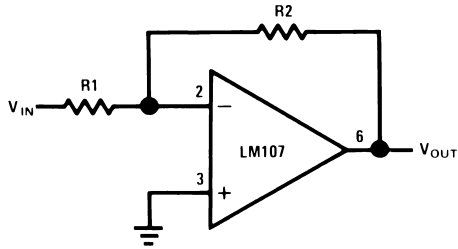




**Note:** National Semiconductor recommends replacing 2N2920 and 2N3728 matched pairs with LM394 in all application circuits.

## Section 1—Basic Circuits

**Inverting Amplifier**

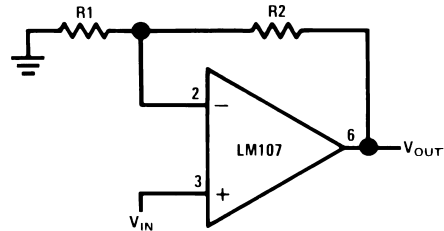


00705701

$$V_{OUT} = -\frac{R_2}{R_1} V_{IN}$$

$$R_{IN} = R_1$$

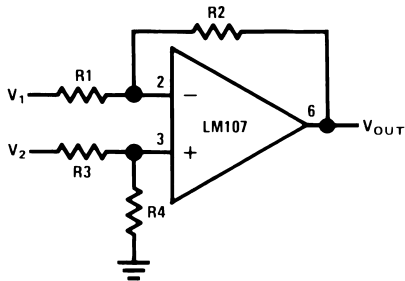
**Non-Inverting Amplifier**



00705702

$$V_{OUT} = \frac{R_1 + R_2}{R_1} V_{IN}$$

**Difference Amplifier**



00705703

$$V_{OUT} = \left( \frac{R_1 + R_2}{R_3 + R_4} \right) \frac{R_4}{R_1} V_2 - \frac{R_2}{R_1} V_1$$

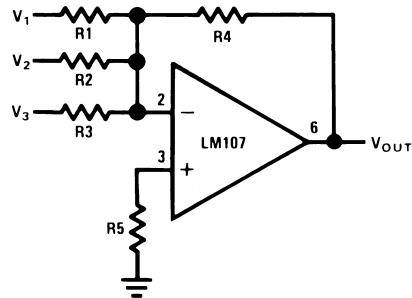
For  $R_1 = R_3$  and  $R_2 = R_4$

$$V_{OUT} = \frac{R_2}{R_1} (V_2 - V_1)$$

$$R_1 // R_2 = R_3 // R_4$$

For minimum offset error due to input bias current

**Inverting Summing Amplifier**



00705704

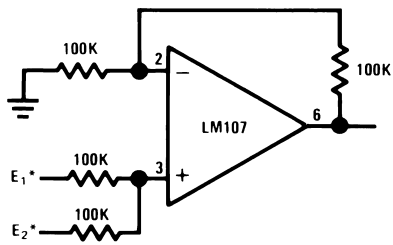
$$V_{OUT} = -R_4 \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right)$$

$$R_5 = R_1 // R_2 // R_3 // R_4$$

For minimum offset error due to input bias current

Section 1—Basic Circuits (Continued)

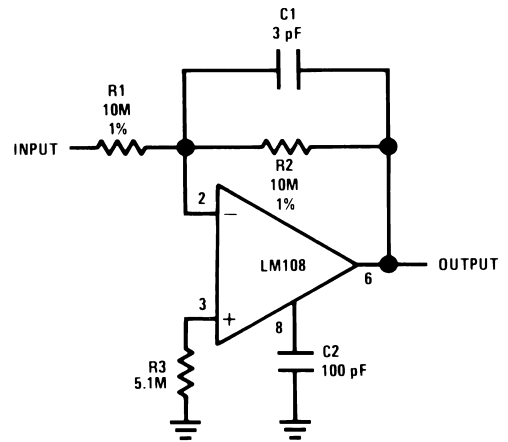
Non-Inverting Summing Amplifier



00705705

\* $R_S = 1k$  for 1% accuracy

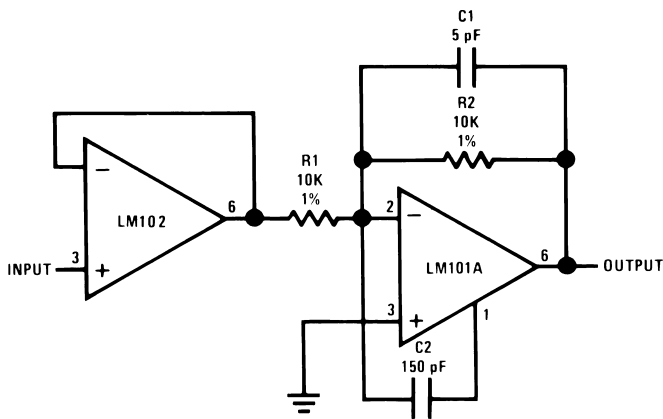
Inverting Amplifier with High Input Impedance



00705706

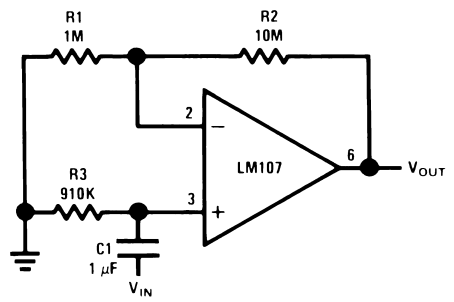
\*Source Impedance less than 100k gives less than 1% gain error.

Fast Inverting Amplifier with High Input Impedance



00705707

Non-Inverting AC Amplifier



00705708

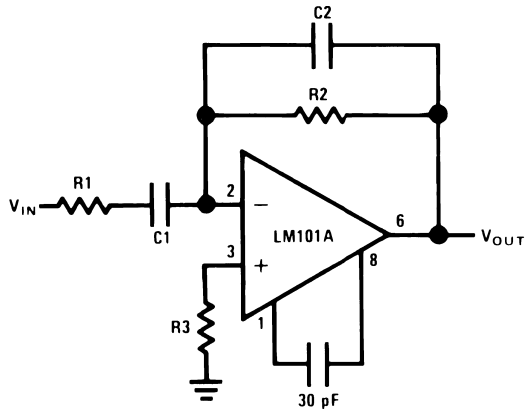
$$V_{OUT} = \frac{R1 + R2}{R1} V_{IN}$$

$$R_{IN} = R3$$

$$R3 = R1 // R2$$

Section 1—Basic Circuits (Continued)

Practical Differentiator



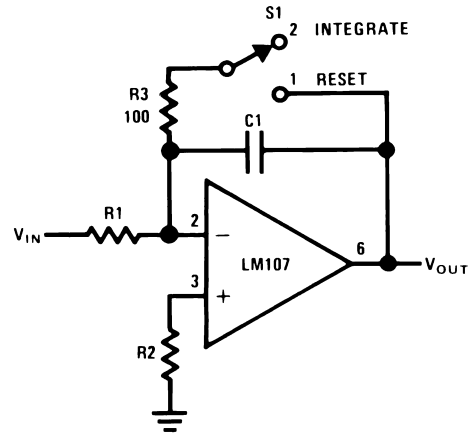
00705709

$$f_c = \frac{1}{2\pi R_2 C_1}$$

$$f_h = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi R_2 C_2}$$

$$f_c < f_h < f_{\text{unity gain}}$$

Integrator



00705710

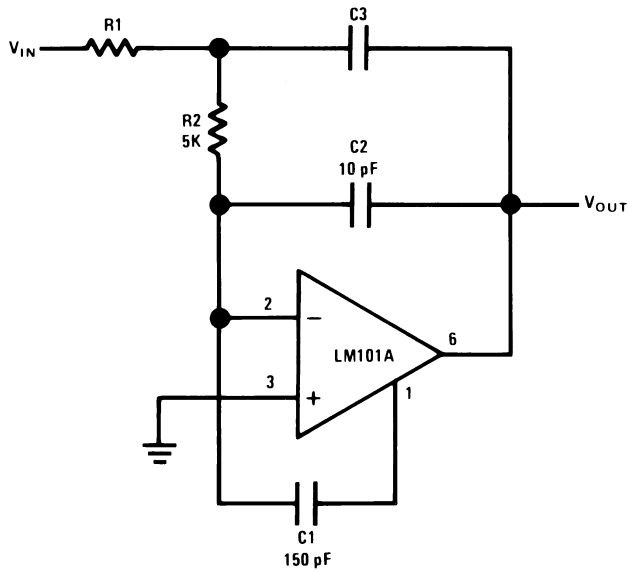
$$V_{OUT} = -\frac{1}{R_1 C_1} \int_{t_1}^{t_2} V_{IN} dt$$

$$f_c = \frac{1}{2\pi R_1 C_1}$$

$$R_1 = R_2$$

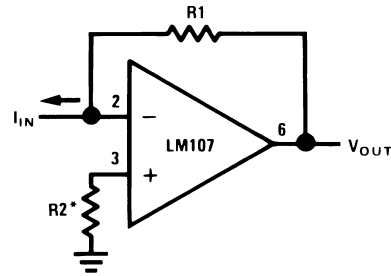
For minimum offset error due to input bias current

Fast Integrator



00705711

Current to Voltage Converter



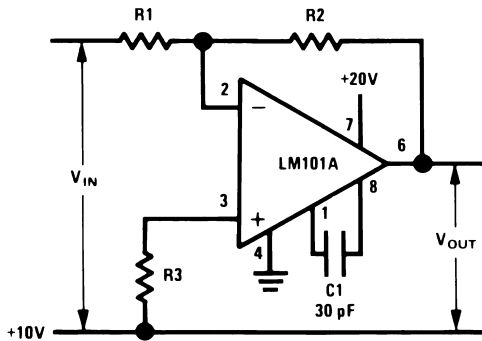
00705712

$$V_{OUT} = I_{IN} R_1$$

\*For minimum error due to bias current  $R_2 = R_1$

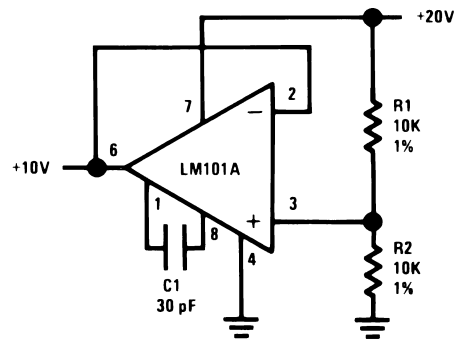
**Section 1—Basic Circuits** (Continued)

**Circuit for Operating the LM101 without a Negative Supply**



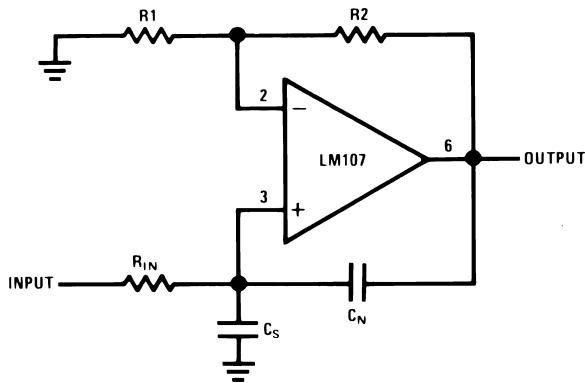
00705713

**Circuit for Generating the Second Positive Voltage**



00705714

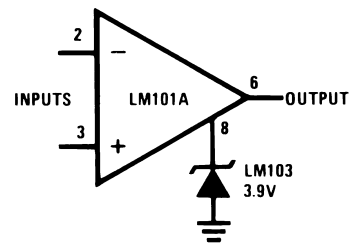
**Neutralizing Input Capacitance to Optimize Response Time**



00705715

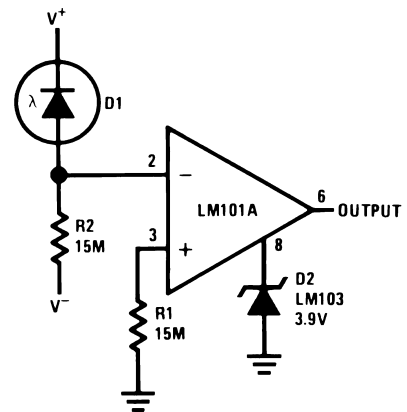
$$C_N \leq \frac{R_1}{R_2} C_S$$

**Voltage Comparator for Driving DTL or TTL Integrated Circuits**



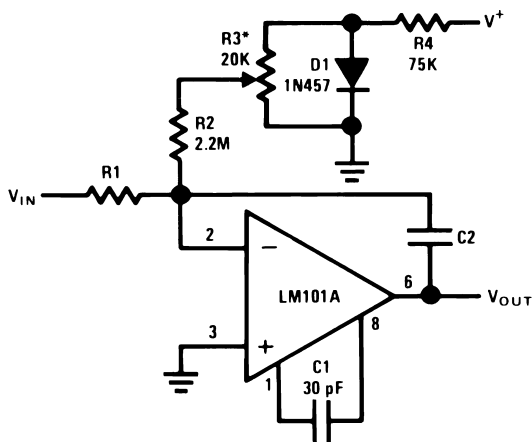
00705717

**Threshold Detector for Photodiodes**



00705718

**Integrator with Bias Current Compensation**



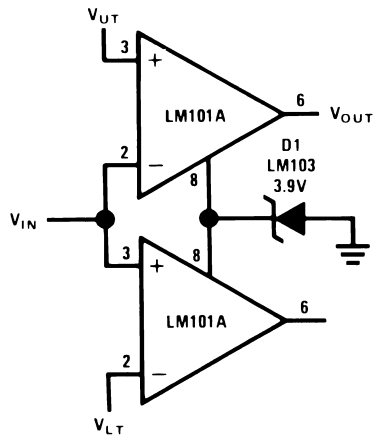
00705716

\*Adjust for zero integrator drift.

