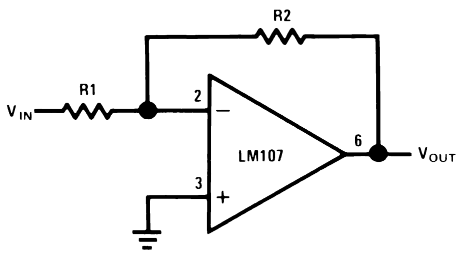
Op Amp Circuit Collection

National Semiconductor
Application Note 31
September 2002

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

Section 1—Basic Circuits

Inverting Amplifier

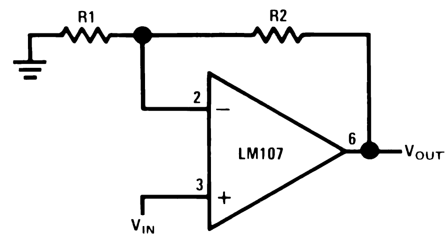


00705701

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

$$R_{IN} = R1$$

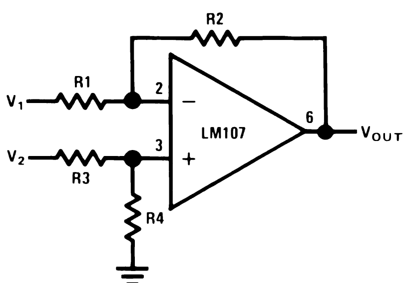
Non-Inverting Amplifier



00705702

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

Difference Amplifier



00705703

$$V_{OUT} = \left(\frac{R1 + R2}{R3 + R4}\right) \frac{R4}{R1} V_2 - \frac{R2}{R1} V_1$$

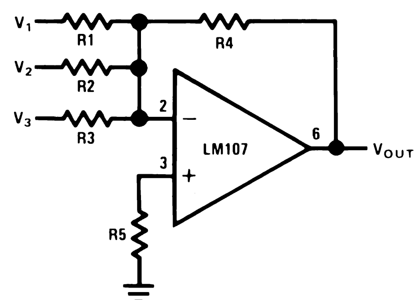
For R1 = R3 and R2 = R4

$$V_{OUT} = \frac{R2}{R1} (V_2 - V_1)$$

$$R1 // R2 = R3 // R4$$

For minimum offset error due to input bias current

Inverting Summing Amplifier



00705704

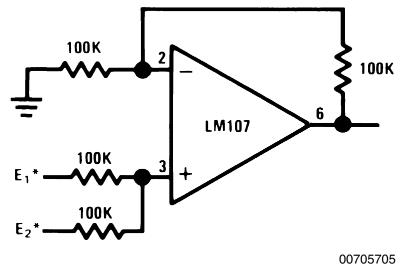
$$V_{OUT} = -R4 \left(\frac{V_1}{R1} + \frac{V_2}{R2} + \frac{V_3}{R3}\right)$$

R5 = R1//R2//R3//R4

For minimum offset error due to input bias current

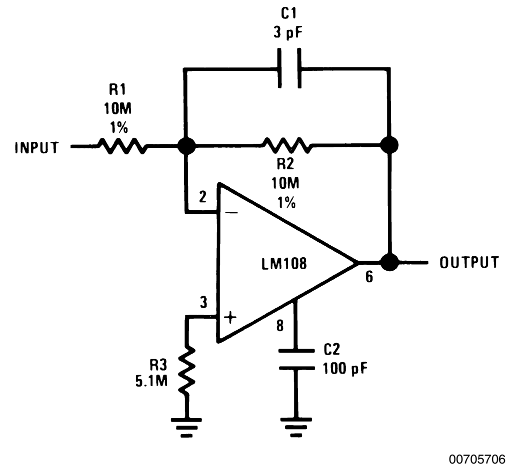
Section 1—Basic Circuits (Continued)

Non-Inverting Summing Amplifier



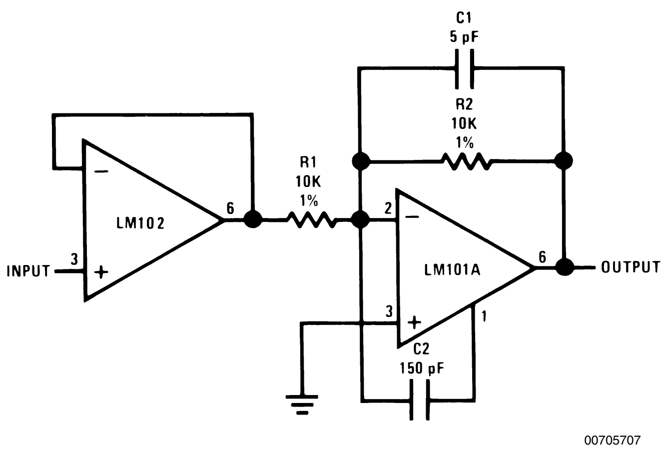
*R_S = 1k for 1% accuracy

Inverting Amplifier with High Input Impedance

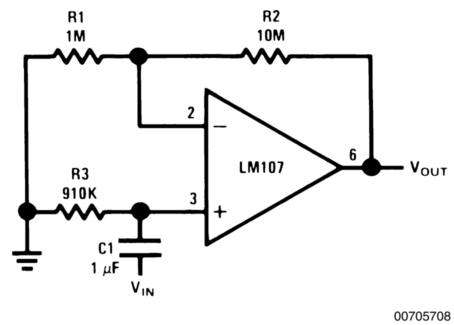


*Source Impedance less than 100k gives less than 1% gain error.

Fast Inverting Amplifier with High Input Impedance



Non-Inverting AC Amplifier



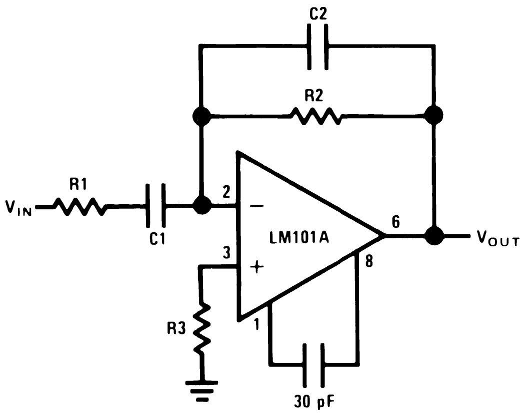
$$V_{OUT} = \frac{R1 + R2}{R1} V_{IN}$$

R_{IN} = R3

R3 = R1//R2

Section 1—Basic Circuits (Continued)

Practical Differentiator



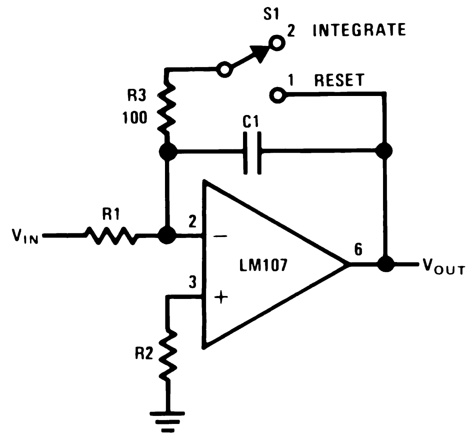
00705709

$$f_c = \frac{1}{2\pi R2C1}$$

$$f_h = \frac{1}{2\pi R1C1} = \frac{1}{2\pi R2C2}$$

$$f_c \ll f_h \ll f_{unity\ gain}$$

Integrator



00705710

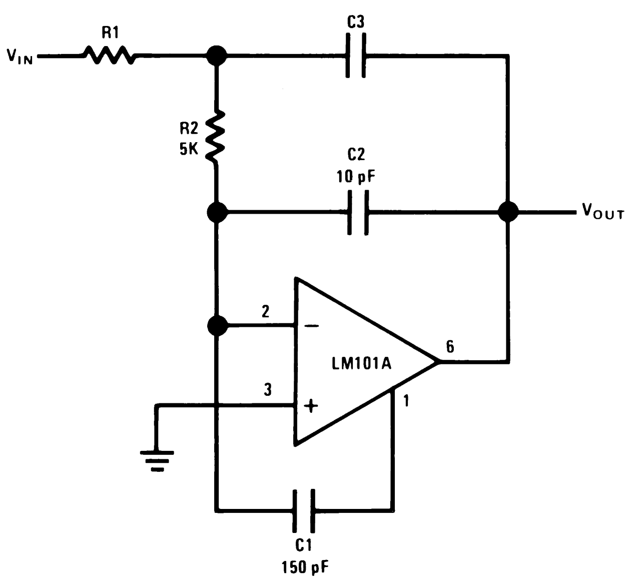
$$V_{OUT} = -\frac{1}{R1C1}\int_{t_1}^{t_2} V_{IN}\,dt$$

$$f_c = \frac{1}{2\pi R1C1}$$

$$R1 = R2$$

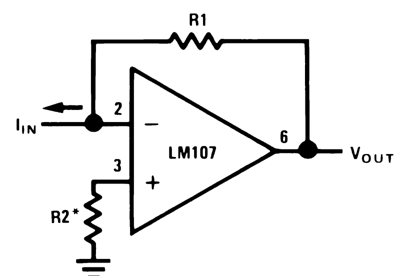
For minimum offset error due to input bias current

Fast Integrator



00705711

Current to Voltage Converter



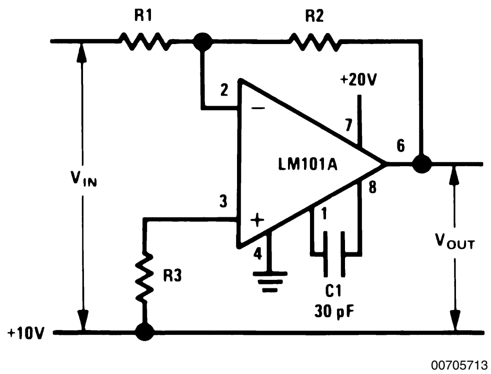
00705712

$V_{OUT} = I_{IN}$ R1

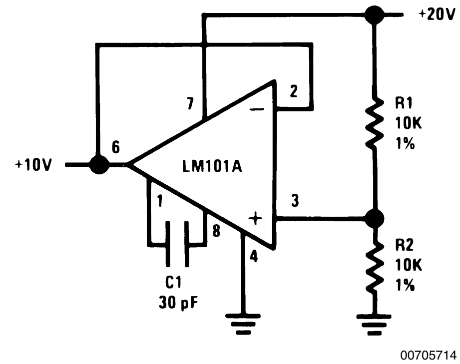
*For minimum error due to bias current R2 = R1

Section 1—Basic Circuits (Continued)

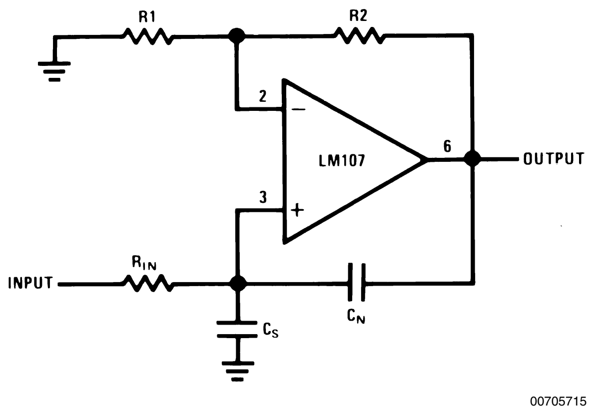
Circuit for Operating the LM101 without a Negative Supply



Circuit for Generating the Second Positive Voltage

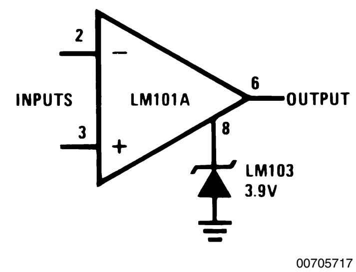


Neutralizing Input Capacitance to Optimize Response Time

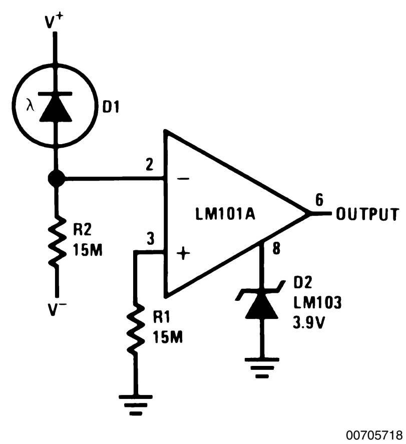


$$C_N \leq \frac{R1}{R2} C_S$$

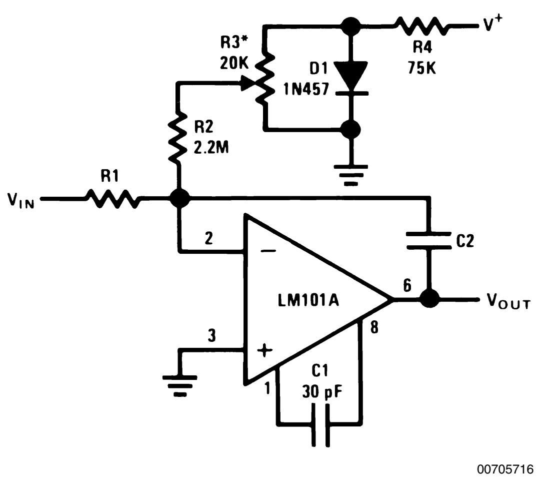
Voltage Comparator for Driving DTL or TTL Integrated Circuits



Threshold Detector for Photodiodes



Integrator with Bias Current Compensation

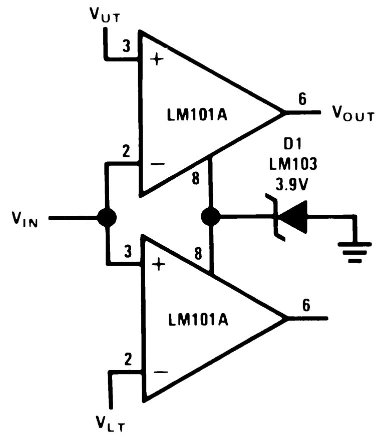


*Adjust for zero integrator drift.

