# VSOA204x Series Operational Amplifiers

## 1 Introduction

The VSOA204x family of single-, dual-, and quad-channel amplifiers features a maximized ratio of gain bandwidth (GBW) to supply current and is ideal for battery-powered applications such as portable instrumentations, portable medical equipments, wearable fitness devices, and wireless remote sensors. Featuring rail-to-rail input and output swings, 15 kHz bandwidth of combined with ultra-low supply current (typical 600 nA at 5.0 V per amplifier) and low noise (6.3 $\mu V_{PP}$ at 0.1 to 10 Hz), the VSOA204x family is an excellent choice for precision, cost-optimized, “Always ON” sensing applications.

The robust design of the VSOA204x amplifiers provides ease-of-use to the circuit designer: integrated RF/EMI rejection filter, no phase reversal in overdrive conditions, and high electro-static discharge (ESD) protection (3kV HBM). The VSOA204x amplifiers are optimized for operation at voltages as low as +1.7 V (±0.85 V) and up to+5.5 V (±2.75 V) over the extended temperature range of -40°C to +85°C.

The VSOA2041 (single) is available in SOT23-5L packages. The VSOA2042 (dual) is offered in SOP8, and MSOP8 packages. The quad of VSOA2044 is offered in SOP14 and TSSOP14 packages.

## 2 Features

- Ultra-Low Power Preserves Battery Life
  - 600 nA Supply Current (Typically at 5 V) Per Amplifier
- Single 1.7 V to 5.5 V Supply Voltage Range
  - Can be Powered From the Same 1.8V/2.5V/3.3V/5V System Rails
- 15 kHz GBW
- Low Input Offset Voltage: 0.6 mV
- Low Noise: 6.3 $\mu V_{PP}$ at 0.1 to 10 Hz
- 1 pA Input Bias Current
- Rail-to-Rail Input and Output
- Extended Temperature Range:
  - −40°C to +85°C

## 3 Applications

- Battery-Powered Instruments:
  - Consumer, Industrial, Medical, Notebooks
- Wearable Fitness Devices
- Wireless Sensors:
  - Home Security, Remote Sensing, Wireless Metering
- Sensor Signal Conditioning:
  - Sensor Interfaces, Loop-Powered, Active Filters

## 4 Available Packages

| PART NUMBER | PACKAGE |
|---|---|
| VSOA2041-M5N | SOT-23-5L |
| 2042-PAN | SOP8 |
| VSOA2042-PDN | MSOP8 |
| VSOA2044-PHN | SOP14 |
| VSOA2044-PIN | TSSOP14 |

# 7 Specifications

## 7.1 Absolute Maximum Ratings

**(over operating ambient temperature range, unless otherwise specified)(1)**

| CHARACTERISTIC | | SYMBOL | VALUE | UNIT |
|---|---|---|---|---|
| Supply voltage[($V_+$) - ($V_-$)] | | $V_S$ | 10 | V |
| Signal input pins | Voltage(2) | | (V-)-0.5V ~ (V+)+0.5V | V |
| | Current(2) | | ±10 | mA |
| Output short-circuit | | $T_{sc}$ | Continuous(3) | mA |
| Maximum junction temperature | | $T_{J\ MAX}$ | 150 | °C |
| Storage temperature | | $T_{stg}$ | -65 ~ 150 | °C |
| Soldering temperature & time | | $T_{solder}$ | 260°C, 10s | - |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum rated conditions for extended periods may affect device reliability.

(2) Input pins are diode-clamped to the power-supply rails. Current limit input signals that can swing more than 0.5V beyond the supply rails to 10mA or less.

(3) Short circuits from outputs to $V_S$ can cause excessive heating and eventual destruction. A heat sink may be required to keep the junction temperature below the absolute maximum. This depends on the power supply voltage and how many amplifiers are shorted. Thermal resistance varies with the amount of PC board metal connected to the package. The specified values are for short traces connected to the leads.

## 7.2 Recommend Operating Conditions

**(over operating ambient temperature range, unless otherwise specified)**

| PARAMETER | | SYMBOL | MIN. | NOM. | MAX. | UNIT |
|---|---|---|---|---|---|---|
| Power supply range | $T_A$ = -40 ~ 85℃ | $V_S$ | 1.7 | - | 5.5 | V |
| Operating ambient temperature | | $T_A$ | -40 | - | 85 | °C |

# 7 Specifications

## 7.3 ESD Ratings

| ESD RATINGS | | VALUE | UNIT |
|---|---|---|---|
| Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(4) | 3000 | V |
| | Charged-device model (CDM), per JEDEC specification JESD22-C101(5) | 2000 | |

(4) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.
(5) JEDEC document JEP157 states that 250V CDM allows safe manufacturing with a standard ESD control process.

## 7.4 Thermal Information

| THERMAL METRIC(6) | SYMBOL | VSOA156x Series | | UNIT |
|---|---|---|---|---|
| Junction-to-ambient thermal resistance | $R_{\Theta JA}$ | **SOT-23-5L** | **SOP8** | °C/W |
| | | 192.3 | 125.0 | |
| | | **MSOP8** | **SOP14** | |
| | | 201.6 | 115.7 | |
| | | **TSSOP14** | **-** | |
| | | 119.0 | - | |
| Reference maximum power dissipation for continuous operation | $P_{D\ Ref}$ | **SOT-23-5L** | **SOP8** | W |
| | | 0.65 | 1.00 | |
| | | **MSOP8** | **SOP14** | |
| | | 0.62 | 1.08 | |
| | | **TSSOP14** | **-** | |
| | | 1.05 | - | |

(6) $T_A$ = 25°C, measured on evaluation board with 1oz. copper traces of minimum pad size, all device outputs were active.

