

## 600 nA, Rail-to-Rail Input/Output Op Amps

### Features

- Low Quiescent Current: 600 nA/Amplifier (typ)
- Rail-to-Rail Input:  $-0.3V$  to  $V_{DD}+0.3V$
- Rail-to-Rail Output:  $V_{SS}+0.1V$  to  $V_{DD}-0.1V$
- Gain Bandwidth Product: 14 kHz (typ)
- Wide Supply Voltage Range: 1.4V to 5.5V
- Unity Gain Stable
- Available in Single, Dual, and Quad
- Chip Select (CS) with MCP6043

### Applications

- Toll Both Tags
- Wearable Products
- Temperature Measurement
- Battery Powered

### Available Tools

- Spice macro models (at [www.microchip.com](http://www.microchip.com))
- FilterLab™ Software (at [www.microchip.com](http://www.microchip.com))

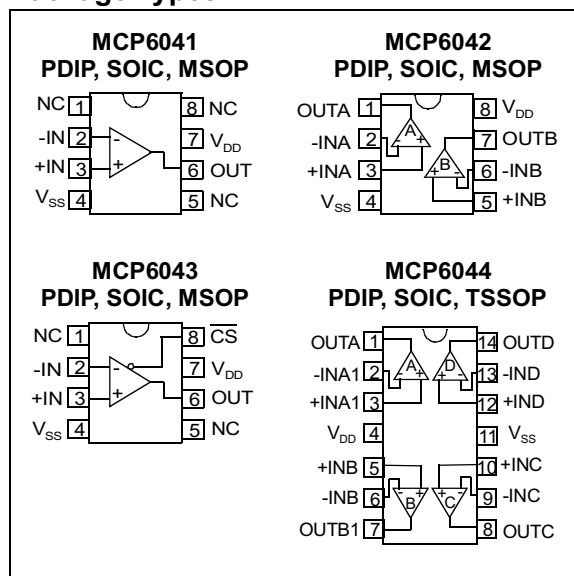
### Description

The MCP6041/2/3/4 family of operational amplifiers from Microchip Technology, Inc. operate with a single supply voltage as low as 1.4V, while drawing less than 1  $\mu A$  of quiescent current per amplifier. These devices are also designed to support rail-to-rail input and output operation. This combination of features supports battery-powered and portable applications.

The MCP6041/2/3/4 amplifiers have a typical gain bandwidth product of 14 kHz and are unity gain stable. These specs make these operational amplifiers appropriate for low frequency applications, such as battery current monitoring and sensor conditioning.

The MCP6041/2/3/4 family operational amplifiers are offered in single (MCP6041), single with a Chip Select (CS) feature (MCP6043), dual (MCP6042) and quad (MCP6044) configurations.

### Package Types



# MCP6041/2/3/4

## 1.0 ELECTRICAL CHARACTERISTICS

### 1.1 Maximum Ratings\*

$V_{DD}$ .....	7.0V
All inputs and outputs w.r.t. ....	$V_{SS} - 0.3V$ to $V_{DD} + 0.3V$
Difference Input voltage .....	$ V_{DD} - V_{SS} $
Output Short Circuit Current .....	continuous
Current at Input Pin .....	$\pm 2$ mA
Current at Output and Supply Pins .....	$\pm 30$ mA
Storage temperature .....	$-65^{\circ}\text{C}$ to $+150^{\circ}\text{C}$
Ambient temp. with power applied .....	$-55^{\circ}\text{C}$ to $+125^{\circ}\text{C}$
ESD protection on all pins (HBM) .....	$\geq 4$ kV

\***Notice:** Stresses above those listed under “Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

### PIN FUNCTION TABLE

NAME	FUNCTION
+IN/+INA/+INB/+INC/+IND	Non-inverting Input Terminals
-IN/-INA/-INB/-INC/-IND	Inverting Input Terminals
$V_{DD}$	Positive Power Supply
$V_{SS}$	Negative Power Supply
OUT/OUTA/OUTB/OUTC/OUTD	Output Terminals
CS	Chip Select
NC	No internal connection to IC

### DC CHARACTERISTICS\*

Unless otherwise indicated, all limits are specified for $V_{DD} = +1.4V$ to $+5.5V$ , $V_{SS} = \text{GND}$ , $T_A = 25^{\circ}\text{C}$ , $V_{CM} = V_{DD}/2$ , $R_L = 1\text{ M}\Omega$ to $V_{DD}/2$ , and $V_{OUT} \sim V_{DD}/2$						
PARAMETERS	SYMBOL	MIN	TYP	MAX	UNITS	CONDITIONS
<b>Input Offset</b>						
Input Offset Voltage	$V_{OS}$	-3	—	+3	mV	$T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$
Drift with Temperature,	$dV_{OS}/dT$	—	$\pm 1.5$	—	$\mu\text{V}/^{\circ}\text{C}$	
Power Supply Rejection	PSRR	70	85	—	dB	
<b>Input Bias Current and Impedance</b>						
Input Bias Current	$I_B$	—	1	—	pA	$T_A = -40^{\circ}\text{C}$ to $+85^{\circ}$
Input Bias Current Over Temperature	$I_B$	—	—	100	pA	
Input Offset Current	$I_{OS}$	—	1	—	pA	
Common Mode Input Impedance	$Z_{CM}$	—	$10^{13}  6$	—	$\Omega  \text{pF}$	
Differential Input Impedance	$Z_{DIFF}$	—	$10^{13}  6$	—	$\Omega  \text{pF}$	
<b>Common Mode</b>						
Common-Mode Input Range	$V_{CMR}$	$V_{SS} - 0.3$	—	$V_{DD} + 0.3$	V	$V_{DD} = 5V$ , $V_{CM} = -0.3$ to $5.3V$
Common-Mode Rejection Ratio	CMRR	62	80	—	dB	
		60	75	—	dB	
		60	80	—	dB	$V_{DD} = 5V$ , $V_{CM} = -0.3$ to $2.5V$
<b>Open Loop Gain</b>						
DC Open Loop Gain	$A_{OL}$	95	115	—	dB	$R_L = 50\text{ k}\Omega$ to $V_{DD}/2$ , $100\text{ mV} < V_{OUT} < (V_{DD} - 100\text{ mV})$
<b>Output</b>						
Maximum Output Voltage Swing	$V_{OL}$ , $V_{OH}$	$V_{SS} + 10$	—	$V_{DD} - 10$	mV	$R_L = 50\text{ k}\Omega$ to $V_{DD}/2$
Linear Region Output Voltage Swing	VOVR	$V_{SS} + 100$	—	$V_{DD} - 100$	mV	$R_L = 50\text{ k}\Omega$ to $V_{DD}/2$ , $A_{OL} \geq 95\text{ dB}$
Output Short Circuit Current	$I_O$	—	21	—	mA	$V_{OUT} = 2.5V$ , $V_{DD} = 5V$
<b>Power Supply</b>						
Supply Voltage	$V_{DD}$	1.4	—	5.5	V	$I_O = 0$
Quiescent Current per amplifier	$I_O$	0.3	0.6	1.0	$\mu\text{A}$	

## AC CHARACTERISTICS

Unless otherwise indicated, all limits are specified for  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$

PARAMETERS	SYMBOL	MIN	TYP	MAX	UNITS	CONDITIONS
Gain Bandwidth Product	GBWP	—	14	—	kHz	
Slew Rate	SR	—	3.0	—	V/ms	
Phase Margin	PM	—	65	—	°	G = +1
Input Voltage Noise	$E_n$	—	5.0	—	$\mu\text{Vp-p}$	f = 0.1 Hz to 10 Hz
Input Voltage Noise Density	$e_n$	—	170	—	nV/ $\sqrt{\text{Hz}}$	f = 1 kHz
Input Current Noise Density	$i_n$	—	0.6	—	fA/ $\sqrt{\text{Hz}}$	f = 1 kHz

## SPECIFICATIONS FOR MCP6043 CHIP SELECT FEATURE

Unless otherwise indicated, all limits are specified for  $V_{DD} = +1.4V$  to  $+5.5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$

PARAMETERS	SYMBOL	MIN	TYP	MAX	UNITS	CONDITIONS
<b>CS Low Specifications</b>						
$\overline{\text{CS}}$ Logic Threshold, Low	$V_{IL}$	$V_{SS}$	—	$V_{SS} + 0.3$	V	For entire $V_{DD}$ range
$\overline{\text{CS}}$ Input Current, Low	$I_{CSL}$	—	5	—	pA	$\overline{\text{CS}} = V_{SS}$
<b>CS High Specifications</b>						
$\overline{\text{CS}}$ Logic Threshold, High	$V_{IH}$	$V_{DD} - 0.3$	—	$V_{DD}$	V	For entire $V_{DD}$ range
$\overline{\text{CS}}$ Input Current, High	$I_{CSH}$	—	5	—	pA	$\overline{\text{CS}} = V_{DD}$
$\overline{\text{CS}}$ Input High, GND Current	$I_Q$	—	20	—	pA	$\overline{\text{CS}} = V_{DD}$
Amplifier Output Leakage, $\overline{\text{CS}}$ High	—	—	20	—	pA	$\overline{\text{CS}} = V_{DD}$
<b>Dynamic Specifications</b>						
$\overline{\text{CS}}$ Low to Amplifier Output High Turn-on Time	$t_{ON}$	—	2	50	ms	$\overline{\text{CS}}$ low = $V_{SS} + 0.3V$ , G = +1V/V, $V_{OUT} = 0.9V_{DD}/2$
$\overline{\text{CS}}$ High to Amplifier Output High Z	$t_{OFF}$	—	10	—	$\mu\text{s}$	$\overline{\text{CS}}$ high = $V_{DD} - 0.3V$ , G = +1V/V, $V_{OUT} = 0.1V_{DD}/2$
Hysteresis	$V_{HYST}$	—	0.6	—	V	$V_{DD} = 5V$

## TEMPERATURE SPECIFICATIONS

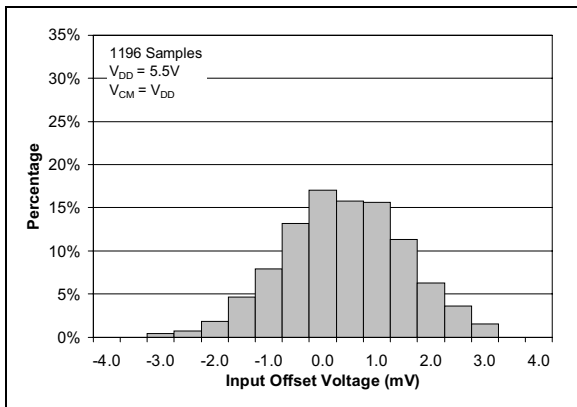
Unless otherwise indicated, all limits are specified for  $V_{DD} = +1.4V$  to  $+5.5V$ ,  $V_{SS} = GND$

PARAMETERS	SYMBOL	MIN	TYP	MAX	UNITS	CONDITIONS
<b>Temperature Ranges</b>						
Specified Temperature Range	$T_A$	-40		+85	°C	
Operating Temperature Range	$T_A$	-40		+85	°C	
Storage Temperature Range	$T_A$	-65		+150	°C	
<b>Thermal Package Resistances</b>						
Thermal Resistance, 8L-PDIP	$\theta_{JA}$	—	85	—	°C/W	
Thermal Resistance, 8L-SOIC	$\theta_{JA}$	—	163	—	°C/W	
Thermal Resistance, 8L-MSOP	$\theta_{JA}$	—	206	—	°C/W	
Thermal Resistance, 14L-PDIP	$\theta_{JA}$	—	70	—	°C/W	
Thermal Resistance, 14L-SOIC	$\theta_{JA}$	—	120	—	°C/W	
Thermal Resistance, 14L-TSSOP	$\theta_{JA}$	—	100	—	°C/W	

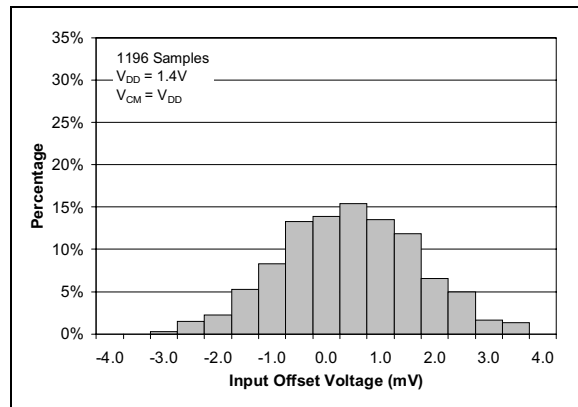
# MCP6041/2/3/4

## 2.0 TYPICAL PERFORMANCE CURVES

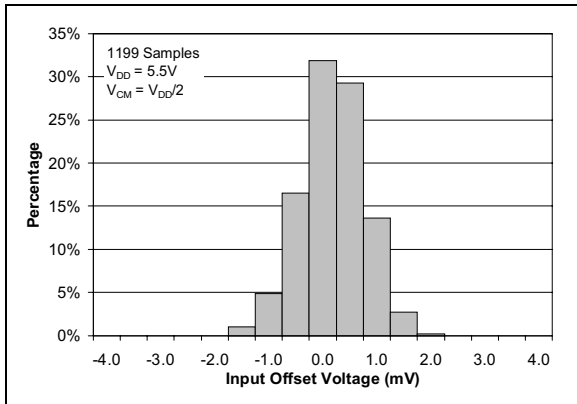
**Note:** Unless otherwise indicated,  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$ .



