



**THE DATASHEET OF  
LT1996CMS#TRPBF**



# Precision, 100 $\mu$ A Gain Selectable Amplifier

## FEATURES

- Pin Configurable as a Difference Amplifier, Inverting and Noninverting Amplifier
- **Difference Amplifier**  
Gain Range 9 to 117  
CMRR >80dB
- **Noninverting Amplifier**  
Gain Range 0.008 to 118
- **Inverting Amplifier**  
Gain Range -0.08 to -117
- **Gain Error: <0.05%**
- **Gain Drift: < 3ppm/°C**
- **Wide Supply Range: Single 2.7V to Split  $\pm$ 18V**
- **Micropower Operation: 100 $\mu$ A Supply**
- **Input Offset Voltage: 50 $\mu$ V (Max)**
- **Gain Bandwidth Product: 560kHz**
- **Rail-to-Rail Output**
- **Space Saving 10-Lead MSOP and DFN Packages**

## APPLICATIONS

- Handheld Instrumentation
- Medical Instrumentation
- Strain Gauge Amplifiers
- Differential to Single-Ended Conversion

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## DESCRIPTION

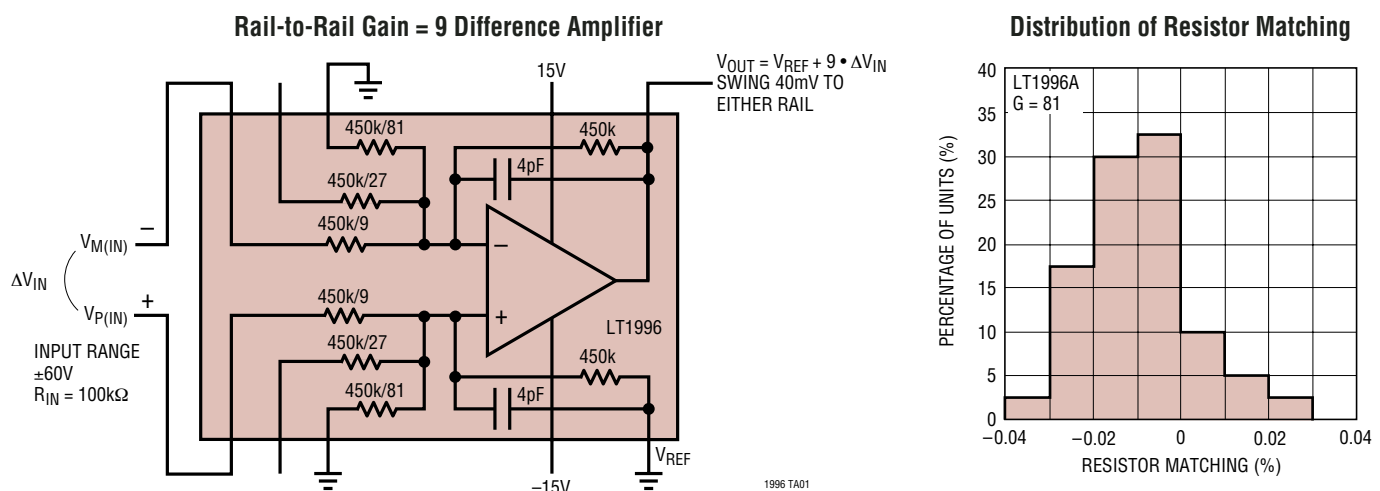
The LT<sup>®</sup>1996 combines a precision operational amplifier with eight precision resistors to form a one-chip solution for accurately amplifying voltages. Gains from -117 to 118 with a gain accuracy of 0.05% can be achieved without any external components. The device is particularly well suited for use as a difference amplifier, where the excellent resistor matching results in a common mode rejection ratio of greater than 80dB.

The amplifier features a 50 $\mu$ V maximum input offset voltage and a gain bandwidth product of 560kHz. The device operates from any supply voltage from 2.7V to 36V and draws only 100 $\mu$ A supply current on a 5V supply. The output swings to within 40mV of either supply rail.

The internal resistors have excellent matching characteristics; variation is 0.05% over temperature with a guaranteed matching temperature coefficient of less than 3ppm/°C. The resistors are also extremely stable over voltage, exhibiting a nonlinearity of less than 10ppm.

The LT1996 is fully specified at 5V and  $\pm$ 15V supplies and from -40°C to 85°C. The device is available in space saving 10-lead MSOP and DFN packages. For an amplifier with selectable gains from -13 to 14, see the LT1991 data sheet.

## TYPICAL APPLICATION



**ABSOLUTE MAXIMUM RATINGS** (Note 1)

|   |               |  |                |
|---|---------------|--|----------------|
| Total Supply Voltage ( $V^+$ to $V^-$ ) ..... | 40V           | Maximum Junction Temperature                   |                |
| Input Voltage (Pins P9/M9, Note 2) .....      | $\pm 60V$     | DD Package .....                               | 125°C          |
| Input Current                                 |               | MS Package .....                               | 150°C          |
| (Pins P27/M27/P81/M81, Note 2) .....          | $\pm 10mA$    | Storage Temperature Range                      |                |
| Output Short-Circuit Duration (Note 3) .....  | Indefinite    | DD Package .....                               | -65°C to 125°C |
| Operating Temperature Range (Note 4) ...      | -40°C to 85°C | MS Package .....                               | -65°C to 150°C |
| Specified Temperature Range (Note 5) ....     | -40°C to 85°C | MSOP-Lead Temperature (Soldering, 10 sec)..... | 300°C          |

**PACKAGE/ORDER INFORMATION**

|  |  |  |  |
|--|--|--|--|
| <p>DD PACKAGE<br/>10-LEAD (3mm x 3mm) PLASTIC DFN<br/><math>T_{JMAX} = 125^\circ C</math>, <math>\theta_{JA} = 160^\circ C/W</math><br/>UNDERSIDE METAL CONNECTED TO <math>V_{EE}</math><br/>(PCB CONNECTION OPTIONAL)</p> | ORDER PART NUMBER                                  | <p>MS PACKAGE<br/>10-LEAD PLASTIC MSOP<br/><math>T_{JMAX} = 150^\circ C</math>, <math>\theta_{JA} = 230^\circ C/W</math></p> | ORDER PART NUMBER                                  |
|  | LT1996CDD<br>LT1996IDD<br>LT1996ACDD<br>LT1996AIDD |  | LT1996CMS<br>LT1996IMS<br>LT1996ACMS<br>LT1996AIMS |
|  | DD PART MARKING*                                   |  | MS PART MARKING*                                   |
|  | LBPC   |  | LTBPB  |

\*Temperature and electrical grades are identified by a label on the shipping container. Consult LTC Marketing for parts specified with wider operating temperature ranges.

**ELECTRICAL CHARACTERISTICS** The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ C$ . Difference amplifier configuration,  $V_S = 5V$ ,  $0V$  or  $\pm 15V$ ;  $V_{CM} = V_{REF} =$  half supply, unless otherwise noted.

| SYMBOL  | PARAMETER         | CONDITIONS  | MIN                                | TYP   | MAX   | UNITS  |   |                 |
|---|-------------------|---|------------------------------------|---|---|--|---|-----------------|
| $\Delta G$  | Gain Error        | $V_S = \pm 15V$ , $V_{OUT} = \pm 10V$ ; $R_L = 10k$           |                                    |   |   |  |   |                 |
|   |                   | $G = 81$ ; LT1996AMS  | ●                                  | $\pm 0.02$  | $\pm 0.05$  | %  |   |                 |
|   |                   | $G = 27$ ; LT1996AMS  | ●                                  | $\pm 0.03$  | $\pm 0.06$  | %  |   |                 |
|   |                   | $G = 9$ ; LT1996AMS   | ●                                  | $\pm 0.03$  | $\pm 0.07$  | %  |   |                 |
|   |                   | $G = 81$ ; LT1996ADD  | ●                                  | $\pm 0.02$  | $\pm 0.05$  | %  |   |                 |
|   |                   | $G = 27$ ; LT1996ADD  | ●                                  | $\pm 0.02$  | $\pm 0.07$  | %  |   |                 |
|   |                   | $G = 9$ ; LT1996ADD   | ●                                  | $\pm 0.03$  | $\pm 0.08$  | %  |   |                 |
|   |                   | $G = 81$ ; LT1996   | ●                                  | $\pm 0.04$  | $\pm 0.12$  | %  |   |                 |
|   |                   | $G = 27$ ; LT1996   | ●                                  | $\pm 0.04$  | $\pm 0.12$  | %  |   |                 |
| GNL   | Gain Nonlinearity | $V_S = \pm 15V$ ; $V_{OUT} = \pm 10V$ ; $R_L = 10k$ ; $G = 9$ | ●                                  | 1   | 10  | ppm  |   |                 |
|   |                   | $\Delta G/\Delta T$   | Gain Drift vs Temperature (Note 6) | $V_S = \pm 15V$ ; $V_{OUT} = \pm 10V$ ; $R_L = 10k$ | ●   | 0.3  | 3 | ppm/ $^\circ C$ |
|   |                   |   |                                    | CMRR  | Common Mode Rejection Ratio, Referred to Inputs (RTI) | $V_S = \pm 15V$ ; $G = 9$ ; $V_{CM} = \pm 15.3V$ |   |                 |
| LT1996AMS   | ●                 | 80  | 100                                |   |   | dB   |   |                 |
| LT1996ADD   | ●                 | 80  | 100                                |   |   | dB   |   |                 |
| LT1996  | ●                 | 70  | 100                                |   |   | dB   |   |                 |
| $V_S = \pm 15V$ ; $G = 27$ ; $V_{CM} = -14.5V$ to $14.3V$ |                   |   |                                    |   |   |  |   |                 |
| LT1996AMS   | ●                 | 95  | 105                                |   |   | dB   |   |                 |
| LT1996ADD   | ●                 | 90  | 105                                | dB  |   |  |   |                 |
| LT1996  | ●                 | 75  | 105                                | dB  |   |  |   |                 |

**ELECTRICAL CHARACTERISTICS** The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . Difference amplifier configuration,  $V_S = 5\text{V}$ ,  $0\text{V}$  or  $\pm 15\text{V}$ ;  $V_{CM} = V_{REF} = \text{half supply}$ , unless otherwise noted.

| SYMBOL                   | PARAMETER  | CONDITIONS  | MIN | TYP   | MAX                 | UNITS                          |            |
|--------------------------|--|---|-----|-------|---------------------|--------------------------------|------------|
| CMRR                     | Common Mode Rejection Ratio (RTI)                        | $V_S = \pm 15\text{V}$ ; $G = 81$ ; $V_{CM} = -14.1\text{V}$ to $13.9\text{V}$<br>LT1996AMS | ●   | 105   | 120                 | dB                             |            |
|                          |  | LT1996ADD   | ●   | 100   | 120                 | dB                             |            |
|                          |  | LT1996  | ●   | 85    | 120                 | dB                             |            |
| $V_{CM}$                 | Input Voltage Range (Note 7)                             | P9/M9 Inputs<br>$V_S = \pm 15\text{V}$ ; $V_{REF} = 0\text{V}$                              | ●   | -15.5 | 15.3                | V                              |            |
|                          |  | $V_S = 5\text{V}$ , $0\text{V}$ ; $V_{REF} = 2.5\text{V}$                                   | ●   | 0.84  | 3.94                | V                              |            |
|                          |  | $V_S = 3\text{V}$ , $0\text{V}$ ; $V_{REF} = 1.25\text{V}$                                  | ●   | 0.98  | 1.86                | V                              |            |
|                          |  | P9/M9 Inputs, P81/M81 Connected to REF<br>$V_S = \pm 15\text{V}$ ; $V_{REF} = 0\text{V}$    | ●   | -60   | 60                  | V                              |            |
|                          |  | $V_S = 5\text{V}$ , $0\text{V}$ ; $V_{REF} = 2.5\text{V}$                                   | ●   | -12.6 | 15.6                | V                              |            |
|                          |  | $V_S = 3\text{V}$ , $0\text{V}$ ; $V_{REF} = 1.25\text{V}$                                  | ●   | -1.25 | 6.8                 | V                              |            |
|                          |  | P27/M27 Inputs<br>$V_S = \pm 15\text{V}$ ; $V_{REF} = 0\text{V}$                            | ●   | -14.5 | 14.3                | V                              |            |
|                          |  | $V_S = 5\text{V}$ , $0\text{V}$ ; $V_{REF} = 2.5\text{V}$                                   | ●   | 0.95  | 3.84                | V                              |            |
|                          |  | $V_S = 3\text{V}$ , $0\text{V}$ ; $V_{REF} = 1.25\text{V}$                                  | ●   | 1     | 1.82                | V                              |            |
|                          |  | P81/M81 Inputs<br>$V_S = \pm 15\text{V}$ ; $V_{REF} = 0\text{V}$                            | ●   | -14.1 | 13.9                | V                              |            |
|                          |  | $V_S = 5\text{V}$ , $0\text{V}$ ; $V_{REF} = 2.5\text{V}$                                   | ●   | 0.99  | 3.81                | V                              |            |
|                          |  | $V_S = 3\text{V}$ , $0\text{V}$ ; $V_{REF} = 1.25\text{V}$                                  | ●   | 1     | 1.8                 | V                              |            |
| $V_{OS}$                 | Op Amp Offset Voltage (Note 8)                           | LT1996AMS, $V_S = 5\text{V}$ , $0\text{V}$  | ●   |       | 15 50<br>135        | $\mu\text{V}$<br>$\mu\text{V}$ |            |
|                          |  | LT1996AMS, $V_S = \pm 15\text{V}$   | ●   |       | 15 80<br>160        | $\mu\text{V}$<br>$\mu\text{V}$ |            |
|                          |  | LT1996MS  | ●   |       | 25 100<br>200       | $\mu\text{V}$<br>$\mu\text{V}$ |            |
|                          |  | LT1996DD  | ●   |       | 25 150<br>250       | $\mu\text{V}$<br>$\mu\text{V}$ |            |
| $\Delta V_{OS}/\Delta T$ | Op Amp Offset Voltage Drift (Note 6)                     |   | ●   | 0.3   | 1                   | $\mu\text{V}/^\circ\text{C}$   |            |
| $I_B$                    | Op Amp Input Bias Current                                |   | ●   | 2.5   | 5                   | nA                             |            |
|                          |  |   | ●   |       | 7.5                 | nA                             |            |
| $I_{OS}$                 | Op Amp Input Offset Current                              | LT1996A   | ●   | 50    | 500                 | pA                             |            |
|                          |  | LT1996  | ●   | 50    | 750<br>1000<br>1500 | pA<br>pA<br>pA                 |            |
| $e_n$                    | Op Amp Input Noise Voltage                               | 0.01Hz to 1Hz   |     | 0.35  |                     | $\mu\text{V}_{P-P}$            |            |
|                          |  | 0.01Hz to 1Hz   |     | 0.07  |                     | $\mu\text{V}_{RMS}$            |            |
|                          |  | 0.1Hz to 10Hz   |     | 0.25  |                     | $\mu\text{V}_{P-P}$            |            |
|                          |  | 0.1Hz to 10Hz   |     | 0.05  |                     | $\mu\text{V}_{RMS}$            |            |
| $e_n$                    | Input Noise Voltage Density<br>(Includes Resistor Noise) | $G = 9$ ; $f = 1\text{kHz}$   |     | 46    |                     | $\text{nV}/\sqrt{\text{Hz}}$   |            |
|                          |  | $G = 117$ ; $f = 1\text{kHz}$   |     | 18    |                     | $\text{nV}/\sqrt{\text{Hz}}$   |            |
| $R_{IN}$                 | Input Impedance (Note 10)                                | P9 (M9 = Ground)  | ●   | 350   | 500                 | 650                            | k $\Omega$ |
|                          |  | P27 (M27 = Ground)  | ●   | 326.9 | 467                 | 607.1                          | k $\Omega$ |
|                          |  | P81 (M81 = Ground)  | ●   | 319.2 | 456                 | 592.8                          | k $\Omega$ |
|                          |  | M9 (P9 = Ground)  | ●   | 35    | 50                  | 65                             | k $\Omega$ |
|                          |  | M27 (P27 = Ground)  | ●   | 11.69 | 16.7                | 21.71                          | k $\Omega$ |
|                          |  | M81 (P81 = Ground)  | ●   | 3.85  | 5.5                 | 7.15                           | k $\Omega$ |

