

# Operational Amplifier Specifications

## Gain, Frequency Response, and Dynamic Limitations

Maxx Seminario

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# Outline

- 1 Introduction: From Ideal to Real
- 2 DC Specifications
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# Why Study Op-Amp Specifications?

## Ideal vs. Real Op-Amps:

- 😊 **Ideal:** Simple analysis, perfect behavior
- 😐 **Real:** Practical limitations exist
- 😞 Ignoring specs → circuit failure!

## Key Questions:

- What gain can I actually achieve?
- How fast can my circuit respond?
- What frequencies can I amplify?
- What errors will appear in my output?

## Real-World Applications:

- Audio amplifiers (20 Hz - 20 kHz)
- Active filters
- Analog sensor systems
- Control systems

## Lecture Objectives

- Understand DC and AC specifications
- Analyze frequency response limitations
- Apply slew rate constraints
- Select appropriate op-amps for applications

# Overview of Key Specifications

| Category | Parameter                     | Typical Value (741) |
|----------|-------------------------------|---------------------|
| DC Specs | Open-loop gain $A_0$          | 200,000 (106 dB)    |
|          | Input offset voltage $V_{OS}$ | 1–5 mV              |
|          | Input bias current $I_B$      | 80 nA               |
| AC Specs | Gain-bandwidth product (GBW)  | 1 MHz               |
|          | Unity-gain frequency $f_t$    | 1 MHz               |
|          | Phase margin                  | 60°                 |
| Dynamic  | Slew rate (SR)                | 0.5 V/ $\mu$ s      |
|          | Full-power bandwidth          | 8 kHz               |
| Other    | CMRR                          | 90 dB               |
|          | PSRR                          | 80 dB               |

## Note

These are **typical values for the 741 op-amp**. Modern op-amps offer better performance

# Open-Loop Gain: Finite, Not Infinite

## Open-Loop Gain $A_0$ :

$$v_{out} = A_0(v_+ - v_-)$$

## Real vs. Ideal:

- **Ideal:**  $A_0 = \infty$
- **Real:**  $A_0 = 10^5 - 10^6$  (100-120 dB)

## Typical Values:

- 741:  $A_0 \approx 200,000$  (106 dB)
- LM324:  $A_0 \approx 100,000$  (100 dB)
- TL081:  $A_0 \approx 200,000$  (106 dB)
- OP07:  $A_0 \approx 1,000,000$  (120 dB)

## Impact on Closed-Loop Gain:

For inverting amplifier with ideal gain:

$$G_{actual} = G_{ideal} \cdot \frac{A_0}{A_0 + 1 + |G_{ideal}|}$$

**Example:**  $G_{ideal} = -100$ ,  $A_0 = 100,000$

$$G_{actual} = -100 \cdot \frac{100,000}{100,101} \approx -99.9$$

## Design Rule

For accurate gain, choose op-amp with:

$$A_0 \gg |G_{closed-loop}|$$

Rule of thumb:  $A_0 > 100 \times |G|$

# Input Referred Offset Voltage

## Definition:

Input offset voltage  $V_{OS}$  is the **differential voltage** required at the inputs to force  $v_{out} = 0$ .

## Physical Cause:

- ☹ Transistor mismatches inside IC
- ☹ Manufacturing variations

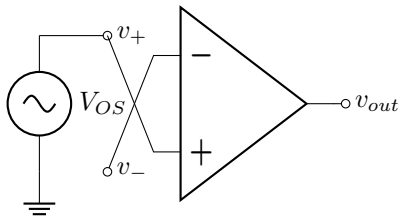


Figure 1: Offset voltage model

## Key Characteristics:

- ☹ **Sample-to-sample variation:** Each IC has different  $V_{OS}$
- ☹ **Not predictable:** Cannot know exact value without measurement
- 😊 **Datasheet specifies range:** Typical and maximum values given
- 😊 **Feedback helps:** Not critical when op-amp is in negative feedback

