LF155/LF156/LF355/LF356/LF357
JFET Input Operational Amplifiers

General Description
These are the first monolithic JFET input operational amplifiers to incorporate well matched, high voltage JFETs on the same chip with standard bipolar transistors (Bi-FET™ Technology). These amplifiers feature low input bias and offset currents/low offset voltage and offset voltage drift, coupled with offset adjust which does not degrade drift or common-mode rejection. The devices are also designed for high slew rate, wide bandwidth, extremely fast settling time, low voltage and current noise and a low 1/f noise corner.

Advantages
- Replace expensive hybrid and module FET op amps
- Rugged JFETs allow blow-out free handling compared with MOSFET input devices
- Excellent for low noise applications using either high or low source impedance—very low 1/f corner
- Offset adjust does not degrade drift or common-mode rejection as in most monolithic amplifiers
- New output stage allows use of large capacitive loads (5,000 pF) without stability problems
- Internal compensation and large differential input voltage capability

Applications
- Precision high speed integrators
- Fast D/A and A/D converters
- High impedance buffers
- Wideband, low noise, low drift amplifiers

Common Features
- Low input bias current: 30pA
- Low Input Offset Current: 3pA
- High input impedance: $10^{12}$Ω
- Low input noise current: 0.01 pA/$\sqrt{\text{Hz}}$
- High common-mode rejection ratio: 100 dB
- Large dc voltage gain: 106 dB

Uncommon Features

<table>
<thead>
<tr>
<th></th>
<th>LF155/ LF355</th>
<th>LF156/ LF356</th>
<th>LF357 (Av=5)</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>µs</td>
</tr>
<tr>
<td>Extremely fast settling time to 0.01%</td>
<td>4</td>
<td>1.5</td>
<td>1.5</td>
<td>µs</td>
</tr>
<tr>
<td>Fast slew rate</td>
<td>5</td>
<td>12</td>
<td>50</td>
<td>V/µs</td>
</tr>
<tr>
<td>Wide gain bandwidth</td>
<td>2.5</td>
<td>5</td>
<td>20</td>
<td>MHz</td>
</tr>
<tr>
<td>Low input noise voltage</td>
<td>20</td>
<td>12</td>
<td>12</td>
<td>nV/$\sqrt{\text{Hz}}$</td>
</tr>
</tbody>
</table>

Simplified Schematic

*3 pF in LF357 series.

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### Absolute Maximum Ratings (Note 1)