Current drift typically 0.1 nA/°C over -55°C to 125°C temperature range.

Section 1—Basic Circuits (Continued)

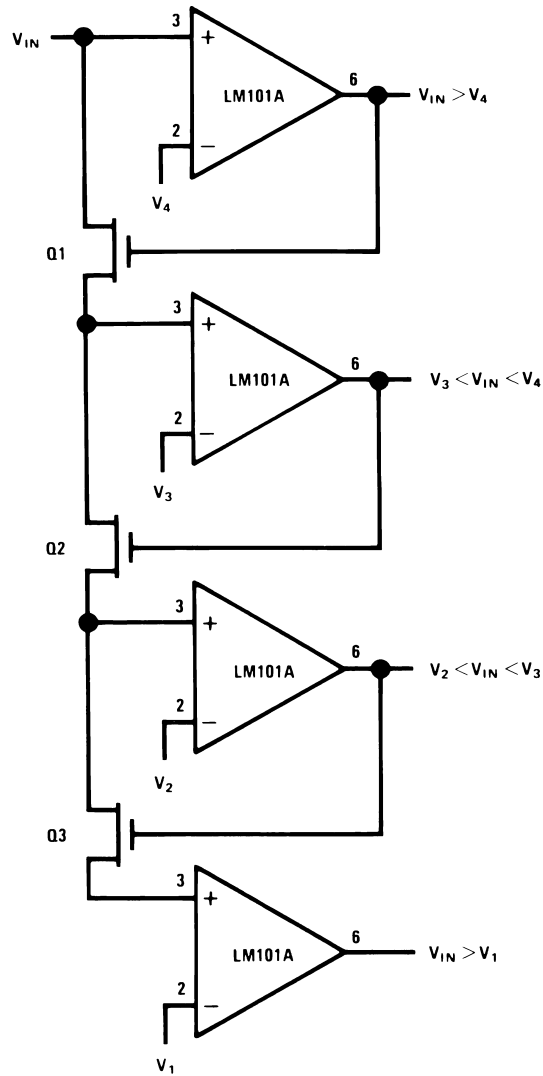
Double-Ended Limit Detector



00705719

$V_{OUT} = 4.6V$  for  $V_{LT} \leq V_{IN} \leq V_{UT}$   
 $V_{OUT} = 0V$  for  $V_{IN} < V_{LT}$  or  $V_{IN} > V_{UT}$

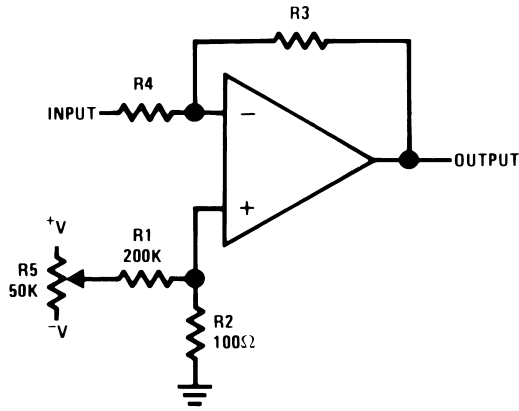
Multiple Aperture Window Discriminator



00705720

**Section 1—Basic Circuits** (Continued)

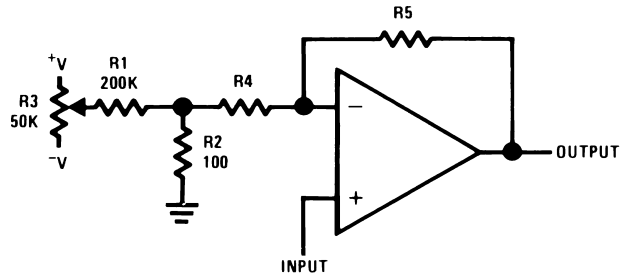
**Offset Voltage Adjustment for Inverting Amplifiers Using Any Type of Feedback Element**



00705721

$$\text{RANGE} = \pm V \left( \frac{R2}{R1} \right)$$

**Offset Voltage Adjustment for Non-Inverting Amplifiers Using Any Type of Feedback Element**

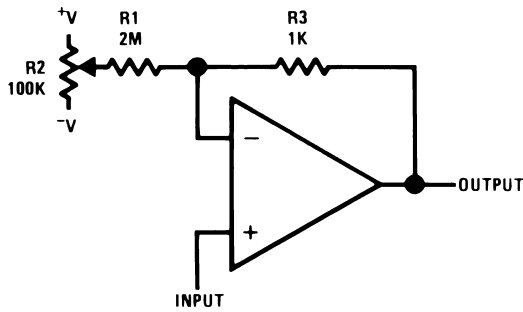


00705722

$$\text{RANGE} = \pm V \left( \frac{R2}{R1} \right)$$

$$\text{GAIN} = 1 + \frac{R5}{R4 + R2}$$

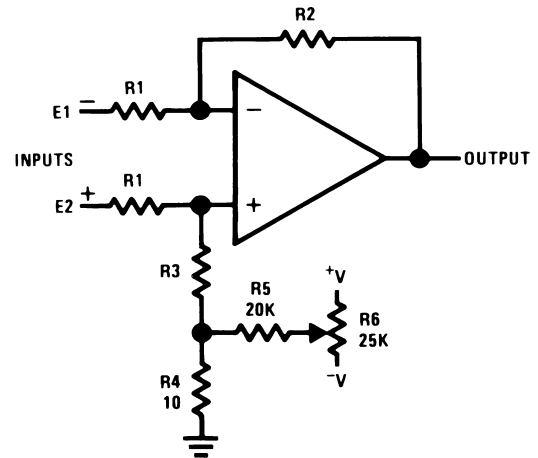
**Offset Voltage Adjustment for Voltage Followers**



00705723

$$\text{RANGE} = \pm V \left( \frac{R3}{R1} \right)$$

**Offset Voltage Adjustment for Differential Amplifiers**



00705724

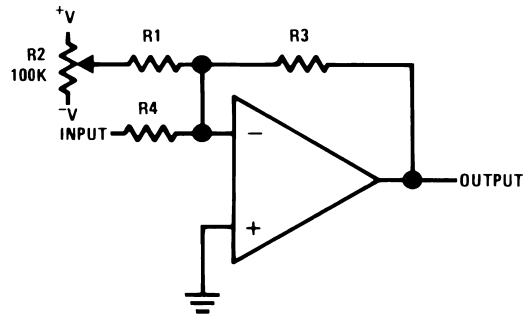
$$R2 = R3 + R4$$

$$\text{RANGE} = \pm V \left( \frac{R5}{R4} \right) \left( \frac{R1}{R1 + R3} \right)$$

$$\text{GAIN} = \frac{R2}{R1}$$

## Section 1—Basic Circuits (Continued)

### Offset Voltage Adjustment for Inverting Amplifiers Using 10 kΩ Source Resistance or Less



00705725

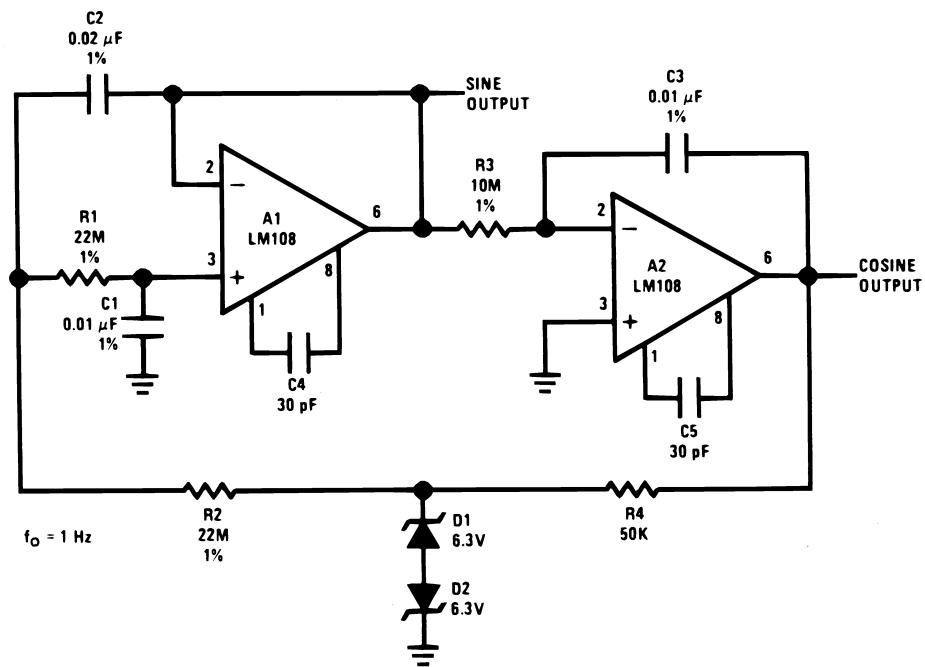
$$R1 = 2000 R3 // R4$$

$$R4 // R3 \leq 10 \text{ k}\Omega$$

$$\text{RANGE} = \pm V \left( \frac{R3 // R4}{R1} \right)$$

## Section 2 — Signal Generation

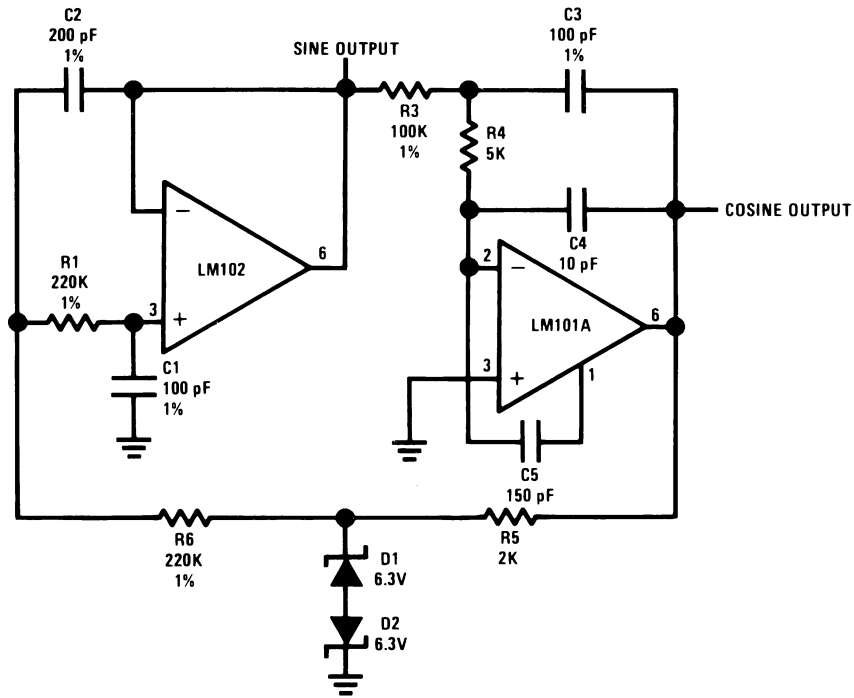
### Low Frequency Sine Wave Generator with Quadrature Output



00705726

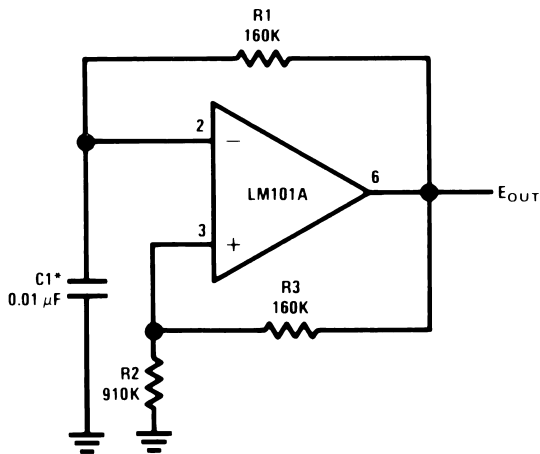
## Section 2 — Signal Generation (Continued)

