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What Does "Rail-to-Rail" Operation Really Mean?

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Agenda

- What does “Rail-to-Rail” output operation mean
- Amplifier Output Stage
- Distortion
- Techniques to Compare Rail-to-Rail Op Amps
- Microchip Op Amps and References

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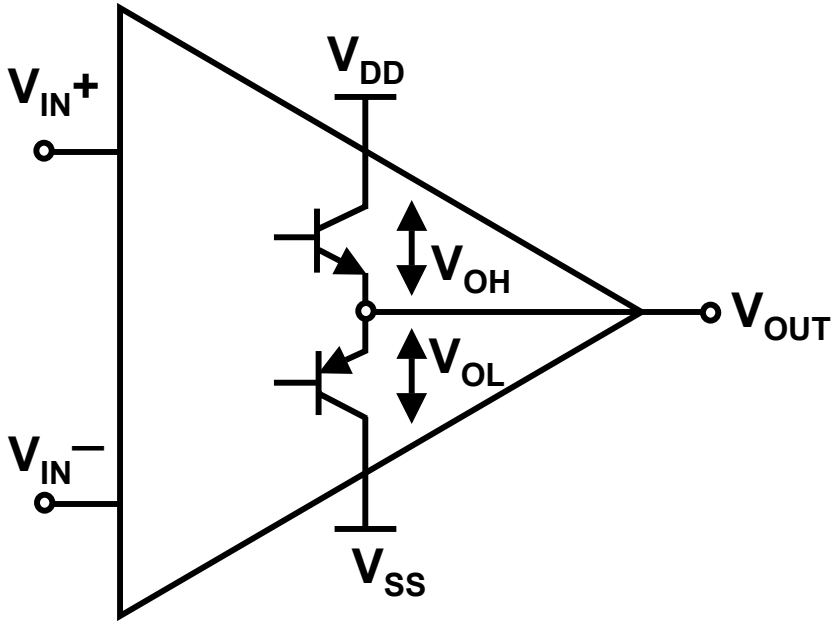
Rail-to-Rail Operation

- Rail means supply voltage (V_{DD} and V_{SS})
- Rail-to-Rail output of amplifier

- In reality:
  - Output can not reach the rails
  - The difference from the rail is called Headroom

Amplifier Output Stage



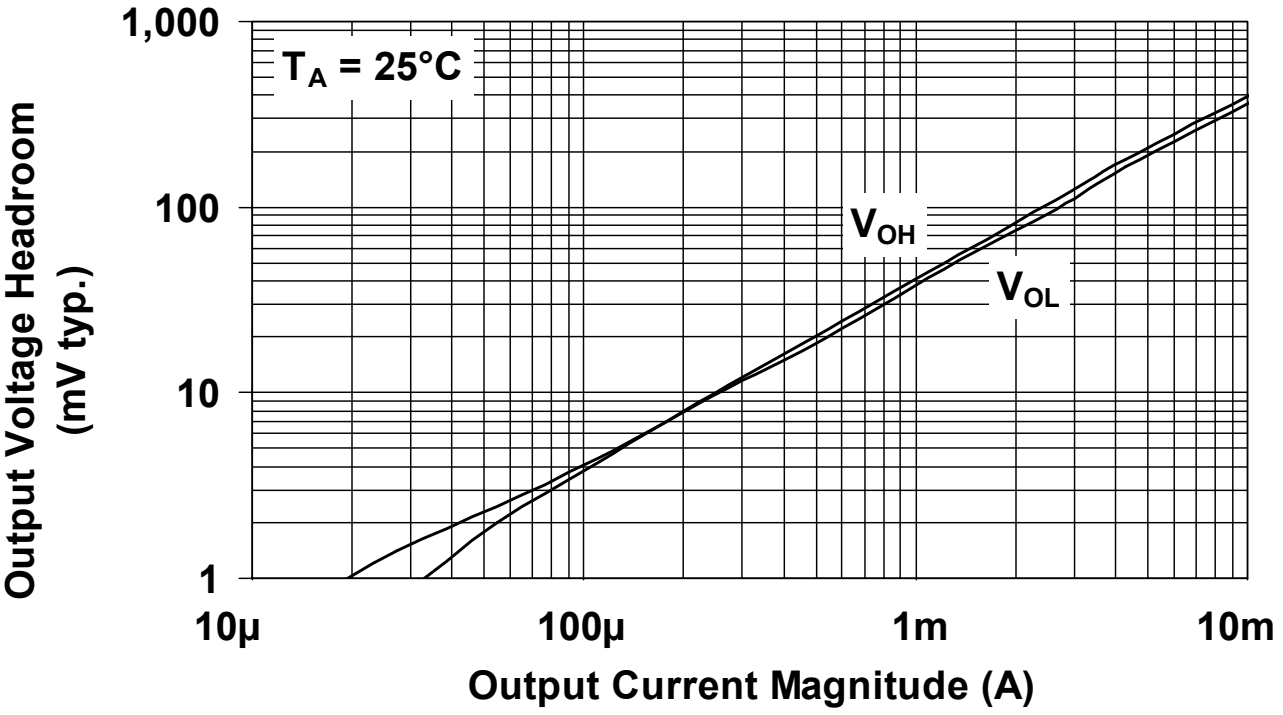
- Push-Pull output
- Headroom
  - Transistor junction drop