## Effect in Non-Inverting Amplifier:

$$V_{out,offset} = V_{OS} \cdot G$$

**Example:**  $V_{OS} = 2 \text{ mV}$ ,  $G = 100$

$$V_{out,offset} = 2 \text{ mV} \times 100 = 200 \text{ mV}$$

# Open-Loop Frequency Response

## Single-Pole Rolloff:

Most op-amps have internally compensated frequency response:

$$A(f) = \frac{A_0}{1 + jf/f_b}$$

where:

- $A_0$  = DC open-loop gain
- $f_b$  = break frequency (3-dB point)

## Magnitude Approximation:

- $f < f_b$ :  $|A| \approx A_0$  (flat)
- $f > f_b$ :  $|A| \approx A_0 f_b / f$  (-20 dB/decade)

## Bode Plot - Open Loop:

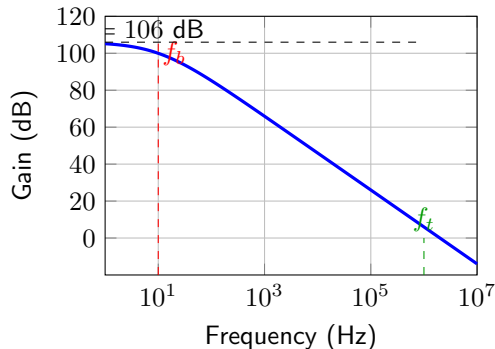


Figure 2: Typical 741 open-loop response

# Gain-Bandwidth Product

## Unity-Gain Frequency $f_t$ :

Frequency where  $|A(f_t)| = 1$  (0 dB):

$$f_t = A_0 \cdot f_b$$

## Gain-Bandwidth Product (GBW):

For frequencies  $f \gg f_b$ :

$$|A(f)| \cdot f = A_0 \cdot f_b = f_t = \text{constant}$$

## Example - 741:

- $A_0 = 200,000$  (106 dB)
- $f_b = 5$  Hz
- $f_t = 200,000 \times 5 = 1$  MHz
- $GBW = 1$  MHz

## Closed-Loop Bandwidth:

For closed-loop gain  $G$ :

$$f_{-3dB} = \frac{f_t}{G}$$

## Gain-Bandwidth Tradeoff

Higher gain  $\rightarrow$  lower bandwidth!

$$G \times BW = f_t = \text{constant}$$

Examples (741,  $f_t = 1$  MHz):

| Gain | Bandwidth |
|------|-----------|
| 1    | 1 MHz     |



# Closed-Loop Frequency Response

## Non-Inverting Amplifier:

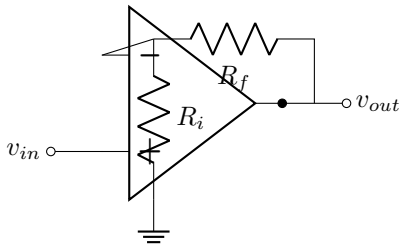


Figure 3: Non-inverting amplifier

## Ideal Gain:

$$G = 1 + \frac{R_f}{R_i}$$

## Frequency Response for Different Gains:

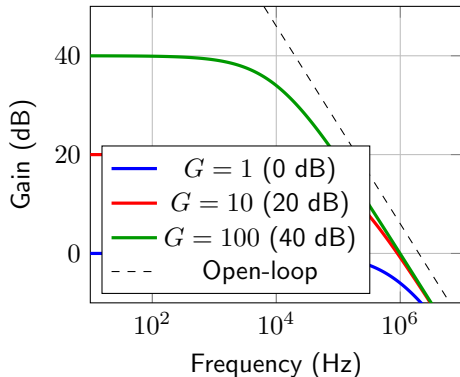


Figure 4: Closed-loop response for various gains

# Phase Margin and Stability

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## Phase Margin (PM):

