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Differential Amplifiers

\[ \text{Diagram showing a differential amplifier circuit with inputs } V_{i1}, V_{i2}, \text{ and outputs } V_{o1}, V_{o2}. \]
Single Input – Single Output Gain
Single Input – Differential Output Gain
Difference Input – Dual Output Gain
Common Mode Gain
\[ \beta = 75 \]

\[ \text{IR3} = (20 - 0.7)/1K = 19.3 \text{ mA} \]
\[ \text{IE1} = 19.3\text{mA}/2 = 9.65 \text{ mA} \]
\[ \text{re} = 26\text{mV}/\text{IE1} = 2.7 \text{ ohms} \]
\[ \text{Ac} = \beta R1/(1+\beta)(\text{re} + 2R3) = 0.94 \]

\[ \text{Ad} = R1/\text{re} = 370 \]
Assume the following:

1) Infinite gain

2) No current flow into the input terminals; i.e., very high input resistance.

3) With these assumptions, the voltages at the input terminals must be the same.
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In the circuit below, since the voltages at the input terminals are the same,

\[ V_o = V_1 \]

Never use the term “Virtual Ground”.

Expand on the simple circuits.

- \( V_1 = -2 \) and \( V_1 = +2 \)
- Put resistors in the feedback paths – no change in \( V_o \)
- Put in a load resistor (tied to \( V_o \)) – no change.
10.0 Operational Amplifiers
Gain of a simple Op-amp circuit.

No current flows into the input terminals.

The current through R1 must be $V_1/R_1$ and it flows through Rf.

\[ V_o = -\frac{R_f}{R_1} V_1 \]

Work several problems
- $V_1 = +2$ and $V_1 = -2$; add a load resistor – no change in results
- Add a battery connected to + terminal
Ignore (b) in above figure.
$V_x = V_1/2$

$V_o = V_1/2 - (V_2 - V_1/2)(100k/100k)$

$V_o = V_1 - V_2$
VAMPL = 2mV
FREQ = 1000
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(a) A circuit diagram showing an operational amplifier with a resistor $R$ and a capacitor $C = 1 \mu F$. The input voltage $v_i(t) = 1$ V, and the output is $v_o(t)$.

(b) A voltage waveform with $-1$ V, indicating $- \frac{1}{RC} = -1$.

(c) A voltage waveform with $-10$ V, indicating $- \frac{1}{RC} = -10$. 

Where $C = 1 \mu F$ and $R = 1$ M$\Omega$. 
I_c = (4-1.5)/2500

V_{out} = -I_c * t/C + 1.5

V_{out} = -(1mA/0.01)t + 1.5 = (-0.1V/sec)t + 1.5V
In the Op Amp circuit below the input source is a square wave generator which becomes connected to the circuit when the switch is closed at $t=0$. Determine the output voltage waveform including the values of high and low voltage and the shape of the output waveform. Sketch the waveform.

Square Wave Source
+2V high
-2V low
Period is 3msec
Starts at +2V when sw is closed
\[ \Delta V_o = -(I \cdot T_1)/C = -(2/2500)(1.5\text{ms})/0.01\text{uF} = -300/2.5 = -120 \text{ V} \]

Vo goes from 0 to -120V in 1.5ms and then back to 0V in 1.5ms.
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V1 = 0
V2 = 2
PW = 3m

V1 = 0
V2 = -3
TD = 5m
PW = 1m
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Time (ms) vs. Voltage (V) plot

-8.0V -6.0V -4.0V -2.0V 0V

0s 2ms 4ms 6ms 8ms 10ms

V(U1:OUT)
10.0 Operational Amplifiers
OP-AMP specs DC offset

\[ V_o = A \cdot V_i = A \left( V_{IO} - \frac{V_o R_1}{R_1 + R_f} \right) \]

\[ V_o \approx V_{IO} \left( R_1 + R_f \right) / R_1 \]

741c 1 mV
Vo (due to $I_{IO}$) = $I_{IO}R_f$
Unity gain bandwidth   \( f_l = A_{VD} f_c \)

Slew Rate   \( \Delta V_o/\Delta t \)
absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

