

# OPA111

## Low Noise Precision *Difet*<sup>®</sup> OPERATIONAL AMPLIFIER

### FEATURES

- LOW NOISE: 100% Tested,  $8\text{nV}/\sqrt{\text{Hz}}$  max (10kHz)
- LOW BIAS CURRENT: 1pA max
- LOW OFFSET: 250 $\mu\text{V}$  max
- LOW DRIFT: 1 $\mu\text{V}/^\circ\text{C}$  max
- HIGH OPEN-LOOP GAIN: 120dB min
- HIGH COMMON-MODE REJECTION: 100dB min

### APPLICATIONS

- PRECISION INSTRUMENTATION
- DATA ACQUISITION
- TEST EQUIPMENT
- OPTOELECTRONICS
- MEDICAL EQUIPMENT—CAT SCANNER
- RADIATION HARD EQUIPMENT

### DESCRIPTION

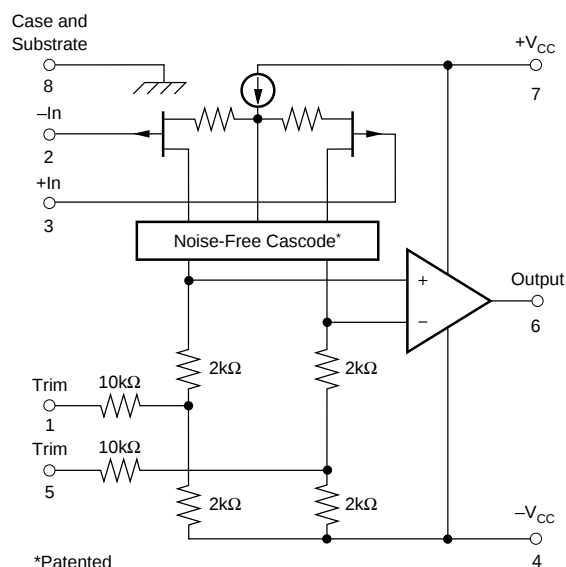
The OPA111 is a precision monolithic dielectrically isolated FET (*Difet*<sup>®</sup>) operational amplifier. Outstanding performance characteristics allow its use in the most critical instrumentation applications.

Noise, bias current, voltage offset, drift, open-loop gain, common-mode rejection, and power supply rejection are superior to BIFET<sup>®</sup> amplifiers.

Very low bias current is obtained by dielectric isolation with on-chip guarding.

Laser trimming of thin-film resistors gives very low offset and drift. Extremely low noise is achieved with patented circuit design techniques. A new cascode design allows high precision input specifications and reduced susceptibility to flicker noise.

Standard 741 pin configuration allows upgrading of existing designs to higher performance levels.



BIFET<sup>®</sup> National Semiconductor Corp., *Difet*<sup>®</sup> Burr-Brown Corp.

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# SPECIFICATIONS

## ELECTRICAL

At  $V_{CC} = \pm 15\text{VDC}$  and  $T_A = +25^\circ\text{C}$  unless otherwise noted.

| PARAMETER                                                                                                                                                                                                                                                                | CONDITION                                                                                                                               | OPA111AM              |                                                |                                                | OPA111BM              |                                                |                                              | OPA111SM              |                                                |                                                | UNITS                                                                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------------------------------------------------|------------------------------------------------|-----------------------|------------------------------------------------|----------------------------------------------|-----------------------|------------------------------------------------|------------------------------------------------|---------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                          |                                                                                                                                         | MIN                   | TYP                                            | MAX                                            | MIN                   | TYP                                            | MAX                                          | MIN                   | TYP                                            | MAX                                            |                                                                           |
| INPUT                                                                                                                                                                                                                                                                    |                                                                                                                                         |                       |                                                |                                                |                       |                                                |                                              |                       |                                                |                                                |                                                                           |
| NOISE<br>Voltage, f <sub>O</sub> = 10Hz<br>f <sub>O</sub> = 100Hz<br>f <sub>O</sub> = 1kHz<br>f <sub>O</sub> = 10kHz<br>f <sub>B</sub> = 10Hz to 10kHz<br>f <sub>B</sub> = 0.1Hz to 10Hz<br>Current, f <sub>B</sub> = 0.1Hz to 10Hz<br>f <sub>O</sub> = 0.1Hz thru 20kHz | 100% Tested<br>100% Tested<br>100% Tested<br>100% Tested<br>100% Tested<br>(1)<br>(1)<br>(1)                                            |                       | 40<br>15<br>8<br>6<br>0.7<br>1.6<br>9.5<br>0.5 | 80<br>40<br>15<br>8<br>1.2<br>3.3<br>15<br>0.8 |                       | 30<br>11<br>7<br>6<br>0.6<br>1.2<br>7.5<br>0.4 | 60<br>30<br>12<br>8<br>1<br>2.5<br>12<br>0.6 |                       | 40<br>15<br>8<br>6<br>0.7<br>1.6<br>9.5<br>0.5 | 80<br>40<br>15<br>8<br>1.2<br>3.3<br>15<br>0.8 | nV/√Hz<br>nV/√Hz<br>nV/√Hz<br>nV/√Hz<br>μVrms<br>μVp-p<br>fAp-p<br>fA/√Hz |
| OFFSET VOLTAGE(2)<br>Input Offset Voltage<br>Average Drift<br>Supply Rejection                                                                                                                                                                                           | V <sub>CM</sub> = 0VDC<br>T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub><br>V <sub>CC</sub> = ±10V to ±18V                       | 90                    | ±100<br>±2<br>110<br>±3                        | ±500<br>±5<br><br>±31                          | 100                   | ±50<br>±0.5<br>110<br>±3                       | ±250<br>±1<br><br>±10                        | 90                    | ±100<br>±2<br>110<br>±3                        | ±500<br>±5<br><br>±31                          | μV<br>μV/°C<br>dB<br>μV/V                                                 |
| BIAS CURRENT(2)<br>Input Bias Current                                                                                                                                                                                                                                    | V <sub>CM</sub> = 0VDC                                                                                                                  |                       | ±0.8                                           | ±2                                             |                       | ±0.5                                           | ±1                                           |                       | ±0.8                                           | ±2                                             | pA                                                                        |
| OFFSET CURRENT(2)<br>Input Offset Current                                                                                                                                                                                                                                | V <sub>CM</sub> = 0VDC                                                                                                                  |                       | ±0.5                                           | ±1.5                                           |                       | ±0.25                                          | ±0.75                                        |                       | ±0.5                                           | ±1.5                                           | pA                                                                        |
| IMPEDANCE<br>Differential<br>Common-Mode                                                                                                                                                                                                                                 |                                                                                                                                         |                       | 10 <sup>13</sup>    1<br>10 <sup>14</sup>    3 |                                                |                       | 10 <sup>13</sup>    1<br>10 <sup>14</sup>    3 |                                              |                       | 10 <sup>13</sup>    1<br>10 <sup>14</sup>    3 |                                                | Ω    pF<br>Ω    pF                                                        |
| VOLTAGE RANGE<br>Common-Mode Input Range<br>Common-Mode Rejection                                                                                                                                                                                                        | V <sub>IN</sub> = ±10VDC                                                                                                                | ±10<br>90             | ±11<br>110                                     |                                                | ±10<br>100            | ±11<br>110                                     |                                              | ±10<br>90             | ±11<br>110                                     |                                                | V<br>dB                                                                   |
| OPEN-LOOP GAIN, DC                                                                                                                                                                                                                                                       |                                                                                                                                         |                       |                                                |                                                |                       |                                                |                                              |                       |                                                |                                                |                                                                           |
| Open-Loop Voltage Gain                                                                                                                                                                                                                                                   | R <sub>L</sub> ≥ 2kΩ                                                                                                                    | 114                   | 125                                            |                                                | 120                   | 125                                            |                                              | 114                   | 125                                            |                                                | dB                                                                        |
| FREQUENCY RESPONSE                                                                                                                                                                                                                                                       |                                                                                                                                         |                       |                                                |                                                |                       |                                                |                                              |                       |                                                |                                                |                                                                           |
| 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(3)                                                                                                                                   | 20Vp-p, R <sub>L</sub> = 2kΩ<br>V <sub>O</sub> = ±10V, R <sub>L</sub> = 2kΩ<br>Gain = -1, R <sub>L</sub> = 2kΩ<br>10V Step<br>Gain = -1 | 16<br><br>1           | 2<br>32<br>2<br>6<br>10<br>5                   |                                                | 16<br><br>1           | 2<br>32<br>2<br>6<br>10<br>5                   |                                              | 16<br><br>1           | 2<br>32<br>2<br>6<br>10<br>5                   |                                                | MHz<br>kHz<br>V/μs<br>μs<br>μs<br>μs                                      |
| RATED OUTPUT                                                                                                                                                                                                                                                             |                                                                                                                                         |                       |                                                |                                                |                       |                                                |                                              |                       |                                                |                                                |                                                                           |
| Voltage Output<br>Current Output<br>Output Resistance<br>Load Capacitance Stability<br>Short Circuit Current                                                                                                                                                             | R <sub>L</sub> = 2kΩ<br>V <sub>O</sub> = ±10VDC<br>DC, Open Loop<br>Gain = +1                                                           | ±11<br>±5.5<br><br>10 | ±12<br>±10<br>100<br>1000<br>40                |                                                | ±11<br>±5.5<br><br>10 | ±12<br>±10<br>100<br>1000<br>40                |                                              | ±11<br>±5.5<br><br>10 | ±12<br>±10<br>100<br>1000<br>40                |                                                | V<br>mA<br>Ω<br>pF<br>mA                                                  |
| POWER SUPPLY                                                                                                                                                                                                                                                             |                                                                                                                                         |                       |                                                |                                                |                       |                                                |                                              |                       |                                                |                                                |                                                                           |
| Rated Voltage<br>Voltage Range, Derated<br>Performance<br>Current, Quiescent                                                                                                                                                                                             |                                                                                                                                         | ±5                    | ±15<br><br><br>2.5                             | ±18<br>3.5                                     | ±5                    | ±15<br><br><br>2.5                             | ±18<br>3.5                                   | ±5                    | ±15<br><br><br>2.5                             | ±18<br>3.5                                     | VDC<br>VDC<br>mA                                                          |
| TEMPERATURE RANGE                                                                                                                                                                                                                                                        |                                                                                                                                         |                       |                                                |                                                |                       |                                                |                                              |                       |                                                |                                                |                                                                           |
| Specification<br>Operating<br>Storage<br>θ Junction-Ambient                                                                                                                                                                                                              | Ambient Temp.<br>Ambient Temp.<br>Ambient Temp.                                                                                         | -25<br>-55<br>-65     | <br><br>200                                    | +85<br>+125<br>+150                            | -25<br>-55<br>-65     | <br><br>200                                    | +85<br>+125<br>+150                          | -55<br>-55<br>-65     | <br><br>200                                    | +125<br>+125<br>+150                           | °C<br>°C<br>°C<br>°C/W                                                    |

