Amplifier Selection Guide

1Q 2003

Includes:
- High Speed
- Isolation
- Difference and Instrumentation
- Pulse Width Modulation Drivers
- Power Operational Amplifiers
- Integrating
- Voltage-Controlled Gain
- Logarithmic
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- Audio

Real World Signal Processing

Burr-Brown Products from Texas Instruments
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# Introduction and Table of Contents

Texas Instruments offers a wide range of amplifiers that vary in performance, functionality and technology. Whether your design requires low-noise, high-precision or low-voltage micropower signal conditioning, TI’s amplifier portfolio will meet your requirements and with a variety of micropackage options.

## Why TI Amplifiers?
- High performance—maximum performance, minimum power.
- Largest portfolio of op amps in the industry.
- Cost-efficient signal conditioning solutions.
- Maximize your signal chain performance.

## TI offers devices useful anywhere analog applications require:
- High reliability
- Precision
- Wide dynamic range
- Wide bandwidth
- Wide temperature range
- Stability over time

## Recently Released Products
- **OPA363**—1.8 V, RRIO, low noise, excellent CMRR.
- **OPA335**—zero-drift, low-power, CMOS amplifier.
- **OPA354**—100-MHz, RRIO, CMOS amplifier family.
- **OPA356**—200-MHz, RRO, CMOS amplifier family.
- **OPA348**—1-MHz, 45-µA, RRIO, CMOS amplifier family.
- **SC70 package now available for OPA348, OPA349, OPA347.**
- **TPA2006**—1.1-W, mono, Class-D, filter-free, audio power amplifier.
- **LOG2112**—dual version of the LOG112 with 7.5 decades of dynamic range.
- **TLV349x**—1.8-V, high-speed, low-power, push-pull comparator.
- **INA330**—thermistor signal amp for temperature control.

## Operational Amplifiers

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Operational Amplifiers

Texas Instruments offers a wide range of op amp types including high precision, micropower, low voltage, high speed and rail-to-rail in several different process technologies. TI has developed the industry’s largest selection of low power and low voltage op amps with features designed to satisfy a very wide range of applications. To help facilitate the selection process, an interactive online op amp parametric search engine is available at amplifier.ti.com/search with links to all op amp specifications.

Design Considerations
Choosing the best op amp for an application involves consideration of a variety of interrelated requirements. In doing so, designers must trade-off often conflicting size, cost and performance objectives. Even experienced engineers can find the task daunting but it need not be. Keeping in mind the following issues, the choice can quickly be narrowed to a manageable few.

Supply voltage (V_S)—tables include low-voltage (< 2.7 V min) and wide voltage range (> 5 V min) sections. Other op amp selection criteria (e.g. precision) can be quickly examined in the supply range column for an appropriate choice. Applications operating from a single power supply may require rail-to-rail performance and consideration of precision-related parameters.

Precision—primarily associated with input offset voltage (V_OS) and its change with respect to temperature drift, PSRR and CMRR. It is generally used to describe op amps with low input offset voltage and low input offset voltage temperature drift. Precision op amps are required when amplifying tiny signals from thermocouples and other low-level sensors. High-gain or multi-stage circuits may require low offset voltage.

Gain-bandwidth product (GBW)—the gain bandwidth of a voltage-feedback op amp determines its useful bandwidth in an application. The available bandwidth is approximately equal to the gain bandwidth divided by the closed-loop gain of the application. For voltage feedback amplifiers, GBW is a constant. Many applications require much wider bandwidth to achieve low distortion, excellent linearity, good gain accuracy, gain flatness or other behavior that is influenced by feedback factors.

Power (I_Q requirements)—a significant issue in many applications. Because op amps can have a considerable impact on the overall system power budget, quiescent current, especially in battery-powered applications, is a key design consideration.

Rail-to-rail performance—rail-to-rail output provides maximum output voltage swing for widest dynamic range. This may be particularly important with low operating

### Table: Operational Amplifiers

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<th>Supply Voltage</th>
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<th>Typical Applications</th>
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<td>V_S ≤ 5 V</td>
<td>Rail-to-Rail, Low Power, Precision, Small Packages</td>
<td>Battery-Powered, Handheld</td>
<td>CMOS</td>
<td>OPA3xx, TLVxxxx</td>
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<tr>
<td>V_S ≤ 16 V</td>
<td>Rail-to-Rail, Low Noise, Low Voltage Offset, Precision, Small Packages</td>
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<td>CMOS</td>
<td>OPA3xx, TLVxxxx, OPA7xx</td>
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<tr>
<td>V_S ≤ +38 V</td>
<td>Low Input Bias Current, Low Offset Current, High Input Impedance</td>
<td>Industrial, Test Equipment, ONET, High-end Audio</td>
<td>FET, DIFET</td>
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<td>V_S ≤ +44 V</td>
<td>Low Voltage Offset, Low Drift</td>
<td>Industrial, Test Equipment, ONET, High-end Audio</td>
<td>Bipolar</td>
<td>OPA2xx, TLVxxxx</td>
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<td>±5 V to ±15 V</td>
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<td>XDSL, Video, Professional Imaging, Data Converter Signal Conditioning</td>
<td>DIFET, High-Speed Bipolar, BiCOM</td>
<td>OPA8xx*, THSxxxx*</td>
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<tr>
<td>2.7 V ≤ V_S ≤ 5 V</td>
<td>High Speed on Single Supply</td>
<td>Consumer Imaging, Data Converter Signal Conditioning, Safety-Critical Automotive</td>
<td>High-Speed CMOS</td>
<td>OPA35xx, OPA68xx*, THSxxxx*</td>
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</table>

*See high-speed section, page 13.*
Op Amp Naming Conventions

**Channels**
- Single = No Character
- Dual = 2
- Triple = 3
- Quad = 4

**Amp Class**
- TLV = Low Supply Voltage
- TLC = 5 V CMOS
- TLE = Wide Supply Voltage

**Base Model**
- 100 = FET
- 200 = Bipolar
- 300 = CMOS (≤ 5.5 V)
- 400 = High Voltage (> 40 V)
- 500 = High Power (> 200 mA)
- 600 = High Speed (> 50 MHz)

**Channels And Shutdown Options**
- 0 = Single With Shutdown
- 1 = Single
- 2 = Dual
- 3 = Dual With Shutdown
- 4 = Quad
- 5 = Quad With Shutdown

Voltage

Voltage where signal swings are limited. Rail-to-rail input capability is often required to achieve maximum signal swing in buffer (G = 1) single-supply applications. It can be useful in other applications, depending on amplifier gain and biasing considerations.

Voltage noise ($V_n$) — amplifier-generated noise may limit the ultimate dynamic range, accuracy or resolution of a system. Low-noise op amps can improve accuracy even in slow DC measurements.

Input bias current ($I_B$) — can create offset error by reacting with source or feedback impedances. Applications with high source impedance or high impedance feedback elements (such as transimpedance amplifiers or integrators) often require low input bias current. FET-input and CMOS op amps generally provide very low input bias current.

Slew rate — the maximum rate of change of the amplifier output. It is important when driving large signals to high frequency.

Package size — TI offers a wide variety of micropackages, including SOT23 and SC70 and small, high power-dissipating PowerPAD™ packages to meet space-sensitive and high-output drive requirements. Many TI single channel op amps are available in SOT23, with some dual amplifiers in SOT23-8.

Shutdown mode — an enable/disable function that places the amp in a high impedance state, reducing quiescent current in many cases to less than 1 µA. Allows designers to use wide bandwidth op amps in lower power apps.

Decompensated amplifiers — for applications with gain greater than unity gain (G = 1), decompensated amps provide significantly higher bandwidth, improved slew rate and lower distortion over their unity-gain stable counterparts on the same quiescent current or noise.

Op Amp Rapid Selector

The tables on the following pages have been divided and subdivided into several categories to help quickly narrow the alternatives.

**Precision**
- $V_{OS} \leq 500 \mu V$

**Low Noise**
- $V_{N} \leq 10 nV/\sqrt{Hz}$

**Low Voltage**
- $V_S \leq 2.7 V$

**Low Power**
- $I_O \leq 1 \text{mA/ch}$

**Low Input Bias Current**
- $I_B \leq 100 \text{pA}$

**Wide Bandwidth**
- $GBW \geq 5 \text{MHz}$

---

**Low Voltage**
- $V_S \leq 2.7 V$

**Low Input Bias Current**
- $I_B \leq 100 \text{pA}$

**Low Power**
- $I_O \leq 1 \text{mA/ch}$

**Wide Gain Bandwidth**
- $GBW \geq 5 \text{MHz}$

---

**Wide Voltage**
- $\pm 5 V \leq V_S \leq \pm 20 V$

**Precision**
- $V_{OS} \leq 500 \mu V$

**Low Power**
- $I_O \leq 1 \text{mA/ch}$

**Low Input Bias Current**
- $I_B \leq 100 \text{pA}$

**Wide Bandwidth**
- $GBW \geq 5 \text{MHz}$

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**General Purpose**

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### Precision Operational Amplifiers (V_{OS} ≤ 500 µV) Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>V_{in} (min)</th>
<th>V_{in} (max)</th>
<th>I_{P} (mA)</th>
<th>GBW (MHz typ)</th>
<th>Slew Rate (V/µs typ)</th>
<th>V_{OS} (nV/°C) (max)</th>
<th>Offset Drift (µV/°C typ)</th>
<th>CMRR (dB)</th>
<th>V_{min at 1 kHz (V/Hz)} (typ)</th>
<th>Supply Rail</th>
<th>Package(s)</th>
<th>Price</th>
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<td>3.8 3.8</td>
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1 New products appear in BOLD RED. x indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown. y indicates: no character = single, 2 = dual, 3 = triple, 4 = quad. 2 Suggested resale price in U.S. dollars in quantities of 1,000.
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<th>GBW (MHz) (typ)</th>
<th>Slew Rate (V/µs) (typ)</th>
<th>V_{OS} at 25°C (mV) (max)</th>
<th>V_{OS} Offset (mV) (max)</th>
<th>I_{B} (pA) (max)</th>
<th>CMRR (dB) (max)</th>
<th>V_{in} at 1 kHz (nV/Hz) (typ)</th>
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**Precision, Wide Bandwidth GBW ≥ 5 MHz (typ)**

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<th>V_{OS} (V)</th>
<th>V_{in} (V)</th>
<th>I_{B}Per CH. (mA)</th>
<th>GBW (MHz) (typ)</th>
<th>Slew Rate (V/µs) (typ)</th>
<th>V_{OS} at 25°C (mV) (max)</th>
<th>V_{OS} Offset (mV) (max)</th>
<th>I_{B} (pA) (max)</th>
<th>CMRR (dB) (max)</th>
<th>V_{in} at 1 kHz (nV/Hz) (typ)</th>
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1New products appear in **BOLD RED**. x indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown. y indicates: no character = single, 2 = dual, 3 = triple, 4 = quad. 2Suggested resale price in U.S. dollars in quantities of 1,000.

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### Low-Voltage Operational Amplifiers (V_{S} ≤ 2.7 V) Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>V_{S} (V)</th>
<th>V_{in} (V)</th>
<th>I_{B}Per CH. (mA)</th>
<th>GBW (MHz) (typ)</th>
<th>Slew Rate (V/µs) (typ)</th>
<th>V_{Ss} (25°C) (mV) (max)</th>
<th>Offset Drift (µV/°C) (typ)</th>
<th>I_{B} (pA) (max)</th>
<th>CMRR (dB) (max)</th>
<th>V_{in} at 1 kHz (nV/Hz) (typ)</th>
<th>Rail-to-Rail</th>
<th>Package(s)</th>
<th>Price</th>
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<tbody>
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<thead>
<tr>
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<th>Vos (V)</th>
<th>Ios (max)</th>
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<th>Slew Rate (V/µs (typ))</th>
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<th>Iq (pA (max))</th>
<th>Vin ± (V (max))</th>
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<td>60</td>
<td>39</td>
<td>I/O</td>
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1New products appear in **BOLD RED**. x indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown. y indicates: no character = single, 2 = dual, 3 = triple, 4 = quad. 2Suggested resale price in U.S. dollars in quantities of 1,000.
### Low-Voltage Operational Amplifiers (V_S ≤ 2.7 V) Selection Guide (Continued)

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>SHDN</th>
<th>V_S (V) (min)</th>
<th>I_{ch} Per Ch. (mA) (max)</th>
<th>GBW (MHz) (typ)</th>
<th>V_{OS} (25°C) (mV) (max)</th>
<th>Offset Drift (µV/°C) (typ)</th>
<th>I_{B} (pA) (max)</th>
<th>V_{IN} at 1 kHz (mV/Hz) (typ)</th>
<th>Rail-to-Rail</th>
<th>Package(s)</th>
<th>Price</th>
</tr>
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<tbody>
<tr>
<td>TLV277x</td>
<td>SS, High Slew Rate</td>
<td>1, 2, 4</td>
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<td>2.5</td>
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<td>4.8</td>
<td>9</td>
<td>2.5</td>
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<td>6</td>
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<td>150</td>
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<td>OPAm357</td>
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<td>OPAm358</td>
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### Low-Power Operational Amplifiers (I_O ≤ 1 mA) Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>SHDN</th>
<th>V_S (V) (min)</th>
<th>I_{ch} Per Ch. (mA) (max)</th>
<th>GBW (MHz) (typ)</th>
<th>V_{OS} (25°C) (mV) (max)</th>
<th>Offset Drift (µV/°C) (typ)</th>
<th>I_{B} (pA) (max)</th>
<th>V_{IN} at 1 kHz (mV/Hz) (typ)</th>
<th>Rail-to-Rail</th>
<th>Package(s)</th>
<th>Price</th>
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<td>TLV240x</td>
<td>2.5 V, sub-µPower, SS</td>
<td>1, 2, 4</td>
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<td>TLV224x</td>
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<td>0.0055</td>
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<td>0.07</td>
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<td>TLV245x</td>
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<td>0.22</td>
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<td>0.035</td>
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<td>10</td>
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<td>Y</td>
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<td>5.5</td>
<td>0.35</td>
<td>2</td>
<td>0.5</td>
<td>0.005</td>
<td>0.02</td>
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<td>Zero Drift, Precision, CMOS, SS</td>
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<tr>
<td>TLV246x</td>
<td>Low Noise, SS, Wide Bandwidth, 25-mA Drive</td>
<td>1, 2, 4</td>
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<td>6</td>
<td>0.575</td>
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<td>14000</td>
<td>11</td>
<td>I/O</td>
</tr>
</tbody>
</table>