<table>
<thead>
<tr>
<th></th>
<th>uA741M</th>
<th>uA741C</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage $V_{CC+}$</td>
<td>22</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Supply voltage $V_{CC-}$</td>
<td>−22</td>
<td>−18</td>
<td>V</td>
</tr>
<tr>
<td>Differential input voltage</td>
<td>±0.5</td>
<td>±0.5</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage any input</td>
<td>±15</td>
<td>±15</td>
<td>V</td>
</tr>
<tr>
<td>Voltage between either offset null terminal (N4, N2) and $V_{CC-}$</td>
<td>±0.5</td>
<td>±0.5</td>
<td>V</td>
</tr>
<tr>
<td>Duration of output short-circuit</td>
<td>unlimited</td>
<td>unlimited</td>
<td></td>
</tr>
<tr>
<td>Continuous total power dissipation at (or below) 25°C free-air temperature (see Note 5)</td>
<td>500</td>
<td>500</td>
<td>mW</td>
</tr>
<tr>
<td>Operating free-air temperature range</td>
<td>−55 to 125</td>
<td>0 to 70</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>−65 to 150</td>
<td>−65 to 150</td>
<td>°C</td>
</tr>
<tr>
<td>Lead temperature 1.6 mm (1/16 inch) from case for 60 seconds</td>
<td>FH, PK, J, RO, or U package</td>
<td>300</td>
<td>°C</td>
</tr>
<tr>
<td>Lead temperature 1.8 mm (1/16 inch) from case for 10 seconds</td>
<td>D, N, or P package</td>
<td>260</td>
<td>°C</td>
</tr>
</tbody>
</table>

NOTES:
1. All voltage values, unless otherwise noted, are with respect to the midpoint between $V_{CC+}$ and $V_{CC-}$.
2. Differential voltages are at the noninverting input terminal with respect to the inverting input terminal.
3. The magnitude of the input voltage may not exceed the magnitude of the supply voltage or 15 volts, whichever is less.
4. The output may be shorted to ground or either power supply. For the uA741M only, the unlimited duration of the short-circuit applies at (or below) 125°C case temperature or 75°C free-air temperature.
5. For operation above 25°C free-air temperature, refer to Dissipation Derating Curves, Section 3. In the J and RO packages, uA741M chips are alloy mounted, uA741C chips are glass mounted.
10.0 Operational Amplifiers

### Electrical Characteristics

**Parameter** | **Test Conditions** | **μA741M** | **μA741C** | **Unit**
--- | --- | --- | --- | ---
V<sub>10</sub> | Input offset voltage | V<sub>Q</sub> = 0 | 25°C | Full range | 1 | 5 | 6 | 1 | 4 | 6 | mV
AV<sub>0</sub> | Offset voltage | V<sub>Q</sub> = 0 | 25°C | Full range | ± 15 | ± 15 | mV
IO | Input offset current | V<sub>Q</sub> = 0 | 25°C | Full range | 500 | 200 | 200 | nA
IB | Input bias current | V<sub>Q</sub> = 0 | 25°C | Full range | 80 | 500 | 500 | nA
V<sub>ICR</sub> | Common-mode input voltage range | | | | ± 12 | ± 13 | ± 12 | ± 13 | V
VOM | Maximum peak output voltage swing | R<sub>L</sub> = 10 kΩ | 25°C | Full range | ± 12 | ± 14 | ± 12 | ± 14 | V
R<sub>L</sub> = 20 kΩ | Full range | ± 12 | ± 12
R<sub>L</sub> = 2 kΩ | 25°C | Full range | ± 10 | ± 12 | ± 10 | ± 13
R<sub>L</sub> = 2 kΩ | Full range | ± 10 | ± 10
AVD | Large-signal differential voltage amplification | R<sub>L</sub> = 20 MΩ | 25°C | Full range | 25 | 15 | V/V
η | Input resistance | V<sub>Q</sub> = 0 | 25°C | See note 6 | 0.3 | 2 | 0.3 | 2 | Ω
Ro | Output impedance | V<sub>Q</sub> = 0 | 25°C | | 75 | 75 |
C<sub>I</sub> | Input capacitance | V<sub>ICR</sub> = V<sub>Q</sub> min | 25°C | | 1.4 | 1.4 | pF
CMRR | Common-mode rejection ratio | | | | 70 | 90 | 70 | 90 | dB
k<sub>SVS</sub> | Supply voltage sensitivity | V<sub>ICR</sub> = ± 9 V | 25°C | Full range | 30 | 150 | 30 | 150 | µV/V
w = ± 15 V | Full range | 150 | 150
k<sub>OS</sub> | Short-circuit output current | | | | ± 25 | ± 40 | ± 25 | ± 40 | mA
i<sub>CC</sub> | Supply current | | | | 1.7 | 2.8 | 1.7 | 2.8 | mA
P<sub>0</sub> | Total power dissipation | | | | 50 | 85 | 50 | 85 | mW

### Operating Characteristics

**Parameter** | **Test Conditions** | **μA741M** | **μA741C** | **Unit**
--- | --- | --- | --- | ---
rp | Rise time | V<sub>Q</sub> = 20 mV. R<sub>L</sub> = 2 kΩ. C<sub>L</sub> = 100 pF. See Figure | 0.3 | 0.3 | µs
Overload factor | | | 5% | 5% |
SR | Slew rate at unity gain | V<sub>Q</sub> = 10 V. R<sub>L</sub> = 2 kΩ. C<sub>L</sub> = 100 pF. See Figure | 0.5 | 0.5 | V/µs