Current drift typically 0.1 n/A˚C over −55˚C to 125˚C temperature range.

Section 1—Basic Circuits (Continued)

Double-Ended Limit Detector

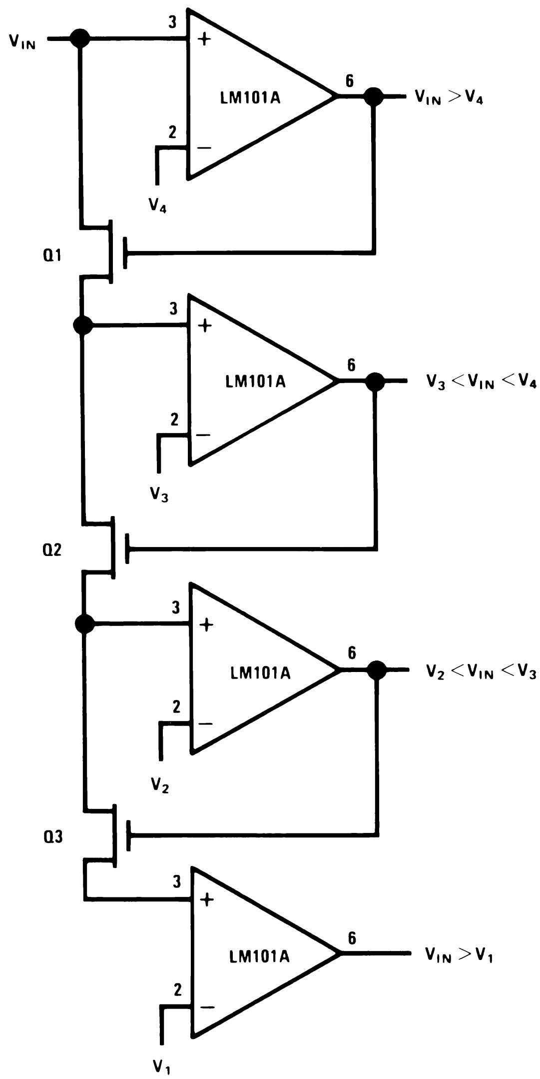


00705719

V_{OUT} = 4.6V for $V_{LT} \leq V_{IN} \leq V_{UT}$

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

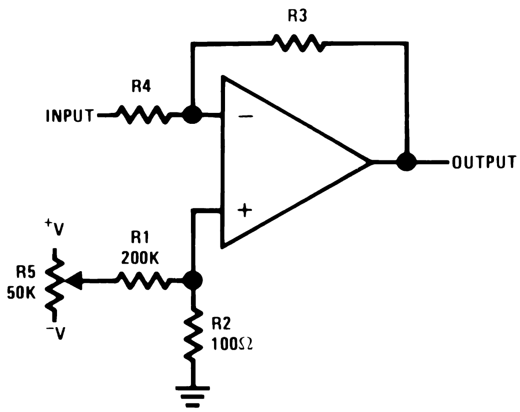
Multiple Aperture Window Discriminator



00705720

Section 1—Basic Circuits (Continued)

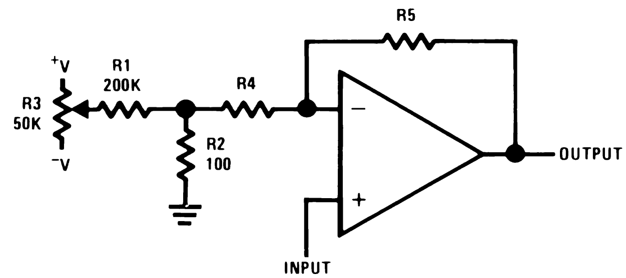
Offset Voltage Adjustment for Inverting Amplifiers Using Any Type of Feedback Element



00705721

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

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

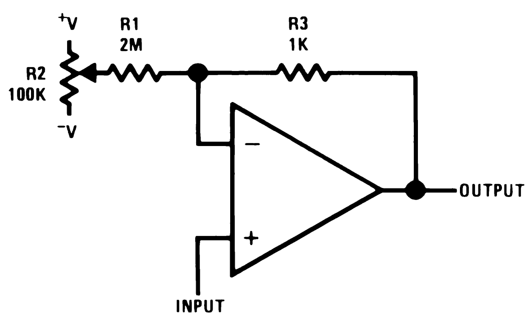


00705722

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

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

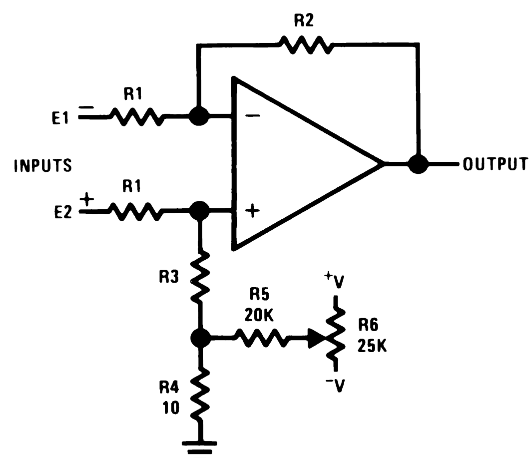
Offset Voltage Adjustment for Voltage Followers



00705723

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

Offset Voltage Adjustment for Differential Amplifiers



00705724

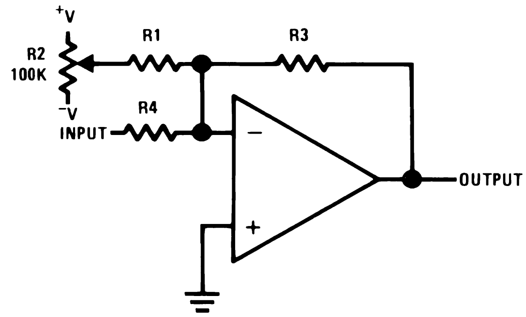
$$R2 = R3 + R4$$

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

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

Section 1—Basic Circuits (Continued)

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



00705725

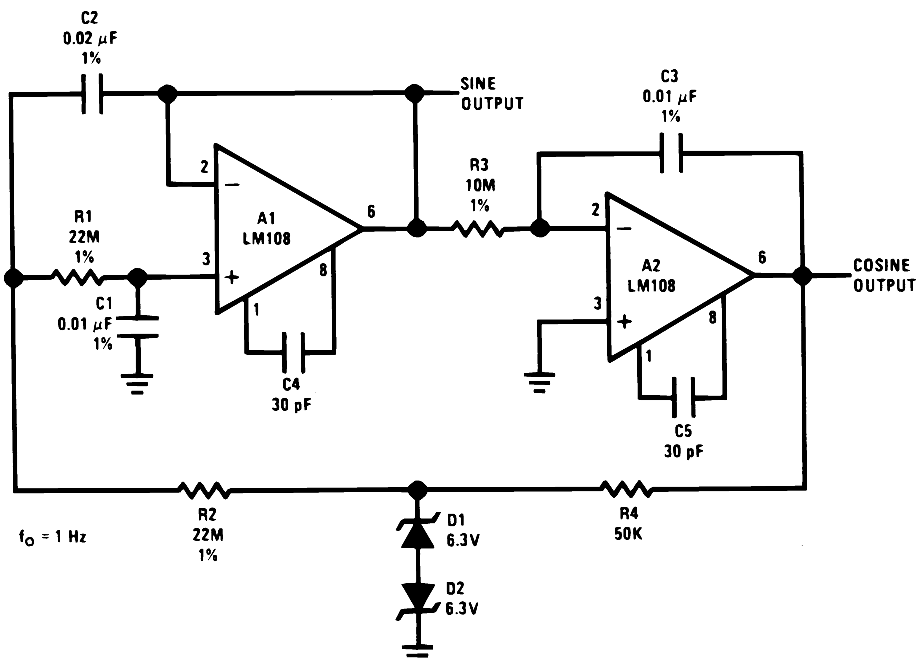
R1 = 2000 R3//R4

R4//R3 ≤ 10 kΩ

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

Section 2 — Signal Generation

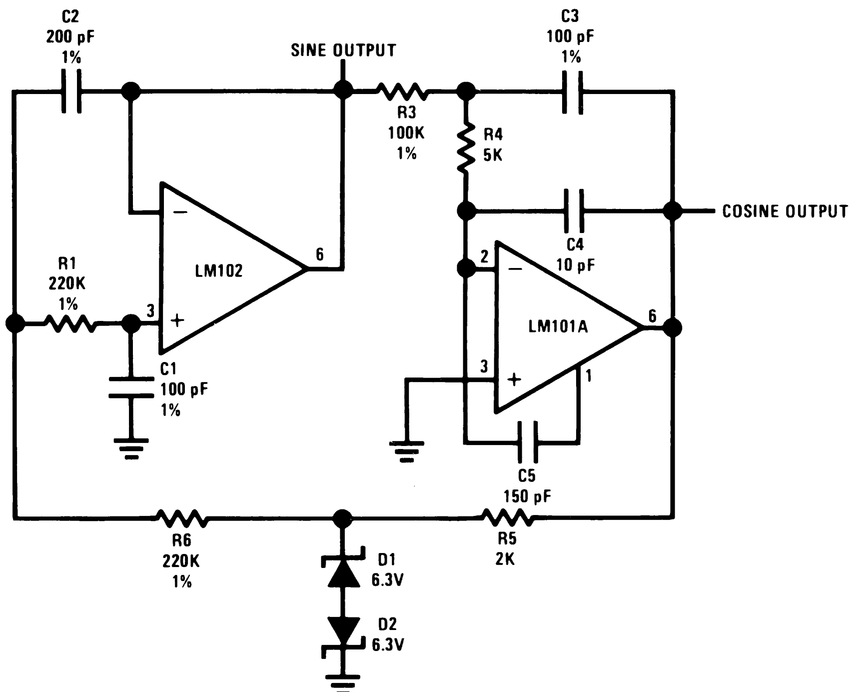
Low Frequency Sine Wave Generator with Quadrature Output



00705726

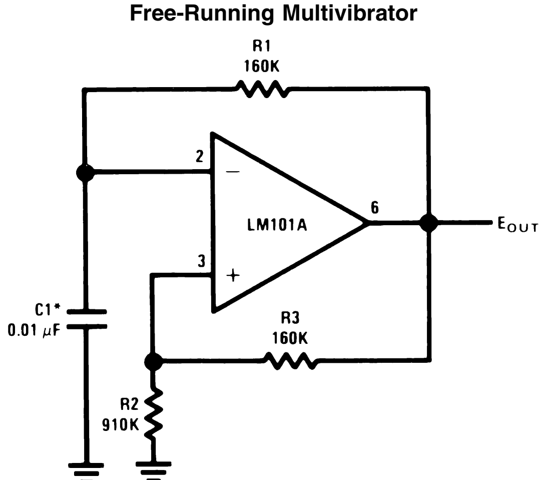
Section 2 — Signal Generation (Continued)