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### Low-Power Operational Amplifiers (I_{Q} ≤ 1 mA) Selection Guide (Continued)

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>SHDN (min)</th>
<th>V_{S} (V) (max)</th>
<th>I_{S} (mA) (max)</th>
<th>I_{P} (pA) (max)</th>
<th>GBW (MHz) (typ)</th>
<th>V_{OS} (±5°C) (mV) (max)</th>
<th>Offset Drift (V/µs) (max)</th>
<th>CMRR (dB) (min)</th>
<th>V_{in} at 1 kHz (nV/Hz) (typ)</th>
<th>I_{B} (µA) (max)</th>
<th>Rail-to-Rail</th>
<th>Package(s)</th>
<th>Price</th>
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<tbody>
<tr>
<td><strong>Low-Power, Low Voltage V_{S} ≤ 2.7 V (min)</strong> (Continued)</td>
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<td>TLV247x</td>
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<td>1.4</td>
<td>2.2</td>
<td>0.4</td>
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<td>MSOP(PDIP, PDIP, SOIC, SOIT23, TSSOP)</td>
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<tr>
<td>TLV278x</td>
<td>1.8 V, Low Power, SS, 8 MHz, Low Bias Current</td>
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<td>MSOP, PDIP, SOIC, SOT23, TSSOP</td>
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<tr>
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<td>CMOS, Wide Bandwidth, SS</td>
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<td>MSOP, PDIP, SOIC, SOT23, TSSOP</td>
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<td>TLV246x</td>
<td>Low Noise, SS, Wide Bandwidth, 25mA Drive</td>
<td>1, 2, 4</td>
<td>Y</td>
<td>2.7</td>
<td>6</td>
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<td>MSOP, SOIC, SOT23, TSSOP</td>
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<td>OPAY364</td>
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<td>MSOP, SOIC, SOT23, TSSOP</td>
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<td>OPAY341</td>
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<td>25</td>
<td>I/O</td>
<td>MSOP, PDIP, SOIC, SOT23</td>
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<td><strong>Wide-Voltage Range Operational Amplifiers (±5 V ≤ V_{S} ≤ ±20 V) Selection Guide</strong></td>
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<td>13</td>
<td>2.8</td>
<td>0.1</td>
<td>0.4</td>
<td>90000</td>
<td>100</td>
<td>2.5</td>
<td>N</td>
<td>N</td>
<td>SOIC</td>
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</tbody>
</table>

### Notes:
- New products appear in **BOLD RED**.
- X indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown.
- Y indicates: no character = single, 2 = dual, 3 = triple, 4 = quad.
- Suggested resale price in U.S. dollars in quantities of 1,000.
## Wide-Voltage Range Operational Amplifiers (±5 V ≤ V_S ≤ ±20 V) Selection Guide (Continued)

### Wide-Voltage, Low Power I_

#### TLE206x
- Description: Low Power, JFET-Input, High Drive
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 2.7
  - V_S (max): 36
  - Offset (V(∞)) (max): 3
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 0.5
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.63

#### OPAy130
- Description: Low Power, FET-Input
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 2.7
  - V_S (max): 36
  - Offset (V(∞)) (max): 2
  - GBW (MHz) (typ): 0.5
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 1.32

#### OPAy277
- Description: High Precision, Low Power
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 2.7
  - V_S (max): 36
  - Offset (V(∞)) (max): 2
  - GBW (MHz) (typ): 0.5
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.92

### Wide-Voltage, Low Input Bias Current I_B ≤ 100 pA (max)

#### OPAy703
- Description: 12 V, CMOS, Low Power
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 4
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.88

#### OPAy704
- Description: 12 V, CMOS, Low Power, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 4
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 1.02

#### OPAy705
- Description: 12 V, CMOS, Low Power, Low Cost
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 4
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 1.21

#### OPAy743
- Description: 12 V, 7 MHz, CMOS, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 3.5
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.46

### Wide-Voltage, Wide Bandwidth GBW ≥ 5 MHz (typ)

#### OPAy743
- Description: 12 V, 7 MHz, CMOS, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 3.5
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.88

#### OPAy704
- Description: 12 V, CMOS, Low Power, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 4
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 1.21

#### OPAy705
- Description: 12 V, CMOS, Low Power, Low Cost
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 4
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 1.02

#### OPAy743
- Description: 12 V, 7 MHz, CMOS, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 3.5
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.88

#### OPAy704
- Description: 12 V, CMOS, Low Power, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 4
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 1.21

#### OPAy705
- Description: 12 V, CMOS, Low Power, Low Cost
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 4
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 1.02

#### OPAy743
- Description: 12 V, 7 MHz, CMOS, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 3.5
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.88

### Wide-Voltage, Wide Bandwidth GBW ≥ 5 MHz (typ)

#### OPAy743
- Description: 12 V, 7 MHz, CMOS, G ≥ 5
- Specifications:
  - Ch.: 1, 2
  - V_S (min): 3.5
  - V_S (max): 12
  - Offset (V(∞)) (max): 1
  - GBW (MHz) (typ): 2
  - I_B (pA) (max): 1
  - CMRR 1 kHz (dB): 25000
  - Rail-to-Rail: 100
  - Price: 0.88

### Notes
1. x indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown. y indicates: no character = single, 2 = dual, 3 = triple, 4 = quad. 2Suggested resale price in U.S. dollars in quantities of 1,000.
## Wide-Voltage Range Operational Amplifiers (±5 V ≤ V_S ≤ ±20 V) Selection Guide (Continued)

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>V_S (V) (min)</th>
<th>I_{CC} (max)</th>
<th>GBW (MHz) (typ)</th>
<th>Slew Rate (V/µs) (max)</th>
<th>V_OS (µV/°C) (max)</th>
<th>I_{OS} (µA) (max)</th>
<th>CMRR (dB) (min)</th>
<th>V_{IN} at 1 kHz (nV/Hz) (typ)</th>
<th>Single Supply</th>
<th>Rail-to-Rail</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC08x</td>
<td>Low Noise, Wide Bandwidth, 1, 2, 4</td>
<td>4.5</td>
<td>16</td>
<td>2.5</td>
<td>10</td>
<td>16</td>
<td>1.2</td>
<td>50</td>
<td>100</td>
<td>8.5</td>
<td>Y</td>
<td>N</td>
<td>0.46</td>
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<tr>
<td>OPA132</td>
<td>Wide Bandwidth, FET-Input, 1, 2, 4</td>
<td>4.5</td>
<td>36</td>
<td>4.8</td>
<td>8</td>
<td>20</td>
<td>0.5</td>
<td>2</td>
<td>50</td>
<td>96</td>
<td>8</td>
<td>N</td>
<td>1.35</td>
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<tr>
<td>OPA227</td>
<td>Precision, Ultra-Low Noise, 1, 2, 4</td>
<td>5</td>
<td>36</td>
<td>3.8</td>
<td>8</td>
<td>2.3</td>
<td>0.075</td>
<td>0.1</td>
<td>10000</td>
<td>120</td>
<td>3</td>
<td>N</td>
<td>1.01</td>
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<td>OPA228</td>
<td>Precision, Ultra-Low Noise, G = 5</td>
<td>5</td>
<td>36</td>
<td>3.8</td>
<td>33</td>
<td>10</td>
<td>0.075</td>
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<td>120</td>
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<td>N</td>
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<td>OPA627</td>
<td>Ultra-Low THD+N, Wide Bandwidth, Precision</td>
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<td>9</td>
<td>36</td>
<td>7.5</td>
<td>16</td>
<td>55</td>
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<td>4</td>
<td>106</td>
<td>5.2</td>
<td>N</td>
<td>9.63</td>
</tr>
</tbody>
</table>

1x indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown. Y indicates: no character = single, 2 = dual, 3 = triple, 4 = quad.

### General Purpose Operational Amplifiers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>V_S (V) (min)</th>
<th>I_{CC} (max)</th>
<th>GBW (MHz) (typ)</th>
<th>Slew Rate (V/µs) (max)</th>
<th>V_OS (µV/°C) (max)</th>
<th>I_{OS} (µA) (max)</th>
<th>CMRR (dB) (min)</th>
<th>V_{IN} at 1 kHz (nV/Hz) (typ)</th>
<th>Single Supply</th>
<th>Rail-to-Rail</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF353</td>
<td>JFET-Input</td>
<td>2</td>
<td>7</td>
<td>36</td>
<td>3.25</td>
<td>3</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>18</td>
<td>N</td>
<td>Y</td>
<td>0.24</td>
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<tr>
<td>LM358,</td>
<td>Dual, Quad, General Purpose</td>
<td>2, 4</td>
<td>32</td>
<td>0.6, 0.7</td>
<td>0.3</td>
<td>1.2</td>
<td>0.5</td>
<td>—</td>
<td>—</td>
<td>10000</td>
<td>65</td>
<td>40, 35</td>
<td>0.18</td>
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<td>LM358A</td>
<td>General Purpose</td>
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<td>32</td>
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<td>50</td>
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<td>1</td>
<td>7</td>
<td>5</td>
<td>250</td>
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<td>Y</td>
<td>Y</td>
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<td>LMV224S</td>
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<td>1</td>
<td>7</td>
<td>5</td>
<td>250</td>
<td>39</td>
<td>Y</td>
<td>Y</td>
<td>0.35</td>
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<td>Y</td>
<td>PDIP, SOIC, CDIP, LCCC</td>
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<td>4</td>
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<td>Y</td>
<td>PDIP, Wide SOIC, CDIP, LCCC</td>
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<td>10</td>
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<td>0.5</td>
<td>6</td>
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<td>45</td>
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<td>70</td>
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<td>8</td>
<td>10</td>
<td>13, 9</td>
<td>4</td>
<td>800</td>
<td>70</td>
<td>45</td>
<td>N</td>
<td>PDIP, SOIC, SOP</td>
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<td>NE5532/</td>
<td>Precision, Low Offset</td>
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<td>6</td>
<td>36</td>
<td>5</td>
<td>0.6</td>
<td>0.3</td>
<td>0.15</td>
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<td>100, 94</td>
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<td>30</td>
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<td>3</td>
<td>1.7</td>
<td>6</td>
<td>—</td>
<td>500</td>
<td>70</td>
<td>8</td>
<td>0.28</td>
</tr>
<tr>
<td>TL06x/A/B</td>
<td>Low Power, JFET-Input</td>
<td>1, 2, 4</td>
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<td>3.5</td>
<td>15</td>
<td>6, 3</td>
<td>10, 18</td>
<td>4, 0.2, 0.2</td>
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<td>TL07x/A/B</td>
<td>Low Noise, JFET-Input</td>
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<td>13</td>
<td>10</td>
<td>0.4</td>
<td>0.2, 0.2</td>
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<td>70, 80</td>
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<tr>
<td>TL08x/A/B</td>
<td>JFET-Input</td>
<td>1, 2, 4</td>
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<td>2.8</td>
<td>3</td>
<td>13</td>
<td>15</td>
<td>18</td>
<td>0.4, 0.2</td>
<td>0.2</td>
<td>70, 75, 75</td>
<td>18</td>
<td>0.29</td>
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<tr>
<td>TL347x</td>
<td>High Slew Rate</td>
<td>2, 4</td>
<td>4</td>
<td>36</td>
<td>4.5</td>
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<td>13</td>
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<td>500</td>
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<td>TLV236x</td>
<td>High Performance, Low Voltage, RRO</td>
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<td>2</td>
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<td>3</td>
<td>6</td>
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<td>150</td>
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<td>UA741,</td>
<td>General Purpose</td>
<td>1, 2</td>
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<td>36</td>
<td>2.8</td>
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<td>0.5</td>
<td>6</td>
<td>—</td>
<td>500</td>
<td>70</td>
<td>Y</td>
<td>0.28</td>
</tr>
</tbody>
</table>

1Suggested resale price in U.S. dollars in quantities of 1,000.
Texas Instruments develops high-speed amps using state-of-the-art processes that generate leading edge performance. Used in next-generation, high-speed signal chains and analog-to-digital drive circuits, high-speed amps are loosely defined as any amplifier having at least 50-MHz of bandwidth and at least 100-V/µs slew rate. High speed amps from TI come in several different types and supply voltage options.

**Design Considerations**

**Voltage feedback type**—the most commonly used amp and the basic building block of most analog signal chains such as gain blocks, filtering, level shifting, buffering, etc. Most voltage-feedback amps are unity-gain stable, though some are decompensated to provide wider bandwidth, faster slew rate and lower noise.

**Current feedback type**—most commonly seen in video or xDSL line driver applications, or sockets where extremely fast slew rate is needed. Current-feedback amps are not ideal for filtering applications, as a capacitor in the feedback path can result in unstable operation.

**High-Speed Amplifiers Selection Tree**

- **Fully differential**—the fully differential input and output topology has the primary benefit of reducing even order harmonics, thereby reducing total harmonic distortion. This rejects common-mode components in the signal and provides a larger output swing to the load relative to single-ended amplifiers. Fully differential amplifiers are well-suited to driving analog-to-digital converters. A V<sub>COM</sub> pin sets the output common-mode voltage required by most data converters.

