

OPA128

# Difet® Electrometer-Grade OPERATIONAL AMPLIFIER

## FEATURES

- ULTRA-LOW BIAS CURRENT: 75fA max
- LOW OFFSET: 500µV max
- LOW DRIFT: 5µV/°C max
- HIGH OPEN-LOOP GAIN: 110dB min
- HIGH COMMON-MODE REJECTION: 90dB min
- IMPROVED REPLACEMENT FOR AD515 AND AD549

## APPLICATIONS

- ELECTROMETER
- MASS SPECTROMETER
- CHROMATOGRAPH
- ION GAUGE
- PHOTODETECTOR
- RADIATION-HARD EQUIPMENT

## DESCRIPTION

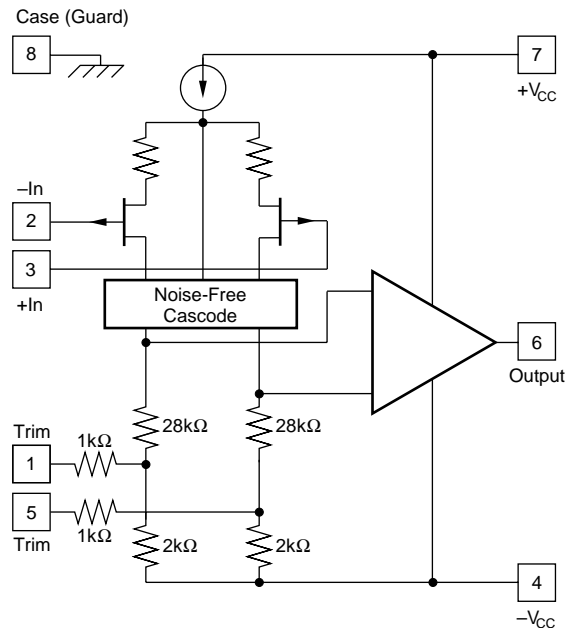
The OPA128 is an ultra-low bias current monolithic operational amplifier. Using advanced geometry dielectrically-isolated FET (*Difet*®) inputs, this monolithic amplifier achieves a performance level exceeding even the best hybrid electrometer amplifiers.

Laser-trimmed thin-film resistors give outstanding voltage offset and drift performance.

A noise-free cascode and low-noise processing give the OPA128 excellent low-level signal handling capabilities. Flicker noise is very low.

The OPA128 is an improved pin-for-pin replacement for the AD515.

*Difet*® Burr-Brown Corp.



OPA128 Simplified Circuit

# SPECIFICATIONS

## ELECTRICAL

At  $V_{CC} = \pm 15\text{VDC}$  and  $T_A = +25^\circ\text{C}$ , unless otherwise noted. Pin 8 connected to ground.

