What Does “Rail-to-Rail” Operation Really Mean?
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
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 $V_{OUT} \to V_{DD}$:
  \[ V_{DD} - V_{OUT} = V_{OH} \]

- When $V_{OUT} \to V_{SS}$:
  \[ V_{OUT} - V_{SS} = V_{OL} \]
Amplifier Output Stage

- Headroom increases with increasing output current
Output Distortion

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

Voltage vs. Time

$V_{DD} = 5V$

$R_L = 10k\Omega$

$T_A = 25^\circ C$

$V_{OUT}$
Amplifier Non-Linearity

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

![Graph showing non-linearity and rails](image-url)

- $T_A = 25^\circ C$
- $R_L = 10k\Omega$
- $V_{DD} = 5.5 \text{ V}$
- $V_{CM} = V_{SS}$

Non-linear Regions
Amplifier Linearity

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

- $A_{VOL} = \frac{\Delta V_{OS}}{\Delta V_{OUT}}$

- two point measurement:
  - $V_{OS} \rightarrow V_{OUT} = 300\text{mV}$
  - $V_{OS} \rightarrow V_{OUT} = V_{DD} - 300\text{mV}$  
    (300mV for MCP6001)
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
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
# Microchip Op Amps

## Rail-to-Rail Operation

<table>
<thead>
<tr>
<th>Part number</th>
<th>I/O Range</th>
<th>$V_{DD}$ (V) Range</th>
<th>$I_Q$ (µA) max</th>
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<tr>
<td>MCP6271</td>
<td>R/R I/O</td>
<td>2.0-5.5</td>
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<td>MCP601</td>
<td>R/R O</td>
<td>2.7-5.5</td>
<td>325µA</td>
</tr>
</tbody>
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**R/R I/O → Rail-to-Rail Input/Output**
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
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
WebSeminar: April 21, 2004

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