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

<table>
<thead>
<tr>
<th></th>
<th>LF155/6</th>
<th>LF356B</th>
<th>LF355/6/7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>±22V</td>
<td>±22V</td>
<td>±18V</td>
</tr>
<tr>
<td>Differential Input Voltage</td>
<td>±40V</td>
<td>±40V</td>
<td>±30V</td>
</tr>
<tr>
<td>Input Voltage Range (Note 2)</td>
<td>±20V</td>
<td>±20V</td>
<td>±16V</td>
</tr>
<tr>
<td>Output Short Circuit Duration</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>$T_{j,\text{max}}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-Package</td>
<td>150°C</td>
<td>115°C</td>
<td>115°C</td>
</tr>
<tr>
<td>N-Package</td>
<td>100°C</td>
<td>100°C</td>
<td>100°C</td>
</tr>
<tr>
<td>M-Package</td>
<td>100°C</td>
<td>100°C</td>
<td>100°C</td>
</tr>
<tr>
<td>Power Dissipation at $T_A = 25°C$ (Notes 1, 8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-Package (Still Air)</td>
<td>560 mW</td>
<td>400 mW</td>
<td>400 mW</td>
</tr>
<tr>
<td>H-Package (400 LF/Min Air Flow)</td>
<td>1200 mW</td>
<td>1000 mW</td>
<td>1000 mW</td>
</tr>
<tr>
<td>N-Package</td>
<td>670 mW</td>
<td>670 mW</td>
<td></td>
</tr>
<tr>
<td>M-Package</td>
<td>380 mW</td>
<td>380 mW</td>
<td></td>
</tr>
<tr>
<td>Thermal Resistance (Typical) $\theta_{JA}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-Package (Still Air)</td>
<td>160°C/W</td>
<td>160°C/W</td>
<td>160°C/W</td>
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<tr>
<td>H-Package (400 LF/Min Air Flow)</td>
<td>65°C/W</td>
<td>65°C/W</td>
<td>65°C/W</td>
</tr>
<tr>
<td>N-Package</td>
<td>130°C/W</td>
<td>130°C/W</td>
<td></td>
</tr>
<tr>
<td>M-Package</td>
<td>195°C/W</td>
<td>195°C/W</td>
<td></td>
</tr>
<tr>
<td>(Typical) $\theta_{JC}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-Package</td>
<td>23°C/W</td>
<td>23°C/W</td>
<td>23°C/W</td>
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<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>
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<td>Soldering Information (Lead Temp.)</td>
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<td></td>
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</tr>
<tr>
<td>Metal Can Package</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Soldering (10 sec.)</td>
<td>300°C</td>
<td>300°C</td>
<td>300°C</td>
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<tr>
<td>Dual-In-Line Package</td>
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<tr>
<td>Soldering (10 sec.)</td>
<td>260°C</td>
<td>260°C</td>
<td>260°C</td>
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<tr>
<td>Small Outline Package</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Vapor Phase (60 sec.)</td>
<td>215°C</td>
<td>215°C</td>
<td></td>
</tr>
<tr>
<td>Infrared (15 sec.)</td>
<td>220°C</td>
<td>220°C</td>
<td></td>
</tr>
<tr>
<td>See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ESD tolerance</td>
<td>(100 pF discharged through 1.5 kΩ)</td>
<td>1000V</td>
<td>1000V</td>
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### DC Electrical Characteristics (Note 2)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>LF155/6</th>
<th>LF356B</th>
<th>LF355/6/7</th>
<th>Units</th>
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<tbody>
<tr>
<td>$V_{OS}$</td>
<td>Input Offset Voltage</td>
<td>$R_o=500\Omega$, $T_A=25°C$ Over Temperature</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>$\Delta V_{OS}/\Delta T$</td>
<td>Average TC of Input Offset Voltage</td>
<td>$R_o=500\Omega$</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>$\mu V/°C$</td>
</tr>
<tr>
<td>$\Delta T/\Delta V_{OS}$</td>
<td>Change in Average TC with $V_{OS}$ Adjust</td>
<td>$R_o=500\Omega$, (Note 4)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>$\mu V/°C$ per mV</td>
</tr>
<tr>
<td>$I_{OS}$</td>
<td>Input Offset Current</td>
<td>$T_J=25°C$, (Notes 3, 5) $T_J\leq T_{HIGH}$</td>
<td>3</td>
<td>20</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>$I_B$</td>
<td>Input Bias Current</td>
<td>$T_J=25°C$, (Notes 3, 5) $T_J\leq T_{HIGH}$</td>
<td>30</td>
<td>100</td>
<td>30</td>
<td>100</td>
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<tr>
<td>$R_{IN}$</td>
<td>Input Resistance</td>
<td>$T_J=25°C$</td>
<td>$10^{12}$</td>
<td>$10^{12}$</td>
<td>$10^{12}$</td>
<td>Ω</td>
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### DC Electrical Characteristics (Continued)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
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<th>LF356B</th>
<th>LF355/6/7</th>
<th>Units</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Min</td>
<td>Typ</td>
</tr>
<tr>
<td>$A_{VOL}$</td>
<td>Large Signal Voltage</td>
<td>$V_{S} = \pm 15 V$, $T_A = 25^\circ C$</td>
<td>50</td>
<td>200</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Gain</td>
<td>Over Temperature</td>
<td>25</td>
<td></td>
<td></td>
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<tr>
<td>$V_O$</td>
<td>Output Voltage Swing</td>
<td>$V_{S} = \pm 15 V$, $R_L = 10k$</td>
<td>±12</td>
<td>±13</td>
<td>±12</td>
<td>±12</td>
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<tr>
<td></td>
<td></td>
<td>$V_{S} = \pm 15 V$, $R_L = 2k$</td>
<td>±10</td>
<td>±10</td>
<td>±10</td>
<td>±10</td>
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<tr>
<td>$V_{CM}$</td>
<td>Input Common-Mode</td>
<td>$V_{S} = \pm 15 V$</td>
<td>±11</td>
<td>+15.1</td>
<td>±11</td>
<td>±15.1</td>
</tr>
<tr>
<td></td>
<td>Voltage Range</td>
<td>$-$12</td>
<td></td>
<td></td>
<td>$-$12</td>
<td></td>
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<tr>
<td>CMRR</td>
<td>Common-Mode</td>
<td>Rejection Ratio</td>
<td>85</td>
<td>100</td>
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<td>85</td>
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<tr>
<td>PSRR</td>
<td>Supply Voltage</td>
<td>Rejection Ratio</td>
<td>(Note 6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ratio</td>
<td></td>
<td>85</td>
<td>100</td>
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<td>85</td>
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### DC Electrical Characteristics