Headroom

- When $V_{OUT} \rightarrow V_{DD}$:
  $V_{DD} - V_{OUT} = V_{OH}$
- When $V_{OUT} \rightarrow V_{SS}$:
  $V_{OUT} - V_{SS} = V_{OL}$

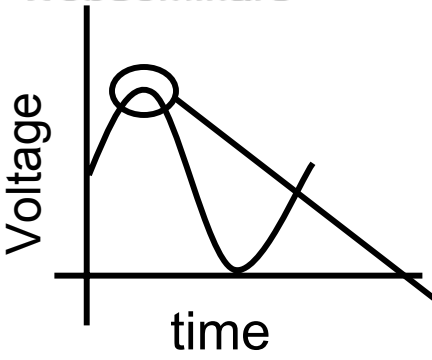
Amplifier Output Stage

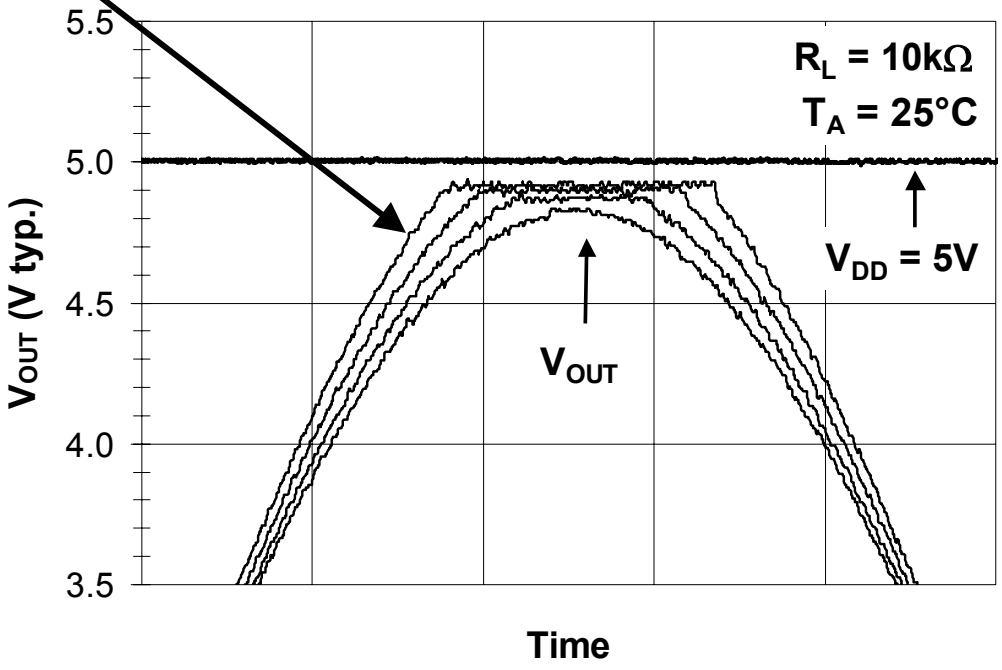
- Headroom increases with increasing output current