**ELECTRICAL CHARACTERISTICS** The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . Difference amplifier configuration,  $V_S = 5\text{V}, 0\text{V}$  or  $\pm 15\text{V}$ ;  $V_{CM} = V_{REF} = \text{half supply}$ , unless otherwise noted.

| SYMBOL                       | PARAMETER                                 | CONDITIONS  | MIN | TYP        | MAX           | UNITS                  |  |
|------------------------------|---|---|-----|------------|---------------|------------------------|--|
| $\Delta R$                   | Resistor Matching (Note 9)                | G = 81; LT1996AMS   | ●   | $\pm 0.02$ | $\pm 0.05$    | %                      |  |
|                              |   | G = 27; LT1996AMS   | ●   | $\pm 0.03$ | $\pm 0.06$    | %                      |  |
|                              |   | G = 9; LT1996AMS  | ●   | $\pm 0.03$ | $\pm 0.07$    | %                      |  |
|                              |   | G = 81; LT1996ADD   | ●   | $\pm 0.02$ | $\pm 0.05$    | %                      |  |
|                              |   | G = 27; LT1996ADD   | ●   | $\pm 0.02$ | $\pm 0.07$    | %                      |  |
|                              |   | G = 9; LT1996ADD  | ●   | $\pm 0.03$ | $\pm 0.08$    | %                      |  |
|                              |   | G = 81; LT1996  | ●   | $\pm 0.04$ | $\pm 0.12$    | %                      |  |
|                              |   | G = 27; LT1996  | ●   | $\pm 0.04$ | $\pm 0.12$    | %                      |  |
|                              |   | G = 9; LT1996   | ●   | $\pm 0.04$ | $\pm 0.12$    | %                      |  |
| $\Delta R/\Delta T$          | Resistor Temperature Coefficient (Note 6) | Resistor Matching   | ●   | 0.3        | 3             | ppm/ $^\circ\text{C}$  |  |
|                              |   | Absolute Value  | ●   | -30        |               | ppm/ $^\circ\text{C}$  |  |
| PSRR                         | Power Supply Rejection Ratio              | $V_S = \pm 1.35\text{V}$ to $\pm 18\text{V}$ (Note 8)               | ●   | 105        | 135           | dB                     |  |
|                              | Minimum Supply Voltage                    |   | ●   | 2.4        | 2.7           | V                      |  |
| $V_{OUT}$                    | Output Voltage Swing (to Either Rail)     | No Load   |     |            |               |                        |  |
|                              |   | $V_S = 5\text{V}, 0\text{V}$  |     | 40         | 55            | mV                     |  |
|                              |   | $V_S = 5\text{V}, 0\text{V}$  | ●   |            | 65            | mV                     |  |
|                              |   | $V_S = \pm 15\text{V}$  | ●   |            | 110           | mV                     |  |
|                              |   | 1mA Load  |     |            |               |                        |  |
|                              |   | $V_S = 5\text{V}, 0\text{V}$  |     | 150        | 225           | mV                     |  |
| $V_S = 5\text{V}, 0\text{V}$ | ●   |   | 275 | mV         |               |                        |  |
| $V_S = \pm 15\text{V}$       | ●   |   | 300 | mV         |               |                        |  |
| $I_{SC}$                     | Output Short-Circuit Current (Sourcing)   | Drive Output Positive;<br>Short Output to Ground                    | ●   | 8<br>4     | 12            | mA<br>mA               |  |
|                              | Output Short-Circuit Current (Sinking)    | Drive Output Negative;<br>Short Output to $V_S$ or Midsupply        | ●   | 8<br>4     | 21            | mA<br>mA               |  |
| BW                           | -3dB Bandwidth                            | G = 9   |     | 38         |               | kHz                    |  |
|                              |   | G = 27  |     | 17         |               | kHz                    |  |
|                              |   | G = 81  |     | 7          |               | kHz                    |  |
| GBWP                         | Op Amp Gain Bandwidth Product             | f = 10kHz   |     | 560        |               | kHz                    |  |
| $t_r, t_f$                   | Rise Time, Fall Time                      | G = 9; 0.1V Step; 10% to 90%  |     | 8          |               | $\mu\text{s}$          |  |
|                              |   | G = 81; 0.1V Step; 10% to 90%                                       |     | 40         |               | $\mu\text{s}$          |  |
| $t_S$                        | Settling Time to 0.01%                    | G = 9; $V_S = 5\text{V}, 0\text{V}$ ; 2V Step                       |     | 85         |               | $\mu\text{s}$          |  |
|                              |   | G = 9; $V_S = 5\text{V}, 0\text{V}$ ; -2V Step                      |     | 85         |               | $\mu\text{s}$          |  |
|                              |   | G = 9; $V_S = \pm 15\text{V}$ ; 10V Step                            |     | 110        |               | $\mu\text{s}$          |  |
|                              |   | G = 9; $V_S = \pm 15\text{V}$ ; -10V Step                           |     | 110        |               | $\mu\text{s}$          |  |
| SR                           | Slew Rate                                 | $V_S = 5\text{V}, 0\text{V}$ ; $V_{OUT} = 1\text{V}$ to $4\text{V}$ | ●   | 0.06       | 0.12          | $\text{V}/\mu\text{s}$ |  |
|                              |   | $V_S = \pm 15\text{V}$ ; $V_{OUT} = \pm 10\text{V}$                 | ●   | 0.08       | 0.12          | $\text{V}/\mu\text{s}$ |  |
| $I_S$                        | Supply Current                            | $V_S = 5\text{V}, 0\text{V}$  | ●   | 100        | 110           | $\mu\text{A}$          |  |
|                              |   |   |     |            | 150           | $\mu\text{A}$          |  |
|                              |   | $V_S = \pm 15\text{V}$  | ●   | 130        | 160           | $\mu\text{A}$          |  |
|                              |   |   |     | 210        | $\mu\text{A}$ |                        |  |

**Note 1:** Absolute Maximum Ratings are those beyond which the life of the device may be impaired.

**Note 2:** The P27/M27 and P81/M81 inputs are protected by ESD diodes to the supply rails. If one of these four inputs goes outside the rails, the input current should be limited to less than 10mA. The P9/M9 inputs can

withstand  $\pm 60\text{V}$  if P81/M81 are grounded and  $V_S = \pm 15\text{V}$  (see Applications Information section about "High Voltage CM Difference Amplifiers").

**Note 3:** A heat sink may be required to keep the junction temperature below absolute maximum ratings.

## ELECTRICAL CHARACTERISTICS

**Note 4:** Both the LT1996C and LT1996I are guaranteed functional over the  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  temperature range.

**Note 5:** The LT1996C is guaranteed to meet the specified performance from  $0^{\circ}\text{C}$  to  $70^{\circ}\text{C}$  and is designed, characterized and expected to meet specified performance from  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  but is not tested or QA sampled at these temperatures. The LT1996I is guaranteed to meet specified performance from  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ .

**Note 6:** This parameter is not 100% tested.

**Note 7:** Input voltage range is guaranteed by the CMRR test at  $V_S = \pm 15\text{V}$ . For the other voltages, this parameter is guaranteed by design and through correlation with the  $\pm 15\text{V}$  test. See the Applications Information section to

determine the valid input voltage range under various operating conditions.

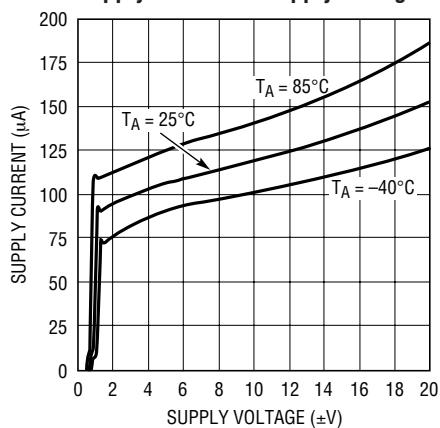
**Note 8:** Offset voltage, offset voltage drift and PSRR are defined as referred to the internal op amp. You can calculate output offset as follows. In the case of balanced source resistance,  $V_{OS, OUT} = V_{OS} \cdot \text{Noise Gain} + I_{OS} \cdot 450\text{k} + I_B \cdot 450\text{k} \cdot (1 - R_P/R_N)$  where  $R_P$  and  $R_N$  are the total resistance at the op amp positive and negative terminal respectively.

**Note 9:** Resistors connected to the minus inputs. Resistor matching is not tested directly, but is guaranteed by the gain error test.

**Note 10:** Input impedance is tested by a combination of direct measurements and correlation to the CMRR and gain error tests.

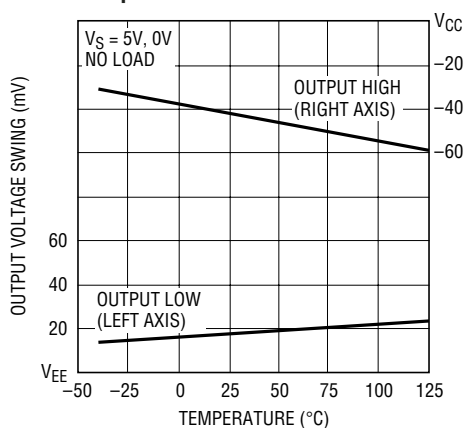
## TYPICAL PERFORMANCE CHARACTERISTICS (Difference Amplifier Configuration)

Supply Current vs Supply Voltage



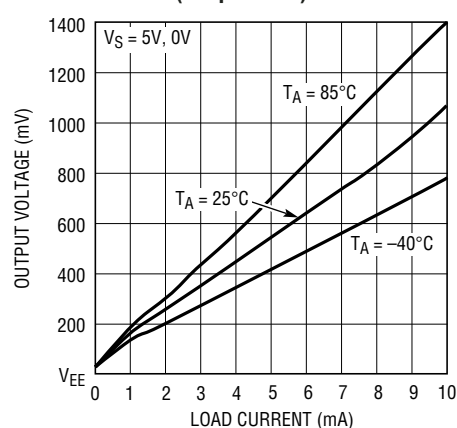
1996 G01

Output Voltage Swing vs Temperature



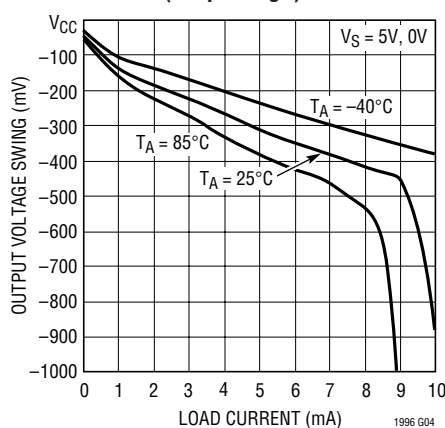
1996 G02

Output Voltage Swing vs Load Current (Output Low)



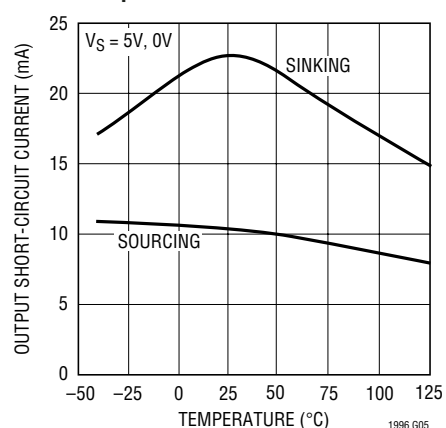
1996 G03

Output Voltage Swing vs Load Current (Output High)



