EE 230
Lecture 16

Nonideal Op Amp Characteristics
Quiz 11

The dc gain of this circuit was measured to be 5 and the 3dB bandwidth was measured to be 600KHz. Determine as many of the following as possible from this information if it is known that the op amp can be modeled as a single-pole lowpass amplifier.

Ao (dc gain of the Op Amp)

P (pole of the Op Amp)

GB (gain-bandwidth product of Op Amp)
And the number is?

1  3  8

4

5

2

6

9

7
And the number is 5.
Quiz 11  Solution:

The dc gain of this circuit was measured to be 5 and the 3dB bandwidth was measured to be 600KHz. Determine as many of the following as possible from this information if it is known that the op amp can be modeled as a single-pole lowpass amplifier.

- $A_o$ (dc gain of the Op Amp)
- $p$ (pole of the Op Amp)
- $GB$ (gain-bandwidth product of Op Amp)

Insufficient information to determine $A_o$ or $p$

$$GB = K_o BW = \left(1 + \frac{R_2}{R_1}\right) BW$$
The dc gain of this circuit was measured to be 5 and the 3dB bandwidth was measured to be 600KHz. Determine as many of the following as possible from this information if it is known that the op amp can be modeled as a single-pole lowpass amplifier.

 Ao (dc gain of the Op Amp) Insufficient information to determine Ao or p

 p (pole of the Op Amp) A_0 or p

 GB (gain-bandwidth product of Op Amp)

\[ GB = \text{K}_o \cdot \text{BW} = (1 + \frac{R_2}{R_1}) \cdot \text{BW} \]

GB = 5 \cdot 600KHz = 3MHz = (18.8M \text{Rad/Sec})
Nonideal op amp characteristics

- Finite Gain
- Finite BW
- Compensation
  - Output Saturation
  - Slew Rate
  - $R_{IN}$ & $R_{OUT}$
  - Offset Voltage
  - Bias Currents
  - CMRR
  - PSRR
  - Offset Current
  - Full Power Bandwidth

Review from Last Time:
Review from Last Time:

Finite GB and BW

\[ A_o \omega_b = GB \]

GB termed Gain-Bandwidth Product

\[ A(s) = \frac{A_o}{s + \frac{\omega_b}{s}} \quad \text{or} \quad A(s) = \frac{GB}{s} \]
Review from Last Time:

Basic inverting or noninverting amplifier useful for measuring GB

Macromodel of op amp

\[
\frac{V_o}{V_i} = \frac{A_o}{1 + \frac{s}{\omega_b}}
\]

If \( C=1F \)

\[
R = \frac{1}{\omega_b}
\]

\[
BW = \frac{GB}{K_o}
\]

\[
BW = \frac{GB}{1 + K_o}
\]
Essentially all op amp circuits designed to operate linearly will be unstable if the input terminals of the operational amplifier are interchanged!!

The ability to make this determination is one of the major reasons for studying stability in this course.
Nonideal op amp characteristics

- Finite Gain
- Finite BW
- Compensation
- Output Saturation
- Slew Rate
- $R_{IN}$ & $R_{OUT}$
- Offset Voltage
- Bias Currents
- CMRR
- PSRR
- Offset Current
- Full Power Bandwidth
Output Saturation

- Voltage Limit → Maximum or minimum output voltages an op amp can provide
- Current Limit → Maximum or minimum output currents an op amp can provide

Often \( V_{\text{omax}} \approx V_{\text{DD}} - 1.2V \)

\( V_{\text{omin}} \approx V_{\text{SS}} + 1.2V \)

Nonlinear distortion is introduced
Output current saturation provides similar limits to what was seen with output voltage saturation.

Usually tell difference between voltage and current saturation by looking at saturation voltage.
Nonideal op amp characteristics

- Finite Gain
- Finite BW
- Compensation
- Output Saturation
- Slew Rate
- $R_{\text{IN}}$ & $R_{\text{OUT}}$
- Offset Voltage
- Bias Currents
- CMRR
- PSRR
- Offset Current
- Full Power Bandwidth
Slew Rate

Maximum Rate of Change at Output of Op Amp.

\[ V_o = \frac{1 + \frac{R_2}{R_1}}{K_0} \]

If \( V_i(t) \) is a square wave of height \( V_m \), ideally \( V_o(t) \) will be a square wave of height \( K_0 V_m \).