### High Frequency Sine Wave Generator with Quadrature Output



00705727

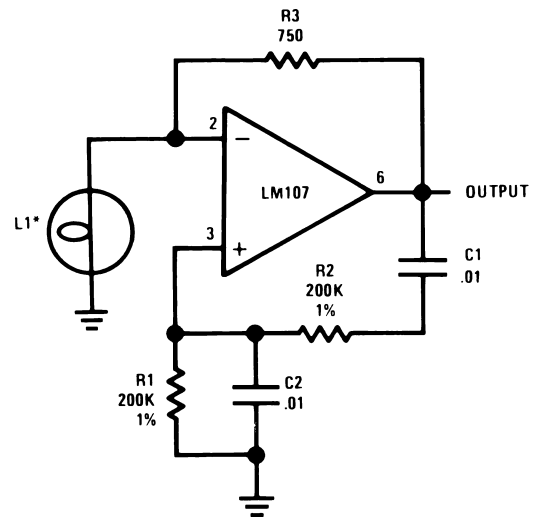
### Free-Running Multivibrator



\*Chosen for oscillation at 100 Hz

00705728

### Wein Bridge Sine Wave Oscillator



00705729

$$R1 = R2$$

$$C1 = C2$$

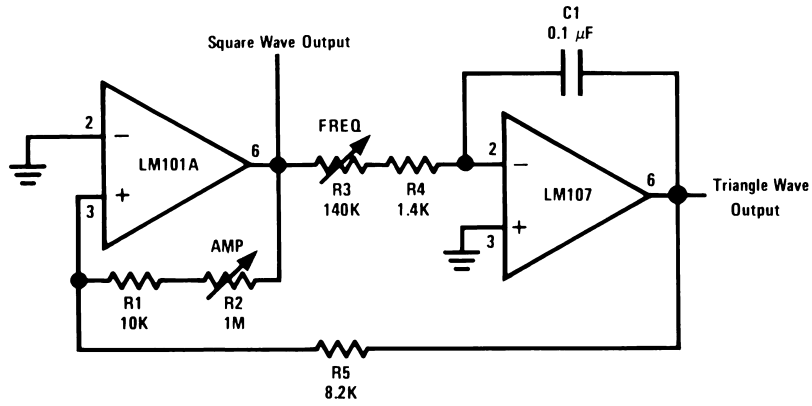
$$f = \frac{1}{2\pi R1 C1}$$

\*Eldema 1869 10V, 14 mA Bulb



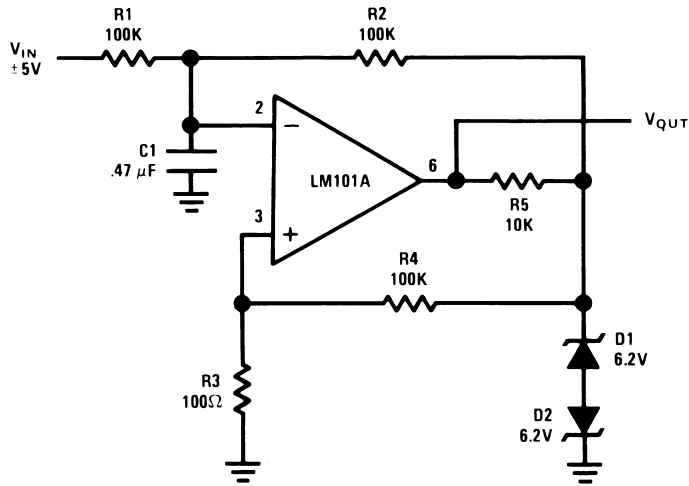
Section 2 — Signal Generation (Continued)

Function Generator



00705730

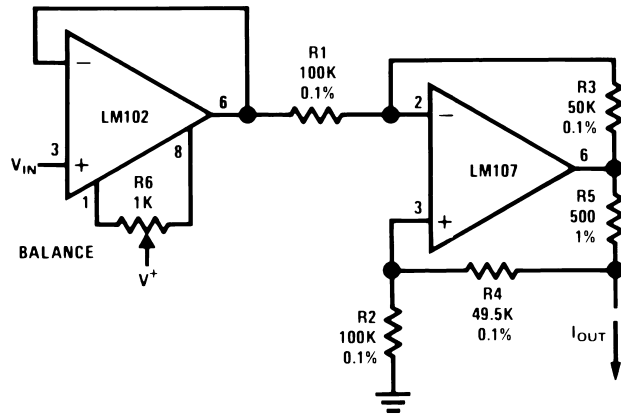
Pulse Width Modulator



00705731

Section 2 — Signal Generation (Continued)

Bilateral Current Source



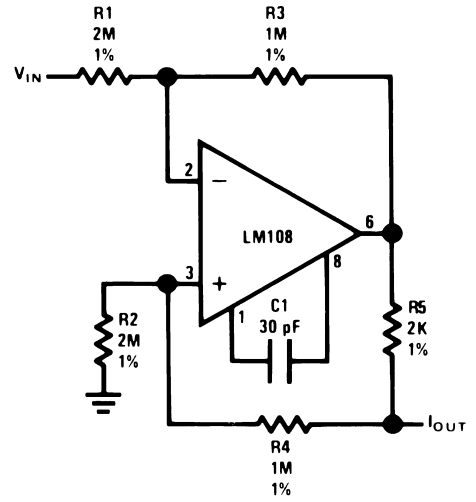
00705732

$$I_{OUT} = \frac{R_3 V_{IN}}{R_1 R_5}$$

$$R_3 = R_4 + R_5$$

$$R_1 = R_2$$

Bilateral Current Source



00705733

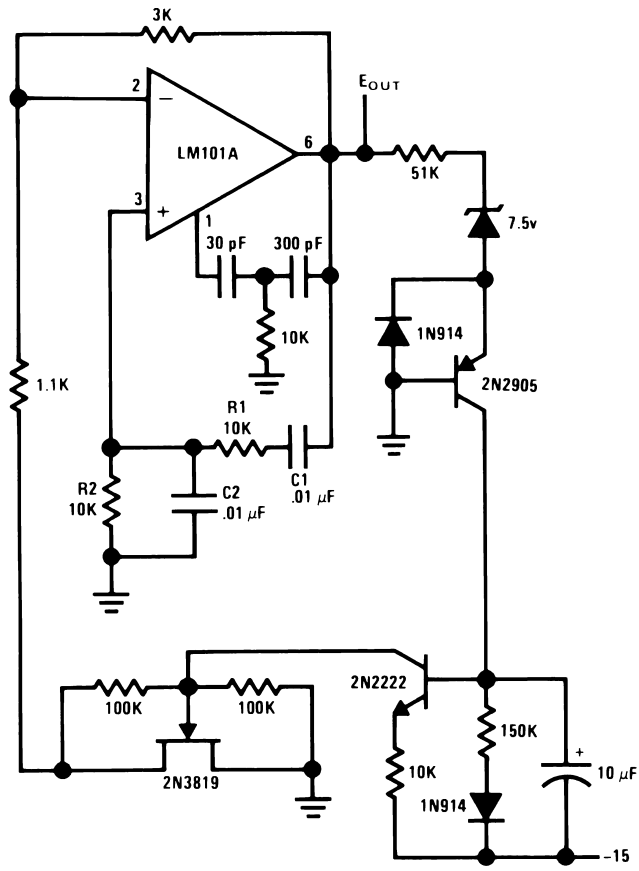
$$I_{OUT} = \frac{R_3 V_{IN}}{R_1 R_5}$$

$$R_3 = R_4 + R_5$$

$$R_1 = R_2$$

Section 2 — Signal Generation (Continued)

Wein Bridge Oscillator with FET Amplitude Stabilization



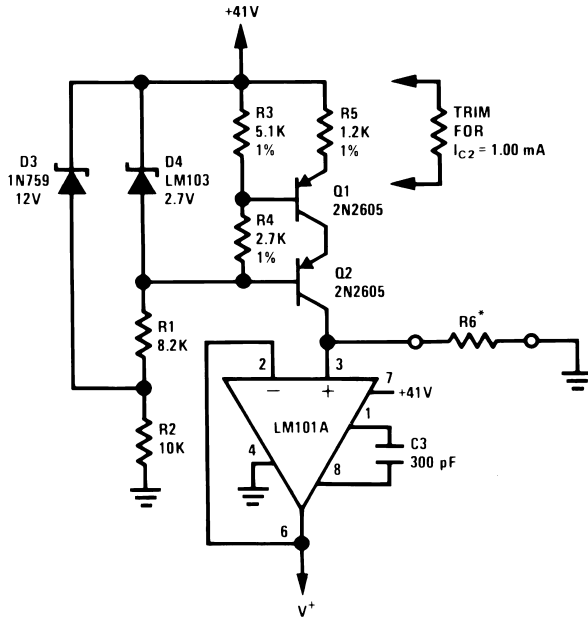
00705734

R1 = R2  
 C1 = C2  

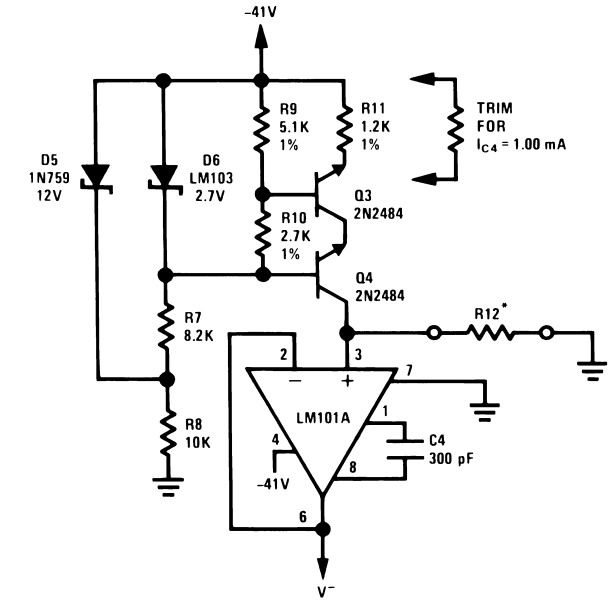
$$f = \frac{1}{2\pi R1 C1}$$

## Section 2 — Signal Generation (Continued)

### Low Power Supply for Integrated Circuit Testing



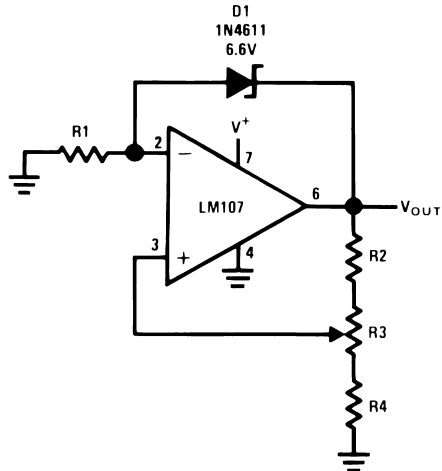
00705735



00705791

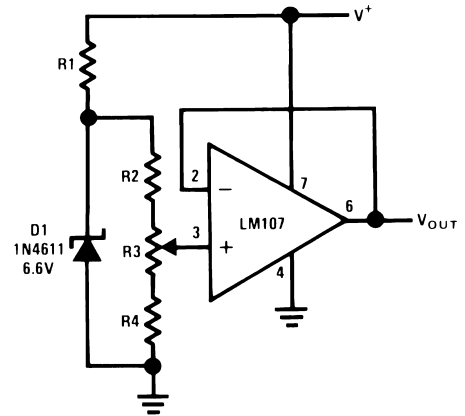
\* $V_{OUT} = 1V/k\Omega$

### Positive Voltage Reference



00705736

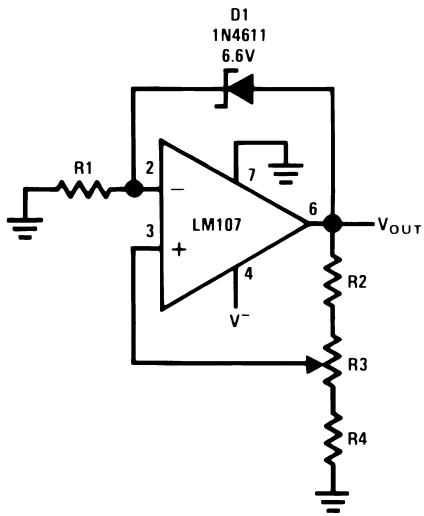
### Positive Voltage Reference



00705737

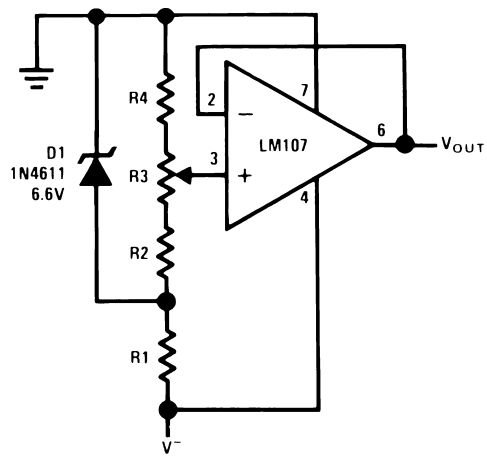
Section 2 — Signal Generation (Continued)