High Frequency Sine Wave Generator with Quadrature Output



00705727

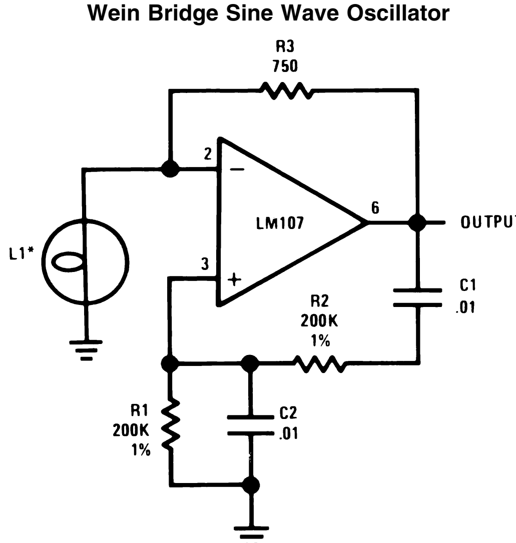
Free-Running Multivibrator



00705728

*Chosen for oscillation at 100 Hz

Wein Bridge Sine Wave Oscillator



00705729

R1 = R2

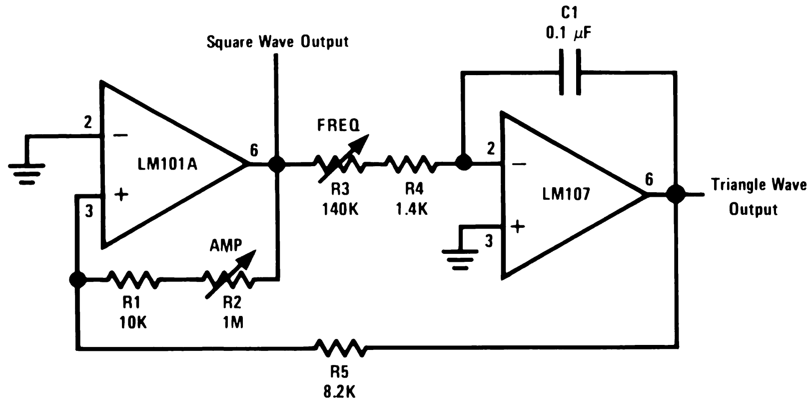
C1 = C2

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

*Eldema 1869 10V, 14 mA Bulb

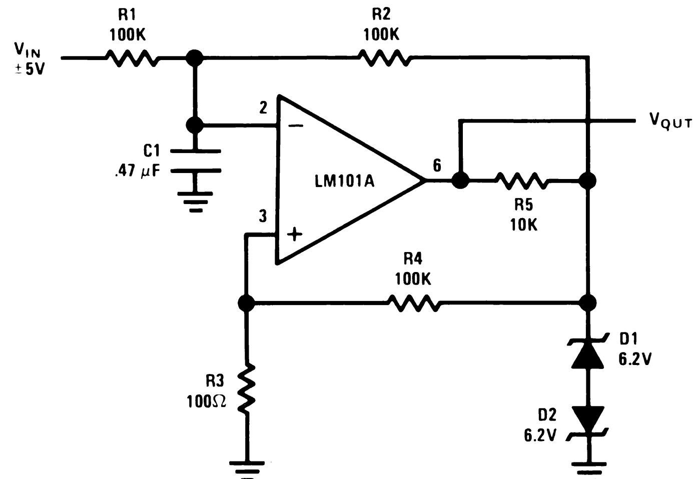
Section 2 — Signal Generation (Continued)

Function Generator



00705730

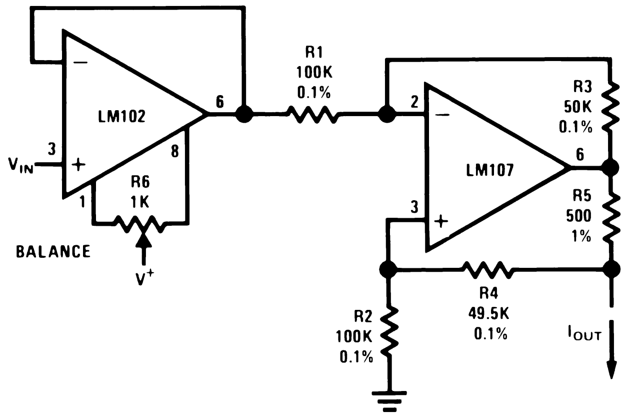
Pulse Width Modulator



00705731

Section 2 — Signal Generation (Continued)

Bilateral Current Source



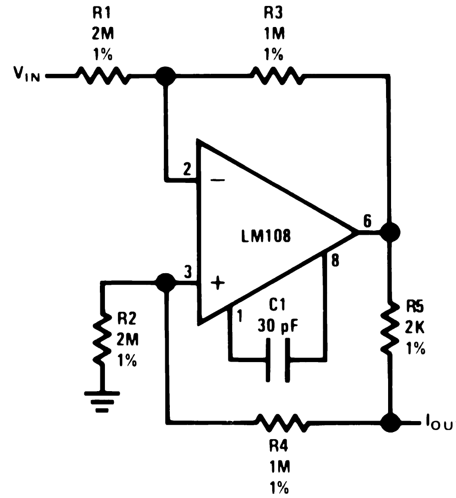
00705732

$$I_{OUT} = \frac{R3\ V_{IN}}{R1\ R5}$$

R3 = R4 + R5

R1 = R2

Bilateral Current Source



00705733

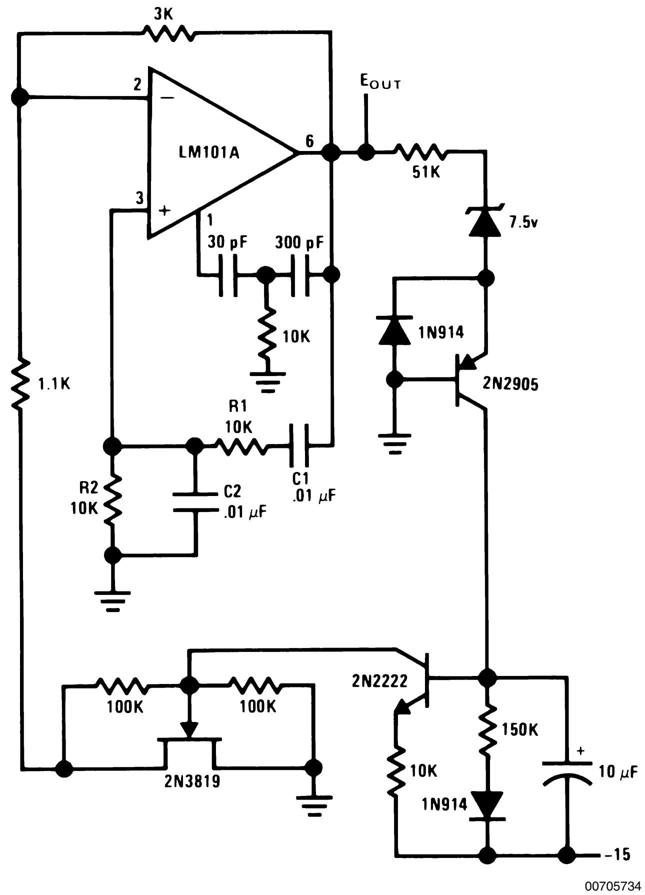
$$I_{OUT} = \frac{R3\ V_{IN}}{R1\ R5}$$

R3 = R4 + R5

R1 = R2

Section 2 — Signal Generation (Continued)

Wein Bridge Oscillator with FET Amplitude Stabilization



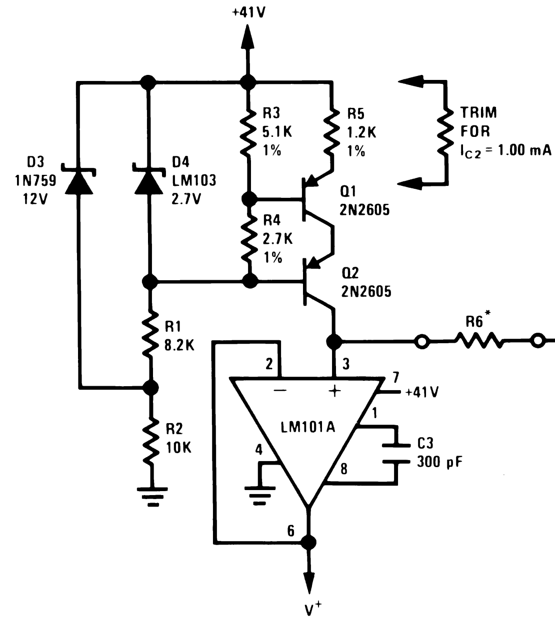
R1 = R2

C1 = C2

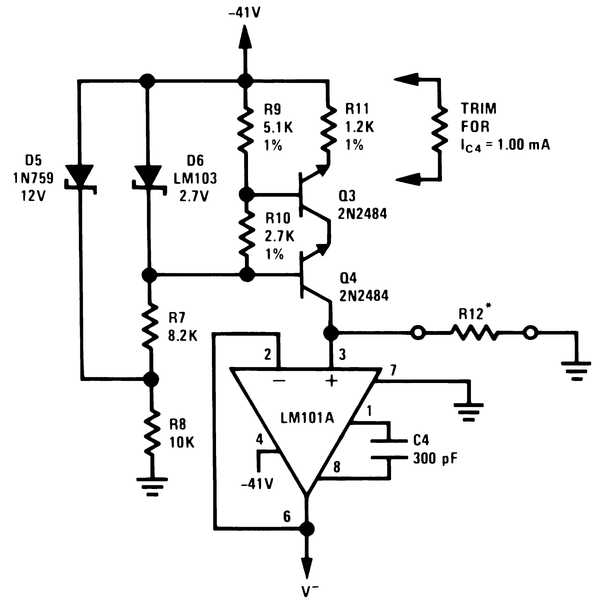
$$f = \frac{1}{2\pi R1\ C1}$$

Section 2 — Signal Generation (Continued)

Low Power Supply for Integrated Circuit Testing



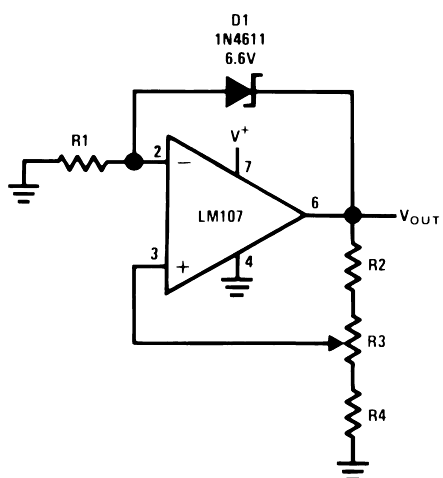
00705735



00705791

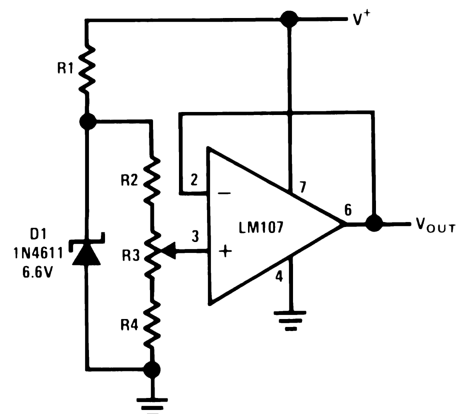
*V_{OUT} = 1V/kΩ

Positive Voltage Reference



00705736

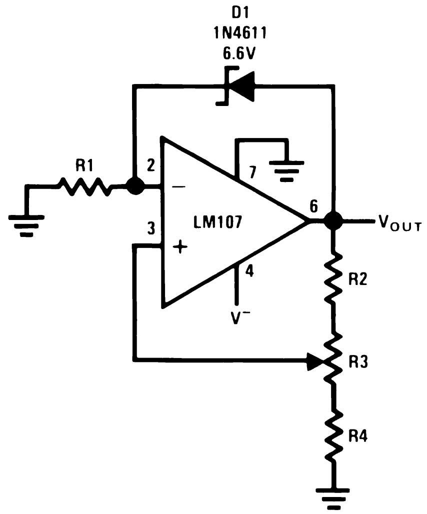
Positive Voltage Reference



00705737

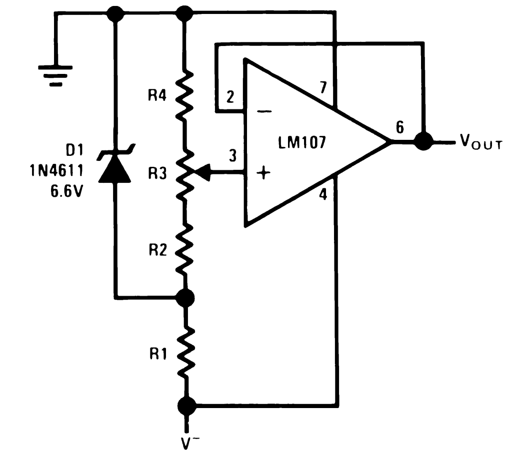
Section 2 — Signal Generation (Continued)

