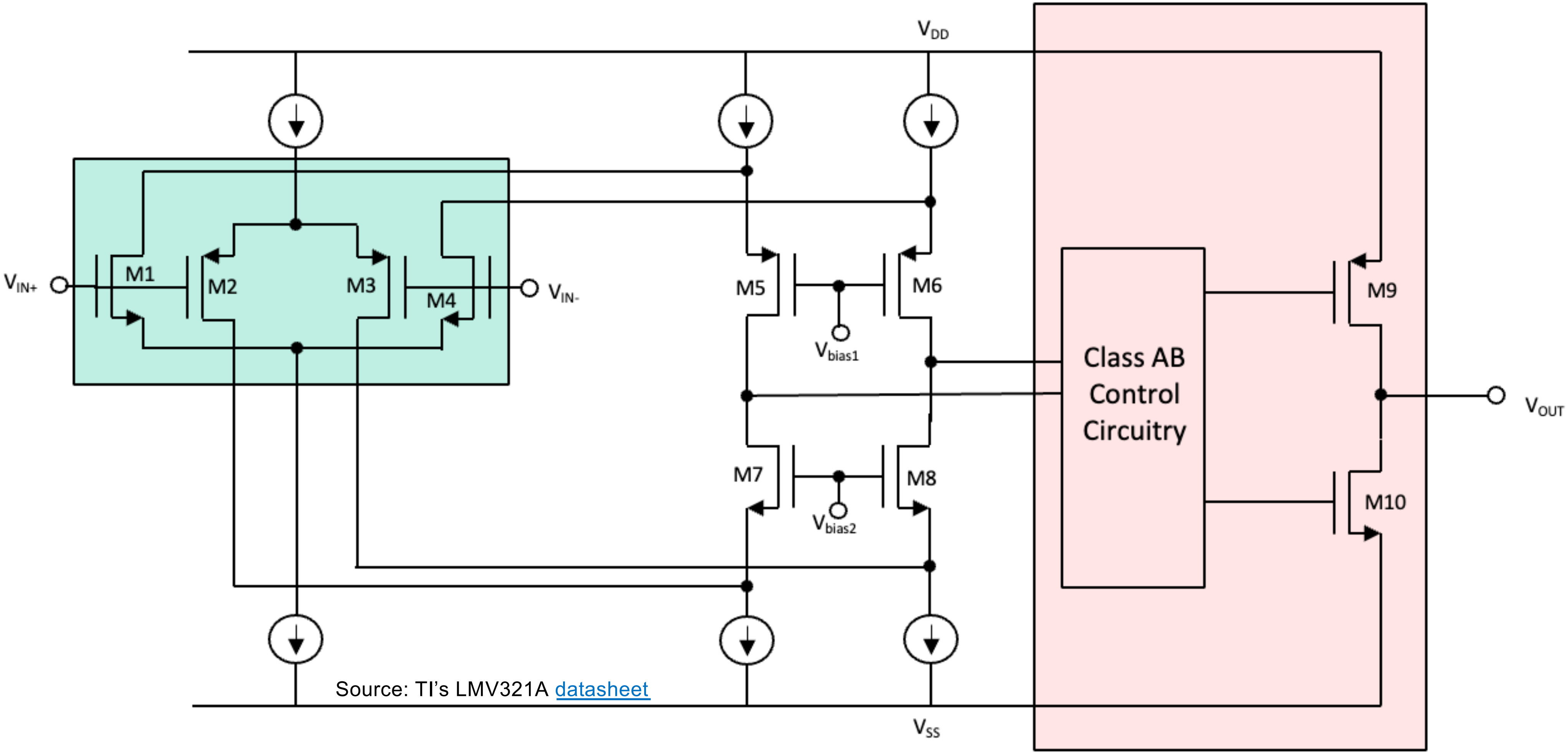
- Yr 1st ADC part 2 Lecture 6, S3-5
- Q4 is emitter follower (Common-Emitter) for sourcing current to Vout (PUSH)
- Q5 is another emitter follower for sinking current from Vout (PULL)
- This is known as a PUSH-PULL or class B amplifer circuit
- $\delta Vout \approx \delta V_{in,}$ i.e. its gain is 1
- Each transistor only operate for half cycle or 180º of a sinewave signal
- Further, Q4 and Q5 requires VBE > 0.7V to start conducting, therefore this amplifier has distortion.