| PARAMETER   | CONDITIONS   | OPA128JM            |   |                        | OPA128KM                                       |                                     |   | OPA128LM            |  |                      | OPA128SM                                       |                                     |  | UNITS   |
|---|--|---------------------|---|------------------------|--|-------------------------------------|---|---------------------|--|----------------------|--|-------------------------------------|--|---|
|   |  | MIN                 | TYP   | MAX                    | MIN  | TYP                                 | MAX   | MIN                 | TYP  | MAX                  | MIN  | TYP                                 | MAX  |   |
| <b>INPUT</b>  |  |                     |   |                        |  |                                     |   |                     |  |                      |  |                                     |  |   |
| <b>BIAS CURRENT<sup>(1)</sup></b><br>Input Bias Current   | $V_{CM} = 0\text{VDC}$ ,<br>$R_L \geq 10\text{k}\Omega$  |                     | $\pm 150$                                       | $\pm 300$              |  | $\pm 75$                            | $\pm 150$                                       |                     | $\pm 40$                                       | $\pm 75$             |  | $\pm 75$                            | $\pm 150$                                      | fA  |
| <b>OFFSET CURRENT<sup>(1)</sup></b><br>Input Offset Current   | $V_{CM} = 0\text{VDC}$ ,<br>$R_L \geq 10\text{k}\Omega$  |                     | 65  |                        |  | 30                                  |   |                     | 30   |                      |  | 30                                  |  | fA  |
| <b>OFFSET VOLTAGE<sup>(1)</sup></b><br>Input Offset Voltage<br>Average Drift<br>Supply Rejection  | $V_{CM} = 0\text{VDC}$<br>$T_A = T_{MIN}$ to $T_{MAX}$   |                     | $\pm 260$                                       | $\pm 1000$<br>$\pm 20$ |  | $\pm 140$                           | $\pm 500$<br>$\pm 10$                           |                     | $\pm 140$                                      | $\pm 500$<br>$\pm 5$ |  | $\pm 140$                           | $\pm 500$<br>$\pm 10$                          | $\mu\text{V}$<br>$\mu\text{V}/^\circ\text{C}$<br>dB<br>$\mu\text{V}/\text{V}$   |
| <b>NOISE</b><br>Voltage: $f_O = 10\text{Hz}$<br>$f_O = 100\text{Hz}$<br>$f_O = 1\text{kHz}$<br>$f_O = 10\text{kHz}$<br>$f_B = 10\text{Hz}$ to $10\text{kHz}$<br>$f_B = 0.1\text{Hz}$ to $10\text{Hz}$<br>Current: $f_B = 0.1\text{Hz}$ to $10\text{Hz}$<br>$f_O = 0.1\text{Hz}$ to $20\text{kHz}$ |  |                     | 92<br>78<br>27<br>15<br>2.4<br>4<br>4.2<br>0.22 |                        | 92<br>78<br>27<br>15<br>2.4<br>4<br>3<br>0.16  |                                     | 92<br>78<br>27<br>15<br>2.4<br>4<br>2.3<br>0.12 |                     | 92<br>78<br>27<br>15<br>2.4<br>4<br>3<br>0.16  |                      |  |                                     |  | $\text{nV}/\sqrt{\text{Hz}}$<br>$\text{nV}/\sqrt{\text{Hz}}$<br>$\text{nV}/\sqrt{\text{Hz}}$<br>$\text{nV}/\sqrt{\text{Hz}}$<br>$\mu\text{Vrms}$<br>$\mu\text{Vp-p}$<br>fA, p-p<br>$\text{fA}/\sqrt{\text{Hz}}$ |
| <b>IMPEDANCE</b><br>Differential<br>Common-Mode   |  |                     | $10^{13} \parallel 1$<br>$10^{15} \parallel 2$  |                        | $10^{13} \parallel 1$<br>$10^{15} \parallel 2$ |                                     | $10^{13} \parallel 1$<br>$10^{15} \parallel 2$  |                     | $10^{13} \parallel 1$<br>$10^{15} \parallel 2$ |                      | $10^{13} \parallel 1$<br>$10^{15} \parallel 2$ |                                     | $10^{13} \parallel 1$<br>$10^{15} \parallel 2$ | $\Omega \parallel \text{pF}$<br>$\Omega \parallel \text{pF}$  |
| <b>VOLTAGE RANGE<sup>(4)</sup></b><br>Common-Mode Input Range<br>Common-Mode Rejection  | $V_{IN} = \pm 10\text{VDC}$  | $\pm 10$            | $\pm 12$  |                        | $\pm 10$                                       | $\pm 12$                            |   | $\pm 10$            | $\pm 12$                                       |                      | $\pm 10$                                       | $\pm 12$                            |  | V<br>dB   |
| <b>OPEN-LOOP GAIN, DC</b>   |  |                     |   |                        |  |                                     |   |                     |  |                      |  |                                     |  |   |
| Open-Loop Voltage Gain  | $R_L \geq 2\text{k}\Omega$   | 94                  | 128   |                        | 110  | 128                                 |   | 110                 | 128  |                      | 110  | 128                                 |  | dB  |
| <b>FREQUENCY RESPONSE</b>   |  |                     |   |                        |  |                                     |   |                     |  |                      |  |                                     |  |   |
| Unity Gain, Small Signal<br>Full Power Response<br>Slew Rate<br>Settling Time, 0.1%<br>0.01%<br>Overload Recovery,<br>50% Overdrive <sup>(3)</sup>  | <sup>(2)</sup><br>20Vp-p, $R_L = 2\text{k}\Omega$<br>$V_O = \pm 10\text{V}$ , $R_L = 2\text{k}\Omega$<br>Gain = -1, $R_L = 2\text{k}\Omega$<br>10V Step<br>Gain = -1 | 0.5<br>0.5          | 1<br>47<br>3<br>5<br>10                         |                        | 0.5<br>1                                       | 1<br>47<br>3<br>5<br>10             |   | 0.5<br>1            | 1<br>47<br>3<br>5<br>10                        |                      | 0.5<br>1                                       | 1<br>47<br>3<br>5<br>10             |  | MHz<br>kHz<br>V/ $\mu\text{s}$<br>$\mu\text{s}$<br>$\mu\text{s}$<br>$\mu\text{s}$   |
| <b>RATED OUTPUT</b>   |  |                     |   |                        |  |                                     |   |                     |  |                      |  |                                     |  |   |
| Voltage Output<br>Current Output<br>Output Resistance<br>Load Capacitance Stability<br>Short Circuit Current  | $R_L = 2\text{k}\Omega$<br>$V_O = \pm 10\text{VDC}$<br>DC, Open Loop<br>Gain = +1  | $\pm 10$<br>$\pm 5$ | $\pm 13$<br>$\pm 10$<br>100<br>1000             |                        | $\pm 10$<br>$\pm 5$                            | $\pm 13$<br>$\pm 10$<br>100<br>1000 |   | $\pm 10$<br>$\pm 5$ | $\pm 13$<br>$\pm 10$<br>100<br>1000            |                      | $\pm 10$<br>$\pm 5$                            | $\pm 13$<br>$\pm 10$<br>100<br>1000 |  | V<br>mA<br>$\Omega$<br>pF<br>mA   |
| <b>POWER SUPPLY</b>   |  |                     |   |                        |  |                                     |   |                     |  |                      |  |                                     |  |   |
| Rated Voltage<br>Voltage Range,<br>Derated Performance<br>Current, Quiescent  |  |                     | $\pm 15$  |                        | $\pm 15$                                       |                                     | $\pm 15$  |                     | $\pm 15$                                       |                      | $\pm 15$                                       |                                     | $\pm 15$                                       | VDC<br>VDC<br>mA  |
| <b>TEMPERATURE RANGE</b>  |  |                     |   |                        |  |                                     |   |                     |  |                      |  |                                     |  |   |
| Specification<br>Operating<br>Storage<br>$\theta$ Junction-Ambient  | Ambient Temp.<br>Ambient Temp.<br>Ambient Temp.  | 0<br>-55<br>-65     |   | +70<br>+125<br>+150    | 0<br>-55<br>-65                                |                                     | +70<br>+125<br>+150                             | 0<br>-55<br>-65     |  | +70<br>+125<br>+150  | -55<br>-55<br>-65                              |                                     | +125<br>+125<br>+150                           | $^\circ\text{C}$<br>$^\circ\text{C}$<br>$^\circ\text{C}$<br>$^\circ\text{C}/\text{W}$   |

NOTES: (1) Offset voltage, offset current, and bias current are measured with the units fully warmed up. Bias current doubles approximately every  $11^\circ\text{C}$ . (2) Small signal tested. (3) Overload recovery is defined as the time required for the output to return from saturation to linear operation following the removal of a 50% input overdrive. (4) If it is possible for the input voltage to exceed the supply voltage, a series protection resistor should be added to limit input current to 0.5mA. The input devices can withstand overload currents of 0.3mA indefinitely without damage.

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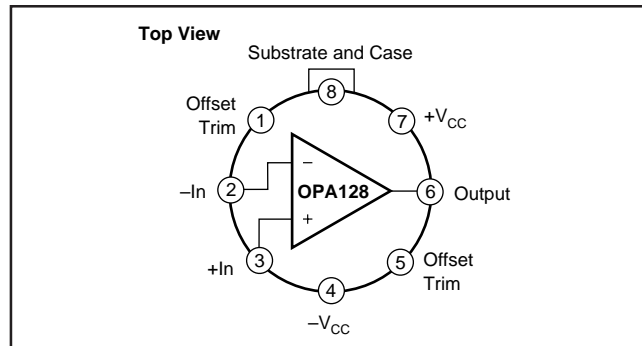
## ELECTRICAL (FULL TEMPERATURE RANGE SPECIFICATIONS)

At  $V_{CC} = \pm 15\text{VDC}$  and  $T_A = T_{MIN}$  and  $T_{MAX}$ , unless otherwise noted.