$T_A = T_S = 25^\circ C$, $V_S = \pm 15 V$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LF155</th>
<th>LF355</th>
<th>LF156/356B</th>
<th>LF356</th>
<th>LF357</th>
<th>Units</th>
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<tbody>
<tr>
<td>Supply Current</td>
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<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Typ</td>
<td>Max</td>
<td>Typ</td>
<td>Max</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

### AC Electrical Characteristics

$T_A = T_S = 25^\circ C$, $V_S = \pm 15 V$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>LF155/355</th>
<th>LF156/356B</th>
<th>LF156/356/ LF356B</th>
<th>LF357</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Typ</td>
<td>Min</td>
<td>Typ</td>
<td>Typ</td>
<td>Typ</td>
<td>V/µs</td>
</tr>
<tr>
<td>SR</td>
<td>Slew Rate</td>
<td>LF155/6: $A_{V}=1$, LF357: $A_{V}=5$</td>
<td>5</td>
<td>7.5</td>
<td>12</td>
<td>50</td>
<td>V/µs</td>
</tr>
<tr>
<td>GBW</td>
<td>Gain Bandwidth Product</td>
<td></td>
<td>2.5</td>
<td>5</td>
<td>20</td>
<td></td>
<td>MHz</td>
</tr>
<tr>
<td>t_S</td>
<td>Settling Time to 0.01%</td>
<td>(Note 7)</td>
<td>4</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>µs</td>
</tr>
<tr>
<td>$e_{n}$</td>
<td>Equivalent Input Noise</td>
<td>$R_S=1000\Omega$</td>
<td>25</td>
<td>15</td>
<td>15</td>
<td>nV/√Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voltage</td>
<td>$f=100\mathrm{Hz}$</td>
<td>20</td>
<td>12</td>
<td>12</td>
<td>nV/√Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$f=1000\mathrm{Hz}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i_n</td>
<td>Equivalent Input</td>
<td>$f=100\mathrm{Hz}$</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>pA/√Hz</td>
<td></td>
</tr>
<tr>
<td>Current Noise</td>
<td>$f=1000\mathrm{Hz}$</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>pA/√Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{IN}$</td>
<td>Input Capacitance</td>
<td></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>pF</td>
<td></td>
</tr>
</tbody>
</table>

### Notes for Electrical Characteristics

**Note 1:** The maximum power dissipation for these devices must be derated at elevated temperatures and is dictated by $T_j\max$, $I_{JA}$, and the ambient temperature, $T_A$. The maximum available power dissipation at any temperature is $P_j = (T_j\max - T_A)R_{JA}$ or the $25^\circ C$ $P_{j\max}$, whichever is less.