Bipolar output Stage – Class AB output



- Q8 push emitter follower sourcing current
- Q9, Q10 pull emitter follower sinking current
- D1, D2 forward bias due to I_1
- Keep Q8 and Q9 in linear region – reduce distortion
- Q9 PNP has poor current gain
- Combine with Q10 NPN to boost current gain
- Q9, Q10 - called a "**Sziklai**" pair (different from Darlington pair)
- $A_v \approx 1$

Class AB output of MOSFET op-amp



Source: TI's LMV321A datasheet

- Improved output stage cannot drive low impedance load, say 8Ω speaker.

Output Short-Circuit Current	I_{SC}	—	±6	—	mA	V_{DD} = 1.8V
(Source: MCP6001 datasheet)		—	±23	—	mA	V_{DD} = 5.5V

Op-amp Output Specifications

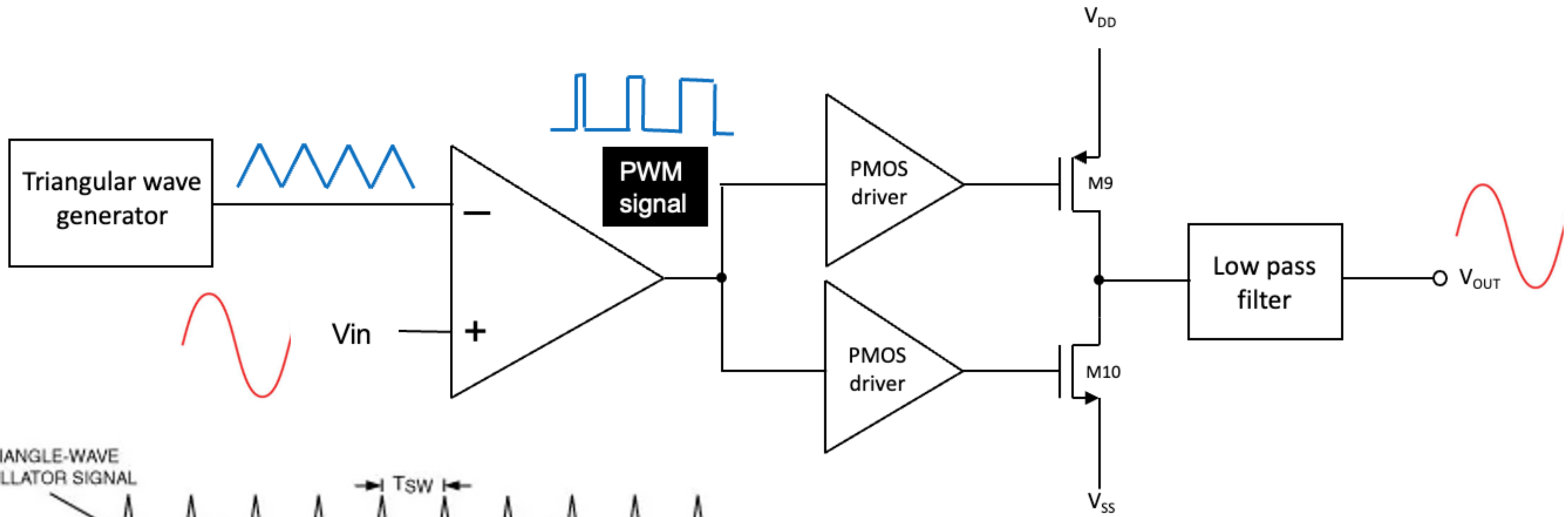
- These are the output specifications for the MCP6001 op-amp.