Negative Voltage Reference



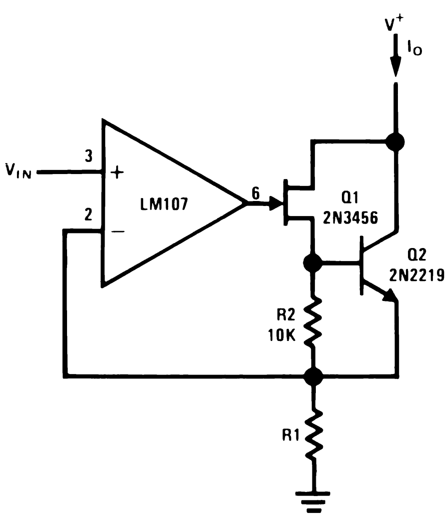
00705738

Negative Voltage Reference



00705739

Precision Current Sink

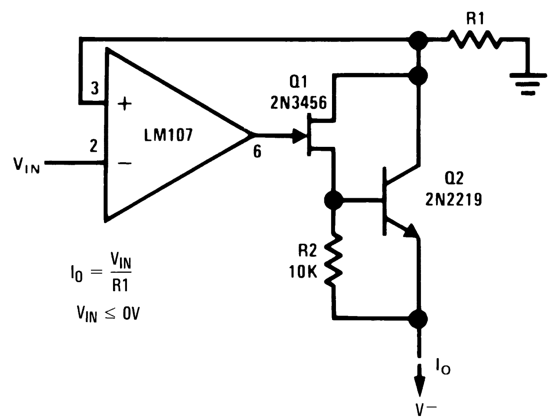


00705740

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

$V_{IN} \geq 0V$

Precision Current Source



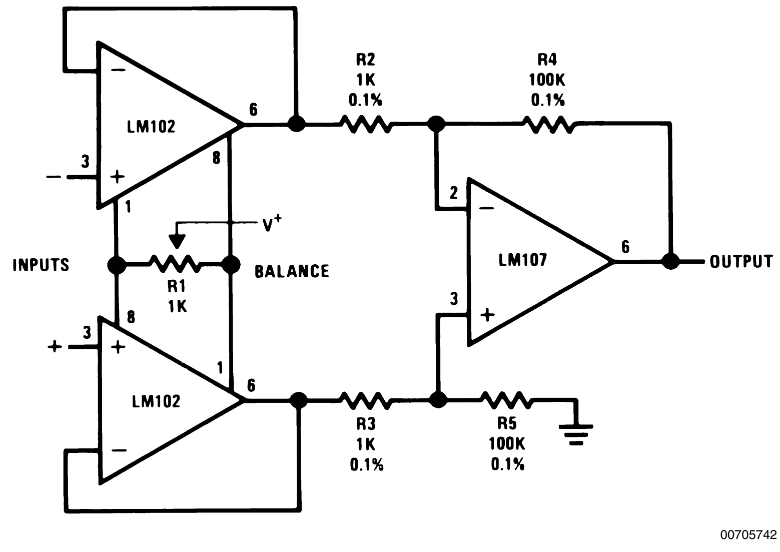
$I_O = \frac{V_{IN}}{R1}$

$V_{IN} \leq 0V$

00705741

Section 3 — Signal Processing

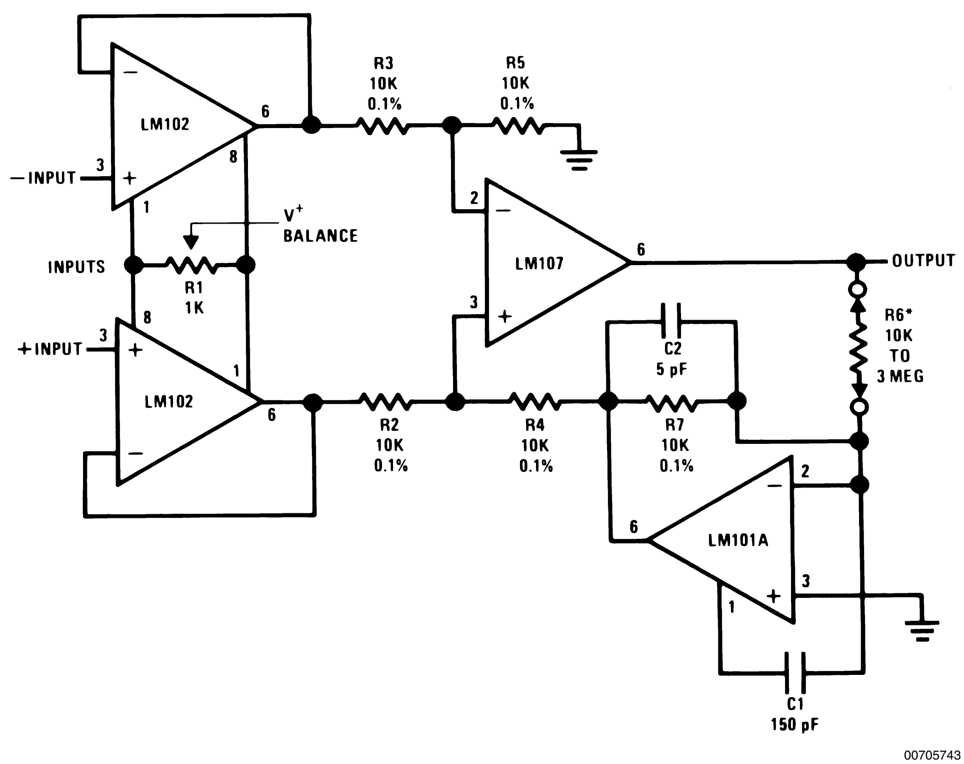
Differential-Input Instrumentation Amplifier



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

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

Variable Gain, Differential-Input Instrumentation Amplifier

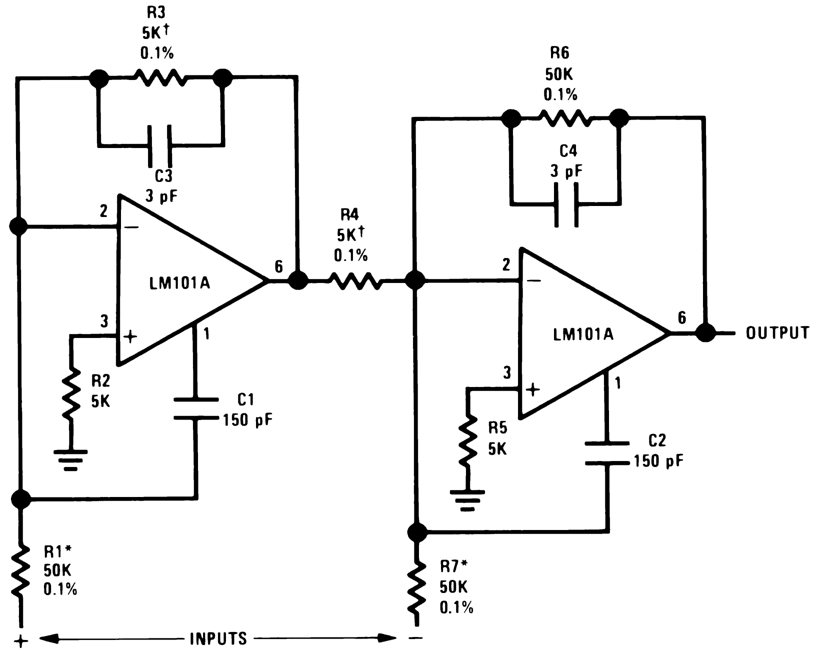


*Gain adjust

$A_V = 10^{-4}$ R6

Section 3 — Signal Processing (Continued)

Instrumentation Amplifier with ±100 Volt Common Mode Range



†Matching determines common mode rejection.

R1 = R5 = 10R2

R2 = R3

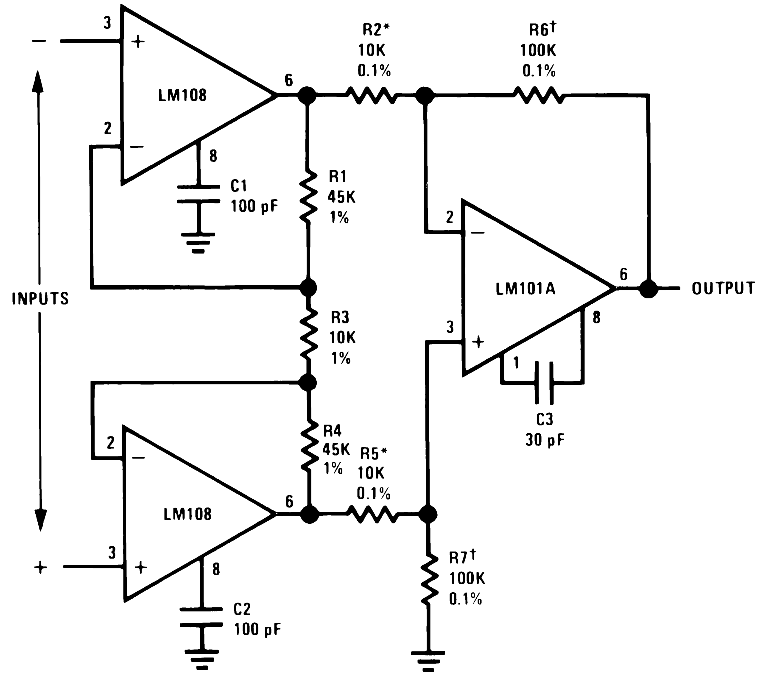
R3 = R4

R1 = R6 = 10R3

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

Section 3 — Signal Processing (Continued)

Instrumentation Amplifier with ±10 Volt Common Mode Range



00705745

R1 = R4

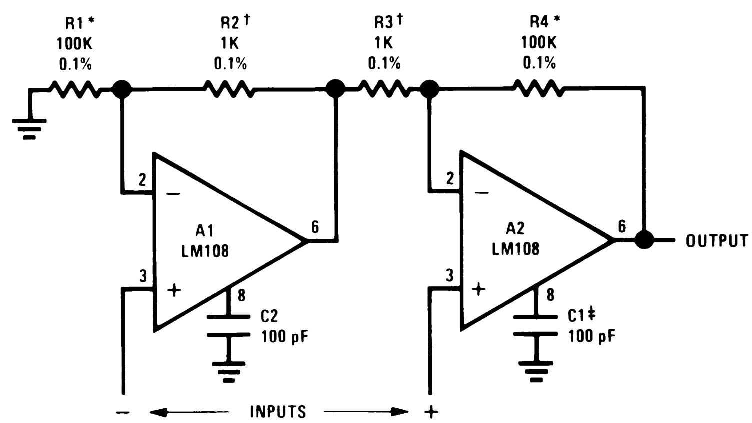
R2 = R5

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

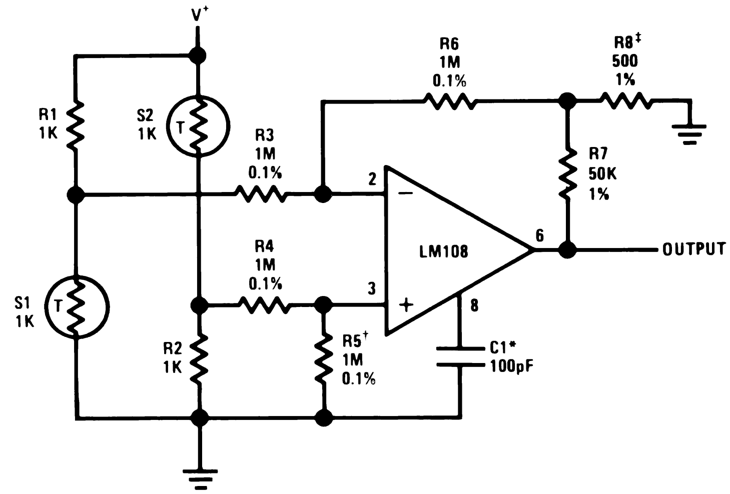
$$A_V = 1 + \frac{R1}{R2}$$

*†Matching Determines CMRR

‡May be deleted to maximize bandwidth

Section 3 — Signal Processing (Continued)

Bridge Amplifier with Low Noise Compensation



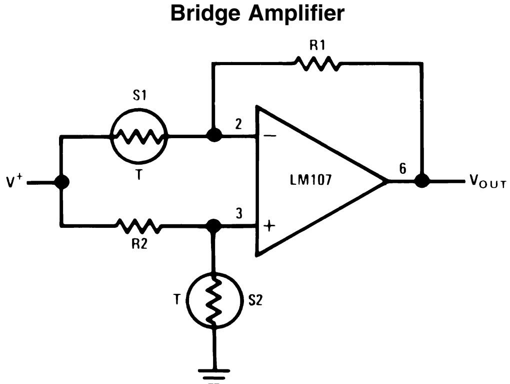
00705747

*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

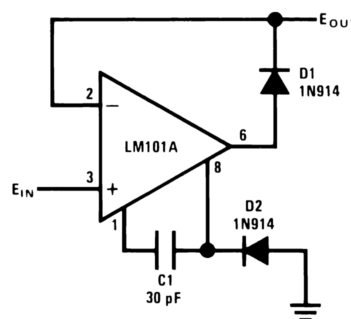


00705748

$$\frac{R1}{R_{S1}} = \frac{R2}{R_{S2}}$$

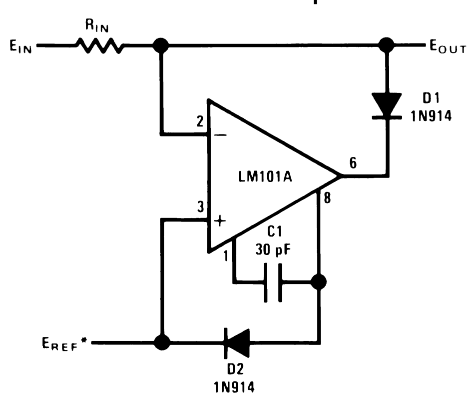
$$V_{OUT} = V^{+} \left(1 - \frac{R1}{R_{S1}}\right)$$

Precision Diode



00705749

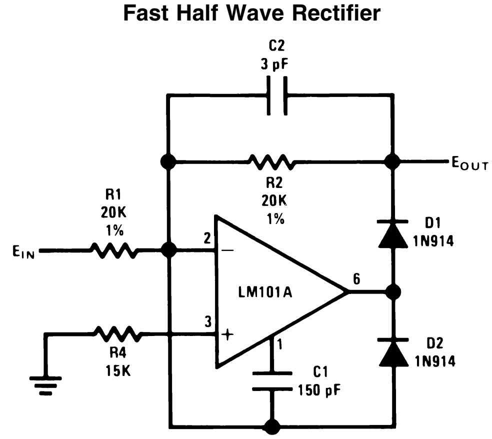
Precision Clamp



00705750

*E_{REF} must have a source impedance of less than 200Ω if D2 is used.