Actual Output:

\[ V_o(t) \]

\( S_R \) in \( V/msec \)

1\( V/msec \) to 100\( V/msec \)
SR with sinusoidal signals

Slew rate limits
\[ V_0 = V_m \sin (\omega t + \theta) \]
\[ \frac{dV_0}{dt} = V_m \cos (\omega t + \theta) \omega < SR \]

To avoid slew distortion

\[ V_m \omega < SR \]

If \( V_m \omega \) significantly larger than \( SR \)

output will become a triangle wave
Nonideal op amp characteristics

- Finite Gain
- Finite BW
- Compensation
- Output Saturation
- Slew Rate
- Offset Voltage
- Bias Currents
- CMRR
- PSRR
- Offset Current
- Full Power Bandwidth

\[ R_{\text{IN}} & R_{\text{OUT}} \]
$R_{IN}$ and $R_{OUT}$

$R_{IN}$ is the input impedance to an op amp
(a few $M\Omega$ for bipolar inputs, many $G\Omega$ for FET input op amps)

$R_{OUT}$ is the output impedance of an op amp
(in the $75\Omega$ range)

Macromodel including $R_{IN}$ and $R_{OUT}$

Several thousand commercially available op amps, specs can vary considerably!
Nonideal op amp characteristics

- Finite Gain
- Finite BW
- Compensation
- Output Saturation
- Slew Rate
- $R_{IN} \& R_{OUT}$
- Offset Voltage
- Bias Currents
- CMRR
- PSRR
- Offset Current
- Full Power Bandwidth
Offset Voltage  (Input Referred Offset Voltage)

$V_0$  

$A_0$  

$V_0$  

$V_{os}$  

$V_{os}$ can be positive or negative

$V_{os}$ is a random variable
$V_{os}$ can be modeled with a dc voltage source in series with input terminal.

Effects of $V_{os}$ on basic noninverting amplifier

$V_0 = V_x \left(1 + \frac{R_2}{R_1}\right) + V_{os} \left(1 + \frac{R_2}{R_1}\right)$
If \( V_i \gg V_{os} \), \( V_{os} \) does not adversely affect performance.

\[ V_i \sim V_{os} \], \( V_{os} \) presents a major problem.

\[ V_i \ll V_{os} \], \( V_{os} \) is very difficult to manage.

\[ V_o = V_i \left(1 + \frac{R_2}{R_1}\right) + V_{os} \left(1 + \frac{R_2}{R_1}\right)\]

If \( V_{os} = 3 \text{mV} \)
\[ V_i = 3 \text{mV} \]
\[ 1 + \frac{R_2}{R_1} = 1000 \]

\[ V_{os,\text{input}} = (3 \text{mV})(1000) = 3 \text{V} \]
\[ V_{o,\text{actual}} = (3 \text{mV})(1000) + (3 \text{mV})(1000) = 6 \text{V} \]
Methods of managing VOs

1) Cap. Coupling
2) Trimming VOs
3) Use the premium on
If \( V_i = V_m \sin \omega t \)

\[ V_{os} = 3 \text{ mV} \]
\[ R_V = 1000 \]

Measurement of \( V_{os} \) (must be on every device if of concern)

\[ V_o = V_{os} (1 + 100) \]

\[ V_{os} = \frac{V_o}{101} \]
End of lecture
Nonideal op amp characteristics

- Finite Gain
- Finite BW
- Compensation
- Output Saturation
- Slew Rate
- $R_{\text{IN}}$ & $R_{\text{OUT}}$
- Offset Voltage
- Bias Currents
- CMRR
- PSRR
- Offset Current
- Full Power Bandwidth
Bias and Offset Currents

$I_{\text{BIAS}}$ is small for bipolar input op amps, extremely small for FET input op amps.

Can be neglected in most designs regardless of whether FET or Bipolar input.

Typical question on many interviews

\[ I_{\text{OFFSET}} = I_{\text{BIAS1}} - I_{\text{BIAS2}} \]

$I_{\text{OFFSET}}$ is a random variable with zero mean for most designs.