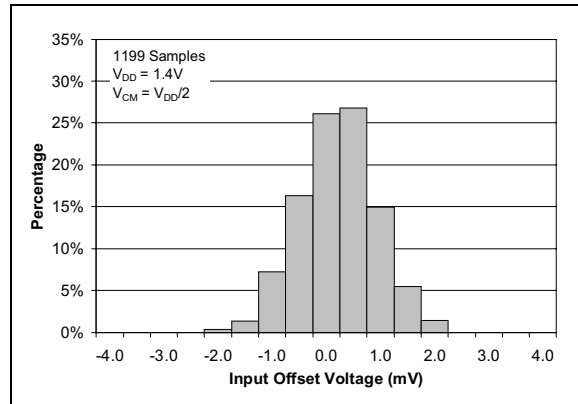
**FIGURE 2-1:** Histogram of Input Offset Voltage with  $V_{DD} = 5.5V$ ,  $V_{CM} = V_{DD}$



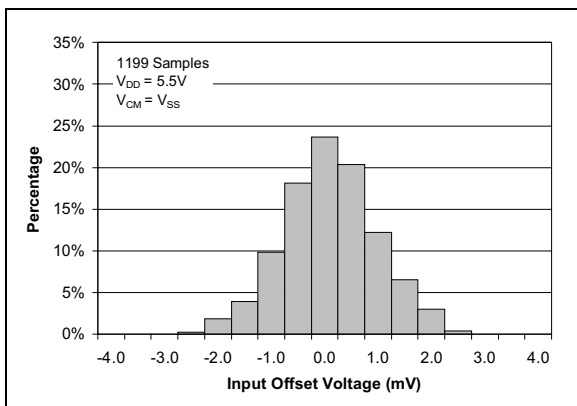
**FIGURE 2-4:** Histogram of Input Offset Voltage with  $V_{DD} = 1.4V$ ,  $V_{CM} = V_{DD}$



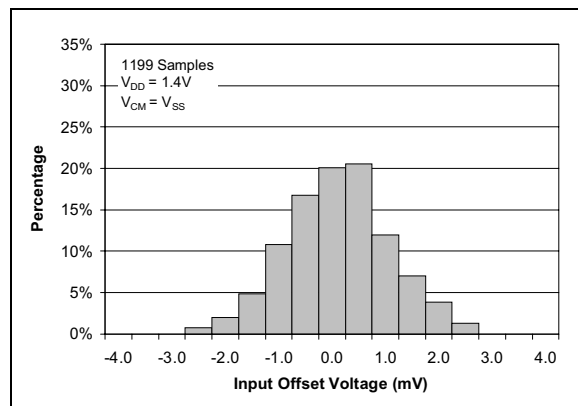
**FIGURE 2-2:** Histogram of Input Offset Voltage with  $V_{DD} = 5.5V$ ,  $V_{CM} = V_{DD}/2$



**FIGURE 2-5:** Histogram of Input Offset Voltage with  $V_{DD} = 1.4V$ ,  $V_{CM} = V_{DD}/2$

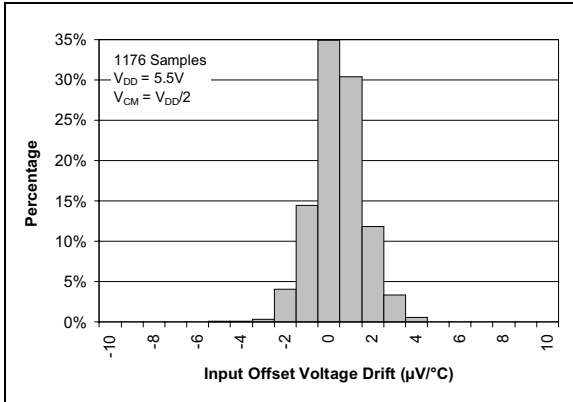


**FIGURE 2-3:** Histogram of Input Offset Voltage with  $V_{DD} = 5.5V$ ,  $V_{CM} = V_{SS}$

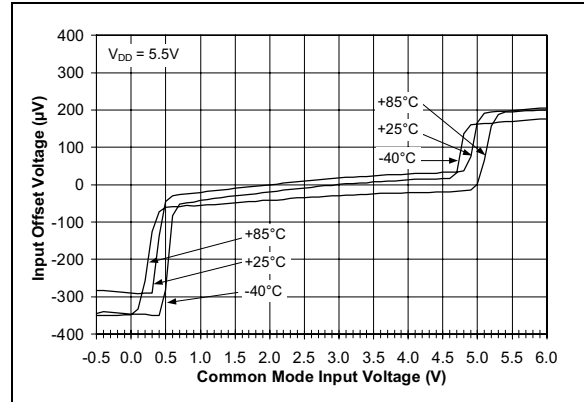


**FIGURE 2-6:** Histogram of Input Offset Voltage with  $V_{DD} = 1.4V$ ,  $V_{CM} = V_{SS}$

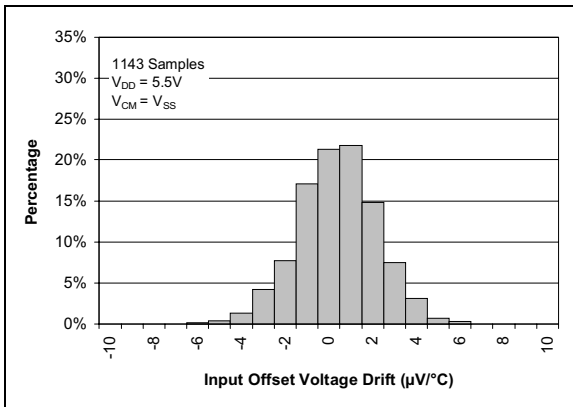
**Note:** Unless otherwise indicated,  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$ .



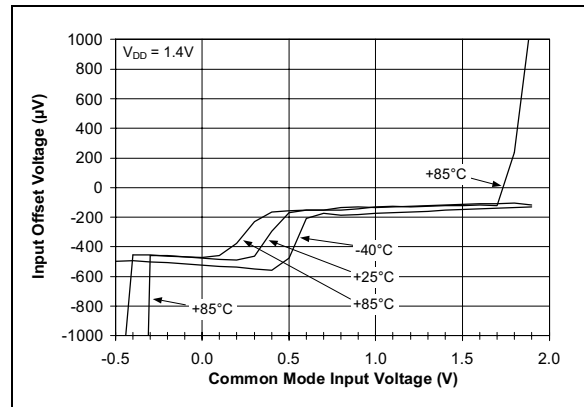
**FIGURE 2-7:** Histogram of Input Offset Voltage Drift with  $V_{DD} = 5.5V$ ,  $V_{CM} = V_{DD}/2$



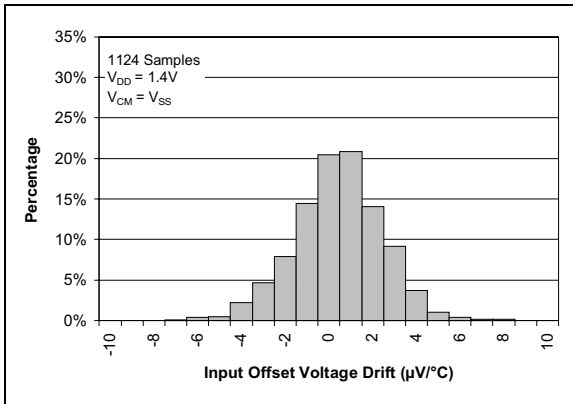
**FIGURE 2-10:** Input Offset Voltage vs. Common Mode Input Voltage vs. Temperature with  $V_{DD} = 5.5V$



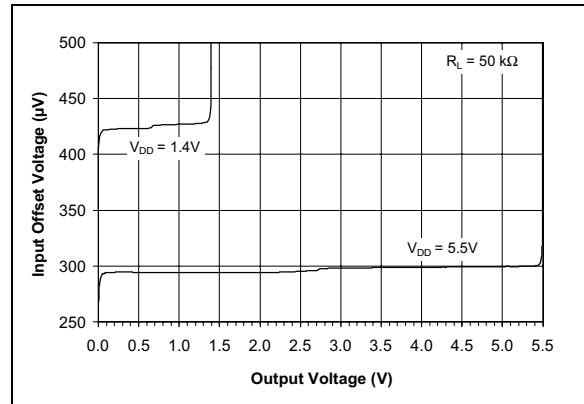
**FIGURE 2-8:** Histogram of Input Offset Voltage Drift with  $V_{DD} = 5.5V$ ,  $V_{CM} = V_{SS}$



**FIGURE 2-11:** Input Offset Voltage vs. Common Mode Input Voltage vs. Temperature with  $V_{DD} = 1.4V$



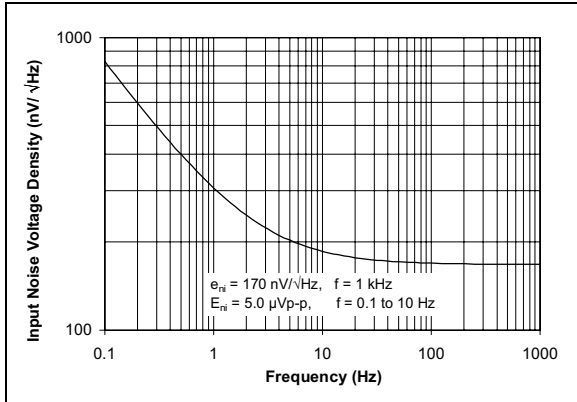
**FIGURE 2-9:** Histogram of Input Offset Voltage Drift with  $V_{DD} = 1.4V$ ,  $V_{CM} = V_{SS}$



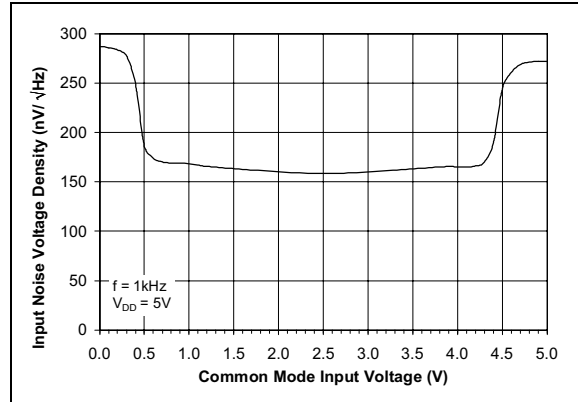
**FIGURE 2-12:** Input Offset Voltage vs. Output Voltage vs. Power Supply Voltage

# MCP6041/2/3/4

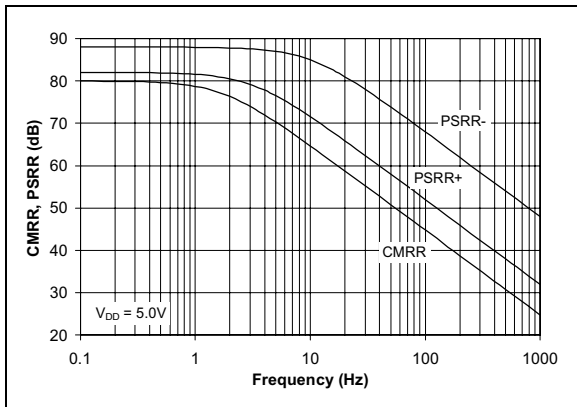
**Note:** Unless otherwise indicated,  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1 M\Omega$  to  $V_{DD}/2$ ,  $C_L = 60 pF$ , and  $V_{OUT} \sim V_{DD}/2$ .