# 7 Specifications

## 7.5 Electrical Characteristics

**($V_S$ = 5.0V, $T_A$ = +25°C, $V_{CM}$ = $V_S$ /2, $V_O$ = $V_S$ /2, and $R_L$ = 10kΩ connected to $V_S$ /2, unless otherwise noted. Boldface limits apply over the specified temperature range, $T_A$= -40 to +85 °C.**

| CHARACTERISTIC | SYMBOL | TEST CONDITIONS | MIN. | TYP. | MAX. | UNIT |
|---|---|---|---|---|---|---|
| OFFSET VOLTAGE | | | | | | |
| Input offset voltage | $V_{OS}$ | - | - | ±0.6 | ±3.0 | mV |
| Offset voltage drift | $V_{OS}$ TC | $T_A$ = −40 to +125 °C | - | ±1 | ±3 | nV/°C |
| Power supply rejection ratio | PSRR | $V_S$ = 1.7 to 5.5 V, $V_{CM}$ < (V+) − 2V | 76 | 92 | - | dB |
| | | $T_A$ = −40 to +125 ℃ | 72 | - | - | |
| INPUT BIAS CURRENT | | | | | | |
| Input bias current | $I_B$ | - | - | 1 | - | pA |
| | | $T_A$ = +85 °C | - | 150 | - | |
| Input offset current | $I_{OS}$ | - | - | 5 | - | pA |
| NOISE | | | | | | |
| Input voltage noise | $V_n$ | f = 0.1 to 10 Hz | - | 6.3 | - | $\mu V_{PP}$ |
| Input voltage noise density | $e_n$ | f = 1 kHz | - | 177 | - | nV/√Hz |
| | | f = 100 Hz | - | 184 | - | |
| Input current noise density | $I_n$ | f = 1 kHz | - | 10 | - | fA/√Hz |
| INPUT VOLTAGE | | | | | | |
| Common-mode voltage range | $V_{CM}$ | - | (V-) − 0.1 | - | (V+) + 0.1 | V |
| | | $T_A$ = −40 to +85 ℃ | (V-) | - | (V+) +0.1 | |
| Common-mode rejection ratio | CMRR | $V_S$ = 5.5 V, $V_{CM}$ = −0.1 to 5.5 V | 67 | 84 | - | dB |
| | | $V_{CM}$ = 0 to 5.3 V, $T_A$ = −40 to +85℃ | 64 | - | - | |
| | | $V_S$ = 1.8 V, $V_{CM}$ = −0.1 to 1.8 V | 65 | 79 | - | |
| | | $V_{CM}$ = 0 to 1.6 V, $T_A$ = −40 to +85℃ | 62 | - | - | |
| INPUT IMPEDANCE | | | | | | |
| Input resistance | $R_{IN}$ | - | 100 | - | - | GΩ |
| Input capacitance | $C_{IN}$ | Differential | - | 2.0 | - | pF |
| | | Common mode | - | 3.5 | - | |
| OPEN-LOOP GAIN | | | | | | |
| Open-loop voltage gain | $A_{VOL}$ | $R_L$ = 50 kΩ, $V_O$ = 0.05 to 3.5 V | 80 | 97 | - | dB |
| | | $T_A$ = −40 to +85 ℃ | 75 | - | - | |
| | | $R_L$ = 5 kΩ, $V_O$ = 0.15 to 3.5 V | 68 | 82 | - | |
| | | $T_A$ = −40 to +85 ℃ | 64 | - | - | |
| FREQUENCY RESPONSE | | | | | | |
| Gain bandwidth product | GBW | - | - | 15 | - | kHz |
| Slew rate | SR | G = +1, $C_L$ = 50 pF, $V_O$ = 1.5 to 3.5 V | - | 6 | - | V/ms |

# 7 Specifications

## 7.5 Electrical Characteristics (conitnued)

**($V_S$ = 5.0V, $T_A$ = +25°C, $V_{CM}$ = $V_S$ /2, $V_O$ = $V_S$ /2, and $R_L$ = 10kΩ connected to $V_S$ /2, unless otherwise noted. Boldface limits apply over the specified temperature range, $T_A$ = -40 to +85 °C.**