$I_{\text{BIAS}}$ around 50 nA for 741, $I_{\text{OFFSET}}$ around 3nA for 741.
The μA741 is a general-purpose operational amplifier featuring offset-voltage null capability. The high common-mode input voltage range and the absence of latch-up make the amplifier ideal for voltage-follower applications. The device is short-circuit protected and the internal frequency compensation ensures stability without external components. A low value potentiometer may be connected between the offset null inputs to null out the offset voltage as shown in Figure 2.

The μA741C is characterized for operation from 0°C to 70°C. The μA741I is characterized for operation from −40°C to 85°C. The μA741M is characterized for operation over the full military temperature range of −55°C to 125°C.
### AVAILABLE OPTIONS

<table>
<thead>
<tr>
<th>$T_A$</th>
<th>SMALL OUTLINE (D)</th>
<th>CHIP CARRIER (FK)</th>
<th>CERAMIC DIP (J)</th>
<th>CERAMIC DIP (JG)</th>
<th>PLASTIC DIP (P)</th>
<th>TSSOP (PW)</th>
<th>FLAT PACK (U)</th>
<th>CHIP FORM (Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C to 70°C</td>
<td>μA741CD</td>
<td></td>
<td>μA741CP</td>
<td>μA741CPW</td>
<td>μA741Y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>−40°C to 85°C</td>
<td>μA741ID</td>
<td>μA741IFK</td>
<td>μA741MJ</td>
<td>μA741MJG</td>
<td>μA741MU</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>−55°C to 125°C</td>
<td>μA741MFK</td>
<td>μA741MJ</td>
<td>μA741MJG</td>
<td>μA741MJG</td>
<td>μA741MU</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The D package is available taped and reeled. Add the suffix R (e.g., μA741CDR).

### Schematic

![Schematic Diagram]

**Component Count**

- Transistors: 22
- Resistors: 11
- Diode: 1
- Capacitor: 1

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**Texas Instruments**

POST OFFICE BOX 655303 • DALLAS, TEXAS 75265
μA741Y chip information

This chip, when properly assembled, displays characteristics similar to the μA741C. Thermal compression or ultrasonic bonding may be used on the doped-aluminum bonding pads. Chips may be mounted with conductive epoxy or a gold-silicon preform.

CHIP THICKNESS: 15 TYPICAL
BONDING PADS: 4 × 4 MINIMUM
T_Jmax = 150°C.
TOLERANCES ARE ±10%.
ALL DIMENSIONS ARE IN MILS.
### absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

<table>
<thead>
<tr>
<th>Parameter</th>
<th>µA741C</th>
<th>µA741I</th>
<th>µA741M</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage, VCC⁺ (see Note 1)</td>
<td>18</td>
<td>22</td>
<td>22</td>
<td>V</td>
</tr>
<tr>
<td>Supply voltage, VCC⁻ (see Note 1)</td>
<td>−18</td>
<td>−22</td>
<td>−22</td>
<td>V</td>
</tr>
<tr>
<td>Differential input voltage, V ID (see Note 2)</td>
<td>±15</td>
<td>±30</td>
<td>±30</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage, V₁ any input (see Notes 1 and 3)</td>
<td>±15</td>
<td>±15</td>
<td>±15</td>
<td>V</td>
</tr>
<tr>
<td>Voltage between offset null (either OFFSET N1 or OFFSET N2) and VCC⁻</td>
<td>±15</td>
<td>±0.5</td>
<td>±0.5</td>
<td>V</td>
</tr>
<tr>
<td>Duration of output short circuit (see Note 4)</td>
<td>unlimited</td>
<td>unlimited</td>
<td>unlimited</td>
<td></td>
</tr>
<tr>
<td>Continuous total power dissipation</td>
<td>See Dissipation Rating Table</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating free-air temperature range, TA</td>
<td>0 to 70</td>
<td>−40 to 85</td>
<td>−55 to 125</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>−65 to 150</td>
<td>−65 to 150</td>
<td>−65 to 150</td>
<td>°C</td>
</tr>
<tr>
<td>Case temperature for 60 seconds</td>
<td>FK package</td>
<td>260</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Lead temperature 1.6 mm (1/16 inch) from case for 60 seconds</td>
<td>J, JG, or U package</td>
<td>300</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Lead temperature 1.6 mm (1/16 inch) from case for 10 seconds</td>
<td>D, P, or PW package</td>
<td>260</td>
<td>260</td>
<td>°C</td>
</tr>
</tbody>
</table>