NOTES: (1) Sample tested—this parameter is guaranteed. (2) Offset voltage, offset current, and bias current are measured with the units fully warmed up. (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.

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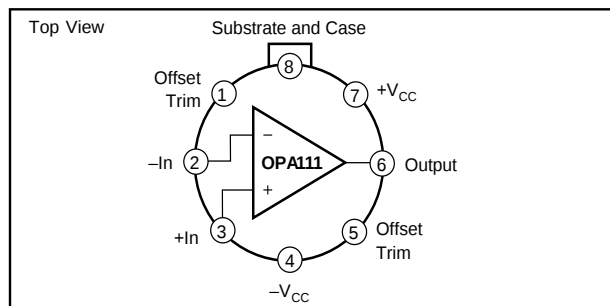
## ELECTRICAL (FULL TEMPERATURE RANGE SPECIFICATIONS)

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

| PARAMETER                                                                                  | CONDITION                                                                | OPA111AM             |                          |                           | OPA111BM           |                            |                          | OPA111SM           |                          |                           | UNITS                     |
|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|----------------------|--------------------------|---------------------------|--------------------|----------------------------|--------------------------|--------------------|--------------------------|---------------------------|---------------------------|
|                                                                                            |                                                                          | MIN                  | TYP                      | MAX                       | MIN                | TYP                        | MAX                      | MIN                | TYP                      | MAX                       |                           |
| TEMPERATURE RANGE                                                                          |                                                                          |                      |                          |                           |                    |                            |                          |                    |                          |                           |                           |
| Specification Range                                                                        | Ambient Temp.                                                            | −25                  |                          | +85                       | −25                |                            | +85                      | −55                |                          | +125                      | °C                        |
| INPUT                                                                                      |                                                                          |                      |                          |                           |                    |                            |                          |                    |                          |                           |                           |
| OFFSET VOLTAGE <sup>(1)</sup><br>Input Offset Voltage<br>Average Drift<br>Supply Rejection | V <sub>CM</sub> = 0VDC<br><br>V <sub>CC</sub> = ±10V to ±18V             | 86                   | ±220<br>±2<br>100<br>±10 | ±1000<br>±5<br>100<br>±50 | 90                 | ±110<br>±0.5<br>100<br>±10 | ±500<br>±1<br>100<br>±32 | 86                 | ±300<br>±2<br>100<br>±10 | ±1500<br>±5<br>100<br>±50 | μV<br>μV/°C<br>dB<br>μV/V |
| BIAS CURRENT <sup>(1)</sup><br>Input Bias Current                                          | V <sub>CM</sub> = 0VDC                                                   |                      | ±50                      | ±250                      |                    | ±30                        | ±130                     |                    | ±820                     | ±4100                     | pA                        |
| OFFSET CURRENT <sup>(1)</sup><br>Input Offset Current                                      | V <sub>CM</sub> = 0VDC                                                   |                      | ±30                      | ±200                      |                    | ±15                        | ±100                     |                    | ±510                     | ±3100                     | pA                        |
| VOLTAGE RANGE<br>Common-Mode Input Range<br>Common-Mode Rejection                          | V <sub>IN</sub> = ±10VDC                                                 | ±10<br>86            | ±11<br>100               |                           | ±10<br>90          | ±11<br>100                 |                          | ±10<br>86          | ±11<br>100               |                           | V<br>dB                   |
| OPEN-LOOP GAIN, DC                                                                         |                                                                          |                      |                          |                           |                    |                            |                          |                    |                          |                           |                           |
| Open-Loop Voltage Gain                                                                     | R <sub>L</sub> ≥ 2kΩ                                                     | 110                  | 120                      |                           | 114                | 120                        |                          | 110                | 120                      |                           | dB                        |
| RATED OUTPUT                                                                               |                                                                          |                      |                          |                           |                    |                            |                          |                    |                          |                           |                           |
| Voltage Output<br>Current Output<br>Short Circuit Current                                  | R <sub>L</sub> = 2kΩ<br>V <sub>O</sub> = ±10VDC<br>V <sub>O</sub> = 0VDC | ±10.5<br>±5.25<br>10 | ±11<br>±10<br>40         |                           | ±11<br>±5.25<br>10 | ±11.5<br>±10<br>40         |                          | ±11<br>±5.25<br>10 | ±11.5<br>±10<br>40       |                           | V<br>mA<br>mA             |
| POWER SUPPLY                                                                               |                                                                          |                      |                          |                           |                    |                            |                          |                    |                          |                           |                           |
| Current, Quiescent                                                                         | I <sub>O</sub> = 0mADC                                                   |                      | 2.5                      | 3.5                       |                    | 2.5                        | 3.5                      |                    | 2.5                      | 3.5                       | mA                        |

NOTES: (1) Offset voltage, offset current, and bias current are measured with the units fully warmed up.