- **FET-input amplifiers**—have higher input impedance than typical bipolar amps and are more conducive to interfacing to high impedance sources, such as photodiodes in transimpedance circuits.

- **Video amplifiers**—can be used in a number of different ways, but generally are in the signal path for amplifying, buffering, filtering or driving video output lines. Typically, the specifications of interest are differential gain and differential phase. Current-feedback amps are typically used in video applications, because of their combination of high slew rate and excellent output drive.

- **Fixed and variable gain**—amps are also available with either a fixed gain, or a gain that can be varied either digitally with a few control pins, or linearly with a control voltage. Fixed gain amplifiers are fixed internally with gain setting resistors, usually expecting a specified load. Variable gain amplifiers can have different gain ranges, and can also be fully differential.

**Packaging**—high-speed amplifiers typically come in surface-mount packages, because parasitics of DIP packages can limit performance. Industry standard surface-mount packages (SOIC, MSOP, TSSOP and SOT23) handle the highest-speed bandwidth. For bandwidths approaching 1 GHz and higher, the leadless MSOP package decreases inductance and capacitance.

**Evaluation boards**—all high-speed amps have an associated Evaluation Module (EVM). EVMs are a very important part of high-speed amplifier evaluation, as layout is a critical to design success. To make layout simple, Gerber files of these boards are available. See page 37 for more information.

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**High-Speed Amplifiers Selection Tree**

<table>
<thead>
<tr>
<th>Voltage Feedback</th>
<th>Current Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Speed &lt; 500 MHz</strong></td>
<td><strong>General Purpose</strong></td>
</tr>
<tr>
<td>THS4001</td>
<td>±5 V to ±15 V Operational</td>
</tr>
<tr>
<td>THS4011/4012</td>
<td>OPA655</td>
</tr>
<tr>
<td>THS4051/4052</td>
<td>OPA656</td>
</tr>
<tr>
<td>THS4081/4082</td>
<td>OPA657 (G &gt; 7)</td>
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<tr>
<td>THS4041/4042</td>
<td>THS4601</td>
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<td>THS4120/4121</td>
<td>OPA355/355/355</td>
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<td>OPA354/354/354</td>
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<td>OPA357/357</td>
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<td>THS7030*</td>
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<td>THS4122/422</td>
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<td>THS2612/2613/2614/2618/2818</td>
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<td>THS4271</td>
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*Preview devices appear in BLUE.*
### High-Speed Amplifiers Selection Guide

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1New products appear in **BOLD RED**. Preview devices appear in **BOLD BLUE**. 2Suggested resale price in U.S. dollars in quantities of 1,000.
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<th>$I_O$ per Ch. (mA) (typ)</th>
<th>$I_O$ (mA) (typ)</th>
<th>Package(s)</th>
<th>Price</th>
</tr>
</thead>
</table>

1 New products appear in **BOLD RED**. Preview devices appear in **BOLD BLUE**. 2 Suggested resale price in U.S. dollars in quantities of 1,000.
## High-Speed Amplifiers Selection Guide (Continued)

<table>
<thead>
<tr>
<th>Device1</th>
<th>Ch.</th>
<th>SHDN Voltage (V)</th>
<th>Supply Voltage (V)</th>
<th>A&lt;sub&gt;CL&lt;/sub&gt; (min)</th>
<th>BW at A&lt;sub&gt;CL&lt;/sub&gt; (MHz) (typ)</th>
<th>BW (G = +2) (MHz) (typ)</th>
<th>GBW Product (MHz)</th>
<th>Slew Rate (V/µs)</th>
<th>Time 2 Vpp</th>
<th>V&lt;sub&gt;N&lt;/sub&gt; (nV/µH) (typ)</th>
<th>I&lt;sub&gt;B&lt;/sub&gt; (µA) (max)</th>
<th>I&lt;sub&gt;Q&lt;/sub&gt; (µA) (max)</th>
<th>Package(s)</th>
<th>Price1</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>Y</td>
<td>±5, ±5</td>
<td>210</td>
<td>170</td>
<td>—</td>
<td>—</td>
<td>820</td>
<td>11</td>
<td>—</td>
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<td>SOT23, SOIC</td>
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<td>—</td>
<td>±5, ±5</td>
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<td>—</td>
<td>—</td>
<td>820</td>
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<td>2100</td>
<td>8</td>
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<td>2100</td>
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<td>1800</td>
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<td>1000</td>
<td>70</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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<td>±5, ±15</td>
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<td>1900</td>
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<td>—</td>
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<td>—</td>
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<td>100</td>
<td>—</td>
<td>—</td>
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<td>100</td>
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<td>—</td>
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<td>2.5</td>
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<td>4</td>
<td>4.2</td>
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<tr>
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<td>—</td>
<td>±5, ±5, ±15</td>
<td>100</td>
<td>100</td>
<td>1000</td>
<td>60</td>
<td>—</td>
<td>—</td>
<td>0.16</td>
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<td>4</td>
<td>4.2</td>
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<td>±5, ±5, ±15</td>
<td>175</td>
<td>—</td>
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<td>43</td>
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<td>4.2</td>
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<tr>
<td>THS6092/93</td>
<td>2</td>
<td>Y</td>
<td>±5, ±5</td>
<td>100</td>
<td>—</td>
<td>600</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<td>2</td>
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<td>4.2</td>
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<td>70</td>
<td>300</td>
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<td>0.1</td>
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<td>4</td>
<td>4.2</td>
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<td>—</td>
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<td>80</td>
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<td>—</td>
<td>0.3</td>
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</table>

1New products appear in **BOLD RED**. Preview devices appear in **BOLD BLUE**. 2Suggested resale price in U.S. dollars in quantities of 1,000.
Comparator ICS are specialized op amps designed to compare two input voltages and provide a logic state output. They can be considered one-bit analog-to-digital converters.

The TI comparator portfolio consists of a variety of products with various performance characteristics, including: fast (ns) response time, wide input voltage ranges, extremely low quiescent current consumption and op amp and comparator combination ICS.

In general, if a fast response time is required, always use a comparator.

**Design Considerations**

**Output topology**
- **Open collector**—connects to the logic supply through a pull-up resistor and allows comparators to interface to a variety of logic families.
- **Push-pull**—does not require a pull-up resistor. Because the output swings rail-to-rail, the logic level is dependent on the voltage supplies of the comparator.

**Comparator vs. Op Amp**

<table>
<thead>
<tr>
<th>Speed (Response time)</th>
<th>Logic Output</th>
<th>Wide Diff. Input Range</th>
<th>Precision</th>
</tr>
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<tbody>
<tr>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
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</table>

**Comparator Product Portfolio Snapshot**

**Comparators Selection Guide**

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Channels</th>
<th>I_{CQ} per Ch. (mA) (max)</th>
<th>Output Current (mA) (min)</th>
<th>t_{RESP} Low-to-High (µs)</th>
<th>V_{IL} (V) (min)</th>
<th>V_{IH} (V) (max)</th>
<th>V_{OS} (5°C) (mV) (max)</th>
<th>Output Type</th>
<th>Package(s)</th>
<th>Price</th>
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</thead>
<tbody>
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<td><strong>High Speed t_{RESP} ≤ 0.1 µs</strong></td>
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<tr>
<td>TL714</td>
<td>Linear</td>
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<td>0.008</td>
<td>4.75</td>
<td>5.25</td>
<td>10</td>
<td>Open Drain/Collector</td>
<td>PDIP, SOT23</td>
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<td>5</td>
<td>10</td>
<td>3</td>
<td>Open Drain/Collector</td>
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<td>TL3116</td>
<td>Ultra Fast, Low Power, Precision</td>
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<td>0.0099</td>
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<td>10</td>
<td>3</td>
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<td>SDIC, TSSOP</td>
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<td>TL712</td>
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<td>–0.6</td>
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<td>30</td>
<td>7.5</td>
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<td>PDIP, SDIC, SOP, TSSOP</td>
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<td><strong>Low Power I_{CQ} &lt; 0.5 mA</strong></td>
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<tr>
<td>TLV340x</td>
<td>Nanopower, Open Drain, RRI0</td>
<td>1, 2, 4</td>
<td>0.00055</td>
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<td>2.5</td>
<td>16</td>
<td>3.6</td>
<td>Open Drain/Collector</td>
<td>MSOP, PDIP, SDIC, SOT23, TSSOP</td>
<td>0.56</td>
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</tbody>
</table>

1x indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown. y indicates: no character = single, 2 = dual, 3 = triple, 4 = quad. 2Suggested resale price in U.S. dollars in quantities of 1,000.
## Comparators Selection Guide (continued)

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>$I_{CH}$ (mA) (max)</th>
<th>Output Current (mA) (min)</th>
<th>$t_{rise}$ Low-to-High (ps)</th>
<th>$V_{IL}$ (V) (min)</th>
<th>$V_{OH}$ (V) (max)</th>
<th>$V_{OL}$ (25°C) (mV) (max)</th>
<th>Output Type</th>
<th>Package(s)</th>
<th>Price</th>
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<tbody>
<tr>
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<td>TLV370x</td>
<td>Nanopower, Push-Pull, RRIO</td>
<td>1, 2, 4</td>
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<td>36</td>
<td>2.5</td>
<td>16</td>
<td>5</td>
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<td>MSOP, PDIP, SOIC, SOT23, TSSOP</td>
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<td>TLV349x</td>
<td>Low Voltage, Excellent Speed/Power</td>
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<td>&lt; 0.1</td>
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<td>15</td>
<td>Push Pull</td>
<td>SOT23, SOIC, TSSOP</td>
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<td>Sub-Micropower, Op Amp and Comparator, RRIO</td>
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<td>16</td>
<td>5</td>
<td>Open Drain/Collector</td>
<td>MSOP, PDIP, SOIC, TSSOP</td>
<td>0.84</td>
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<tr>
<td><strong>Low Voltage $V_{OL} ≤ 2.7$ V (min)</strong></td>
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<tr>
<td>TLC370x</td>
<td>Fast, Low Power</td>
<td>2</td>
<td>0.02</td>
<td>4</td>
<td>1.1</td>
<td>3</td>
<td>16</td>
<td>5</td>
<td>Push Pull</td>
<td>PDIP, SOIC, TSSOP</td>
<td>0.35</td>
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<tr>
<td>TL339x</td>
<td>Linear</td>
<td>2</td>
<td>0.02</td>
<td>6</td>
<td>1.1</td>
<td>3</td>
<td>16</td>
<td>5</td>
<td>Open Drain/Collector</td>
<td>PDIP, SOIC, SOP, TSSOP</td>
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<tr>
<td>LP2901</td>
<td>Quad, Low Power, Open Drain</td>
<td>4</td>
<td>0.025</td>
<td>—</td>
<td>1.3</td>
<td>5</td>
<td>30</td>
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<td>Open Drain/Collector</td>
<td>PDIP, SOIC</td>
<td>0.56</td>
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<tr>
<td>TLV349x</td>
<td>Low Voltage, Excellent Speed/Power</td>
<td>1, 2, 4</td>
<td>0.0012</td>
<td>—</td>
<td>&lt; 0.1</td>
<td>1.8</td>
<td>5.5</td>
<td>15</td>
<td>Push Pull</td>
<td>SOT23, SOIC, TSSOP</td>
<td>0.55</td>
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<tr>
<td>TLV370x</td>
<td>Nanopower, Push-Pull, RRIO</td>
<td>1, 2, 4</td>
<td>0.00008</td>
<td>—</td>
<td>36</td>
<td>2.5</td>
<td>16</td>
<td>5</td>
<td>Push Pull</td>
<td>MSOP, PDIP, SOIC, SOT23, TSSOP</td>
<td>0.56</td>
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<tr>
<td><strong>Combination Comparators and Op Amps</strong></td>
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<tr>
<td>TLV230x</td>
<td>Sub-Micropower, Op Amp and Comparator, RRIO</td>
<td>2</td>
<td>0.0017</td>
<td>—</td>
<td>55</td>
<td>2.5</td>
<td>16</td>
<td>5</td>
<td>Open Drain/Collector</td>
<td>MSOP, PDIP, SOIC, TSSOP</td>
<td>0.84</td>
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<tr>
<td>TLV270x</td>
<td>Sub-Micropower, Op Amp and Comparator, RRIO</td>
<td>2, 4</td>
<td>0.0019</td>
<td>—</td>
<td>36</td>
<td>2.5</td>
<td>16</td>
<td>5</td>
<td>Push Pull</td>
<td>MSOP, PDIP, SOIC, TSSOP</td>
<td>0.84</td>
</tr>
</tbody>
</table>

1New products appear in **BOLD RED**. $x$ indicates: 0 = single with shutdown, 1 = single, 2 = dual, 3 = dual with shutdown, 4 = quad, 5 = quad with shutdown. $y$ indicates: no character = single, 2 = dual, 3 = triple, 4 = quad. 2Suggested resale price in U.S. dollars in quantities of 1,000.
The difference amplifier is a moderate input impedance, closed-loop, fixed-gain block that allows the acquisition of signals in the presence of ground loops and noise. These devices can be used in a variety of circuit applications—precision, general-purpose, audio, low-power, high-speed and high-common-mode voltage applications.

**Difference Amplifier**

The basic difference amplifier employs an op amp and four on-chip precision, laser-trimmed resistors. The INA132, for example, operates on 2.7-V to 36-V supplies and consumes only 160 µA. It has a differential gain of 1 and high common-mode rejection. The output signal can be offset by applying a voltage to the Ref pin. The output sense pin can be connected directly at the load to reduce gain error. Because the resistor network divides down the input voltages, difference amplifiers can operate with input signals that exceed the power supplies.

**INA132 Block Diagram**

A five-resistor version of the simple difference amplifier results in a device that can operate with very high levels of common-mode voltage—far beyond the supply rails. For example, the INA117 can sense differential signals in the presence of common-mode voltages as high as ±200 V while being powered from ±15 V. This device is very useful in measuring current from a high-voltage power supply through a high-side shunt resistor.