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

**NOTES:**
1. All voltage values, unless otherwise noted, are with respect to the midpoint between VCC⁺ and VCC⁻.
2. Differential voltages are at IN⁺ with respect to IN⁻.
3. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 V, whichever is less.
4. The output may be shorted to ground or either power supply. For the µA741M only, the unlimited duration of the short circuit applies at (or below) 125°C case temperature or 75°C free-air temperature.

### DISSIPATION RATING TABLE

<table>
<thead>
<tr>
<th>PACKAGE</th>
<th>T A ≤ 25°C POWER RATING</th>
<th>DERATING FACTOR</th>
<th>DERATE ABOVE T A</th>
<th>T A = 70°C POWER RATING</th>
<th>T A = 85°C POWER RATING</th>
<th>T A = 125°C POWER RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>500 mW</td>
<td>5.8 mW/°C</td>
<td>64°C</td>
<td>464 mW</td>
<td>377 mW</td>
<td>N/A</td>
</tr>
<tr>
<td>FK</td>
<td>500 mW</td>
<td>11.0 mW/°C</td>
<td>105°C</td>
<td>500 mW</td>
<td>500 mW</td>
<td>275 mW</td>
</tr>
<tr>
<td>J</td>
<td>500 mW</td>
<td>11.0 mW/°C</td>
<td>105°C</td>
<td>500 mW</td>
<td>500 mW</td>
<td>275 mW</td>
</tr>
<tr>
<td>JG</td>
<td>500 mW</td>
<td>8.4 mW/°C</td>
<td>90°C</td>
<td>500 mW</td>
<td>500 mW</td>
<td>210 mW</td>
</tr>
<tr>
<td>P</td>
<td>500 mW</td>
<td>N/A</td>
<td>N/A</td>
<td>500 mW</td>
<td>500 mW</td>
<td>N/A</td>
</tr>
<tr>
<td>PW</td>
<td>525 mW</td>
<td>4.2 mW/°C</td>
<td>25°C</td>
<td>336 mW</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>U</td>
<td>500 mW</td>
<td>5.4 mW/°C</td>
<td>57°C</td>
<td>432 mW</td>
<td>351 mW</td>
<td>135 mW</td>
</tr>
</tbody>
</table>
### Electrical Characteristics