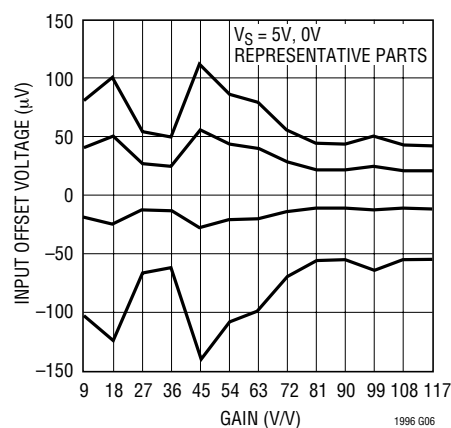
1996 G04

Output Short-Circuit Current vs Temperature



1996 G05

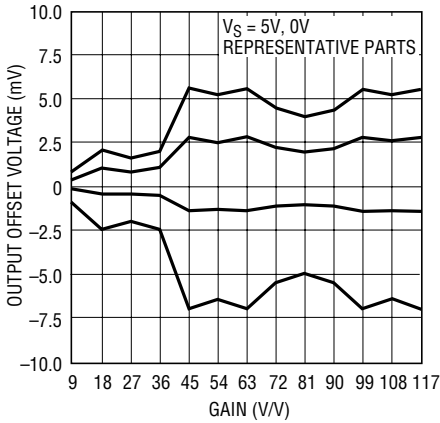
Input Offset Voltage vs Difference Gain



1996 G06

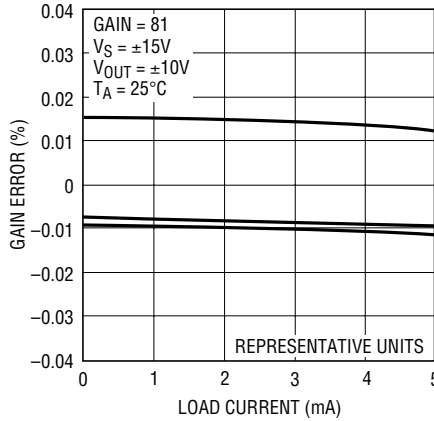
**TYPICAL PERFORMANCE CHARACTERISTICS** (Difference Amplifier Configuration)

**Output Offset Voltage vs Difference Gain**



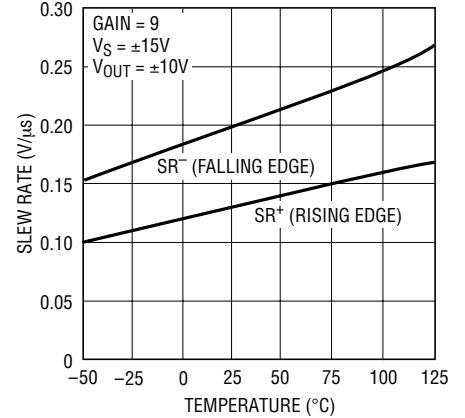
1996 G07

**Gain Error vs Load Current**



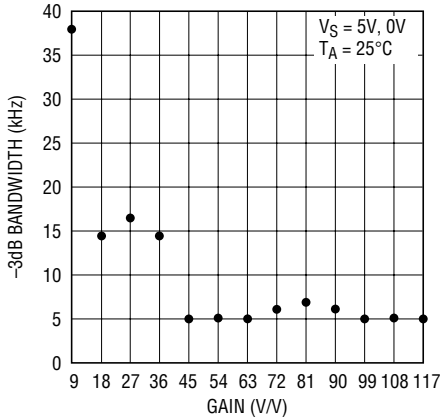
1996 G08

**Slew Rate vs Temperature**



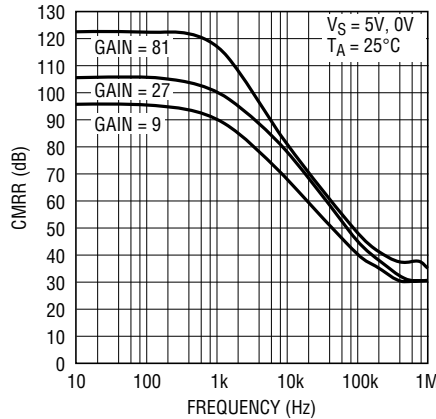
1996 G09

**Bandwidth vs Gain**



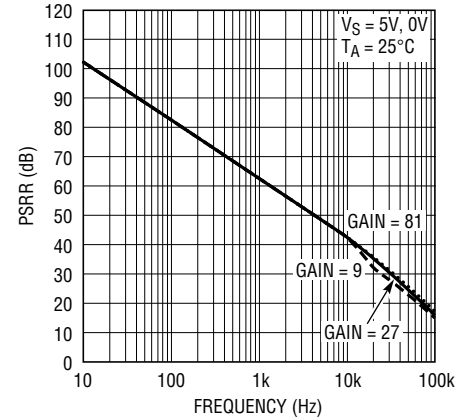
1996 G10

**CMRR vs Frequency**



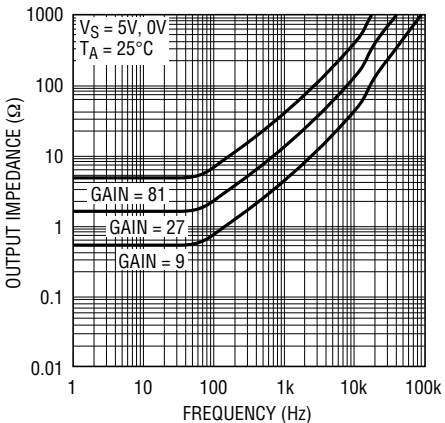
1996 G11

**PSRR vs Frequency**



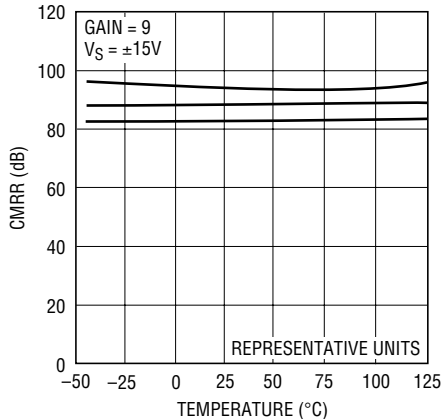
1996 G12

**Output Impedance vs Frequency**



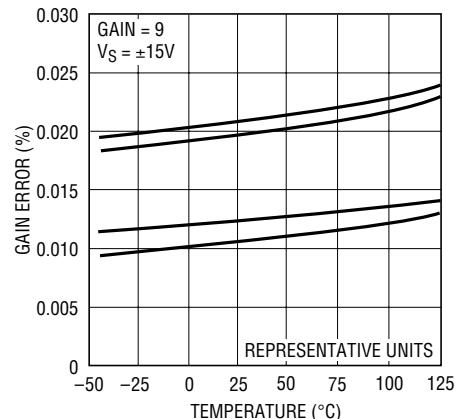
1996 G13

**CMRR vs Temperature**



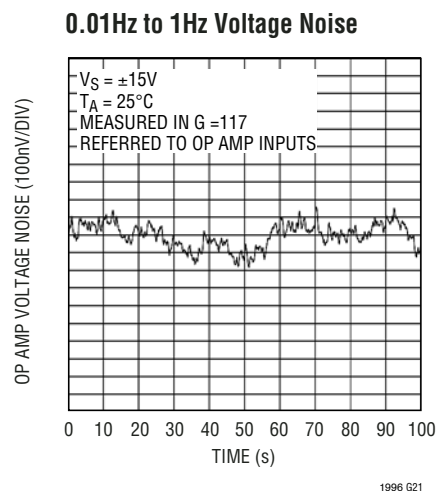
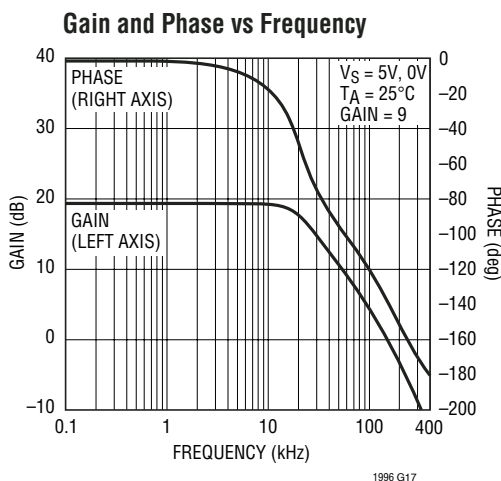
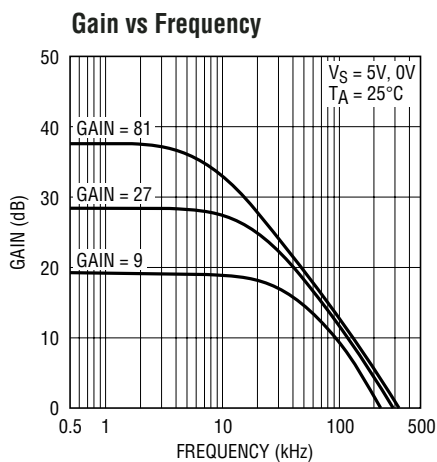
1996 G14

**Gain Error vs Temperature**

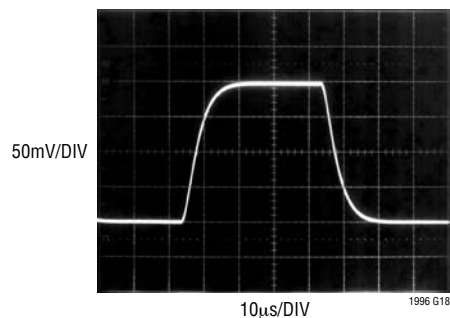


1996 G15

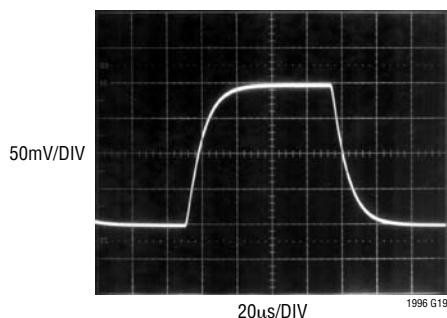
## TYPICAL PERFORMANCE CHARACTERISTICS (Difference Amplifier Configuration)



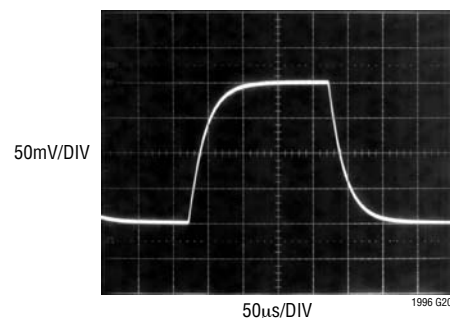
**Small Signal Transient Response, Gain = 9**



**Small Signal Transient Response, Gain = 27**



**Small Signal Transient Response, Gain = 81**



## PIN FUNCTIONS (Difference Amplifier Configuration)

**P9 (Pin 1):** Noninverting Gain-of-9 input. Connects a 50k internal resistor to the op amp's noninverting input.

**P27 (Pin 2):** Noninverting Gain-of-27 input. Connects a (50k/3) internal resistor to the op amp's noninverting input.

**P81 (Pin 3):** Noninverting Gain-of-81 input. Connects a (50k/9) internal resistor to the op amp's noninverting input.

**VEE (Pin 4):** Negative Power Supply. Can be either ground (in single supply applications), or a negative voltage (in split supply applications).

**REF (Pin 5):** Reference Input. Sets the output level when difference between inputs is zero. Connects a 450k internal

resistor to the op amp's noninverting input.

**OUT (Pin 6):** Output.  $V_{OUT} = V_{REF} + 9 \cdot (V_{P1} - V_{M1}) + 27 \cdot (V_{P3} - V_{M3}) + 81 \cdot (V_{P9} - V_{M9})$ .

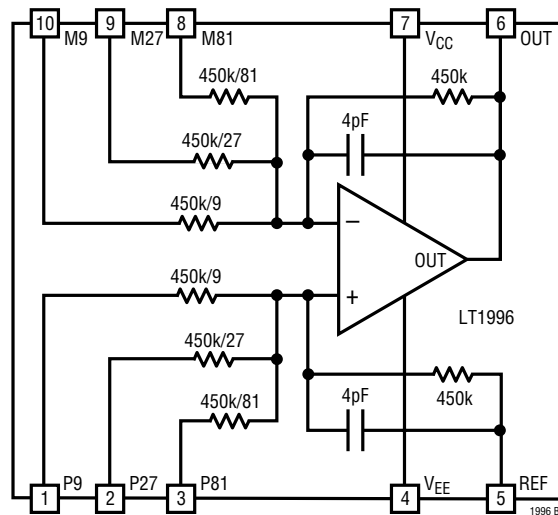
**VCC (Pin 7):** Positive Power Supply. Can be anything from 2.7V to 36V above the VEE voltage.

**M81 (Pin 8):** Inverting Gain-of-81 input. Connects a (50k/9) internal resistor to the op amp's inverting input.

**M27 (Pin 9):** Inverting Gain-of-27 input. Connects a (50k/3) internal resistor to the op amp's inverting input.

**M9 (Pin 10):** Inverting Gain-of-9 input. Connects a 50k internal resistor to the op amp's inverting input.

## BLOCK DIAGRAM



## APPLICATIONS INFORMATION

### Introduction

The LT1996 may be the last op amp you ever have to stock. Because it provides you with several precision matched resistors, you can easily configure it into several different classical gain circuits without adding external components. The several pages of simple circuits in this data sheet demonstrate just how easy the LT1996 is to use. It can be configured into difference amplifiers, as well as into inverting and noninverting single ended amplifiers. The fact that the resistors and op amp are provided together in such a small package will often save you board space and reduce complexity for easy probing.

### The Op Amp

The op amp internal to the LT1996 is a precision device with  $15\mu\text{V}$  typical offset voltage and  $3\text{nA}$  input bias current. The input offset current is extremely low, so matching the source resistance seen by the op amp inputs will provide for the best output accuracy. The op amp inputs are not rail-to-rail, but extend to within  $1.2\text{V}$  of  $V_{\text{CC}}$  and  $1\text{V}$

of  $V_{\text{EE}}$ . For many configurations though, the chip inputs will function rail-to-rail because of effective attenuation to the +input. The output is truly rail-to-rail, getting to within  $40\text{mV}$  of the supply rails. The gain bandwidth product of the op amp is about  $560\text{kHz}$ . In noise gains of 2 or more, it is stable into capacitive loads up to  $500\text{pF}$ . In noise gains below 2, it is stable into capacitive loads up to  $100\text{pF}$ .