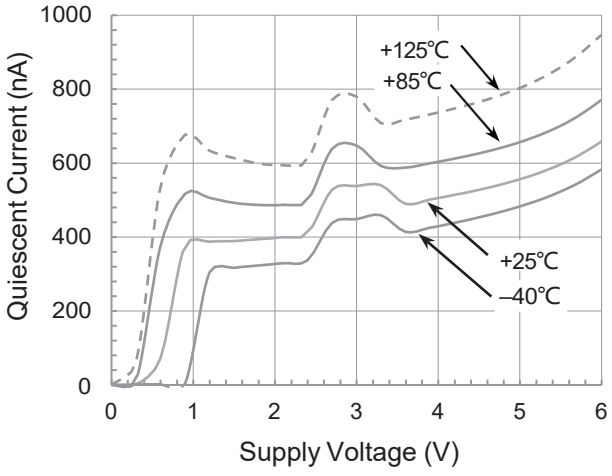
| CHARACTERISTIC | SYMBOL | TEST CONDITIONS | MIN. | TYP. | MAX. | UNIT |
|---|---|---|---|---|---|---|
| **OUTPUT** | | | | | | |
| High output voltage swing | $V_{OH}$ | $R_L$ = 50 kΩ | (V+) –7 | (V+) –4 | - | mV |
| | | $R_L$ = 5 kΩ | (V+) –65 | (V+) –40 | - | |
| Low output voltage swing | $V_{OL}$ | $R_L$ = 50 kΩ | - | (V-) +3 | (V-) +5 | mV |
| | | $R_L$ = 5 kΩ | - | (V-) +27 | (V-) +42 | |
| Short-circuit current | $I_{SC}$ | Source current through 10Ω | 20 | 27 | - | mA |
| | | Sink current through 10Ω | - | -33 | -25 | |
| **POWER SUPPLY** | | | | | | |
| Operating supply voltage | $V_S$ | $T_A$ = -40 to +85 ℃ | 1.7 | - | 5.5 | V |
| Quiescent current (per amplifier) | $I_Q$ | $V_S$ = 1.8 V, $T_A$ = +25 ℃ | - | 450 | 650 | μA |
| | | $V_S$ = 5.0 V, $T_A$ = +25 ℃ | - | 600 | 880 | |

# 7 Specifications

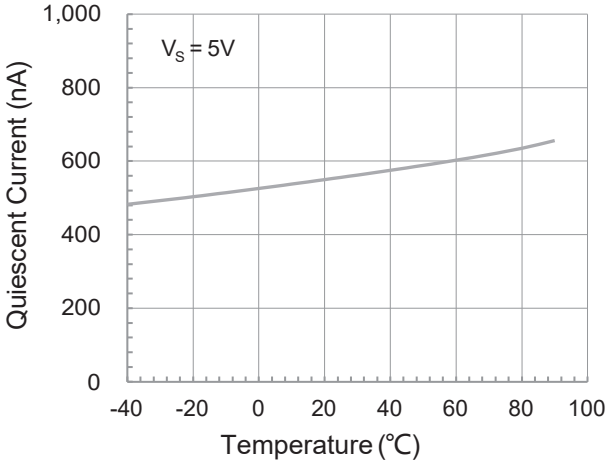
## 7.6 Typical Characteristics

**At $T_A$ = +25℃, $V_{CM}$ = $V_S$ /2, and $R_L$ = 10kΩ connected to $V_S$ /2, unless otherwise noted.**

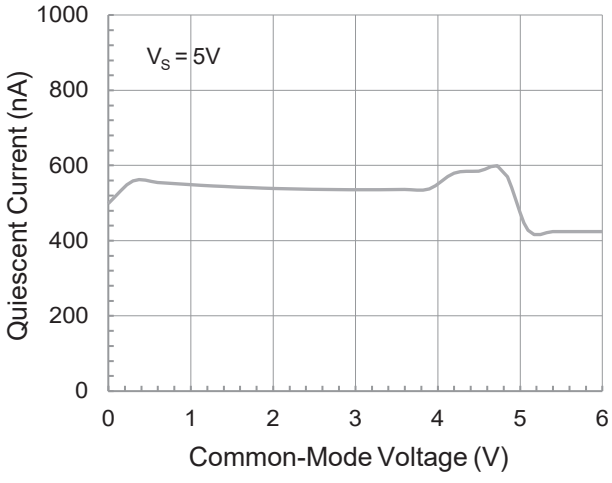
**Quiescent Current vs. Supply Voltage**