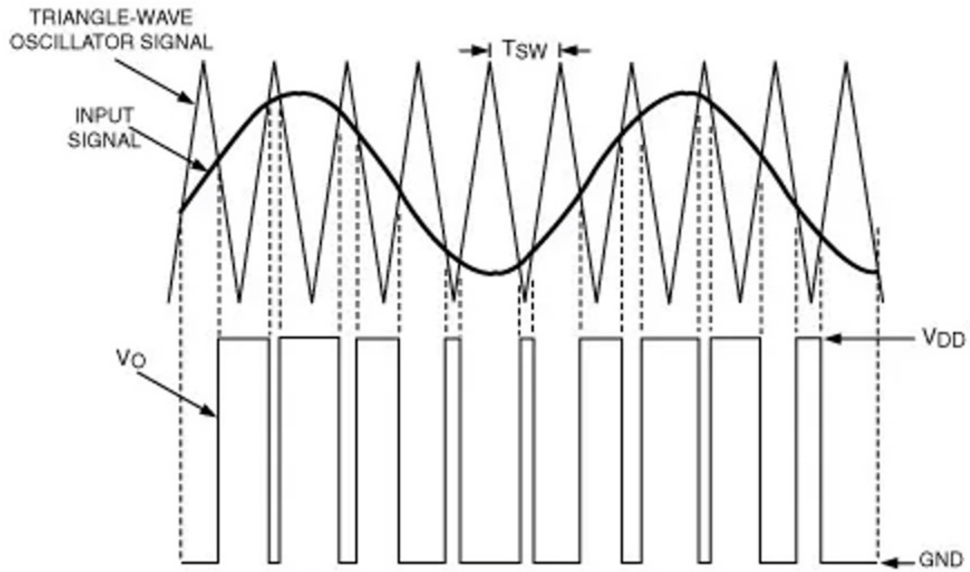
Output						
Maximum Output Voltage Swing	V_{OL}, V_{OH}	V_{SS} + 25	—	V_{DD} – 25	mV	V_{DD} = 5.5V, 0.5V input overdrive
Output Short-Circuit Current	I_{SC}	—	±6	—	mA	V_{DD} = 1.8V
		—	±23	—	mA	V_{DD} = 5.5V

Highlighted entries are implemented in the MCP6001 LTSpice model.