**INA117 Block Diagram**

**Design Considerations**

- **Power supply**—common-mode voltage is always a function of the supply voltage. The INA103 instrumentation amplifier is designed to operate on voltages up to ±25 V, while the INA122 difference amp can be operated from a 2.2-V supply.
- **Output voltage swing**—lower supply voltage often drives the need to maximize dynamic range by swinging close to the rails.
- **Common-mode input voltage range (CMV)**—selection of the most suitable difference amp begins with an understanding of the input voltage range. Some offer resistor networks that divide down the input voltages, allowing operation with input signals that exceed the power supplies. A five-resistor version of the simple difference amplifier results in a device that can operate with very high levels of common-mode voltage—far beyond the supply rails.
- **Gain**—signal amplification needed for desired circuit function must be considered. With the uncommitted on-chip op amp the INA145 and the INA146 can be configured for gains of 0.1 to 1000.
- **Sensor impedance**—should be less than \(1/1000\) of difference amp impedance to retain CMR and gain accuracy. In other words, the amp input impedance should be 1,000 times higher than the source impedance.
- **Offset voltage drift (µV/°C)**—input offset voltage changes over temperature. This is more critical in applications with changing ambient temperature.
- **Quiescent current**—often of high importance in battery-powered applications, where amplifier power consumption can greatly influence battery life.
- **Slew rate**—if the signal is reporting a temperature, force or pressure, slew rate is not generally of great concern. If the signal is for an electronic event, (e.g. current, power output) a fast transition is needed.
- **Common-mode rejection**—a measure of unwanted signal rejection and the amp's ability to extract a signal from surrounding DC, power line or other electrical noise.

**Should I use a Difference or Instrumentation Amplifier?**

Difference amplifiers excel when measuring signals with common-mode voltages greater than the power supply rails, when there is a low power requirement, when a small package is needed, when the source impedance is low or when a low-cost differential amp is required. The difference amp is a building block of the instrumentation amp.

Instrumentation amps are designed to amplify low-level differential signals in the presence of high-common-mode voltage. Generally, using an adjustable gain block, they are well suited to single-supply applications. The three-op-amp topology works well down to Gain = 1, with a performance advantage in AC CMR. The two-op-amp topology is appropriate for tasks requiring a small package footprint and a gain of 5 or greater. It is the best choice for low-voltage, single-supply applications.
## Difference Amplifiers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Ch.</th>
<th>Gain</th>
<th>Offset Drift (µV/°C) (max)</th>
<th>CMRR (dB) (min)</th>
<th>BW (MHz) (typ)</th>
<th>Output Voltage Swing (V) (min)</th>
<th>Power Supply (V)</th>
<th>Iₒ Per Ch. (mA) (max)</th>
<th>Package(s)</th>
<th>Price¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Purpose</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INA132</td>
<td>Micropower, High Precision</td>
<td>1</td>
<td>1</td>
<td>250</td>
<td>5</td>
<td>76</td>
<td>0.3 (V+) – 1 to (V–) + 0.5</td>
<td>+2.7 to +36</td>
<td>0.185</td>
<td>DIP, SO</td>
<td>0.99</td>
</tr>
<tr>
<td>INA2132</td>
<td>Dual INA132</td>
<td>2</td>
<td>1</td>
<td>250</td>
<td>5</td>
<td>76</td>
<td>0.3 (V+) – 1 to (V–) + 0.5</td>
<td>+2.7 to +36</td>
<td>0.185</td>
<td>DIP, SO</td>
<td>0.99</td>
</tr>
<tr>
<td>INA133</td>
<td>High Precision, Fast</td>
<td>1</td>
<td>1</td>
<td>450</td>
<td>5</td>
<td>80</td>
<td>1.5 (V+) – 1.5 to (V–) + 1</td>
<td>±2.25 to ±18</td>
<td>1.2</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
</tr>
<tr>
<td>INA2133</td>
<td>Dual INA133</td>
<td>2</td>
<td>1</td>
<td>450</td>
<td>5</td>
<td>80</td>
<td>1.5 (V+) – 1.5 to (V–) + 1</td>
<td>±2.25 to ±18</td>
<td>1.2</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
</tr>
<tr>
<td>INA143</td>
<td>High Precision, G = 10 or 1/10</td>
<td>1</td>
<td>10, 1/10</td>
<td>250</td>
<td>3</td>
<td>86</td>
<td>0.15 (V+) – 1 to (V–) + 0.5</td>
<td>±2.25 to ±18</td>
<td>1.2</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
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<tr>
<td>INA2143</td>
<td>Dual INA143</td>
<td>2</td>
<td>10, 1/10</td>
<td>250</td>
<td>3</td>
<td>86</td>
<td>0.15 (V+) – 1 to (V–) + 0.5</td>
<td>±2.25 to ±18</td>
<td>1.2</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
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<tr>
<td>INA145</td>
<td>Resistor Programmable Gain</td>
<td>1</td>
<td>1</td>
<td>750</td>
<td>5</td>
<td>86</td>
<td>0.7 (V+) – 0.2 to (V–) + 0.2</td>
<td>+2.7 to +20</td>
<td>0.85</td>
<td>MSOP-8</td>
<td>1.10</td>
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<tr>
<td>INA2145</td>
<td>Dual INA145</td>
<td>2</td>
<td>1</td>
<td>750</td>
<td>5</td>
<td>86</td>
<td>0.7 (V+) – 0.2 to (V–) + 0.2</td>
<td>+2.7 to +20</td>
<td>0.85</td>
<td>MSOP-8</td>
<td>1.10</td>
</tr>
<tr>
<td>INA146</td>
<td>High Precision, High Precision</td>
<td>1</td>
<td>1</td>
<td>750</td>
<td>5</td>
<td>86</td>
<td>0.5 (V+) – 0.2 to (V–) + 0.2</td>
<td>±2.25 to ±18</td>
<td>0.7</td>
<td>SOIC-8</td>
<td>1.40</td>
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<tr>
<td>INA2146</td>
<td>Dual INA146</td>
<td>2</td>
<td>1</td>
<td>750</td>
<td>5</td>
<td>86</td>
<td>0.5 (V+) – 0.2 to (V–) + 0.2</td>
<td>±2.25 to ±18</td>
<td>0.7</td>
<td>SOIC-8</td>
<td>1.40</td>
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<tr>
<td>INA152</td>
<td>Micropower, High Precision</td>
<td>1</td>
<td>1</td>
<td>750</td>
<td>5</td>
<td>86</td>
<td>0.7 (V+) – 1 to (V–) + 0.5</td>
<td>±2.25 to ±18</td>
<td>1.2</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
</tr>
<tr>
<td>INA154</td>
<td>High Speed, Precision, G = 1</td>
<td>1</td>
<td>1</td>
<td>750</td>
<td>5</td>
<td>86</td>
<td>0.7 (V+) – 1 to (V–) + 0.5</td>
<td>±2.25 to ±18</td>
<td>1.2</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
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<tr>
<td>INA157</td>
<td>High Speed, G = 2 or 1/2</td>
<td>1</td>
<td>2, 1/2</td>
<td>500</td>
<td>20</td>
<td>86</td>
<td>0.5 (V+) – 1 to (V–) + 0.5</td>
<td>±2.25 to ±18</td>
<td>0.7</td>
<td>SOIC-8</td>
<td>0.99</td>
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<tr>
<td><strong>Audio</strong></td>
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<tr>
<td>INA134</td>
<td>Low Distortion: 0.0005%</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>2</td>
<td>74</td>
<td>3.1 (V+) – 2 to (V–) + 2</td>
<td>±4 to ±18</td>
<td>2.9</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
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<tr>
<td>INA2134</td>
<td>Dual INA134</td>
<td>2</td>
<td>1</td>
<td>1000</td>
<td>2</td>
<td>74</td>
<td>3.1 (V+) – 2 to (V–) + 2</td>
<td>±4 to ±18</td>
<td>2.9</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
</tr>
<tr>
<td>INA137</td>
<td>Low Distortion, G = 1/2 or 2</td>
<td>1</td>
<td>2, 1/2</td>
<td>1000</td>
<td>2</td>
<td>74</td>
<td>4 (V+) – 2 to (V–) + 2</td>
<td>±4 to ±18</td>
<td>2.9</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
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<tr>
<td>INA2137</td>
<td>Dual INA137</td>
<td>2</td>
<td>2, 1/2</td>
<td>1000</td>
<td>2</td>
<td>74</td>
<td>4 (V+) – 2 to (V–) + 2</td>
<td>±4 to ±18</td>
<td>2.9</td>
<td>SOIC-8/-14</td>
<td>0.99</td>
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<tr>
<td><strong>High-Common-Mode Voltage</strong></td>
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<tr>
<td>INA1171</td>
<td>±200-V CM Range</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>20</td>
<td>86</td>
<td>0.2 (V+) – 2 to (V–) + 2</td>
<td>±5 to ±18</td>
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<td>SOIC-8</td>
<td>2.70</td>
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<td>INA146</td>
<td>±100-V CM Range, Prog. Gain</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>20</td>
<td>86</td>
<td>0.2 (V+) – 2 to (V–) + 2</td>
<td>±5 to ±18</td>
<td>2.0</td>
<td>SOIC-8</td>
<td>1.60</td>
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<tr>
<td>INA148</td>
<td>±200-V CM Range, 1-MΩ Input</td>
<td>1</td>
<td>1</td>
<td>1000</td>
<td>20</td>
<td>86</td>
<td>0.2 (V+) – 2 to (V–) + 2</td>
<td>±5 to ±18</td>
<td>2.0</td>
<td>SOIC-8</td>
<td>1.95</td>
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<tr>
<td><strong>High-Side Current Shunt Monitor</strong></td>
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<tr>
<td>INA138</td>
<td>36 V max</td>
<td>1</td>
<td>1</td>
<td>200 µA/V</td>
<td>1000</td>
<td>100</td>
<td>0.8 (V+) – 0.8 to (V–) + 0.8</td>
<td>+2.7 to 36</td>
<td>0.045</td>
<td>SOT23-5</td>
<td>0.95</td>
</tr>
<tr>
<td>INA139</td>
<td>High Speed, 40 V max</td>
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<td>1</td>
<td>1000 µA/V</td>
<td>1000</td>
<td>100</td>
<td>0.8 (V+) – 0.8 to (V–) + 0.8</td>
<td>+2.7 to 40</td>
<td>0.125</td>
<td>SOT23-5</td>
<td>0.95</td>
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<tr>
<td>INA168</td>
<td>60 V max</td>
<td>1</td>
<td>1</td>
<td>200 µA/V</td>
<td>1000</td>
<td>100</td>
<td>0.8 (V+) – 0.8 to (V–) + 0.8</td>
<td>+2.7 to 60</td>
<td>0.045</td>
<td>SOT23-5</td>
<td>1.15</td>
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<tr>
<td>INA169</td>
<td>High Speed, 60 V max</td>
<td>1</td>
<td>1</td>
<td>1000 µA/V</td>
<td>1000</td>
<td>100</td>
<td>0.8 (V+) – 0.8 to (V–) + 0.8</td>
<td>+2.7 to 60</td>
<td>0.125</td>
<td>SOT23-5</td>
<td>1.15</td>
</tr>
<tr>
<td>INA170</td>
<td>High-Side Bi-directional</td>
<td>1</td>
<td>1</td>
<td>1000 µA/V</td>
<td>1000</td>
<td>100</td>
<td>0.8 (V+) – 0.8 to (V–) + 0.8</td>
<td>+2.7 to 60</td>
<td>0.125</td>
<td>MSOP-8</td>
<td>1.21</td>
</tr>
</tbody>
</table>

¹Suggested resale price in U.S. dollars in quantities of 1,000. ²–55 to +125 version available.
The instrumentation amplifier (IA) is a high input impedance, closed-loop fixed-or adjustable-gain block that allows the amplification of low-level signals in the presence of common-mode errors and noise. TI offers many types of instrumentation amplifiers including single-supply, low-power, high-speed and low-noise devices. These instrumentation amplifiers are available in either the traditional three-op-amp or in the cost-effective two-op-amp topology.

**Three-Op-Amp Version**

The three-op-amp topology is the benchmark for instrumentation amplifier performance. These devices provide a wide gain range (down to \( G = 1 \)) and generally offer the highest performance. Symmetrical inverting and non-inverting gain paths provide better common-mode rejection at high frequencies. Some types use current-feedback-type input op amps which maintain excellent bandwidth in high gain.

**Two-Op-Amp Version**

The two-op-amp topology can provide wider common-mode voltage range, especially in low-voltage, single-supply applications. Their simpler internal circuitry allows lower cost, lower quiescent current and smaller package sizes. This topology, however, does not lend itself to gains less than four (INA125) or five (all others).

Two-op-amp topology provides wider common-mode range in low-voltage, single-supply applications.

**Design Considerations**

**Supply voltage**—TI has developed a series of low voltage, single-supply, rail-to-rail instrumentation amps suitable for a wide variety of applications requiring maximum dynamic signal range.

**Gain requirement**—for high-gain applications consider a low total noise device, as drift, input bias current and voltage offset all contribute to error.

**Common-mode voltage range**—the voltage input range over which the amplifier can operate and the differential pair behaves as a linear amplifier for differential signals.

**Input bias current**—can be an important factor in many applications, especially those sensing a low current or where the sensor impedance is very high. The INA116 requires only 3-fA (\( 10^{-15} \)) typical of input bias current.

**Offset voltage and drift**—IAs are generally used in high-gain applications, where any amp errors are amplified by the circuit gain. This can become a significant portion of the overall signal unless \( V_{OS} \) and drift are taken into account. Bipolar amps excel in limiting voltage errors related to offset and drift in low source impedance applications.