### The Resistors

The resistors internal to the LT1996 are very well matched SiChrome based elements protected with barrier metal. Although their absolute tolerance is fairly poor ( $\pm 30\%$ ), their matching is to within  $0.05\%$ . This allows the chip to achieve a CMRR of  $80\text{dB}$ , and gain errors within  $0.05\%$ . The resistor values are  $(450\text{k}/9)$ ,  $(450\text{k}/27)$ ,  $(450\text{k}/81)$  and  $450\text{k}$ , connected to each of the inputs. The resistors have power limitations of  $1\text{watt}$  for the  $450\text{k}$  and  $(450\text{k}/81)$  resistors,  $0.3\text{watt}$  for the  $(450\text{k}/27)$  resistors and  $0.5\text{watt}$  for the  $(450\text{k}/9)$  resistors; however, in practice, power dissipation will be limited well below these values by the

## APPLICATIONS INFORMATION

maximum voltage allowed on the input and REF pins. The 50k resistors connected to the M9 and P9 inputs are isolated from the substrate, and can therefore be taken beyond the supply voltages. The naming of the pins “P9,” “P27,” “P81,” etc., is based on their admittances relative to the feedback and REF admittances. Because it has 9 times the admittance, the voltage applied to the P9 input has 9 times the effect of the voltage applied to the REF input.

### Bandwidth

The bandwidth of the LT1996 will depend on the gain you select (or more accurately the noise gain resulting from the gain you select). In the lowest configurable gain of 1, the  $-3\text{dB}$  bandwidth is limited to 450kHz, with peaking of about 2dB at 280kHz. In the highest configurable gains, bandwidth is limited to 5kHz.

### Input Noise

The LT1996 input noise is comprised of the Johnson noise of the internal resistors ( $\sqrt{4kTR}$ ), and the input voltage noise of the op amp. Paralleling all four resistors to the +input gives a  $3.8\text{k}\Omega$  resistance, for  $8\text{nV}/\sqrt{\text{Hz}}$  of voltage noise. The equivalent network on the  $-$ input gives another  $8\text{nV}/\sqrt{\text{Hz}}$ , and the op amp  $14\text{nV}/\sqrt{\text{Hz}}$ . Taking their RMS sum gives a total  $18\text{nV}/\sqrt{\text{Hz}}$  input referred noise floor. Output noise depends on configuration and noise gain.

### Input Resistance

The LT1996 input resistances vary with configuration, but once configured are apparent on inspection. Note that resistors connected to the op amp's  $-$ input are looking into a virtual ground, so they simply parallel. Any feedback resistance around the op amp does not contribute to input resistance. Resistors connected to the op amp's +input are looking into a high impedance, so they add as parallel or series depending on how they are connected, and whether or not some of them are grounded. The op amp +input itself presents a very high  $\text{G}\Omega$  impedance. In the

classical noninverting op amp configuration, the LT1996 presents the high input impedance of the op amp, as is usual for the noninverting case.

### Common Mode Input Voltage Range

The LT1996 valid common mode input range is limited by three factors:

1. Maximum allowed voltage on the pins
2. The input voltage range of the internal op amp
3. Valid output voltage

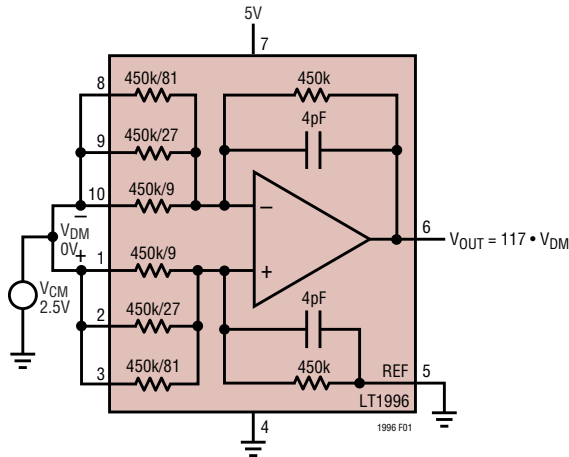
The maximum voltage allowed on the P27, M27, P81 and M81 inputs includes the positive and negative supply plus a diode drop. These pins should not be driven more than a diode drop outside of the supply rails. This is because they are connected through diodes to internal manufacturing post-package trim circuitry, and through a substrate diode to  $V_{EE}$ . If more than 10mA is allowed to flow through these pins, there is a risk that the LT1996 will be detrimmed or damaged. The P9 and M9 inputs do not have clamp diodes or substrate diodes or trim circuitry and can be taken well outside the supply rails. The maximum allowed voltage on the P9 and M9 pins is  $\pm 60\text{V}$ .

The input voltage range of the internal op amp extends to within 1.2V of  $V_{CC}$  and 1V of  $V_{EE}$ . The voltage at which the op amp inputs common mode is determined by the voltage at the op amp's +input, and this is determined by the voltages on pins P9, P27, P81 and REF. (See “Calculating Input Voltage Range” section.) This is true provided that the op amp is functioning and feedback is maintaining the inputs at the same voltage, which brings us to the third requirement.

For valid circuit function, the op amp output must not be clipped. The output will clip if the input signals are attempting to force it to within 40mV of its supply voltages. This usually happens due to too large a signal level, but it can also occur with zero input differential and must therefore be included as an example of a common mode problem.

## APPLICATIONS INFORMATION

Consider Figure 1. This shows the LT1996 configured as a gain of 117 difference amplifier on a single supply with



**Figure 1. Difference Amplifier Cannot Produce 0V on a Single Supply. Provide a Negative Supply, or Raise Pin 5, or Provide 400µV of V<sub>DM</sub>**

the output REF connected to ground. This is a great circuit, but it does not support V<sub>DM</sub> = 0V at any common mode because the output clips into ground while trying to produce 0V<sub>OUT</sub>. It can be fixed simply by declaring the valid input differential range not to extend below +0.4mV, or by elevating the REF pin above 40mV, or by providing a negative supply.

### Calculating Input Voltage Range

Figure 2 shows the LT1996 in the generalized case of a difference amplifier, with the inputs shorted for the common mode calculation. The values of R<sub>F</sub> and R<sub>G</sub> are dictated by how the P inputs and REF pin are connected. By superposition we can write:

$$V_{INT} = V_{EXT} \cdot (R_F / (R_F + R_G)) + V_{REF} \cdot (R_G / (R_F + R_G))$$

Or, solving for V<sub>EXT</sub>:

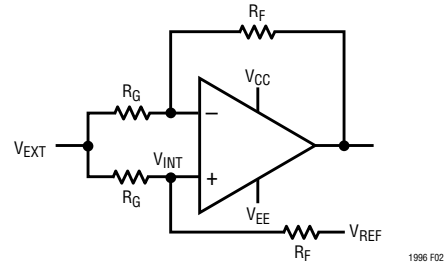
$$V_{EXT} = V_{INT} \cdot (1 + R_G / R_F) - V_{REF} \cdot R_G / R_F$$

But valid V<sub>INT</sub> voltages are limited to V<sub>CC</sub> - 1.2V and V<sub>EE</sub> + 1V, so:

$$\text{MAX } V_{EXT} = (V_{CC} - 1.2) \cdot (1 + R_G / R_F) - V_{REF} \cdot R_G / R_F$$

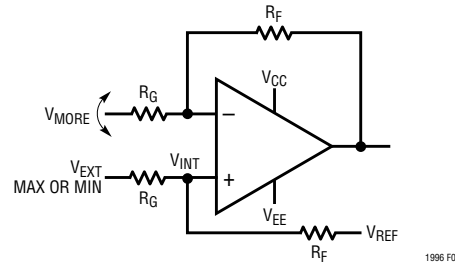
and:

$$\text{MIN } V_{EXT} = (V_{EE} + 1) \cdot (1 + R_G / R_F) - V_{REF} \cdot R_G / R_F$$



**Figure 2. Calculating CM Input Voltage Range**

These two voltages represent the high and low extremes of the common mode input range, if the other limits have not already been exceeded (1 and 3, above). In most cases, the inverting inputs M9 through M81 can be taken further than these two extremes because doing this does not move the op amp input common mode. To calculate the limit on this additional range, see Figure 3. Note that, with



**Figure 3. Calculating Additional Voltage Range of Inverting Inputs**

V<sub>MORE</sub> = 0, the op amp output is at V<sub>REF</sub>. From the max V<sub>EXT</sub> (the high cm limit), as V<sub>MORE</sub> goes positive, the op amp output will go more negative from V<sub>REF</sub> by the amount V<sub>MORE</sub> • R<sub>F</sub>/R<sub>G</sub>, so:

$$V_{OUT} = V_{REF} - V_{MORE} \cdot R_F / R_G$$

Or:

$$V_{MORE} = (V_{REF} - V_{OUT}) \cdot R_G / R_F$$

The most negative that V<sub>OUT</sub> can go is V<sub>EE</sub> + 0.04V, so:

$$\text{Max } V_{MORE} = (V_{REF} - V_{EE} - 0.04V) \cdot R_G / R_F$$

(should be positive)

The situation where this function is negative, and therefore problematic, when V<sub>REF</sub> = 0 and V<sub>EE</sub> = 0, has already been dealt with in Figure 1. The strength of the equation is demonstrated in that it provides the three solutions

## APPLICATIONS INFORMATION

suggested in Figure 1: raise  $V_{REF}$ , lower  $V_{EE}$ , or provide some negative  $V_{MORE}$ .

Likewise, from the lower common mode extreme, making the negative input more negative will raise the output voltage, limited by  $V_{CC} - 0.04V$ .

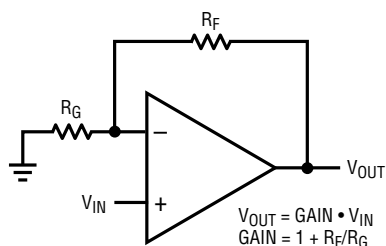
$$\text{MIN } V_{MORE} = (V_{REF} - V_{CC} + 0.04V) \cdot R_G/R_F$$

(should be negative)

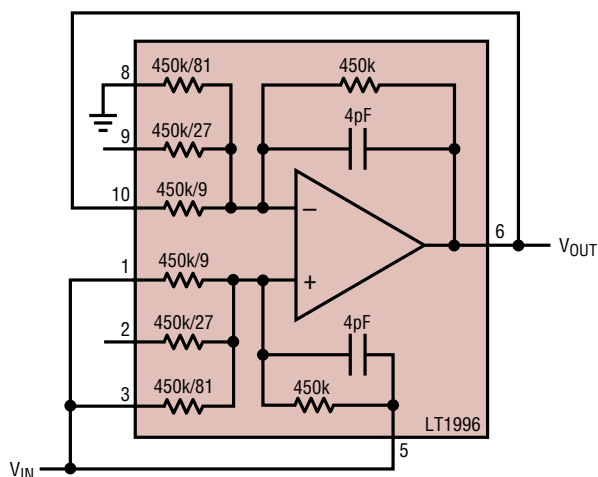
Again, the additional input range calculated here is only available provided the other remaining constraint is not violated, the maximum voltage allowed on the pin.

### The Classical Noninverting Amplifier: High Input Z

Perhaps the most common op amp configuration is the noninverting amplifier. Figure 4 shows the textbook



CLASSICAL NONINVERTING OP AMP CONFIGURATION. YOU PROVIDE THE RESISTORS.



CLASSICAL NONINVERTING OP AMP CONFIGURATION IMPLEMENTED WITH LT1996.  $R_F = 45k$ ,  $R_G = 5.6k$ , GAIN = 9.1.

GAIN IS ACHIEVED BY GROUNDING, FLOATING OR FEEDING BACK THE AVAILABLE RESISTORS TO ARRIVE AT DESIRED  $R_F$  AND  $R_G$ .

WE PROVIDE YOU WITH <0.1% RESISTORS.

1996 F04

representation of the circuit on the top. The LT1996 is shown on the bottom configured in a precision gain of 9.1. One of the benefits of the noninverting op amp configuration is that the input impedance is extremely high. The LT1996 maintains this benefit. Given the finite number of available feedback resistors in the LT1996, the number of gain configurations is also finite. The complete list of such Hi-Z input noninverting gain configurations is shown in Table 1. Many of these are also represented in Figure 5 in schematic form. Note that the P-side resistor inputs have been connected so as to match the source impedance seen by the internal op amp inputs. Note also that gain and noise gain are identical, for optimal precision.

**Table 1. Configuring the M Pins for Simple Noninverting Gains. The P Inputs are driven as shown in the examples on the next page**

| Gain | M81, M27, M9 Connection |          |          |
|------|-------------------------|----------|----------|
|      | M81                     | M27      | M9       |
| 1    | Output                  | Output   | Output   |
| 1.08 | Output                  | Output   | Grounded |
| 1.11 | Output                  | Float    | Grounded |
| 1.30 | Output                  | Grounded | Output   |
| 1.32 | Float                   | Output   | Grounded |
| 1.33 | Output                  | Grounded | Float    |
| 1.44 | Output                  | Grounded | Grounded |
| 3.19 | Grounded                | Output   | Output   |
| 3.7  | Float                   | Grounded | Output   |
| 3.89 | Grounded                | Output   | Float    |
| 4.21 | Grounded                | Output   | Grounded |
| 9.1  | Grounded                | Float    | Output   |
| 10   | Float                   | Float    | Grounded |
| 11.8 | Grounded                | Grounded | Output   |
| 28   | Float                   | Grounded | Float    |
| 37   | Float                   | Grounded | Grounded |
| 82   | Grounded                | Float    | Float    |
| 91   | Grounded                | Float    | Grounded |
| 109  | Grounded                | Grounded | Float    |
| 118  | Grounded                | Grounded | Grounded |