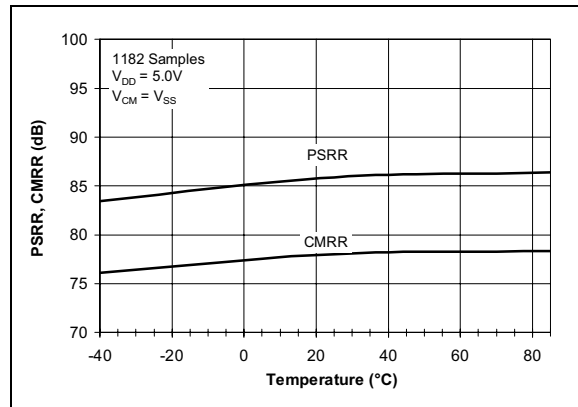
**FIGURE 2-13:** Input Noise Voltage Density vs. Frequency



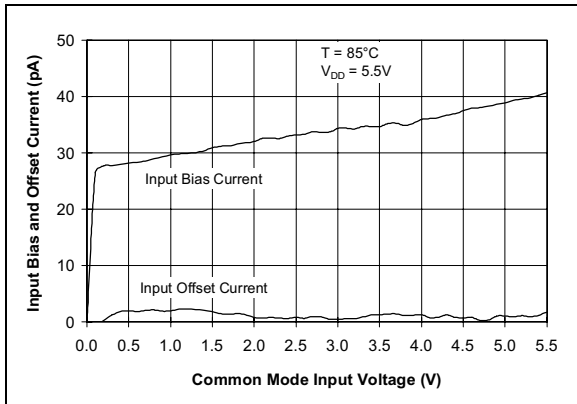
**FIGURE 2-16:** Input Noise Voltage Density vs. Common Mode Input Voltage



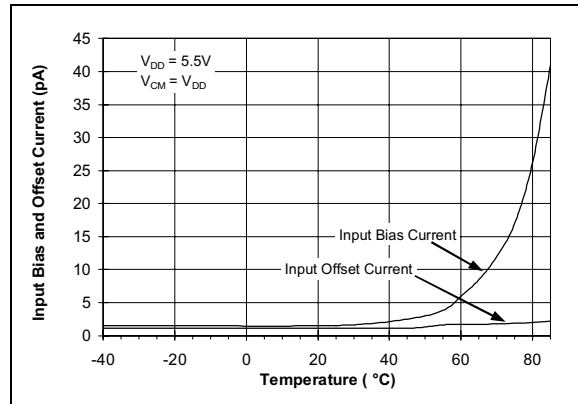
**FIGURE 2-14:** Common Mode Rejection Ratio, Power Supply Rejection Ratio vs. Frequency



**FIGURE 2-17:** Common Mode Rejection Ratio, Power Supply Rejection Ratio vs. Temperature

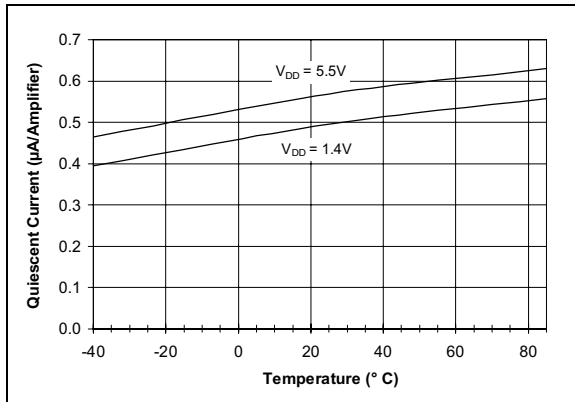


**FIGURE 2-15:** Input Bias, Offset Currents vs. Common Mode Input Voltage with Temperature =  $85^\circ C$

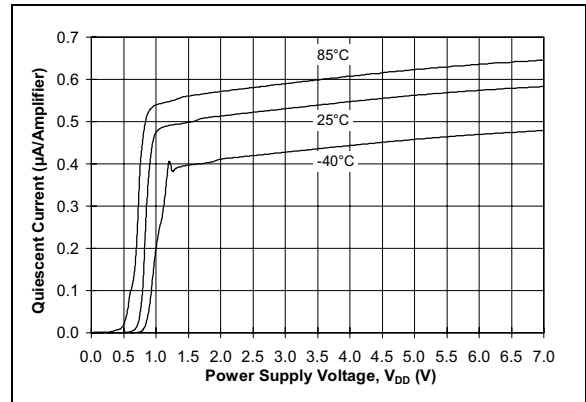


**FIGURE 2-18:** Input Bias, Offset Currents vs. Temperature

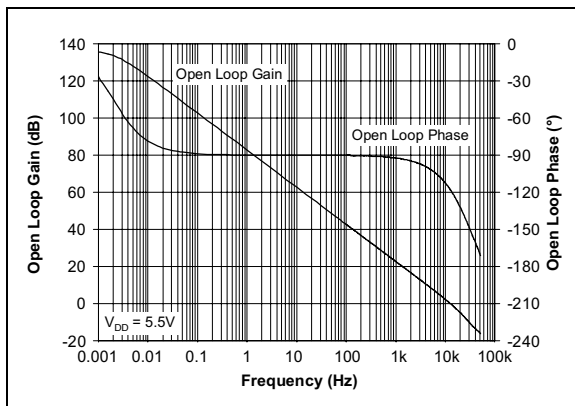
**Note:** Unless otherwise indicated,  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$ .



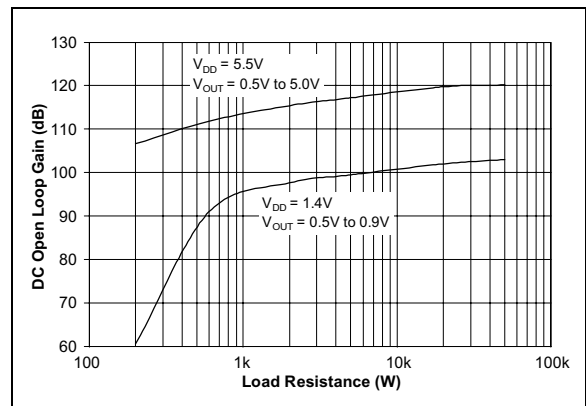
**FIGURE 2-19:** Quiescent Current vs. Temperature vs. Power Supply Voltage



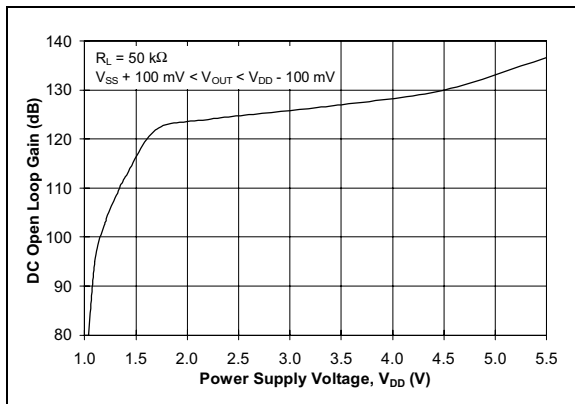
**FIGURE 2-22:** Quiescent Current vs. Power Supply Voltage vs. Temperature



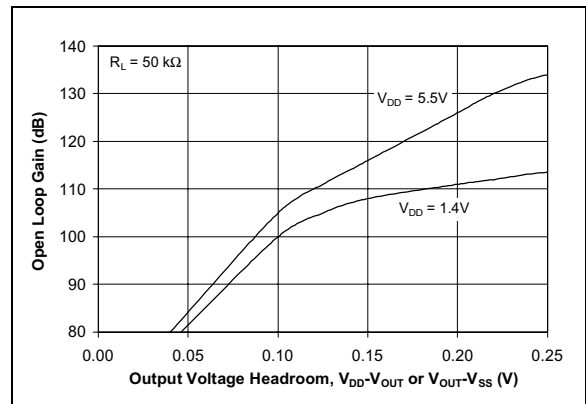
**FIGURE 2-20:** Open Loop Gain, Phase vs. Frequency with  $V_{DD} = 5.5V$



**FIGURE 2-23:** Open Loop Gain vs. Load Resistance vs. Power Supply Voltage



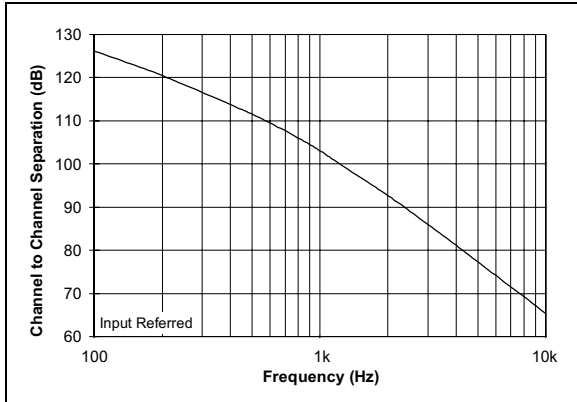
**FIGURE 2-21:** Open Loop Gain vs. Power Supply Voltage



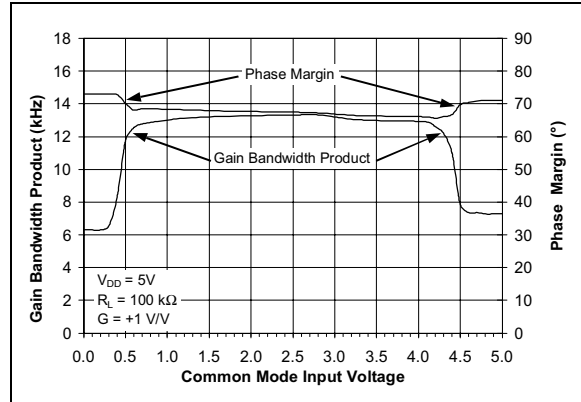
**FIGURE 2-24:** Open Loop Gain vs. Output Voltage Headroom vs. Power Supply Voltage

# MCP6041/2/3/4

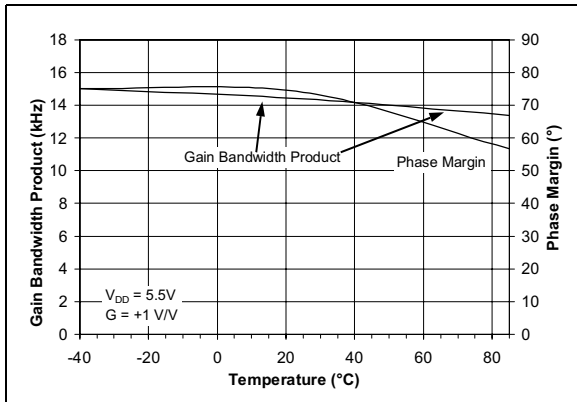
**Note:** Unless otherwise indicated,  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$ .