**Current-feedback vs. voltage-feedback input stage**—appropriate for designers needing higher bandwidth or a more consistent 3-dB rolloff frequency than voltage feedback input stage instrumentation amps and have a 3-dB rolloff at essentially the same frequency in both \( G = 1 \) and \( G = 10 \) configurations.

**Technical Information**

Instrumentation amplifiers (IA) accurately output the difference between the input signals providing Common-Mode Rejection (CMR). It is the key parameter and main purpose for using this type of device. CMR measures the device’s ability to reject signals that are common to both inputs.

IAs are often used to amplify the differential output of a bridge sensor, amplifying the tiny bridge output signals while rejecting the large common-mode voltage. They provide excellent accuracy and performance, yet require minimal quiescent current. Gain is usually set with a single external resistor.

In some applications unwanted common-mode signals may be less conspicuous. Real-world ground interconnections are not perfect. What may, at first, seem to be a viable single-ended amplifier application can become an accumulation of errors. Error voltages caused by currents flowing in ground loops sum with the desired input signal and are amplified by a single-ended input amp. Even very low impedance grounds can have induced voltages from stray magnetic fields. As accuracy requirements increase, it becomes more difficult to design accurate circuits with a single-ended input amplifier. The differential input instrumentation amplifier is the answer.
### Single-Supply Instrumentation Amplifiers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Gain</th>
<th>Non Linearity (%)</th>
<th>Input Offset Current (nA)</th>
<th>Offset at G = 100 (µV)</th>
<th>Offset Drift at G = 100 (µV/°C)</th>
<th>CMRR at G = 100 (dB)</th>
<th>BW at G = 100 (kHz)</th>
<th>Noise 1 kHz (nV/Hz)</th>
<th>Power Supply (V)</th>
<th>Iq per Amp (µA)</th>
<th>Package(s)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>INA321</td>
<td>RRO, SHDN, Low Offset and Gain Error, Wide Temp</td>
<td>5 to 10000</td>
<td>0.01</td>
<td>0.01</td>
<td>1000</td>
<td>7</td>
<td>90</td>
<td>50</td>
<td>100</td>
<td>2.7 to 5.5</td>
<td>0.06</td>
<td>MSOP-8</td>
<td>1.10</td>
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1. *New products appear in BOLD RED.* 2. Suggested resale price in U.S. dollars in quantities of 1,000. 3. Typical. 4. Internal +40-V input protection. 5. –40°C to +85°C.
## Dual-Supply Instrumentation Amplifiers Selection Guide

<table>
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<tr>
<th>Device</th>
<th>Description</th>
<th>Gain</th>
<th>Non Linearity (%)</th>
<th>Input Offset Current (nA)</th>
<th>Input Offset at G = 100 (µV)</th>
<th>CMRR at G = 100 (dB)</th>
<th>BW at G = 100 (kHz)</th>
<th>Noise 1 kHz (nV/Hz)</th>
<th>Power Supply (V)</th>
<th>$I_o$ (max) (µA)</th>
<th>Package(s)</th>
<th>Price (DIP)</th>
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<tr>
<td>INA217</td>
<td>Precision, Low Drift, Audio, Mic PreAmp, THD+N = 0.09% SSM2017 Replacement</td>
<td>1 to 10000</td>
<td>0.00063</td>
<td>12000</td>
<td>300</td>
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<td>–100</td>
<td>800</td>
<td>1.3</td>
<td>±4.5 to ±1.8</td>
<td>DIP-8, SO-16</td>
<td>2.35</td>
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</tbody>
</table>

1. Suggested resale price in U.S. dollars in quantities of 1,000.
2. Internal +40-V input protection.
3. Typical.
4. Parts also available in a dual version.
Digitally Programmable Gain Amplifiers

Programmable gain instrumentation amplifiers (PGA) are extremely versatile data acquisition input amplifiers that provide digital control of gain for improved accuracy and extended dynamic range. Many have inputs that are protected to ±40 V even with the power supply off. A single input amplifier type can be connected to a variety of sensors or signals. Under processor control, the switched gain extends the dynamic range of the system.

All PGA-series amps have TTL- or CMOS-compatible inputs for easy microprocessor interface. Inputs are laser trimmed for low offset voltage and low drift to allow use without the need of external components.

Design Considerations

Primary
Digitally selected gain required—two pins allow the selection of up to four different gain states. A PGA202 and PGA203 can be put in series for greater gain selection.

Non-linearity (accuracy)—depends heavily on what is being fed. A 16-bit converter will require significantly better accuracy (i.e. lower non-linearity) than a 10-bit converter.

Secondary
Gain error and drift—for higher gain, high-precision applications will require closer attention to drift and gain error.

Connecting two programmable gain amps can provide binary gain steps \( G = 1 \) to \( G = 64 \).

Digitaly Programmable Gain Amplifiers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Gain (%)</th>
<th>Non Linearity at ( G = 100 ) (max)</th>
<th>Offset ( \mu \text{V} ) (max)</th>
<th>Offset Drift ( \mu \text{V/°C} ) (max)</th>
<th>CMRR at ( G = 100 ) (dB) (min)</th>
<th>BW at ( G = 100 ) (kHz) (typ)</th>
<th>Noise at 1kHz (nV/\text{Hz}) (typ)</th>
<th>Power Supply (V)</th>
<th>( I_d ) (mA) (max)</th>
<th>Package(s)</th>
<th>Price</th>
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<tr>
<td>3606</td>
<td>High-Resolution Hybrid</td>
<td>1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024</td>
<td>0.01</td>
<td>22</td>
<td>1</td>
<td>100</td>
<td>40</td>
<td>30</td>
<td>±8 to ±18</td>
<td>10</td>
<td>Module-32</td>
<td>201.12</td>
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<td>PGA103</td>
<td>Precision, Single-Ended Input</td>
<td>1, 10, 100</td>
<td>0.01</td>
<td>500</td>
<td>2 (typ)</td>
<td>—</td>
<td>250</td>
<td>11</td>
<td>±4.5 to ±18</td>
<td>3.5</td>
<td>SDL-8</td>
<td>3.90</td>
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<tr>
<td>PGA202</td>
<td>High Speed, FET-Input, 50-pA ( I_d )</td>
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<td>0.012</td>
<td>1000</td>
<td>12</td>
<td>92</td>
<td>1000</td>
<td>12</td>
<td>±4.5 to ±18</td>
<td>6.5</td>
<td>DIP-14</td>
<td>7.28</td>
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<tr>
<td>PGA203</td>
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<td>0.012</td>
<td>1000</td>
<td>12</td>
<td>92</td>
<td>1000</td>
<td>12</td>
<td>±4.5 to ±18</td>
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<td>DIP-14</td>
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<tr>
<td>PGA204</td>
<td>High Precision, Gain Error: 0.25%</td>
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<td>0.002</td>
<td>50</td>
<td>0.25</td>
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<td>10</td>
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<td>±4.5 to ±18</td>
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<tr>
<td>PGA205</td>
<td>Gain Drift: 0.024 ppm/°C²</td>
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<td>50</td>
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<td>PGA207</td>
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<td>2 (typ)</td>
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<td>600</td>
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<td>±4.5 to ±18</td>
<td>12.4</td>
<td>DIP-16, SDL-16</td>
<td>11.14</td>
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</table>

¹Suggested resale price in U.S. dollars in quantities of 1,000. ²Internal +40-V input protection.
The voltage-controlled gain amplifier (VCA) provides linear-dB gain and gain-range control with high impedance inputs. Available in single and dual configurations, the VCA series is designed to be used as a flexible gain-control element in a variety of electronic systems. With a broad gain-control range, both gain and attenuation control are provided for maximum flexibility.

**Design Considerations**

**Primary**

- **Input frequency**—VCA series capable of processing input frequencies up to 20 MHz.
- **Noise (nV/√Hz)**—as low as 1 nV/√Hz total noise (max).
- **Variable gain range**—to 45 dB for VCA261x series, 77 dB for VCA610.

**Secondary**

- **Number of channels**—VCA610 is single channel; VCA261x are all dual channel.

Distortion—low second-harmonic distortion (~40 dB min) with low crosstalk (70 dB at max gain, 5 MHz).

**Technical Information**

The broad attenuation range can be used for gradual or controlled channel turn-on or turn-off where abrupt gain changes can create artifacts and other errors.

**Typical Applications**

- Ultrasound systems
- Wireless receivers
- Test equipment

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### Voltage-Controlled Gain Amplifiers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>$V_n$ (nV/√Hz)</th>
<th>Bandwidth (MHz) (typ)</th>
<th>Specified at $V_n$ (V)</th>
<th>Number of Channels</th>
<th>Variable Gain Range (dB)</th>
<th>Package(s)</th>
<th>Price</th>
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<td>VCA2612</td>
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<td>VCA2614</td>
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<td>5</td>
<td>2</td>
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<td>7.95</td>
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<tr>
<td>VCA2616</td>
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<td>40</td>
<td>5</td>
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<td>TQFP</td>
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<td>VCA610</td>
<td>2.2</td>
<td>1</td>
<td>5</td>
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<td>77</td>
<td>SOP</td>
<td>11.12</td>
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<tr>
<td>VCA2618</td>
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<td>5</td>
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<td>TQFP</td>
<td>7.95</td>
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<tr>
<td>THS7530</td>
<td>1.27</td>
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<td>5</td>
<td>1</td>
<td>46</td>
<td>PowerPAD™</td>
<td>3.65</td>
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</tbody>
</table>

1. Suggested resale price in U.S. dollars in quantities of 1,000.
Audio Amplifiers

Consumers are enjoying new ways to listen to music, books and news, while demanding more flexibility, better quality and multi-function products. There is an ever-increasing demand for high-end entertainment for the everyday consumer. The market expects the best listening experience from any audio format and source, mobile or stationary and at a competitive price.

By offering flexible, cost-efficient, end-to-end audio solutions, TI provides OEMs/ODMs with faster time to market and one-stop shopping. TI’s complete audio solutions include best-in-class silicon, systems expertise, software and support. By leveraging the programmability, performance headroom and design flexibility of TI’s leading DSP and analog technologies, customers have the ability to build audio products with more functionality that offer a true, lifelike sound experience at a lower overall system cost.

Design Considerations

Primary

Output power—supply voltage and load impedance limit the level of output power (i.e. volume) an audio power amp (APA) can drive. Always verify that the desired output power is theoretically possible with the equation

$$P_O = \frac{V_o^2}{R_L}$$

where $V_o$ is the RMS voltage of the output signal and $R_L$ is the load impedance.

Output configuration—there are two types of output configurations, single-ended (SE) and bridge-tied load (BTL). An SE configuration is where one end of the load is connected to the APA and the other end of the load is connected to ground. Used primarily in headphone applications or where the audio power amplifier and speaker are in different enclosures. A BTL configuration is where both ends of the load are connected to an APA. This configuration effectively quadruples the output power capability of the system, and is used primarily in applications that are space constrained and where the APA and speaker are in the same enclosure.

Total Harmonic Distortion + Noise—harmonic distortion is distortion at frequencies that are whole number multiples of the test tone frequency. THD+N is typically specified for rated output power at 1 kHz. Values below 0.5 percent to 0.3 percent are negligible to the untrained ear.

Amplifier technology (Class-D and Class-AB)—Class-D and Class-AB are the most common APAs in consumer electronics, because of their great performance and low cost. Class-D amps are very efficient and provide the longest battery life and lowest heat dissipation. Class-AB amps offer the greatest selection of features (e.g. digital volume control and bass boost).

Secondary

Digital volume control—this input changes the gain of the APA when digital high or low pulses are applied to the UP and DOWN pins.

DC volume control—internal gain settings that are controlled by the VOLUME pin.

Integrated gain settings—the internal gain settings are controlled via the input pins GAIN0 and GAIN1.

DEPOP—circuitry internal to the APA. It minimizes voltage spikes when the APA turns on, off or transitions in or out of shutdown mode.

MUX—allows two different audio sources to the APA that are controlled independently of the amplifier configuration.

Shutdown—circuitry that places the APA in a very-low-power consumption standby state.

Technical Information

TI APAs are easy to design with requiring only a few external components.

Power supply capacitors—$C_{VDD}$ minimizes THD by filtering off the low frequency noise and the high frequency transients.

Input capacitors—in the typical application an input capacitor, $C_{IN}$, is required to allow the amplifier to bias the input signal to the proper dc level for optimum operation. $C_{IN}$ is usually in the 0.1 µF to 10 µF range for good low-frequency response.

Points to Consider When Choosing an Audio Power Amplifier (APA)

- Is the APA driving speakers or headphones?
- What is the impedance of the headphones or speakers: 4 Ω, 8 Ω, 32 Ω?
- Is the application stereo, mono or multichannel?
- Is the supply voltage ≤ 3 V, 5 V, 12 V or ≥ 18 V?
- What is the required output power?
- Is there a need for volume control?
- Is the APA input single-ended or differential?

Digital audio power amplifiers require unique considerations. The latest information is located at www.ti.com/digitalaudioapps.html.
Audio Amplifiers

Bypass capacitor—$C_{\text{BYPASS}}$ controls the start up time and helps to reduce the THD. Typically this capacitor is ten times larger than the input decoupling capacitors ($C_{\text{IN}}$).

Layout—by respecting basic rules, Class-D amplifiers’ layout can be made easy. Decoupling caps must be close to the device, the output loop must be small to avoid the use of a filter and the differential input traces must be kept together to limit the RF rectification. Analog $V_{\text{DD}}$ and switching $V_{\text{DD}}$ need to be separated back to the supply source.

Migration path—APA products are in a constant evolution moving from Class-AB mono speaker drivers to optimized stereo Class-D amplifiers with advanced features. The latest generation is the most cost effective for the application.