**Figure 4. The LT1996 as a Classical Noninverting Op Amp**

APPLICATIONS INFORMATION

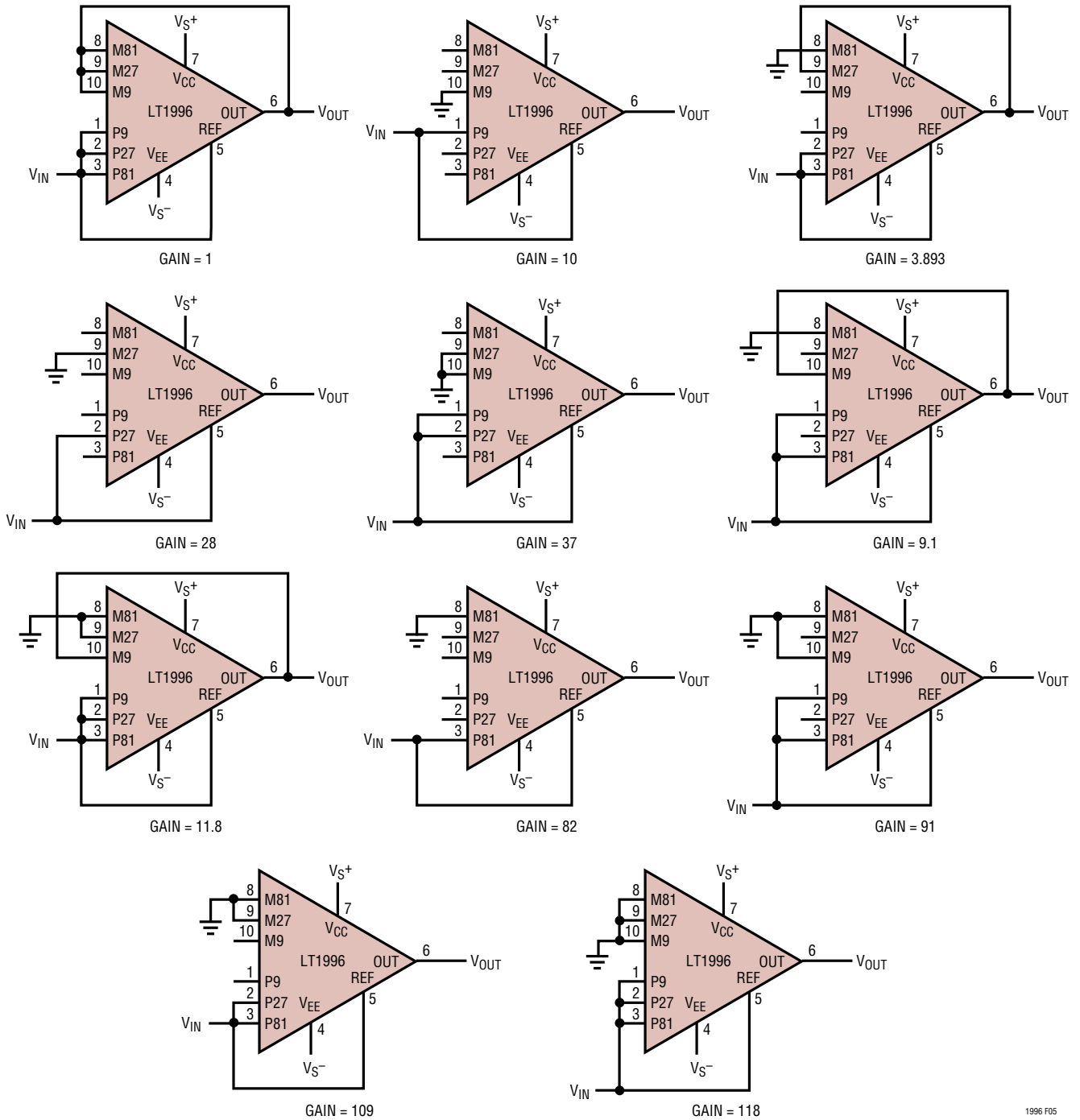


Figure 5. Some Implementations of Classical Noninverting Gains Using the LT1996. High Input Z Is Maintained

1996 F05

## APPLICATIONS INFORMATION

### Attenuation Using the P Input Resistors

Attenuation happens as a matter of fact in difference amplifier configurations, but it is also used for reducing peak signal level or improving input common mode range even in single ended systems. When signal conditioning indicates a need for attenuation, the LT1996 resistors are ready at hand. The four precision resistors can provide several attenuation levels, and these are tabulated in Table 2 as a design reference.

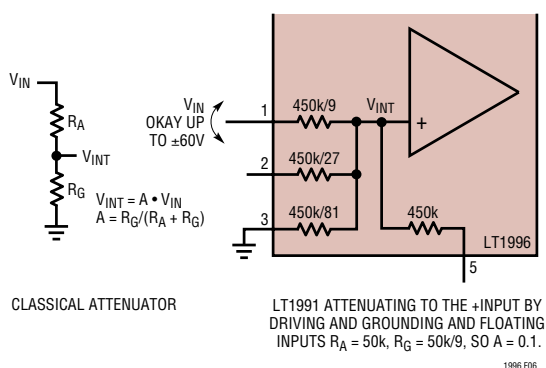


Figure 6. LT1996 Provides for Easy Attenuation to the Op Amp's +Input. The P9 Input Can Be Taken Well Outside of the Supplies

Because the attenuations and the noninverting gains are set independently, they can be combined. This provides high gain resolution, about 700 unique gains between 0.0085 and 118, as plotted in Figure 7. This is too large a number to tabulate, but the designer can calculate achievable gain by taking the vector product of the gains and attenuations in Tables 1 and 2, and seeking the best match. Average gain resolution is 1.5%, with worst case steps of about 50% as seen in Figure 7.

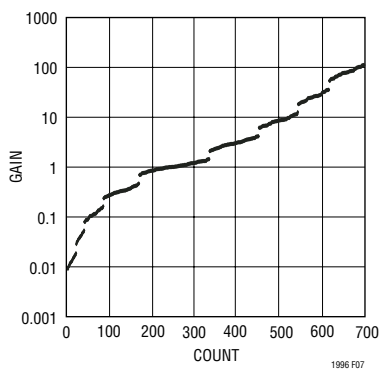


Figure 7. Over 600 Unique Gain Settings Achievable with the LT1996 by Combining Attenuation with Noninverting Gain

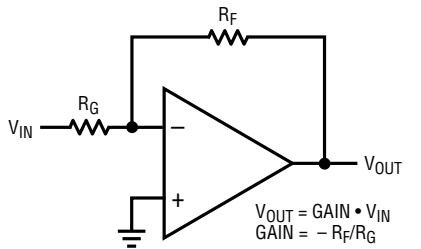
Table 2. Configuring the P Pins for Various Attenuations. Those Shown in Bold Are Functional Even When the Input Drive Exceeds the Supplies

| A             | P81, P27, P9, REF Connection |          |               |          |
|---------------|------------------------------|----------|---------------|----------|
|               | P81                          | P27      | P9            | REF      |
| 0.0085        | Grounded                     | Grounded | Grounded      | Driven   |
| 0.0092        | Grounded                     | Grounded | Float         | Driven   |
| 0.0110        | Grounded                     | Float    | Grounded      | Driven   |
| 0.0122        | Grounded                     | Float    | Float         | Driven   |
| 0.0270        | Float                        | Grounded | Grounded      | Driven   |
| 0.0357        | Float                        | Grounded | Float         | Driven   |
| <b>0.0763</b> | Grounded                     | Grounded | <b>Driven</b> | Grounded |
| <b>0.0769</b> | Grounded                     | Grounded | <b>Driven</b> | Float    |
| 0.0847        | Grounded                     | Grounded | Driven        | Driven   |
| <b>0.0989</b> | Grounded                     | Float    | <b>Driven</b> | Grounded |
| <b>0.1</b>    | Grounded                     | Float    | <b>Driven</b> | Float    |
| 0.110         | Grounded                     | Float    | Driven        | Driven   |
| 0.229         | Grounded                     | Driven   | Grounded      | Grounded |
| 0.231         | Grounded                     | Driven   | Grounded      | Float    |
| 0.237         | Grounded                     | Driven   | Grounded      | Driven   |
| <b>0.243</b>  | Float                        | Grounded | <b>Driven</b> | Grounded |
| 0.248         | Grounded                     | Driven   | Float         | Grounded |
| <b>0.25</b>   | Float                        | Grounded | <b>Driven</b> | Float    |
| 0.25          | Grounded                     | Driven   | Float         | Float    |
| 0.257         | Grounded                     | Driven   | Float         | Driven   |
| 0.270         | Float                        | Grounded | Driven        | Driven   |
| 0.305         | Grounded                     | Driven   | Driven        | Grounded |
| 0.308         | Grounded                     | Driven   | Driven        | Float    |
| 0.314         | Grounded                     | Driven   | Driven        | Driven   |
| 0.686         | Driven                       | Grounded | Grounded      | Grounded |
| 0.692         | Driven                       | Grounded | Grounded      | Float    |
| 0.695         | Driven                       | Grounded | Grounded      | Driven   |
| 0.730         | Float                        | Driven   | Grounded      | Grounded |
| 0.743         | Driven                       | Grounded | Float         | Grounded |
| 0.75          | Float                        | Driven   | Grounded      | Float    |
| 0.752         | Driven                       | Grounded | Float         | Driven   |
| 0.757         | Float                        | Driven   | Grounded      | Driven   |
| 0.763         | Driven                       | Grounded | Driven        | Grounded |
| 0.769         | Driven                       | Grounded | Driven        | Float    |
| 0.771         | Driven                       | Grounded | Driven        | Driven   |
| 0.890         | Driven                       | Float    | Grounded      | Grounded |
| <b>0.9</b>    | Float                        | Float    | <b>Driven</b> | Grounded |
| 0.901         | Driven                       | Float    | Grounded      | Driven   |
| 0.915         | Driven                       | Driven   | Grounded      | Grounded |
| 0.923         | Driven                       | Driven   | Grounded      | Float    |
| 0.924         | Driven                       | Driven   | Grounded      | Driven   |
| 0.964         | Float                        | Driven   | Float         | Grounded |
| 0.973         | Float                        | Driven   | Driven        | Grounded |
| 0.988         | Driven                       | Float    | Float         | Grounded |
| 0.989         | Driven                       | Float    | Driven        | Grounded |
| 0.991         | Driven                       | Driven   | Float         | Grounded |
| 0.992         | Driven                       | Driven   | Driven        | Grounded |

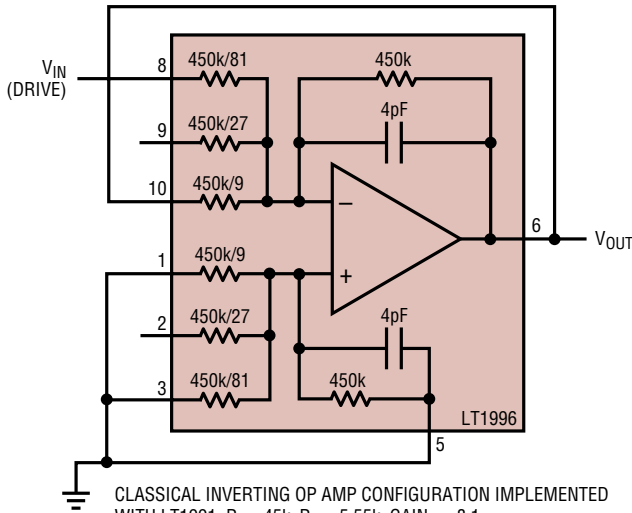
# APPLICATIONS INFORMATION

## Inverting Configuration

The inverting amplifier, shown in Figure 8, is another classical op amp configuration. The circuit is actually identical to the noninverting amplifier of Figure 4, except that  $V_{IN}$  and GND have been swapped. The list of available gains is shown in Table 3, and some of the circuits are shown in Figure 9. Noise gain is  $1+|Gain|$ , as is the usual case for inverting amplifiers. Again, for the best DC performance, match the source impedance seen by the op amp inputs.



CLASSICAL INVERTING OP AMP CONFIGURATION. YOU PROVIDE THE RESISTORS.



CLASSICAL INVERTING OP AMP CONFIGURATION IMPLEMENTED WITH LT1991.  $R_F = 45k$ ,  $R_G = 5.55k$ ,  $GAIN = -8.1$ .

GAIN IS ACHIEVED BY GROUNDING, FLOATING OR FEEDING BACK THE AVAILABLE RESISTORS TO ARRIVE AT DESIRED  $R_F$  AND  $R_G$ .

WE PROVIDE YOU WITH <0.1% RESISTORS.

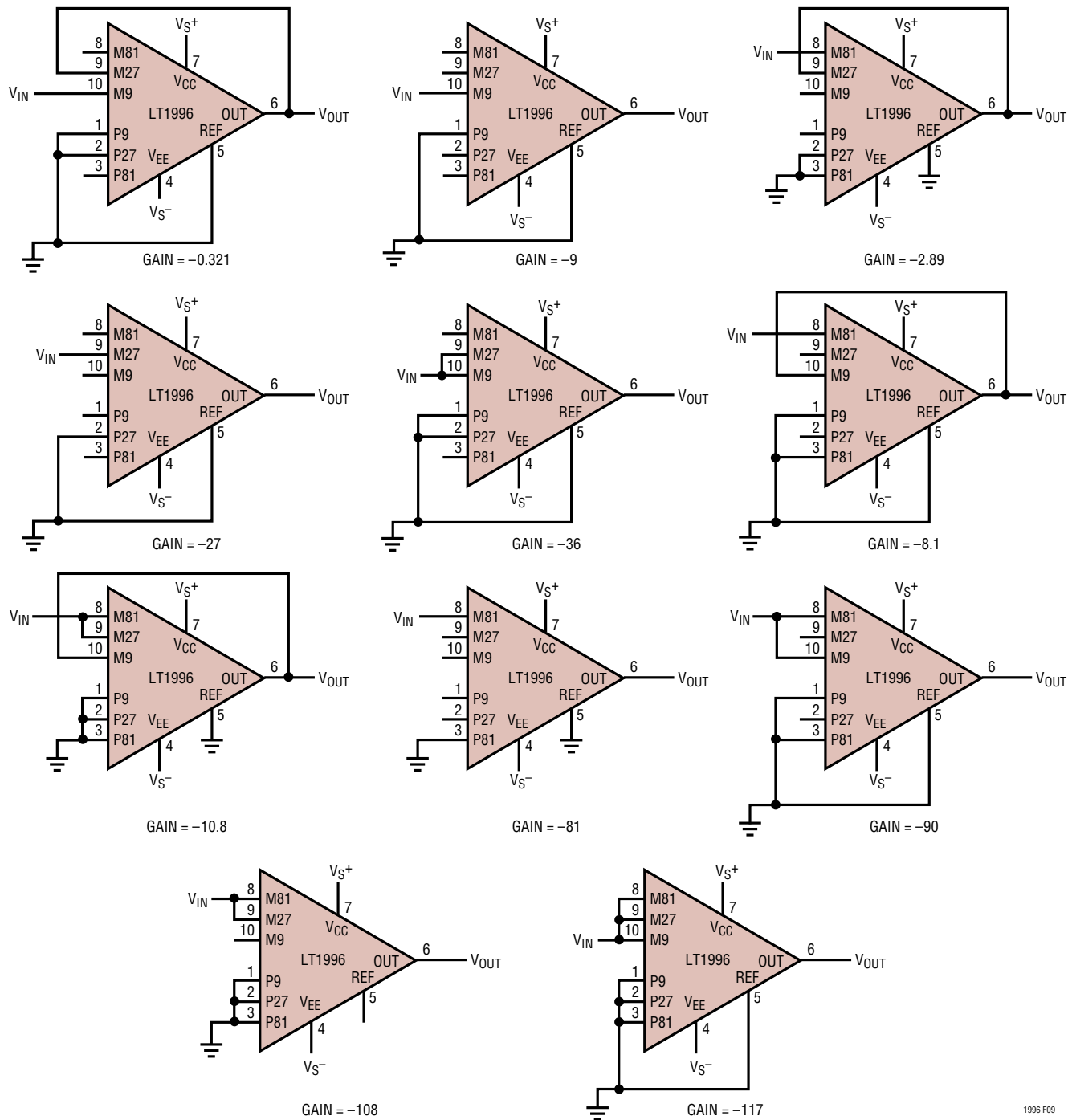
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Table 3. Configuring the M Pins for Simple Inverting Gains

