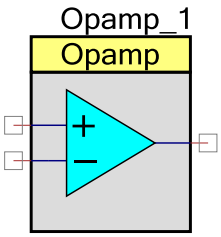
# Operational Amplifier (Opamp)

1.50

## Features




- Follower or Opamp configuration
- Unity gain bandwidth > 3.0 MHz
- Input offset voltage 2.0 mV max
- Rail-to-rail inputs and output
- Output direct low resistance connection to pin
- 25 mA output current
- Programmable power and bandwidth
- Internal connection for follower (saves pin)

## General Description

The Opamp component provides a low voltage, low power operational amplifier and may be internally connected as a voltage follower. The inputs and output may be connected to internal routing nodes, directly to pins, or a combination of internal and external signals. The Opamp is suitable for interfacing with high impedance sensors, buffering the output of voltage DACs, driving up to 25 mA; and constructing active filters in any standard topology.

## Input/Output Connections

This section describes the various input and output connections for the Opamp. An asterisk (*) in the list of I/Os indicates that the I/O may be hidden on the symbol under the conditions listed in the description of that I/O.

### Non-Inverting – Analog

When the Opamp is configured as a follower, this I/O is the voltage input. If the Opamp is configured as an Opamp, this I/O acts as the standard Opamp non-inverting input.

### Inverting – Analog *

When the Opamp component is configured for Opamp mode, this I/O is the normal inverting input. When the Opamp is configured for Follower mode, this I/O is hard-connected to the output and the I/O is unavailable.

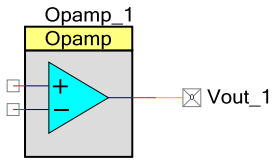
PRELIMINARY

### Vout – Analog

The output is directly connected to a pin. It is capable of driving 25 mA and can be connected to internal loads using the analog routing fabric. When used for internal routing, the output remains connected to the pin.

## Schematic Macro Information

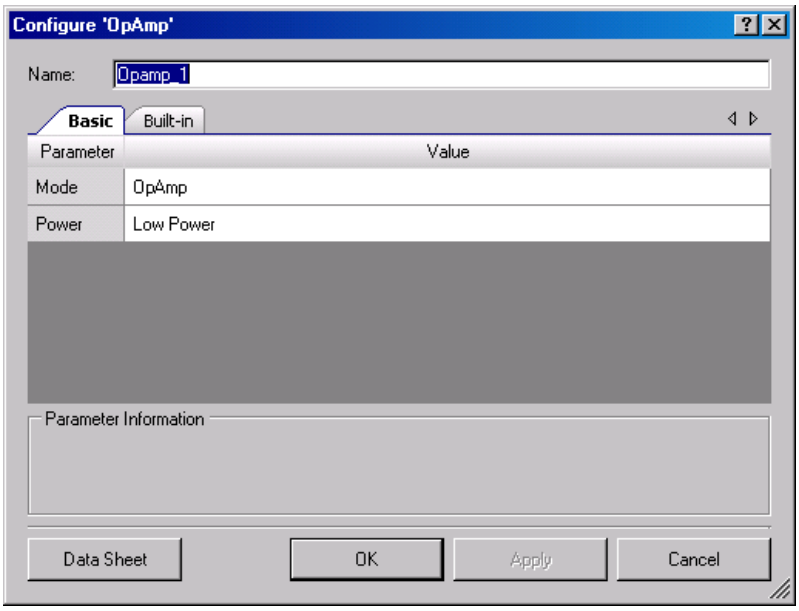
The default Opamp in the Component Catalog is a schematic macro using an Opamp component with default settings. The Opamp component is connected to an analog Pins component named Vout_1.




## Parameters and Setup

Drag an Opamp component onto your design and double-click it to open the Configure dialog.

**Figure 1 Configure Opamp Dialog**

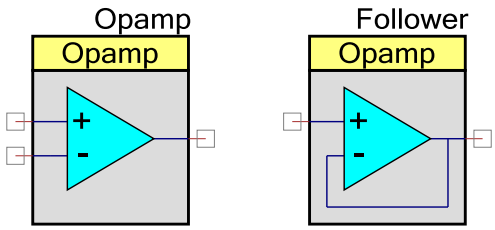



The Opamp has the following parameters:

### Mode

This parameter allows you to select between two configurations: "Opamp" and "Follower". In Opamp mode, all three terminals are available for connection. In Follower mode, the inverting input is internally connected to the output to create a voltage follower. Opamp is the default configuration.