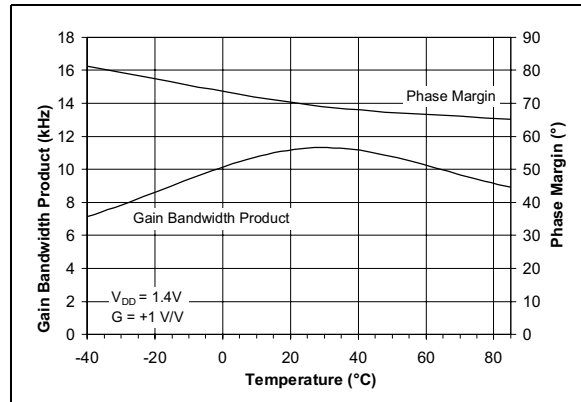
**FIGURE 2-25:** Channel to Channel Separation vs. Frequency (MCP6042 and MCP6044 only)



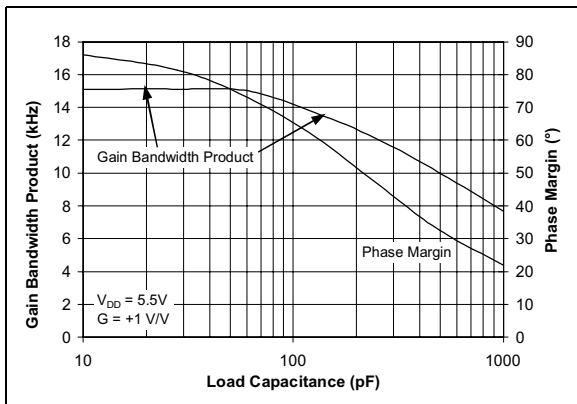
**FIGURE 2-28:** Gain Bandwidth Product, Phase Margin vs. Common Mode Input Voltage with Unity Gain



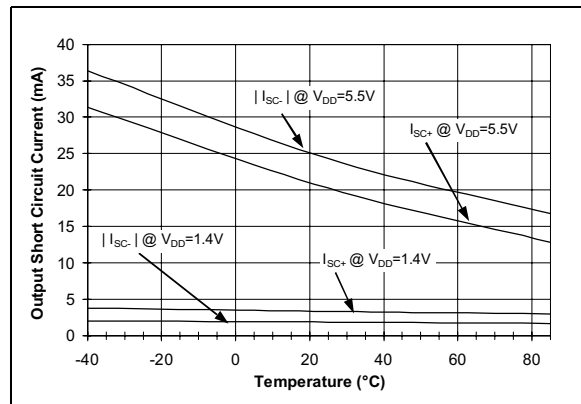
**FIGURE 2-26:** Gain Bandwidth Product, Phase Margin vs. Temperature with  $V_{DD} = 5.5V$ , Unity Gain



**FIGURE 2-29:** Gain Bandwidth Product, Phase Margin vs. Temperature with  $V_{DD} = 1.4V$ , Unity Gain



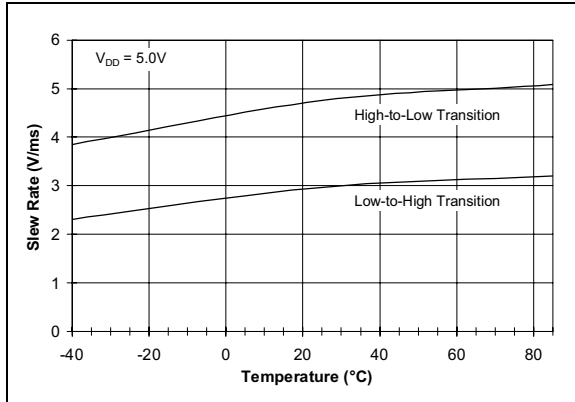
**FIGURE 2-27:** Gain Bandwidth Product, Phase Margin vs. Load Capacitance with Unity Gain



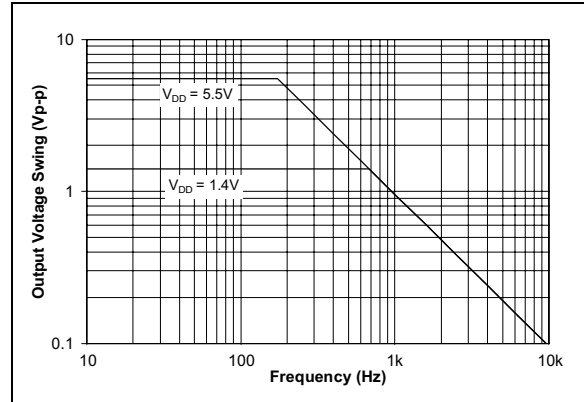
**FIGURE 2-30:** Output Short Circuit Current vs. Temperature vs. Power Supply Voltage



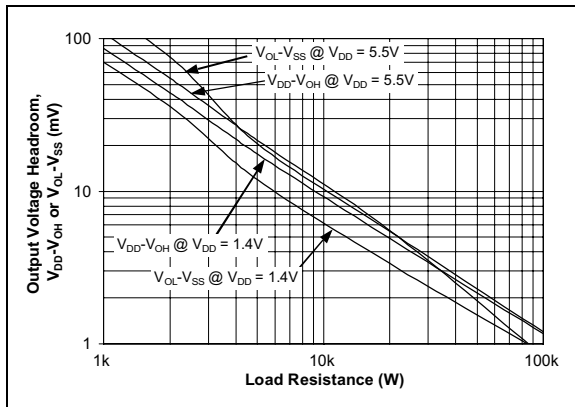
**Note:** Unless otherwise indicated,  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$ .



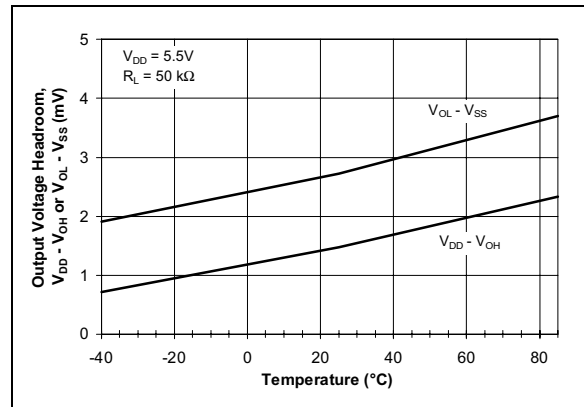
**FIGURE 2-31:** Slew Rate vs. Temperature



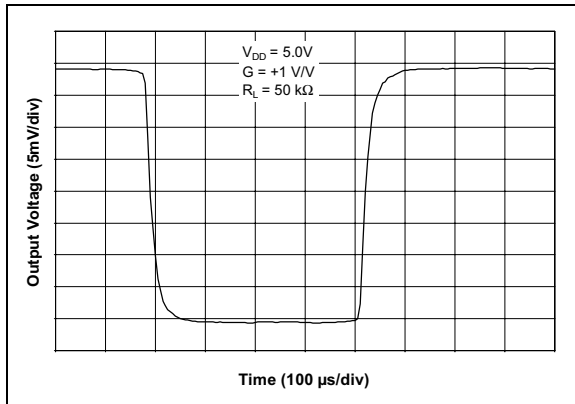
**FIGURE 2-34:** Output Voltage Swing vs. Frequency vs. Power Supply Voltage



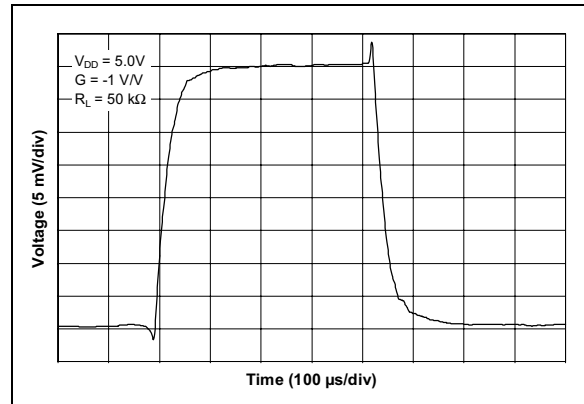
**FIGURE 2-32:** Output Voltage Headroom vs. Load Resistance vs. Power Supply Voltage



**FIGURE 2-35:** Output Voltage Headroom vs. Temperature



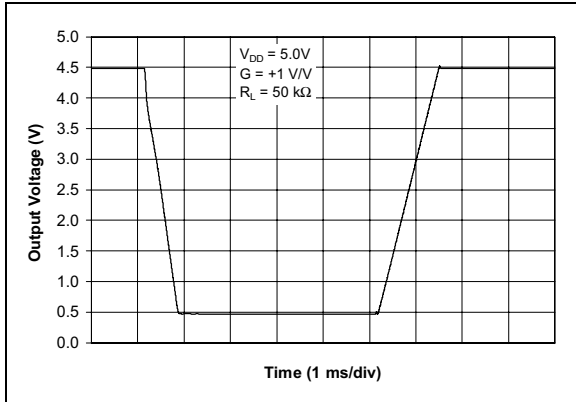
**FIGURE 2-33:** Small Signal Non-Inverting Pulse Response



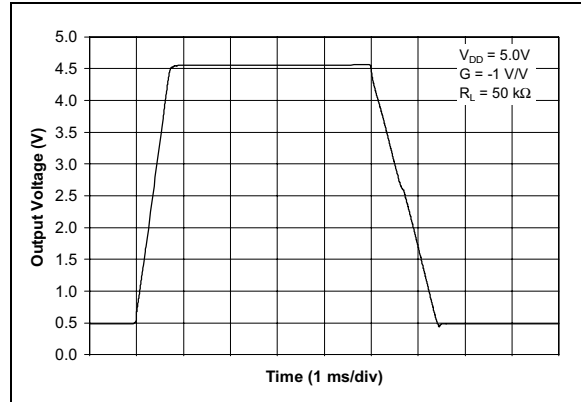
**FIGURE 2-36:** Small Signal Inverting Pulse Response

# MCP6041/2/3/4

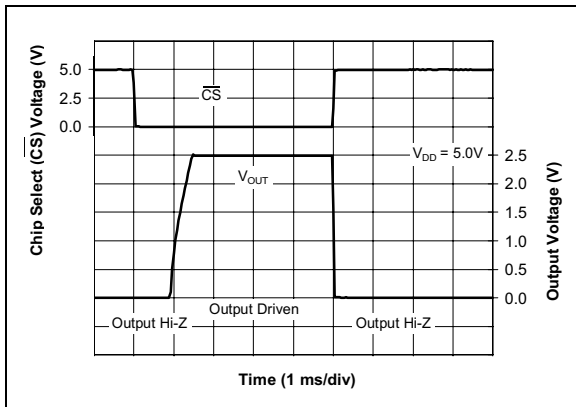
**Note:** Unless otherwise indicated,  $V_{DD} = +5V$ ,  $V_{SS} = GND$ ,  $T_A = 25^\circ C$ ,  $V_{CM} = V_{DD}/2$ ,  $R_L = 1\text{ M}\Omega$  to  $V_{DD}/2$ ,  $C_L = 60\text{ pF}$ , and  $V_{OUT} \sim V_{DD}/2$ .