Audio Power Amplifiers Product Portfolio Overview
<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Stereo/ Mono Speaker Drive</th>
<th>Stereo/ Mono Headphone Drive</th>
<th>Output Power (W)</th>
<th>V&lt;sub&gt;oc&lt;/sub&gt; (V)</th>
<th>V&lt;sub&gt;in&lt;/sub&gt; (V)</th>
<th>THD+N at 1 kHz (%)</th>
<th>PSRR (dB)</th>
<th>I&lt;sub&gt;th&lt;/sub&gt; (mA)</th>
<th>I&lt;sub&gt;s&lt;/sub&gt; (pA)</th>
<th>Min Load Impedance (Ω)</th>
<th>Input MUX</th>
<th>SHDN (Active Low/High)</th>
<th>Int. Gain</th>
<th>DC Volume Control</th>
<th>Digital Volume Control</th>
<th>Package(s)</th>
<th>Package Symbolization</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPA3001D1</td>
<td>Mono, Class-D, Differential Input</td>
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<td>—</td>
<td>20</td>
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<tr>
<td>TPA3002D2</td>
<td>Stereo, Class-D, Differential Input</td>
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<td>7</td>
<td>8</td>
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<td>8</td>
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<tr>
<td>TPA3032D3</td>
<td>Mono, Class-D, Differential Input and Class-AB Headphone Amp with Depop</td>
<td>M</td>
<td>S</td>
<td>10</td>
<td>8</td>
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<td>0.5</td>
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<td>Mono, Headphone Drive, Summing Inputs Feature, Optimized for Fidelity</td>
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1New products appear in **BOLD RED**. 2Suggested resale price in U.S. dollars in quantities of 1,000.
### Audio Power Amplifiers Selection Guide (Continued)

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<th>Device¹</th>
<th>Description</th>
<th>Stereo/ Mono Drive</th>
<th>Output Power (W)</th>
<th>V&lt;sub&gt;CC&lt;/sub&gt; (V)</th>
<th>V&lt;sub&gt;DD&lt;/sub&gt; (V)</th>
<th>THD+N at 1 kHz (%)</th>
<th>PSRR (dB)</th>
<th>I&lt;sub&gt;Q&lt;/sub&gt; Per Ch. (mA)</th>
<th>I&lt;sub&gt;SDP&lt;/sub&gt; (µA)</th>
<th>Min Load Impedance (Ω)</th>
<th>Input MUX</th>
<th>SHDN (Active Low/High)</th>
<th>DC Volume Control</th>
<th>Digital Volume Control</th>
<th>Package(s)</th>
<th>Package Symbolization</th>
<th>Price²</th>
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¹ New products appear in **BOLD RED.** ² Suggested resale price in U.S. dollars in quantities of 1,000.
## Audio Signal Amplifiers Selection Guide

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<tr>
<th>Device</th>
<th>Description</th>
<th>Channels</th>
<th>Supply Voltage (V)</th>
<th>THD+N (%)</th>
<th>Slew Rate (V/µs)</th>
<th>GBW (MHz)</th>
<th>Package(s)</th>
<th>Price</th>
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1New products appear in **BOLD RED**.

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## Digitally Programmable Gain Audio Amplifiers Selection Guide

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<th>THD+N at 1kHz (%)</th>
<th>Crosstalk at 1 kHz (%)</th>
<th>Power Supply (V)</th>
<th>Voltage Swing (Vp-p)</th>
<th>Package(s)</th>
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1New products appear in **BOLD RED**.

1Suggested resale price in U.S. dollars in quantities of 1,000.

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## Digital Amplifiers Power Stage Selection Guide

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<th>Fs (kHz)</th>
<th>Fs (kHz)</th>
<th>Dynamic Range (dB)</th>
<th>Power (WRMS at 6 Ω)</th>
<th>THD+N at 1kHz (%)</th>
<th>Efficiency (%)</th>
<th>Package(s)</th>
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<td>192</td>
<td>96</td>
<td>43</td>
<td>&lt; 0.08</td>
<td>&gt; 90</td>
<td>HTSSOP-32</td>
<td>3.19</td>
</tr>
<tr>
<td>TASS01D</td>
<td>Stereo, 100 W, Power Stage</td>
<td>2</td>
<td>32</td>
<td>192</td>
<td>101</td>
<td>100</td>
<td>&lt; 0.08</td>
<td>&gt; 90</td>
<td>HTSSOP-56</td>
<td>—</td>
</tr>
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</table>

1New products appear in **BOLD RED**.

1Suggested resale price in U.S. dollars in quantities of 1,000.

---

## Digital Audio PWM Processors Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Channels</th>
<th>Sample Frequency (kHz)</th>
<th>Dynamic Range (dB)</th>
<th>THD+N (% of System Performance)</th>
<th>Bits</th>
<th>Package(s)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASS026</td>
<td>6</td>
<td>32 to 192</td>
<td>96</td>
<td>&lt; 0.08</td>
<td>16, 20, 24</td>
<td>PGFP-64</td>
<td>7.27</td>
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<tr>
<td>TASS036</td>
<td>6</td>
<td>32 to 192</td>
<td>100</td>
<td>&lt; 0.08</td>
<td>16, 20, 24</td>
<td>PGFP-80</td>
<td>13.90</td>
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<tr>
<td>TASS001</td>
<td>2</td>
<td>32 to 96</td>
<td>96</td>
<td>&lt; 0.08</td>
<td>16, 20, 24</td>
<td>PGFP-48</td>
<td>2.53</td>
</tr>
<tr>
<td>TASS010</td>
<td>2</td>
<td>32 to 192</td>
<td>96</td>
<td>&lt; 0.08</td>
<td>16, 20, 24</td>
<td>PGFP-48</td>
<td>3.17</td>
</tr>
<tr>
<td>TASS012</td>
<td>2</td>
<td>32 to 192</td>
<td>102</td>
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<td>16, 20, 24</td>
<td>PGFP-48</td>
<td>5.89</td>
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<tr>
<td>TASS015*</td>
<td>2</td>
<td>32 to 192</td>
<td>110</td>
<td>&lt; 0.01</td>
<td>16, 20, 24</td>
<td>PGFP-48</td>
<td>25.00</td>
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</table>

1Suggested resale price in U.S. dollars in quantities of 1,000.

*Requires equibit license.
### Power Amplifiers and Buffers

**Power Amplifiers Selection Guide**

<table>
<thead>
<tr>
<th>Device</th>
<th>$I_{OUT}$ (A)</th>
<th>$V_S$ (V)</th>
<th>Bandwidth (MHz)</th>
<th>Slew Rate (V/µs)</th>
<th>$I_Q$ (mA) (max)</th>
<th>$V_{OS}$ (mV) (max)</th>
<th>$V_O$ Drift (±%V/°C) (max)</th>
<th>$I_B$ (µA) (max)</th>
<th>Package(s)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>3581</td>
<td>0.03</td>
<td>±64 to ±150</td>
<td>5 at $G = 1$</td>
<td>20</td>
<td>8</td>
<td>3</td>
<td>25</td>
<td>0.02</td>
<td>TO-3</td>
<td>122.68</td>
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<tr>
<td>3583</td>
<td>0.075</td>
<td>±70 to ±150</td>
<td>5 at $G = 1$</td>
<td>30</td>
<td>8.5</td>
<td>3</td>
<td>23</td>
<td>0.02</td>
<td>TO-3</td>
<td>99.57</td>
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<tr>
<td>3584</td>
<td>0.015</td>
<td>±70 to ±150</td>
<td>50</td>
<td>150</td>
<td>6.5</td>
<td>3</td>
<td>25</td>
<td>0.02</td>
<td>TO-3</td>
<td>99.57</td>
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<tr>
<td>OPA445/B</td>
<td>0.015</td>
<td>10 to 40</td>
<td>2</td>
<td>15</td>
<td>4.7</td>
<td>3</td>
<td>5 (±3)</td>
<td>0.1</td>
<td>TO99, DIP8, SO8</td>
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<tr>
<td>OPA452</td>
<td>0.05</td>
<td>20 to 80</td>
<td>1.8</td>
<td>7.2</td>
<td>5</td>
<td>5</td>
<td>5 (±3)</td>
<td>0.1</td>
<td>TO220-7, DD Pak-7</td>
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<tr>
<td>OPA453</td>
<td>0.05</td>
<td>20 to 80</td>
<td>7.5</td>
<td>23</td>
<td>5.5</td>
<td>3</td>
<td>6 (±3)</td>
<td>0.1</td>
<td>TO220-7, DD Pak-7</td>
<td>2.40</td>
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<tr>
<td>OPA512</td>
<td>15</td>
<td>±10 to ±50</td>
<td>5</td>
<td>4</td>
<td>35</td>
<td>3</td>
<td>40</td>
<td>20</td>
<td>TO-3</td>
<td>59.31</td>
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<tr>
<td>OPA541</td>
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<td>±10 to ±40</td>
<td>full power 55 kHz</td>
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<td>6</td>
<td>1</td>
<td>30</td>
<td>0.05</td>
<td>TO-3, ZIP</td>
<td>10.55</td>
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<tr>
<td>OPA2541</td>
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<td>±10 to ±40</td>
<td>full power 55 kHz</td>
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<td>50</td>
<td>1</td>
<td>30</td>
<td>0.05</td>
<td>TO-3</td>
<td>39.40</td>
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<td>OPA544</td>
<td>2</td>
<td>20 to 70</td>
<td>1.4</td>
<td>8</td>
<td>12</td>
<td>5</td>
<td>10</td>
<td>0.1</td>
<td>TO220-5, DD Pak-5</td>
<td>6.68</td>
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<tr>
<td>OPA544/B</td>
<td>0.5</td>
<td>20 to 70</td>
<td>1.4</td>
<td>8</td>
<td>12</td>
<td>5</td>
<td>10</td>
<td>0.1</td>
<td>ZIP11</td>
<td>11.43</td>
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<tr>
<td>OPA547</td>
<td>0.5</td>
<td>8 to 60</td>
<td>1</td>
<td>6</td>
<td>10</td>
<td>5</td>
<td>25</td>
<td>0.1</td>
<td>ZIP11</td>
<td>11.43</td>
</tr>
<tr>
<td>OPA548</td>
<td>3</td>
<td>8 to 60</td>
<td>1</td>
<td>10</td>
<td>17</td>
<td>10</td>
<td>30</td>
<td>500</td>
<td>TO220-7, DD Pak-7</td>
<td>4.14</td>
</tr>
<tr>
<td>OPA549</td>
<td>8</td>
<td>8 to 60</td>
<td>0.9</td>
<td>9</td>
<td>26</td>
<td>5</td>
<td>20</td>
<td>500</td>
<td>ZIP11</td>
<td>10.96</td>
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<tr>
<td>OPA551</td>
<td>0.2</td>
<td>8 to 60</td>
<td>3</td>
<td>15</td>
<td>7</td>
<td>3</td>
<td>7 (±3)</td>
<td>0.1</td>
<td>DIP8, SO8, DD Pak-7</td>
<td>1.66</td>
</tr>
<tr>
<td>OPA552</td>
<td>0.2</td>
<td>8 to 60</td>
<td>12</td>
<td>24</td>
<td>7</td>
<td>3</td>
<td>7 (±3)</td>
<td>0.1</td>
<td>DIP8, SO8, DD Pak-7</td>
<td>1.66</td>
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<tr>
<td>OPA581</td>
<td>1.2</td>
<td>7 to 16</td>
<td>17</td>
<td>50</td>
<td>50</td>
<td>20</td>
<td>500 (±3)</td>
<td>0.1</td>
<td>HTSSOP-20</td>
<td>2.50</td>
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<tr>
<td>TLV411x</td>
<td>0.3</td>
<td>2.5 to 6</td>
<td>2.7</td>
<td>1.6</td>
<td>1</td>
<td>3.5</td>
<td>3 (±3)</td>
<td>0.05</td>
<td>PDIP, MSOP, SOIC</td>
<td>0.65</td>
</tr>
</tbody>
</table>

1Suggested resale price in U.S. dollars in quantities of 1,000.

**Buffers Selection Guide**

<table>
<thead>
<tr>
<th>Device</th>
<th>$V_{IN}$ (±5 V)</th>
<th>$V_{OUT}$ (±5 V)</th>
<th>$A_{CM}$ Stable Gain (V/V)</th>
<th>BW at $A_{CM}$ (MHz)</th>
<th>Slew Rate (V/µs)</th>
<th>Settling Time (0.01%) (ms)</th>
<th>THD (±3 dB) (typ)</th>
<th>Diff Gain (%)</th>
<th>Diff Phase (°)</th>
<th>$V_{IN}$ at Flatband (nV/Hz) (typ)</th>
<th>$V_{OS}$ (mV) (max)</th>
<th>$I_{Q}$ (µA) (max)</th>
<th>Package(s)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUF600</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>320</td>
<td>3400</td>
<td>20</td>
<td>—</td>
<td>62</td>
<td>0.5</td>
<td>0.02</td>
<td>5.2</td>
<td>30</td>
<td>3.5</td>
<td>DIP, SOIC</td>
</tr>
<tr>
<td>BUF601</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>320</td>
<td>3600</td>
<td>20</td>
<td>—</td>
<td>60</td>
<td>0.4</td>
<td>0.03</td>
<td>4.8</td>
<td>30</td>
<td>3.5</td>
<td>SOIC</td>
</tr>
<tr>
<td>BUF634</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>180</td>
<td>2000</td>
<td>200</td>
<td>—</td>
<td>250</td>
<td>0.4</td>
<td>0.04</td>
<td>4</td>
<td>100</td>
<td>0.1</td>
<td>DIP, SOIC, TO220-5, DD Pak-5</td>
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<tr>
<td>OPA633</td>
<td>Yes</td>
<td>—</td>
<td>1</td>
<td>260</td>
<td>2500</td>
<td>50</td>
<td>100</td>
<td>—</td>
<td>0.1</td>
<td>15</td>
<td>——</td>
<td>35</td>
<td>DIP</td>
<td>5.15</td>
</tr>
</tbody>
</table>

1Suggested resale price in U.S. dollars in quantities of 1,000.
Pulse Width Modulation Drivers

Texas Instruments’ pulse width modulation (PWM) power drivers are ideal for any application that requires high current at low voltages, such as electromechanical devices, thermoelectric coolers or laser diodes. The DRV59x devices feature integrated power transistors, which save considerable circuit board area compared to discrete implementations. The H-bridge output configuration allows for bi-directional current flow from a single power supply. Unlike the operation of linear drivers, PWM operation offers efficiencies as great as 90 percent, resulting in less power wasted as heat and reduced demand on the power supply. The devices in the DRV59x family may be analog or digitally controlled and operate from 0 to 100 percent duty cycle.

