Design ideas in this guide use the following devices. A complete device list and corresponding data sheets for these products can be found at www.microchip.com

**Programmable Gain Amplifiers:**
- MCP6S21
- MCP6S22
- MCP6S26
- MCP6S28

**Operational Amplifiers:**
- MCP601
- MCP616
- MCP6021
- MCP6281
- MCP6041
- TC1029
- TC1030
- MCP606
- MCP6001
- MCP6241
- MCP6291
- MCP6141
- TC1034

**Comparators:**
- MCP6541
- TC1027
- TC1039
- MCP6546
- TC1037
- TC1041
High Performance Devices for a Variety of Precision and Embedded Systems Applications

PROGRAMMABLE GAIN AMPLIFIERS, OPERATIONAL AMPLIFIERS AND COMPARATORS - OVERVIEW

It is vital for designers of embedded control products to select the most suitable controller and companion devices. Embedded control products are found in all market segments: consumer, PC peripherals, telecommunications, automotive and industrial. Most embedded control products must meet special requirements: cost effectiveness, low-power, small-footprint and a high level of system integration.

Microchip has established itself as a leading supplier of embedded control solutions. The combination of high performance mixed-signal and linear analog products provide the basis for this leadership. Microchip’s extensive family of Programmable Gain Amplifiers (PGAs), Operational Amplifiers and Comparators are an example of the innovation and improvement in design that Microchip is committed to deliver to our customers.

PROGRAMMABLE GAIN AMPLIFIERS AND OPERATIONAL AMPLIFIERS

Microchip’s family of programmable gain amplifiers and operational amplifiers are suitable for low power, precision and general purpose applications.

The **MCP6271, MCP6281** and **MCP6291** families are also targeted for low-cost precision applications. These devices are characterized with a Extended Temperature range of -40°C to +125°C, which are ideal for automotive applications.

Microchip’s **MCP601, MCP6001** and **MCP6241**, are low-cost op amps suitable for general purpose applications such as signal amplification, sensor buffer or driving an analog-to-digital converters.

The **MCP6041** and **MCP6141** are 600 nA, rail-to-rail input and output op amps that are ideal for battery powered applications.

The **MCP606** and **MCP616** families also consume very low current and provide wide Gain Bandwidth Product. These op amps are targeted for low power precision applications with very low offset voltage.

COMPARATORS

Several comparators are offered with low supply voltage (1.8) and low supply current (1µA). Examples include the **MCP6541, TC1039, TC1038** and the **MCP6546** family of push-pull and open-drain comparators, which are designed for very low power single-supply applications.

The **MCP6541, TC1039, and TC1038** families of comparators have a push-pull output that interfaces with CMOS/TTL logic. The output limits supply current surges and dynamic power consumption while switching.

The **MCP6546** family of comparators has an open-drain output that can be pulled up to 10V supply.

The linear building blocks such as **TC1027, TC1039**, and **TC1041**, have integrated reference voltage and shutdown which makes them ideal for low power portable applications.
Microchip’s industry first precision Programmable Gain Amplifiers (PGAs), the MCP6S21/2/6/8, comes with Serial Peripheral Interface (SPI) and up to eight multiplexed input channels. This PGA is configured in a non-inverting configuration with gains of 1, 2, 4, 5, 8, 10, 16 or 32V/V that can be digitally selected using a microcontroller. The input channels are also selected using the digital interface. These devices come with an internal register that allow the user to select gains, channels and shutdown the device.

These amplifiers were designed with the embedded control system in mind. The typical complexity of multiple sensor systems is reduced to one amplifier that the microcontroller can control. This reduces the demand on the microcontroller I/O and allows control over the level gain. One superior amplifier can be used to perform the functions of multiple amplifiers at a lower cost.

**MCP6S21/2/6/8 Key Features:**
- Multiplexed Inputs: 1, 2, 6 or 8 channels
- 8 gain selections: +1, +2, +4, +5, +8, +10, +16 or +32V/V
- Serial Peripheral Interface (SPI)
- Rail-to-Rail Input and Output
- Low Gain Error: ±1% (max.)
- Low Offset: ±275 µV (max.)
- High Bandwidth: 2 to 12 MHz (typ)
- Low Noise: 10 nV/√Hz at 10 kHz (typ)
- Low Supply Current: 1.0 mA (typ.)
- Single Supply: 2.5V to 5.5V

**MCP6S21/2/6/8 Typical Applications:**
- A/D Converter Driver
- Multiplexed Analog Applications
- Data Acquisition
- Industrial Instrumentation
- Test Equipment
- Medical Instrumentation