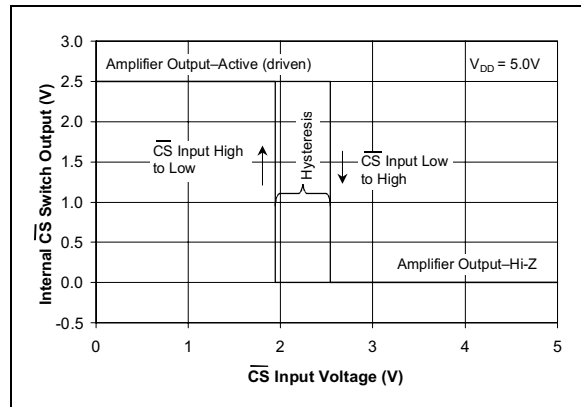
**FIGURE 2-37:** Large Signal Non-Inverting Pulse Response



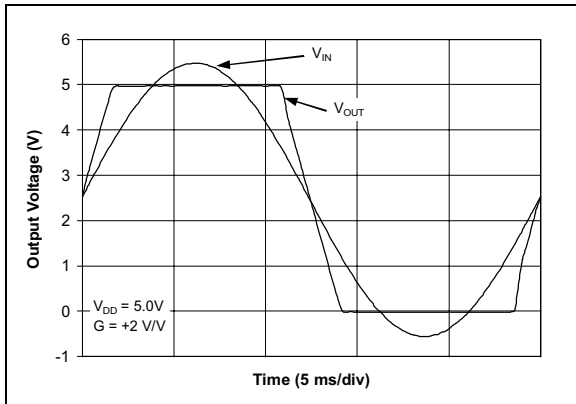
**FIGURE 2-40:** Large Signal Inverting Pulse Response



**FIGURE 2-38:** Chip Select ( $\overline{CS}$ ) to Amplifier Output Response Time (MCP6043 only)



**FIGURE 2-41:** Chip Select ( $\overline{CS}$ ) Hysteresis (MCP6043 only)



**FIGURE 2-39:** The MCP6041/2/3/4 family shows no phase reversal (for information only—the Maximum Absolute Input Voltage is still  $V_{SS}-0.3V$  and  $V_{DD}+0.3V$ )

## 3.0 APPLICATIONS INFORMATION

The MCP6041/2/3/4 family of operational amplifiers are fabricated on Microchip's state-of-the-art CMOS process. They are unity gain stable and suitable for a wide range of applications requiring very low power consumption. With these op amps, the power supply pin needs to be by-passed with a 0.1  $\mu\text{F}$  capacitor.

### 3.1 Rail to Rail Input

The input stage of the family of devices uses two differential input stages in parallel; one operates at low  $V_{\text{CM}}$  (common mode input voltage) and the other at high  $V_{\text{CM}}$ . With this topology, the MCP6041/2/3/4 family operates with  $V_{\text{CM}}$  up to 300 mV past either supply rail. The Input Offset Voltage is measured at both  $V_{\text{CM}} = V_{\text{SS}} - 0.3\text{V}$  and  $V_{\text{DD}} + 0.3\text{V}$  to ensure proper operation.

### 3.2 Output Loads and Battery Life

The MCP6041/2/3/4 op amp family has outstanding quiescent current, which supports battery-powered applications. There is minimal quiescent current glitching when chip select ( $\overline{\text{CS}}$ ) is raised or lowered. This prevents excessive current draw, and reduced battery life, when the part is turned off or on.

Heavy resistive loads at the output can cause excessive battery drain. Driving a DC voltage of 2.5V across a 100 k $\Omega$  load resistor will cause the supply current to increase by 25  $\mu\text{A}$ , depleting the battery 43 times as fast as  $I_{\text{Q}}$  (0.6  $\mu\text{A}$ ) alone.

High frequency signals (fast edge rate) across capacitive loads will also significantly increase supply current. For instance, a 0.1  $\mu\text{F}$  capacitor at the output presents an AC impedance of 15.9 k $\Omega$  (1/2 $\pi$ fC) to a 100 Hz sine wave. It can be shown that the average power drawn from the battery by a 5.0Vp-p sine wave (1.77Vrms), under these conditions, is:

$$\begin{aligned} P_{\text{SUPPLY}} &= (V_{\text{DD}} - V_{\text{SS}})(I_{\text{Q}} + V_{\text{L}(p-p)}fC_{\text{L}}) \\ &= (5\text{V})(0.6\mu\text{A} + 5.0\text{V}_{p-p} \cdot 100\text{Hz} \cdot 0.1\mu\text{F}) \\ &= 3.0\mu\text{W} + 50\mu\text{W} \end{aligned}$$

This will drain the battery 18 times as fast as  $I_{\text{Q}}$  alone.

### 3.3 Rail to Rail Output

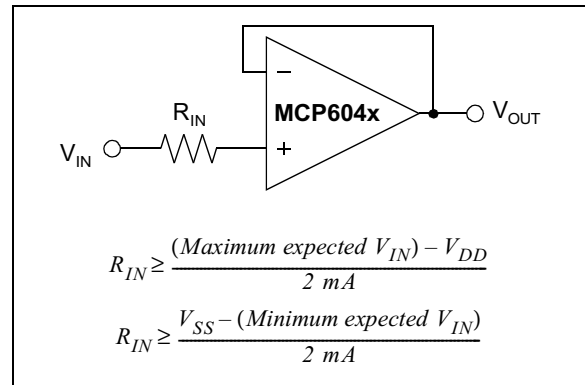
The output voltage range of the MCP6041/2/3/4 family is specified two ways. The first specification, Maximum Output Voltage Swing, defines the maximum swing possible under a particular output load. According to the spec table, the output can reach  $\leq 10$  mV of either supply rail when  $R_{\text{L}} = 50$  k $\Omega$ . See Figure 2-32 for information on Maximum Output Voltage Swing vs. load resistance.

The second specification, Linear Region Output Voltage Swing, details the output voltage range that supports the specified Open Loop Gain ( $A_{\text{OL}} \geq 95$  dB with  $R_{\text{L}} = 50$  k $\Omega$ ).

### 3.4 Input Voltage and Phase Reversal

The MCP6041/2/3/4 op amp family uses CMOS transistors at the input. It is designed to not exhibit phase inversion when the input pins exceed the supply voltages. Figure 2-39 shows an input voltage exceeding both supplies with no resulting phase inversion.

The maximum operating  $V_{\text{CM}}$  (common mode input voltage) that can be applied to the inputs is  $V_{\text{SS}} - 0.3\text{V}$  and  $V_{\text{DD}} + 0.3\text{V}$ . Voltage on the input that exceed this absolute maximum rating can cause excessive current to flow in or out of the input pins. Current beyond  $\pm 2$  mA can cause possible reliability problems. Applications that exceed this rating must be externally limited with an input resistor as shown in Figure 3-1.



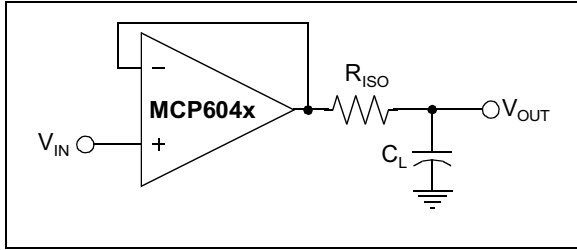
**FIGURE 3-1:** An input resistor,  $R_{\text{IN}}$ , should be used to limit excessive input current if the inputs exceed the Absolute Maximum specification

### 3.5 Capacitive Load and Stability

Driving capacitive loads can cause stability problems with voltage feedback op amps. A buffer configuration ( $G = +1$ ) is the most sensitive to capacitive loads. Figure 2-27 shows how increasing the load capacitance will decrease the phase margin. A phase margin above 60° is best, but 45° is still usable. As can be seen, up to  $C_{\text{L}} = 150$  pF can be placed on the MCP6041/2/3/4 op amp outputs without any problems, while 250 pF is useable with 45° phase margin.

When the op amp is required to drive large capacitive loads ( $C_{\text{L}} > 150$  pF), then a small series resistor ( $R_{\text{ISO}}$  in Figure 3-2) at the output of the amplifier improves the phase margin. This resistor makes the output load resistive at higher frequencies, which improves the phase margin. The bandwidth reduction caused by the capacitive load, however, is not changed. To select  $R_{\text{ISO}}$ , start with 1 k $\Omega$ , then use the MCP6041 SPICE macro model and bench testing to adjust  $R_{\text{ISO}}$  until the frequency response peaking is reasonable. Use the smallest reasonable value.

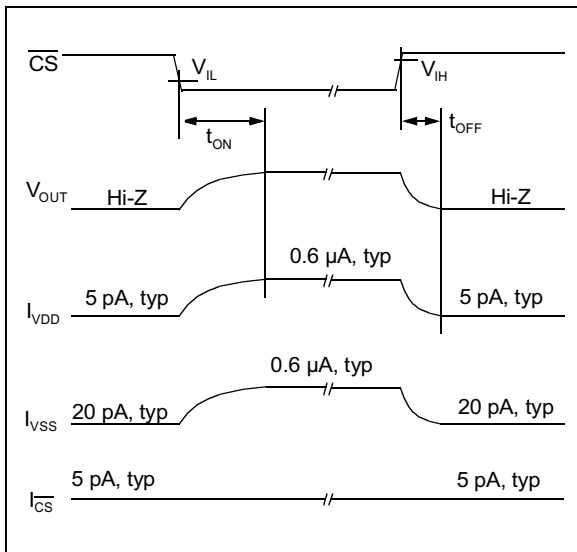
# MCP6041/2/3/4



**FIGURE 3-2:** Amplifier circuit for heavy capacitive loads

## 3.6 The MCP6043 Chip Select ( $\overline{CS}$ ) Option

The MCP6043 is a single amplifier with a chip select ( $\overline{CS}$ ) option. When  $\overline{CS}$  is pulled high the supply current drops to 20 pA (typ), and goes through the  $\overline{CS}$  pin to  $V_{SS}$ . When this happens, the amplifier is put into a high impedance state. By pulling  $\overline{CS}$  low, the amplifier is enabled. If the  $\overline{CS}$  pin is left floating, the amplifier will not operate properly. Figure 3-3 shows the output voltage and supply current response to a  $\overline{CS}$  pulse.



**FIGURE 3-3:** Timing Diagram for the  $\overline{CS}$  function on the MCP6043 op amp

## 3.7 Layout Considerations

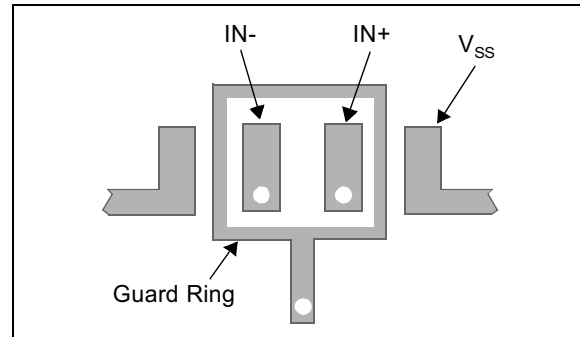
Good PC board layout techniques will help you achieve the performance shown in the specs and Typical Performance Curves. It will also help you minimize EMC (Electro-Magnetic Compatibility) issues.

### 3.7.1 SURFACE LEAKAGE

In applications where low input bias current is critical, PC board surface leakage effects and signal coupling from trace to trace need to be considered.

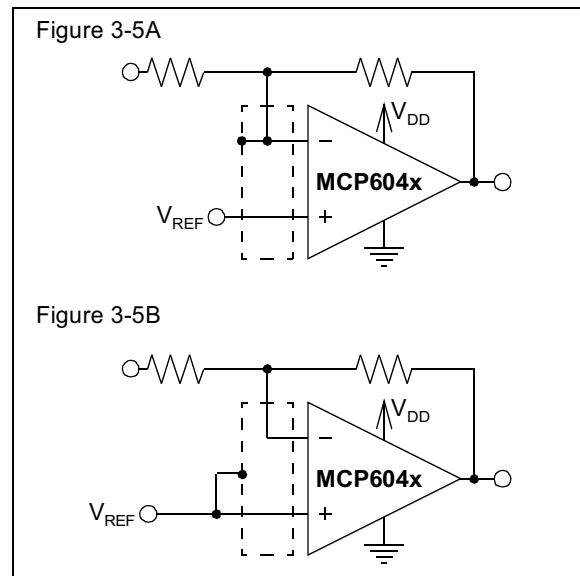
Surface leakage is caused by a difference in voltage between traces, combined with high humidity, dust or other contamination on the board. Under low humidity conditions, a typical resistance between nearby traces is  $10^{12}\Omega$ . A 5V difference would cause 5 pA of current to flow; this is greater than the input current of the MCP6041/2/3/4 family at 25°C (1 pA, typ).