**Figure 2 Configuration Options**




### Power

The Opamp works over a wide range of operating currents. Higher operating current increases Opamp bandwidth. The **Power** parameter allows you to select the power level:

- In High and Medium power modes, the output is a class AB stage, enabling direct drive of substantial output currents.
- In Low power mode, the output is a class A stage with limited current drive.
- In Slow mode, the output is a class A stage.

  The Slow mode is used for low-power transimpedance amplifiers (TIAs). The Slow mode has the same drive capability as low power, but includes additional compensation for circuit topologies with higher than normal input capacitance as is often seen in photo sensors and other current-output sensors of various types.

  Wider bandwidth TIAs can be implemented using the medium or high power settings. In this case, exercise the usual care in dealing with compensation for capacitively loaded sources.

# Placement

Each Opamp is directly connected to specific GPIOs.

| | Non-inverting input | Inverting input | Output |
|---|---|---|---|
| opamp_0 | P0[2] | P0[3] | P0[1] |
| opamp_1 | P3[5] | P3[4] | P3[6] |
| opamp_2 | P0[4] | P0[5] | P0[0] |
| opamp_3 | P3[3] | P3[2] | P3[7] |

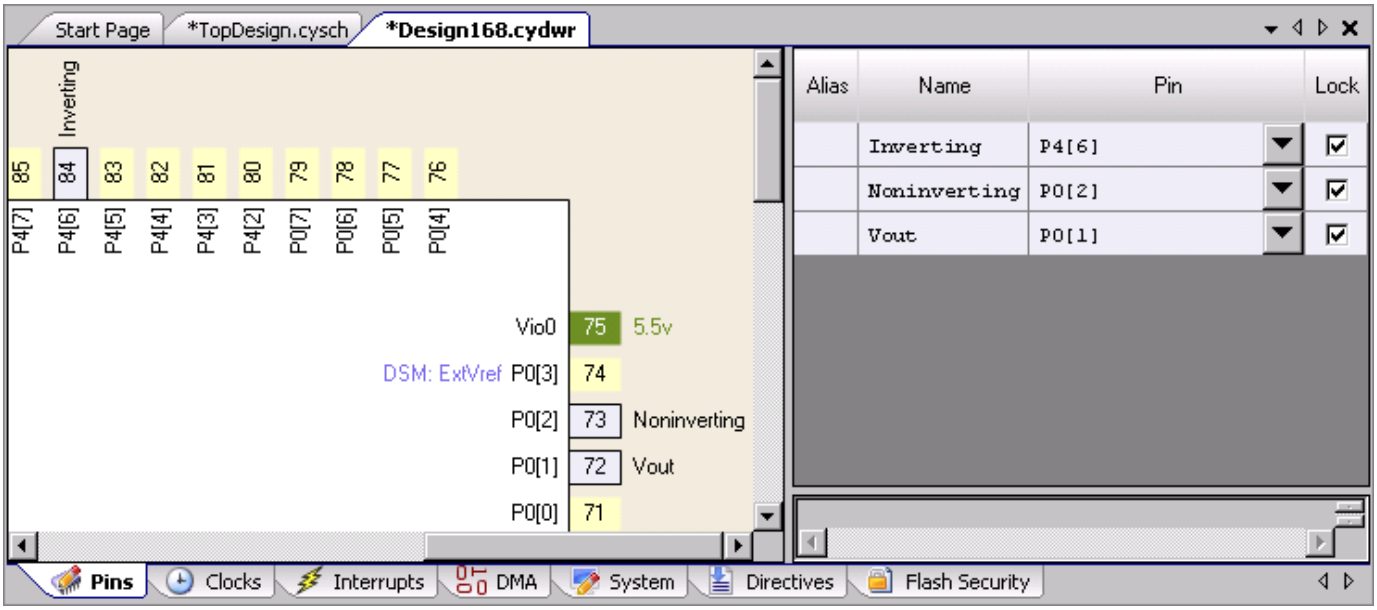
Refer to the device data sheet for the part being used for the specific physical pin connections.

Input signals may use the analog global routing buses in addition to the dedicated input pins. Using the direct connections utilizes fewer internal routing resources and results in lower route resistance and capacitance. The output pin associated with each specific location will always be driven by the Opamp, when enabled.