Amount of additional phase shift (beyond  $-180^\circ$ ) at unity-gain frequency before instability:

$$PM = 180^\circ + \phi(f_t)$$

## Stability Criteria:

- $PM > 45^\circ$ : stable, good damping
- $PM \approx 60^\circ$ : optimal (typical design)
- $PM < 30^\circ$ : marginal, may oscillate
- $PM \leq 0^\circ$ : unstable

Compensation

## Bode Plot - Phase Response:

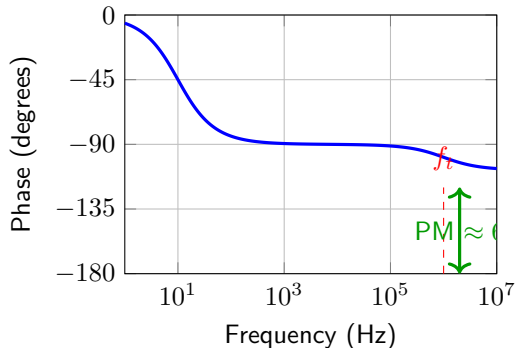


Figure 5: Phase response showing phase margin

# Small Signal AC Model

## Frequency-Dependent Model:

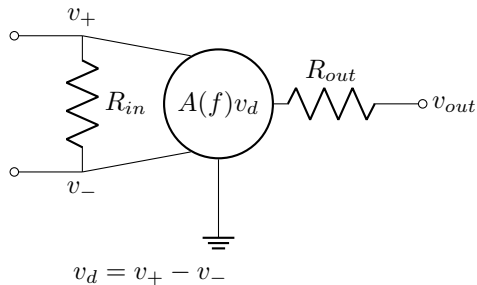


Figure 6: Small-signal AC model

## Frequency-Dependent Gain:

## Typical Parameter Values:

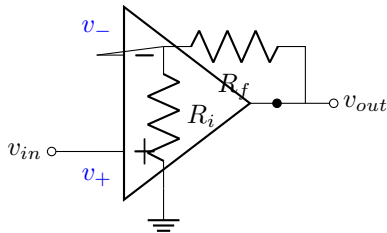
| Parameter | Typical (741) |
|-----------|---------------|
| $R_{in}$  | 2 M $\Omega$  |
| $R_{out}$ | 75 $\Omega$   |
| $A_0$     | 200,000 V/V   |
| $f_b$     | 5 Hz          |
| $f_t$     | 1 MHz         |

## Analysis Steps:

- 1 Replace op-amp with AC model
- 2 Apply frequency-dependent  $A(f)$
- 3 Solve for transfer function

# Closed-Loop Gain Derivation

## Non-Inverting Amplifier Analysis:



## Feedback factor:

$$\beta = \frac{R_i}{R_i + R_f}$$

## Ideal closed-loop gain:

## Actual Closed-Loop Gain:

With finite open-loop gain  $A(f)$ :

$$G(f) = \frac{v_{out}}{v_{in}} = \frac{A(f)}{1 + A(f)\beta}$$

Substituting  $A(f) = A_0/(1 + jf/f_b)$ :

$$G(f) = \frac{G_{ideal}}{1 + jf/f_{-3dB}}$$

where the 3-dB frequency is:

$$f_{-3dB} = f_b(1 + A_0\beta) \approx A_0\beta f_b = \frac{f_t}{G_{ideal}}$$

# Example: Bandwidth Calculation

**Problem:** Design a non-inverting amplifier with gain of 20 using a 741 op-amp ( $f_t = 1$  MHz). Find the bandwidth.

**Given:**

- Desired gain:  $G = 20$
- Op-amp: 741 with  $f_t = 1$  MHz

**Design:**

$$G = 1 + \frac{R_f}{R_i} = 20$$

$$\frac{R_f}{R_i} = 19$$

Choose  $R_i = 1 \text{ k}\Omega$ , then:

**Bandwidth:**

$$f_{-3dB} = \frac{f_t}{G} = \frac{1 \text{ MHz}}{20} = 50 \text{ kHz}$$

**Verification:**

$$G \times BW = 20 \times 50 \text{ kHz} = 1 \text{ MHz} = f_t \quad \checkmark$$