Negative Voltage Reference



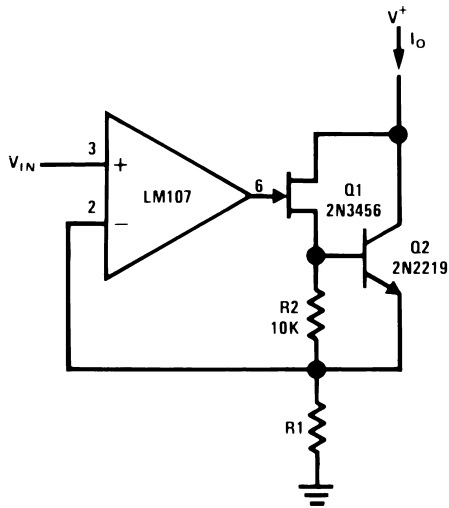
00705738

Negative Voltage Reference



00705739

Precision Current Sink

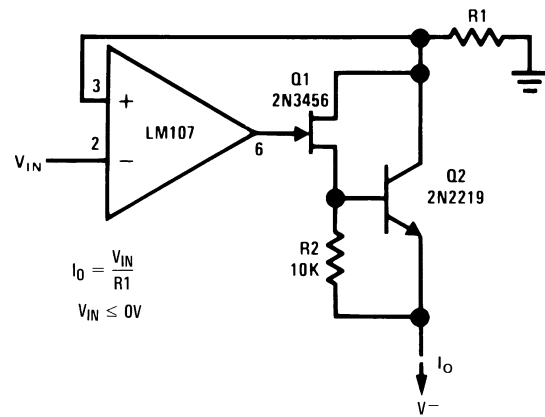


00705740

$$I_o = \frac{V_{IN}}{R1}$$

$$V_{IN} \geq 0V$$

Precision Current Source



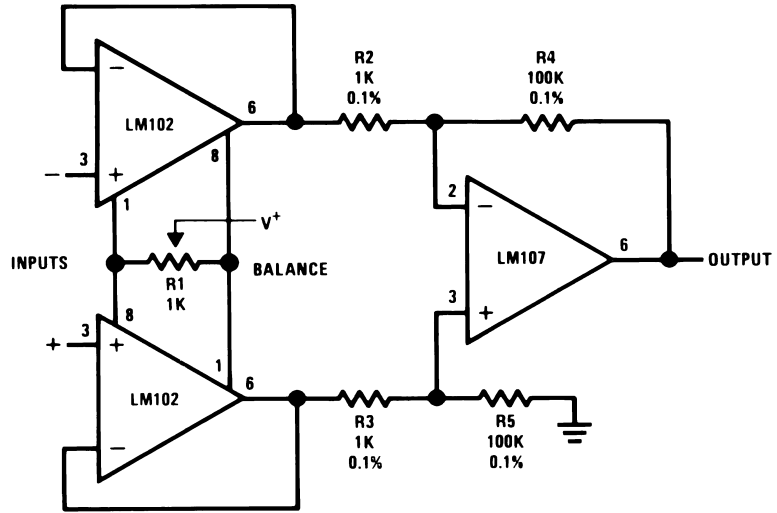
$$I_o = \frac{V_{IN}}{R1}$$

$$V_{IN} \leq 0V$$

00705741

## Section 3 — Signal Processing

### Differential-Input Instrumentation Amplifier

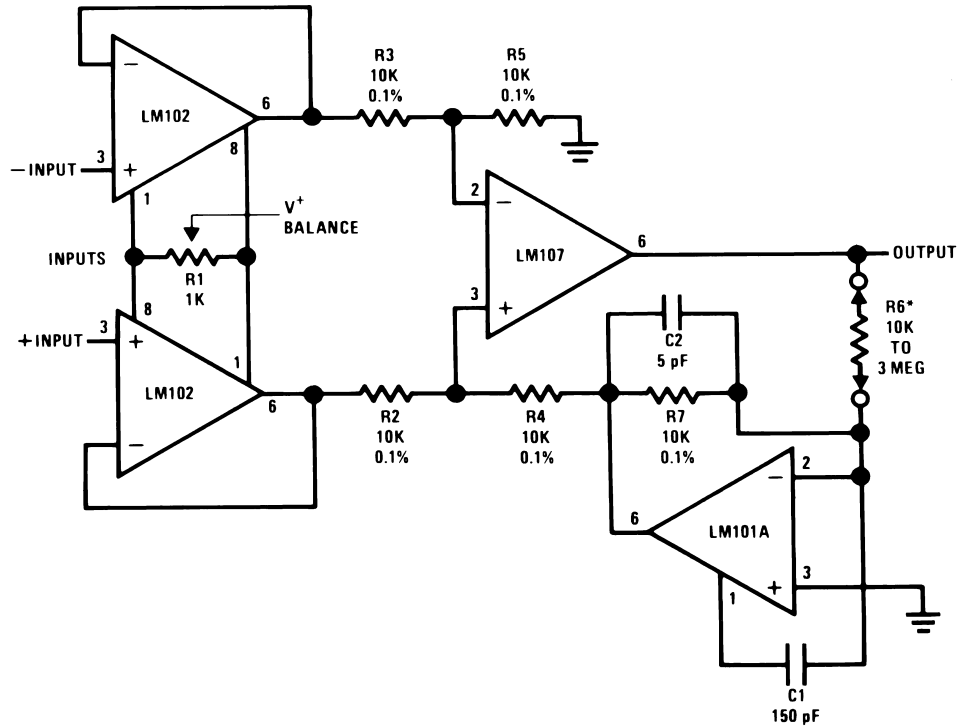


00705742

$$\frac{R4}{R2} = \frac{R5}{R3}$$

$$A_v = \frac{R4}{R2}$$

### Variable Gain, Differential-Input Instrumentation Amplifier

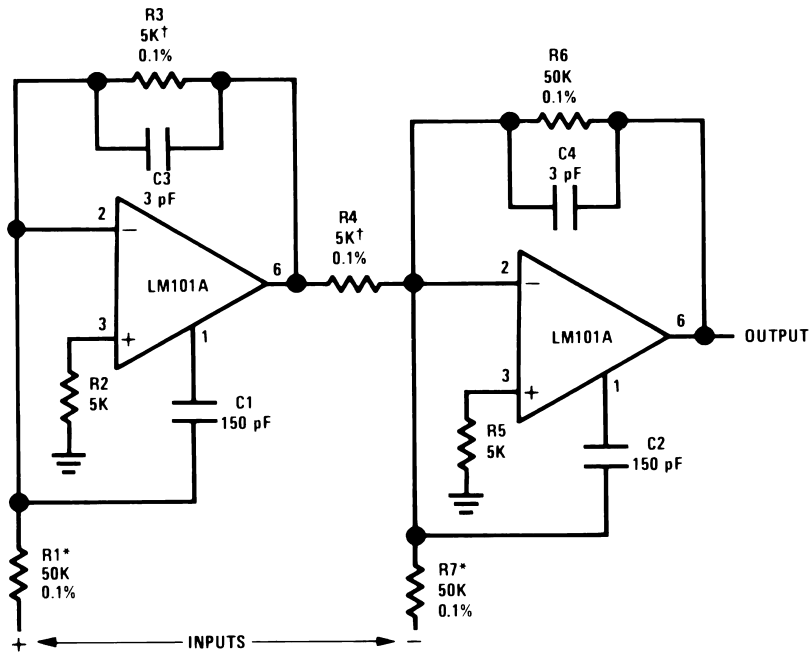


00705743

\*Gain adjust  
 $A_v = 10^{-4} R6$

Section 3 — Signal Processing (Continued)

Instrumentation Amplifier with ±100 Volt Common Mode Range



00705744

†Matching determines common mode rejection.

$$R1 = R5 = 10R2$$

$$R2 = R3$$

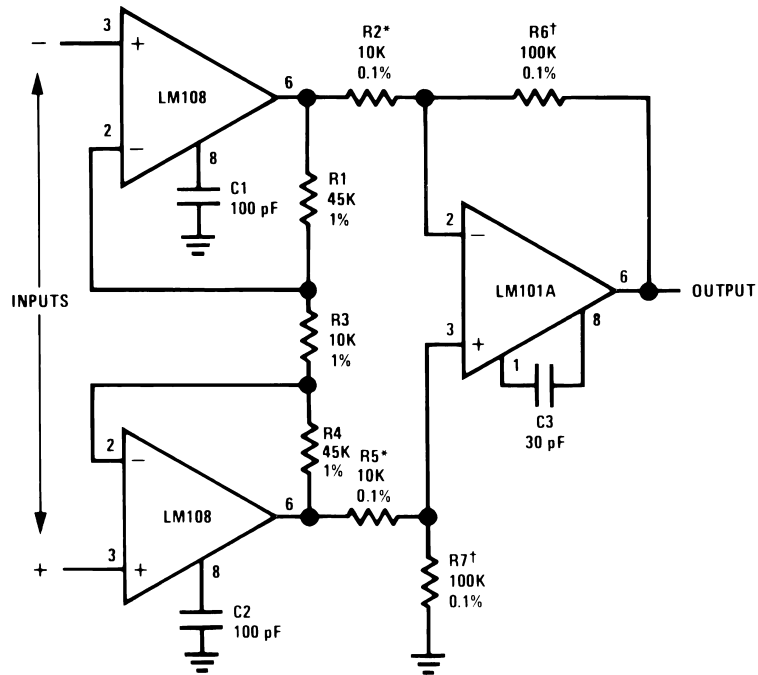
$$R3 = R4$$

$$R1 = R6 = 10R3$$

$$A_v = \frac{R7}{R6}$$

Section 3 — Signal Processing (Continued)

Instrumentation Amplifier with ±10 Volt Common Mode Range

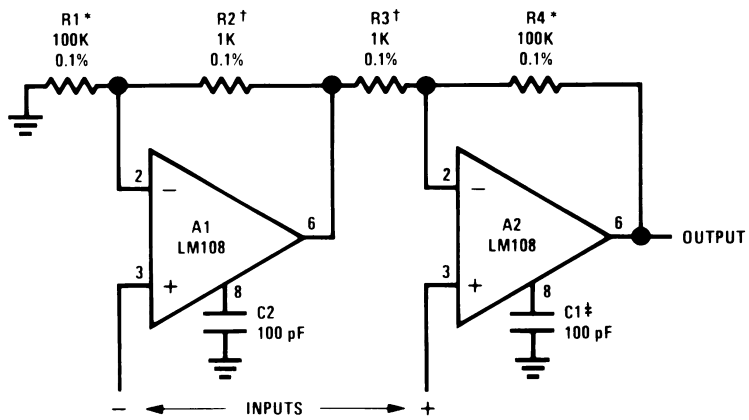


00705745

R1 = R4  
 R2 = R5  
 R6 = R7  
 †\*Matching Determines CMRR

$$A_v = \frac{R6}{R2} \left( 1 + \frac{2R1}{R3} \right)$$

High Input Impedance Instrumentation Amplifier



00705746

R1 = R4; R2 = R3

$$A_v = 1 + \frac{R1}{R2}$$

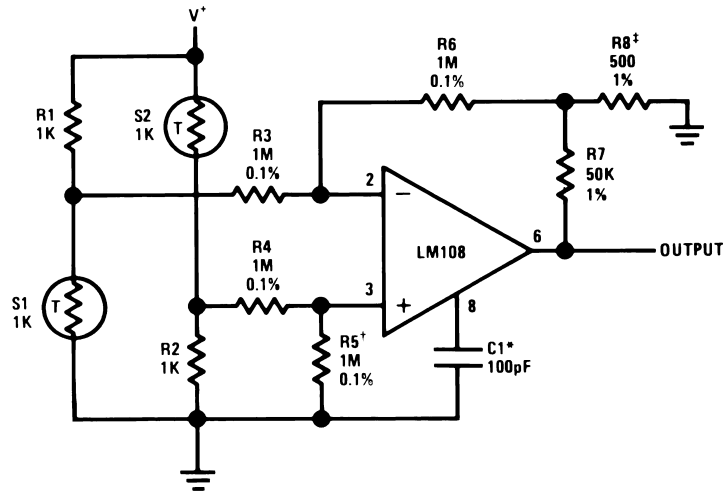
\*†Matching Determines CMRR

‡May be deleted to maximize bandwidth



Section 3 — Signal Processing (Continued)

Bridge Amplifier with Low Noise Compensation



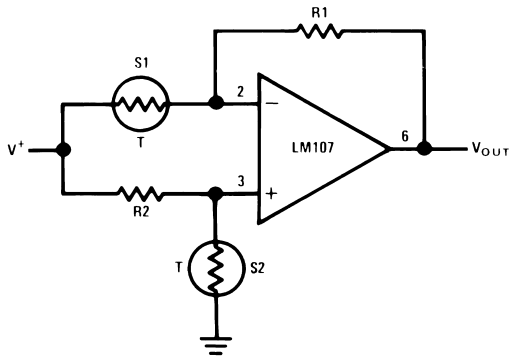
00705747

\*Reduces feed through of power supply noise by 20 dB and makes supply bypassing unnecessary.