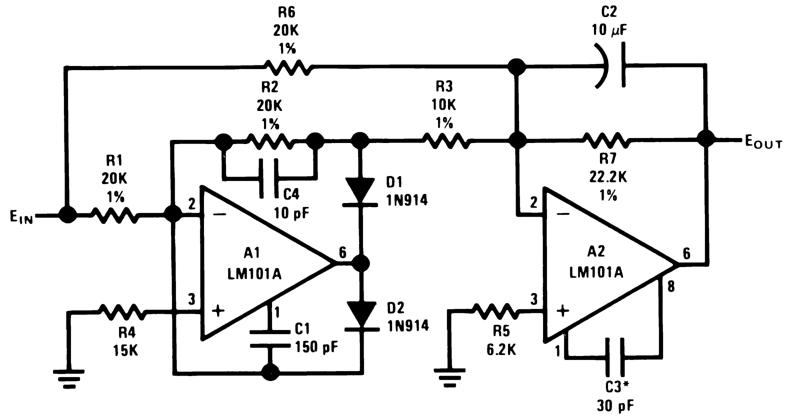
Fast Half Wave Rectifier



00705751

Section 3 — Signal Processing (Continued)

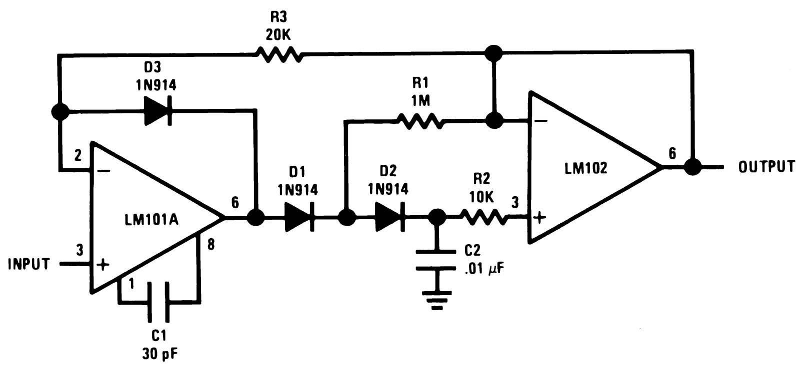
Precision AC to DC Converter



00705752

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

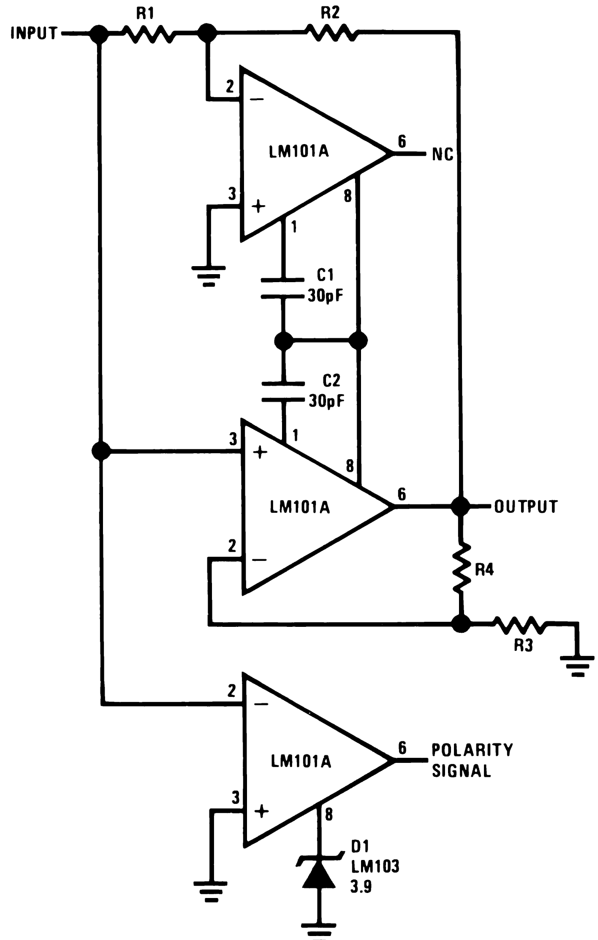
Low Drift Peak Detector



00705753

Section 3 — Signal Processing (Continued)

Absolute Value Amplifier with Polarity Detector

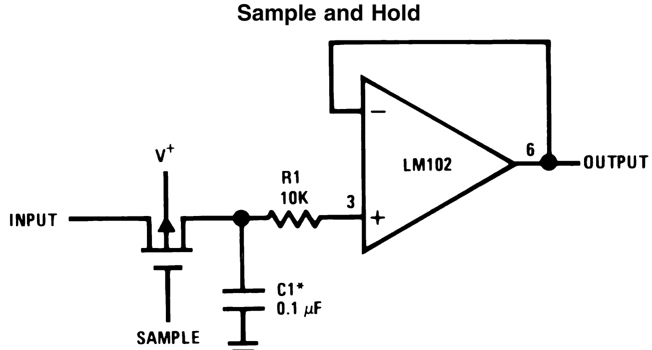


00705754

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

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

Sample and Hold

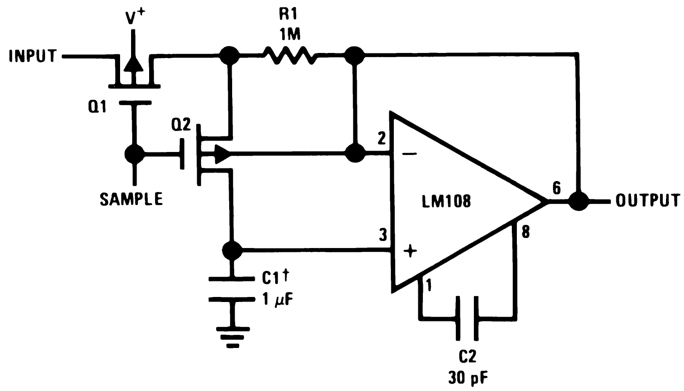


00705755

*Polycarbonate-dielectric capacitor

Section 3 — Signal Processing (Continued)

Sample and Hold

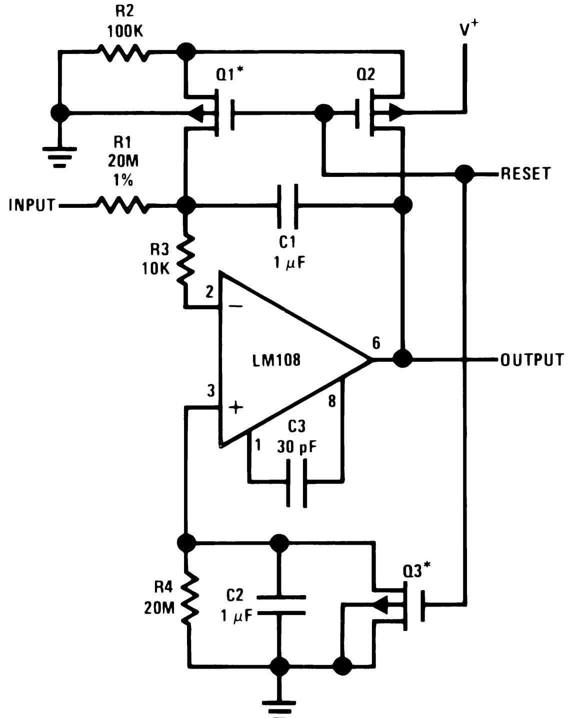


00705756

*Worst case drift less than 2.5 mV/sec

†Teflon, Polyethylene or Polycarbonate Dielectric Capacitor

Low Drift Integrator



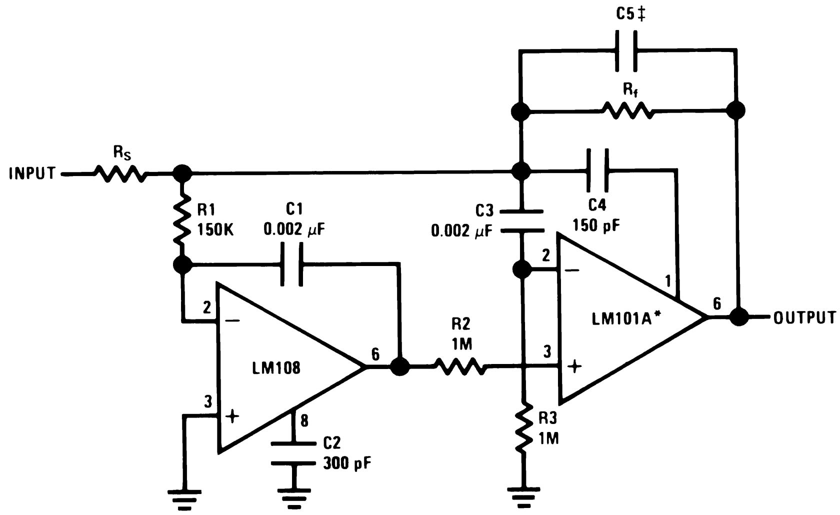
00705757

*Q1 and Q3 should not have internal gate-protection diodes.

Worst case drift less than 500 µV/sec over −55˚C to +125˚C.

Section 3 — Signal Processing (Continued)

Fast† 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.