Design Considerations

Supply voltage—selection begins with the power supply voltages available in the system. TI’s family PWM power drivers operate from 2.8 V to 5.5 V.

Output current and output voltage—the load to be connected to the power driver will also help determine the proper PWM power driver solution. The maximum output current required by the load should be known. The DRV590 can sink or source up to 1.2 A, while the DRV591, DRV592, DRV593 and DRV594 can each sink or source up to 3 A. The maximum output voltage capability of the driver may be calculated as follows:

\[ V_O(\text{max}) = V_S - [I_O(\text{max}) \cdot 2 \cdot R_{\text{DS(on)}}] \]

Efficiency—the lower the on-resistance \( R_{\text{DS(on)}} \) of the output power transistors, the greater the efficiency. Typically, \( R_{\text{DS(on)}} \) is specified per transistor. In an H-bridge output configuration, two output transistors are in series with the load. To quickly estimate the efficiency, use the following equation:

\[ \text{Efficiency} = \frac{R_L}{[R_L + (2 \cdot R_{\text{DS(on)}})]} \]

Analog or digital control—the DRV590, DRV591, DRV593 and DRV594 each accept a DC voltage input signal, either from an analog control loop (i.e. PID controller) or from a DAC. The DRV592 accepts a PWM input signal up to 1 MHz, which may be generated by a microcontroller, FPGA or DSP.

Output filter—in some applications, a low-pass filter is placed between each output of the PWM driver and the load to remove the switching frequency components. A second-order filter consisting of an inductor and capacitor is commonly used, with the cut-off frequency of the filter typically chosen to be at least an order of magnitude lower than the switching frequency. For example, for the DRV593 (shown above), the switching frequency is 500 kHz and the cut-off frequency is chosen to be 15.9 kHz. The component values are calculated using the following formula:

\[ F_C = \frac{1}{[2 \cdot \pi \cdot (\sqrt{L \cdot C})]} \]

The inductor value is typically chosen to be as large as possible, and is then used to calculate the required capacitor value for the desired cut-off frequency.

PWM Power Drivers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Output Current (A) (typ)</th>
<th>Supply Voltage (V)</th>
<th>Switching Frequency (kHz)</th>
<th>( R_{\text{DS(on)}} ) (Ω)</th>
<th>CMV Range (V)</th>
<th>( I_O ) (mA)</th>
<th>Fault indicator for thermal, over-current and under-voltage conditions</th>
<th>Package(s)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRV590</td>
<td>1.2</td>
<td>2.8 to 5.5</td>
<td>500</td>
<td>0.4</td>
<td>1.2 to 3.8</td>
<td>4</td>
<td>—</td>
<td>PowerPAD™, SOIC, TSSOP</td>
<td>6.96</td>
</tr>
<tr>
<td>DRV591</td>
<td>3</td>
<td>2.8 to 5.5</td>
<td>100/500</td>
<td>0.065</td>
<td>1.2 to 3.8</td>
<td>7</td>
<td>✔</td>
<td>9 x 9 mm PowerPAD™ Quad Flatpack</td>
<td>12.34</td>
</tr>
<tr>
<td>DRV592</td>
<td>3</td>
<td>2.8 to 5.5</td>
<td>100</td>
<td>0.065</td>
<td>—</td>
<td>7</td>
<td>✔</td>
<td>9 x 9 mm PowerPAD™ Quad Flatpack</td>
<td>11.90</td>
</tr>
<tr>
<td>DRV593</td>
<td>3</td>
<td>2.8 to 5.5</td>
<td>100/500</td>
<td>0.065</td>
<td>1.2 to 3.8</td>
<td>7</td>
<td>✔</td>
<td>9 x 9 mm PowerPAD™ Quad Flatpack</td>
<td>11.90</td>
</tr>
<tr>
<td>DRV594</td>
<td>3</td>
<td>2.8 to 5.5</td>
<td>100</td>
<td>0.065</td>
<td>1.2 to 3.8</td>
<td>7</td>
<td>✔</td>
<td>9 x 9 mm PowerPAD™ Quad Flatpack</td>
<td>11.90</td>
</tr>
</tbody>
</table>

\(^1\)Suggested resale price in U.S. dollars in quantities of 1,000.
The 4-20 mA transmitter provides a versatile instrumentation amplifier (IA) input with a current-loop output, allowing analog signals to be sent over long distances without loss of accuracy. Many of these devices also include scaling, offsetting, sensor excitation and linearization circuitry.

**Design Solutions**

XTR101, XTR115 and XTR116 provide general-purpose 2-wire (loop powered) conversion of signal input voltages or currents to the 4-20 mA standard output. They contain reference voltage or current sources for ease of scaling or sensor excitation where hardware linearization is not needed.

The XTR110 is a 3-wire 4-20 mA converter from 0 V to 5 V or 0 V to 10 V voltage inputs. The RCV420 is an accurate 4-20 mA input to 0 V to 5 V output receiver that introduces only a 1.5 V drop in the 4-20 mA loop.

XTR105, XTR112 and XTR114 provide current source sensor excitation and hardware linearization for 100 Ω, 1 kΩ and 10 kΩ RTDs.

**XTR108 Digitally Programmable Analog Sensor Conditioning**

The XTR106 provides an accurate 2.5 V or 5 V sensor excitation voltage for conditioning bridge transducers and includes hardware linearization.

The XTR108 provides a digitally controlled analog signal path for RTD signal conditioning. The XTR108 allows for digital calibration of sensor and transmitter errors via a standard digital serial interface, eliminating expensive potentiometers or circuit value changes. Calibration settings can be stored in an inexpensive EEPROM for easy retrieval during routine operation.

---

### 4-20 mA Transmitters and Receiver Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Sensor Excitation</th>
<th>Loop Voltage (V)</th>
<th>Full-Scale Input Range</th>
<th>Output Range (mA)</th>
<th>Additional Power Available (V at mA)</th>
<th>Package(s)</th>
<th>Price 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2-Wire General Purpose</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XTR101</td>
<td>IA with Current Excitation</td>
<td>Two 1 mA</td>
<td>11.6 to 40</td>
<td>5 mV to 1 V</td>
<td>4-20</td>
<td>—</td>
<td>DIP-14, SOIC-16</td>
<td>7.34</td>
</tr>
<tr>
<td>XTR115</td>
<td>( V_{\text{REF}} = 2.5 ) V</td>
<td>( V_{\text{REF}} = 2.5 ) V</td>
<td>40 µA to 200 µA</td>
<td>4-20</td>
<td>—</td>
<td>SOIC-8</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>XTR116</td>
<td>( V_{\text{REF}} = 4.096 ) V</td>
<td>( V_{\text{REF}} = 4.096 ) V</td>
<td>40 µA to 200 µA</td>
<td>4-20</td>
<td>—</td>
<td>SOIC-8</td>
<td>0.95</td>
<td></td>
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<tr>
<td><strong>3-Wire General Purpose</strong></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>XTR110</td>
<td>Selectable Input/Output Ranges</td>
<td>( V_{\text{REF}} = 10 ) V</td>
<td>13.5 to 40</td>
<td>0 V to 5 V, 0 V to 10 V</td>
<td>4-20, 0-20, 5-25</td>
<td>—</td>
<td>DIP-16</td>
<td>6.35</td>
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<td><strong>4-20mA Current Loop Receiver</strong></td>
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<td>RCV420</td>
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<tr>
<td>XTR105</td>
<td>100-Ω RTD Conditioner</td>
<td>Two 800 µA</td>
<td>7.5 to 38</td>
<td>5 mV to 1 V</td>
<td>4-20</td>
<td>5.1 at 1</td>
<td>DIP-14, SOIC-14</td>
<td>3.75</td>
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<tr>
<td>XTR112</td>
<td>High-Resolution RTD Conditioner</td>
<td>Two 250 µA</td>
<td>7.5 to 38</td>
<td>5 mV to 1 V</td>
<td>4-20</td>
<td>5.1 at 1</td>
<td>DIP-14, SOIC-14</td>
<td>3.75</td>
</tr>
<tr>
<td>XTR114</td>
<td>High-Resolution RTD Conditioner</td>
<td>Two 100 µA</td>
<td>7.5 to 38</td>
<td>5 mV to 1 V</td>
<td>4-20</td>
<td>5.1 at 1</td>
<td>DIP-14, SOIC-14</td>
<td>3.75</td>
</tr>
<tr>
<td><strong>2-Wire Bridge Sensor Conditioner with Linearization</strong></td>
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<td></td>
</tr>
<tr>
<td>XTR106</td>
<td>Bridge Conditioner</td>
<td>5 V and 2.5 V</td>
<td>7.5 to 38</td>
<td>5 mV to 1 V</td>
<td>4-20</td>
<td>5.1 at 1</td>
<td>DIP-14, SOIC-14</td>
<td>3.75</td>
</tr>
<tr>
<td><strong>2-Wire RTD Conditioner with Digital Calibration for Linearization, Span and Offset</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XTR108</td>
<td>100-Ω to 1-kΩ RTD Conditioner, 6-Channel Input Mux, Extra Op Amp Can Convert to Voltage Sensor Excitation, Calibration Stored in External EEPROM</td>
<td>Two 500 µA</td>
<td>7.5 to 24</td>
<td>5 mV to 320 mV</td>
<td>4-20</td>
<td>5.1 at 2.1</td>
<td>SSOP-24</td>
<td>3.21</td>
</tr>
</tbody>
</table>

1 Suggested resale price in U.S. dollars in quantities of 1,000.
The logarithmic amplifier is a versatile integrated circuit that computes the logarithm of an input current relative to a reference current or the log of the ratio of two input currents. Logarithmic amplifiers can compress an extremely wide input dynamic range (up to 7½ decades) into an easily measured output voltage. Accurate matched bipolar transistors provide excellent logarithmic conformity over a wide input current range. On-chip compensation achieves accurate scaling over a wide operating temperature range.

The LOG101, LOG102 and LOG104 are designed for optical networking, photodiode signal compression, analog signal compression and logarithmic computation for instrumentation. Some log amps, such as the LOG102, feature additional uncommitted op amps for use in a variety of functions including gain scaling, inverting, filtering, offsetting and level comparison to detect loss of signal.

The new LOG2112 is a dual version of the LOG112 and includes 2 log amps, 2 output amps and a single shared internal voltage reference.

### Design Considerations
- **Output scaling**—amplifier output is either 0.5 V or 1.0 V per decade and is the equivalent to the gain setting in a voltage input amp.
- **Quiescent current**—lowest in LOG101 and LOG104.
- **Conformity error**—measure with 1 nA to 1 mA converted to 5 V. 16-bits of dynamic range are achievable.

### Technical Information
Log amplifiers provide a very wide dynamic range (140 dB+), extremely good DC accuracy and excellent performance over the full temperature range.

### Logarithmic Amplifiers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Scale Factor (V/decade)</th>
<th>Input Current Range (nA)</th>
<th>Input Current Range (mA)</th>
<th>Conformity Error (Initial 5 decades) (%)</th>
<th>Conformity Error (Initial 5 decades) (°C typ/temp)</th>
<th>Offset Voltage (Input Amplifiers) (mV) (max)</th>
<th>Vth (V) (min)</th>
<th>Input Per. Ch. (mA) (max)</th>
<th>Reference Type</th>
<th>Auxiliary Op Amps</th>
<th>Package(s)</th>
<th>Price</th>
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</thead>
<tbody>
<tr>
<td>LOG100</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.002</td>
<td>5 ±12 ±18</td>
<td>9</td>
<td>External</td>
<td>—</td>
<td>Hermetic</td>
<td>—</td>
<td>Ceramic DIP-14</td>
<td>82.99</td>
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<tr>
<td>LOG101</td>
<td>1</td>
<td>0.1</td>
<td>3.5</td>
<td>0.2</td>
<td>0.0001 ±4.5 ±18</td>
<td>1.5</td>
<td>1.5</td>
<td>External</td>
<td>—</td>
<td>SO-8</td>
<td>15.65</td>
<td></td>
</tr>
<tr>
<td>LOG102</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.3</td>
<td>0.0002 ±4.5 ±18</td>
<td>1.5</td>
<td>1.5</td>
<td>2</td>
<td>External</td>
<td>2</td>
<td>SO-14</td>
<td>18.65</td>
</tr>
<tr>
<td>LOG104</td>
<td>0.5</td>
<td>0.1</td>
<td>3.5</td>
<td>0.2</td>
<td>0.00001 ±4.5 ±18</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>External</td>
<td>SO-8</td>
<td>15.65</td>
<td></td>
</tr>
<tr>
<td>LOG112</td>
<td>0.5</td>
<td>0.1</td>
<td>3.5</td>
<td>0.2</td>
<td>0.000001 ±4.5 ±18</td>
<td>1.5</td>
<td>1.75</td>
<td>2.5 V Internal</td>
<td>1</td>
<td>SO-14</td>
<td>18.65</td>
<td></td>
</tr>
<tr>
<td>LOG2112</td>
<td>0.5</td>
<td>0.1</td>
<td>3.5</td>
<td>0.2</td>
<td>0.000001 ±4.5 ±18</td>
<td>1.5</td>
<td>1.75</td>
<td>2.5 V Internal</td>
<td>1</td>
<td>SO-16</td>
<td>22.30</td>
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</table>

1New products appear in **BOLD RED**. 2Suggested resale price in U.S. dollars in quantities of 1,000. 3Dual LOG112.
Integrating amplifiers provide a precision, lower noise alternative to conventional transimpedance op amp circuits which require a very high value feedback resistor. Designed to measure input currents over an extremely wide dynamic range, integrating amplifiers incorporate a FET op amp, integrating capacitors, and low-leakage FET switches. Integrating low-level input current for a user-defined period, the resulting voltage is stored on the integrating capacitor, held for accurate measurement and then reset. Input leakage of the IVC102 is just 750 fA. It can measure bipolar input currents.