## CONNECTION DIAGRAM



## ABSOLUTE MAXIMUM RATINGS

|                                              |                    |
|----------------------------------------------|--------------------|
| Supply                                       | $\pm 18\text{VDC}$ |
| Internal Power Dissipation <sup>(1)</sup>    | 750mW              |
| Differential Input Voltage <sup>(2)</sup>    | $\pm 36\text{VDC}$ |
| Input Voltage Range <sup>(2)</sup>           | $\pm 18\text{VDC}$ |
| Storage Temperature Range                    | -65°C to +150°C    |
| Operating Temperature Range                  | -55°C to +125°C    |
| Lead Temperature (soldering, 10s)            | +300°C             |
| Output Short Circuit Duration <sup>(3)</sup> | Continuous         |
| Junction Temperature                         | +175°C             |

NOTES: (1) Packages must be derated based on  $\theta_{JC} = 150^\circ\text{C/W}$  or  $\theta_{JA} = 300^\circ\text{C/W}$ . (2) For supply voltages less than  $\pm 18\text{VDC}$ , the absolute maximum input voltage is equal to  $+18\text{V} > V_{IN} > -V_{CC} - 6\text{V}$ . See Figure 2. (3) Short circuit may be to power supply common only. Rating applies to +25°C ambient. Observe dissipation limit and  $T_J$ .

## PACKAGE INFORMATION

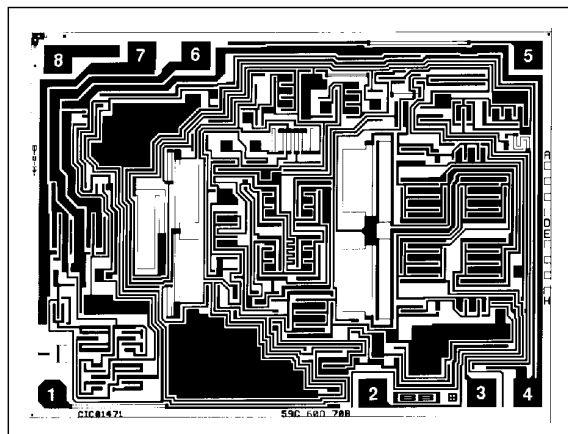
| MODEL    | PACKAGE | PACKAGE DRAWING NUMBER <sup>(1)</sup> |
|----------|---------|---------------------------------------|
| OPA111AM | TO-99   | 001                                   |
| OPA111BM | TO-99   | 001                                   |
| OPA111SM | TO-99   | 001                                   |

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

## ORDERING INFORMATION

| MODEL    | PACKAGE | TEMPERATURE RANGE | OFFSET VOLTAGE, MAX ( $\mu\text{V}$ ) |
|----------|---------|-------------------|---------------------------------------|
| OPA111AM | TO-99   | -25°C to +85°C    | $\pm 500$                             |
| OPA111BM | TO-99   | -25°C to +85°C    | $\pm 250$                             |
| OPA111SM | TO-99   | -55°C to +125°C   | $\pm 500$                             |

## DICE INFORMATION



OPA111AD DIE TOPOGRAPHY

| PAD | FUNCTION        |
|-----|-----------------|
| 1   | Offset Trim     |
| 2   | -In             |
| 3   | +In             |
| 4   | -V <sub>s</sub> |
| 5   | Offset Trim     |
| 6   | Output          |
| 7   | +V <sub>s</sub> |
| 8   | Substrate       |

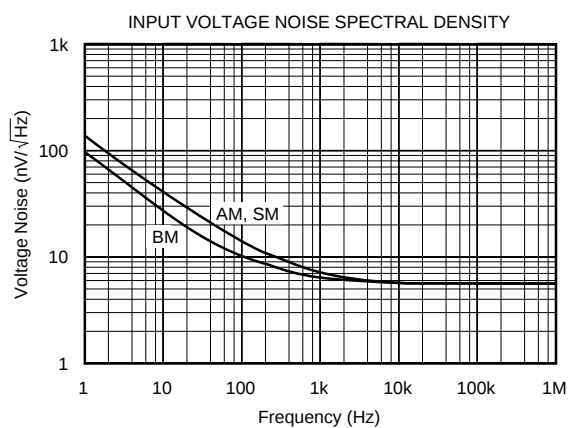
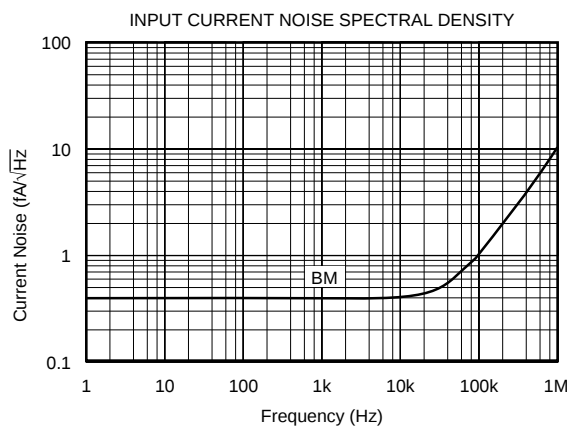
**Substrate Bias:** This Dielectrically-Isolated Substrate is normally connected to common.

## MECHANICAL INFORMATION

|                   | MILS (0.001") | MILLIMETERS       |
|-------------------|---------------|-------------------|
| Die Size          | 95 x 71 ±5    | 2.41 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          |                   |
| Transistor Count: | 44            |                   |