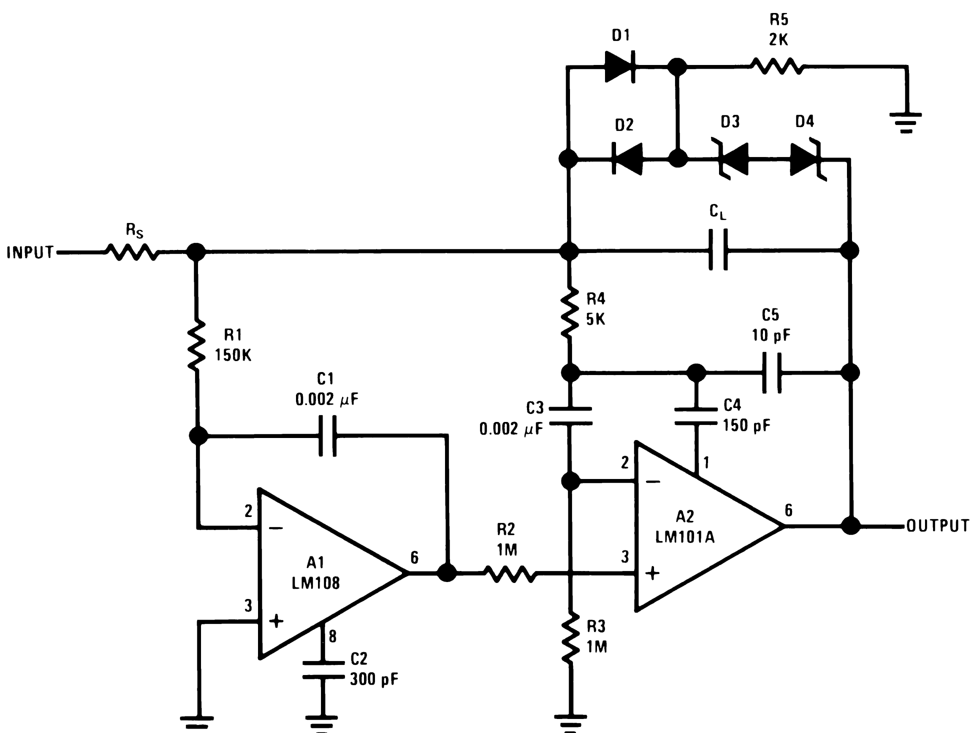
†Power Bandwidth: 250 kHz

Small Signal Bandwidth: 3.5 MHz

Slew Rate: 10V/μs

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

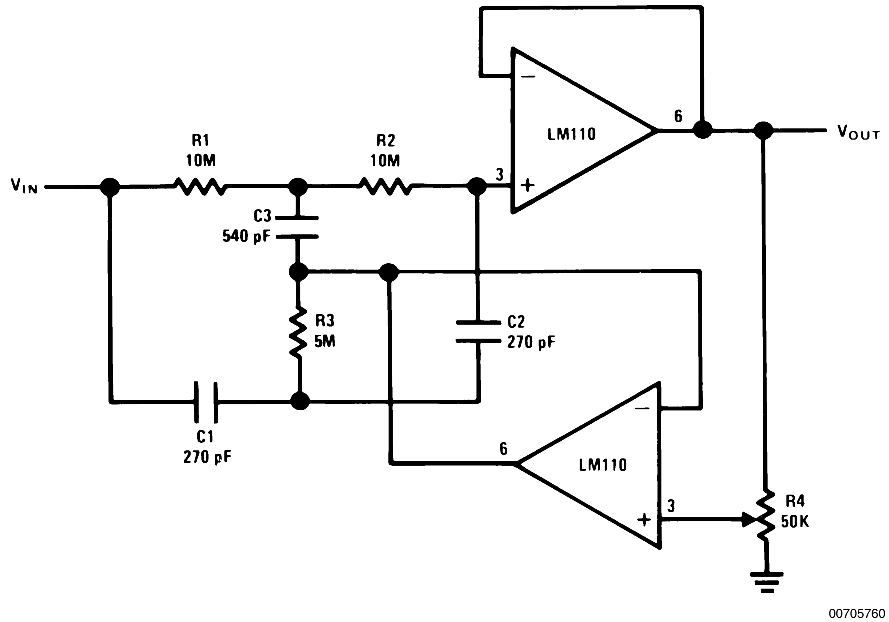
Fast Integrator with Low Input Current



00705759

Section 3 — Signal Processing (Continued)

Adjustable Q Notch Filter



$$f_O = \frac{1}{2\pi R1C1}$$

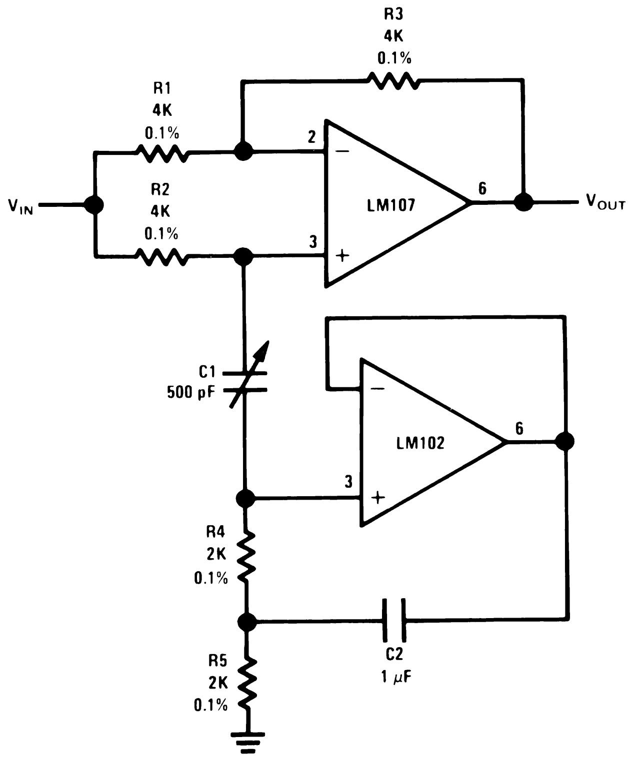
$$= 60\ Hz$$

R1 = R2 = R3

C1 = C2 = C23

Section 3 — Signal Processing (Continued)

Easily Tuned Notch Filter

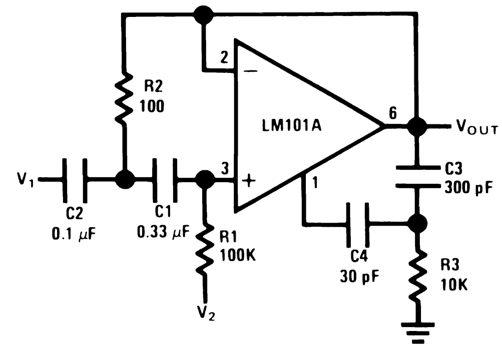


00705761

R4 = R5
R1 = R3
R4 = ½ R1

$$f_O = \frac{1}{2\pi R4\sqrt{C1C2}}$$

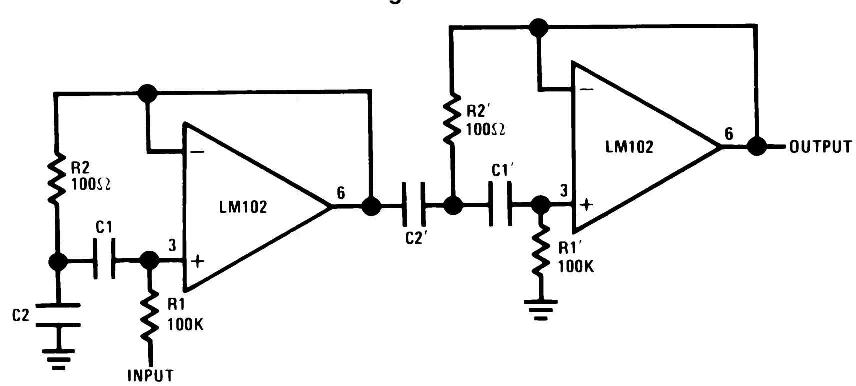
Tuned Circuit



00705762

$$f_O = \frac{1}{2\pi\sqrt{R1R2C1C2}}$$

Two-Stage Tuned Circuit

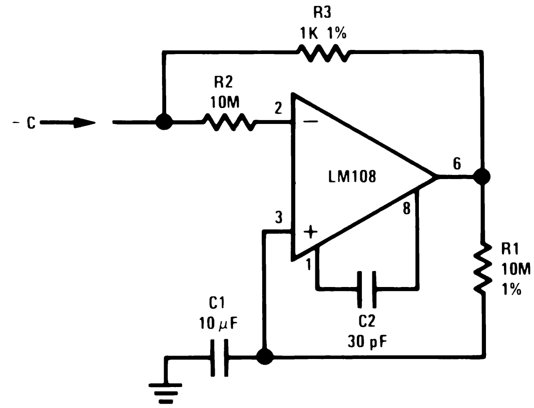


00705763

$$f_O = \frac{1}{2\pi\sqrt{R1R2C1C2}}$$

Section 3 — Signal Processing (Continued)

Negative Capacitance Multiplier



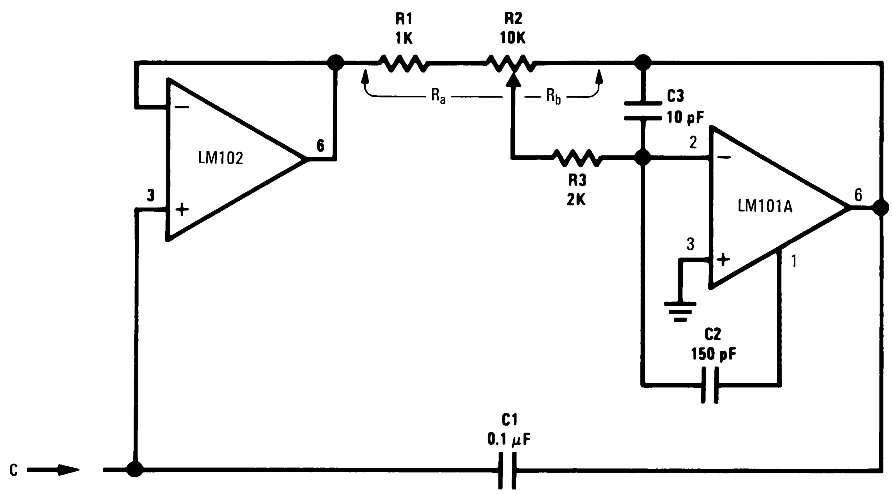
00705765

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

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

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

Variable Capacitance Multiplier

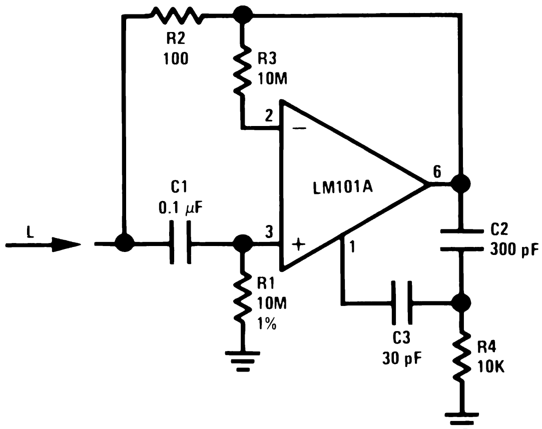


00705766

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

Section 3 — Signal Processing (Continued)