†Trim for best common mode rejection

‡Gain adjust

Bridge Amplifier

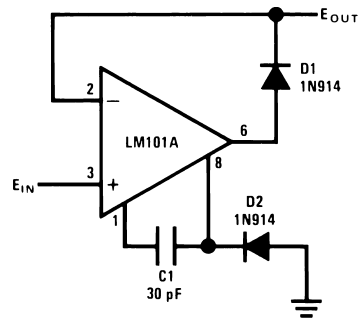


00705748

$$\frac{R1}{RS1} = \frac{R2}{RS2}$$

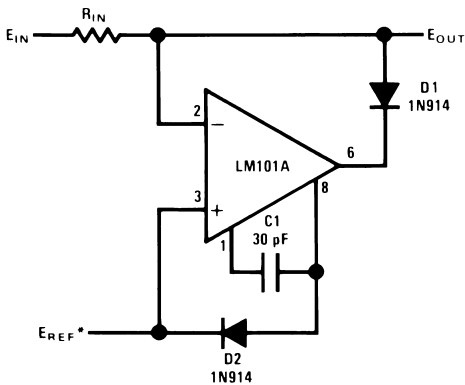
$$V_{OUT} = V^+ \left( 1 - \frac{R1}{RS1} \right)$$

Precision Diode



00705749

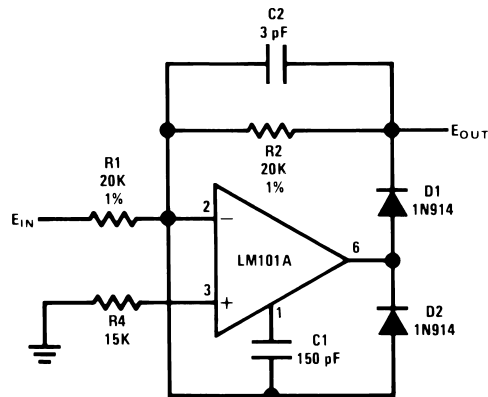
Precision Clamp



00705750

\*E<sub>REF</sub> must have a source impedance of less than 200Ω if D2 is used.

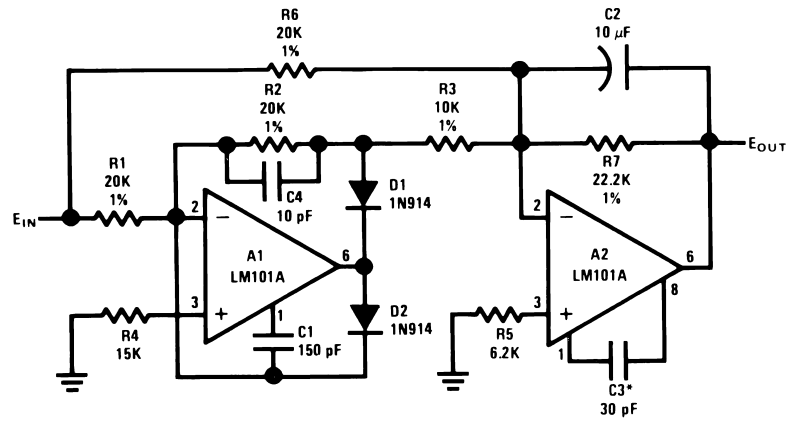
Fast Half Wave Rectifier



00705751

## Section 3 — Signal Processing (Continued)

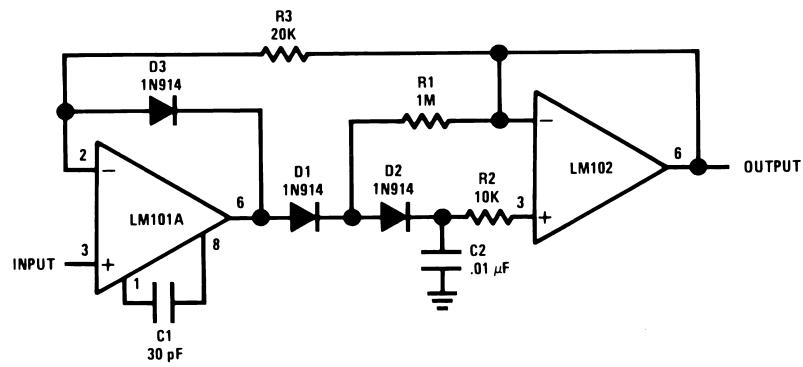
### Precision AC to DC Converter



00705752

\*Feedforward compensation can be used to make a fast full wave rectifier without a filter.

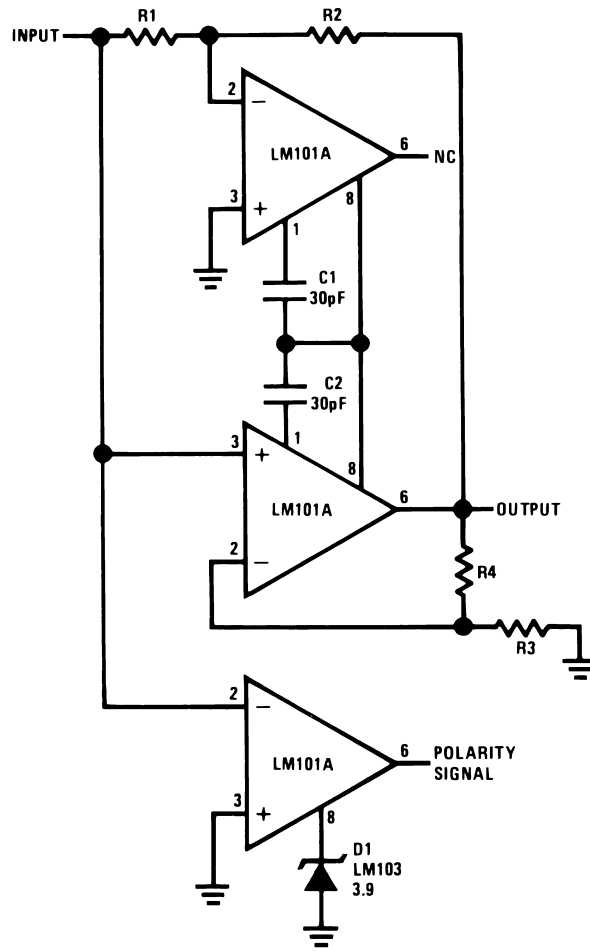
### Low Drift Peak Detector



00705753

Section 3 — Signal Processing (Continued)

Absolute Value Amplifier with Polarity Detector

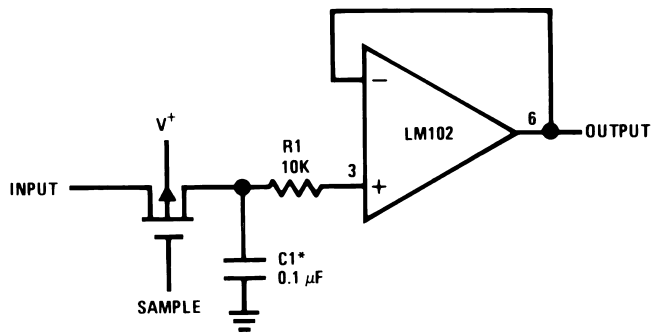


00705754

$$V_{OUT} = -|V_{IN}| \times \frac{R2}{R1}$$

$$\frac{R2}{R1} = \frac{R4 + R3}{R3}$$

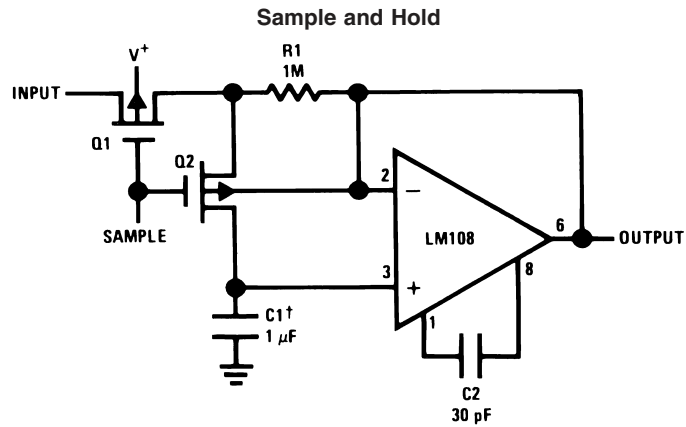
Sample and Hold



00705755

\*Polycarbonate-dielectric capacitor

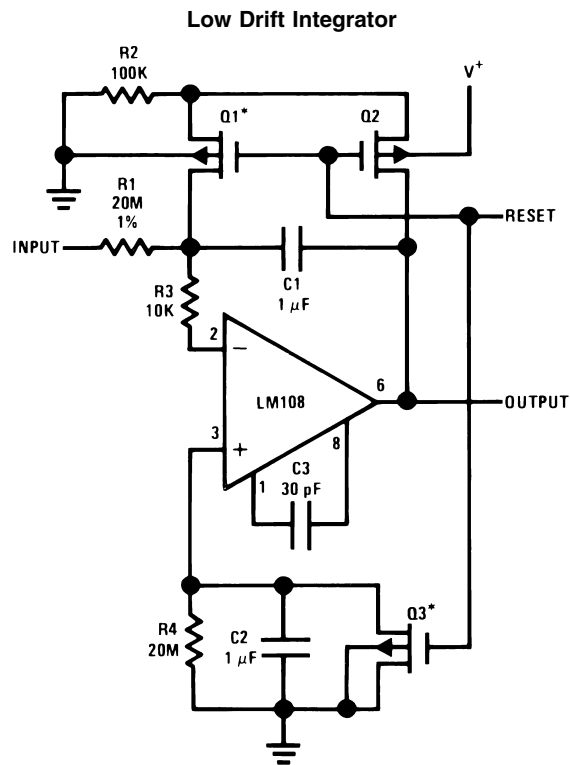
## Section 3 — Signal Processing (Continued)



00705756

\*Worst case drift less than 2.5 mV/sec

†Teflon, Polyethylene or Polycarbonate Dielectric Capacitor

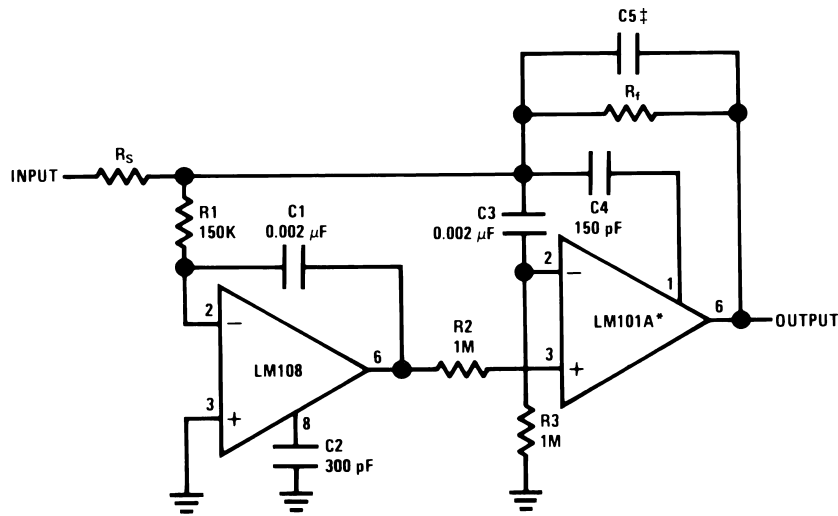


00705757

\*Q1 and Q3 should not have internal gate-protection diodes.  
Worst case drift less than 500  $\mu$ V/sec over  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

Section 3 — Signal Processing (Continued)

Fast<sup>†</sup> Summing Amplifier with Low Input Current



00705758

\*In addition to increasing speed, the LM101A raises high and low frequency gain, increases output drive capability and eliminates thermal feedback.