Ports P0[3] and P3[2] are also used for connection to a capacitor for bypassing the bandgap reference supplied to the ADC, for a reference output, or for an input from an external reference. When these reference connections are used, routing to the Opamp inverting inputs must be done through the analog global routing buses.

The following shows one example of how the Opamp may be connected using the Design-Wide Resources Pin Editor.

**Figure 3 Example placement**




# Resources

The Opamp component uses one Opamp resource per instance. When used in the Opamp mode with external components (that is, not routing the output through the analog globals), no routing resources are used.

# Application Programming Interface

Application Programming Interface (API) routines allow you to configure the component using software. The following table lists and describes the interface to each function. The subsequent sections cover each function in more detail.

By default, PSoC Creator assigns the instance name "Opamp_1" to the first instance of a component in a given design. You can rename it to any unique value that follows the syntactic rules for identifiers. The instance name becomes the prefix of every global function name, variable, and constant symbol. For readability, the instance name used in the following table is "Opamp".

| Function | Description |
|---|---|
| void Opamp_Init(void) | Initializes or restores default Opamp configuration. |
| void Opamp_Enable(void) | Enables the Opamp. |
| void Opamp_Start(void) | Turns on the Opamp and sets the power level to the value chosen during the parameter selection. |
| void Opamp_Stop(void) | Disable Opamp (power down) |
| void Opamp_SetPower(uint8 power) | Set the power level. |
| void Opamp_Sleep(void) | Stops and saves the user configuration. |
| void Opamp_Wakeup(void) | Restores and enables the user configuration. |
| void Opamp_SaveConfig(void) | Empty function. Provided for future usage. |
| void Opamp_RestoreConfig(void) | Empty function. Provided for future usage. |

## Global Variables

| Variable | Description |
|---|---|
| Opamp_initVar | Indicates whether the Opamp has been initialized. The variable is initialized to 0 and set to 1 the first time Opamp_Start() is called. This allows the component to restart without reinitialization after the first call to the Opamp_Start() routine.<br>If reinitialization of the component is required, then the Opamp_Init() function can be called before the Opamp_Start() or Opamp_Enable() function. |

## void Opamp_Init(void)

**Description:** Initializes or restores default Opamp configuration.

**Parameters:** None

**Return Value:** None

**Side Effects:** All registers will be reset to their initial values. This will reinitialize the component.

## void Opamp_Enable(void)

**Description:** Enables the Opamp.

**Parameters:** None

**Return Value:** None

**Side Effects:** None

## void Opamp_Start(void)

**Description:** Turns on the Opamp and sets the power level to the value chosen during the parameter selection.

**Parameters:** None

**Return Value:** None

**Side Effects:** None

## void Opamp_Stop(void)

**Description:** Turn off the Opamp and enable its lowest power state.

**Parameters:** None

**Return Value:** None

**Side Effects:** None

## void Opamp_SetPower(uint8 power)

**Description:** Sets the power level.

**Parameters:** (uint8) power: Sets the power level to one of four settings, Slow, Low, Medium, or High.

| Power Setting | Notes |
|---|---|
| Opamp_SLOWPOWER | Least power, compensated for TIA. |
| Opamp_LOWPOWER | Least power, reduced bandwidth |
| Opamp_MEDPOWER | |
| Opamp_HIGHPOWER | Highest bandwidth |

**Return Value:** None

**Side Effects:** None

## void Opamp_Sleep(void)

**Description:** Stops the component operation. Saves the configuration registers and the component enable state. Should be called just prior to entering sleep.

**Parameters:** None

**Return Value:** None

**Side Effects:** None

## void Opamp_Wakeup(void)

**Description:** Restores the component enable state and configuration registers. Should be called just after awaking from sleep.

**Parameters:** None

**Return Value:** None

**Side Effects:** None

## void Opamp_SaveConfig(void)

**Description:** Empty function. Provided for future usage.

**Parameters:** None

**Return Value:** None

**Side Effects:** None

## void Opamp_RestoreConfig(void)

**Description:** Empty function. Provided for future usage.

**Parameters:** None

**Return Value:** None

**Side Effects:** None

# Sample Firmware Source Code

The following is a C language example demonstrating the basic functionality of the Opamp component. This example assumes the component has been placed in a design with the default name "Opamp_1."