**Conclusion**

The amplifier will have a flat gain of 20 (26 dB) from DC up to 50 kHz, then roll off at

# Slew Rate: Large Signal Limitation

## Definition:

**Slew Rate (SR)** is the maximum rate of change of the output voltage:

$$SR = \left| \frac{dv_{out}}{dt} \right|_{max} \quad (V/\mu s)$$

## Physical Cause:

- Limited internal charging current
- Compensation capacitor charging time
- Transistor saturation

## Typical Values:

- 741:  $SR = 0.5 \text{ V}/\mu s$
- TL081:  $SR = 13 \text{ V}/\mu s$

## Slew Rate Limiting:

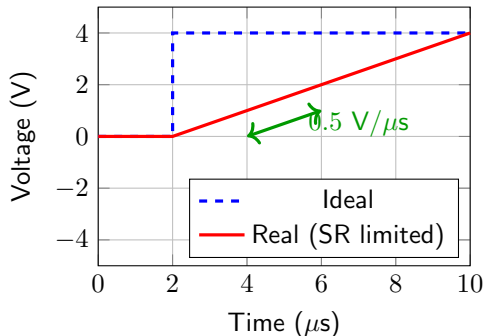


Figure 7: Step response with slew-rate limiting

# Slew Rate and Sinusoidal Signals

## Sinusoidal Output:

For  $v_{out}(t) = V_p \sin(2\pi ft)$ :

$$\frac{dv_{out}}{dt} = 2\pi f V_p \cos(2\pi ft)$$

Maximum slope:

$$\left| \frac{dv_{out}}{dt} \right|_{max} = 2\pi f V_p$$

**No Distortion Condition:**

$$2\pi f V_p \leq SR$$

**Full-Power Bandwidth:**

## Slew-Rate Distortion:

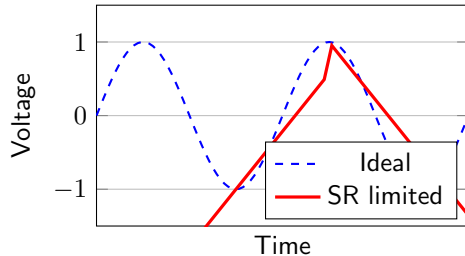


Figure 8: Slew-rate distortion of sine wave

**Example - 741:**

$SR = 0.5 \text{ V}/\mu\text{s}$ ,  $V_p = 10 \text{ V}$ :

$$0.5 \times 10^6$$

# Full-Power Bandwidth vs. Small-Signal Bandwidth

## Two Different Bandwidths:

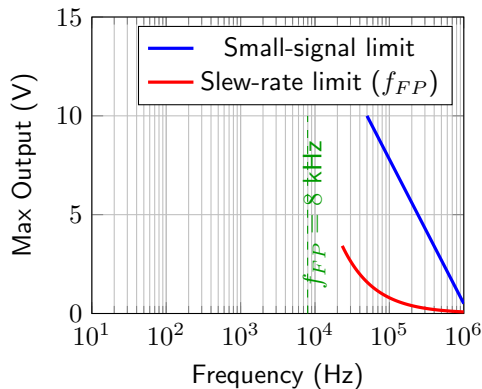
### 1. Small-Signal Bandwidth $f_{-3dB}$ :

- Determined by GBW product
- $f_{-3dB} = f_t/G$
- Valid for small output swings

### 2. Full-Power Bandwidth $f_{FP}$ :

- Determined by slew rate
- $f_{FP} = SR/(2\pi V_p)$
- Valid for large output swings

## Comparison Plot:



## Design Rule

Actual usable bandwidth:

Figure 9: 741:  $G = 1$ ,  $SR = 0.5 \text{ V}/\mu\text{s}$ ,  $f_t = 1$



# Settling Time and Rise Time

## Settling Time $t_s$ :

Time for output to reach and stay within a specified error band (typically  $\pm 0.1\%$  or  $\pm 0.01\%$ ) of final value.