The simplest technique to reduce surface leakage is using a guard ring around sensitive pins (or traces). The guard ring is biased at the same voltage as the sensitive pin or trace; Figure 3-4 shows an example of a typical layout.



**FIGURE 3-4:** Example of Guard Ring layout

Circuit schematics for different guard ring implementations are shown in Figure 3-5. Figure 3-5A biases the guard ring to the input common mode voltage, which is most effective for non-inverting gains, including unity gain. Figure 3-5B biases the guard ring to a reference voltage ( $V_{REF}$ , which can be ground). This is useful for inverting gains and precision photo sensing circuits.



**FIGURE 3-5:** Two possible guard ring connection strategies to reduce surface leakage effects

### 3.7.2 COMPONENT PLACEMENT

Separate digital from analog, and low speed from high speed. This helps prevent crosstalk.

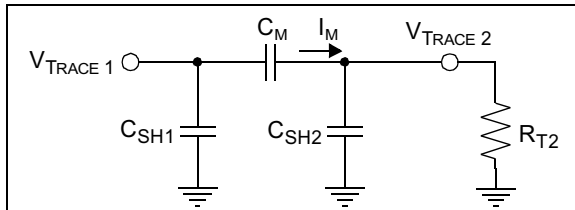
Keep sensitive traces short and straight. Separate them from interfering components and traces. This is especially important for high frequency (low rise time) signals.

Use a 0.1  $\mu\text{F}$  supply bypass capacitor within 0.1" (2.5 mm) of the  $V_{\text{DD}}$  pin. It must connect directly to the ground plane.

### 3.7.3 SIGNAL COUPLING

The input pins of the MCP6041/2/3/4 family of op amps are high impedance, which allows noise injection. This noise can be capacitively or magnetically coupled. In either case, using a ground plane helps reduce noise injection.

When noise is coupled capacitively, the ground plane provides shunt capacitance to ground for high frequency signals; [Figure 3-6](#) shows the equivalent circuit. The coupled current,  $I_M$ , produces a lower voltage ( $V_{\text{TRACE 2}}$ ) on the victim trace when the trace to ground plane capacitance ( $C_{\text{SH2}}$ ) is large, and the terminating resistor ( $R_{\text{T2}}$ ) is small. Increasing the distance between traces, and using wider traces, also helps.



**FIGURE 3-6:** Equivalent circuit for capacitive coupling between traces on a PC board (with ground plane)

When noise is coupled magnetically, ground plane reduces the mutual inductance between traces. This occurs because the ground return current at high frequencies will follow a path directly beneath the signal trace. Increasing the separation between traces makes a significant difference. Changing the direction of one of the traces can also reduce magnetic coupling.

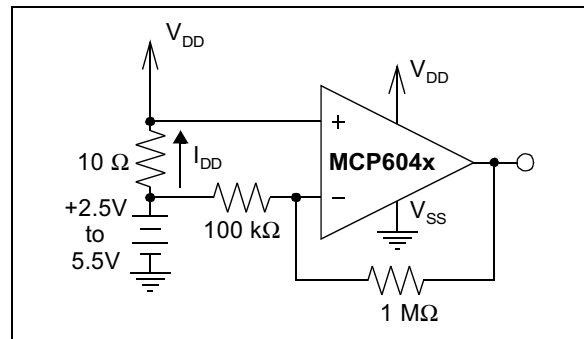
If these techniques are not enough, it may help to place guard traces next to the victim trace. They should be on both sides of the victim trace, and as close as possible. Connect the guard traces to ground plane at both ends, and in the middle for long traces.

## 3.8 Typical Applications

### 3.8.1 BATTERY CURRENT SENSING

The MCP6041/2/3/4 op amps' Common Mode Input Range, which goes 300 mV beyond both supply rails, supports their use in high side and low side battery current sensing applications. The very low quiescent current (0.6  $\mu\text{A}$ , typ) help prolong battery life, and the rail-to-rail output allows you to detect low currents.

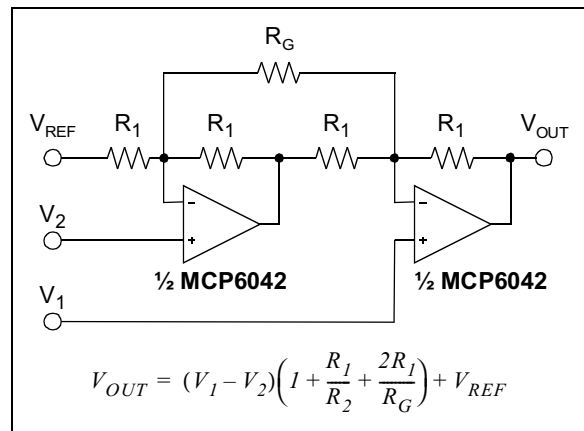
[Figure 3-7](#) shows a high side battery current sensor circuit. The 10  $\Omega$  resistors are sized to minimize power losses. The battery current ( $I_{\text{DD}}$ ) through the 10  $\Omega$  resistor causes its top terminal to be more negative than the bottom terminal. This keeps the common mode input voltage of the op amp  $\leq V_{\text{DD}}$ , which is within its allowed range. The output of the op amp can reach  $V_{\text{DD}} - 0.1\text{mV}$  (see [Figure 2-32](#)), which is a smaller error than the offset voltage.



**FIGURE 3-7:** High Side Battery Current Sensor

### 3.8.2 INSTRUMENTATION AMPLIFIER

The MCP6041/2/3/4 op amp is well suited for conditioning sensor signals in battery-powered applications. [Figure 3-8](#) shows a two op amp instrumentation amplifier, using the MCP6042, that works well for applications requiring rejection of common mode noise at higher gains. The reference voltage ( $V_{\text{REF}}$ ) is supplied by a low impedance source. In single supply applications,  $V_{\text{REF}}$  is typically  $V_{\text{DD}}/2$ .



**FIGURE 3-8:** Two Op Amp Instrumentation Amplifier

# MCP6041/2/3/4

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## 4.0 SPICE MACRO MODEL

The Spice macro model for the MCP6041, MCP6042, MCP6043 and MCP6044 simulates the typical amplifier performance of: offset voltage, DC power supply rejection, input capacitance, DC common mode rejection, open loop gain over frequency, phase margin, output swing, DC power supply current, power supply current change with supply voltage, input common mode range, output voltage range vs. load, and input voltage noise.

The characteristics of the MCP6041, MCP6042, MCP6043, and MCP6044 amplifiers are similar in terms of performance and behavior. This single op amp macro model supports all four devices with the exception of the chip select function of the MCP6043, which is not modeled.

The listing for this macro model is shown on the next page. The most recent revision of the model can be downloaded from Microchip's web site at [www.microchip.com](http://www.microchip.com)