| Gain   | M81, M27, M9 Connection |        |        |
|--------|-------------------------|--------|--------|
|        | M81                     | M27    | M9     |
| -0.083 | Output                  | Output | Drive  |
| -0.110 | Output                  | Float  | Drive  |
| -0.297 | Output                  | Drive  | Output |
| -0.321 | Float                   | Output | Drive  |
| -0.329 | Output                  | Drive  | Float  |
| -0.439 | Output                  | Drive  | Drive  |
| -2.19  | Drive                   | Output | Output |
| -2.7   | Float                   | Drive  | Output |
| -2.89  | Drive                   | Output | Float  |
| -3.21  | Drive                   | Output | Drive  |
| -8.1   | Drive                   | Float  | Output |
| -9     | Float                   | Float  | Drive  |
| -10.8  | Drive                   | Drive  | Output |
| -27    | Float                   | Drive  | Float  |
| -36    | Float                   | Drive  | Drive  |
| -81    | Drive                   | Float  | Float  |
| -90    | Drive                   | Float  | Drive  |
| -108   | Drive                   | Drive  | Float  |
| -117   | Drive                   | Drive  | Drive  |

Figure 8. The LT1996 as a Classical Inverting Op Amp. Note the Circuit Is Identical to the Noninverting Amplifier, Except that  $V_{IN}$  and Ground Have Been Swapped

# APPLICATIONS INFORMATION



**Figure 9. It Is Simple to Get Precision Inverting Gains with the LT1996. Input Impedance Varies from 3.8kΩ (Gain = -117) to 50kΩ (Gain = -9)**

1996 F09

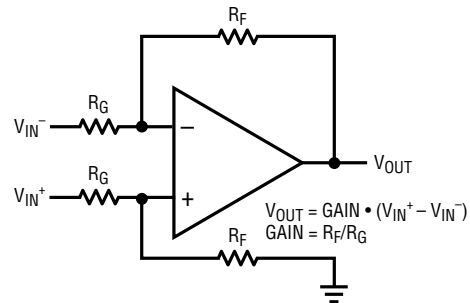
## APPLICATIONS INFORMATION

### Difference Amplifiers

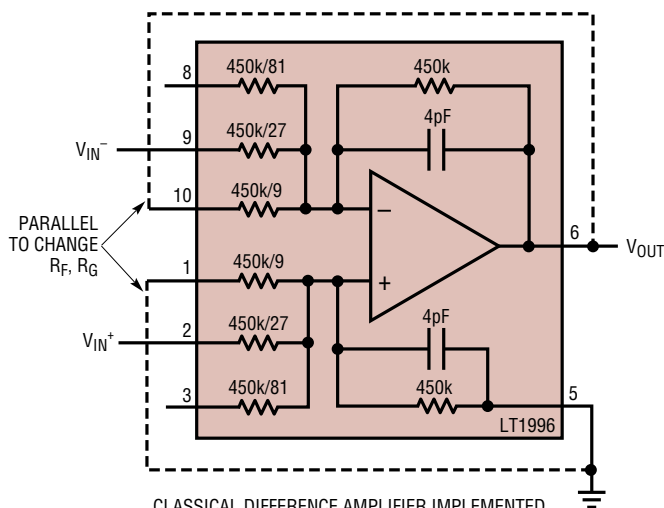
The resistors in the LT1996 allow it to easily make difference amplifiers also. Figure 10 shows the basic 4-resistor difference amplifier and the LT1996. A difference gain of 27 is shown, but notice the effect of the additional dashed connections. By connecting the 50k resistors in parallel, the gain is reduced by a factor of 10. Of course, with so many resistors, there are many possible gains. Table 4 shows the difference gains and how they are achieved. Note that, as for inverting amplifiers, the noise gain is 1 more than the signal gain.

**Table 4. Connections Giving Difference Gains for the LT1996**

| Gain     | V <sub>IN</sub> <sup>+</sup> | V <sub>IN</sub> <sup>-</sup> | Output   | GND (REF) |
|----------|------------------------------|------------------------------|----------|-----------|
| 0.083    | P9                           | M9                           | M27, M81 | P27, P81  |
| 0.110    | P9                           | M9                           | M81      | P81       |
| 0.297    | P27                          | M27                          | M9, M81  | P9, P81   |
| 0.321    | P9                           | M9                           | M27      | P27       |
| 0.329    | P27                          | M27                          | M81      | P81       |
| 0.439    | P9, P27                      | M9, M27                      | M81      | P81       |
| 2.189    | P81                          | M81                          | M9, M27  | P9, P27   |
| 2.700    | P27                          | M27                          | M9       | P9        |
| 2.893    | P81                          | M81                          | M27      | P27       |
| 3.214    | P9, P81                      | M9, M81                      | M27      | P27       |
| 8.1      | P81                          | M81                          | M9       | P9        |
| <b>9</b> | P9                           | M9                           |          |           |
| 10.8     | P27, P81                     | M27, M81                     | M9       | P9        |
| 27       | P27                          | M27                          |          |           |
| 36       | P9, P27                      | M9, M27                      |          |           |
| 81       | P81                          | M81                          |          |           |
| 90       | P9, P81                      | M9, M81                      |          |           |
| 108      | P27, P81                     | M27, M81                     |          |           |
| 117      | P9, P27, P81                 | M9, M27, M81                 |          |           |



CLASSICAL DIFFERENCE AMPLIFIER USING THE LT1991



CLASSICAL DIFFERENCE AMPLIFIER IMPLEMENTED WITH LT1991. R<sub>F</sub> = 450k, R<sub>G</sub> = 16.7k, GAIN = 3.

ADDING THE DASHED CONNECTIONS CONNECTS THE TWO 450k RESISTOR IN PARALLEL, SO R<sub>F</sub> IS REDUCED TO 45k. GAIN BECOMES 45k/16.7k = 2.7.

1996 F10

**Figure 10. Difference Amplifier Using the LT1996. Gain Is Set Simply by Connecting the Correct Resistors or Combinations of Resistors. Gain of 27 Is Shown, with Dashed Lines Modifying It to Gain of 2.7. Noise Gain Is Optimal**

APPLICATIONS INFORMATION

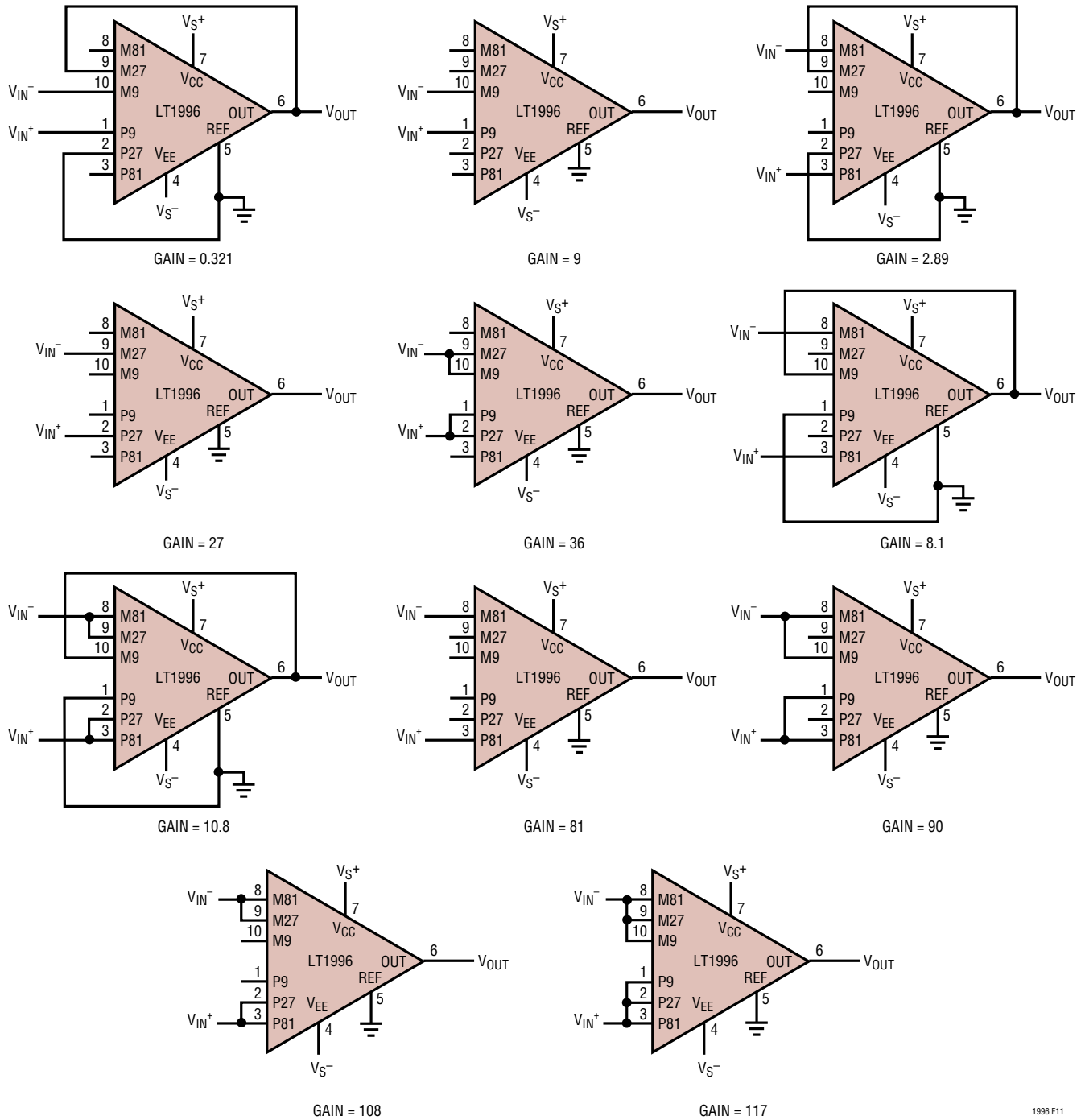
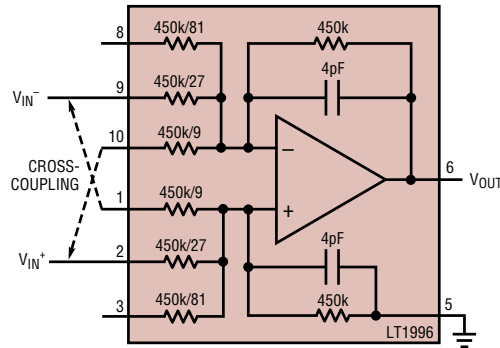
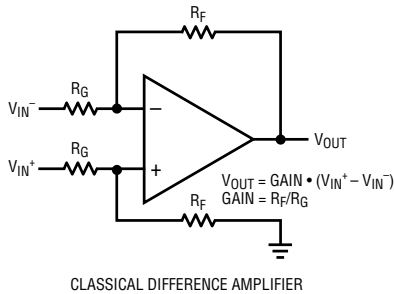


Figure 11. Many Difference Gains Are Achievable Just by Strapping the Pins

1996 F11

APPLICATIONS INFORMATION



CLASSICAL DIFFERENCE AMPLIFIER IMPLEMENTED WITH LT1991.  $R_F = 450k$ ,  $R_G = 16.7k$ ,  $GAIN = 27$ . GAIN CAN BE ADJUSTED BY "CROSS COUPLING." MAKING THE DASHED CONNECTIONS REDUCE THE GAIN FROM 27 TO 18. WHEN CROSS COUPLING, SEE WHAT IS CONNECTED TO THE  $V_{IN+}$  VOLTAGE. CONNECTING P27 AND M9 GIVES  $27 - 9 = 18$ . CONNECTIONS TO  $V_{IN-}$  ARE SYMMETRIC: M27 AND P9. 1996 F10

Figure 12. Another Method of Selecting Difference Gain Is "Cross-Coupling." The Additional Method Means the LT1996 Provides Extra Integer Gains

Difference Amplifier: Additional Integer Gains Using Cross-Coupling

Figure 12 shows the basic difference amplifier as well as the LT1996 in a difference gain of 27. But notice the effect of the additional dashed connections. This is referred to as "cross-coupling" and has the effect of reducing the differential gain from 27 to 18. Using this method, additional integer gains are achievable, as shown in Table 5 below. Note that the equations can be written by inspection from the  $V_{IN+}$  connections, and that the  $V_{IN-}$  connections are simply the opposite (swap P for M and M for P). The method is the same as for the LT1991, except that the LT1996 applies a multiplier of 9. Noise gain, bandwidth, and input impedance specifications for the various cases are also tabulated, as these are not obvious. Schematics are provided in Figure 13.