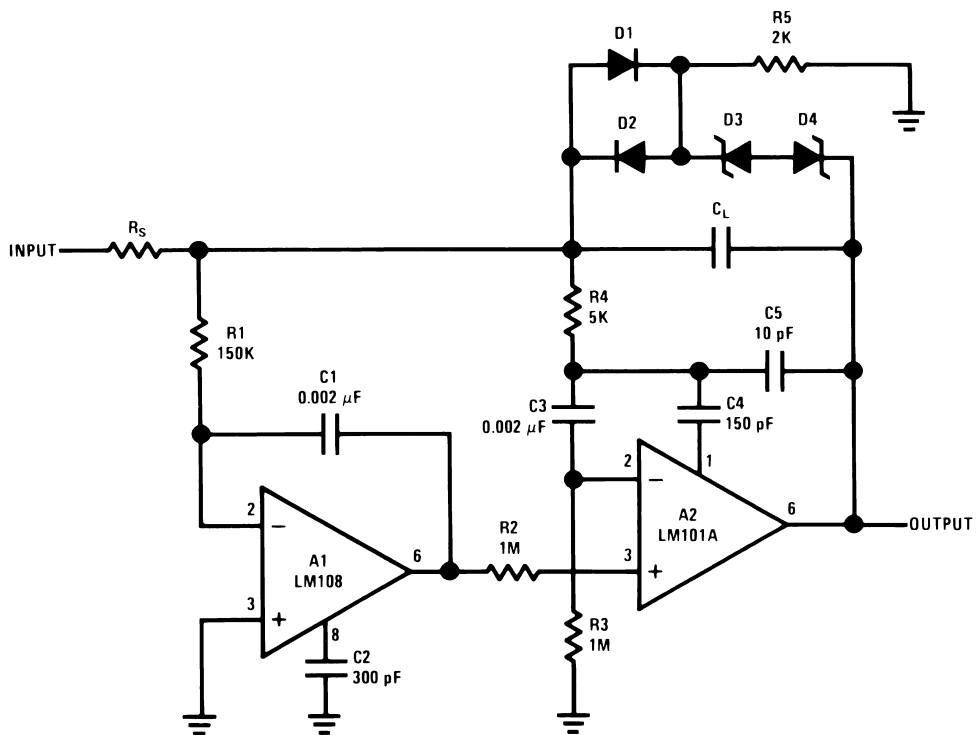
†Power Bandwidth: 250 kHz

Small Signal Bandwidth: 3.5 MHz

Slew Rate: 10V/μs

$$C5 = \frac{6 \times 10^{-8}}{R_f}$$

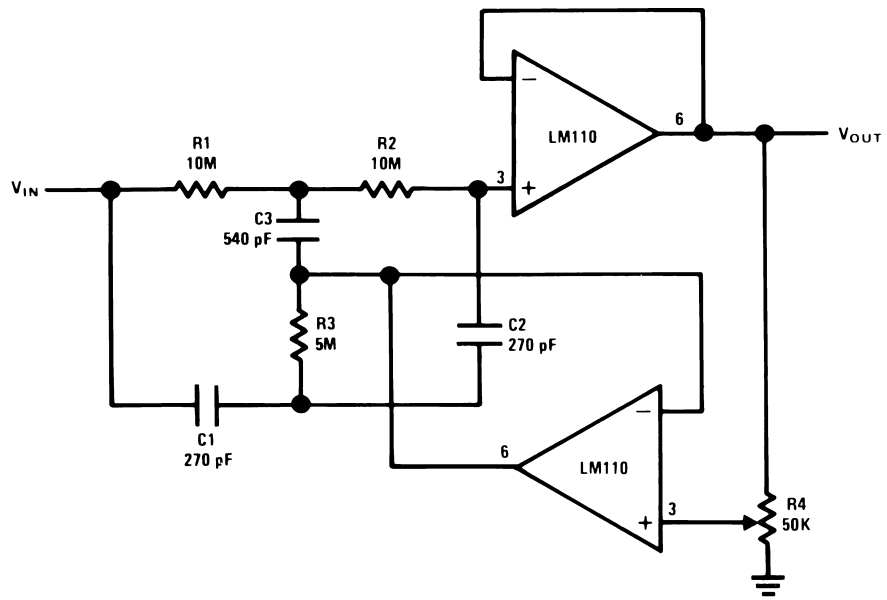
Fast Integrator with Low Input Current



00705759

## Section 3 — Signal Processing (Continued)

Adjustable Q Notch Filter



00705760

$$f_0 = \frac{1}{2\pi R1 C1}$$

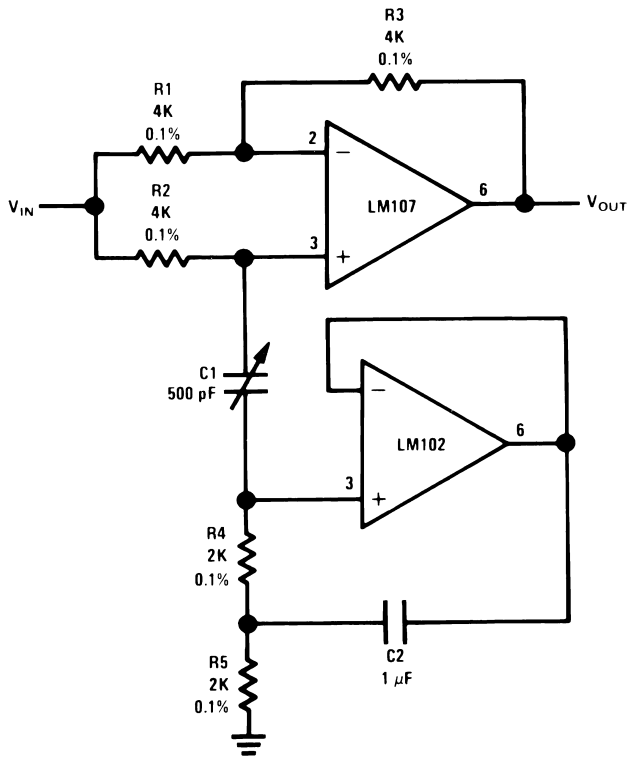
$$= 60 \text{ Hz}$$

$$R1 = R2 = R3$$

$$C1 = C2 = C23$$

Section 3 — Signal Processing (Continued)

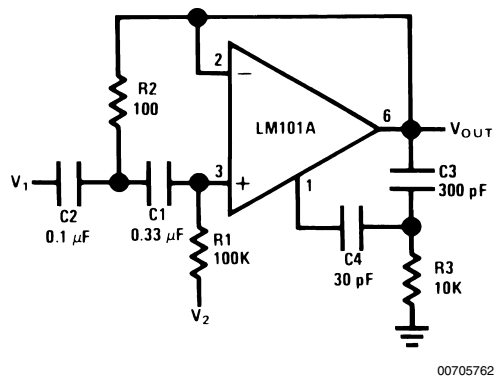
Easily Tuned Notch Filter



00705761

$R4 = R5$   
 $R1 = R3$   
 $R4 = \frac{1}{2} R1$   
 $f_o = \frac{1}{2\pi R4 \sqrt{C1 C2}}$

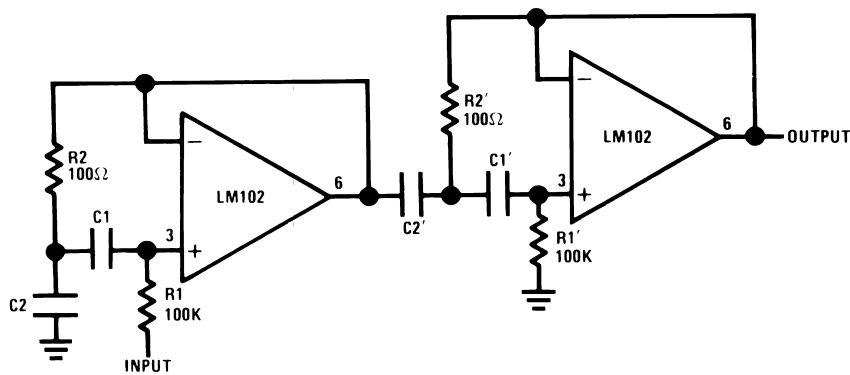
Tuned Circuit



00705762

$$f_o = \frac{1}{2\pi \sqrt{R1 R2 C1 C2}}$$

Two-Stage Tuned Circuit

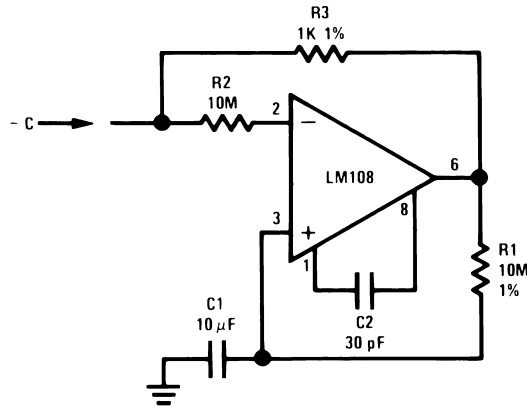


00705763

$$f_o = \frac{1}{2\pi \sqrt{R1 R2 C1 C2}}$$

Section 3 — Signal Processing (Continued)

Negative Capacitance Multiplier



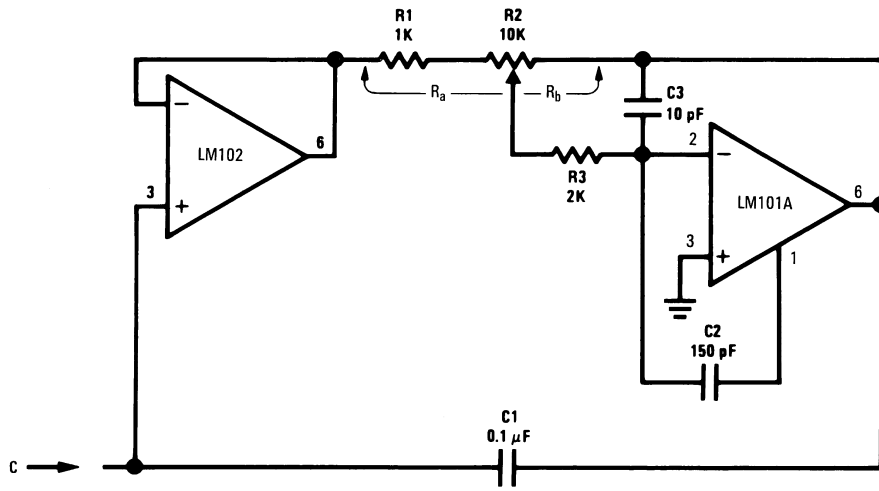
00705765

$$C = \frac{R2}{R3} C1$$

$$I_L = \frac{V_{OS} + R2 I_{OS}}{R3}$$

$$R_S = \frac{R3(R1 + R_{IN})}{R_{IN} A_{VO}}$$

Variable Capacitance Multiplier

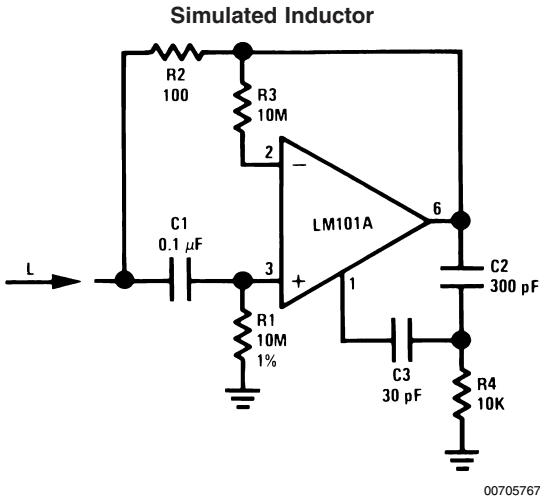


00705766

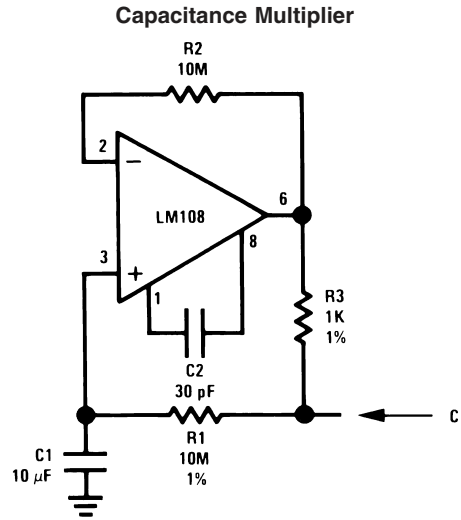
$$C = \left( 1 + \frac{R_b}{R_a} \right) C_1$$



Section 3 — Signal Processing (Continued)



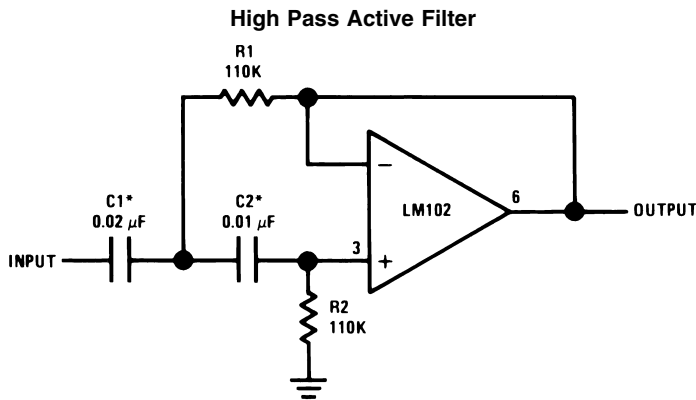
$L \geq R1 R2 C1$   
 $R_S = R2$   
 $R_P = R1$



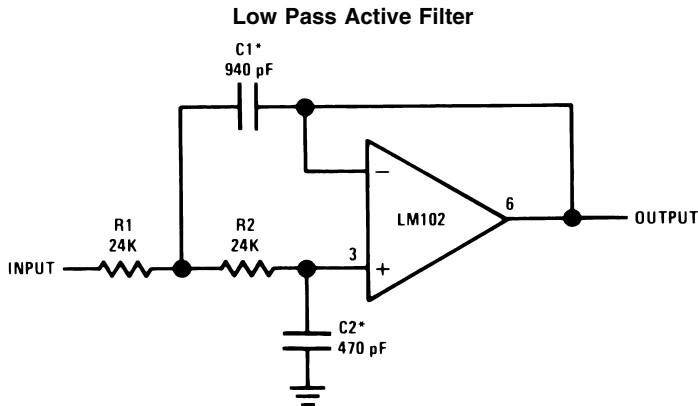
$$C = \frac{R1}{R3} C1$$

$$I_L = \frac{V_{os} + I_{os} R1}{R3}$$

$$R_S = R3$$



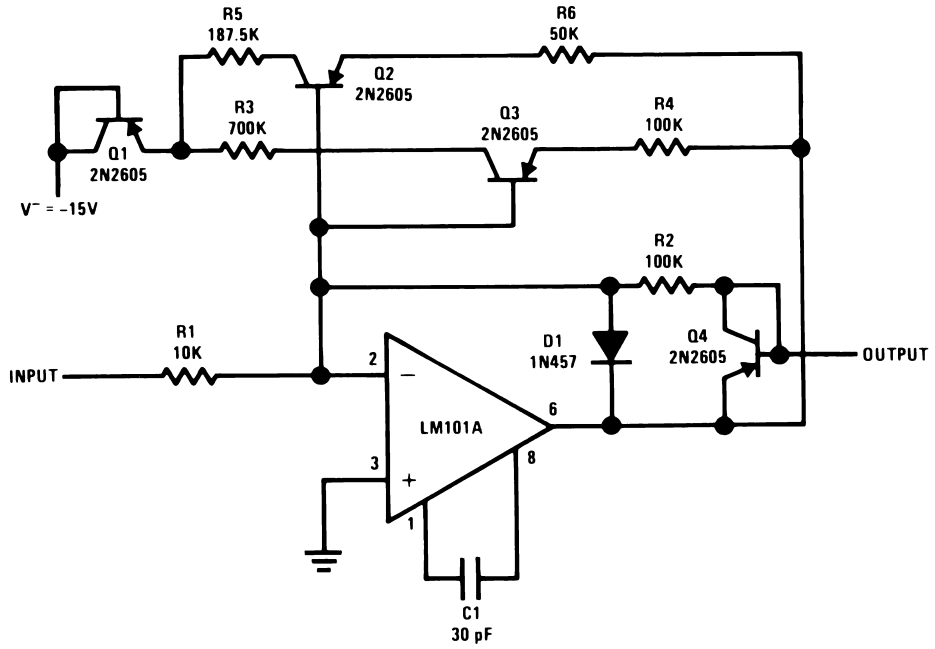
\*Values are for 100 Hz cutoff. Use metalized polycarbonate capacitors for good temperature stability.