Electrical characteristics at specified free-air temperature, V<sub>CC</sub> = ±15 V (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>TA†</th>
<th>μA741C</th>
<th>μA741I, μA741M</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;sub&gt;IO&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0</td>
<td>25°C</td>
<td>1</td>
<td>6</td>
<td>mV</td>
</tr>
<tr>
<td>ΔV&lt;sub&gt;IO(adj)&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0</td>
<td>25°C</td>
<td>±15</td>
<td>±15</td>
<td>mV</td>
</tr>
<tr>
<td>I&lt;sub&gt;IO&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0</td>
<td>25°C</td>
<td>20</td>
<td>200</td>
<td>nA</td>
</tr>
<tr>
<td>I&lt;sub&gt;B&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0</td>
<td>25°C</td>
<td>80</td>
<td>500</td>
<td>nA</td>
</tr>
<tr>
<td>V&lt;sub&gt;ICR&lt;/sub&gt;</td>
<td></td>
<td>25°C</td>
<td>±12</td>
<td>±12</td>
<td>V</td>
</tr>
<tr>
<td>V&lt;sub&gt;OM&lt;/sub&gt;</td>
<td>R&lt;sub&gt;L&lt;/sub&gt; ≥ 10 kΩ</td>
<td>25°C</td>
<td>±12</td>
<td>±12</td>
<td>V</td>
</tr>
<tr>
<td>A&lt;sub&gt;V&lt;/sub&gt;D</td>
<td>R&lt;sub&gt;L&lt;/sub&gt; ≥ 2 kΩ</td>
<td>25°C</td>
<td>20</td>
<td>200</td>
<td>V/mV</td>
</tr>
<tr>
<td>r&lt;sub&gt;i&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = ±10 V</td>
<td>25°C</td>
<td>15</td>
<td>25</td>
<td>Ω</td>
</tr>
<tr>
<td>r&lt;sub&gt;o&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0</td>
<td>25°C</td>
<td>75</td>
<td>75</td>
<td>Ω</td>
</tr>
<tr>
<td>C&lt;sub&gt;i&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0</td>
<td>25°C</td>
<td>1.4</td>
<td>1.4</td>
<td>pF</td>
</tr>
<tr>
<td>CMRR</td>
<td>V&lt;sub&gt;IC&lt;/sub&gt; = V&lt;sub&gt;ICR&lt;/sub&gt;</td>
<td>25°C</td>
<td>70</td>
<td>70</td>
<td>dB</td>
</tr>
<tr>
<td>k&lt;sub&gt;S&lt;/sub&gt;VS</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = ±9 V to ±15 V</td>
<td>25°C</td>
<td>30</td>
<td>150</td>
<td>μV/V</td>
</tr>
<tr>
<td>I&lt;sub&gt;OS&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0, No load</td>
<td>25°C</td>
<td>±25</td>
<td>±40</td>
<td>mA</td>
</tr>
<tr>
<td>I&lt;sub&gt;CC&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0, No load</td>
<td>25°C</td>
<td>1.7</td>
<td>2.8</td>
<td>mA</td>
</tr>
<tr>
<td>P&lt;sub&gt;D&lt;/sub&gt;</td>
<td>V&lt;sub&gt;O&lt;/sub&gt; = 0, No load</td>
<td>25°C</td>
<td>50</td>
<td>85</td>
<td>mW</td>
</tr>
</tbody>
</table>

† All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified. Full range for μA741C is 0°C to 70°C, the μA741I is −40°C to 85°C, and the μA741M is −55°C to 125°C.

### Operating Characteristics

Operating characteristics, V<sub>CC</sub> = ±15 V, TA = 25°C

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>μA741C</th>
<th>μA741I, μA741M</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>τ&lt;sub&gt;r&lt;/sub&gt;</td>
<td>V&lt;sub&gt;I&lt;/sub&gt; = 20 mV, R&lt;sub&gt;L&lt;/sub&gt; = 2 kΩ, C&lt;sub&gt;L&lt;/sub&gt; = 100 pF, See Figure 1</td>
<td>0.3</td>
<td>0.3</td>
<td>μs</td>
</tr>
<tr>
<td>Overshoot factor</td>
<td>V&lt;sub&gt;I&lt;/sub&gt; = 10 V, R&lt;sub&gt;L&lt;/sub&gt; = 2 kΩ, C&lt;sub&gt;L&lt;/sub&gt; = 100 pF, See Figure 1</td>
<td>5%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>V&lt;sub&gt;I&lt;/sub&gt; = 10 V, R&lt;sub&gt;L&lt;/sub&gt; = 2 kΩ, C&lt;sub&gt;L&lt;/sub&gt; = 100 pF, See Figure 1</td>
<td>0.5</td>
<td>0.5</td>
<td>V/μs</td>
</tr>
</tbody>
</table>
electrical characteristics at specified free-air temperature, $V_{CC} = \pm 15$ V, $T_A = 25^\circ$C (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>$\mu$A741Y</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IO}$</td>
<td>$V_O = 0$</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>$\Delta V_{IO(adj)}$</td>
<td>$V_O = 0$</td>
<td>$\pm 15$</td>
<td>mV</td>
</tr>
<tr>
<td>$I_{IB}$</td>
<td>$V_O = 0$</td>
<td>$20$</td>
<td>$200$ nA</td>
</tr>
<tr>
<td>$V_{ICR}$</td>
<td>$R_L = 10 , k\Omega$</td>
<td>$\pm 12$</td>
<td>$\pm 13$ V</td>
</tr>
<tr>
<td>$V_{OM}$</td>
<td>$R_L = 2 , k\Omega$</td>
<td>$\pm 10$</td>
<td>$\pm 13$ V</td>
</tr>
<tr>
<td>$AVD$</td>
<td>$R_L \geq 2 , k\Omega$</td>
<td>20</td>
<td>200 V/mV</td>
</tr>
<tr>
<td>$r_i$</td>
<td>$R_L = 2 , k\Omega$, See Note 5</td>
<td>0.3</td>
<td>2 M$\Omega$</td>
</tr>
<tr>
<td>$r_o$</td>
<td>$V_O = 0$, See Note 5</td>
<td>75</td>
<td>$\Omega$</td>
</tr>
<tr>
<td>$C_i$</td>
<td></td>
<td>1.4</td>
<td>pF</td>
</tr>
<tr>
<td>$CMRR$</td>
<td>$V_{IC} = V_{ICR}$min</td>
<td>70</td>
<td>90 dB</td>
</tr>
<tr>
<td>$k_{SVS}$</td>
<td>$V_{CC} = \pm 9$ V to $\pm 15$ V</td>
<td>30</td>
<td>150 $\mu$V/V</td>
</tr>
<tr>
<td>$I_{OS}$</td>
<td>$V_O = 0$, No load</td>
<td>$\pm 25$</td>
<td>$\pm 40$ mA</td>
</tr>
<tr>
<td>$I_{CC}$</td>
<td>$V_O = 0$, No load</td>
<td>1.7</td>
<td>2.8 mA</td>
</tr>
<tr>
<td>$PD$</td>
<td>$V_O = 0$, No load</td>
<td>50</td>
<td>85 mW</td>
</tr>
</tbody>
</table>