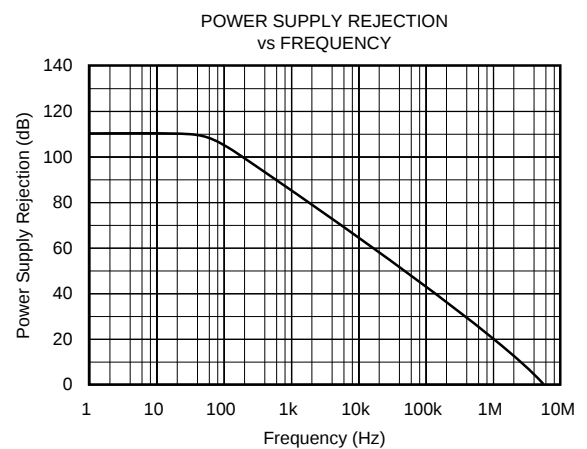
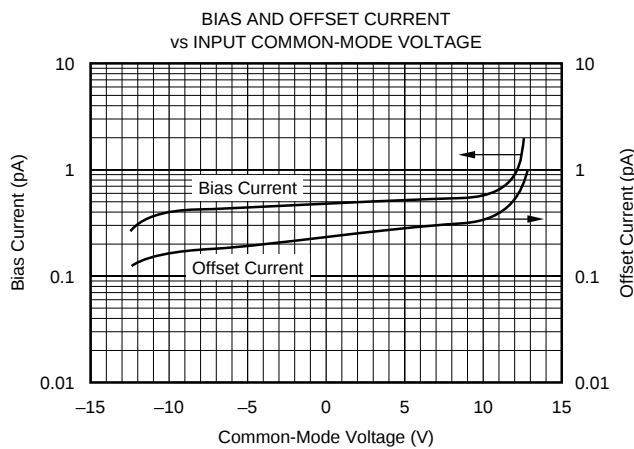
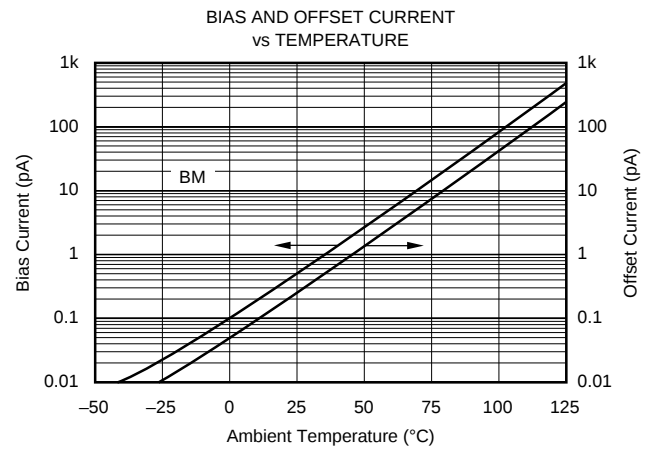
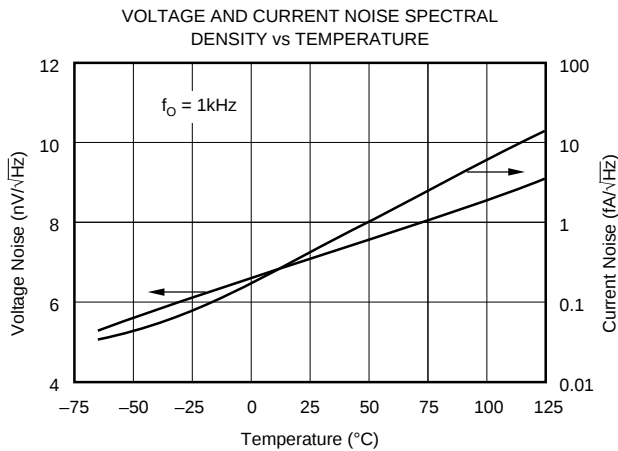
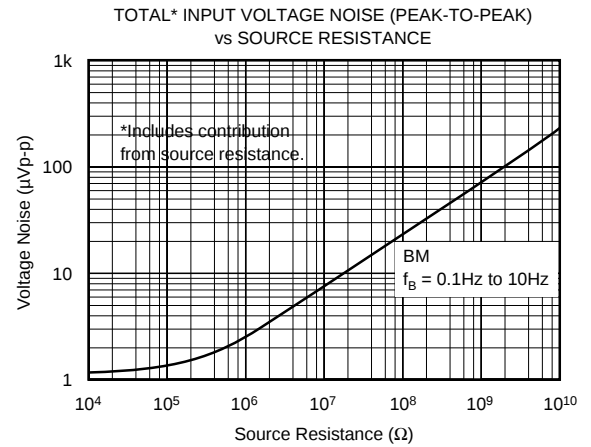
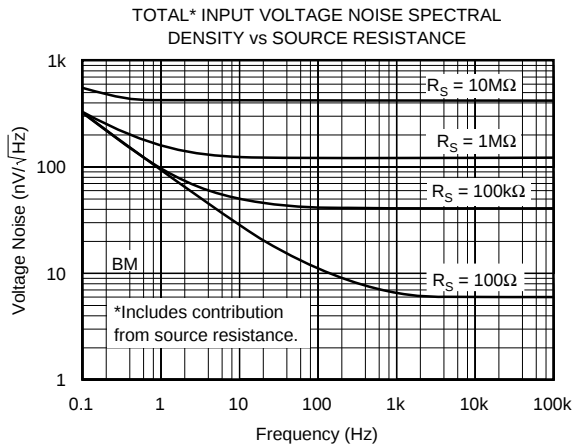
## TYPICAL PERFORMANCE CURVES

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



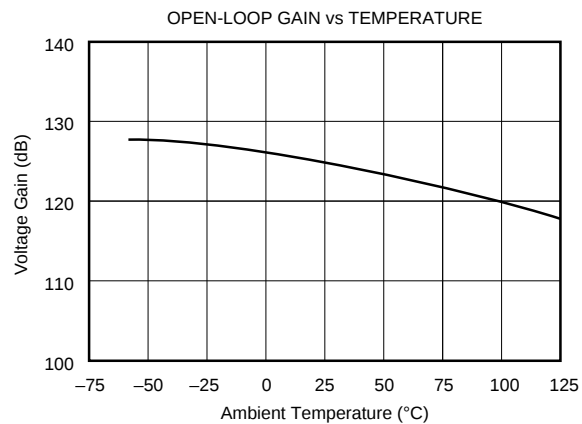
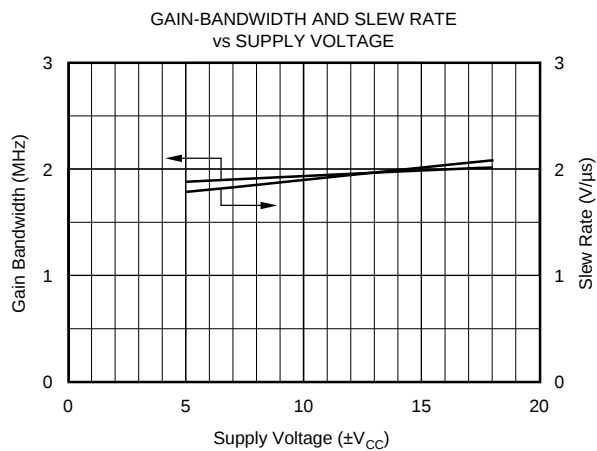
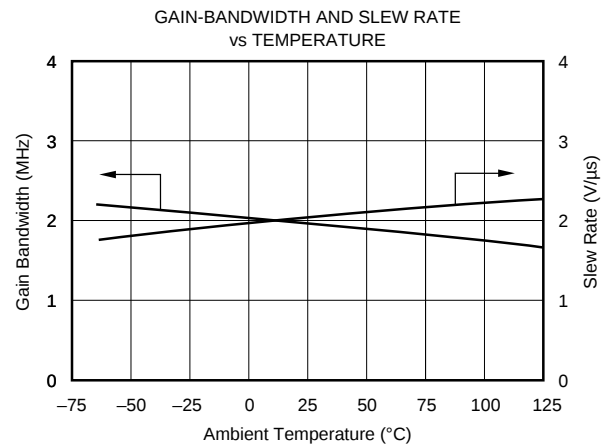
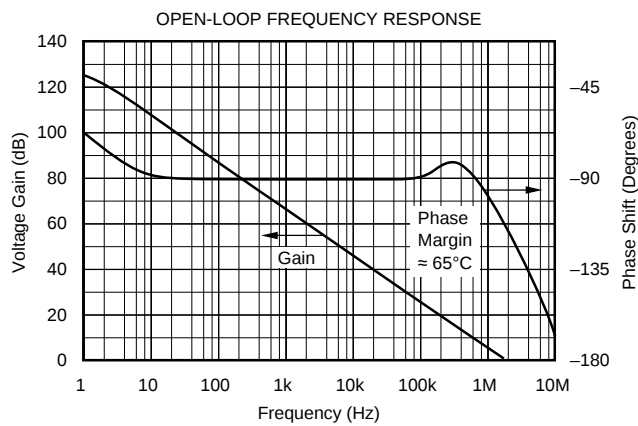
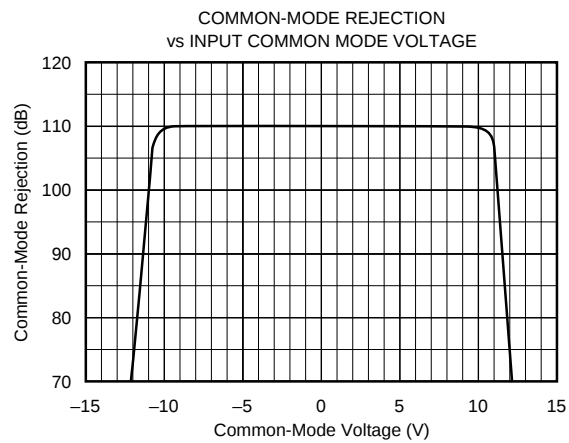
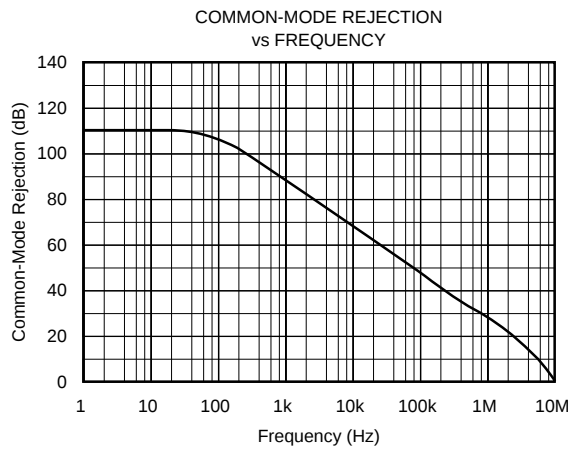
# TYPICAL PERFORMANCE CURVES (CONT)