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```
.SUBCKT MCP6041 1 2 3 4 5
*
*      | | | | |
*      | | | | Output
*      | | | Negative Supply
*      | | Positive Supply
*      | Inverting Input
*      Non-inverting Input
*
* Macromodel for the MCP6041/2/3/4 op amp family:
*   MCP6041 (single)
*   MCP6042 (dual)
*   MCP6043 (single w/ CS; chip select is not modeled)
*   MCP6044 (quad)
*
* Revision History:
*   REV A: 7-9-01 created KEB
*
* Recommendations:
*   Use PSPICE (other simulators may require translation)
*   For a quick, effective design, use a combination of: data sheet
*   specs, bench testing, and simulations with this macromodel
*   For high impedance circuits, set GMIN=100F in the .OPTIONS
*   statement
*
* Supported:
*   Typical performance at room temperature (25 degrees C)
*   DC, AC, Transient, and Noise analyses.
*   Most specs, including: offsets, PSRR, CMRR, input impedance,
*   open loop gain, voltage ranges, supply current, ... , etc.
*
* Not Supported:
*   Chip Select (MCP6043)
*   Variation in specs vs. Power Supply Voltage
*   Distortion (detailed non-linear behavior)
*   Temperature analysis
*   Process variation
*   Behavior outside normal operating region
*
* Input Stage
V10  3 10 -0.3
R10  10 11 78K
R11  10 12 78K
C11  11 12 4.9P
C12  1  0 6P
E12  1 14 POLY(4) 20 0 21 0 26 0 27 0  1M 1 1 1 1
G12  14  0 POLY(2) 22 0 23 0  1.5P 1U 1U
M12  11 14 15 15 NMI
C13  14  2 3P
M14  12  2 15 15 NMI
G14  2  0 POLY(2) 24 0 25 0  0.5P 1U 1U
C14  2  0 6P
```

# MCP6041/2/3/4

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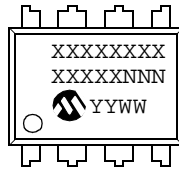
```
I15 15 4 500N
V16 16 4 0.18
D16 16 15 DL
V13 3 13 0.00
D13 14 13 DL
*
* Noise Sources
I20 21 20 17.2N
D20 20 0 DN1
D21 0 21 DN1
I22 23 22 588U
D22 22 0 DN23
D23 0 23 DN23
I24 25 24 588U
D24 24 0 DN23
D25 0 25 DN23
*
* PSRR and CMRR
G26 0 26 POLY(1) 3 4 110U -20U
R26 26 0 1
G27 0 27 POLY(2) 1 3 2 4 -275U 50U 50U
R27 27 0 1
*
* Open Loop Gain, Slew Rate
G30 0 30 POLY(1) 12 11 0 1MEG
R30 30 0 1
C30 30 0 11.4
G31 0 31 POLY(1) 30 0 0 1
R31 31 0 1
C31 31 0 775N
*
* Output Stage
G40 0 40 POLY(1) 45 5 0 22.7M
D41 40 41 DL
R41 41 0 1K
D42 42 40 DL
R42 42 0 1K
G43 3 0 POLY(1) 41 0 100N 1M
G47 0 4 POLY(1) 42 0 100N -1M
E43 43 0 POLY(1) 3 0 0 1
E47 47 0 POLY(1) 4 0 0 1
V44 43 44 1M
D44 45 44 DLS
D46 46 45 DLS
V46 46 47 1M
G45 47 45 POLY(2) 31 0 3 4 0 8U 4U
R45 45 47 125K
R48 45 5 44
C48 5 0 2P
*
* Models
.MODEL NMI NMOS L=2 W=42
.MODEL DL D N=1 IS=1F
.MODEL DLS D N=1M IS=1F
.MODEL DN1 D IS=1F KF=1.13E-18 AF=1
.MODEL DN23 D IS=1F KF=3E-20 AF=1
*
.ENDS MCP6041
```



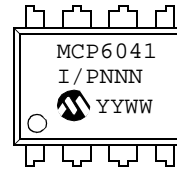
## 5.0 PACKAGING INFORMATION

### 5.1 Package Marking Information

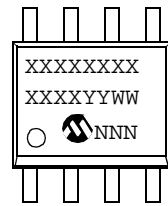
8-Lead PDIP (300 mil)



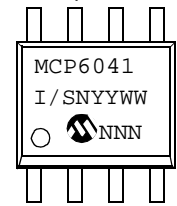
Example:



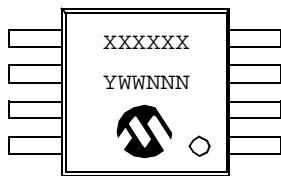
8-Lead SOIC (150 mil)



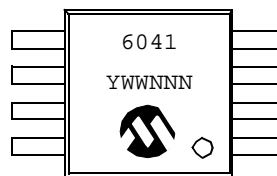
Example:



8-Lead MSOP



Example:



<b>Legend:</b>	XX...X	Customer specific information*
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week '01')
	NNN	Alphanumeric traceability code

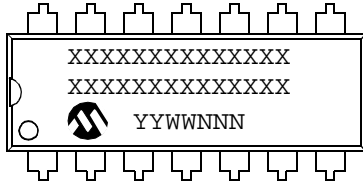
<b>Note:</b>	In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line thus limiting the number of available characters for customer specific information.
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\* Standard marking consists of Microchip part number, year code, week code, traceability code (facility code, mask rev#, and assembly code). For marking beyond this, certain price adders apply. Please check with your Microchip Sales Office.

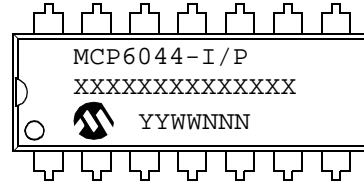
# MCP6041/2/3/4

## Package Marking Information (Continued)

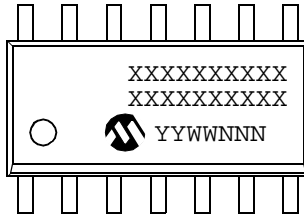
14-Lead PDIP (300 mil) (MCP6044)



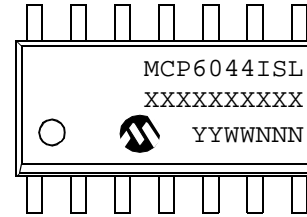
Example:



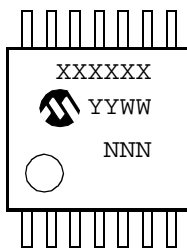
14-Lead SOIC (150 mil) (MCP6044)



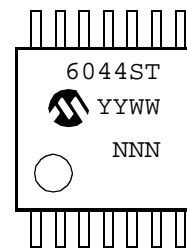
Example:



14-Lead TSSOP (MCP6044)



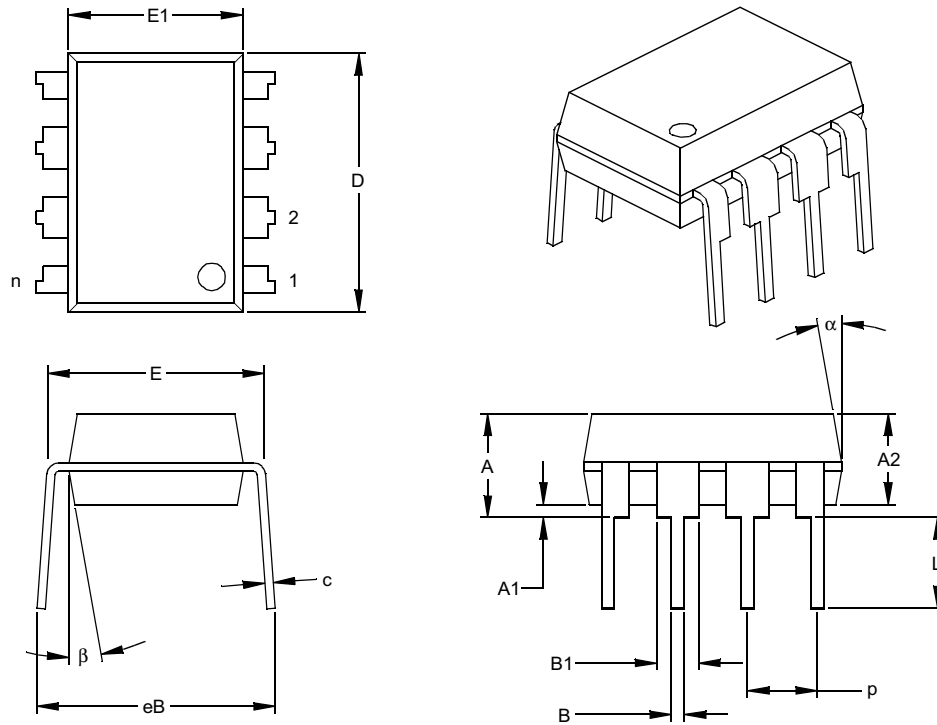
Example:



<b>Legend:</b>	XX...X	Customer specific information*
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week '01')
	NNN	Alphanumeric traceability code
<b>Note:</b>	In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line thus limiting the number of available characters for customer specific information.	

\* Standard marking consists of Microchip part number, year code, week code, traceability code (facility code, mask rev#, and assembly code). For marking beyond this, certain price adders apply. Please check with your Microchip Sales Office.

## 8-Lead Plastic Dual In-line (P) – 300 mil (PDIP)



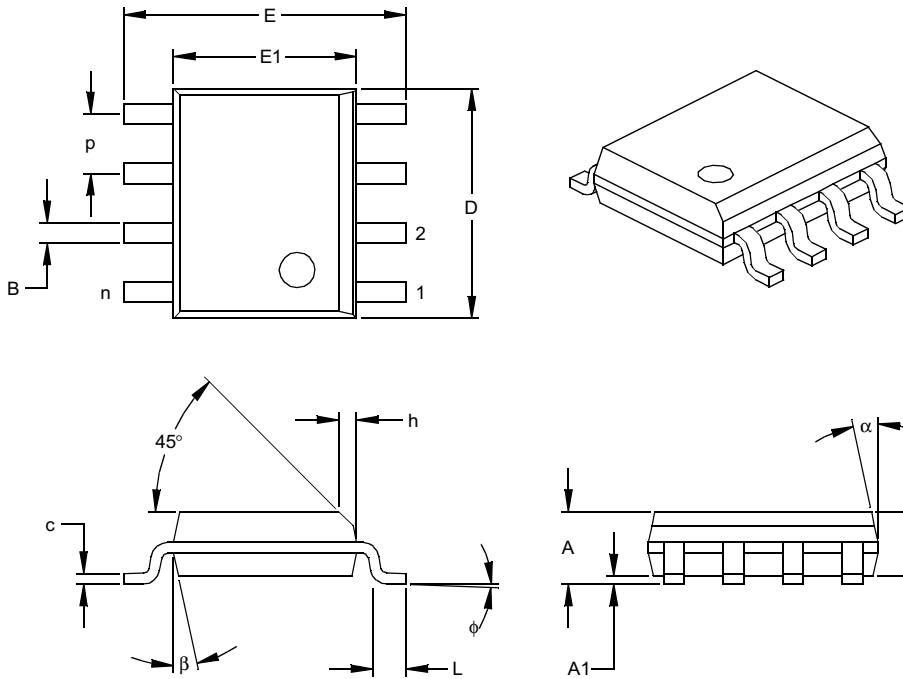
Dimension Limits	Units	INCHES*			MILLIMETERS		
		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		8			8	
Pitch	p		.100			2.54	
Top to Seating Plane	A	.140	.155	.170	3.56	3.94	4.32
Molded Package Thickness	A2	.115	.130	.145	2.92	3.30	3.68
Base to Seating Plane	A1	.015			0.38		
Shoulder to Shoulder Width	E	.300	.313	.325	7.62	7.94	8.26
Molded Package Width	E1	.240	.250	.260	6.10	6.35	6.60
Overall Length	D	.360	.373	.385	9.14	9.46	9.78
Tip to Seating Plane	L	.125	.130	.135	3.18	3.30	3.43
Lead Thickness	c	.008	.012	.015	0.20	0.29	0.38
Upper Lead Width	B1	.045	.058	.070	1.14	1.46	1.78
Lower Lead Width	B	.014	.018	.022	0.36	0.46	0.56
Overall Row Spacing	§ eB	.310	.370	.430	7.87	9.40	10.92
Mold Draft Angle Top	α	5	10	15	5	10	15
Mold Draft Angle Bottom	β	5	10	15	5	10	15

\* Controlling Parameter  
 § Significant Characteristic

Notes:  
 Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.  
 JEDEC Equivalent: MS-001  
 Drawing No. C04-018

# MCP6041/2/3/4

## 8-Lead Plastic Small Outline (SN) – Narrow, 150 mil (SOIC)



Units		INCHES*			MILLIMETERS		
Dimension Limits		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		8			8	
Pitch	p		.050			1.27	
Overall Height	A	.053	.061	.069	1.35	1.55	1.75