**Product Specifications: Programmable Gain Amplifiers**

<table>
<thead>
<tr>
<th>Device</th>
<th>Switching Channels</th>
<th>-3 dB Bandwidth (MHz)</th>
<th>Gain Steps (V/V)</th>
<th>Supply Current (mA Typ.)</th>
<th>Supply Voltage (V)</th>
<th>VOSS (±µV)</th>
<th>Noise (nV/√Hz Typ.)</th>
<th>Packages</th>
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<tbody>
<tr>
<td>MCP6S21</td>
<td>1</td>
<td>2 to 12</td>
<td>1, 2, 4, 5, 8, 10, 16, 32</td>
<td>1.0</td>
<td>2.5 to 5.5</td>
<td>275</td>
<td>10</td>
<td>8PDIP, 8SOIC, 8MSOP</td>
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<tr>
<td>MCP6S22</td>
<td>2</td>
<td>2 to 12</td>
<td>1, 2, 4, 5, 8, 10, 16, 32</td>
<td>1.0</td>
<td>2.5 to 5.5</td>
<td>275</td>
<td>10</td>
<td>8PDIP, 8SOIC, 8MSOP</td>
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<td>MCP6S26</td>
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<td>2 to 12</td>
<td>1, 2, 4, 5, 8, 10, 16, 32</td>
<td>1.0</td>
<td>2.5 to 5.5</td>
<td>275</td>
<td>10</td>
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<td>MCP6S28</td>
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<td>1, 2, 4, 5, 8, 10, 16, 32</td>
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<td>2.5 to 5.5</td>
<td>275</td>
<td>10</td>
<td>16PDIP, 16SOIC</td>
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</table>
High Performance Devices for a Variety of Precision and Embedded Systems Applications

5 MHz and 10 MHz BANDWIDTH OPERATIONAL AMPLIFIERS FOR PRECISION APPLICATIONS

Microchip offers wide bandwidth rail-to-rail input and output op amps for precision applications. The **MCP6021** family of op amps has a Total Harmonic Distortion (THD) plus Noise ratio of 0.00064% with 600Ω load at a gain of +1V/V. This device is ideal for single-supply audio applications. The **MCP6291** and **MCP6281** families are also targeted for low cost precision applications. These devices are characterized with the Extended Temperature range of -40°C to +125°C, which are ideal for automotive applications.

Microchip provides an active filter design software known as Filterlab® free of charge. This software simplifies the high-pass, low-pass, and band-pass filter design procedures. The Butterworth, Bessel and Chebychev filters can be implemented in Sallen-Key and Multiple Feedback configurations using this software.

Download free at [www.microchip.com](http://www.microchip.com)

### MCP6021 Operational Amplifier Key Features:
- Rail-to-Rail Input/Output
- Gain Bandwidth Product: 10 MHz (typ.)
- Low Noise: 8.7 nV/Hz (typ.), at 10 kHz
- Low Offset Voltage:
  - Industrial Temperature: ±500 µV (max.)
  - Extended Temperature: ±250 µV (max.)
- Mid-Supply Reference Voltage ($V_{REF}$)
- Low Supply Current: 1 mA (typ.)
- Total Harmonic Distortion: 0.00053% (typ., G = 1)
- Power Supply Range: 2.5V to 5.5V
- Temperature Range:
  - Industrial: -40°C to +85°C
  - Extended: -40°C to +125°C

### Operational Amplifiers Applications:
- Automotive
- Driving A/D Converters
- Multi-Pole Active Filters
- Barcode Scanners
- Audio Processing
- Communications
- DAC Buffer
- Test Equipment
- Medical Instrumentation
- Portable Equipment
- Photodiode Pre-amps
- Analog Filters
- Notebooks and PDAs
- Battery-powered Systems

### Product Specifications: Operational Amplifiers

<table>
<thead>
<tr>
<th>Device</th>
<th>Op Amp</th>
<th>Bandwidth (MHz Typ.)</th>
<th>Slew Rate (V/µs Typ.)</th>
<th>Current (mA Typ.)</th>
<th>Supply Voltage (V)</th>
<th>Offset Voltage (± µV max.)</th>
<th>Temp. Range (°C)</th>
<th>Packages</th>
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<tbody>
<tr>
<td>MCP6021</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td>2.5 to 5.5</td>
<td>500</td>
<td>-40 to +85</td>
<td>PDIP, SOIC, MSOP, TSSOP</td>
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<tr>
<td>MCP6021</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td>2.5 to 5.5</td>
<td>250</td>
<td>-40 to +125</td>
<td>PDIP, SOIC, MSOP, TSSOP</td>
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<td>MCP6291</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
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<td>7</td>
<td>1</td>
<td>2.4 to 5.5</td>
<td>3000</td>
<td>-40 to +125</td>
<td>PDIP, SOIC, MSOP, TSSOP</td>
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<td>MCP6281</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
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<td>2.5</td>
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<td>2.2V to 5.5V</td>
<td>3000</td>
<td>-40 to +125</td>
<td>PDIP, SOIC, MSOP, TSSOP</td>
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</table>
High Performance Devices for a Variety of Precision and Embedded Systems Applications

LOW-COST GENERAL PURPOSE OPERATIONAL AMPLIFIERS

Microchip offers a number of low-cost op amps that are suitable for general purpose applications such as signal amplification, sensor buffer or driving an analog-to-digital converter. These op amps provide competitive bandwidth per given quiescent current. For example, the MCP6001 device has a high phase margin which makes it ideal for capacitive load applications. The low supply voltage, low quiescent current and wide bandwidth makes the MCP6001 ideal for battery-powered applications.