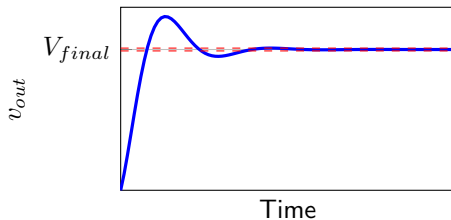


Figure 10: Settling time to  $\pm 1\%$  band

## Rise Time $t_r$ :

Time for output to rise from 10

## Relationship to Bandwidth:

$$t_r \approx \frac{0.35}{f_{-3dB}}$$

## Example - Unity-Gain Buffer (741):

$f_{-3dB} = f_t = 1 \text{ MHz}$ :

$$t_r = \frac{0.35}{1 \text{ MHz}} = 0.35 \mu\text{s} = 350 \text{ ns}$$

# Common-Mode Rejection Ratio (CMRR)

## Definition:

Ratio of differential gain to common-mode gain:

$$CMRR = \frac{A_d}{A_{cm}} = \frac{|A(v_+ - v_-)|}{|A(v_{cm})|}$$

Usually expressed in dB:

$$CMRR_{dB} = 20 \log_{10}(CMRR)$$

## Typical Values:

- 741:  $CMRR = 90 \text{ dB}$
- OP07:  $CMRR = 110 \text{ dB}$
- TL081:  $CMRR = 86 \text{ dB}$

## Effect of Finite CMRR:

Common-mode input  $v_{cm}$  appears as:

$$v_{error} = \frac{v_{cm}}{CMRR}$$

## Example:

$v_{cm} = 5 \text{ V}$ ,  $CMRR = 90 \text{ dB} = 31,623$ :

$$v_{error} = \frac{5}{31,623} = 158 \mu\text{V}$$

## Frequency Dependence:



# Power Supply Rejection Ratio (PSRR)

## Definition:

Measure of how well op-amp rejects power supply variations:

$$PSRR = \frac{\Delta V_{supply}}{\Delta V_{os}}$$

Usually expressed in dB:

$$PSRR_{dB} = 20 \log_{10}(PSRR)$$

## Typical Values:

- 741: PSRR = 80 dB (+ supply)
- OP07: PSRR = 110 dB
- TL081: PSRR = 80 dB

## Effect of Finite PSRR:

Ripple on supply  $\Delta V_{supply}$  appears as offset:

$$V_{os,induced} = \frac{\Delta V_{supply}}{PSRR}$$

## Example:

100 mV ripple, PSRR = 80 dB = 10,000:

$$V_{os,induced} = \frac{100 \text{ mV}}{10,000} = 10 \mu\text{V}$$

Power Supply Design

For low-noise applications:

# Input and Output Impedances (Real)

## Input Impedance:

### Differential input impedance:

- BJT input (741):  $R_{in} \approx 2 \text{ M}\Omega$
- JFET input (TL081):  $R_{in} \approx 10^{12} \Omega$
- CMOS input:  $R_{in} \approx 10^{13} \Omega$

### Common-mode input impedance:

- Usually much higher
- Typically in  $\text{G}\Omega$  range

## Effect on Source Loading

For source impedance  $R_s$ :

$$\frac{v_{in,actual}}{v_{in,theoretical}} = \frac{R_{in}}{R_{in} + R_s}$$

## Output Impedance:

**Open-loop:**  $R_{out} \approx 50 - 100 \Omega$  (typical)

**Closed-loop** (with feedback):

$$R_{out,CL} = \frac{R_{out}}{1 + A\beta}$$

For large loop gain  $A\beta$ :

$$R_{out,CL} \approx \frac{R_{out}}{A\beta} \ll 1 \Omega$$

## Maximum Output Current:

- 741:  $I_{out,max} \approx \pm 25 \text{ mA}$
- TL081:  $I_{out,max} \approx \pm 20 \text{ mA}$

# Output Voltage Swing Limitations

## Output Swing vs. Supply:

Output cannot reach supply rails:

$$V_{out,min} = -V_{EE} + V_{sat}$$

$$V_{out,max} = +V_{CC} - V_{sat}$$

where  $V_{sat}$  is the saturation voltage.