Output Distortion

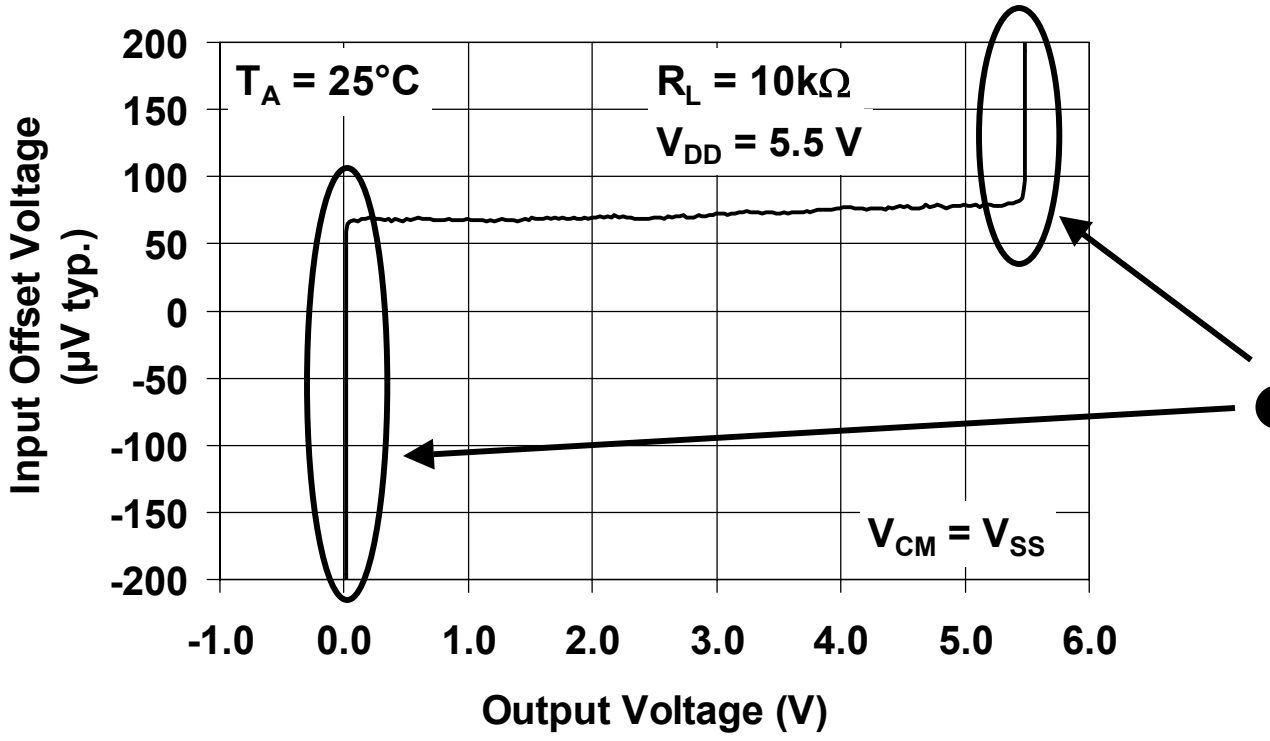
- Signal distortion (clipping)
- Approaching the rail distorts the output