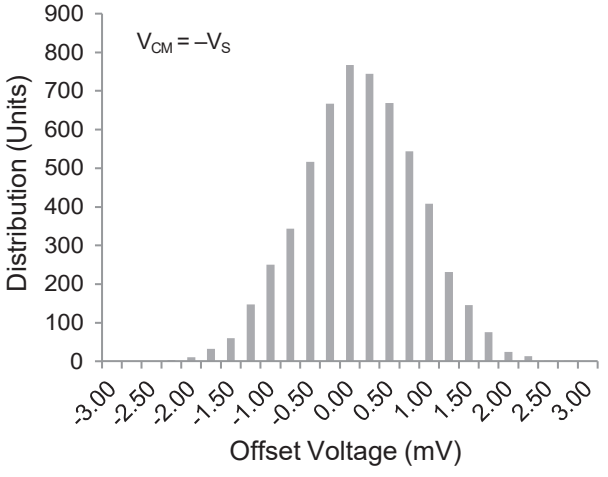

**Quiescent Current vs. Temperature**



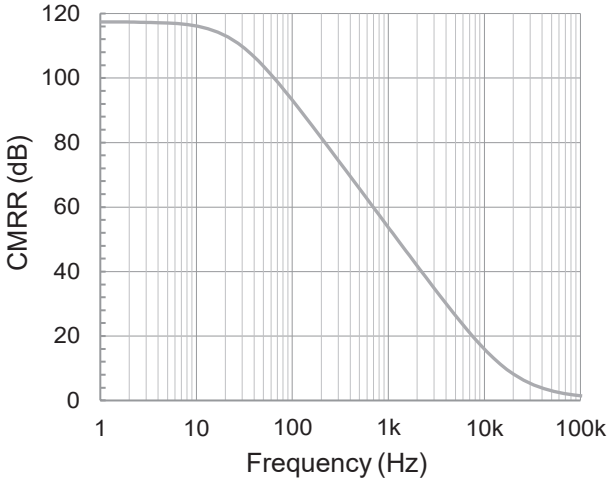

**Quiescent Current vs. Input Common-Mode Voltage**



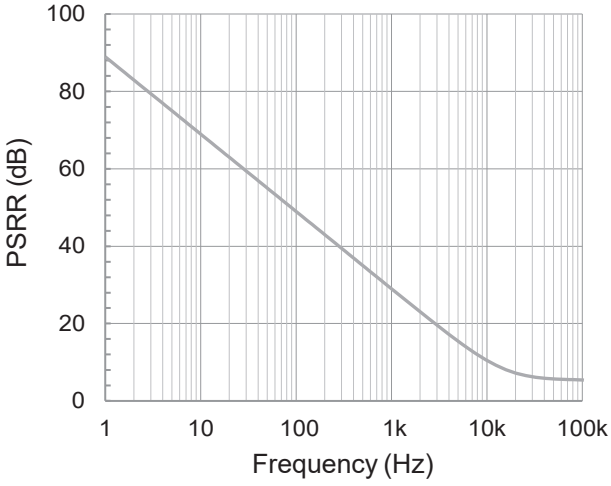

**Offset Voltage Production Distribution**




**Common-mode Rejection Ratio vs. Frequency**




**Power Supply Rejection Ratio vs. Frequency**

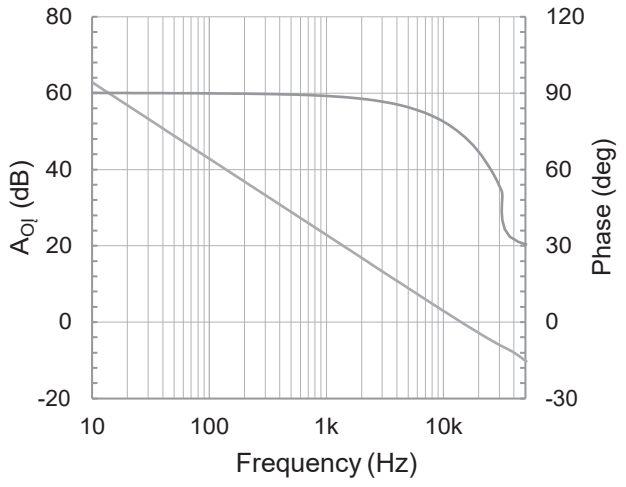


# 7 Specifications

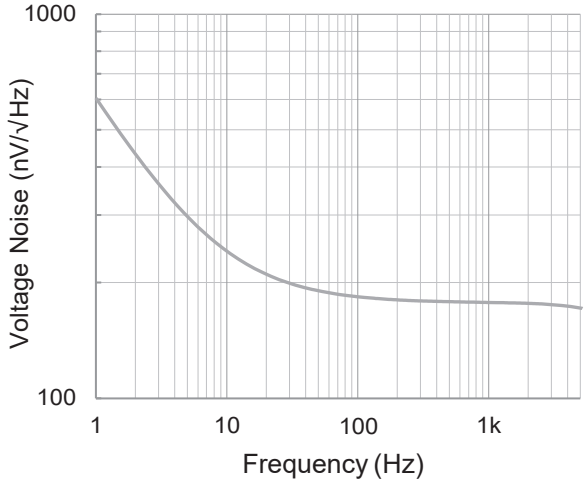
## 7.5 Typical Characteristics (continued)

**At $T_A$ = +25℃, $V_{CM}$ = $V_S$ /2, and $R_L$ = 10kΩ connected to $V_S$ /2, unless otherwise noted.**

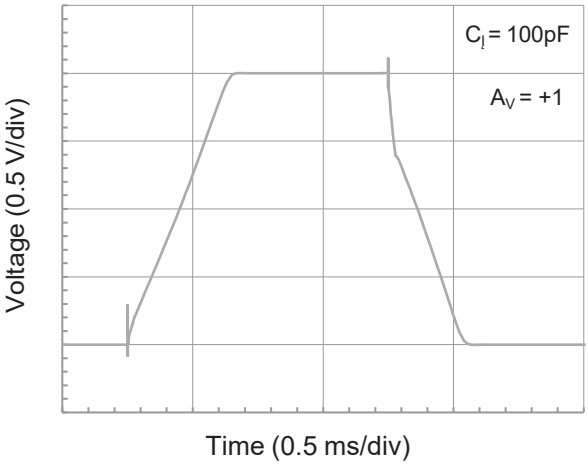
**Open-loop Gain and Phase vs. Frequency**