**Note** If you rename your component you must also edit the example code as appropriate to match the component name you specify.

```
#include <device.h>

void main()
{
    Opamp_1_Start();

}
```

# DC and AC Electrical Characteristics

The following values are based on characterization data. Specifications are valid for -40° C ≤ $T_A$ ≤ 85° C and $T_J$ ≤ 100° C except where noted. Unless otherwise specified in the tables below, all Typical values are for $T_A$ = 25° C, Vdda = 5.0 V, Power = High, output referenced to analog ground, Vssa.

## 5.0 V/3.3 V DC Electrical Characteristics

| Parameter | Description | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| Vos | Input Offset Voltage | Vdda=3.3 V, 25 C, P=Slow | na | 0.5 | 2 | mV |
| | | Vdda=3.3 V, 25 C, P=Low | na | 0.5 | 2 | mV |
| | | Vdda=3.3 V, 25 C, P=Med | na | 0.5 | 2 | mV |
| | | Vdda=3.3 V, 25 C, P=High | na | 0.5 | 2 | mV |
| TCVos | Temp. coeff. input offset voltage, absolute value | P=Slow | na | tbc | tbc | uV/°C |
| | | P=Low | na | tbc | tbc | uV/°C |
| | | P=Med | na | tbc | tbc | uV/°C |
| | | P=High | na | tbc | tbc | uV/°C |
| $A_{VOL}$ | Open Loop Gain | P=Slow, Cload=15pF | tbc | tbc | na | dB |
| | | P=Low, Cload=15pF | tbc | tbc | na | dB |
| | | P=Med, Cload=15pF | tbc | tbc | na | dB |
| | | P=High, Cload=15pF | tbc | tbc | na | dB |

| Parameter | Description | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| Rin | Input resistance | Positive gain, non-inverting input | | tbc | tbc | Megohms |
| Cin | Input capacitance | Not including routing capacitance | na | tbc | tbc | pF |
| Vi | Input voltage range | | Vssa | - | Vdda | mV |
| Vo | Output voltage range | Output load = 1 mA | Vssa + 50 | - | Vdda - 50 | mV |
| Rout | Open loop output impedance | | na | tbd | na | ohms |
| Iout | Output current | Output voltage between Vssa +500 mV and Vdda -500 mV, and Vdda > 2.7 V | 25 | na | na | mA |
| Iout | Output current | Output voltage between Vssa +500 mV and Vdda -500 mV, and Vdda > 1.7 V and Vdda < 2.7 V | 16 | na | na | mA |
| IoutSCsrc | Short circuit current, source | | | | | |
| IoutSCsink | Short circuit current, sink | | | | | |
| Vout_range | Output swing | Gain = 1, Rload = 100k to Vdda/2 | tbc | tbc | tbc | |
| Ge1 | Gain accuracy, in unity gain buffer mode | G=1, Vdda=5.0 V, P=High, Rload = 1 kohm | tbc | tbc | tbc | % |
| CMRR | Common mode rejection ratio | Vincm=0.5 V to Vdda-0.5 V | 70 | - | - | dB |
| PSRR | Power supply rejection ratio | Gain=1, measured as shift in offset voltage at DC | tbc | tbc | | dB |
| Idda | Operating current | Vdda=1.71 V, P=Low | na | tbc | tbc | uA |
| | | Vdda=5.0 V, P=High | na | tbc | tbc | uA |

## Figures

| | |
|---|---|
| Histogram offset voltage 100 parts, 4 per part<br>Power=High<br>X axis mV<br>Y axis % in bins | Voffset vs temperature, Vdda=5.0V<br>Power=High<br>X axis: temp -40 to 85 C<br>Y axis Voffset 1 max<br>2 typ<br>3 min |