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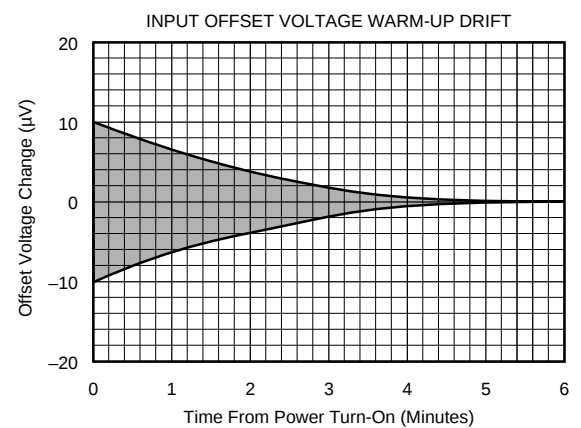
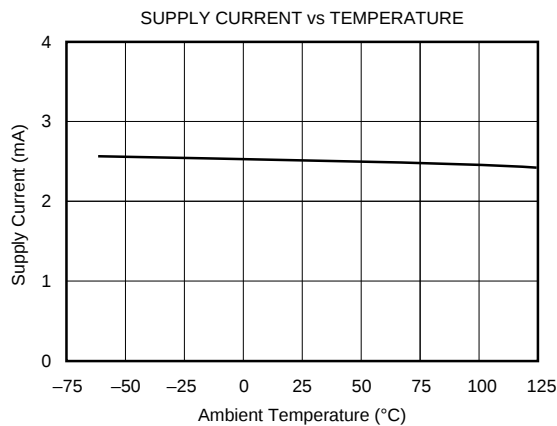
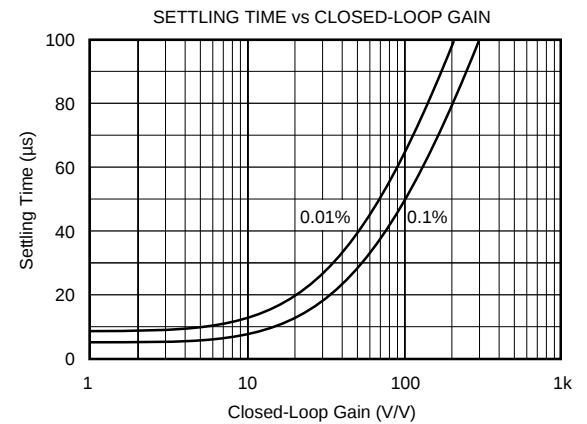
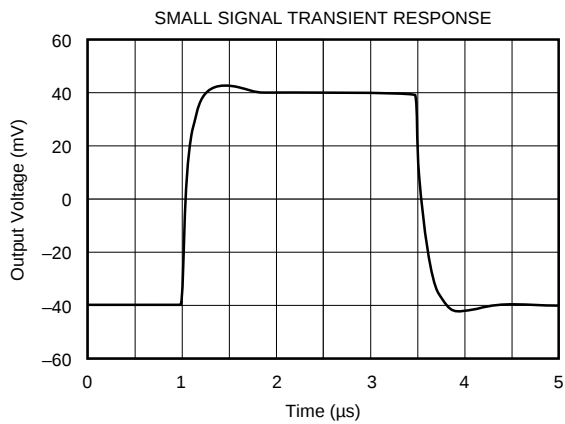
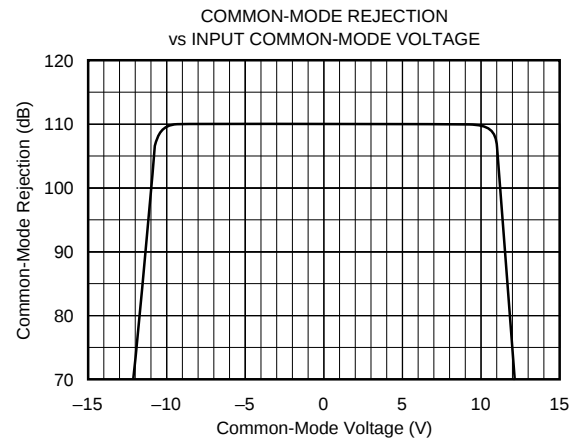
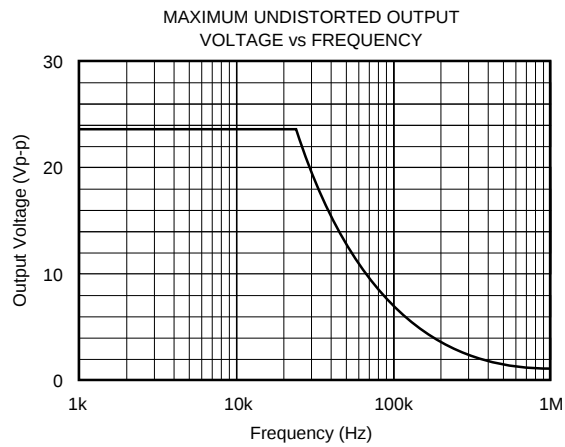
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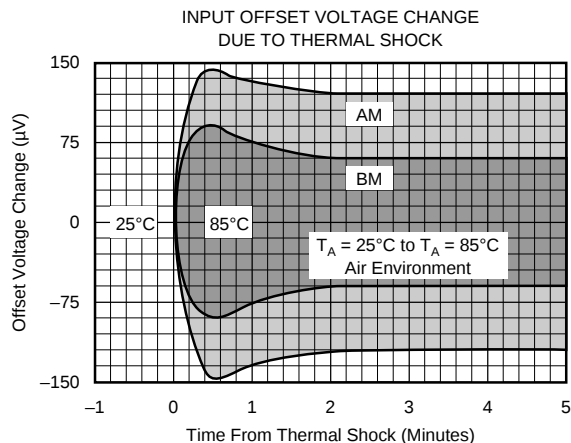
# TYPICAL PERFORMANCE CURVES (CONT)

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



## TYPICAL PERFORMANCE CURVES (CONT)

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



## APPLICATIONS INFORMATION

### OFFSET VOLTAGE ADJUSTMENT

The OPA111 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 offset. Note that the trim (Figure 1) is similar to operational amplifiers such as 741 and AD547. The OPA111 can replace most other amplifiers by leaving the external null circuit unconnected.

### INPUT PROTECTION

Conventional monolithic FET operational amplifiers require external current-limiting resistors to protect their inputs 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  $-V_{CC}$ .

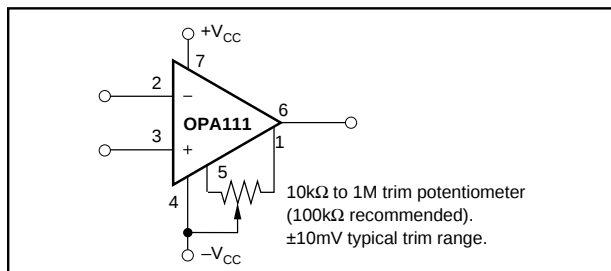


FIGURE 1. Offset Voltage Trim.

Unlike BIFET amplifiers, The **Difet** OPA111 requires input current limiting resistors only if its input voltage is greater than 6V more negative than  $-V_{CC}$ . A  $10\text{k}\Omega$  series resistor will limit input current to a safe level with up to  $\pm 15\text{V}$  input levels, even if both supply voltages are lost.