Simulated Inductor



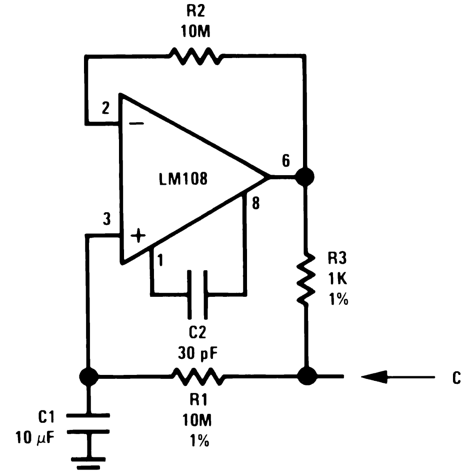
00705767

$L \geq R1\ R2\ C1$

$R_S = R2$

$R_P = R1$

Capacitance Multiplier



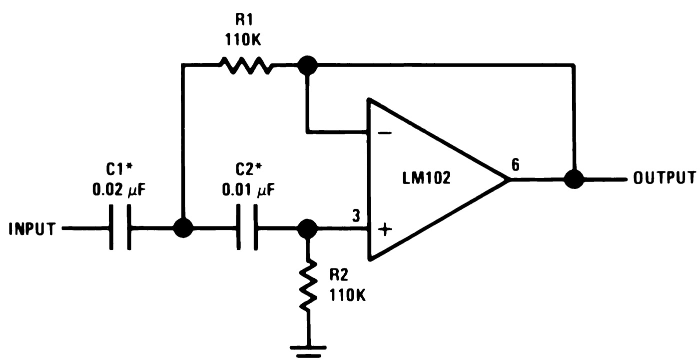
00705768

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

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

$$R_S = R3$$

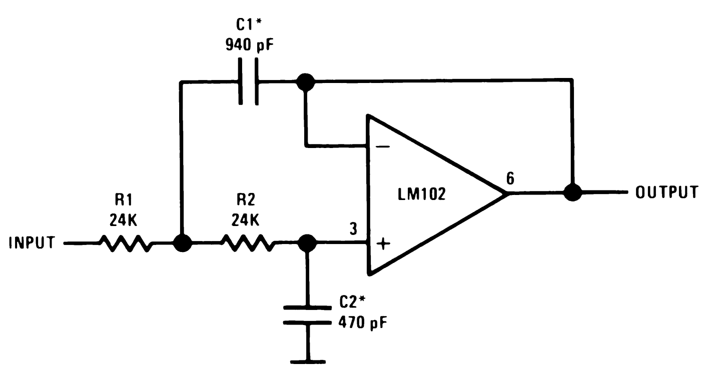
High Pass Active Filter



00705771

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

Low Pass Active Filter

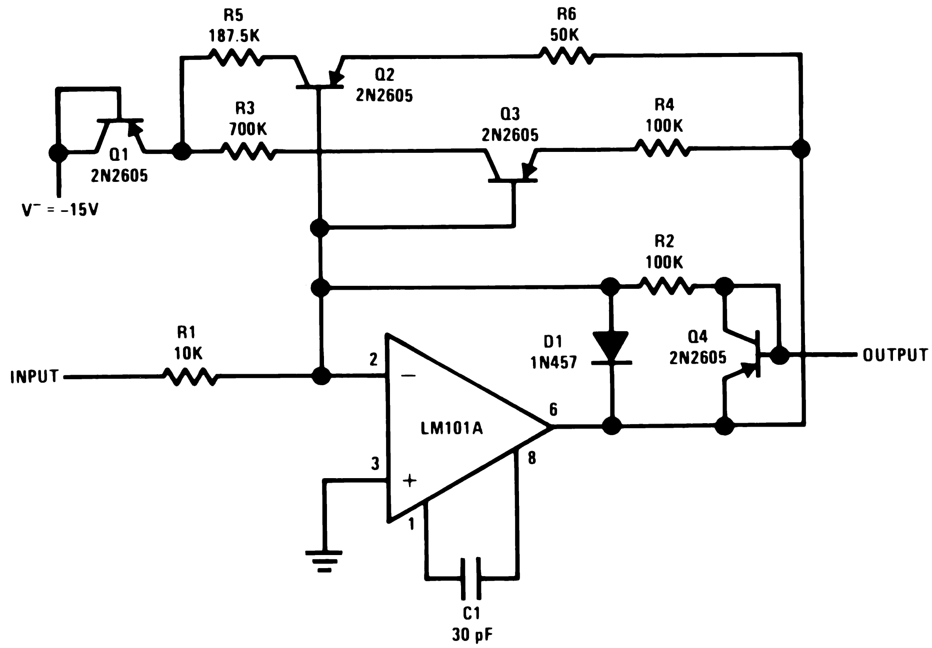


00705772

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

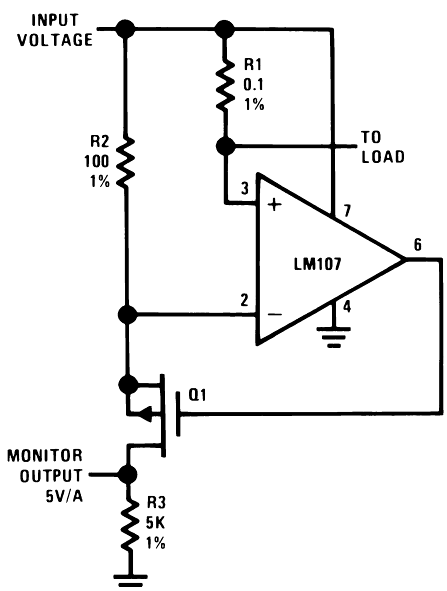
Section 3 — Signal Processing (Continued)

Nonlinear Operational Amplifier with Temperature Compensated Breakpoints



00705773

Current Monitor

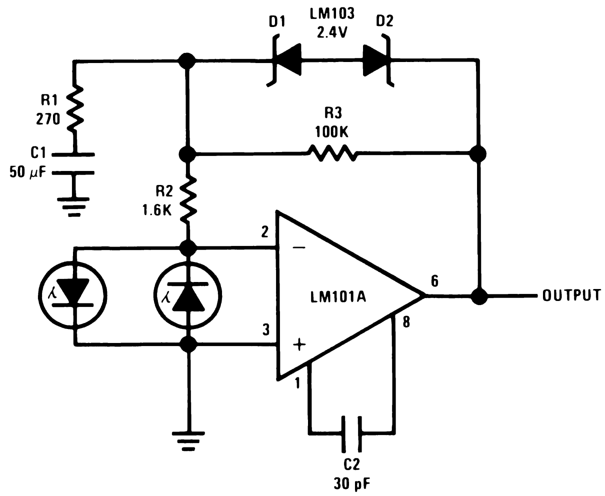


00705774

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

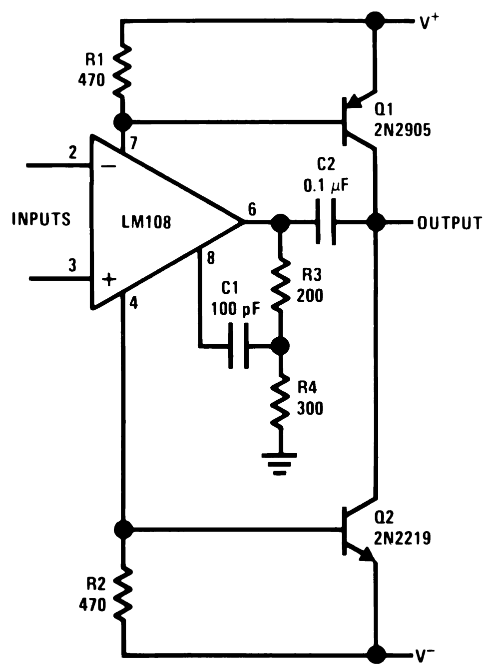
Section 3 — Signal Processing (Continued)

Saturating Servo Preamplifier with Rate Feedback



00705775

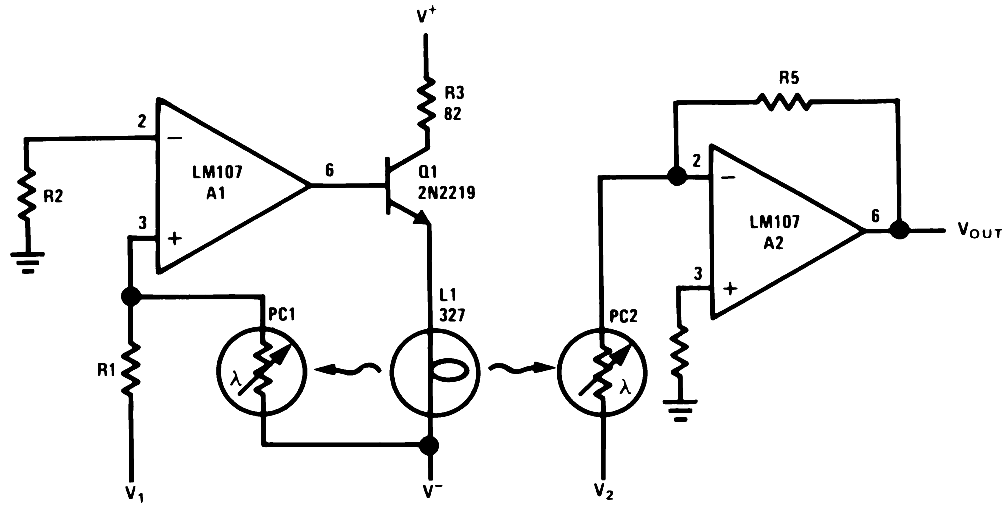
Power Booster



00705776

Section 3 — Signal Processing (Continued)

Analog Multiplier



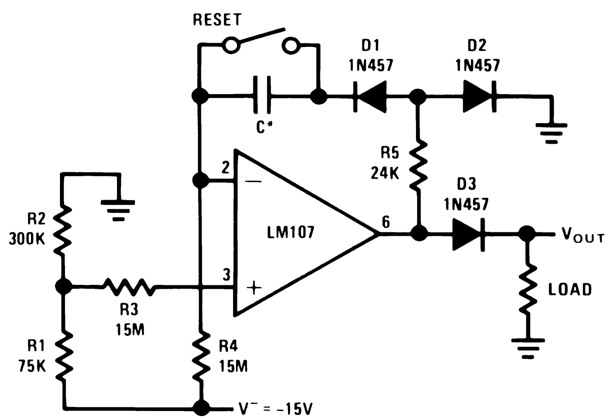
00705777

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

$$V_1 \geq 0$$

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

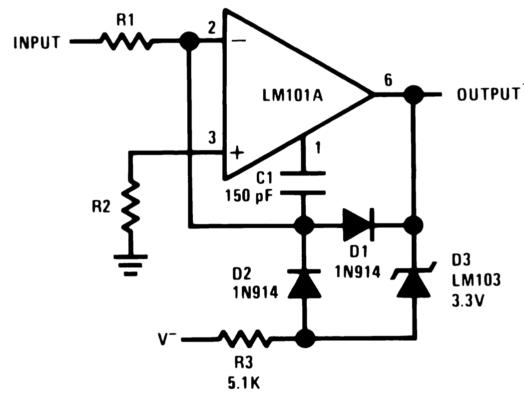
Long Interval Timer



00705778

*Low leakage −0.017 µF per second delay

Fast Zero Crossing Detector



00705779

Propagation delay approximately 200 ns

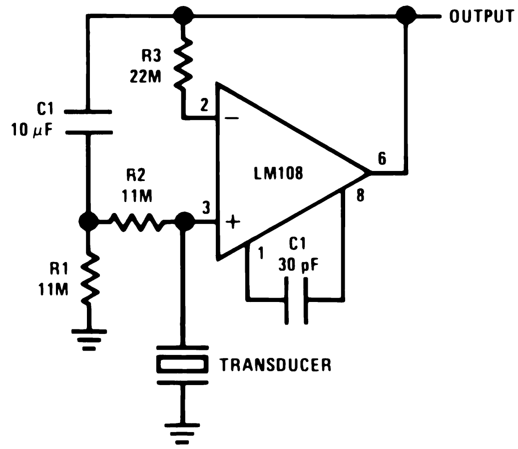
†DTL or TTL fanout of three.

Minimize stray capacitance

Pin 8

Section 3 — Signal Processing (Continued)

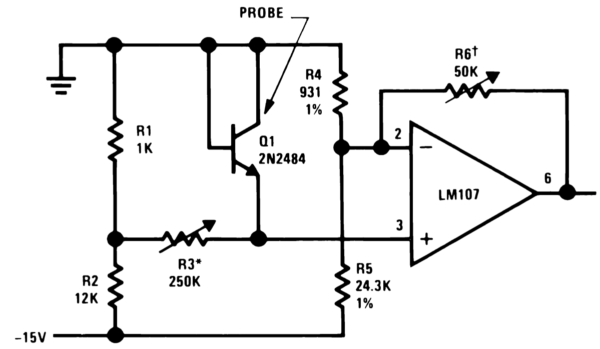
Amplifier for Piezoelectric Transducer



00705780

Low frequency cutoff = R1 C1

Temperature Probe

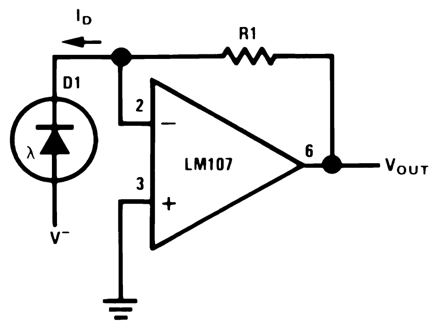


00705781

*Set for 0V at 0˚C

†Adjust for 100 mV/˚C

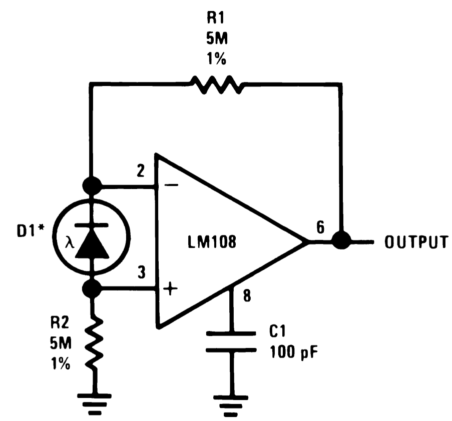
Photodiode Amplifier



00705782

$V_{OUT} = R1\ I_D$

Photodiode Amplifier

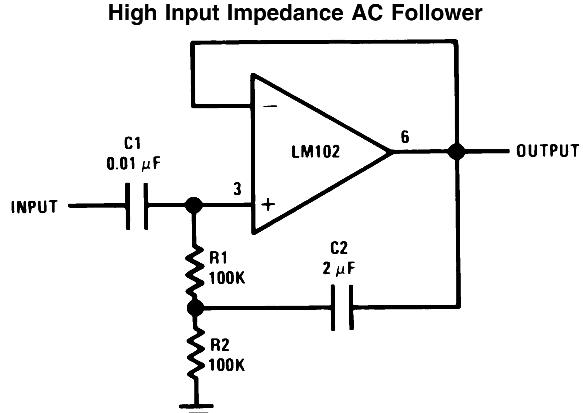


00705783

$V_{OUT} = 10\ V/\mu A$

*Operating photodiode with less than 3 mV across it eliminates leakage currents.