**Note 2:** Unless otherwise specified the absolute maximum negative input voltage is equal to the negative power supply voltage.

**Note 3:** Unless otherwise stated, these test conditions apply:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LF155/1556</th>
<th>LF356B</th>
<th>LF355/6/7</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage, $V_S$</td>
<td>$\pm 15 V$ $\leq V_S \leq 20 V$</td>
<td>$\pm 15 V$ $\leq V_S \leq 20 V$</td>
<td>$V_S = \pm 15 V$</td>
<td></td>
</tr>
<tr>
<td>$T_A$</td>
<td>$-55^\circ C \leq T_A \leq 125^\circ C$</td>
<td>$0^\circ C \leq T_A \leq 70^\circ C$</td>
<td>$0^\circ C \leq T_A \leq 70^\circ C$</td>
<td></td>
</tr>
<tr>
<td>$T_{MIN}$</td>
<td>$+125^\circ C$</td>
<td>$+70^\circ C$</td>
<td>$+70^\circ C$</td>
<td></td>
</tr>
</tbody>
</table>

and $V_{COL}$, $I_{BS}$, and $V_{CB}$ are measured at $V_{CE}=0$.

**Note 4:** The Temperature Coefficient of the adjusted input offset voltage changes only a small amount (0.5 pV/°C typically) for each mV of adjustment from its original unadjusted value. Common-mode rejection and open loop voltage gain are also unaffected by offset adjustment.
Notes for Electrical Characteristics (Continued)

Note 5: The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature, T_J. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation. Pd = T_J * T_A where T_A is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.

Note 6: Supply Voltage Rejection is measured for both supply magnitudes increasing or decreasing simultaneously, in accordance with common practice.

Note 7: Setting time is defined here, for a unity gain inverter connection using 2 kΩ resistors for the LF155B. It is the time required for the error voltage (the voltage at the inverting input pin on the amplifier) to settle to within 0.01% of its final value from the time a 10V step input is applied to the inverter. For the LF357, AV= 5.5, the feedback resistor from output to input is 2 kΩ and the output step is 10V (See Setting Time Test Circuit).

Note 8: Max. Power Dissipation is defined by the package characteristics. Operating the part near the Max. Power Dissipation may cause the part to operate outside guaranteed limits.

Typical DC Performance Characteristics
Curves are for LF155 and LF156 unless otherwise specified.
Typical DC Performance Characteristics

Curves are for LF155 and LF156 unless otherwise specified. (Continued)

Supply Current

Supply Current

Negative Current Limit

Positive Current Limit

Positive Common-Mode Input Voltage Limit

Negative Common-Mode Input Voltage Limit
Typical DC Performance Characteristics

Curves are for LF155 and LF156 unless otherwise specified. (Continued)

**Open Loop Voltage Gain**

![Graph showing Open Loop Voltage Gain vs Supply Voltage](image)

**Output Voltage Swing**

![Graph showing Output Voltage Swing vs Output Load](image)

**Typical AC Performance Characteristics**

**Gain Bandwidth**

![Graph showing Gain Bandwidth vs Temperature](image)

**Gain Bandwidth**

![Graph showing Gain Bandwidth vs Temperature](image)

**Normalized Slew Rate**

![Graph showing Normalized Slew Rate vs Temperature](image)

**Output Impedance**

![Graph showing Output Impedance vs Frequency](image)
Typical AC Performance Characteristics (Continued)

Output Impedance

LF155 Small Signal Pulse Response, $A_V = +1$

LF155 Large Signal Pulse Response, $A_V = +1$

LF156 Small Signal Pulse Response, $A_V = +1$

LF156 Large Signal Pulse Response, $A_V = +1$

Inverter Settling Time
Typical AC Performance Characteristics (Continued)