Table 5. Connections Using Cross-Coupling. Note That Equations Can Be Written by Inspection of the  $V_{IN+}$  Column

| Gain | $V_{IN+}$    | $V_{IN-}$    | Gain Equation | Noise Gain | -3dB BW kHz | $R_{IN+}$ Typ k $\Omega$ | $R_{IN-}$ Typ k $\Omega$ |
|------|--------------|--------------|---------------|------------|-------------|--------------------------|--------------------------|
| 18   | P27, M9      | M27, P9      | $27 - 9$      | 39         | 14          | 46                       | 16                       |
| 45   | P81, M27, M9 | M81, P27, P9 | $81 - 27 - 9$ | 117        | 5           | 12                       | 6                        |
| 54   | P81, M27     | M81, P27     | $81 - 27$     | 108        | 5           | 16                       | 6                        |
| 63   | P81, P9, M27 | M81, M9, P27 | $81 + 9 - 27$ | 117        | 5           | 16                       | 5                        |
| 72   | P81, M9      | M81, P9      | $81 - 9$      | 90         | 6           | 45                       | 6                        |
| 99   | P81, P27, M9 | M81, M27, P9 | $81 + 27 - 9$ | 117        | 5           | 45                       | 4                        |

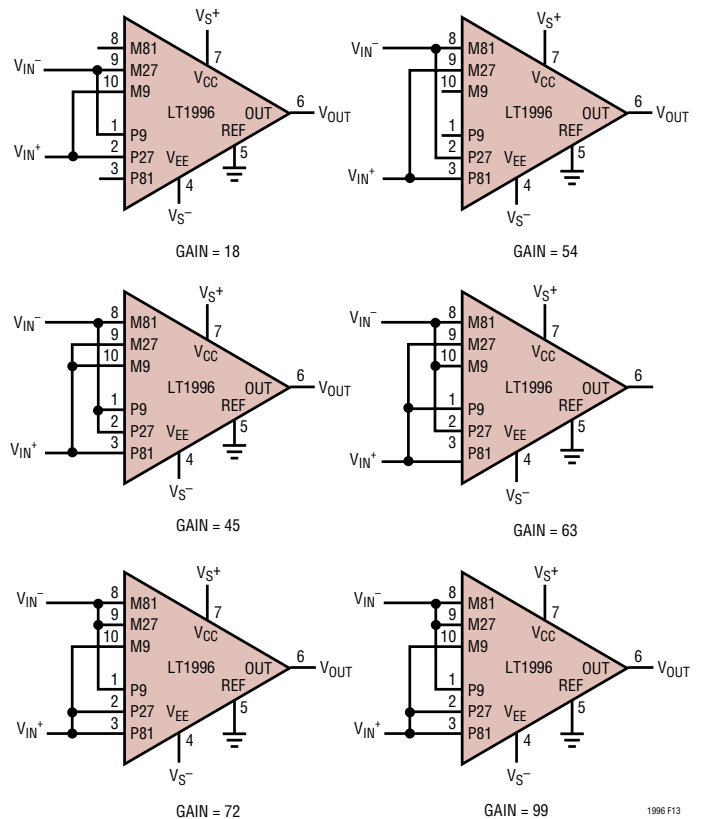


Figure 13. Integer Gain Difference Amplifiers Using Cross-Coupling 1996 F13

## APPLICATIONS INFORMATION

### High Voltage CM Difference Amplifiers

This class of difference amplifier remains to be discussed. Figure 14 shows the basic circuit on the top. The effective input voltage range of the circuit is extended by the fact that resistors  $R_T$  attenuate the common mode voltage seen by the op amp inputs. For the LT1996, the most useful resistors for  $R_G$  are the M9 and P9 50kΩ resistors, because they do not have diode clamps to the supplies and therefore can be taken outside the supplies. As before, the input CM of the op amp is the limiting factor and is set by the voltage at the op amp +input,  $V_{INT}$ . By superposition we can write:

$$V_{INT} = V_{EXT} \cdot (R_F || R_T) / (R_G + R_F || R_T) + V_{REF} \cdot (R_G || R_T) / (R_F + R_G || R_T) + V_{TERM} \cdot (R_F || R_G) / (R_T + R_F || R_G)$$

Solving for  $V_{EXT}$ :

$$V_{EXT} = (1 + R_G / (R_F || R_T)) \cdot (V_{INT} - V_{REF} \cdot (R_G || R_T) / (R_F + R_G || R_T)) - V_{TERM} \cdot (R_F || R_G) / (R_T + R_F || R_G)$$

Given the values of the resistors in the LT1996, this equation has been simplified and evaluated, and the resulting equations provided in Table 6. As before, substituting  $V_{CC} - 1.2$  and  $V_{EE} + 1$  for  $V_{LIM}$  will give the valid upper and lower common mode extremes respectively. Following are sample calculations for the case shown in Figure 14, right-hand side. Note that P81 and M81 are terminated so row 3 of Table 6 provides the equation:

$$\begin{aligned} \text{MAX } V_{EXT} &= 91/9 \cdot (V_{CC} - 1.2V) - V_{REF}/9 - 9 \cdot V_{TERM} \\ &= (10.11) \cdot (10.8) - 0.11(2.5) - 9(10) = 18.9V \end{aligned}$$

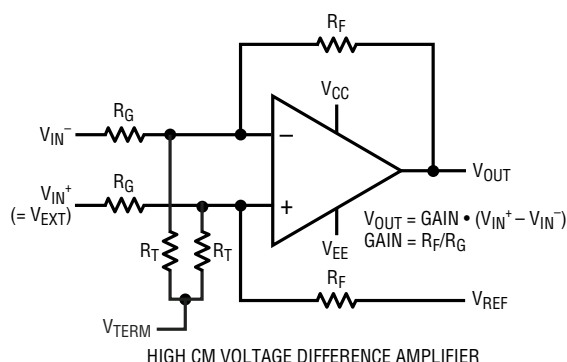
and:

$$\begin{aligned} \text{MIN } V_{EXT} &= 91/9 \cdot (V_{EE} + 1V) - V_{REF}/9 - 9 \cdot V_{TERM} \\ &= (10.11)(1) - 0.11(2.5) - 9(10) = -80.2V \end{aligned}$$

but this exceeds the 60V absolute maximum rating of the P9, M9 pins, so  $-60V$  becomes the de facto negative common mode limit. Several more examples of high CM circuits are shown in Figures 15, 16, 17 for various supplies.

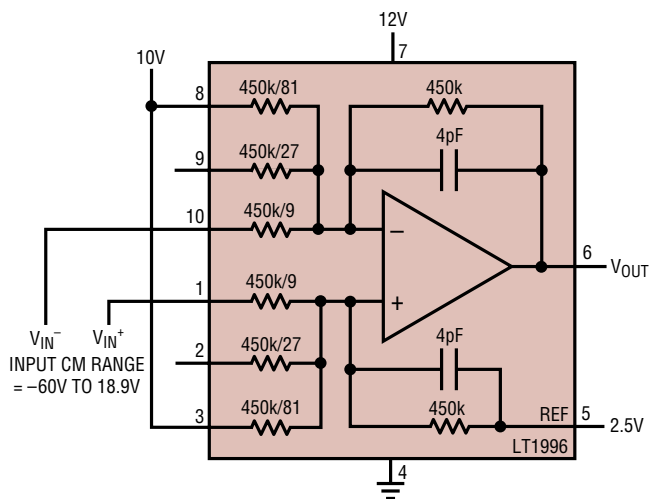
Table 6. HighV CM Connections Giving Difference Gains for the LT1996

| Gain | $V_{IN}^+$ | $V_{IN}^-$ | $R_T$                | Noise Gain | Max, Min $V_{EXT}$<br>(Substitute $V_{CC} - 1.2$ ,<br>$V_{EE} + 1$ for $V_{LIM}$ ) |
|------|------------|------------|----------------------|------------|--|
| 9    | P9         | M9         |                      | 10         | $10/9 \cdot V_{LIM} - V_{REF}/9$   |
| 9    | P9         | M9         | P27, M27             | 37         | $37/9 \cdot V_{LIM} - V_{REF}/9 - 3 \cdot V_{TERM}$                                |
| 9    | P9         | M9         | P81, M81             | 91         | $91/9 \cdot V_{LIM} - V_{REF}/9 - 9 \cdot V_{TERM}$                                |
| 9    | P9         | M9         | P27  P81<br>M27  M81 | 118        | $118/9 \cdot V_{LIM} - V_{REF}/9 - 12 \cdot V_{TERM}$                              |



HIGH CM VOLTAGE DIFFERENCE AMPLIFIER

INPUT CM TO OP AMP IS ATTENUATED BY RESISTORS  $R_T$  CONNECTED TO  $V_{TERM}$ .



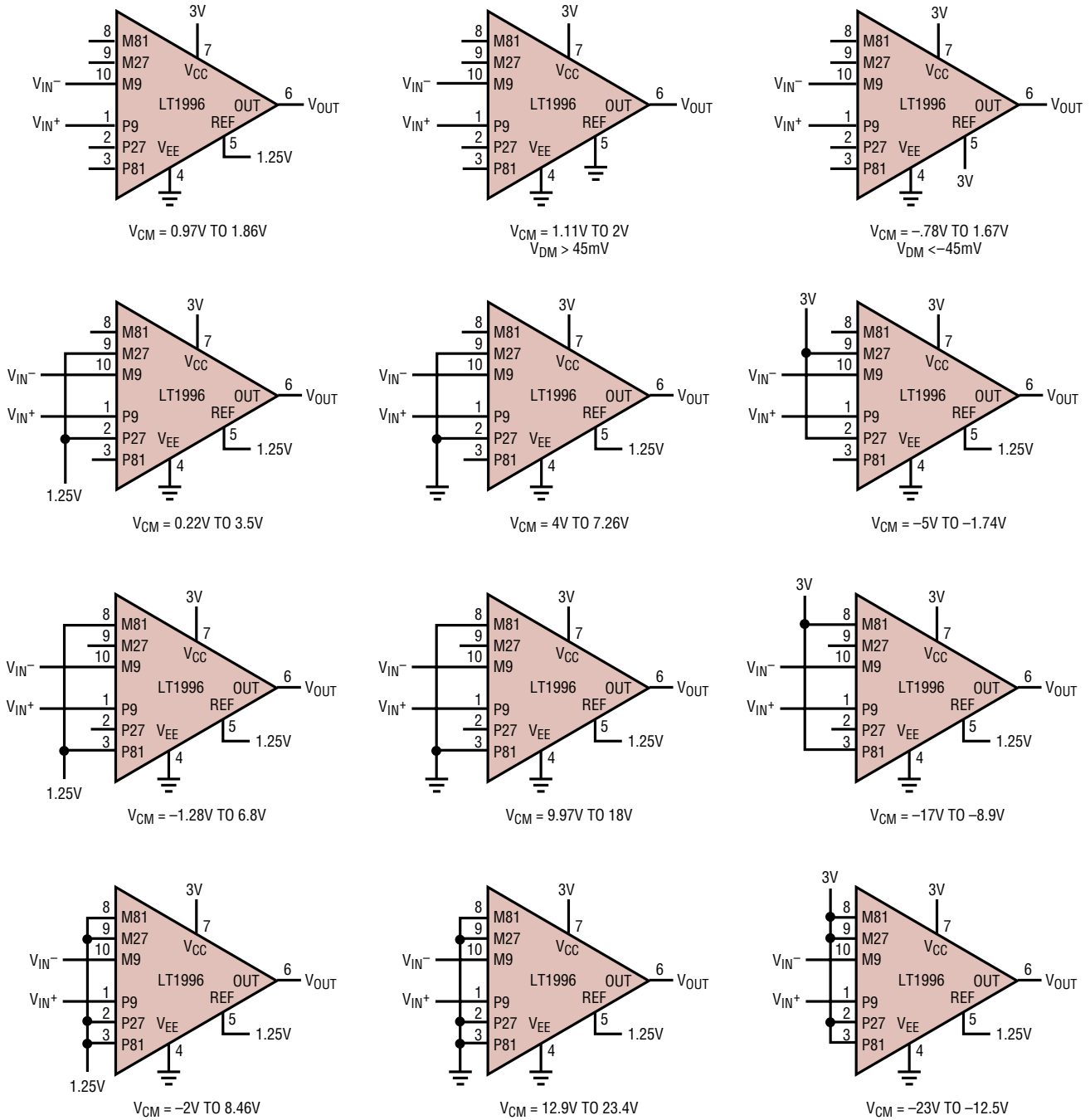
HIGH NEGATIVE CM VOLTAGE DIFFERENCE AMPLIFIER IMPLEMENTED WITH LT1996.  
 $R_F = 450k$ ,  $R_G = 50k$ ,  $R_T = 5.55k$ ,  $GAIN = 9$

$V_{TERM} = 10V = V_{CC} = 12V$ ,  $V_{REF} = 2.5V$ ,  $V_{EE} = 0V$ .