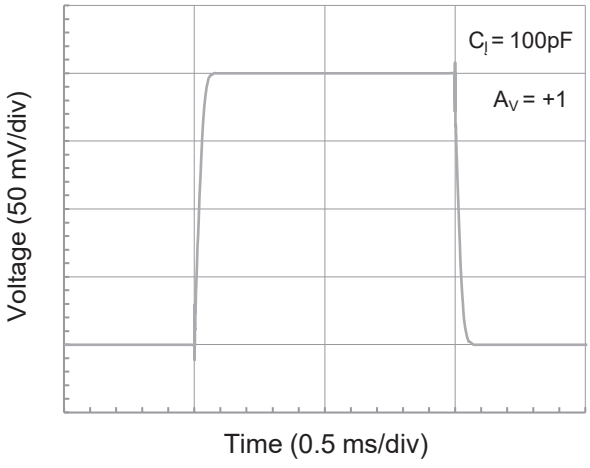

**Input Voltage Noise Spectral Density vs. Frequency**



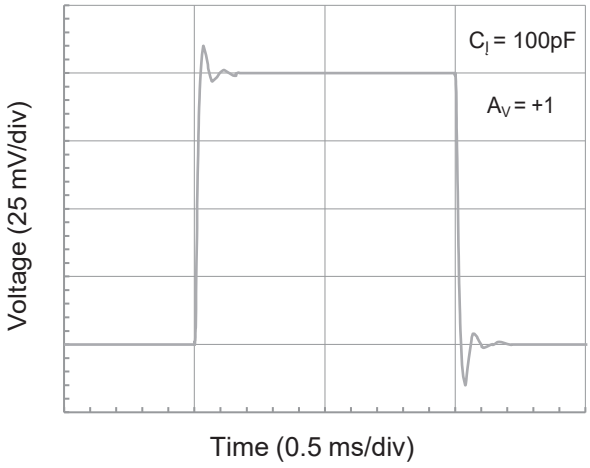

**Large Signal Step Response (2V Step)**



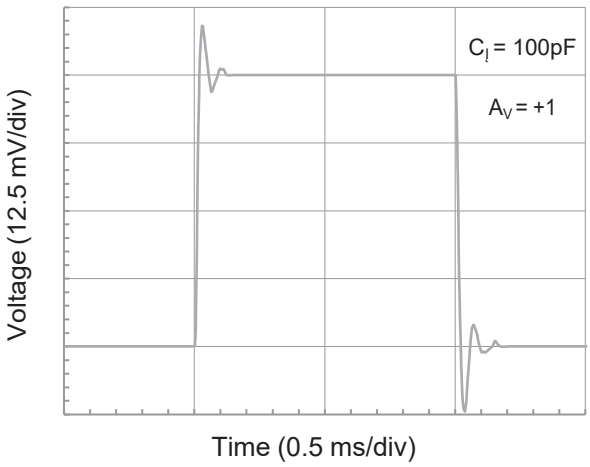

**Small Signal Step Response (200mV Step)**




**Small Signal Step Response (100mV Step)**




**Small Signal Step Response (50mV Step)**

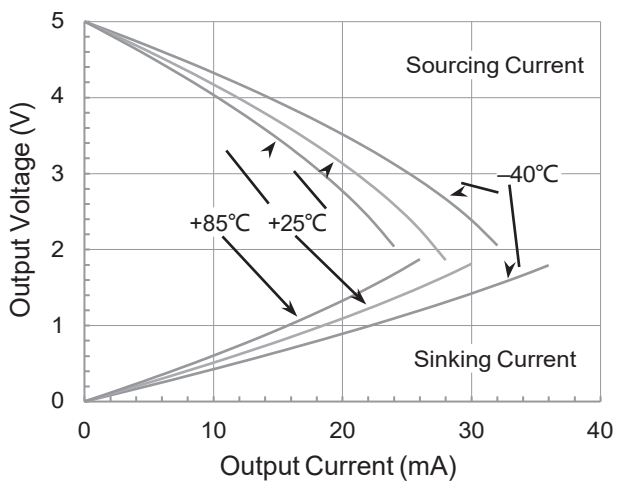


# 7 Specifications

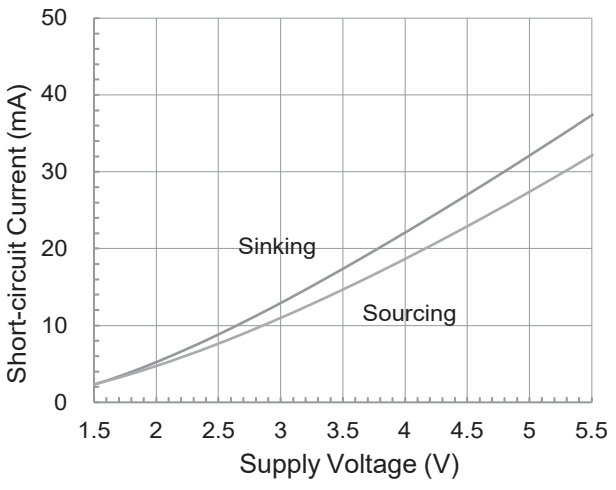
## 7.5 Typical Characteristics (continued)

**At $T_A$ = +25℃, $V_{CM}$ = $V_S$ /2, and $R_L$ = 10kΩ connected to $V_S$ /2, unless otherwise noted.**

**Output Voltage Swing vs. Output Current**




**Short-circuit Current vs. Supply Voltage**



# 8 Detailed Description

## 8.1 Description

Featuring a maximized ratio of GBW-to-supply current, low operating supply voltage, low input bias current, and rail-to-rail inputs and outputs, the VSOA204x family is an excellent choice for precision or general-purpose, low-current, low-voltage, battery-powered applications. These CMOS operational amplifiers consume an ultra-low 600nA (typically at 5V supply voltage) supply current per amplifier. The VSOA204x family is unity-gain stable with a 15kHz GBW product, driving capacitive loads up to 250pF.