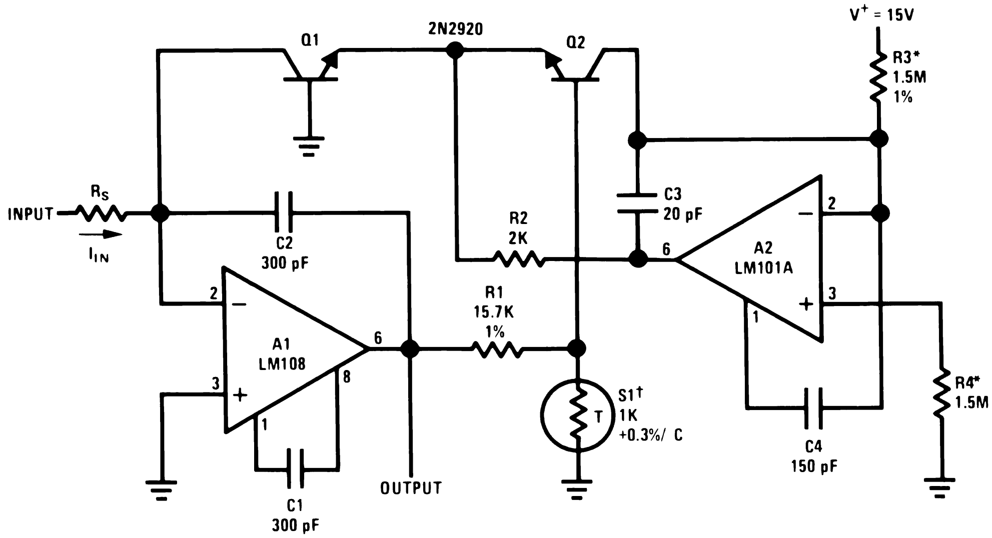
High Input Impedance AC Follower



00705784

Section 3 — Signal Processing (Continued)

Temperature Compensated Logarithmic Converter



00705785

10 nA < I_{IN} < 1 mA

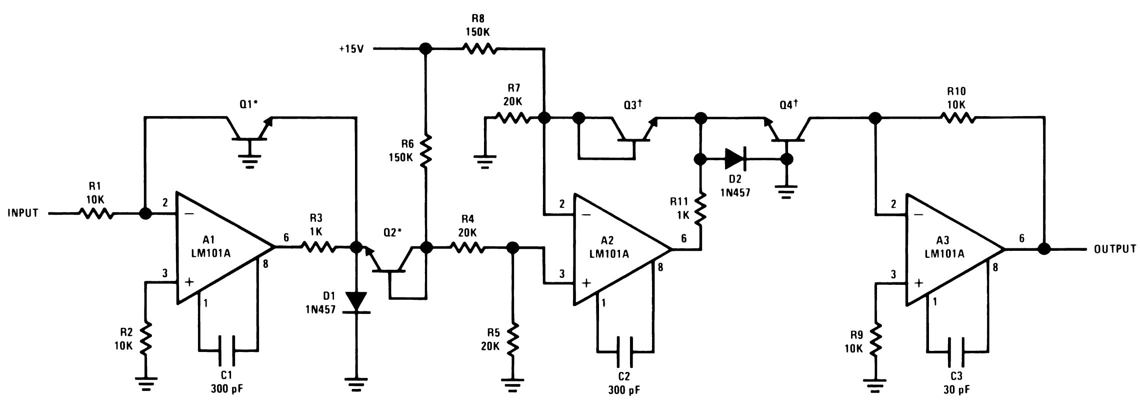
Sensitivity is 1V per decade

†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

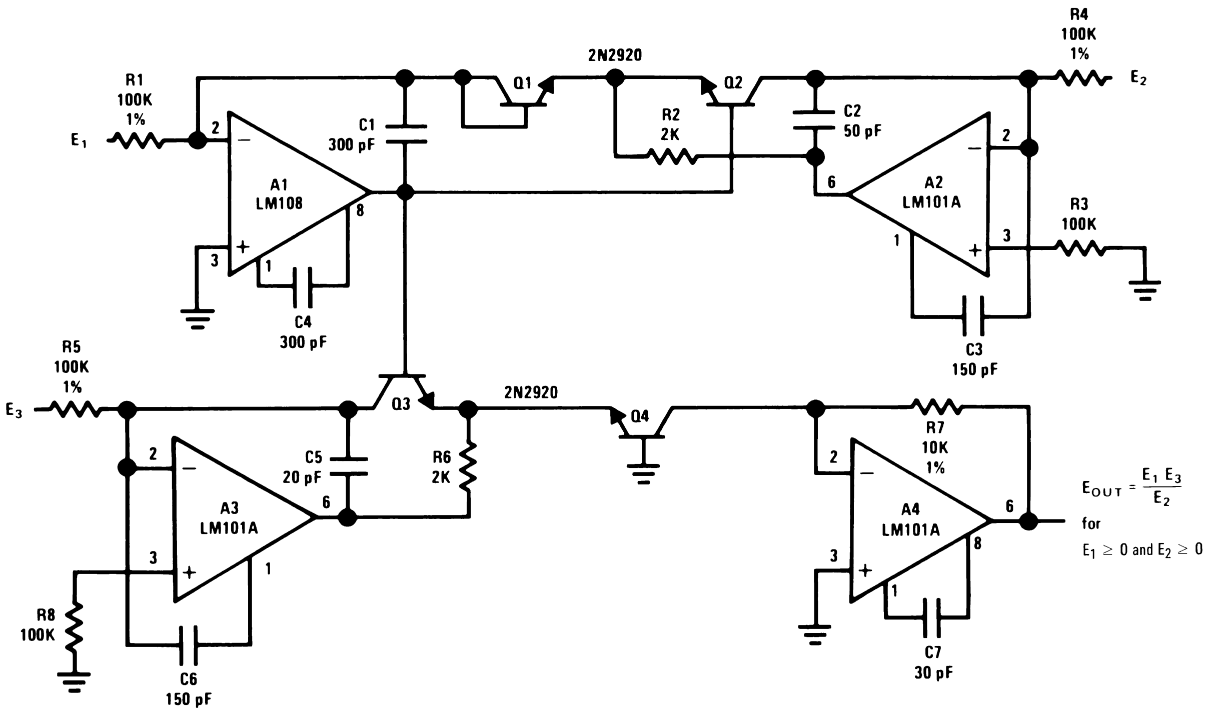


00705786

*†2N3728 matched pairs

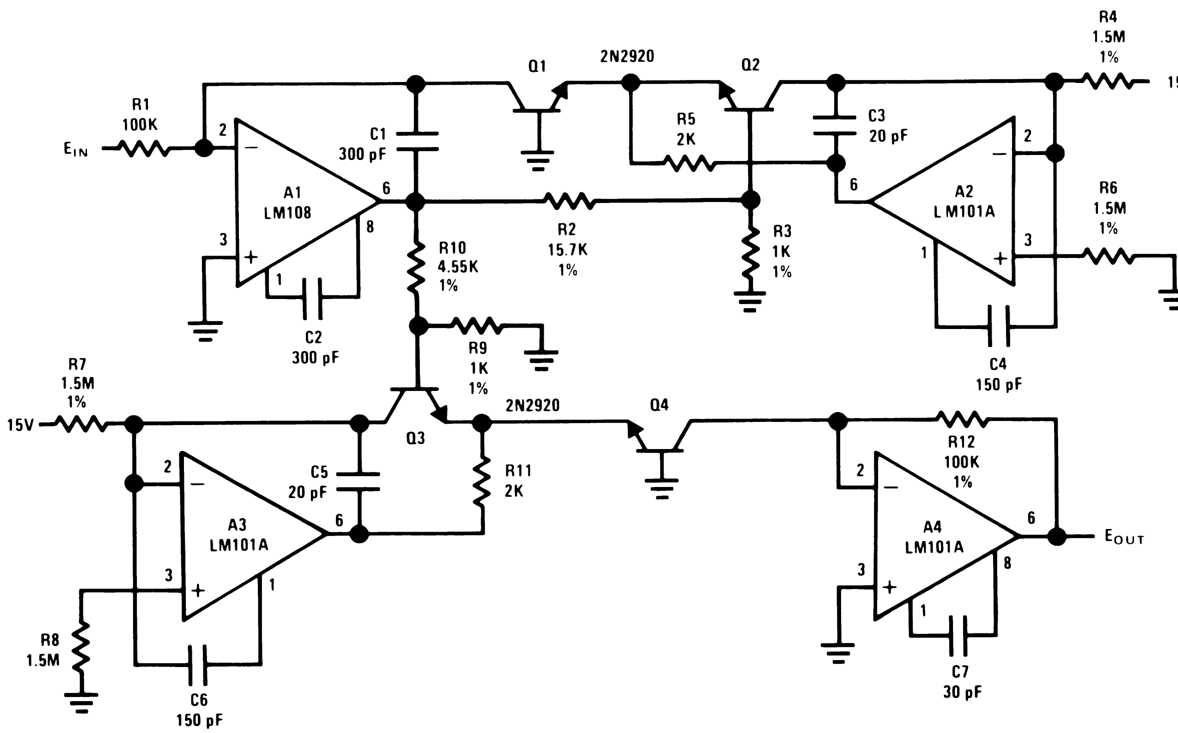
Section 3 — Signal Processing (Continued)

Multiplier/Divider



00705787

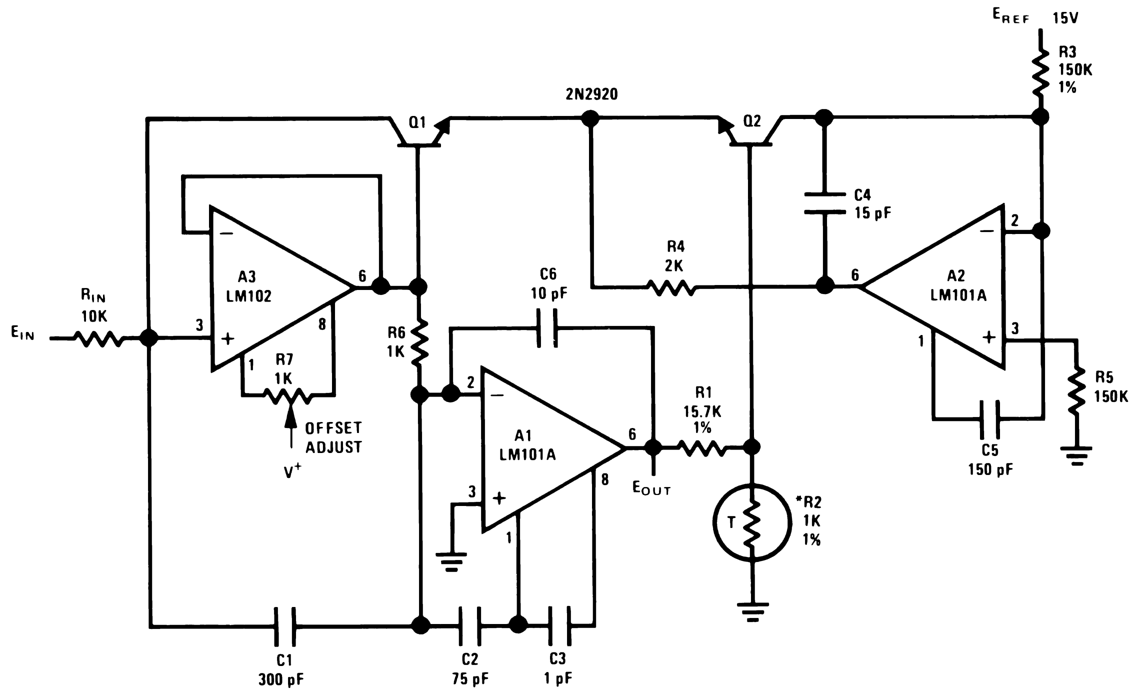
Cube Generator



00705788

Section 3 — Signal Processing (Continued)

Fast Log Generator

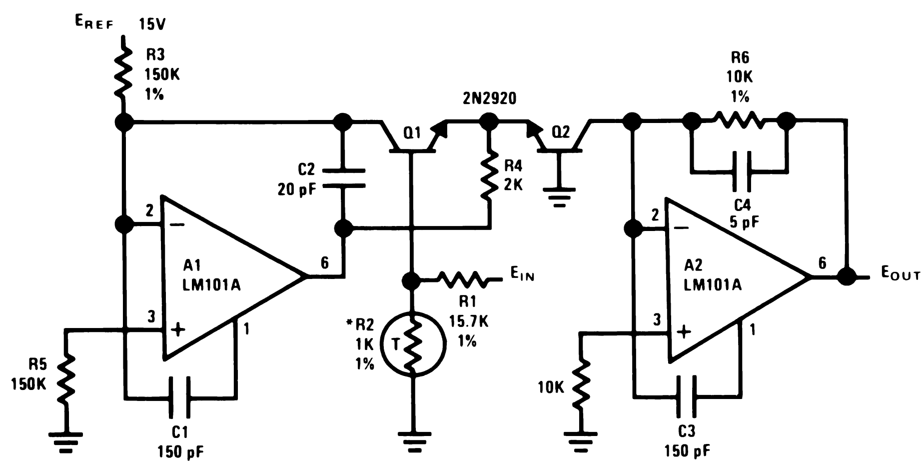


00705789

†1 kΩ (±1%) at 25˚C, +3500 ppm/˚C.

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

Anti-Log Generator



00705790

†1 kΩ (±1%) at 25˚C, +3500 ppm/˚C.

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

Notes

National Semiconductor Corporation
Americas
Email: support@nsc.com

www.national.com

National Semiconductor Europe
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507