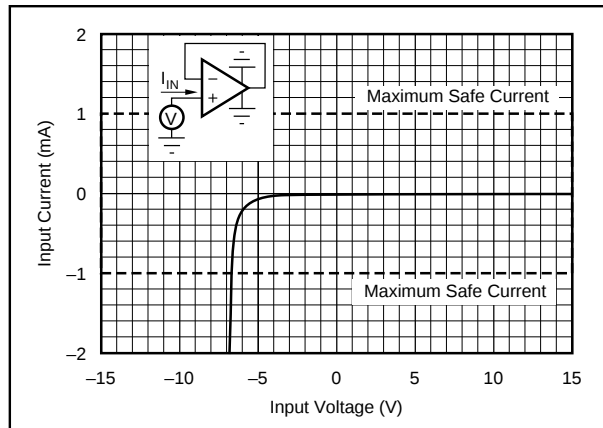


FIGURE 2. Input Current vs Input Voltage with  $\pm V_{CC}$  Pins Grounded.

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 OPA111. To avoid leakage problems, it is recommended that the signal input lead of the OPA111 be wired to a Teflon standoff. If the OPA111 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 3).

If guarding is not required, pin 8 (case) should be connected to ground.

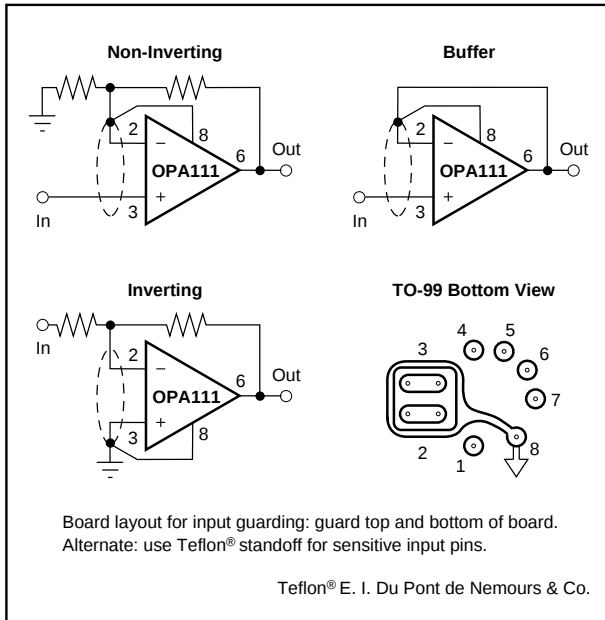


FIGURE 3. Connection of Input Guard.

### NOISE: FET VERSUS BIPOLAR

Low noise circuit design requires careful analysis of all noise sources. External noise sources can dominate in many cases, so consider the effect of source resistance on overall operational amplifier noise performance. At low source impedances, the lower voltage noise of a bipolar operational amplifier is superior, but at higher impedances the high current noise of a bipolar amplifier becomes a serious liability. Above about 15k $\Omega$ , the OPA111 will have a lower total noise than an OP-27 (see Figure 4).

### BIAS CURRENT CHANGE VERSUS COMMON-MODE VOLTAGE

The input bias current of most popular BIFET operational amplifiers are affected by common-mode voltage (Figure 5). Higher input FET gate-to-drain voltage causes leakage and ionization (bias) currents to increase. Due to its cascode input stage, the extremely low bias current of the OPA111 is not compromised by common-mode voltage.

### APPLICATIONS CIRCUITS

Figures 6 through 18 are circuit diagrams of various applications for the OPA111.

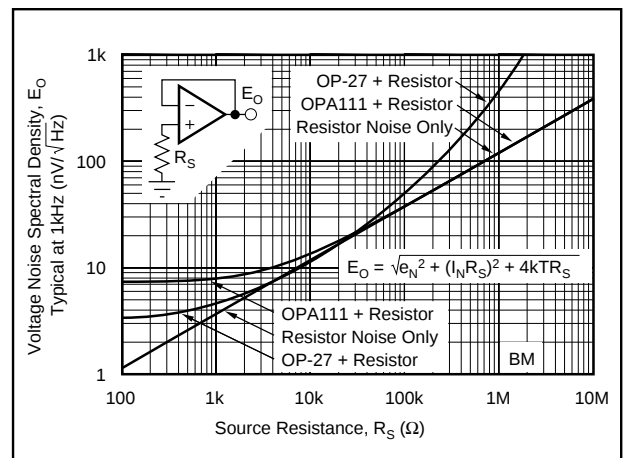


FIGURE 4. Voltage Noise Spectral Density vs Source Resistance.

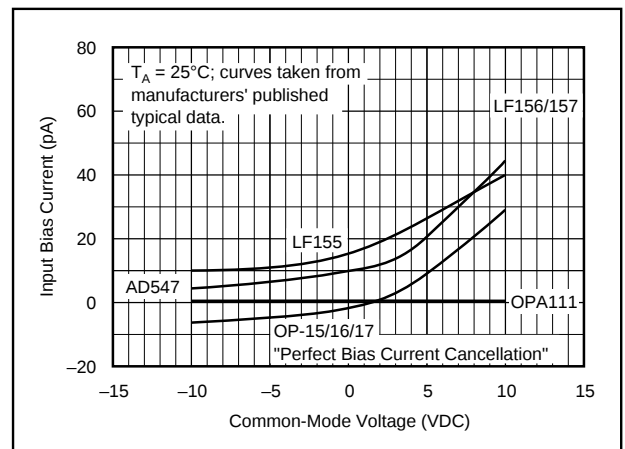


FIGURE 5. Input Bias Current vs Common-Mode Voltage.

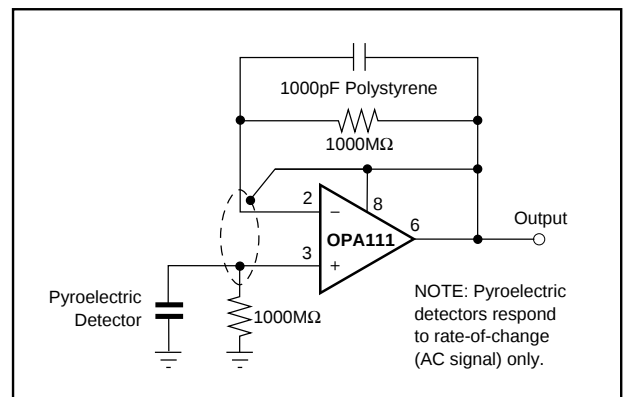


FIGURE 6. Pyroelectric Infrared Detector.

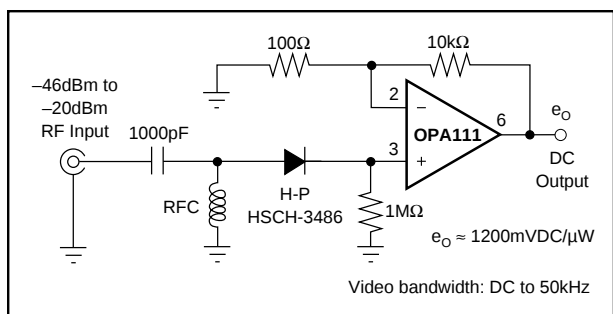


FIGURE 7. Zero-Bias Schottky Diode Square-Law RF Detector.

