EE105
Microelectronic Devices and Circuits

Prof. Ming C. Wu
wu@eecs.berkeley.edu
511 Sutardja Dai Hall (SDH)
Practical Op-Amps

• Linear Imperfections:
  – Finite open-loop gain ($A_0 < \infty$)
  – Finite input resistance ($R_i < \infty$)
  – Non-zero output resistance ($R_o > 0$)
  – Finite bandwidth / Gain-BW Trade-off

• Other (non-linear) imperfections:
  – Slew rate limitations
  – Finite swing
  – Offset voltage
  – Input bias and offset currents
  – Noise and distortion
Offset Voltage
Trimming of Offset Voltage

The output dc offset voltage of an op amp can be trimmed to zero by connecting a potentiometer to the two offset-nulling terminals. The wiper of the potentiometer is connected to the negative supply of the op amp.
Input Bias Currents and Offset Currents

- Some op-amps (bipolar) have input bias currents that need to flow for the op-amp to function properly.
- They are typically very small, ~ 100 nA, but may differ slightly (by 10 nA).

\[ I_B = \frac{I_{B1} + I_{B2}}{2} \]

\[ I_{OS} = |I_{B1} - I_{B2}| \]
Effect of Input Bias Current in Amplifier Circuit

In the absence of input voltage, the output should be zero for ideal Op Amp. However, with non-zero $I_B$,

$$V_O = I_{B1}R_2 \approx I_B R_2$$
Reducing the Effect of Input Bias Currents
Output Saturation

• The output voltage swing is limited by
  1. Saturation voltage (usually a volt or two lower than power supply voltage)
  2. Maximum output current (in case of small load resistance)

• Output waveform appears to be “clipped” when either condition happens
Slew Rate

Amplifier output is limited by "slew rate": maximum rate of change possible at output

\[ SR = \left. \frac{dv_o}{dt} \right|_{\text{max}} \]

SR is specified in datasheet in V/µs.

Note

SR limit is different from bandwidth limit:
• Limited bandwidth is a linear phenomenon, it does not change the shape of input sinusoid
• SR limitation can cause nonlinear distortion to input sinusoidal signal

Output not able to follow input; Slope limited by SR
Comparison of Slew Rate and Bandwidth Limits

For step function input waveform, both SR and bandwidth limits cause the output to rise with a finite slope, but there is an important difference:

Slew rate limited output:
Slope = SR

Bandwidth limited output:
Slope = \omega_t V < SR
(V is the steady state output voltage)
Full-Power Bandwidth

For ideal sinusoidal output
\[ v_o = V_o \sin \omega t \]

Rate of change cannot exceed SR:
\[ \frac{dv_o}{dt} = V_o \omega \cdot \cos \omega t \leq SR \]

Full-power bandwidth:
The frequency at which SR-limited distortion starts to occur for an output sinusoid with maximum rated output voltage, \( V_{\text{omax}} \),
\[ \omega_M V_{\text{omax}} = SR \]
\[ f_M = \frac{SR}{2\pi V_{\text{omax}}} \]
Op Amp Catalog (ti.com)

https://www.ti.com/amplifier-circuit/op-amps/products.html#