Amplifier Non-Linearity

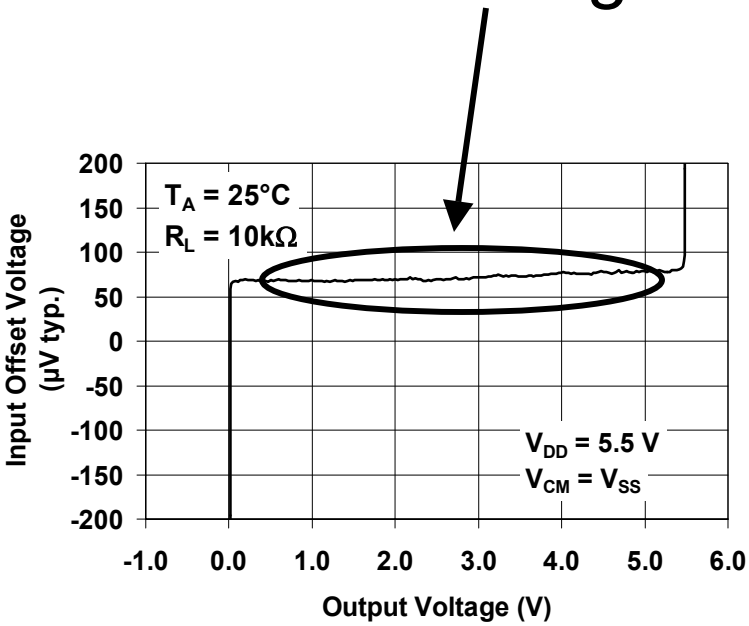
- Non-linearity when $V_{OUT} \rightarrow$ the rails



- Non-linear Regions

Amplifier Linearity

- Open Loop Gain (A_{VOL}) measurement range
  - provides the clue to determine the linear region



- $A_{VOL} = \Delta V_{OS}/\Delta V_{OUT}$
  - two point measurement:

$V_{OS} \rightarrow V_{OUT} = 300mV$

$V_{OS} \rightarrow V_{OUT} = V_{DD} - 300mV$ (300mV for MCP6001)

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Amplifier Linearity

- What causes the distortion?
  - transistors no longer in linear operation
- Linear Region
  - Specified in measurement conditions
  - Recommended headroom for MCP6001
    - 300mV with 10kΩ load to $V_{DD}/2$
  - sink/source current dependent

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Rail-to-Rail Output Amplifiers Comparison Techniques

- Compare headroom vs. sink/source current
- Compare the A_{VOL} measurement range
- Do bench verification
  - Compare expected vs. measured output voltage

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Microchip Op Amps

Part number	I/O Range	V_{DD} (V) Range	I_Q (µA) max
MCP6271	R/R I/O	2.0-5.5	240
MCP6281	R/R I/O	2.2-5.5	570
MCP6291	R/R I/O	2.4-5.5	1300
MCP6S21	R/R I/O	2.5-5.5	1300
MCP6241	R/R I/O	1.8-5.5	50
MCP6001	R/R I/O	1.8-5.5	100
MCP6140	R/R I/O	1.4-5.4	1
MCP6041	R/R I/O	1.4-5.5	1
MCP6021	R/R I/O	2.5-5.5	1400
TC1034	R/R I/O	1.8-5.5	8µA
MCP606	R/R O	2.5-5.5	25µA
MCP616	R/R O	2.3-5.6	25µA
MCP601	R/R O	2.7-5.5	325µA

R/R I/O → Rail-to-Rail Input/Output

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Conclusion

- Amplifier output can not reach the rails
- Headroom is dependent on sink/source current
- Approaching the rails introduces distortion
- Bench test device to determine linear region

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References

- Application Notes
  - ADN009*, What Does "Rail-to-Rail" Operation Really Mean?*
  - ADN003, *Select the Right Operational Amplifier for your Filtering Circuits*
  - AN699, *Anti-Aliasing, Analog Filters for Data Acquisition Systems*
  - *AN722, Operational Amplifier Topologies and DC Specifications*
  - AN723, *Operational Amplifier AC Specifications and Applications*
  - AN695, *Interfacing Pressure Sensors to Microchip's Analog Peripherals*
  - AN737, *Using Digital Potentiometers to Design Low Pass Adjustable Filters*
  - AN246, *Driving the Analog Inputs of a SAR A/D Converter*
  - AN688, *Layout Tips for 12-Bit A/D Converter Application*
  - *AN884, Driving Capacitive Loads With Op Amps*

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