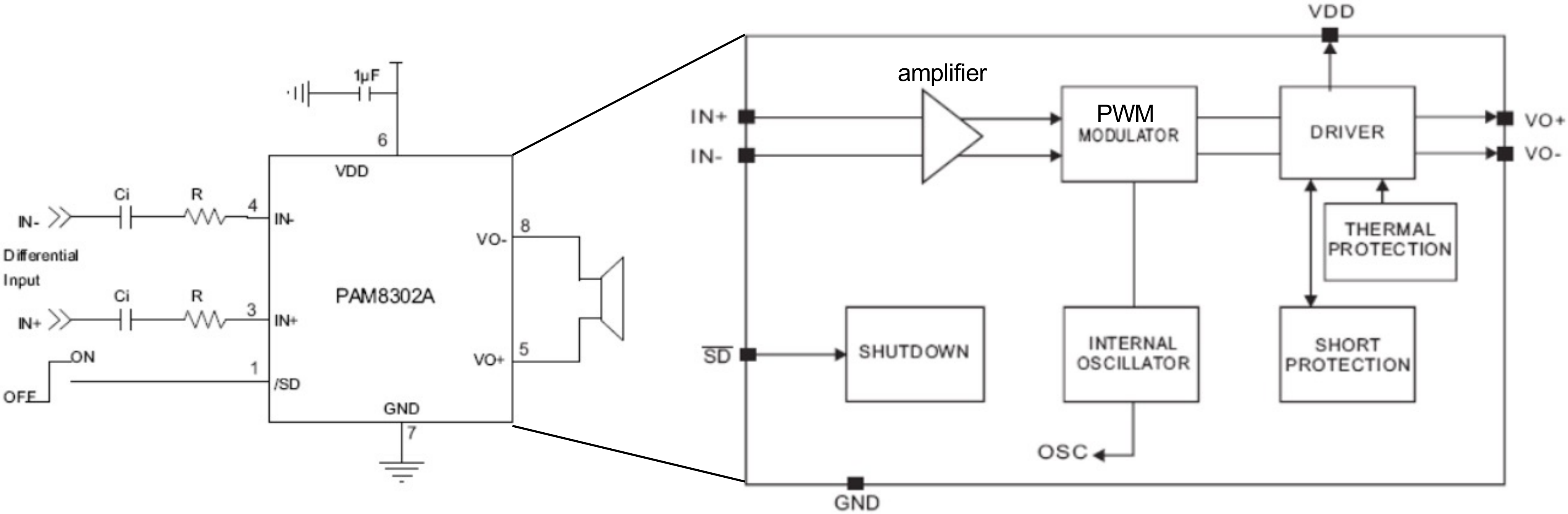
Source: MCP6001 datasheet

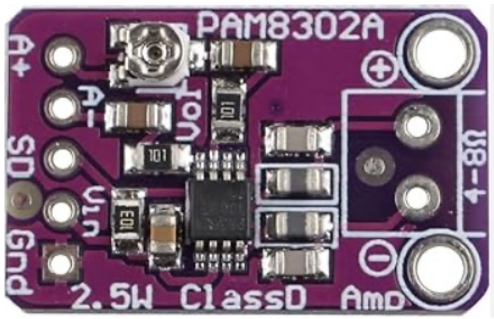
Block Diagram of a Class D amplifier





The PAM8302A Audio Amplifier

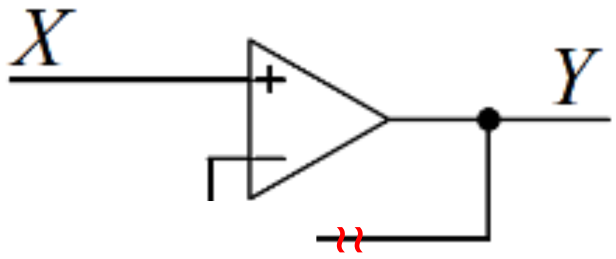




- 2.5W Output at 10% THD with a 4Ω Load and 5V Power Supply
- Filterless, Low Quiescent Current and Low EMI
- High Efficiency up to 88%
- Superior Low Noise
- Short Circuit Protection

Stability issue in op-amps

- Op-amp as an amplifier always uses NEGATIVE FEEDBACK to determine the gain.
- Consider this unity gain buffer: break the loop in the feedback path.
- Due to delay, could feedback a signal that is 180º out of phase relative to input.
- The negative feedback now become positive feedback, leading to oscillation.