## 8.2 Feature Description

### Rail-to-Rail Input

The input common-mode voltage range of the VSOA204x series extends 100mV beyond the negative and positive supply rails. This performance is achieved with a complementary input stage: an N-channel input differential pair in parallel with a P-channel differential pair. The N-channel pair is active for input voltages close to the positive rail, typically (V+) -1.4 V to the positive supply, whereas the P-channel pair is active for inputs from 100mV below the negative supply to approximately (V+) -1.4 V. There is a small transition region, typically (V+) -1.2 V to (V+) -1 V, in which both pairs are on. This 200mV transition region can vary up to 20mV with process variation. Thus, the transition region (both stages on) can range from (V+) -1.4 V to (V+) -1.2 V on the low end, up to (V+) -1 V to (V+) -0.8 V on the high end. Within this transition region, PSRR, CMRR, offset voltage, offset drift, and THD can be degraded compared to device operation outside this region.

The typical input bias current of the VSOA204x during normal operation is approximately 1pA. In overdriven conditions, the bias current can increase significantly. The most common cause of an overdriven condition occurs when the operational amplifier is outside of the linear range of operation. When the output of the operational amplifier is driven to one of the supply rails, the feedback loop requirements cannot be satisfied and a differential input voltage develops across the input pins. This differential input voltage results in activation of parasitic diodes inside the front-end input chopping switches that combine with electromagnetic interference (EMI) filter resistors to create the equivalent circuit. Notice that the input bias current remains within specification in the linear region.

### Rail-to-Rail Output

Designed as a micro-power, low-noise operational amplifier, the VSOA204x delivers a robust output drive capability. A class AB output stage with common- source transistors is used to achieve full rail-to-rail output swing capability. For resistive loads up to 50kΩ， the output swings typically to within 4mV of either supply rail regardless of the power supply voltage applied. Different load conditions change the ability of the amplifier to swing close to the rails. For resistive loads up to 2kΩ, the output swings typically to within 40mV of the positive supply rail and within 27mV of the negative supply rail.

### EMI Rejection Ratio

Circuit performance is often adversely affected by high frequency EMI. When the signal strength is low and transmission lines are long, an op-amp must accurately amplify the input signals. However, all op-amp pins — the non-inverting input, inverting input, positive supply, negative supply, and output pins — are susceptible to EMI signals. These high frequency signals are coupled into an op-amp by various means, such as conduction, near field radiation, or far field radiation. For example, wires and printed circuit board (PCB) traces can act as antennas and pick up high frequency EMI signals.

Amplifiers do not amplify EMI or RF signals due to their relatively low bandwidth. However, due to the nonlinearities of the input devices, op-amps can rectify these out of band signals. When these high frequency signals are rectified, they appear as a dc offset at the output.

The VSOA204x op-amps have integrated EMI filters at their input stage. A mathematical method of measuring EMIRR is defined as follows:

$$EMIRR = 20\ log(V_{IN\_PEAK}/\Delta V_{OOS})$$

# 9 Application and Implementation

## 9.1 Typical Application Circuits

### Input EMI Filter and Clamp Circuit

Figure 9-1 shows the input EMI filter and clamp circuit. The VSOA204x op-amps have internal ESD protection diodes (D1, D2, D3, and D4) that are connected between the inputs and each supply rail. These diodes protect the input transistors in the event of electrostatic discharge and are reverse biased during normal operation. This protection scheme allows voltages as high as approximately 500mV beyond the rails to be applied at the input of either terminal without causing permanent damage. These ESD protection current-steering diodes also provide in-circuit, input overdrive protection, as long as the current is limited to 10mA as stated in the Absolute Maximum Ratings.

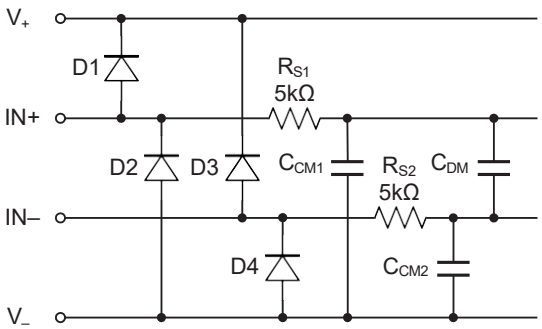



**Figure 9-1. Input EMI Filter and Clamp Circuit**

Operational amplifiers vary in susceptibility to EMI. If conducted EMI enters the operational amplifier, the dc offset at the amplifier output can shift from its nominal value when EMI is present. This shift is a result of signal rectification associated with the internal semiconductor junctions. Although all operational amplifier pin functions can be affected by EMI, the input pins are likely to be the most susceptible. The EMI filter of the VSOA204x family is composed of two 5kΩ input series resistors ($R_{S1}$ and $R_{S2}$), two common-mode capacitors ($C_{CM1}$ and $C_{CM2}$), and a differential capacitor (CDM). These RC networks set the -3dB low-pass cutoff frequencies at 35MHz for common-mode signals, and at 22MHz for differential signals.

### Capacitive Load and Stability

The VSOA204x family of operational amplifiers can safely drive capacitive loads of up to 250pF in any configuration. As with most amplifiers, driving larger capacitive loads than specified may cause excessive overshoot and ringing, or even oscillation. A heavy capacitive load reduces the phase margin and causes the amplifier frequency response to peak. Peaking corresponds to overshooting or ringing in the time domain. Therefore, it is recommended that external compensation be used if the VSOA204x family requires greater capacitive-drive capability. This compensation is particularly important in the unity-gain configuration, which is the worst case for stability.