## Typical Saturation Voltages:

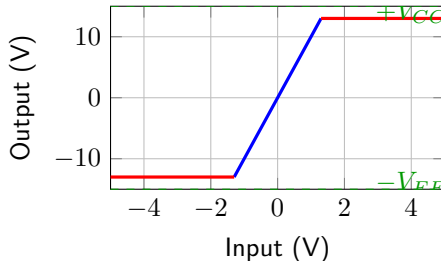
- 741:  $V_{sat} \approx 2 \text{ V}$
- TL081:  $V_{sat} \approx 1.5 \text{ V}$
- Rail-to-rail op-amps:  $V_{sat} \approx 50 \text{ mV}$

## Example - 741 with $\pm 15 \text{ V}$ supplies:

$$V_{out,max} = +15 - 2 = +13 \text{ V}$$

$$V_{out,min} = -15 + 2 = -13 \text{ V}$$

Output swing:  $\pm 13 \text{ V}$  (not  $\pm 15 \text{ V}$ !)



# Choosing the Right Op-Amp

| Application            | Key Specs                | Recommended               |
|------------------------|--------------------------|---------------------------|
| General purpose        | Low cost, moderate specs | 741, LM324, TL081         |
| Precision DC amplifier | Low $V_{OS}$ , low drift | OP07, OP177, LT1013       |
| High-speed             | High SR, high $f_t$      | LM318, THS4031, AD8099    |
| Audio                  | Low noise, good THD      | NE5532, OPA2134, LM4562   |
| Low power              | Low supply current       | TLV2371, LMC7101, MAX4236 |
| High input impedance   | JFET/CMOS input          | TL081, CA3140, LMC6482    |
| Single supply          | Rail-to-rail I/O         | LM358, LMV321, MCP6002    |
| Instrumentation        | High CMRR, low noise     | INA128, AD620, LT1167     |

## Selection Process

# Comparison of Common Op-Amps

## Op-Amp Specifications

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#### Summary

| Part    | $A_0$ (dB) | $f_t$ (MHz) | SR (V/ $\mu$ s) | $V_{OS}$ (mV) | $I_B$      | Type                     |
|---------|------------|-------------|-----------------|---------------|------------|--------------------------|
| 741     | 106        | 1           | 0.5             | 1-5           | 80 nA      | BJT, general             |
| LM324   | 100        | 1           | 0.5             | 2-7           | 45 nA      | BJT, quad, single supply |
| TL081   | 106        | 3           | 13              | 3-15          | 50 pA      | JFET, high $Z_{in}$      |
| OP07    | 120        | 0.6         | 0.3             | 0.025-0.075   | 2 nA       | BJT, precision           |
| OP177   | 126        | 0.6         | 0.3             | 0.01-0.025    | 0.5 nA     | BJT, ultra-precision     |
| LM318   | 100        | 15          | 70              | 2-10          | 150 nA     | BJT, high-speed          |
| THS4031 | 110        | 100         | 370             | 0.5           | 10 $\mu$ A | BJT, very high-speed     |
| NE5532  | 100        | 10          | 9               | 0.5-4         | 200 nA     | BJT, low-noise audio     |
| LMC6482 | 106        | 1.5         | 1.1             | 0.4-1.5       | 2 fA       | CMOS, rail-to-rail       |
| CA3140  | 100        | 4.5         | 9               | 2-15          | 10 pA      | BiMOS, high $Z_{in}$     |