† All characteristics are measured under open-loop conditions with zero common-mode voltage unless otherwise specified.

NOTE 5: This typical value applies only at frequencies above a few hundred hertz because of the effects of drift and thermal feedback.

operating characteristics, $V_{CC} = \pm 15$ V, $T_A = 25^\circ$C

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>$\mu$A741Y</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_r$</td>
<td>$V_I = 20$ mV, $R_L = 2 , k\Omega$, $C_L = 100 , pF$, See Figure 1</td>
<td>0.3</td>
<td>$\mu$s</td>
</tr>
<tr>
<td>Overshoot factor</td>
<td></td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>$SR$</td>
<td>$V_I = 10$ V, $R_L = 2 , k\Omega$, $C_L = 100 , pF$, See Figure 1</td>
<td>0.5</td>
<td>V/$\mu$s</td>
</tr>
</tbody>
</table>
PARAMETER MEASUREMENT INFORMATION

Figure 1. Rise Time, Overshoot, and Slew Rate

APPLICATION INFORMATION

Figure 2 shows a diagram for an input offset voltage null circuit.

Figure 2. Input Offset Voltage Null Circuit
TYPICAL CHARACTERISTICS†

**INPUT OFFSET CURRENT vs FREE-AIR TEMPERATURE**

![Graph showing input offset current vs free-air temperature](image)

**INPUT BIAS CURRENT vs FREE-AIR TEMPERATURE**

![Graph showing input bias current vs free-air temperature](image)

**MAXIMUM PEAK OUTPUT VOLTAGE vs LOAD RESISTANCE**

![Graph showing maximum peak output voltage vs load resistance](image)

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.
TYPICAL CHARACTERISTICS

MAXIMUM PEAK OUTPUT VOLTAGE

vs

FREQUENCY

Figure 6

OPEN-LOOP SIGNAL DIFFERENTIAL

VOLTAGE AMPLIFICATION

vs

SUPPLY VOLTAGE

Figure 7

OPEN-LOOP LARGE-SIGNAL DIFFERENTIAL

VOLTAGE AMPLIFICATION

vs

FREQUENCY

Figure 8
**TYPICAL CHARACTERISTICS**

**COMMON-MODE REJECTION RATIO**

\[ \text{CMRR} = \text{Common-Mode Rejection Ratio} \quad \text{dB} \]

- \( V_{CC+} = 15 \text{ V} \)
- \( V_{CC-} = -15 \text{ V} \)
- \( B_S = 10 \text{ k} \Omega \)
- \( T_A = 25^\circ \text{C} \)

---

**OUTPUT VOLTAGE**

\[ V_O = \text{Output Voltage} \quad \text{mV} \]