| PARAMETER  | CONDITIONS   | OPA128JM                  |                            |                                | OPA128KM                  |                            |                              | OPA128LM                  |                            |                      | OPA128SM                  |                 |                                | UNITS   |
|--|--|---------------------------|----------------------------|--------------------------------|---------------------------|----------------------------|------------------------------|---------------------------|----------------------------|----------------------|---------------------------|-----------------|--------------------------------|---|
|  |  | MIN                       | TYP                        | MAX                            | MIN                       | TYP                        | MAX                          | MIN                       | TYP                        | MAX                  | MIN                       | TYP             | MAX                            |   |
| <b>TEMPERATURE RANGE</b>   |  |                           |                            |                                |                           |                            |                              |                           |                            |                      |                           |                 |                                |   |
| Specification Range  | Ambient Temp.  | 0                         |                            | +70                            | 0                         |                            | +70                          | 0                         |                            | +70                  | -55                       |                 | +125                           | °C  |
| <b>INPUT</b>   |  |                           |                            |                                |                           |                            |                              |                           |                            |                      |                           |                 |                                |   |
| <b>BIAS CURRENT<sup>(1)</sup></b><br>Input Bias Current  | $V_{CM} = 0\text{VDC}$   |                           | $\pm 2.5$                  | $\pm 8$                        |                           | $\pm 1.3$                  | $\pm 4$                      |                           | $\pm 0.7$                  | $\pm 2$              |                           | $\pm 43$        | $\pm 170$                      | pA  |
| <b>OFFSET CURRENT<sup>(1)</sup></b><br>Input Offset Current                                      | $V_{CM} = 0\text{VDC}$   |                           | 1.1                        |                                |                           | 0.6                        |                              |                           | 0.6                        |                      |                           | 18              |                                | pA  |
| <b>OFFSET VOLTAGE<sup>(1)</sup></b><br>Input Offset Voltage<br>Average Drift<br>Supply Rejection | $V_{CM} = 0\text{VDC}$   |                           |                            | $\pm 2.2\text{mV}$<br>$\pm 20$ |                           |                            | $\pm 1\text{mV}$<br>$\pm 10$ |                           |                            | $\pm 750$<br>$\pm 5$ |                           |                 | $\pm 1.5\text{mV}$<br>$\pm 10$ | $\mu\text{V}$<br>$\mu\text{V}/^\circ\text{C}$<br>dB<br>$\mu\text{V}/\text{V}$ |
| <b>VOLTAGE RANGE<sup>(2)</sup></b><br>Common-Mode Input Range<br>Common-Mode Rejection           | $V_{IN} = \pm 10\text{VDC}$  | $\pm 10$<br>74            | $\pm 11$<br>114<br>$\pm 2$ |                                | $\pm 10$<br>80            | $\pm 11$<br>114<br>$\pm 2$ |                              | $\pm 10$<br>80            | $\pm 11$<br>114<br>$\pm 2$ |                      | $\pm 10$<br>74            | $\pm 11$<br>104 |                                | V<br>dB   |
| <b>OPEN-LOOP GAIN, DC</b>  |  |                           |                            |                                |                           |                            |                              |                           |                            |                      |                           |                 |                                |   |
| Open-Loop Voltage Gain   | $R_L \geq 2\text{k}\Omega$   | 90                        | 125                        |                                | 104                       | 125                        |                              | 104                       | 125                        |                      | 90                        | 122             |                                | dB  |
| <b>RATED OUTPUT</b>  |  |                           |                            |                                |                           |                            |                              |                           |                            |                      |                           |                 |                                |   |
| Voltage Output<br>Current Output<br>Short Circuit Current  | $R_L = 2\text{k}\Omega$<br>$V_O = \pm 10\text{VDC}$<br>$V_O = 0\text{VDC}$ | $\pm 10$<br>$\pm 5$<br>10 |                            |                                | $\pm 10$<br>$\pm 5$<br>10 |                            |                              | $\pm 10$<br>$\pm 5$<br>10 |                            |                      | $\pm 10$<br>$\pm 5$<br>10 |                 |                                | V<br>mA<br>mA   |
| <b>POWER SUPPLY</b>  |  |                           |                            |                                |                           |                            |                              |                           |                            |                      |                           |                 |                                |   |
| Current, Quiescent   | $I = 0\text{mADC}$   |                           | 0.9                        | 1.8                            |                           | 0.9                        | 1.8                          |                           | 0.9                        | 1.8                  |                           | 0.9             | 2                              | mA  |

NOTES: (1) Offset voltage, offset current, and bias current are measured with the units fully warmed up. (2) If it is possible for the input voltage to exceed the supply voltage, a series protection resistor should be added to limit input current to 0.5mA. The input devices can withstand overload currents of 0.3mA indefinitely without damage.

## CONNECTION DIAGRAM



## ABSOLUTE MAXIMUM RATINGS

|  |   |
|--|---|
| Supply                                       | $\pm 18\text{VDC}$                          |
| Internal Power Dissipation <sup>(1)</sup>    | 500mW                                       |
| Differential Input Voltage                   | $\pm 36\text{VDC}$                          |
| Input Voltage Range                          | $\pm 18\text{VDC}$                          |
| Storage Temperature Range                    | $-65^\circ\text{C}$ to $+150^\circ\text{C}$ |
| Operating Temperature Range                  | $-55^\circ\text{C}$ to $+125^\circ\text{C}$ |
| Lead Temperature (soldering, 10s)            | $+300^\circ\text{C}$                        |
| Output Short Circuit Duration <sup>(2)</sup> | Continuous                                  |
| Junction Temperature                         | $+175^\circ\text{C}$                        |

NOTES: (1) Packages must be derated based on  $\theta_{CA} = 150^\circ\text{C}/\text{W}$  or  $\theta_{JA} = 200^\circ\text{C}/\text{W}$ . (2) Short circuit may be to power supply common only. Rating applies to  $+25^\circ\text{C}$  ambient. Observe dissipation limit and  $T_J$ .

## ORDERING INFORMATION

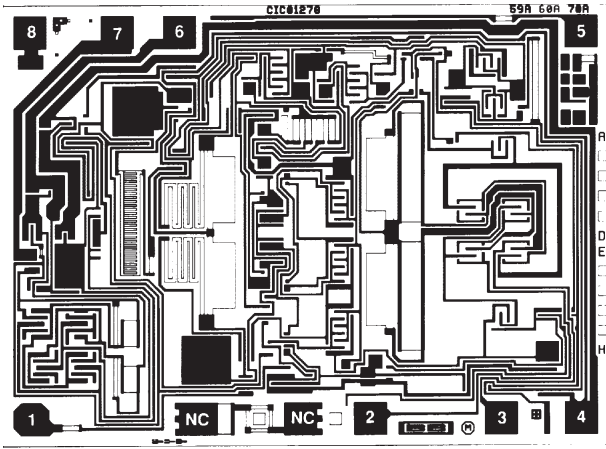
| PRODUCT  | PACKAGE | TEMPERATURE RANGE                           | BIAS CURRENT, max (fA) |
|----------|---------|---|------------------------|
| OPA128JM | TO-99   | $0^\circ\text{C}$ to $+70^\circ\text{C}$    | $\pm 300$              |
| OPA128KM | TO-99   | $0^\circ\text{C}$ to $+70^\circ\text{C}$    | $\pm 150$              |
| OPA128LM | TO-99   | $0^\circ\text{C}$ to $+70^\circ\text{C}$    | $\pm 75$               |
| OPA128SM | TO-99   | $-55^\circ\text{C}$ to $+125^\circ\text{C}$ | $\pm 150$              |

## PACKAGE INFORMATION

| PRODUCT  | PACKAGE | PACKAGE DRAWING NUMBER <sup>(1)</sup> |
|----------|---------|---------------------------------------|
| OPA128JM | TO-99   | 001                                   |
| OPA128KM | TO-99   | 001                                   |
| OPA128LM | TO-99   | 001                                   |
| OPA128SM | TO-99   | 001                                   |