\*Values are for 10 kHz cutoff. Use silvered mica capacitors for good temperature stability.

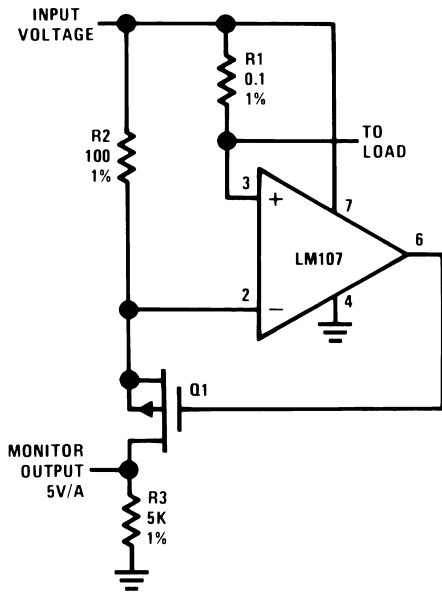
Section 3 — Signal Processing (Continued)

Nonlinear Operational Amplifier with Temperature Compensated Breakpoints



00705773

Current Monitor

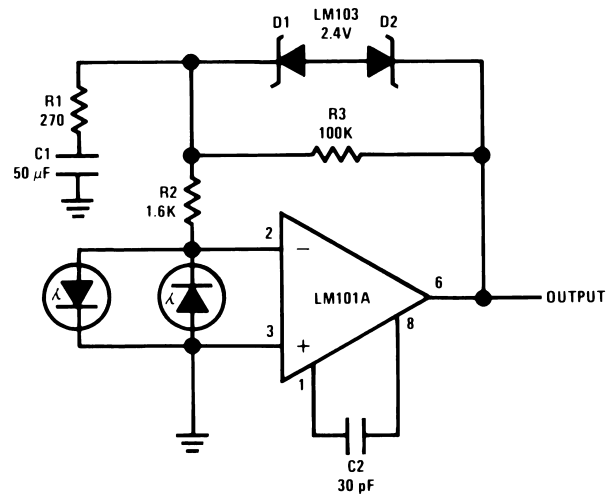


00705774

$$V_{OUT} = \frac{R1 R3}{R2} I_L$$

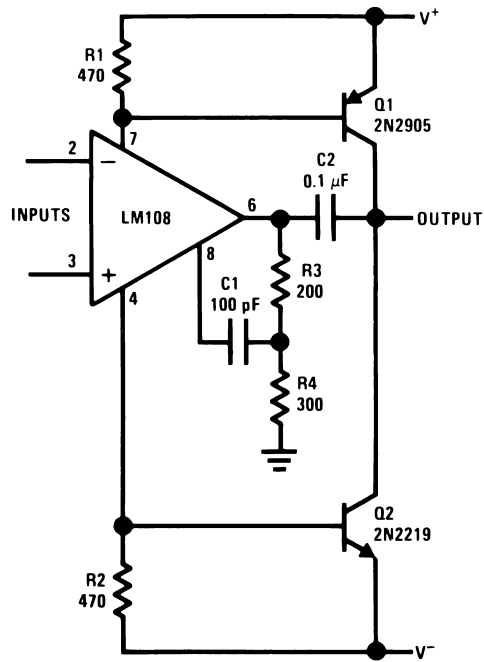
Section 3 — Signal Processing (Continued)

Saturating Servo Preamplifier with Rate Feedback



00705775

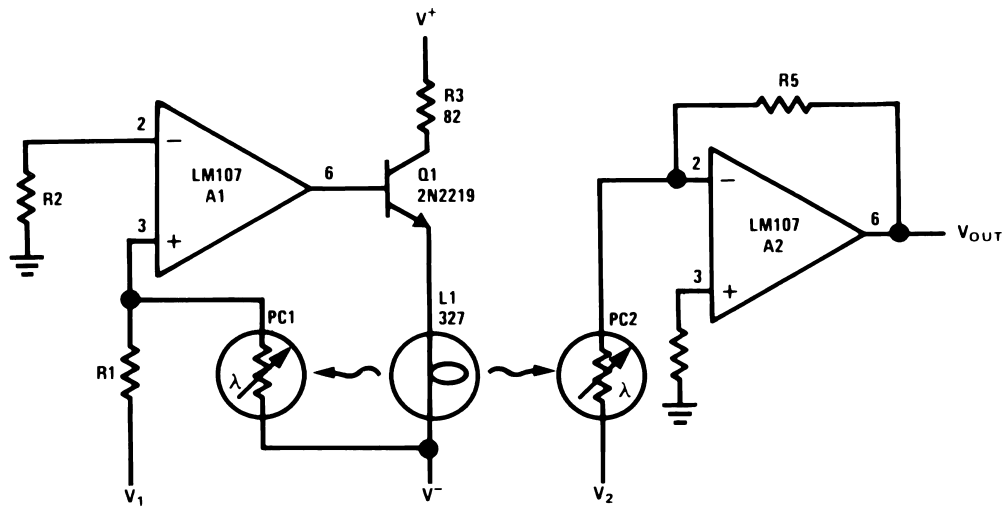
Power Booster



00705776

Section 3 — Signal Processing (Continued)

Analog Multiplier



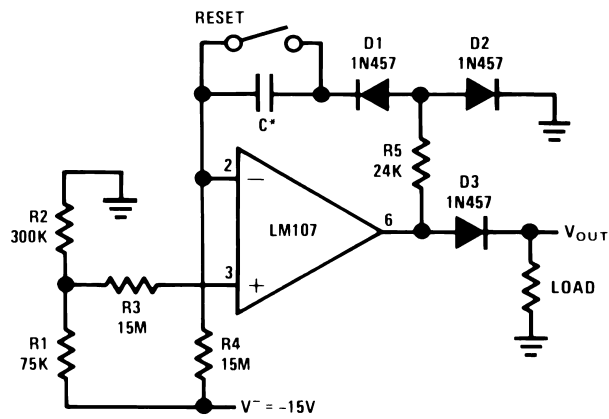
00705777

$$R5 = R1 \left( \frac{V^-}{10} \right)$$

$$V_1 \geq 0$$

$$V_{OUT} = \frac{V_1 V_2}{10}$$

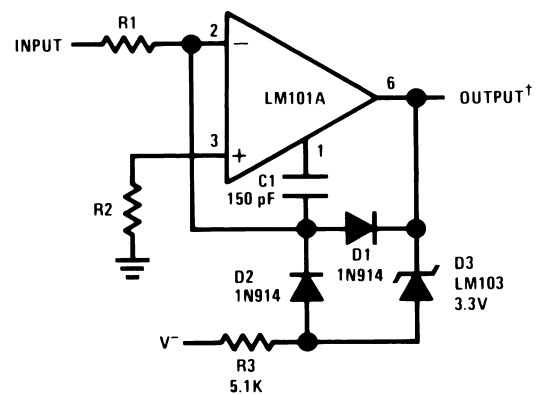
Long Interval Timer



\*Low leakage -0.017 μF per second delay

00705778

Fast Zero Crossing Detector

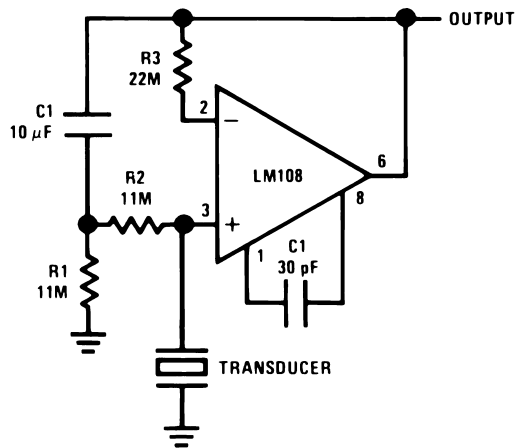


00705779

Propagation delay approximately 200 ns  
 †DTL or TTL fanout of three.  
 Minimize stray capacitance  
 Pin 8

Section 3 — Signal Processing (Continued)

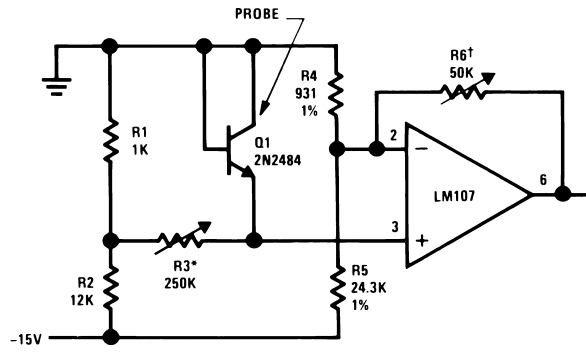
Amplifier for Piezoelectric Transducer



00705780

Low frequency cutoff =  $R1 C1$

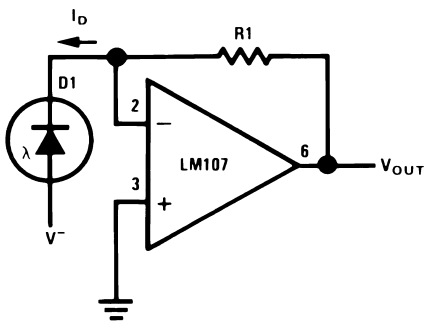
Temperature Probe



00705781

\*Set for 0V at 0°C  
 †Adjust for 100 mV/°C

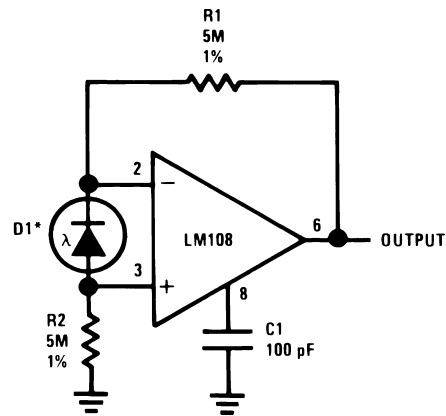
Photodiode Amplifier



00705782

$V_{OUT} = R1 I_D$

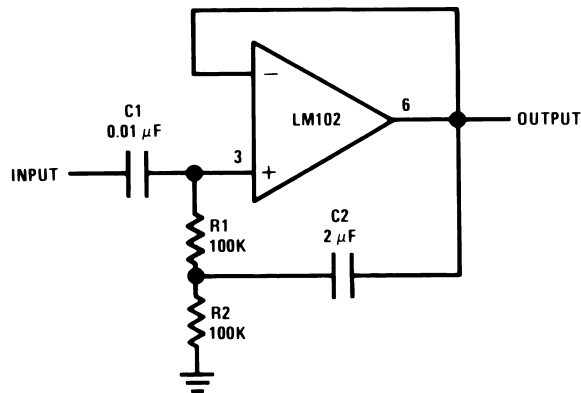
Photodiode Amplifier



00705783

$V_{OUT} = 10 V/\mu A$   
 \*Operating photodiode with less than 3 mV across it eliminates leakage currents.