1996 F14

Figure 14. Extending CM Input Range

APPLICATIONS INFORMATION



1996 F15

Figure 15. Common Mode Ranges for Various LT1996 Difference Amp Configurations on  $V_S = 3V, 0V$ , with Gain = 9

# APPLICATIONS INFORMATION

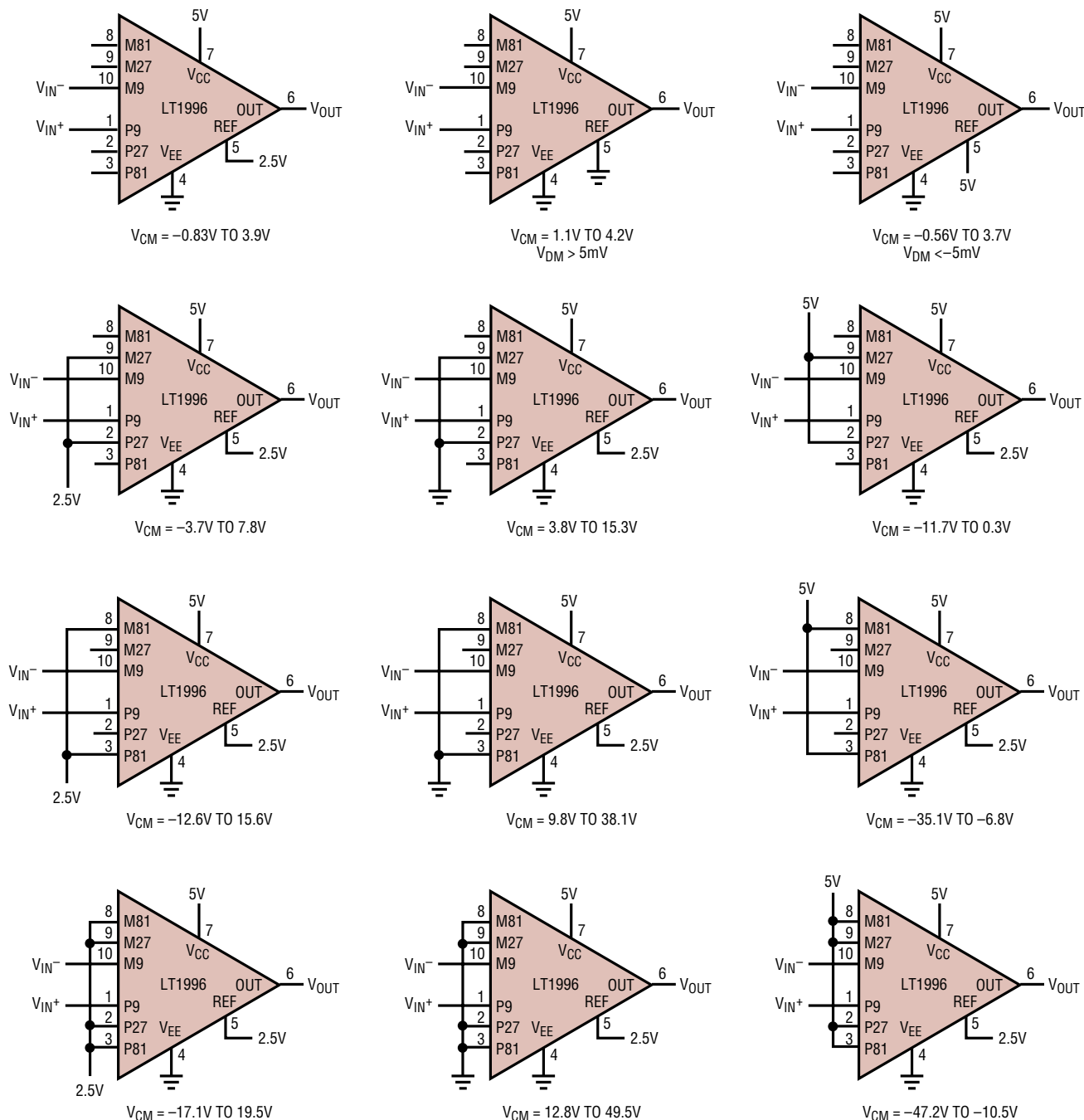
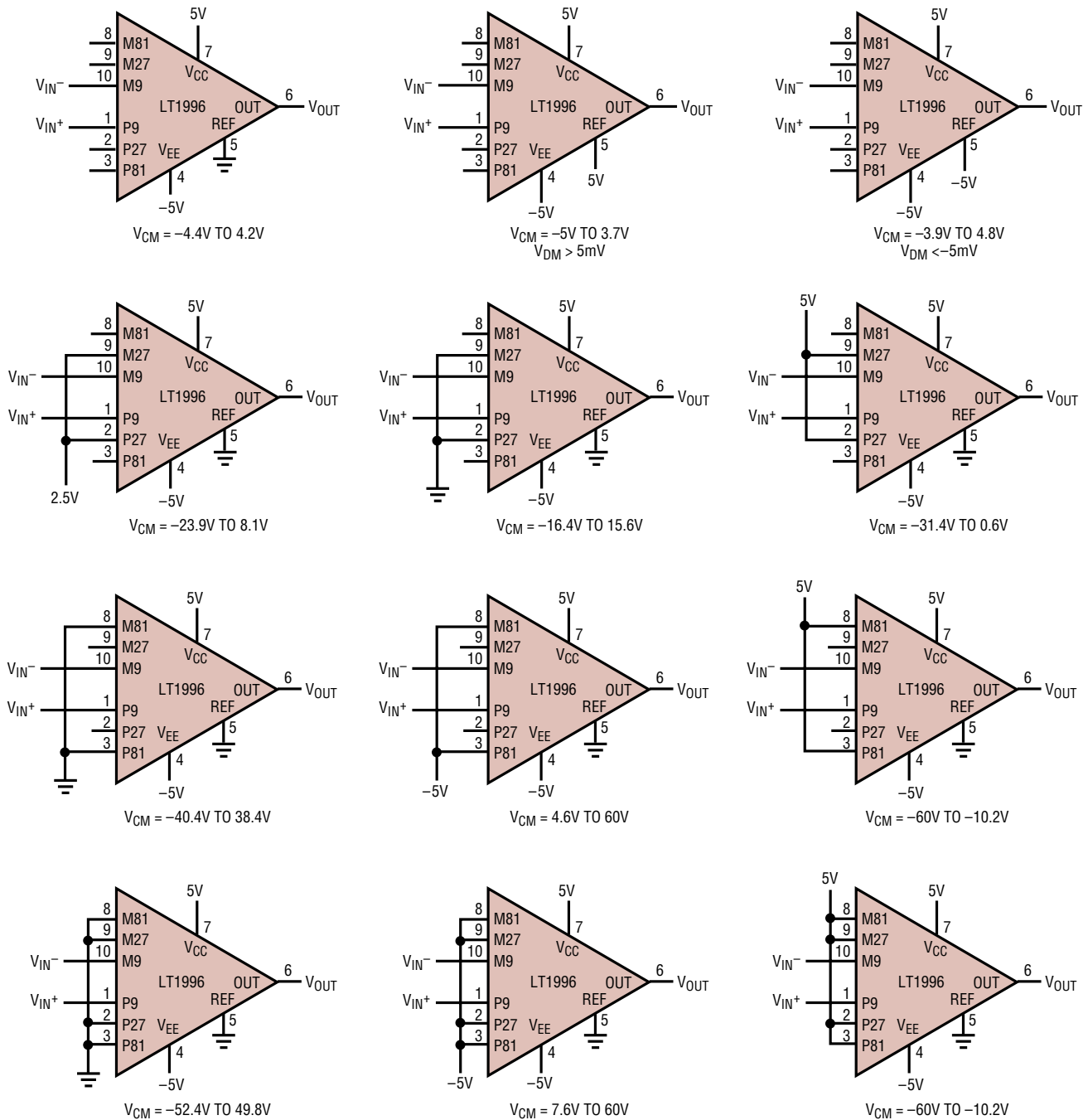


Figure 16. Common Mode Ranges for Various LT1996 Difference Amp Configurations on  $V_S = 5V, 0V$ , with Gain = 9

1996 F16

APPLICATIONS INFORMATION

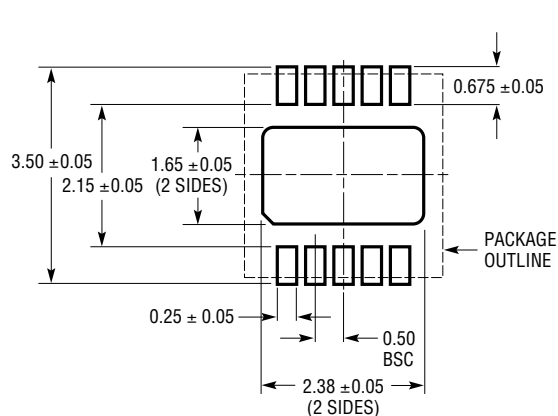


1996 F17

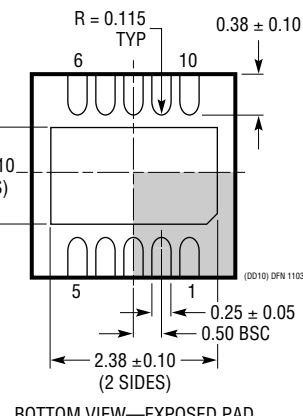
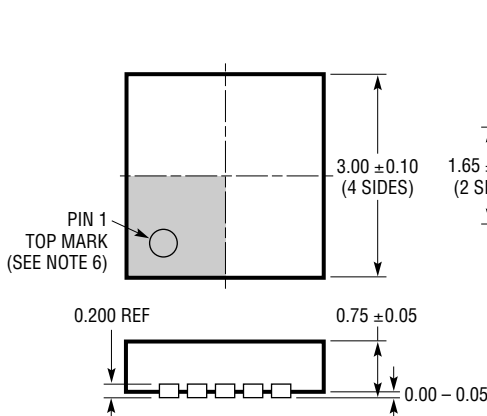
Figure 17. Common Mode Ranges for Various LT1996 Difference Amp Configurations on  $V_S = \pm 5V$ , with Gain = 9

# PACKAGE DESCRIPTION

## DD Package 10-Lead Plastic DFN (3mm × 3mm) (Reference LTC DWG # 05-08-1699)

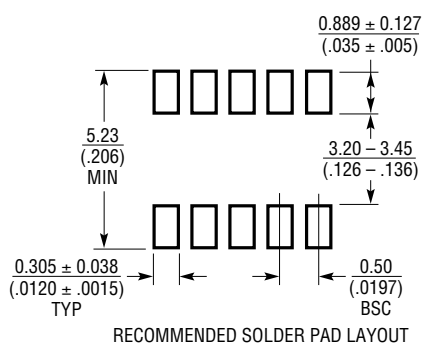


RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS

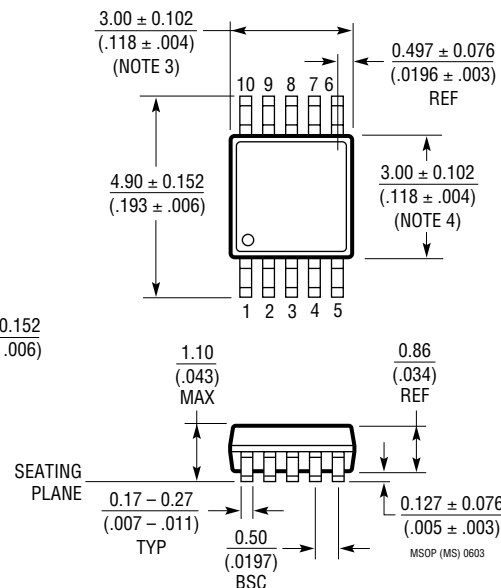
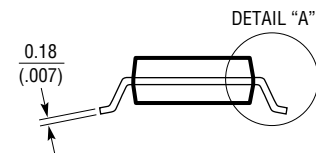
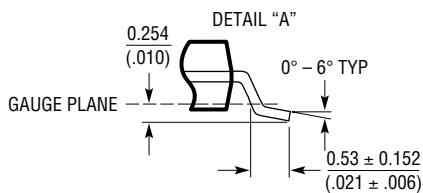


NOTE:

1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE M0-229 VARIATION OF (WEED-2). CHECK THE LTC WEBSITE DATA SHEET FOR CURRENT STATUS OF VARIATION ASSIGNMENT
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. DIMENSIONS OF EXPOSED PAD ON BOTTOM OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.15mm ON ANY SIDE
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE TOP AND BOTTOM OF PACKAGE



RECOMMENDED SOLDER PAD LAYOUT

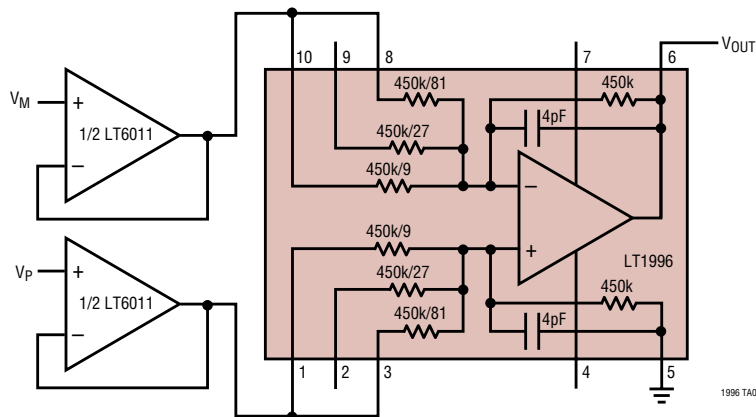


NOTE:

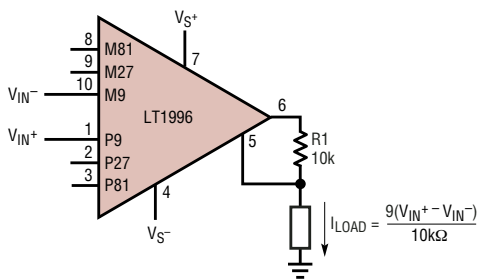
1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS. INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

# TYPICAL APPLICATION

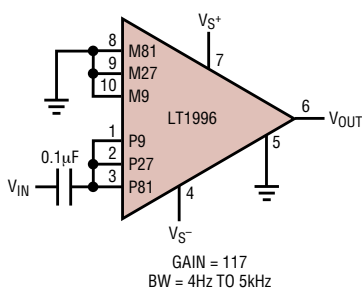
Micropower  $A_V = 90$  Instrumentation Amplifier



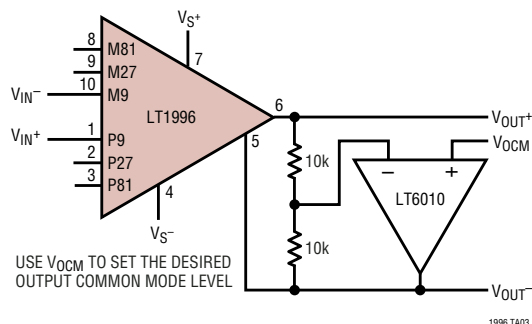
Bidirectional Controlled Current Source



AC Coupled Amplifier



Differential Input/Output  $G = 9$  Amplifier



## RELATED PARTS

| PART NUMBER          | DESCRIPTION                                     | COMMENTS  |
|----------------------|---|---|
| LT1990               | High Voltage Difference Amplifier               | $\pm 250V$ Input Common Mode, Micropower, Pin Selectable Gain = 1, 10                       |
| LT1991               | Precision, $100\mu A$ Gain Selectable Amplifier | Gain Resistors of 450k, 150k, 50k   |
| LT1995               | 30MHz, $1000V/\mu s$ Gain Selectable Amplifier  | High Speed, Pin Selectable Gain = -7 to 8   |
| LT6010/LT6011/LT6012 | Single/Dual/Quad Precision Op Amp               | Similar Performance as LT1996 Diff Amp, $135\mu A$ , $14nV/\sqrt{Hz}$ , Rail-to-Rail Out    |
| LT6013/LT6014        | Single/Dual Precision Op Amp                    | Lower Noise $A_V \geq 5$ Version of LT1991, $145\mu A$ , $8nV/\sqrt{Hz}$ , Rail-to-Rail Out |
| LTC6910-X            | Programmable Gain Amplifiers                    | 3 Gain Configurations, Rail-to-Rail Input and Output  |

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