Molded Package Thickness	A2	.052	.056	.061	1.32	1.42	1.55
Standoff §	A1	.004	.007	.010	0.10	0.18	0.25
Overall Width	E	.228	.237	.244	5.79	6.02	6.20
Molded Package Width	E1	.146	.154	.157	3.71	3.91	3.99
Overall Length	D	.189	.193	.197	4.80	4.90	5.00
Chamfer Distance	h	.010	.015	.020	0.25	0.38	0.51
Foot Length	L	.019	.025	.030	0.48	0.62	0.76
Foot Angle	φ	0	4	8	0	4	8
Lead Thickness	c	.008	.009	.010	0.20	0.23	0.25
Lead Width	B	.013	.017	.020	0.33	0.42	0.51
Mold Draft Angle Top	α	0	12	15	0	12	15
Mold Draft Angle Bottom	β	0	12	15	0	12	15

\* Controlling Parameter

§ Significant Characteristic

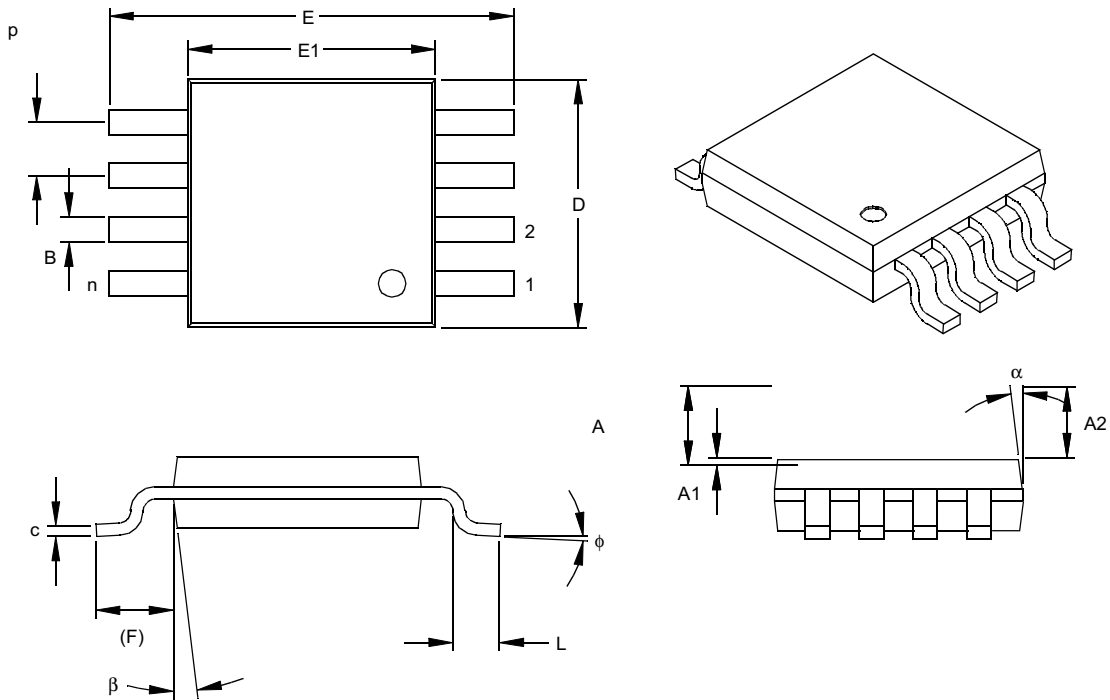
**Notes:**

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

JEDEC Equivalent: MS-012

Drawing No. C04-057

## 8-Lead Plastic Micro Small Outline Package (MS) (MSOP)



Units		INCHES			MILLIMETERS*		
Dimension Limits		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		8				8
Pitch	p	.026			0.65		
Overall Height	A			.044			1.18
Molded Package Thickness	A2	.030	.034	.038	0.76	0.86	0.97
Standoff §	A1	.002		.006	0.05		0.15
Overall Width	E	.184	.193	.200	4.67	4.90	5.08
Molded Package Width	E1	.114	.118	.122	2.90	3.00	3.10
Overall Length	D	.114	.118	.122	2.90	3.00	3.10
Foot Length	L	.016	.022	.028	0.40	0.55	0.70
Footprint (Reference)	F	.035	.037	.039	0.90	0.95	1.00
Foot Angle	φ	0		6	0		6
Lead Thickness	c	.004	.006	.008	0.10	0.15	0.20
Lead Width	B	.010	.012	.016	0.25	0.30	0.40
Mold Draft Angle Top	α		7			7	
Mold Draft Angle Bottom	β		7			7	

\*Controlling Parameter  
 § Significant Characteristic

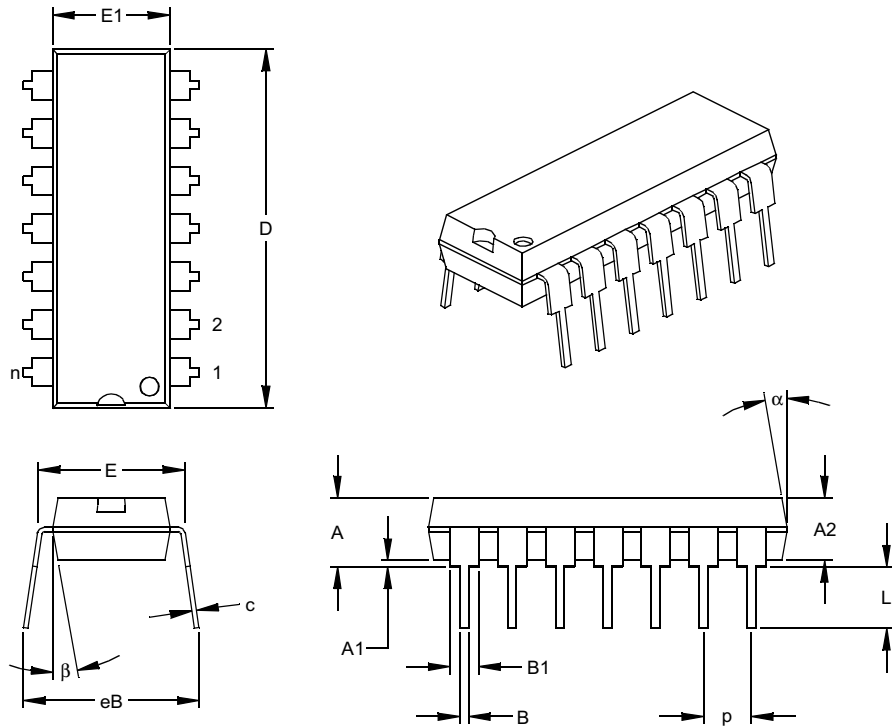
Notes:

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

Drawing No. C04-111

# MCP6041/2/3/4

## 14-Lead Plastic Dual In-line (P) – 300 mil (PDIP)



Dimension Limits	Units	INCHES*			MILLIMETERS		
		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		14			14	
Pitch	p		.100			2.54	
Top to Seating Plane	A	.140	.155	.170	3.56	3.94	4.32
Molded Package Thickness	A2	.115	.130	.145	2.92	3.30	3.68
Base to Seating Plane	A1	.015			0.38		
Shoulder to Shoulder Width	E	.300	.313	.325	7.62	7.94	8.26
Molded Package Width	E1	.240	.250	.260	6.10	6.35	6.60
Overall Length	D	.740	.750	.760	18.80	19.05	19.30
Tip to Seating Plane	L	.125	.130	.135	3.18	3.30	3.43
Lead Thickness	c	.008	.012	.015	0.20	0.29	0.38
Upper Lead Width	B1	.045	.058	.070	1.14	1.46	1.78
Lower Lead Width	B	.014	.018	.022	0.36	0.46	0.56
Overall Row Spacing	§ eB	.310	.370	.430	7.87	9.40	10.92
Mold Draft Angle Top	α	5	10	15	5	10	15
Mold Draft Angle Bottom	β	5	10	15	5	10	15

\* Controlling Parameter

§ Significant Characteristic

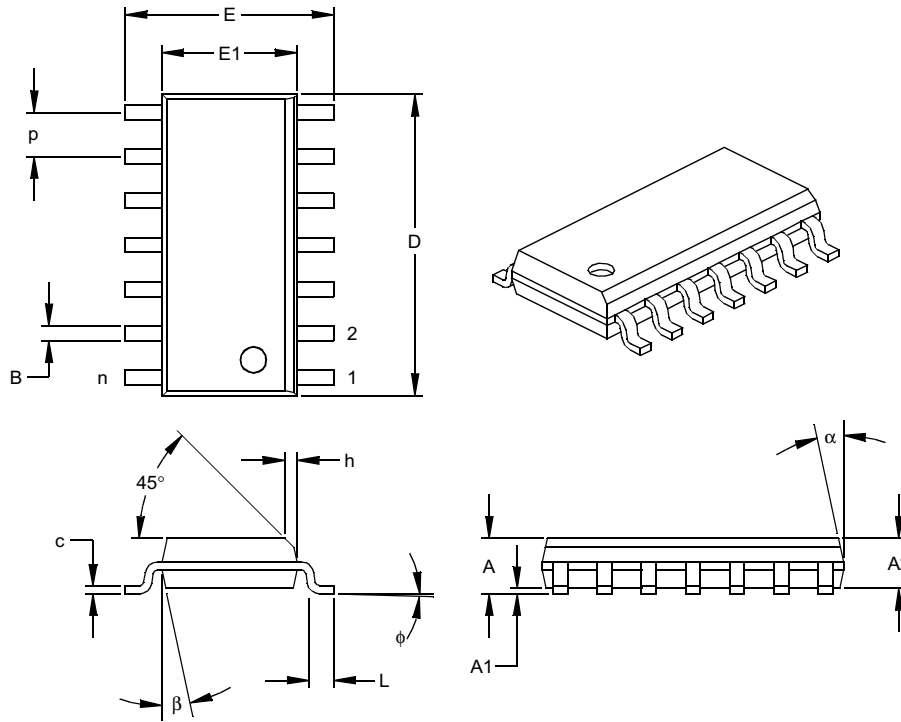
Notes:

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

JEDEC Equivalent: MS-001

Drawing No. C04-005

## 14-Lead Plastic Small Outline (SL) – Narrow, 150 mil (SOIC)



Units		INCHES*			MILLIMETERS		
Dimension Limits		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		14			14	
Pitch	p		.050			1.27	
Overall Height	A	.053	.061	.069	1.35	1.55	1.75
Molded Package Thickness	A2	.052	.056	.061	1.32	1.42	1.55
Standoff §	A1	.004	.007	.010	0.10	0.18	0.25
Overall Width	E	.228	.236	.244	5.79	5.99	6.20
Molded Package Width	E1	.150	.154	.157	3.81	3.90	3.99
Overall Length	D	.337	.342	.347	8.56	8.69	8.81
Chamfer Distance	h	.010	.015	.020	0.25	0.38	0.51
Foot Length	L	.016	.033	.050	0.41	0.84	1.27
Foot Angle	φ	0	4	8	0	4	8
Lead Thickness	c	.008	.009	.010	0.20	0.23	0.25
Lead Width	B	.014	.017	.020	0.36	0.42	0.51
Mold Draft Angle Top	α	0	12	15	0	12	15
Mold Draft Angle Bottom	β	0	12	15	0	12	15

\* Controlling Parameter

§ Significant Characteristic

Notes:

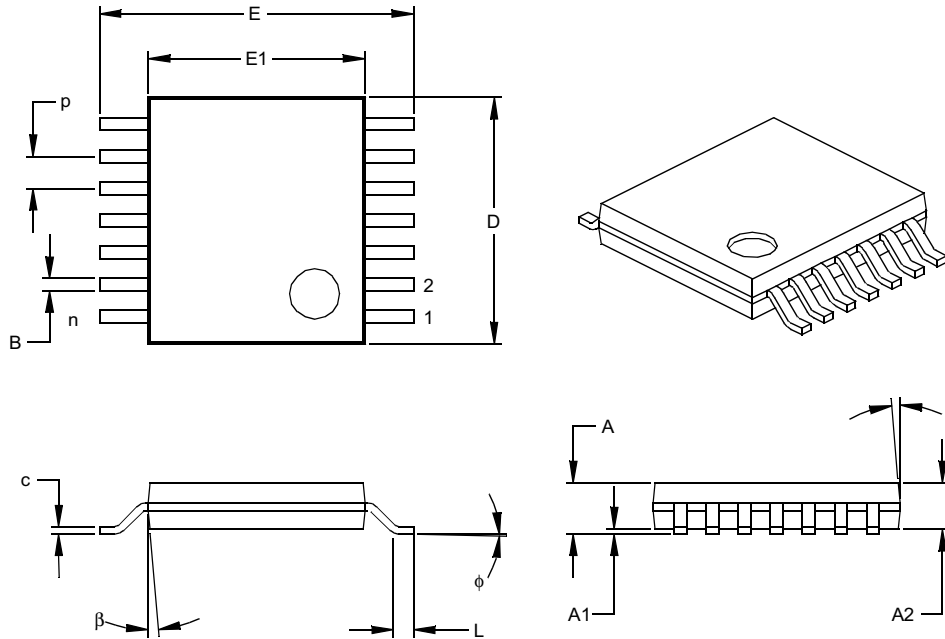
Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

JEDEC Equivalent: MS-012

Drawing No. C04-065

# MCP6041/2/3/4

## 14-Lead Plastic Thin Shrink Small Outline (ST) – 4.4 mm (TSSOP)



Dimension Limits	Units	INCHES			MILLIMETERS*		
		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		14			14	
Pitch	p		.026			0.65	
Overall Height	A			.043			1.10
Molded Package Thickness	A2	.033	.035	.037	0.85	0.90	0.95
Standoff §	A1	.002	.004	.006	0.05	0.10	0.15
Overall Width	E	.246	.251	.256	6.25	6.38	6.50
Molded Package Width	E1	.169	.173	.177	4.30	4.40	4.50
Molded Package Length	D	.193	.197	.201	4.90	5.00	5.10
Foot Length	L	.020	.024	.028	0.50	0.60	0.70
Foot Angle	φ	0	4	8	0	4	8
Lead Thickness	c	.004	.006	.008	0.09	0.15	0.20
Lead Width	B1	.007	.010	.012	0.19	0.25	0.30
Mold Draft Angle Top	α	0	5	10	0	5	10
Mold Draft Angle Bottom	β	0	5	10	0	5	10

\* Controlling Parameter

§ Significant Characteristic

Notes:

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .005" (0.127mm) per side.

JEDEC Equivalent: MO-153

Drawing No. C04-087



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# MCP6041/2/3/4

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Device	Temperature Range	Package
Device:	MCP6041: CMOS Single Op Amp MCP6041T: CMOS Single Op Amp (Tape and Reel for SOIC and MSOP)	
	MCP6042: CMOS Dual Op Amp MCP6042T: CMOS Dual Op Amp (Tape and Reel for SOIC and TSSOP)	
	MCP6043: CMOS Single Op Amp w/CS Function MCP6043T: CMOS Single Op Amp w/CS Function (Tape and Reel for SOIC and MSOP)	
	MCP6044: CMOS Quad Op Amp MCP6044T: CMOS Quad Op Amp (Tape and Reel for SOIC and TSSOP)	
Temperature Range:	I = -40°C to +85°C	
Package:	MS = Plastic MSOP, 8-lead P = Plastic DIP (300 mil Body), 8-lead, 14-lead SN = Plastic SOIC (150 mil Body), 8-lead SL = Plastic SOIC (150 mil Body), 14-lead ST = Plastic TSSOP (4.4mm Body), 14-lead	

**Examples:**

- a) MCP6041-I/P: Industrial temperature, PDIP package.
- b) MCP6042-I/SN: Industrial temperature, SOIC package.
- c) MCP6043-I/MS: Industrial temperature, MSOP package.
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# MCP6041/2/3/4

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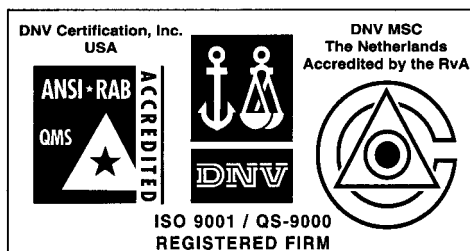
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