A quick and easy way to stabilize the op-amp for capacitive load drive is by adding a series resistor, $R_{ISO}$, between the amplifier output terminal and the load capacitance, as shown in Figure 9-2. $R_{ISO}$ isolates the amplifier output and feedback network from the capacitive load. The bigger the $R_{ISO}$ resistor value, the more stable $V_{OUT}$ will be. Note that this method results in a loss of gain accuracy because $R_{ISO}$ forms a voltage divider with the $R_L$. In unity gain applications with relatively small RL (approximately 5 kΩ), the capacitive load can be increased up to 100pF.

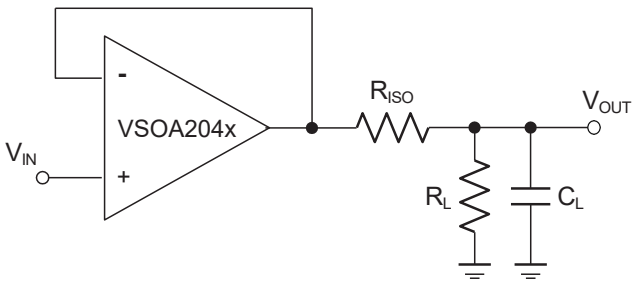



**Figure 9-2. Indirectly Driving Heavy Capacitive Load**

# 9 Application and Implementation

## 9.1 Typical Application Circuits (continued)

### Capacitive Load and Stability (continued)

An improvement circuit is shown in Figure 9-3. It provides DC accuracy as well as AC stability. The RF provides the DC accuracy by connecting the inverting signal with the output.

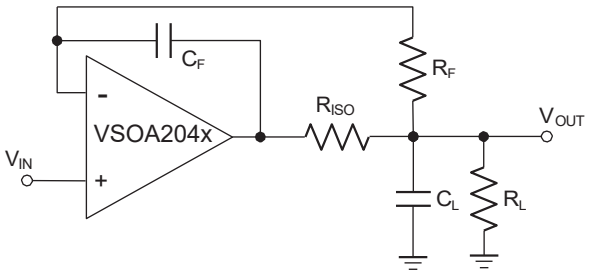



**Figure 9-3. Indirectly Driving Heavy Capacitive Load with DC Accuracy**

The $C_F$ and $R_{ISO}$ serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifier's inverting input, thereby preserving phase margin in the overall feedback loop.

For no-buffer configuration, there are two others ways to increase the phase margin: (a) by increasing the amplifier's gain, or (b) by placing a capacitor in parallel with the feedback resistor to counteract the parasitic capacitance associated with inverting node.

### Input-to-Output Coupling

To minimize capacitive coupling, the input and output signal traces should not be parallel. This helps reduce unwanted positive feedback

### Differential Amplifier

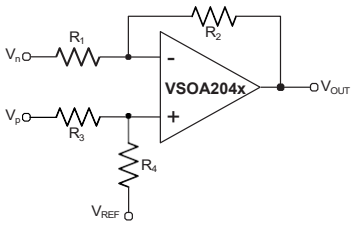



**Figure 9-4. Differential Amplifier**

The circuit shown in Figure 9-4 performs the difference function. If the resistors ratios are equal $R_4/R_3 = R_2/R_1$, then:

$$V_{OOUT} = (V_p - V_n) \times R_2/R_1 + V_{REF}$$

### Portable Gas Meter

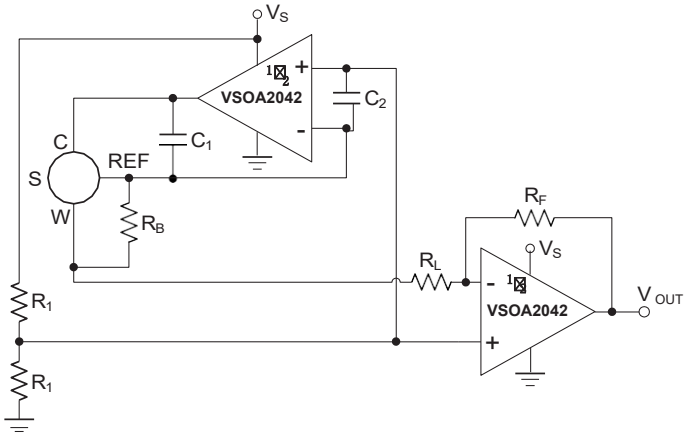
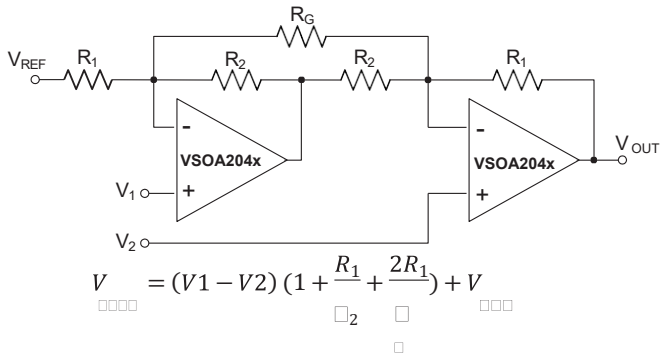



**Figure 9-5. Portable Gas Meter Application**

# 9 Application and Implementation

## 9.1 Typical Application Circuits (continued)

### Instrumentation Amplifier




$$V_{OUT} = (V1 - V2)\left(1 + \frac{R_1}{R_2} + \frac{2R_1}{R_G}\right) + V_{REF}$$

**Figure 9-6. Instrumentation Amplifier**

The VSOA204x family is well suited for conditioning sensor signals in battery-powered applications. Figure 9-6 shows a two op-amp instrumentation amplifier, using the VSOA204x op-amps. The circuit works well for applications requiring rejection of common-mode noise at higher gains. The reference voltage ($V_{REF}$) is supplied by a low-impedance source. In single voltage supply applications, the $V_{REF}$ is typically $V_S/2$.