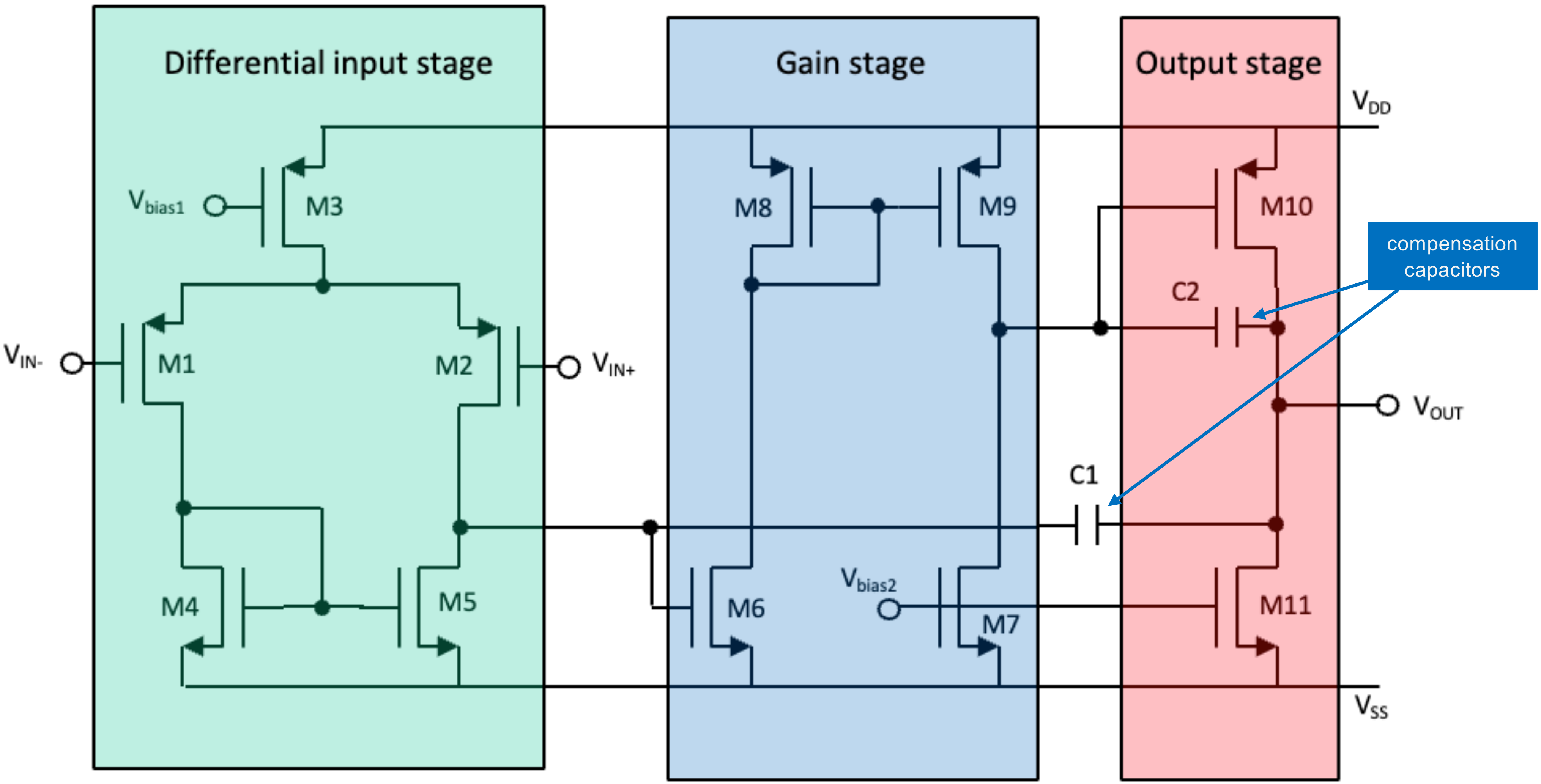


Gain = 1

Stability requirement:

1. The open-loop **gain is > 1**, but the **phase angle** must be **<180º** at **all signal frequencies**, OR
2. The **phase angle** is **≥ 180º**, but the open-loop **gain is < 1** at **all signal frequencies**.