| | |
|---|---|
| Voffset vs VCM at Temperature, Power=High<br>X axis: temp -40 to 85 C<br>Y axis V common morde<br>1 -40C<br>2 25C<br>3 85C | |
| Operating current vs voltage, P=Slow<br>X axis Vdda, 1.7, 2.7, 3.3, 5.0<br>Y axis Op current uA<br>1 max at worst temp<br>2 typ at 25C | Operating current vs voltage, P=Low<br>X axis Vdda, 1.7, 2.7, 3.3, 5.0<br>Y axis Op current uA<br>1 max at worst temp<br>2 typ at 25C |
| Operating current vs voltage, P=Med<br>X axis Vdda, 1.7, 2.7, 3.3, 5.0<br>Y axis Op current uA<br>1 max at worst temp<br>2 typ at 25C | Operating current vs voltage, P=High<br>X axis Vdda, 1.7, 2.7, 3.3, 5.0<br>Y axis Op current uA<br>1 max at worst temp<br>2 typ at 25C |
| Operating current vs temp, P=Slow<br>X axis Temp, -40 to +85C<br>Y axis op current uA<br>1 Typ at 2.7V<br>2 Max at 2.7V<br>3 Typ at 5.5V<br>4 Max at 5.5V | Operating current vs temp, P=Low<br>X axis Temp, -40 to +85C<br>Y axis op current uA<br>1 Typ at 2.7V<br>2 Max at 2.7V<br>3 Typ at 5.5V<br>4 Max at 5.5V |
| Operating current vs temp, P=Med<br>X axis Temp, -40 to +85C<br>Y axis op current uA<br>1 Typ at 2.7V<br>2 Max at 2.7V<br>3 Typ at 5.5V<br>4 Max at 5.5V | Operating current vs temp, P=High<br>X axis Temp, -40 to +85C<br>Y axis op current uA<br>1 Typ at 2.7V<br>2 Max at 2.7V<br>3 Typ at 5.5V<br>4 Max at 5.5V |
| Output voltage vs load current,<br>Vdda=2.7V, P=Slow<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 | Output voltage vs load current,<br>Vdda=2.7V, P=Low<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 |
| Output voltage vs load current,<br>Vdda=2.7V, P=Med<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 | Output voltage vs load current,<br>Vdda=2.7V, P=High<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 |

| | |
|---|---|
| Output voltage vs load current,<br>Vdda=5.0V, P=Slow<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 | Output voltage vs load current,<br>Vdda=5.0V, P=Low<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 |
| Output voltage vs load current,<br>Vdda=5.0V, P=Med<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 | Output voltage vs load current,<br>Vdda=5.0V, P=High<br>X axis output current uA<br>Y axis output voltage<br>1 Vdda-Voh at -40<br>2 Vdda-Voh at 25<br>3 Vdda-Voh at 85<br>4 Vol at -40<br>5 Vol at 25<br>6 Vol at 85 |

## 5.0 V/3.3 V AC Electrical Characteristics

| Parameter | Description | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| GBW_L | Gain Bandwidth Product, P=Low | Gain=1, Vdda=2.7 V, 25 C | tbc | tbc | na | MHz |
| GBW_M | Gain Bandwidth Product, P=Med | Gain=1, Vdda=5.0 V, 25 C | tbc | tbc | na | MHz |
| GBW_H | Gain Bandwidth Product, P=High | Gain=1, Vdda=5.0 V, 25 C | tbc | tbc | na | MHz |
| SR_PSlow | Slew rate, 2 V step | P=Slow, Cload=15pF, Rload=100k | tbc | tbc | na | V/us |
| SR_PLow | | P=Low, Cload=15pF, Rload=100k | tbc | tbc | na | V/us |
| SR_PMed | | P=Med, Cload=15pF, Rload=100k | tbc | tbc | na | V/us |
| SR_PHigh | | P=High, Cload=15pF, Rload=100k | tbc | tbc | na | V/us |
| SR_PHigh200 | | P=High, Cload=200pF, Rload=2k | tbc | tbc | na | V/us |
| Tsettle_PSlow | Settling time to 0.1% | 1.0V step, CLoad= 15pF<br>Vdda= 5.0 V, G=1, P=Slow | na | tbc | tbc | nsec |
| Tsettle_PLow | | 1.0V step, CLoad= 15pF<br>Vdda= 5.0 V, G=1, P=Low | na | tbc | tbc | nsec |
| Tsettle_PMed | | 1.0V step, CLoad= 15pF<br>Vdda= 5.0 V, G=1, P=Med | na | tbc | tbc | nsec |
| Tsettle_PHigh | | 1.0V step, CLoad= 200pF<br>Vdda= 5.0 V, G=1, P=High | na | tbc | tbc | nsec |

| | | | | | | |
|---|---|---|---|---|---|---|
| Vn_PSlow | Input referred voltage noise | f=10 kHz, P=TIA | na | tbc | na | nV/rtHz |
| Vn_Plow | | f=10 kHz, P=Low | na | tbc | na | nV/rtHz |
| Vn_Pmed | | f=10 kHz, P=Med | na | tbc | na | nV/rtHz |
| Vn_Phigh | | f=10 kHz, P=High | na | tbc | na | nV/rtHz |
| $\Phi_M$ | Phase Margin | At unity gain, CLoad= 15pF, P=Low | tbc | tbc | na | deg |
| $\Phi_M$ | | At unity gain, CLoad= 200pF, P=High | tbc | tbc | na | deg |