## Design Tradeoffs

- **Precision vs. Speed:** High precision op-amps often have lower bandwidth
- **Input Type:** BJT (low  $V_{OS}$ ), JFET (low  $I_B$ ), CMOS (ultra-low  $I_B$ )
- **Power vs. Performance:** Lower power  $\rightarrow$  lower speed/drive capability

# Summary: Real Op-Amp Specifications

## DC Specifications:

- Open-loop gain:  $A_0$  (finite, not infinite)
- Input offset voltage:  $V_{OS}$
- Input bias current:  $I_B$
- Input offset current:  $I_{OS}$
- Temperature drift:  $dV_{OS}/dT$ ,  $dI_B/dT$

## Frequency Response:

- Open-loop gain:  
 $A(f) = A_0/(1 + jf/f_b)$
- Unity-gain frequency:  $f_t$
- Gain-bandwidth product:  
 $G \times BW = f_t$

## Dynamic Limitations:

- Slew rate:  $SR$  ( $V/\mu s$ )
- Full-power bandwidth:  
 $f_{FP} = SR/(2\pi V_p)$
- Settling time, rise time
- Output swing limitations

## Other Specifications:

- CMRR (common-mode rejection)
- PSRR (power supply rejection)
- Input impedance:  $R_{in}$
- Output impedance:  $R_{out}$
- Maximum output current



# Key Formulas Reference

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| Parameter              | Formula   |
|------------------------|---|
| Open-loop gain (AC)    | $A(f) = \frac{A_0}{1 + jf/f_b}$                 |
| Unity-gain frequency   | $f_t = A_0 \cdot f_b$                           |
| Closed-loop bandwidth  | $f_{-3dB} = \frac{f_t}{G_{closed}}$             |
| Gain-bandwidth product | $G \times BW = f_t = \text{constant}$           |
| Full-power bandwidth   | $f_{FP} = \frac{SR}{2\pi V_p}$                  |
| Rise time              | $t_r \approx \frac{0.35}{f_{-3dB}}$             |
| Max slew rate          | $SR = \left  \frac{dv_{out}}{dt} \right _{max}$ |
|                        |   |

# Practice Problem 1

**Given:** A non-inverting amplifier using a 741 op-amp ( $f_t = 1$  MHz,  $SR = 0.5$  V/ $\mu$ s) with  $R_i = 1$  k $\Omega$  and  $R_f = 99$  k $\Omega$ .

**Find:**

- (a) The ideal closed-loop gain
- (b) The small-signal bandwidth
- (c) The maximum output voltage swing at 10 kHz without slew-rate distortion
- (d) The full-power bandwidth for  $V_{out,p} = 10$  V

**Hints:**

- $G = 1 + R_f/R_i$
- $f_{-3dB} = f_t/G$
- $SR = 2\pi f V_p$  (for undistorted sine wave)
- $f_{FP} = SR/(2\pi V_p)$

# Practice Problem 1 Solution

**Given:**  $R_i = 1 \text{ k}\Omega$ ,  $R_f = 99 \text{ k}\Omega$ ,  $f_t = 1 \text{ MHz}$ ,  $SR = 0.5 \text{ V}/\mu\text{s}$

**(a) Closed-loop gain:**

$$G = 1 + \frac{R_f}{R_i} = 1 + \frac{99 \text{ k}\Omega}{1 \text{ k}\Omega} = 1 + 99 = 100$$

**(b) Small-signal bandwidth:**

$$f_{-3dB} = \frac{f_t}{G} = \frac{1 \text{ MHz}}{100} = 10 \text{ kHz}$$

**(c) Max output at 10 kHz:**

For no slew-rate distortion:  $SR = 2\pi f V_p$

$$V_p = \frac{SR}{2\pi f} = \frac{0.5 \times 10^6 \text{ V/s}}{2\pi \times 10,000 \text{ Hz}} = 7.96 \text{ V}$$

**(d) Full-power bandwidth for 10 V:**

$$f_{FP} = \frac{SR}{2\pi V_p} = \frac{0.5 \times 10^6}{2\pi \times 10} = 7.96 \text{ kHz}$$