This device is offered in a SOT-23-5 package with three different pin outs. It’s also available in a SC-70-5 package which is 50% smaller than SOT-23-5 package.

MCP6001 Key Features:

- Gain Bandwidth Product: 1 MHz (typ.)
- Rail-to-Rail Input/Output
- Supply Voltage: 1.8V to 5.5V
- Supply Current: I\textsubscript{Q} = 100 \mu A (typ.)
- Phase Margin: 90° (typ.)
- Temperature Range:
  - Industrial: -40°C to +85°C
  - Extended: -40°C to +125°C
- Available in Single, Dual and Quad
- Available in SC-23-5 and SOT-70-5 packages

MCP6001 Applications:

- Automotive
- Portable Equipment
- Photodiode Pre-amps
- Analog Filters
- Notebooks and PDAs
- Battery-powered Systems

Product Specifications: Operational

<table>
<thead>
<tr>
<th>Device</th>
<th>Op Amp</th>
<th>Bandwidth (kHz Typ.)</th>
<th>Slew Rate (V/\mu s Typ.)</th>
<th>Current (\mu A Typ.)</th>
<th>Supply Voltage (V)</th>
<th>Offset Voltage (±mV max.)</th>
<th>Temp. Range (°C)</th>
<th>Packages</th>
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<tbody>
<tr>
<td>MCP601</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
<td>2800</td>
<td>2.3</td>
<td>230</td>
<td>2.7V to 5.5V</td>
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<td>PDIP, SOIC, TSSOP SOT-23-5</td>
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<td>MCP6001</td>
<td>Single, Dual, Quad</td>
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<td>0.6</td>
<td>100</td>
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<td>SC-70-5, SOT-23-5, PDIP SOIC, MSOP</td>
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<td>MCP6271</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
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<td>-40 to +125</td>
<td>PDIP, SOIC, MSOP</td>
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<td>MCP6241</td>
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<td>-40 to +125</td>
<td>PDIP SOIC, SC-70-5, SOT-23-5</td>
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</table>
Microchip's MCP6041 and MCP6141 rail-to-rail input and output op amps draw a maximum of 1 µA quiescent current. These devices provide 14 kHz and 100 kHz of Gain Bandwidth Product, respectively, with a 1.4V to 5.5V supply voltage. The MCP6141 has a minimum stable gain of 10. Both op amps are ideal for battery powered applications such as battery current sensing and wearable devices.

The MCP606 and MCP616 devices also draw very low current and provide wide bandwidth. These op amps are targeted for low power, precision applications with very low offset voltage.

MCP6041 and MCP6141 Key Features:
- Low Quiescent Current: 600 nA Amplifier (typ.)
- Rail-to-Rail Input: -0.3V to VDD +0.3V (max.)
- Rail-to-Rail Output:
  - VSS +10 mV to VDD -10 mV (max.)
- Gain Bandwidth Product: 14 kHz (typ), MCP6041
  - Gain Bandwidth Product: 100 kHz (typ), MCP6141 (G ≥ 10)
- Wide Supply Voltage Range: 1.4V to 5.5V (max.)
- Available in Single, Dual and Quad
- Chip Select (CS) with MCP6043 and MCP6143
- SOT-23-5 package (MCP6041 only)

MCP6041 and MCP6141 Applications:
- Toll Booth Tags
- Wearable Products
- Temperature Measurement
- Battery-powered Systems