- \( V_{CC+} = 15 \text{ V} \)
- \( V_{CC-} = -15 \text{ V} \)
- \( R_L = 2 \text{ k} \Omega \)
- \( C_L = 100 \text{ pF} \)
- \( T_A = 25^\circ \text{C} \)

---

**VOLTAGE-FOLLOWER**

**LARGE-SIGNAL PULSE RESPONSE**

- \( V_{CC+} = 15 \text{ V} \)
- \( V_{CC-} = -15 \text{ V} \)
- \( R_L = 2 \text{ k} \Omega \)
- \( C_L = 100 \text{ pF} \)
- \( T_A = 25^\circ \text{C} \)

---

Figure 8

Figure 9

Figure 10
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LM741
Operational Amplifier

General Description
The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications. The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Features

Connection Diagrams

Metal Can Package

Dual-In-Line or S.O. Package

Ceramic Flatpak

Order Number LM741H, LM741H/883 (Note 1), LM741AH/883 or LM741CH
See NS Package Number H08C

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit
Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 7)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LM741A</th>
<th>LM741</th>
<th>LM741C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>±22V</td>
<td>±22V</td>
<td>±18V</td>
</tr>
<tr>
<td>Power Dissipation (Note 3)</td>
<td>500 mW</td>
<td>500 mW</td>
<td>500 mW</td>
</tr>
<tr>
<td>Differential Input Voltage</td>
<td>±30V</td>
<td>±30V</td>
<td>±30V</td>
</tr>
<tr>
<td>Input Voltage (Note 4)</td>
<td>±15V</td>
<td>±15V</td>
<td>±15V</td>
</tr>
<tr>
<td>Output Short Circuit Duration</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>-55˚C to +125˚C</td>
<td>-55˚C to +125˚C</td>
<td>0˚C to +70˚C</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>-65˚C to +150˚C</td>
<td>-65˚C to +150˚C</td>
<td>-65˚C to +150˚C</td>
</tr>
<tr>
<td>Junction Temperature</td>
<td>150˚C</td>
<td>150˚C</td>
<td>100˚C</td>
</tr>
</tbody>
</table>

Soldering Information

- N-Package (10 seconds): 260˚C
- J- or H-Package (10 seconds): 300˚C
- M-Package
  - Vapor Phase (60 seconds): 215˚C
  - Infrared (15 seconds): 215˚C

See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.

ESD Tolerance (Note 8): 400V

Electrical Characteristics (Note 5)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>LM741A</th>
<th>LM741</th>
<th>LM741C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Offset Voltage</td>
<td>( T_A = 25^\circ C )</td>
<td>0.8</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>( R_S \leq 10 ) kΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R_S \leq 50 ) Ω</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}} )</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R_S \leq 50 ) Ω</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R_S \leq 10 ) kΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Offset Voltage Drift</td>
<td>( T_A = 25^\circ C ), ( V_{SB} = \pm 20V )</td>
<td>±10</td>
<td></td>
<td>±15</td>
</tr>
<tr>
<td>Input Offset Current</td>
<td>( T_A = 25^\circ C )</td>
<td>3.0</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>( T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}} )</td>
<td>70</td>
<td>85</td>
<td>500</td>
</tr>
<tr>
<td>Average Input Offset Current Drift</td>
<td>( T_A = 25^\circ C )</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Bias Current</td>
<td>( T_A = 25^\circ C )</td>
<td>30</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>( T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}} )</td>
<td>0.210</td>
<td>1.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Input Resistance</td>
<td>( T_A = 25^\circ C ), ( V_{SB} = \pm 20V )</td>
<td>1.0</td>
<td>6.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>( T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( V_{SB} = \pm 20V )</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage Range</td>
<td>( T_A = 25^\circ C )</td>
<td>±12</td>
<td></td>
<td>±13</td>
</tr>
<tr>
<td></td>
<td>( T_{\text{AMIN}} \leq T_A \leq T_{\text{AMAX}} )</td>
<td>±12</td>
<td></td>
<td>±13</td>
</tr>
</tbody>
</table>