## Practice Problem 2

**Given:** An inverting amplifier with gain of  $-50$  using an OP07 op-amp:

- $A_0 = 1,000,000$  (120 dB)
- $V_{OS} = 50 \mu\text{V}$  at  $25^\circ\text{C}$
- $dV_{OS}/dT = 0.3 \mu\text{V}/^\circ\text{C}$
- $I_B = 2 \text{ nA}$
- $R_i = 10 \text{ k}\Omega$

**Find:**

- (a)  $R_f$  for the desired gain
- (b) Output offset voltage due to  $V_{OS}$  at  $25^\circ\text{C}$
- (c) Additional output error due to  $I_B$  (worst case)
- (d) Total output offset at  $70^\circ\text{C}$

## Practice Problem 2 Solution

### (a) Feedback resistor:

For inverting amplifier:  $G = -R_f/R_i = -50$

$$R_f = 50 \times R_i = 50 \times 10 \text{ k}\Omega = 500 \text{ k}\Omega$$

### (b) Output offset at 25°C:

Inverting config acts like non-inverting for offset:  $|G| = 1 + R_f/R_i = 51$

$$V_{out,offset} = V_{OS} \times 51 = 50 \mu\text{V} \times 51 = 2.55 \text{ mV}$$

### (c) Error from bias current:

$$V_{error,IB} = I_B \times R_f = 2 \text{ nA} \times 500 \text{ k}\Omega = 1 \text{ mV}$$

### (d) Total offset at 70°C:

$$\Delta T = 70 - 25 = 45^\circ\text{C}$$

$$V_{OS,70} = 50 \mu\text{V} + (0.3 \mu\text{V}/^\circ\text{C}) \times 45^\circ\text{C} = 63.5 \mu\text{V}$$

$$V_{out,total} = (63.5 \mu\text{V} \times 51) + 1 \text{ mV} = 3.24 \text{ mV} + 1 \text{ mV} = 4.24 \text{ mV}$$

# Practice Problem 3

**Scenario:** You need to amplify a 1 kHz sine wave from 100 mV peak to 5 V peak with less than 1% distortion.

**Given two op-amp options:**

- **Option A:**  $f_t = 1 \text{ MHz}$ ,  $\text{SR} = 0.5 \text{ V}/\mu\text{s}$
- **Option B:**  $f_t = 10 \text{ MHz}$ ,  $\text{SR} = 10 \text{ V}/\mu\text{s}$

**Questions:**

- (a) What gain is required?
- (b) Is Option A suitable? Check both bandwidth and slew rate.
- (c) Is Option B suitable? Check both bandwidth and slew rate.
- (d) Which would you choose and why?

# Practice Problem 3 Solution

## (a) Required gain:

$$G = \frac{V_{out,p}}{V_{in,p}} = \frac{5 \text{ V}}{0.1 \text{ V}} = 50$$

## (b) Option A - Check:

Bandwidth:  $f_{-3dB} = f_t/G = 1 \text{ MHz}/50 = 20 \text{ kHz} > 1 \text{ kHz}$  😊

Slew rate: Required  $SR = 2\pi f V_p = 2\pi \times 1000 \times 5 = 31.4 \text{ kV/s} = 0.031 \text{ V}/\mu\text{s}$

Available  $SR = 0.5 \text{ V}/\mu\text{s} > 0.031 \text{ V}/\mu\text{s}$  😊

**Option A is suitable!**

## (c) Option B - Check:

Bandwidth:  $f_{-3dB} = 10 \text{ MHz}/50 = 200 \text{ kHz} \gg 1 \text{ kHz}$  😊

Slew rate: Available  $= 10 \text{ V}/\mu\text{s} \gg 0.031 \text{ V}/\mu\text{s}$  😊

**Option B is also suitable (with margin)!**

**(d) Recommendation:** Choose **Option A** — adequate performance at likely lower cost. Option B is over-specified for this application.