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

## DICE INFORMATION



OPA128 DIE TOPOGRAPHY

| PAD | FUNCTION         |
|-----|------------------|
| 1   | Offset Trim      |
| 2   | -In              |
| 3   | +In              |
| 4   | -V <sub>CC</sub> |
| 5   | Offset Trim      |
| 6   | Output           |
| 7   | +V <sub>CC</sub> |
| 8   | Substrate        |
| NC  | No Connection    |

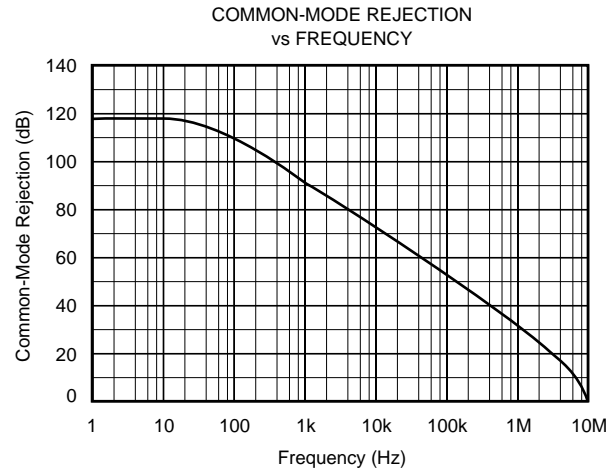
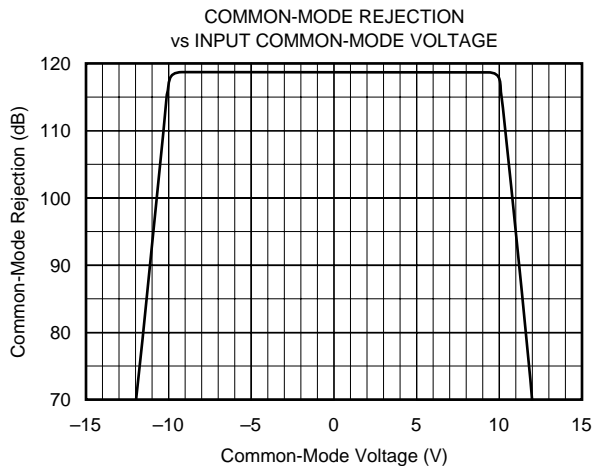
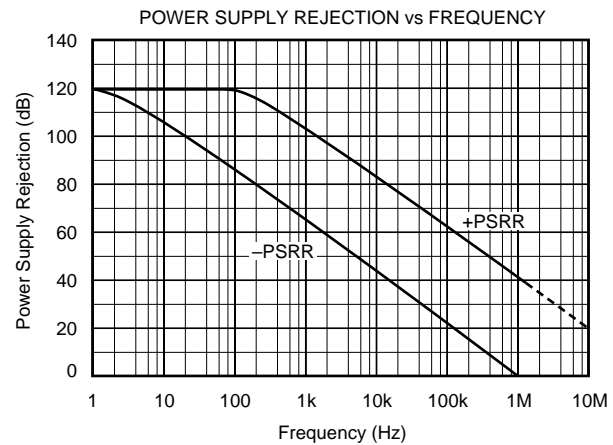
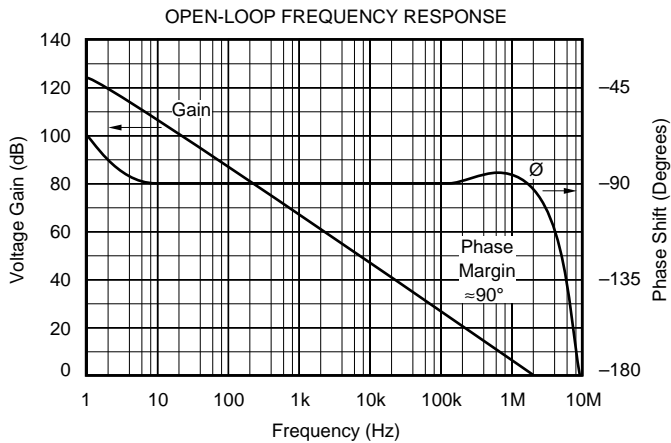
**Substrate Bias:** Isolated, normally connected to common.

## MECHANICAL INFORMATION

|               | MILS (0.001") | MILLIMETERS       |
|---------------|---------------|-------------------|
| Die Size      | 96 x 71 ±5    | 2.44 x 1.80 ±0.13 |
| Die Thickness | 20 ±3         | 0.51 ±0.08        |
| Min. Pad Size | 4 x 4         | 0.10 x 0.10       |
| Backing       |               | None              |