### Product Specifications: Operational Amplifiers

<table>
<thead>
<tr>
<th>Device</th>
<th>Op Amp</th>
<th>Bandwidth (kHz Typ.)</th>
<th>Slew Rate (V/µs Typ.)</th>
<th>Current (µA Typ.)</th>
<th>Supply Voltage (V)</th>
<th>Offset Voltage (±mV max.)</th>
<th>Temp. Range (°C)</th>
<th>Packages</th>
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<td>MCP606</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
<td>155</td>
<td>80</td>
<td>19</td>
<td>2.5 to 5.5</td>
<td>250</td>
<td>-40 to +85</td>
<td>PDIP, SOIC, TSSOP, SOT-23-5</td>
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<td>MCP616</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
<td>190</td>
<td>80</td>
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<td>2.3 to 5.5</td>
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<td>PDIP, SOIC, MSOP</td>
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<tr>
<td>MCP6041</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
<td>14</td>
<td>3</td>
<td>0.6</td>
<td>1.4 to 5.5</td>
<td>3000</td>
<td>-40 to +85</td>
<td>PDIP, SOIC, MSOP, SOT-23-5</td>
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<tr>
<td>MCP6141</td>
<td>Single, Dual, Single w/ Chip Select, Quad</td>
<td>100</td>
<td>24</td>
<td>0.6</td>
<td>1.4 to 5.5</td>
<td>3000</td>
<td>-40 to +85</td>
<td>PDIP, SOIC, MSOP, TSSOP, SOT-23-5</td>
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</table>
Microchip’s family of push-pull and open-drain comparators, the MCP6541 and the MCP6546, are designed for very low power single supply applications. These devices fully operate with a supply voltage as low as 1.6V, while drawing 600 nA (typ.) current. The typical propagation delays of these low power comparator families is 4 µs.

The open-drain output of the MCP6546 family can be used as a level-shifter for up to 10V using a pull-up resistor. It can also be used as a wired-OR logic. The internal input hysteresis eliminates output switching due to internal noise voltage, reducing current draw.

MCP6X4X Key Features:
- Low Quiescent Current: 600 nA/comparator (typ.)
- Rail-to-Rail Input: VSS - 0.3V to VDD + 0.3V
- CMOS/TTL-Compatible Output
- Push-pull and Open-drain output
- Propagation Delay: 4 µs (typ.)
- Wide Supply Voltage Range: 1.6V to 5.5V
- Available in Single, Dual and Quad
- Chip Select (CS) with MCP6543 and MCP6548
- Low Switching Current
- Internal Hysteresis: 3.3 mV (typ.)

MCP6541 and MCP6546 Applications:
- Laptop Computers
- Mobile Phones
- Metering Systems
- Hand-held Electronics
- RC Timers
- Alarm and Monitoring Circuits
- Windowed Comparators
- Multi-vibrators

Product Specifications: Comparators

<table>
<thead>
<tr>
<th>Device</th>
<th>Comparator</th>
<th>Current (µA Typ.)</th>
<th>Supply Voltage (V)</th>
<th>Offset Voltage (±mV max.)</th>
<th>Temperature Range (°C)</th>
<th>Package</th>
<th>Output</th>
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<tbody>
<tr>
<td>MCP6541</td>
<td>Single, Dual, Single w/Chip Select, Quad</td>
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<td>1.6 to 5.5</td>
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<td>PDIP, SOIC, MSOP, TSSOP, SC-70-5</td>
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<td>MCP6546</td>
<td>Single, Dual, Single w/Chip Select, Quad</td>
<td>0.6</td>
<td>1.6 to 5.5</td>
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<td>-40 to +85</td>
<td>PDIP, SOIC, MSOP, TSSOP, SC-70-5</td>
<td>Open-Drain</td>
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<td>TC1027</td>
<td>Quad</td>
<td>18</td>
<td>1.8 to 5.5</td>
<td>5</td>
<td>-40 to +85</td>
<td>PDIP, SOIC, MSOP</td>
<td>Push-Pull</td>
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<tr>
<td>TC1037</td>
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<td>SOT-23</td>
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<td>5</td>
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<td>SOIC, MSOP</td>
<td>Push-Pull</td>
</tr>
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</table>
The MCP6S21/2/6/8 family of one, two, six or eight channel Programmable Gain Amplifiers (PGAs) communicate using a standard 3-wire Serial Peripheral Interface (SPI™) protocol. This application note shows how to program the six channel MCP6S26 PGA gains, channels and shutdown registers using the PIC16C505 microcontroller.

Resistive sensors configured as Wheatstone bridges are primarily used to sense pressure, temperature or loads. An external A/D converter (ADC) and a digitally Programmable Gain Amplifier (PGA) can easily be used to convert the difference in voltage from these resistor bridge sensors to usable digital words for manipulation by the microcontroller.

Photo sensors bridge the gap between light and electronics. Microchip’s Programmable Gain Amplifiers (PGAs) are not well suited for precision applications (such as CT scanners), but they can be effectively used in position photo sensing applications minus the headaches of amplifier stability.

Operational amplifier (op amp) oscillators can be used to accurately measure resistive and capacitive sensors. Oscillator design can be simplified by using the procedure discussed in this application note. The derivation of the design equations provides a method to select the passive components and determine the influence of each component on the frequency of oscillation. The procedure will be demonstrated by analyzing two state-variable RC op amp oscillator circuits.

Although it is simple to measure temperature in a stand-alone system without the help of Microchip’s Programmable Gain Amplifiers, a variety of problems can be eliminated by implementing temperature sensing capability in multiplexed applications with a PGA.

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