## Figures

| | |
|---|---|
| Open Loop Frequency Response, 3.3V, CL=15pF, P=Slow<br>X axis 10 kHz to 10 MHz<br>Y1(left) axis Gain, dB<br>Y2(right)axis Phase, degrees<br>1 Gain, T=-40<br>2 Gain, T=25<br>3 Gain, T=85<br>4 Phase, T=-40<br>5 Phase, T=25<br>6 Phase, T=85 | Open Loop Frequency Response, 3.3V, CL=15pF, P=Low<br>X axis 10 kHz to 10 MHz<br>Y1(left) axis Gain, dB<br>Y2(right)axis Phase, degrees<br>1 Gain, T=-40<br>2 Gain, T=25<br>3 Gain, T=85<br>4 Phase, T=-40<br>5 Phase, T=25<br>6 Phase, T=85 |
| Open Loop Frequency Response, 3.3V, CL=15pF, P=Med<br>X axis 10 kHz to 10 MHz<br>Y1(left) axis Gain, dB<br>Y2(right)axis Phase, degrees<br>1 Gain, T=-40<br>2 Gain, T=25<br>3 Gain, T=85<br>4 Phase, T=-40<br>5 Phase, T=25<br>6 Phase, T=85 | Open Loop Frequency Response, 3.3V, CL=15pF, P=High<br>X axis 10 kHz to 10 MHz<br>Y1(left) axis Gain, dB<br>Y2(right)axis Phase, degrees<br>1 Gain, T=-40<br>2 Gain, T=25<br>3 Gain, T=85<br>4 Phase, T=-40<br>5 Phase, T=25<br>6 Phase, T=85 |
| Closed Loop Gain vs freq, Gain=1, 3.3V, T=25C<br>X axis 10 kHz to 10 MHz<br>Y axis Gain, dB<br>1 P=Low, CL=15pF<br>2 P=Med, CL=15pF<br>3 P=High, CL=200pF<br>4 P=High CL=15pF | Closed Loop Gain vs freq, Gain=10, 3.3V, T-25C<br>X axis 10 kHz to 10 MHz<br>Y axis Gain, dB<br>1 P=Low, CL=15pF<br>2 P=Med, CL=15pF<br>3 P=High, CL=200pF<br>4 P=High CL=15pF |
| Large Signal Step Response, 2V step,<br>G=1, CL=15pF, RL=100k, Vdda=5V, P=low<br>X axis 1 usec/div10 kHz to 10 MHz<br>Y axis 500 mV/div | Large Signal Step Response, 2V step,<br>G=1, CL=15pF, RL=100k, Vdda=5V, P=med<br>X axis 1 usec/div10 kHz to 10 MHz<br>Y axis 500 mV/div |
| Large Signal Step Response, 2V step,<br>G=1, CL=15pF, RL=100k, Vdda=5V, P=high<br>X axis 1 usec/div10 kHz to 10 MHz<br>Y axis 500 mV/div | CMRR vs freq, Vdda = 5.0V, P=high<br>X axis freq 100 Hz to 1.0 MHz<br>Y axis dB |

| | |
|---|---|
| PSRR vs freq, Vdda = 5.0V, P=high<br>X axis freq 100 Hz to 1.0 MHz<br>Y axis dB | Voltage noise, Vdda = 5.0V, P=high<br>Xaxis freq kHz .01 to 1000 kHz<br>Yaxis voltage noise nV/rtHz |

**Note** More specifications at other voltages and graphs may be added after characterization.

# Component Changes

This section lists the major changes in the component from the previous version.

| Version | Description of Changes | Reason for Changes / Impact |
|---|---|---|
| 1.50.b | Minor datasheet edit. | |
| 1.50.a | Minor datasheet edit. | |
| 1.50 | Added Sleep/Wakeup and Init/Enable APIs. | To support low power modes, as well as to provide common interfaces to separate control of initialization and enabling of most components. |

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