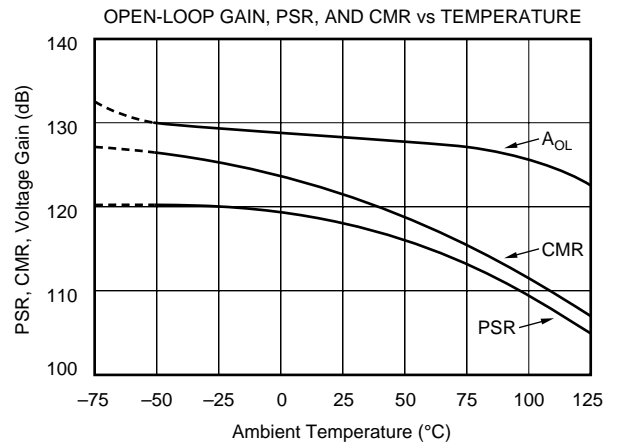
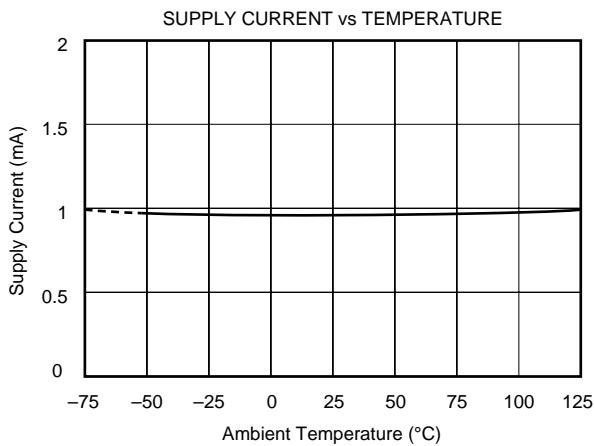
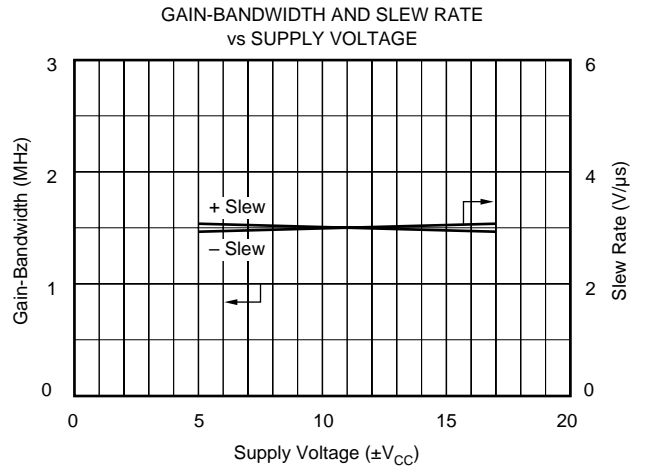
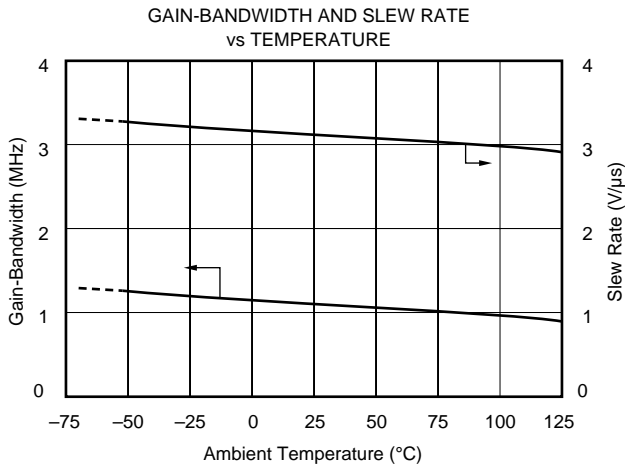
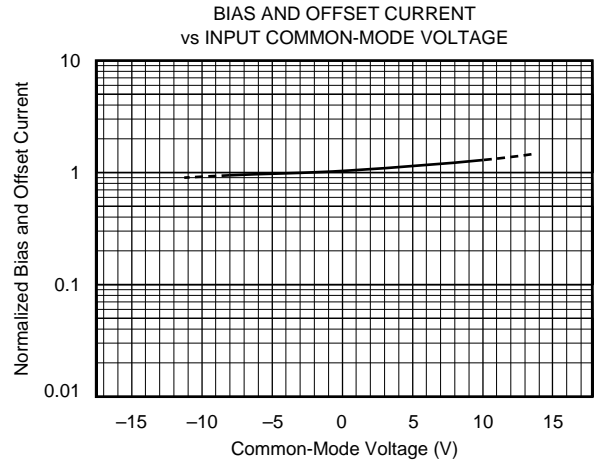
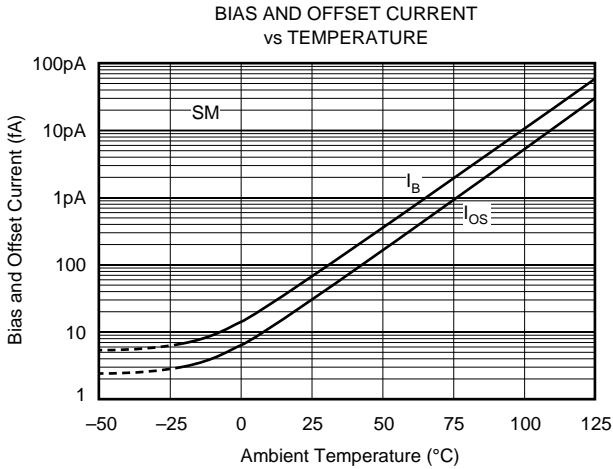
## TYPICAL PERFORMANCE CURVES

At T<sub>A</sub> = +25°C, ±15VDC, unless otherwise noted.



# TYPICAL PERFORMANCE CURVES (CONT)

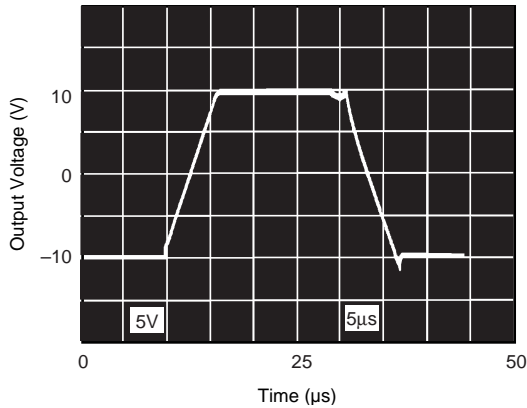
At  $T_A = +25^\circ\text{C}$ ,  $+15\text{VDC}$ , unless otherwise noted.



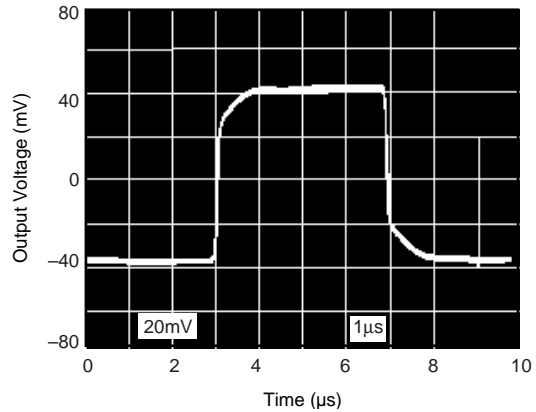
# TYPICAL PERFORMANCE CURVES (CONT)

At  $T_A = +25^\circ\text{C}$ ,  $+15\text{VDC}$ , unless otherwise noted.