The ACF2101 two-channel integrator offers extremely low bias current, low noise, an extremely wide dynamic range and excellent channel isolation. Included on each of the two integrators are precision 100-pF integration capacitors, hold and reset switches and output multiplexers. As a complete circuit on a chip, leakage current and noise pickup errors are eliminated. An output capacitor can be used in addition to, or instead of the internal capacitor depending on design requirements.

**Design Considerations**

**Supply voltage**—while single-supply operation is feasible, bipolar supply operation is most common and will offer the best performance in terms of precision and dynamic range.

**Number of channels**—IVC102 offers a single integrator, while the ACF2101 is a dual.

Integration direction—either into or out of the device. IVC102 is a bipolar input current integrator and will integrate both positive and negative signals. ACF2101 is a unipolar current integrator, with the output voltage integrating negatively.

**Input bias (leakage) current**—often sets a lower limit to the minimum detectable signal input current. Leakage can be subtracted from measurements to achieve extremely low-level current detection (<10 fA). Circuit board leakage currents can also degrade the minimum detectable signal.

**Sampling rate and dynamic range**—the switched integrator is a sampled system controlled by the sampling frequency (fs), which is usually dominated by the integration time. Input signals above the Nyquist frequency (fs/2) create errors by being aliased into the sampling frequency bandwidth.

**Technical Information**

Although these devices use relatively slow op amps, they may be used to measure very fast current pulses. Photodiode or sensor capacitance can store pulse charge temporarily, the charge is then slowly integrated during the next cycle.

See OPT101 data sheet for monolithic photodiode and transimpedance amplifier.

---

### Integrating Amplifiers Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Input Bias Current (fA)</th>
<th>Switching Time (µs)</th>
<th>Useful Sampling Rate (kHz)</th>
<th>Input Current Range (µA)</th>
<th>Package(s)</th>
<th>Price1</th>
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</thead>
<tbody>
<tr>
<td>IVC102</td>
<td>Precision, Low Noise, Bipolar Input Current</td>
<td>100</td>
<td>100</td>
<td>10</td>
<td>0.01 to 100</td>
<td>SO-14</td>
<td>4.31</td>
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<tr>
<td>ACF2101</td>
<td>Dual, Unipolar</td>
<td>100</td>
<td>200</td>
<td>10</td>
<td>0.01 to 100</td>
<td>SO-24</td>
<td>14.82</td>
</tr>
<tr>
<td>Monolithic Photodiode and Transimpedance Amplifier</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPT101</td>
<td>Monolithic Photodiode with Built-in Transimpedance Amp</td>
<td>165</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>DIP, SIP</td>
<td>2.58</td>
</tr>
</tbody>
</table>

1*Suggested resale price in U.S. dollars in quantities of 1,000.*
Isolation Amplifiers

Isolation amplifiers transfer an analog signal across a galvanically isolated barrier. Similar to an optically isolated digital coupler, they generally require an isolated supply to power both sides of the amplifier. Some isolation amplifiers provide an internal isolated power source for the input-side of the amplifier.

Isolation amplifiers can be used to:

- Amplify and measure low-level signals in the presence of high common-mode voltages
- Break ground loops and/or eliminate source ground connections
- Provide an interface between a patient and medical monitoring equipment
- Provide isolation protection to electronic instruments and equipment

**Design Considerations**

- **Isolation voltage rating**—the maximum voltage that can be applied between the input and output sides of the amplifier. This can range up to thousands of volts. AC and DC ratings may differ and application requirements may dictate safety factors or special industry standards.

- **Internal power**—an on-chip DC/DC converter powers the amplifier’s front-end on the ISO103, ISO107 and ISO113. All others require an external isolated power source.

**Isolation type**

- **Optically-coupled**—provide continuous signal transfer using two accurately matched couplers—one for the forward signal path and one for feedback. This assures excellent accuracy.
- **Capacitive-coupled**—transmit a differential pulse-coded representation of the analog input across two matched capacitors. The output section reconstructs the analog signal.
- **Transformer-coupled**—use similar modulation techniques to transmit an AC-modulated signal across the magnetic barrier.

**Leakage current**—cap isolation amps, such as the ISO120/124 series, generally have 0.5-µArms maximum leakage current at 240 V/60 Hz. Opto-isolation amps have leakage current in the 2-µArms maximum range.

**Technical Information**

Isolation amps with internal DC/DC converters provide signal and power across an isolation barrier, with additional power available for driving additional circuitry.

Wide barrier pin spacing and internal insulation allow for high isolation voltage ratings. Reliability is assured by 100 percent barrier breakdown testing that conforms to UL1244 test methods. Low barrier capacitance minimizes AC leakage currents. The ISO103’s high continuous-voltage rating means that the circuit can tolerate isolation voltages to 1500 Vrms. Its 130-dB isolation-mode rejection at 60 Hz is high enough to limit the interference of a 1500 Vrms fault to 0.5 mVrms.

ISO124 Interface to DC/DC Converter

**Isolation Amplifiers Selection Guide**

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Isolation Voltage Cont Peak (DC) (V)</th>
<th>Isolation Voltage Pulse/ Peak (V)</th>
<th>Isolation Mode Rejection DC (dB) (typ)</th>
<th>Gain Nonlinearity (%) (max)</th>
<th>Input Offset Voltage Drift (µV/°C) (max)</th>
<th>Small-Signal Bandwidth (kHz) (typ)</th>
<th>Package(s)</th>
<th>Price1</th>
</tr>
</thead>
<tbody>
<tr>
<td>3650</td>
<td>Opto Coupled</td>
<td>2000</td>
<td>5000</td>
<td>140</td>
<td>0.05</td>
<td>—</td>
<td>15</td>
<td>Hybrid DIP-32</td>
<td>64.43</td>
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<tr>
<td>3656</td>
<td>Transformer Isolation</td>
<td>3500</td>
<td>8000</td>
<td>125</td>
<td>0.05</td>
<td>—</td>
<td>30</td>
<td>ISO Omni-20</td>
<td>101.92</td>
</tr>
<tr>
<td>ISO100</td>
<td>Low Drift, Wide Bandwidth, Opto</td>
<td>750</td>
<td>2500</td>
<td>146</td>
<td>0.07</td>
<td>2</td>
<td>60</td>
<td>DIP-18</td>
<td>58.33</td>
</tr>
<tr>
<td>ISO102</td>
<td>Capacitor Coupled</td>
<td>1500</td>
<td>4000</td>
<td>120</td>
<td>0.012</td>
<td>250</td>
<td>70</td>
<td>DIP-24</td>
<td>51.57</td>
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<tr>
<td>ISO103</td>
<td>Capacitor Isolation, Internal DC/DC</td>
<td>2121</td>
<td>5657</td>
<td>130</td>
<td>0.025</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>77.24</td>
</tr>
<tr>
<td>ISO106</td>
<td>Capacitor Isolation</td>
<td>4950</td>
<td>8000</td>
<td>130</td>
<td>0.025</td>
<td>—</td>
<td>70</td>
<td>—</td>
<td>61.18</td>
</tr>
<tr>
<td>ISO107</td>
<td>Internal DC/DC Converter</td>
<td>3500</td>
<td>8000</td>
<td>100</td>
<td>0.025</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>131.20</td>
</tr>
<tr>
<td>ISO113</td>
<td>Internal DC/DC Converter</td>
<td>2121</td>
<td>5657</td>
<td>130</td>
<td>0.02</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>95.88</td>
</tr>
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<td>ISO120</td>
<td>1500-Vrms Isolation, Buffer</td>
<td>2121</td>
<td>2500</td>
<td>160</td>
<td>0.01</td>
<td>150</td>
<td>60</td>
<td>DIP-24</td>
<td>27.50</td>
</tr>
<tr>
<td>ISO121</td>
<td>2500-Vrms Isolation, Buffer</td>
<td>4850</td>
<td>5600</td>
<td>160</td>
<td>0.01</td>
<td>60</td>
<td>DIP-16, CERDIP-16</td>
<td>36.05</td>
<td></td>
</tr>
<tr>
<td>ISO122</td>
<td>1500-Vrms Isolation, Buffer</td>
<td>2121</td>
<td>2400</td>
<td>160</td>
<td>0.02</td>
<td>200</td>
<td>50</td>
<td>DIP-16, SDIC-28</td>
<td>9.36</td>
</tr>
<tr>
<td>ISO124</td>
<td>1500-Vrms Isolation, Buffer</td>
<td>2121</td>
<td>2400</td>
<td>140</td>
<td>0.01</td>
<td>—</td>
<td>50</td>
<td>DIP-16, SOIC-28</td>
<td>6.95</td>
</tr>
</tbody>
</table>

**Digital Couplers**

| ISO150                      | Dual, Bi-Directional Digital Coupler  | 1500                                | 2400                              | —                                      | —                           | —                                       | —                                 | —           | —      |
| ISO422                      | Differential Bus Transceiver         | —                                   | —                                 | —                                      | —                           | —                                       | —                                 | —           | —      |

1Suggested resale price in U.S. dollars in quantities of 1,000.
Technology Primer
Understanding of the relative advantages of the basic semiconductor technologies will help in selecting the proper device for a specific application.

CMOS amps—when low voltage and/or low power consumption, an excellent speed/power ratio, rail-to-rail performance, low cost and small packaging are primary design considerations, choose a CMOS amp. TI has the world’s most complete portfolio of high-performance, low-power CMOS amps in a variety of micropackages.

High-Speed Bipolar Amps—when the highest speed at the lowest power is required, bipolar technology delivers the best performance. Extremely good power gain gives very high output power and full power bandwidths on the lowest quiescent power. Higher voltage requirements are also only satisfied in bipolar technologies.

Precision Bipolar Amps—excel in limiting errors relating to offset voltage. These include low offset voltage and temperature drift, high open-loop gain and common-mode rejection. Precision bipolar op amps are used extensively in applications where the source impedance is low, such as a thermocouple amplifier, where voltage errors, offset voltage and drift, are crucial to accuracy.

Low I<sub>b</sub> FET Amps—when input impedance is very high, FET-input amps provide better overall precision than bipolar-input amps. Using a bipolar amp in applications with high source impedance (e.g. 500-MΩ pH probe), the offset, drift and noise produced by bias currents flowing through the source would render the circuit virtually useless. When low current errors are required, FET amps provide extremely low input bias current, low offset current and high input impedance.

Dielectrically Isolated FET (DiFET) Amps—DiFET processing enables the design of extremely low input leakage amplifiers by eliminating the substrate junction diode present in junction isolated processes. This technique yields very high precision, low noise op amps. DiFET processes also minimize parasitic capacitance and output transistor saturation effects, resulting in improved bandwidth and wider output swing.

Evaluation Modules
To ease and speed the design process, TI offers evaluation modules (EVMs) for many amplifiers and other analog products. EVMs contain an evaluation board, data sheet and user’s guide.

To find EVMs, visit amplifier.ti.com/evm (right) or the Development Tools section of any individual product folder (below).

Every high speed and audio power amplifier has a fully populated, ready-to-use EVM available. Populated evaluation boards are also available for selected other TI amplifiers. Please see the individual device product folder (left) or contact your local TI sales office for additional choices and availability.

Universal op amp EVMs are unpopulated printed circuit boards that eliminate the need for dual in-line samples in the evaluation of TI amplifiers. These feature:

- Various packages and shutdown
- Ability to evaluate single, dual, or quad amps on several eval spaces per board
- Detachable circuit board development areas for improved portability
- User’s manuals with complete board schematic, board layout and numerous standard example circuits
- Product-level Macro Models, designed for use with SPICE, allow efficient simulation of complex circuits without having to use transistor-level models. Download individual models at amplifier.ti.com/spice

To order your universal op amp EVMs, contact the nearest Product Information Center (PIC) listed on page 39.
# Application Reports

To access any of the following application reports, type the URL `www-s.ti.com/sc/techlit/litnumber` and replace `litnumber` with the number in the Lit Number column. For a complete listing of TI’s amplifier application reports visit amplifier.ti.com/appreports.

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<td>Review of Circuit Theory</td>
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FilterPro™ Design Tool

FilterPro™ MFB and Sallen-Key Design Program is a Windows application that designs Multiple-Feedback and Sallen-Key low-pass filters using op amps, resistors and capacitors. This program supports Bessel, Butterworth and Chebychev filter types and can be used to design filters from 1 to 10 poles. The capacitor values in each stage can be either selected by the computer or entered by the designer. An "always on" prompt window provides context-sensitive help information to the user. The response of the filter is displayed on a graph, showing gain and phase over frequency.

FilterPro MFB and Sallen-Key Program will install on Win9X and WinNT systems. FILTER42 is a DOS program that designs a wide variety of filters using Burr-Brown’s UAF42 Universal Active Filter IC. This state-variable filter provides low-pass, high-pass and band-pass outputs. Notch filters can also be designed.

EGAHPRES and EGAFPXRES are DOS screen dump utilities that can print response plots on HP Laserjet and Epson printers, respectively.

Both programs can be used without documentation but you will eventually need the Application Bulletins for circuit details.

Visit amplifier.ti.com/filterpro for the free download today.

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