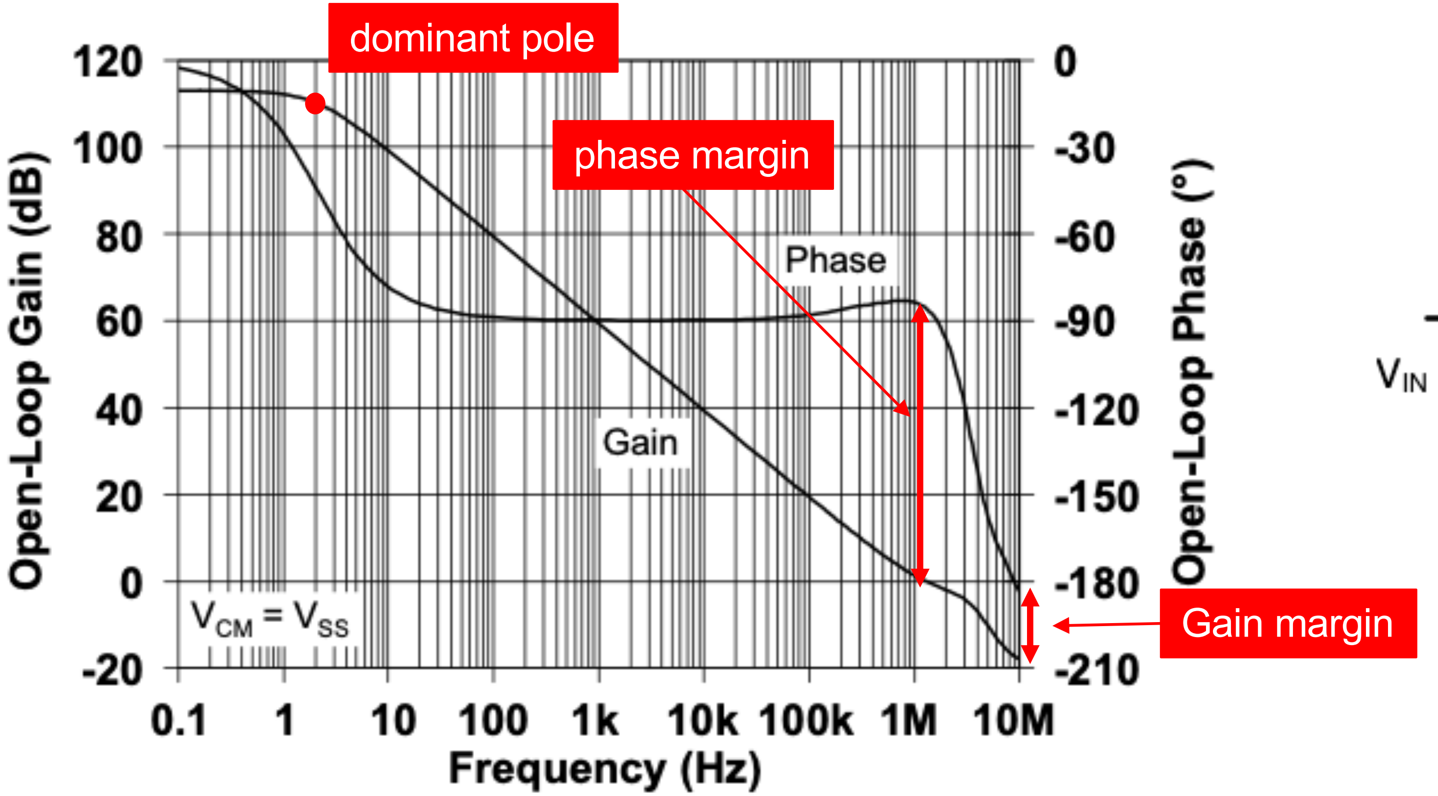
Open-loop gain and compensation capacitors

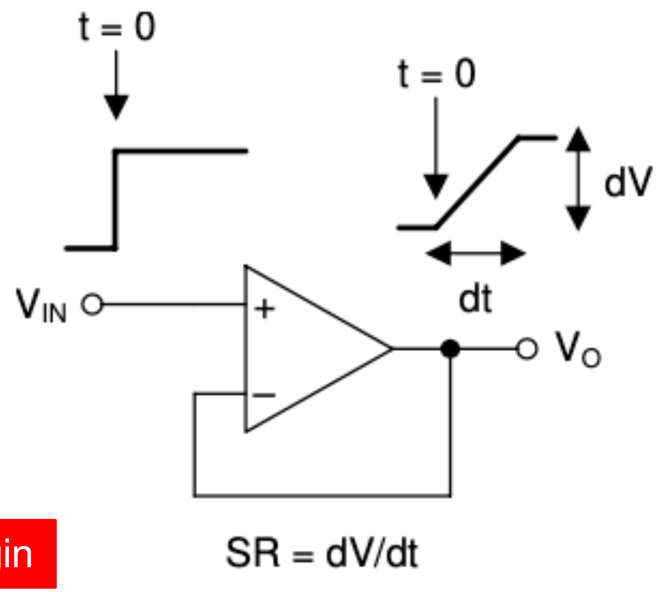


Op-amp Loop Gain specification

Open-Loop Gain						
DC Open-Loop Gain (Large Signal)	A_{OL}	88	112	—	dB	V_{OUT} = 0.3V to V_{DD} – 0.3V, $V_{CM} = V_{SS}$

AC Response						
Gain Bandwidth Product	GBWP	—	1.0	—	MHz	
Phase Margin	PM	—	90	—	°	G = +1 V/V
Slew Rate	SR	—	0.6	—	V/µs	





Source: MCP6001 datasheet