### Battery Monitoring

The low operating voltage and quiescent current of the VSOA204x family make it an excellent choice for battery monitoring applications, as shown in Figure 9-7. In this circuit, $V_{STATUS}$ is high as long as the battery voltage remains above 2V ($V_{REF}$ = 1.2V). A low-power reference is used to set the trip point. Resistor values are selected as follows:

1. RF Selecting: Select $R_F$ such that the current through $R_F$ is approximately 1000x larger than the maximum bias current over temperature:

$$R_F = V_{REF} \div (1000 \times I_{BMAX}) = 1.2V \div (1000 \times 100\,pA) = 12M\Omega \approx 10M\Omega$$

2. Choose the hysteresis voltage, $V_{HYST}$. For battery monitoring applications, 50mV is adequate.

3. Calculate R1 as follows:

$$R_1 = R_F \times (V_{HYST} \div V_{BATT}) \approx 10M\Omega \times (50\text{mV} \div 2.4\text{V}) = 210\text{k}\Omega$$

4. Select a threshold voltage for $V_{IN}$ rising ($V_{TS}$) = 2.0V.

5. Calculate $R_2$ as follows:

$$R_2 = 1 \div [V_{TS} \div (V_{REF} \times R_1) - 1 \div R_1 - 1 \div R_F] = 1 \div [2V \div (1.2V \times 210\text{k}\Omega) - 1 \div 210\text{k}\Omega - 1 \div 10\text{M}\Omega] = 325\text{k}\Omega$$

6. Calculate $R_{BIAS}$: The minimum supply voltage for this circuit is 1.8V. Providing 5µA of supply current assures proper operation. Therefore:

$$R_{BIAS} = (V_{BATTMIN} - V_{REF}) \div I_{BIAS} = (1.8V \div 1.2V) \div 5\mu A = 120\ \text{k}\Omega$$

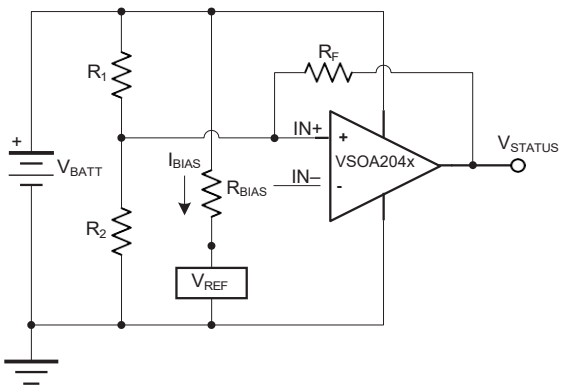



**Figure 9-7. Battery Monitor**

# 9 Application and Implementation

## 9.2 Power Supply Recommendations

### Operating Voltage

The VSOA204x family is fully specified and ensured for operation at voltages as low as +1.7 V (±0.85 V) and up to +5.5 V (±2.75 V). In addition, many specifications apply from –40°C to +85°C . Parameters that vary significantly with operating voltages or temperature are illustrated in the Typical Characteristics graphs.

## 9.3 Layout Guidelines

### Maximizing Performance through Proper Layout

To achieve the maximum performance of the extremely high input impedance and low offset voltage of the VSOA204x op-amps, care is needed in laying out the circuit board. The PCB surface must remain clean and free of moisture to avoid leakage currents between adjacent traces. Surface coating of the circuit board reduces surface moisture and provides a humidity barrier, reducing parasitic resistance on the board. The use of guard rings around the amplifier inputs further reduces leakage currents. Figure 9-8 shows proper guard ring configuration and the top view of a surface-mount layout. The guard ring does not need to be a specific width, but it should form a continuous loop around both inputs. By setting the guard ring voltage equal to the voltage at the non-inverting input, parasitic capacitance is minimized as well. For further reduction of leakage currents, components can be mounted to the PCB using Teflon standoff insulators.

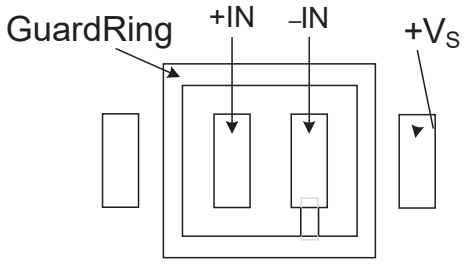



**Figure 9-8. Use a guard ring around sensitive pins**

Other potential sources of offset error are thermoelectric voltages on the circuit board. This voltage, also called Seebeck voltage, occurs at the junction of two dissimilar metals and is proportional to the temperature of the junction. The most common metallic junctions on a circuit board are solder-to- board trace and solder-to-component lead. If the temperature of the PCB at one end of the component is different from the temperature at the other end, the resulting Seebeck voltages are not equal, resulting in a thermal voltage error.

This thermocouple error can be reduced by using dummy components to match the thermoelectric error source. Placing the dummy component as close as possible to its partner ensures both Seebeck voltages are equal, thus canceling the thermocouple error. Maintaining a constant ambient temperature on the circuit board further reduces this error. The use of a ground plane helps distribute heat throughout the board and reduces EMI noise pickup.