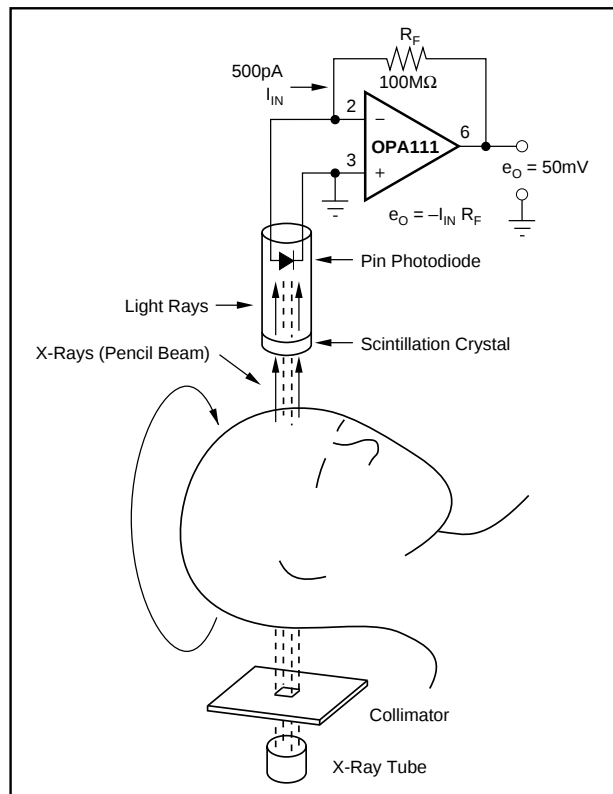


FIGURE 8. Computerized Axial Tomography (CAT) Scanner Channel Amplifier.

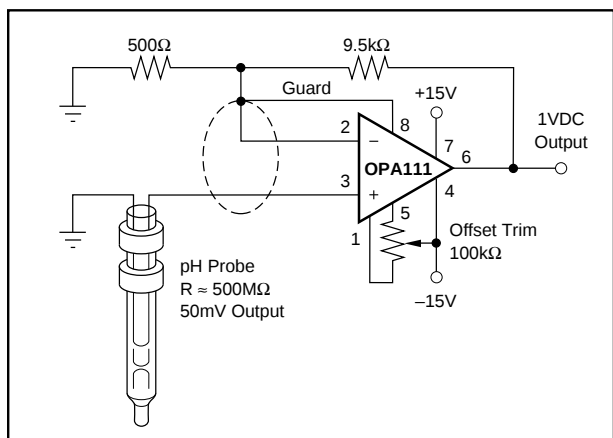


FIGURE 9. High Impedance ( $10^{14}\Omega$ ) Amplifier.

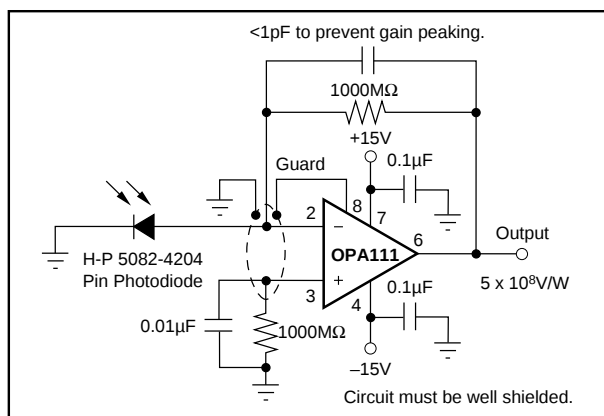


FIGURE 10. Sensitive Photodiode Amplifier.

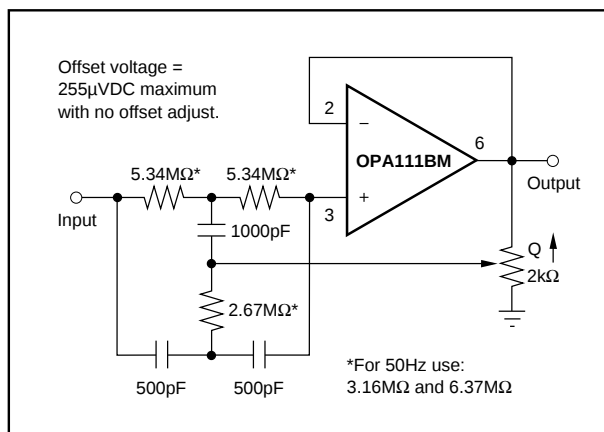


FIGURE 11. 60Hz Reject Filter.

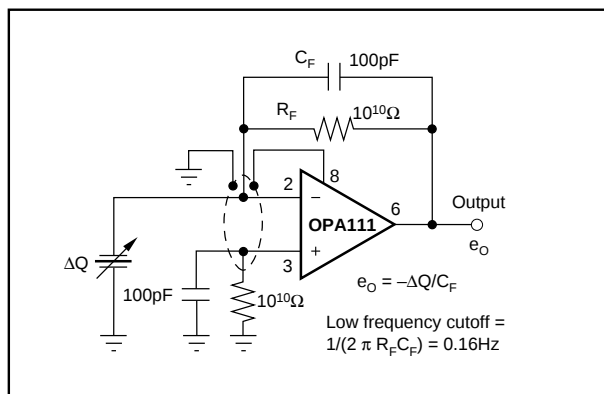


FIGURE 12. Piezoelectric Transducer Charge Amplifier.

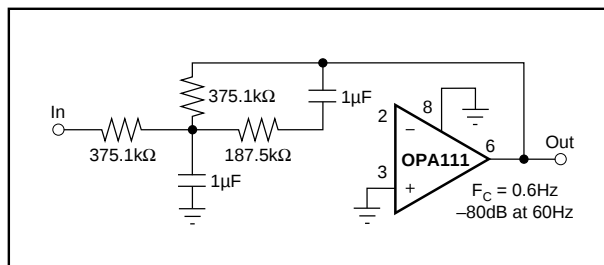


FIGURE 13. 0.6Hz Second-Order Low-Pass Filter.

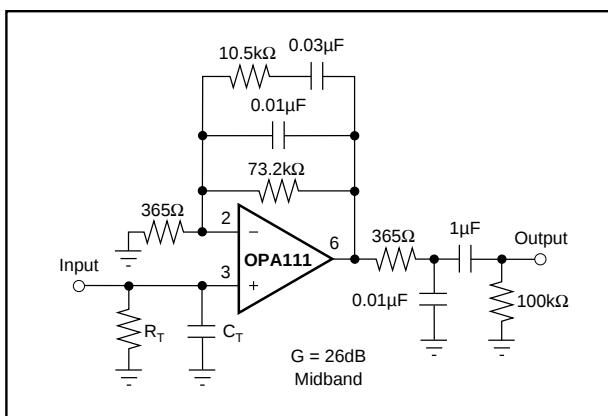


FIGURE 14. RIAA Equalized Phono Preamplifier.

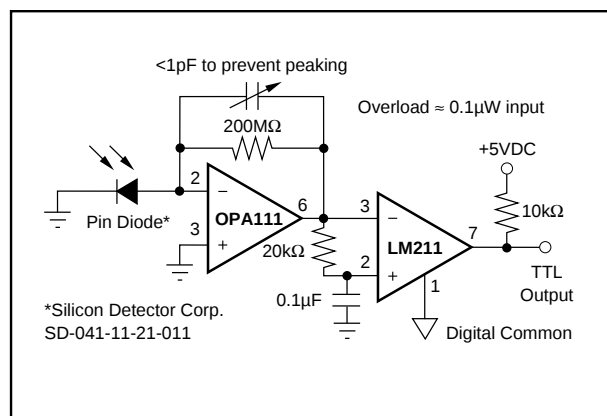


FIGURE 15. High Sensitivity (under 1nW) Fiber Optic Receiver for 9600 Baud Manchester Data.