Inverter Settling Time

Open Loop Frequency Response

Bode Plot

Bode Plot

Bode Plot

Common-Mode Rejection Ratio
Detailed Schematic

Connection Diagrams (Top Views)

Metal Can Package (H)

Dual-In-Line Package (M and N)

*Available per JM38510/11401 or JM38510/11402
Order Number LF155H, LF156H, LF356BH, LF356H, or LF357H
See NS Package Number H06C
Order Number LF356M, LF356MX, LF355N, or LF356N
See NS Package Number M08A or N08E

*C = 3 pF in LF357 series.
Application Hints

These are op amps with JFET input devices. These JFETs have large reverse breakdown voltages from gate to source and drain eliminating the need for clamps across the inputs. Therefore large differential input voltages can easily be accommodated without a large increase in input current. The maximum differential input voltage is independent of the supply voltages. However, neither of the input voltages should be allowed to exceed the negative supply as this will cause large currents to flow which can result in a destroyed unit.

Exceeding the negative common-mode limit on either input will force the output to a high state, potentially causing a reversal of phase to the output. Exceeding the negative common-mode limit on both inputs will force the amplifier output to a high state. In either case does a latch occur since raising the input back within the common-mode range again puts the input stage and thus the amplifier in a normal operating mode.

Exceeding the positive common-mode limit on a single input will not change the phase of the output however, if both inputs exceed the limit, the output of the amplifier will be forced to a high state.

These amplifiers will operate with the common-mode input voltage equal to the positive supply. In fact, the common-mode voltage can exceed the positive supply by approximately 100 mV independent of supply voltage and over the full operating temperature range. The positive supply can therefore be used as a reference on an input as, for example, in a supply current monitor and/or limiter.

Precautions should be taken to ensure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

All of the bias currents in these amplifiers are set by FET current sources. The drain currents for the amplifiers are therefore essentially independent of supply voltage.

As with most amplifiers, care should be taken with lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize "pickup" and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground.

A feedback pole is created when the feedback around any amplifier is resistive. The parallel resistance and capacitance from the input of the device (usually the inverting input) to ac ground set the frequency of the pole. In many instances the frequency of this pole is much greater than the expected 3 dB frequency of the closed loop gain and consequently there is negligible effect on stability margin. However, if the feedback pole is less than approximately six times the expected 3 dB frequency a lead capacitor should be placed from the output to the input of the op amp. The value of the added capacitor should be such that the RC time constant of this capacitor and the resistance it parallels is greater than or equal to the original feedback pole time constant.

Typical Circuit Connections

- $V_{OS}$ is adjusted with a 25k potentiometer
- The potentiometer wiper is connected to $V^*$
- For potentiometers with temperature coefficient of 100 ppm/°C or less the additional drift with adjust $\Delta = 0.5 \mu V/°C/mV$ of adjustment
- Typical overall drift: $5 \mu V/°C \pm (0.5 \mu V/°C/mV$ of adj.)
Typical Circuit Connections (Continued)

Driving Capacitive Loads

- LF155/6 R = 5k
- LF357 R = 1.25k

Due to a unique output stage design, these amplifiers have the ability to drive large capacitive loads and still maintain stability.

- \( C_{L\,max} \approx 0.01 \mu F \)
- Overshoot \( \leq 20\% \)
- Settling time \( (t_s) \approx 5 \mu s \)

LF357. A Large Power BW Amplifier

For distortion \( \leq 1\% \) and a 20 Vp-p \( V_{\text{OUT}} \) swing, power bandwidth is: 500 kHz.