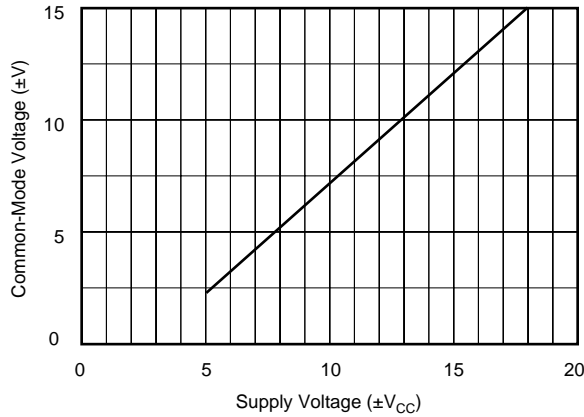
LARGE SIGNAL TRANSIENT RESPONSE



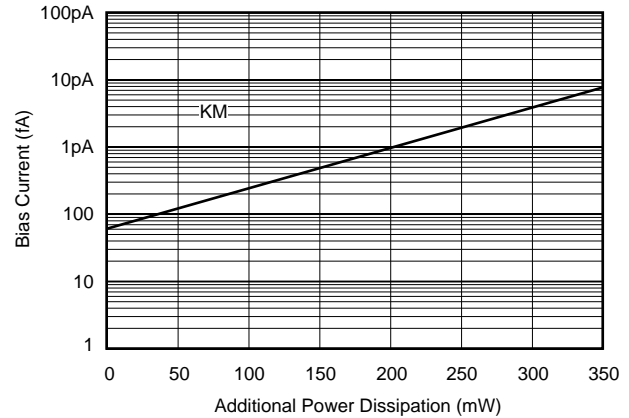
SMALL SIGNAL TRANSIENT RESPONSE



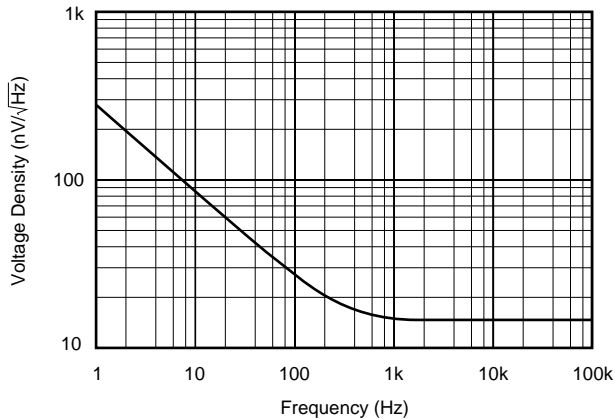
COMMON-MODE INPUT RANGE vs SUPPLY VOLTAGE



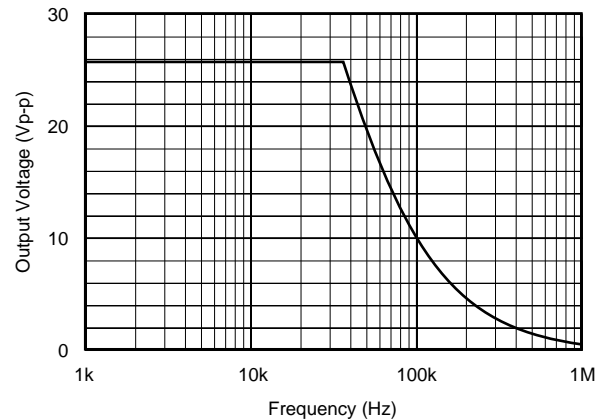
BIAS CURRENT vs ADDITIONAL POWER DISSIPATION



INPUT VOLTAGE NOISE SPECTRAL DENSITY



FULL-POWER OUTPUT vs FREQUENCY



# APPLICATIONS INFORMATION

## OFFSET VOLTAGE ADJUSTMENT

The OPA128 offset voltage is laser-trimmed and will require no further trim for most applications. As with most amplifiers, externally trimming the remaining offset can change drift performance by about  $0.3\mu\text{V}/^\circ\text{C}$  for each  $100\mu\text{V}$  of adjusted effort. Note that the trim (Figure 1) is similar to operational amplifiers such as HA-5180 and AD515. The OPA128 can replace many other amplifiers by leaving the external null circuit unconnected.

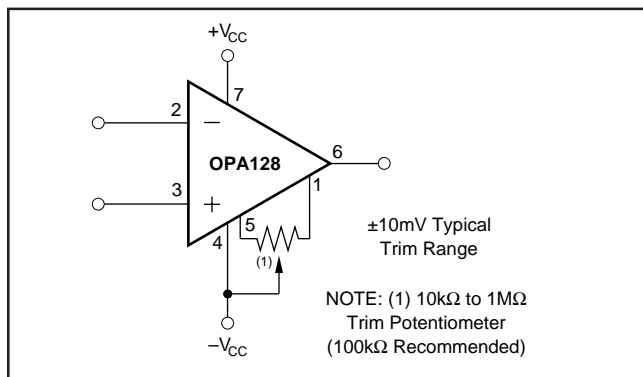


FIGURE 1. Offset Voltage Trim.

## INPUT PROTECTION

Conventional monolithic FET operational amplifiers' inputs must be protected against destructive currents that can flow when input FET gate-to-substrate isolation diodes are forward-biased. Most BIFET® amplifiers can be destroyed by the loss of  $-V_{CC}$ .

Because of its dielectric isolation, no special protection is needed on the OPA128. Of course, the differential and common-mode voltage limits should be observed.

Static damage can cause subtle changes in amplifier input characteristics without necessarily destroying the device. In precision operational amplifiers (both bipolar and FET types), this may cause a noticeable degradation of offset voltage and drift.

Static protection is recommended when handling any precision IC operational amplifier.

## GUARDING AND SHIELDING

As in any situation where high impedances are involved, careful shielding is required to reduce "hum" pickup in input leads. If large feedback resistors are used, they should also be shielded along with the external input circuitry. Leakage currents across printed circuit boards can easily exceed the bias current of the OPA128. To avoid leakage problems, it is recommended that the signal input lead of the OPA128 be wired to a Teflon standoff. If the input is to be soldered directly into a printed circuit board, utmost care must be used in planning the board layout. A "guard" pattern should completely surround the high impedance input leads and should be connected to a low impedance point which is at the signal input potential.

The amplifier case should be connected to any input shield or guard via pin 8. This insures that the amplifier itself is fully surrounded by guard potential, minimizing both leakage and noise pickup (see Figure 2).

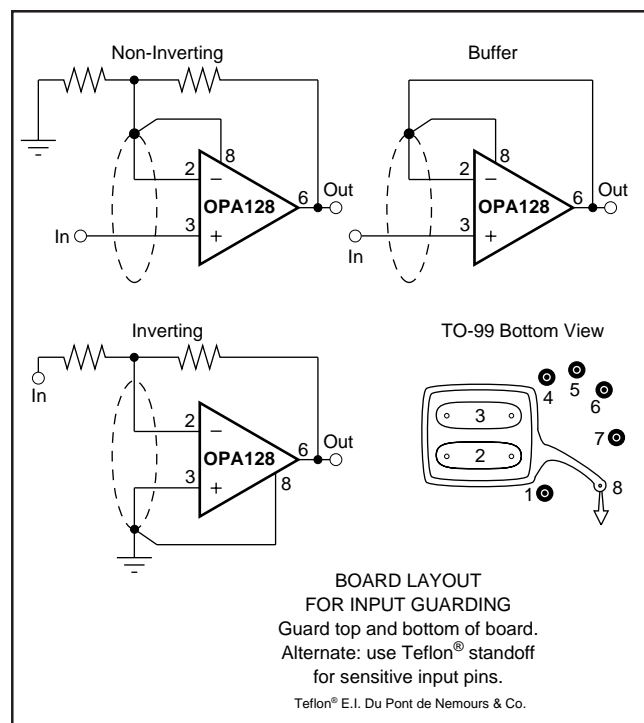


FIGURE 2. Connection of Input Guard.

Triboelectric charge (static electricity generated by friction) can be a troublesome noise source from cables connected to the input of an electrometer amplifier. Special low-noise cable will minimize this effect but the optimum solution is to mount the signal source directly at the electrometer input with short, rigid, wiring to preclude microphonic noise generation.