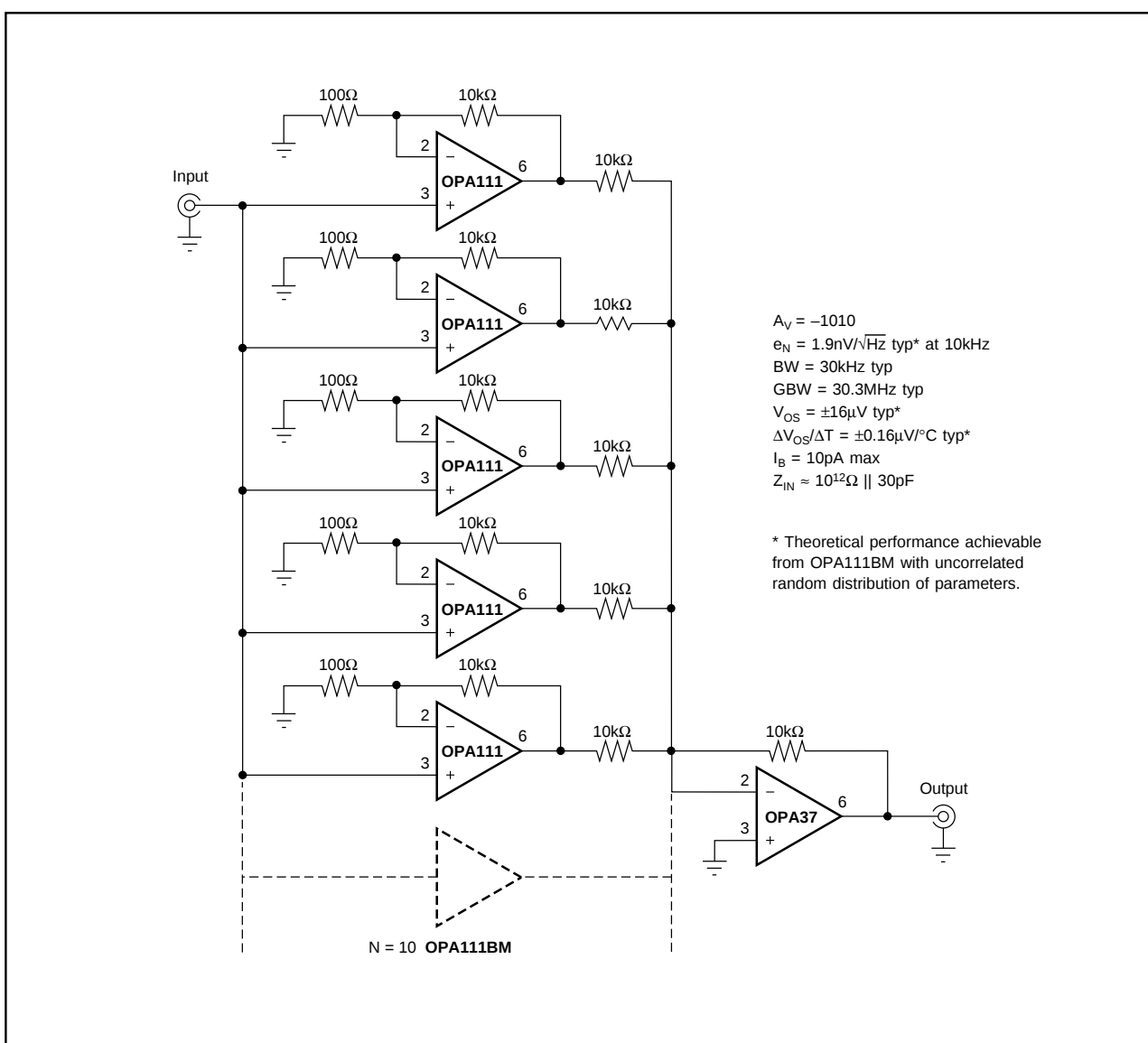


FIGURE 16. 'N' Stage Parallel-Input Amplifier for Reduced Relative Amplifier Noise at the Output.

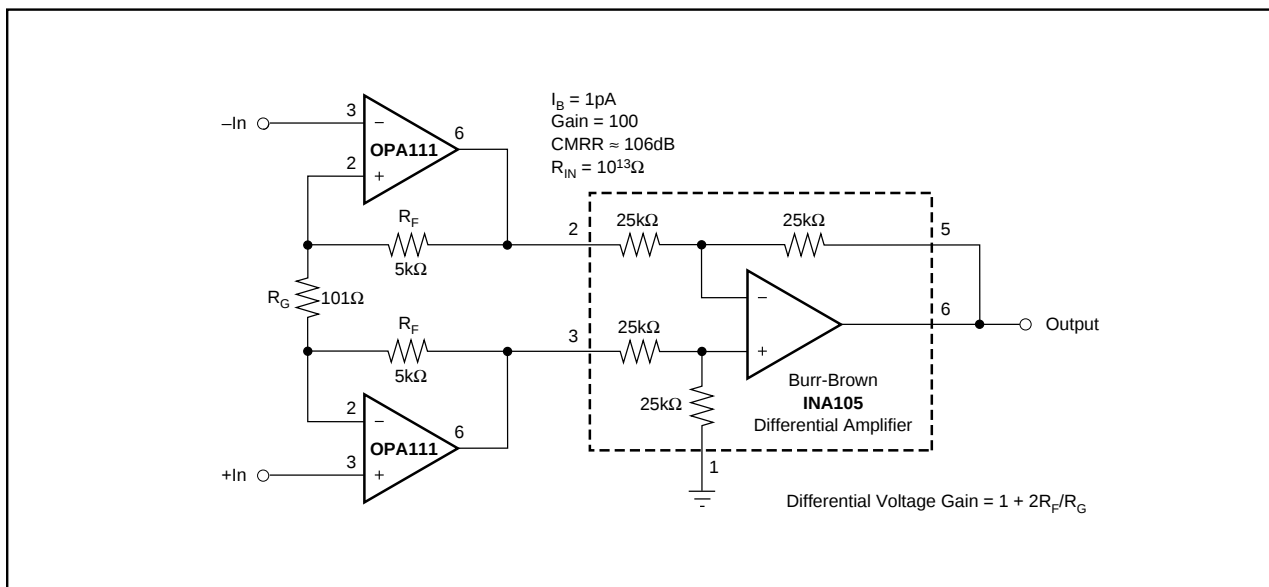


FIGURE 17. FET Input Instrumentation Amplifier.

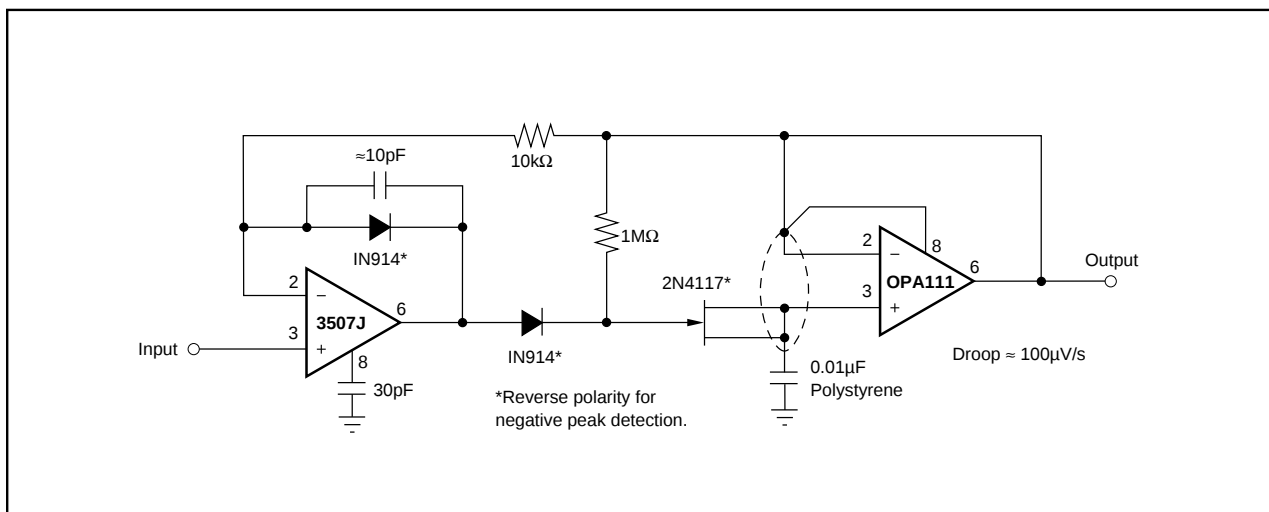


FIGURE 18. Low-Droop Positive Peak Detector.