Typical Applications

Settling Time Test Circuit

- Settling time is tested with the LF155/6 connected as unity gain inverter and LF357 connected for \( A_V = -5 \)
- FET used to isolate the probe capacitance
- Output = 10V step
- \( A_V = -5 \) for LF357
Typical Applications (Continued)

Large Signal Inverter Output, $V_{OUT}$ (from Settling Time Circuit)

- $\Delta V_{OUT}/\Delta T = \pm 0.002\%/^\circ C$
- All resistors and potentiometers should be wire-wound
- P1: drift adjust
- P2: $V_{OUT}$ adjust
- Use LF155 for
  - Low $I_p$
  - Low drift
  - Low supply current
Typical Applications (Continued)

- Dynamic range: $100 \mu A \leq I \leq 1 mA$ (5 decades), $|V_{OC}| = 1V/\text{decade}$
- Transient response: $3 \mu s$ for $\Delta I = 1$ decade
- C1, C2, R2, R3: added dynamic compensation
- $V_{OS}$ adjust the LF156 to minimize quiescent error
- $R_T$: Tel Labs type Q81 + 0.3%/°C

$$|V_{OUT}| = \left[1 + \frac{R_2}{R_T}\right] \frac{kT}{q} \ln V_i \left[\frac{R_2}{V_{REF} R_1}\right] = \log V_i \left[1 \frac{1}{R_{L}}\right] R_2 = 15.7k, R_T = 1k, 0.3%/°C \text{ (for temperature compensation)}$$

Precision Current Monitor

- $V_O = 5 \frac{R_1}{R_2}$ (V/mA of $I_B$)
- $R_1, R_2, R_3$: 0.1% resistors
- Use LF155 for
  - Common-mode range to supply range
  - Low $I_B$
  - Low $V_{OS}$
  - Low Supply Current

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Typical Applications (Continued)

8-Bit D/A Converter with Symmetrical Offset Binary Operation

- R1, R2 should be matched within ±0.05%
- Full-scale response time: 3 µs

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Wide BW Low Noise, Low Drift Amplifier

- Power BW: \( f_{\text{MAX}} = \frac{S_f}{2\pi V_p} \) \( \approx \) 191 kHz
- Parasitic input capacitance \( \text{C1} \approx (3 \text{ pF for LF155, LF156 and LF357 plus any additional layout capacitance}) \) interacts with feedback elements and creates undesirable high frequency pole. To compensate add \( \text{C2} \) such that \( \text{R2 C2} \approx \text{R1 C1} \).
Typical Applications (Continued)

Boosting the LF156 with a Current Amplifier

- $I_{\text{OUT(MAX)}} = 150 \text{ mA}$ (will drive $R_L \geq 100\Omega$)
- $\frac{\Delta V_{\text{OUT}}}{\Delta t} = 0.15 \text{ V/}\mu\text{s}$ (with $C_L$ shown)
- No additional phase shift added by the current amplifier

3 Decades VCO

$$f = \frac{V_C (R_B + R_7)}{8 \ V_{\text{PU}} (R_B R_1) C'} \quad 0 \leq V_C \leq 30\text{V}, \ 10\text{ Hz} \leq f \leq 10\text{ kHz}$$

R1, R4 matched. Linearity 0.1% over 2 decades.
Typical Applications (Continued)

Isolating Large Capacitive Loads

- Overshoot 6%
- $t_r = 10 \mu s$
- When driving large $C_L$, the $V_{OUT}$ slew rate determined by $C_L$ and $I_{OUT(MAX)}$:

\[
\frac{\Delta V_{OUT}}{\Delta t} = \frac{I_{OUT}}{C_L} \approx \frac{0.02}{0.5} \text{ V/} \mu \text{s} = 0.04 \text{ V/} \mu \text{s} \text{ (with } C_L \text{ shown)}
\]

Low Drift Peak Detector

- By adding D1 and $R_o$, $V_{D1}=0$ during hold mode. Leakage of D2 provided by feedback path through $R_t$.
- Leakage of circuit is essentially $I_o$ (LF155, LF156) plus capacitor leakage of $C_p$.
- Diode D3 clamps $V_{OUT}$ (A1) to $V_{IN}-V_{D3}$ to improve speed and to limit reverse bias of D2.
- Maximum input frequency should be $<< \frac{1}{2 \pi R_1 C_{D2}}$ where $C_{D2}$ is the shunt capacitance of D2.
Typical Applications (Continued)