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### Electrical Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>LM741A</th>
<th>LM741</th>
<th>LM741C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large Signal Voltage Gain</strong></td>
<td>$T_A = 25^\circ C$, $R_L \geq 2 , \text{k}\Omega$</td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>$V_S = \pm 20, \text{V}$, $V_O = \pm 15, \text{V}$</td>
<td>50</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>$V_S = \pm 15, \text{V}$, $V_O = \pm 10, \text{V}$</td>
<td>32</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td><strong>Output Voltage Swing</strong></td>
<td>$V_S = \pm 20, \text{V}$, $R_L \geq 10 , \text{k}\Omega$</td>
<td>±16</td>
<td>±16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R_L \geq 2 , \text{k}\Omega$</td>
<td>±15</td>
<td>±15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_S = \pm 15, \text{V}$, $V_O = \pm 10, \text{V}$</td>
<td>±12</td>
<td>±12</td>
<td>±14</td>
</tr>
<tr>
<td></td>
<td>$R_L \geq 2 , \text{k}\Omega$</td>
<td>±10</td>
<td>±10</td>
<td>±13</td>
</tr>
<tr>
<td><strong>Output Short Circuit Current</strong></td>
<td>$T_A = 25^\circ C$, $T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$</td>
<td>10</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>$R_S \leq 10 , \text{k}\Omega$, $V_{\text{CM}} = \pm 12, \text{V}$</td>
<td>80</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td><strong>Common-Mode Rejection Ratio</strong></td>
<td>$T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$, $R_S \leq 50, \text{\Omega}$, $V_{\text{CM}} = \pm 12, \text{V}$</td>
<td>86</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td><strong>Supply Voltage Rejection Ratio</strong></td>
<td>$T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$, $V_S = \pm 20, \text{V}$ to $V_S = \pm 5, \text{V}$</td>
<td>0.25</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R_S \leq 10 , \text{k}\Omega$</td>
<td>6.0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td><strong>Transient Response</strong></td>
<td>$T_A = 25^\circ C$, Unity Gain $R_S \leq 10 , \text{k}\Omega$</td>
<td>0.25</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_S = \pm 20, \text{V}$</td>
<td>6.0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td><strong>Bandwidth (Note 6)</strong></td>
<td>$T_A = 25^\circ C$</td>
<td>0.437</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td><strong>Slew Rate</strong></td>
<td>$T_A = 25^\circ C$, Unity Gain</td>
<td>0.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td><strong>Supply Current</strong></td>
<td>$T_A = 25^\circ C$</td>
<td>1.7</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>$T_A = 25^\circ C$, $V_S = \pm 20, \text{V}$</td>
<td>80</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_S = \pm 15, \text{V}$</td>
<td>50</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td><strong>LM741A</strong></td>
<td>$V_S = \pm 20, \text{V}$</td>
<td>165</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LM741</strong></td>
<td>$V_S = \pm 15, \text{V}$</td>
<td>60</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
| **Note 2:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.
Electrical Characteristics (Note 5)  (Continued)

Note 3: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and $T_j$ max. (listed under “Absolute Maximum Ratings”). $T_j = T_A + (\theta_{JA} P_D)$.

<table>
<thead>
<tr>
<th>Thermal Resistance</th>
<th>Cerdip (J)</th>
<th>DIP (N)</th>
<th>HO8 (H)</th>
<th>SO-8 (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_{JA}$ (Junction to Ambient)</td>
<td>100˚C/W</td>
<td>100˚C/W</td>
<td>170˚C/W</td>
<td>195˚C/W</td>
</tr>
<tr>
<td>$\theta_{JC}$ (Junction to Case)</td>
<td>N/A</td>
<td>N/A</td>
<td>25˚C/W</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 5: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55˚C \leq T_A \leq +125˚C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0˚C \leq T_A \leq +70˚C$.

Note 6: Calculated value from: $BW$ (MHz) = 0.35/Rise Time(µs).

Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 8: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram
Physical Dimensions inches (millimeters) unless otherwise noted

Metal Can Package (H)
NS Package Number H08C
Physical Dimensions  inches (millimeters) unless otherwise noted (Continued)

Ceramic Dual-In-Line Package (J)
Order Number LM741J/883
NS Package Number J08A

Dual-In-Line Package (N)
Order Number LM741CN
NS Package Number N08E
Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

10-Lead Ceramic Flatpak (W)
Order Number LM741W/883, LM741WG-MPR or LM741WG/883
NS Package Number W10A

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