## TESTING

Accurately testing the OPA128 is extremely difficult due to its high level of performance. Ordinary test equipment may not be able to resolve the amplifier's extremely low bias current.

Inaccurate bias current measurements can be due to:

1. Test socket leakage
2. Unclean package
3. Humidity or dew point condensation
4. Circuit contamination from fingerprints or anti-static treatment chemicals
5. Test ambient temperature
6. Load power dissipation

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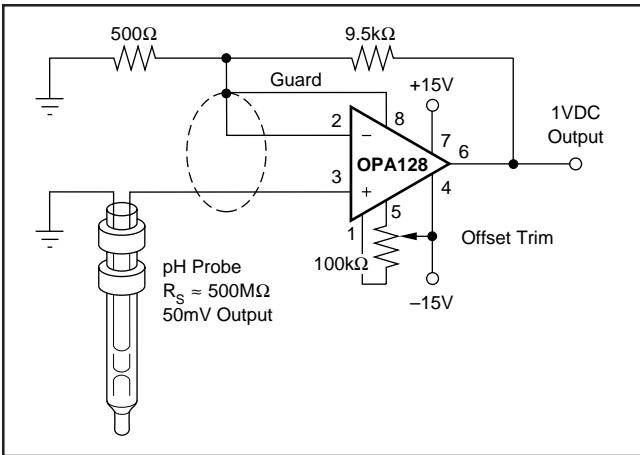


FIGURE 3. High Impedance ( $10^{15}\Omega$ ) Amplifier.

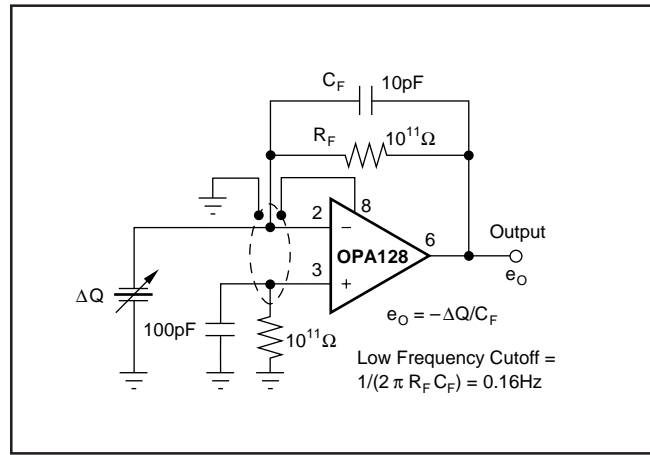


FIGURE 4. Piezoelectric Transducer Charge Amplifier.

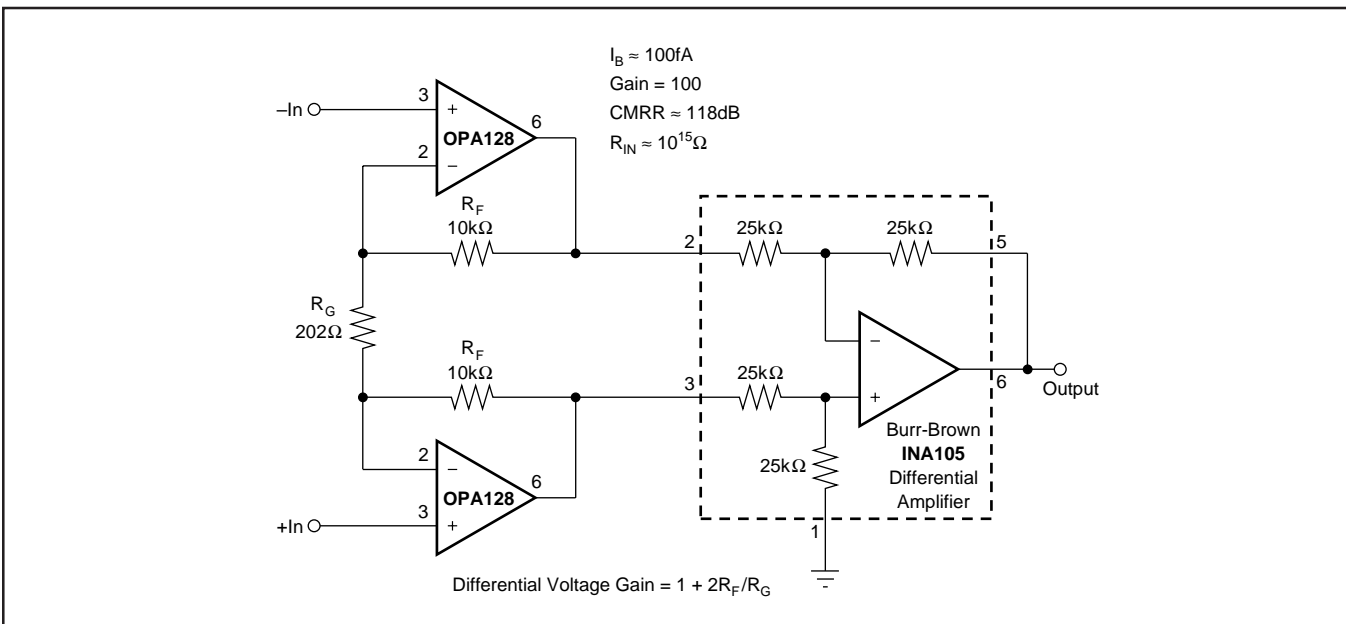


FIGURE 5. FET Input Instrumentation Amplifier for Biomedical Applications.

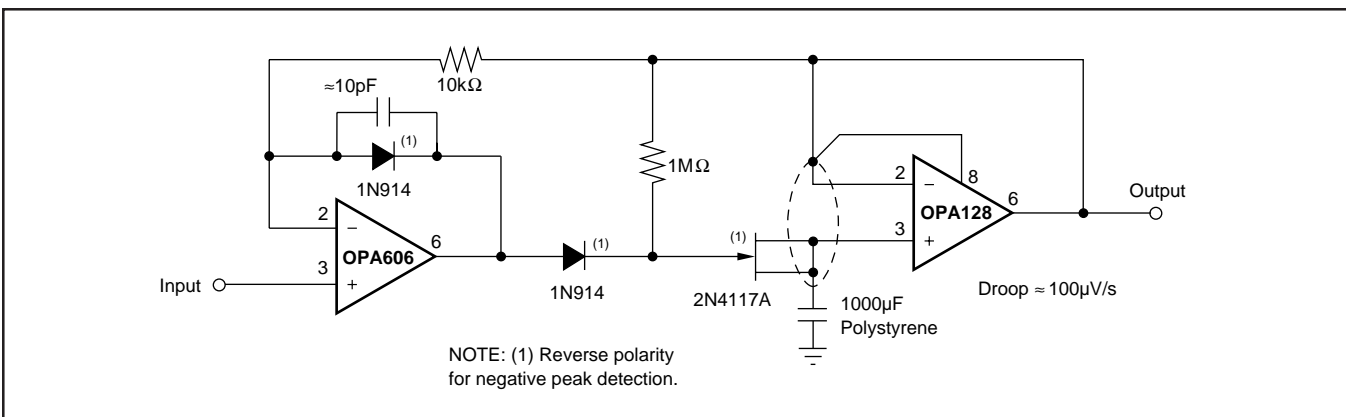


FIGURE 6. Low-Droop Positive Peak Detector.