Non-Inverting Unity Gain Operation for LF157

\[
R_1 C \geq \frac{1}{(2\pi)(5 \text{ MHz})}
\]

\[
R_1 = \frac{R_2 + R_S}{4}
\]

\[A_{V(\text{dc})} = 1\]

\[f_{-3 \text{ dB}} \approx 5 \text{ MHz}\]

Inverting Unity Gain for LF157

\[
R_1 C \geq \frac{1}{(2\pi)(5 \text{ MHz})}
\]

\[
R_1 = \frac{R_2}{4}
\]

\[A_{V(\text{dc})} = -1\]

\[f_{-3 \text{ dB}} \approx 5 \text{ MHz}\]
Typical Applications (Continued)

High Impedance, Low Drift Instrumentation Amplifier

\[ V_{\text{OUT}} = \frac{R_3}{R} \left[ \frac{2R_2}{R_1} + 1 \right] \Delta V, \quad V^- + 2V \leq V_{\text{IN}} \text{ common-mode} \leq V^+ \]

- System $V_{\text{OS}}$ adjusted via $A2 V_{\text{OS}}$ adjust
- Trim $R3$ to boost up CMRR to 120 dB. Instrumentation amplifier resistor array recommended for best accuracy and lowest drift
Typical Applications (Continued)

- Both amplifiers (A1, A2) have feedback loops individually closed with stable responses (overshoot negligible)
- Acquisition time $T_A$, estimated by:

$$T_A = \left[ \frac{2R_{ON} \cdot V_{IN} \cdot C_h}{S_f} \right]^{1/2} \text{ provided that:}$$

$$V_{IN} < 2 \pi S_f R_{ON} C_h \text{ and } T_A > \frac{V_{IN} C_h}{I_{OUT(MAX)}}$$

- If inequality not satisfied: $T_A \geq \frac{V_{IN} C_h}{20 \text{ mA}}$
- LF156 develops full $S_f$ output capability for $V_{IN} \geq 1V$
- Addition of SW2 improves accuracy by putting the voltage drop across SW1 inside the feedback loop
- Overall accuracy of system determined by the accuracy of both amplifiers, A1 and A2
Typical Applications (Continued)

High Accuracy Sample and Hold

- By closing the loop through A2, the $V_{\text{OUT}}$ accuracy will be determined uniquely by A1.
  No $V_{\text{OS}}$ adjust required for A2.
- $T_{\text{a}}$ can be estimated by same considerations as previously but, because of the added propagation delay in the feedback loop (A2) the overshoot is not negligible.
- Overall system slower than fast sample and hold
- R1, Cc: additional compensation
- Use LF156 for
  - Fast settling time
  - Low $V_{\text{OS}}$

High Q Band Pass Filter

- By adding positive feedback (R2)
- Q increases to 40
- $f_{\text{BP}} = 100$ kHz

\[
\frac{V_{\text{OUT}}}{V_{\text{IN}}} = 10 \sqrt{Q}
\]

- Clean layout recommended
- Response to a 1 Vp-p tone burst: 300 $\mu$s
Typical Applications (Continued)

- 2R1 = R = 10 MΩ
- 2C = C1 = 300 pF
- Capacitors should be matched to obtain high Q
- f_{NOTCH} = 120 Hz, notch = -65 dB, Q > 100
- Use LF155 for
  - Low Iᵦ
  - Low supply current
Physical Dimensions  inches (millimeters) unless otherwise noted

Metal Can Package (H)
Order Number LF155H, LF156H, LF356BH, LF356H or LF357H
NS Package Number H06C

Small Outline Package (M)
Order Number LF356M or LF356MX
NS Package Number M08A
PHYSICAL DIMENSIONS

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