Op-amp characteristics

Gain: very high DC ($10^5$-$10^6$), rolls off at higher $f$

Complex gain: $G = \frac{\text{Out}}{\text{Diff}}$

AC sine: amplitude & phase

$\text{Out}$ lags $\Rightarrow$ negative phase

$\text{Diff} = \text{V}_+ - \text{V}_-$

Typically:

$$G = \frac{G_0}{1 + j \frac{\omega}{\omega_0}}$$

Unity gain bandwidth

$$|G(\omega_{BW})| = 1$$

$$\begin{cases} 
1 \text{MHz} - 741 \\
4.5 \text{MHz} - 3140 
\end{cases}$$

-such roll-off of gain = internally compensated op-amps, stable behavior with most (not all!) configurations of passive elements connected between output & inputs
Transfer characteristic

\[ \text{V}_{\text{sout}} = \begin{cases} \text{V}_{\text{sat}+} & \text{for } \text{sat}, \\ \text{V}_{\text{sat}-} & \text{for } \text{active}, \\ \text{V}_{\text{diff}} & \text{for } \text{sat}. \end{cases} \]

Q: \( \text{V}_{\text{diff}} = 1\text{V}, \quad \text{V}_{\text{sout}} \approx 1\text{MV} \) ??
A: no, it saturates

\( |\text{V}_{\text{sat}+}| < 1|\text{V}_{\text{+,}-}| \)
typically by a fraction of 1V for \( \text{V}_{\text{diff}} \)
larger \( \text{V}_{\text{diff}} \) (<mV for full sweep)
\( \text{V}_{\text{diff}} \) is large

- bare op-amp is a **lousy** amplifier

wk4: need negative feedback to build stable amplifier for small voltages

Input offset voltage

\[ \text{V}_{\text{sout}} \neq 0 \]

"built-in error" for 741 or 3140

\[ \text{V}_{\text{sout}} = G \left( \text{V}_{+} + \text{V}_{\text{os}} - \text{V}_{-} \right) \]

can be cancelled, see spec. sheets.
Slew rate & propagation delay

\[ \frac{dS_{\text{out}}}{dt} = \text{slew rate} \]

Typical S.R.
- \(0.5\,\text{V/\mu s}\) for 741
- \(9\,\text{V/\mu s}\) for 3140

\(T_{\text{p.d.}} \approx 100\,\text{ns}, \text{or so (?)}\)

Ideal op-amp (exists in textbooks)

1) Input draw \underline{no current} \quad (R_{\text{in}} \to \infty) \quad "\text{op-amp current rule}"

2) Output resistance is 0

3) \(V_{\text{sat+}} = V_+ \quad \{\text{equal to supply rails values}\}
\quad V_{\text{sat-}} = V_- \)

4) \(G \to \infty\)

5) \(V_{\text{os}} \to 0\), S.R. \(\to \infty\), \(T_{\text{p.d.}} \to 0\)

- Always start with \underline{ideal op-amp}, then apply non-ideal properties \underline{as small perturbations}.
Op-amp circuits

Comparator

\( V_{\text{in}} < V_{\text{ref}} \), \( \Rightarrow \) \( V_{\text{out}} = V_{\text{sat}^+} \)
\( V_{\text{in}} > V_{\text{ref}} \), \( \Rightarrow \) \( V_{\text{out}} = V_{\text{sat}^-} \)

- Analog signal in, digital signal out
- Comparator = simplest 1-bit ADC
- Analog to Digital Converter
  (more in Ch. 12)

Problems with comparator

Simple comp. does not "understand" noise.

Solution: use positive feedback, i.e.
change \( V_{\text{ref}} \) with \( V_{\text{out}} \)
\( \Rightarrow \) Schmitt trigger

\( V_{\text{in}} \) vs time
\( V_{\text{ref}} \) vs time