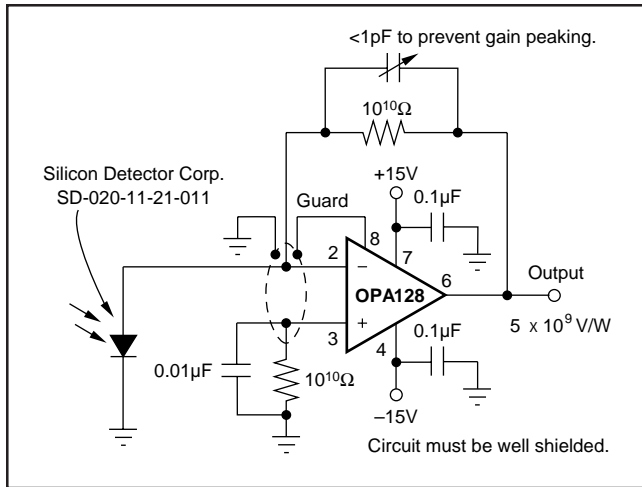


FIGURE 7. Sensitive Photodiode Amplifier.

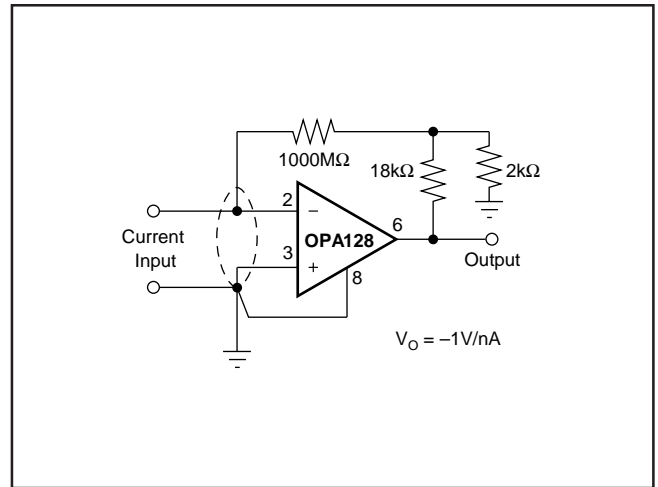


FIGURE 8. Current-to-Voltage Converter.

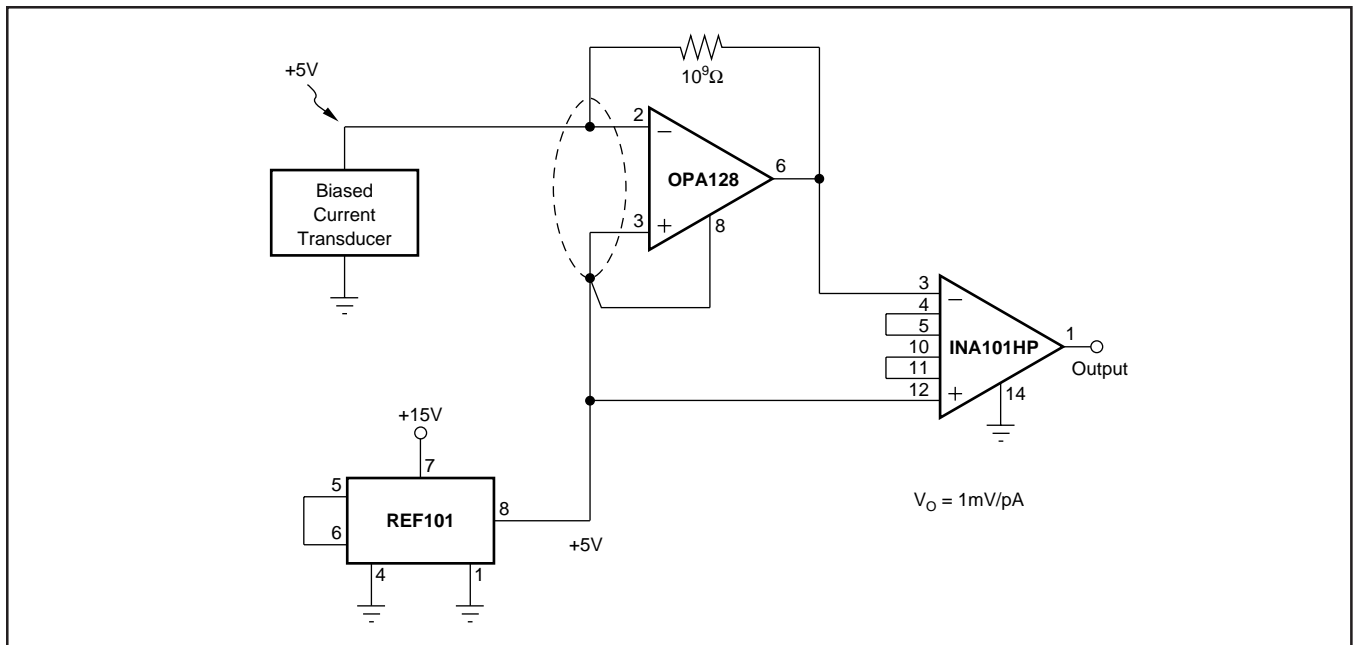


FIGURE 9. Biased Current-to-Voltage Converter.

**PACKAGING INFORMATION**

| Orderable Device | Status <sup>(1)</sup> | Package Type | Package Drawing | Pins | Package Qty | Eco Plan <sup>(2)</sup> | Lead/Ball Finish | MSL Peak Temp <sup>(3)</sup> |
|------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|------------------|------------------------------|
| OPA128JM         | NRND                  | TO-99        | LMC             | 8    | 20          | Green (RoHS & no Sb/Br) | AU               | N / A for Pkg Type           |
| OPA128KM         | NRND                  | TO-99        | LMC             | 8    | 20          | Green (RoHS & no Sb/Br) | AU               | N / A for Pkg Type           |
| OPA128LM         | NRND                  | TO-99        | LMC             | 8    | 20          | Green (RoHS & no Sb/Br) | AU               | N / A for Pkg Type           |
| OPA128SM         | NRND                  | TO-99        | LMC             | 8    | 20          | Green (RoHS & no Sb/Br) | AU               | N / A for Pkg Type           |

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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