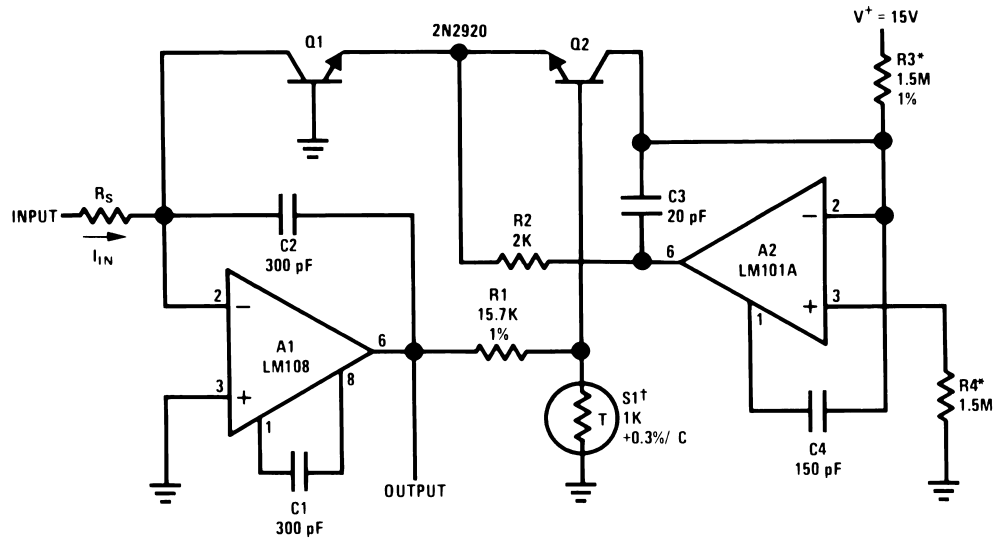
High Input Impedance AC Follower



00705784

Section 3 — Signal Processing (Continued)

Temperature Compensated Logarithmic Converter



00705785

$10 \text{ nA} < I_{IN} < 1 \text{ mA}$

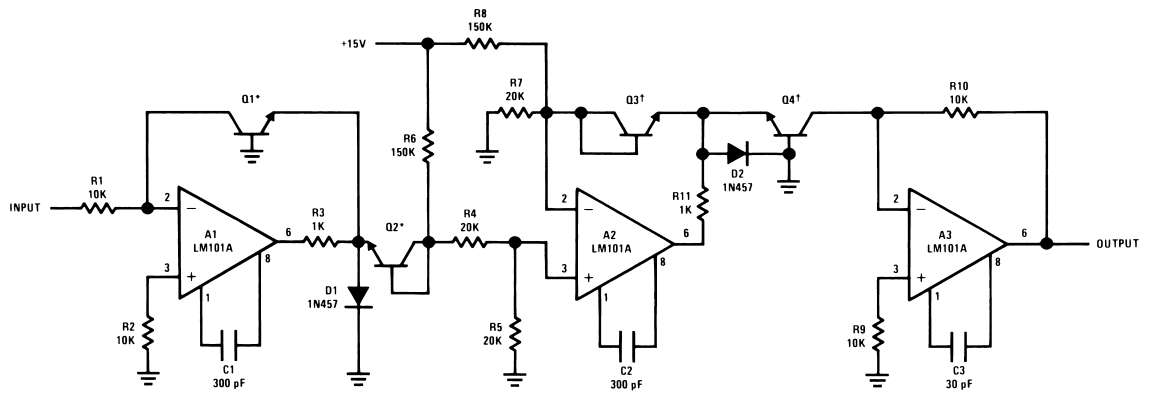
Sensitivity is 1V per decade

†1 kΩ (±1%) at 25°C, +3500 ppm/°C.

Available from Vishay Ultronix, Grand Junction, CO, Q81 Series.

\*Determines current for zero crossing on output: 10 μA as shown.

Root Extractor

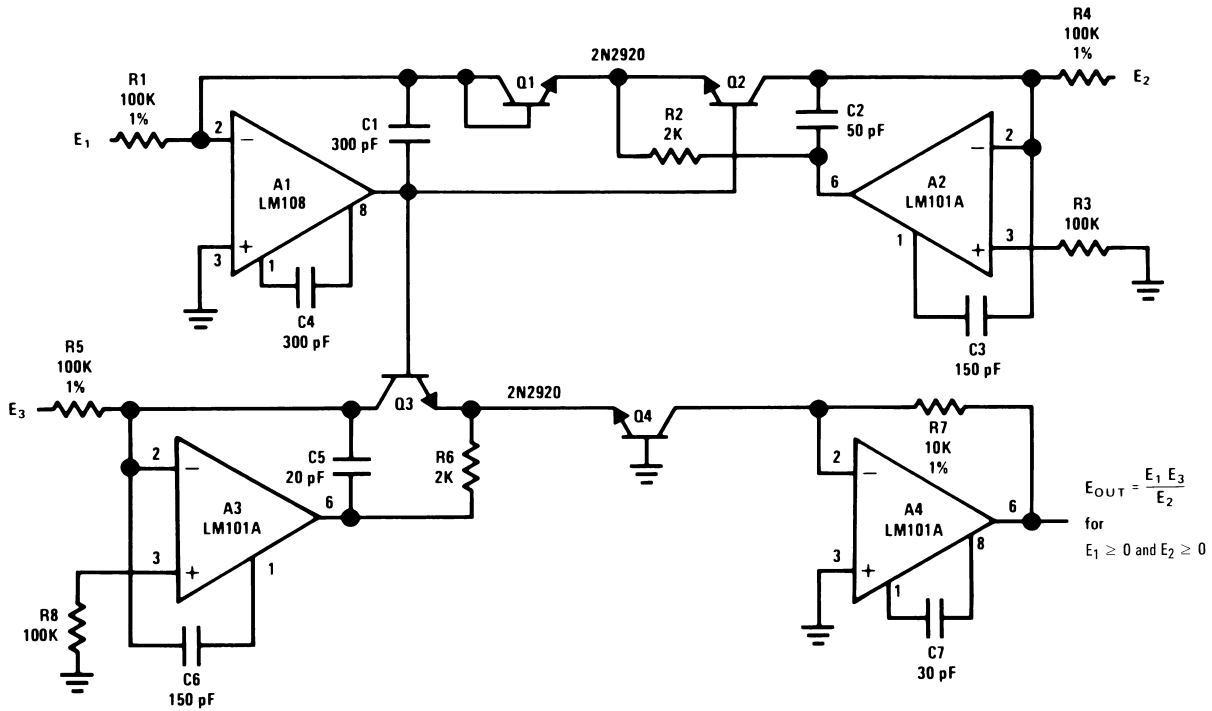


00705786

\*†2N3728 matched pairs

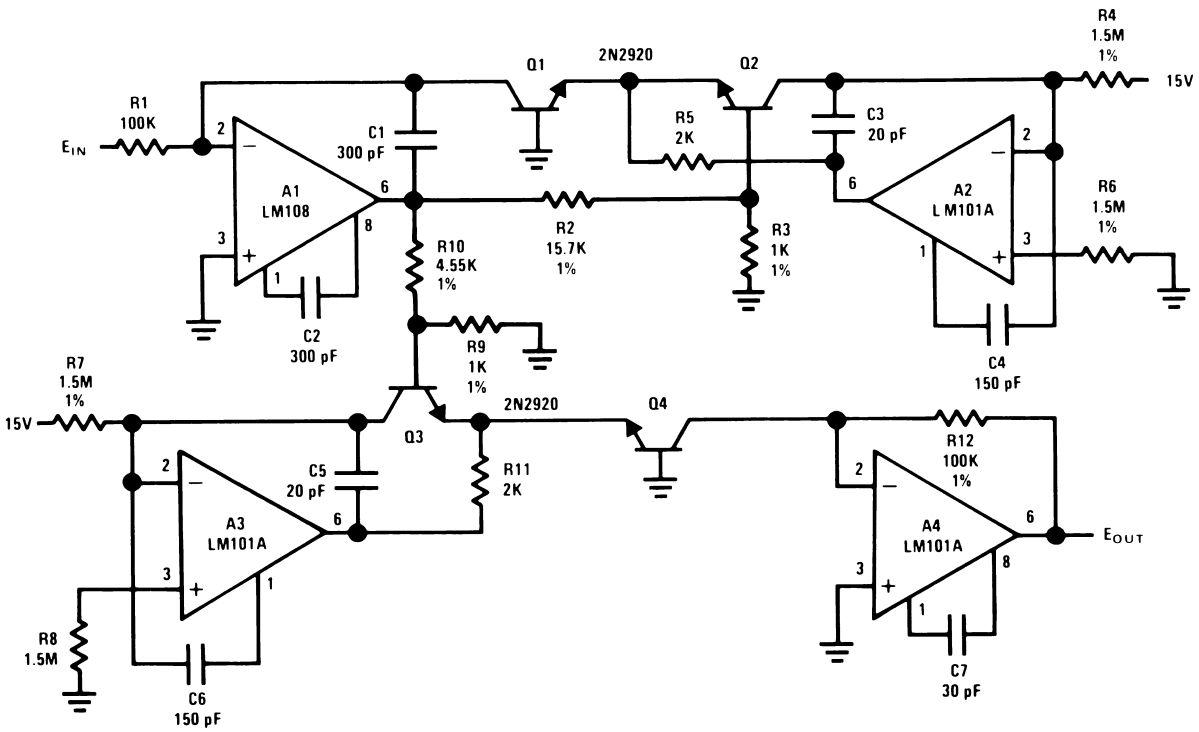
Section 3 — Signal Processing (Continued)

Multiplier/Divider



00705787

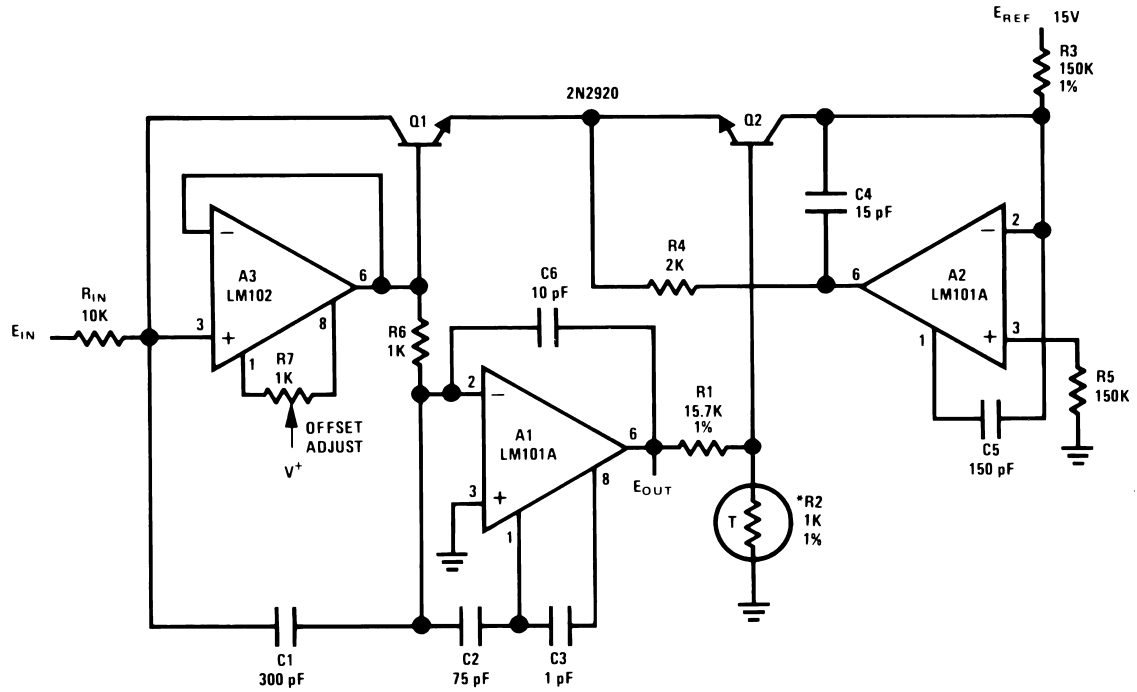
Cube Generator



00705788

Section 3 — Signal Processing (Continued)

Fast Log Generator

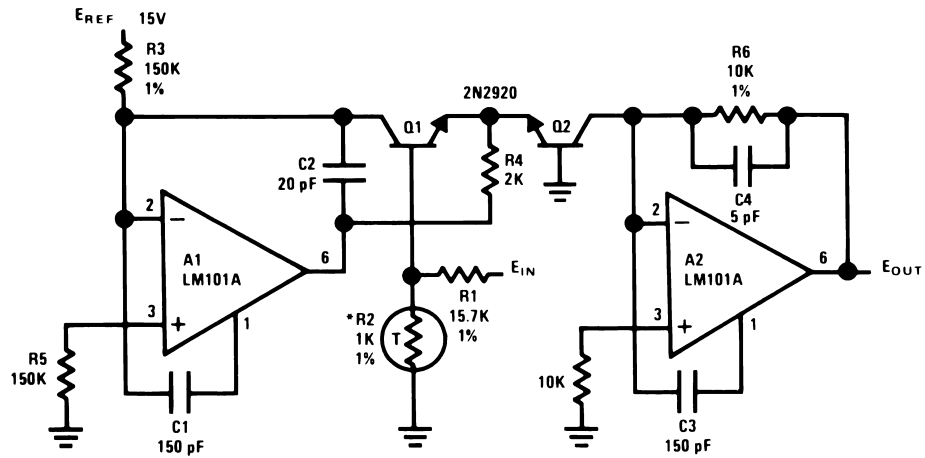


†1 kΩ (±1%) at 25°C, +3500 ppm/°C.

Available from Vishay Ultronic, Grand Junction, CO, Q81 Series.

00705789

Anti-Log Generator



†1 kΩ (±1%) at 25°C, +3500 ppm/°C.

Available from Vishay Ultronic, Grand Junction, CO, Q81 Series.

00705790



## Notes

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



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