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

Section 1—Basic Circuits

**Inverting Amplifier**

\[ V_{\text{OUT}} = -\frac{R_2}{R_1} V_{\text{IN}} \]

\[ R_{\text{IN}} = R_1 \]

**Non-Inverting Amplifier**

\[ V_{\text{OUT}} = \frac{R_1 + R_2}{R_1} V_{\text{IN}} \]

**Difference Amplifier**

\[ V_{\text{OUT}} = \frac{R_1 + R_2}{R_1 + R_4} \frac{R_4}{R_3} V_2 - \frac{R_2}{R_1} V_1 \]

For \( R_1 = R_3 \) and \( R_2 = R_4 \)

\[ V_{\text{OUT}} = \frac{R_2}{R_1} (V_2 - V_1) \]

\[ R_1/R_2 = R_3/R_4 \]

For minimum offset error due to input bias current

**Inverting Summing Amplifier**

\[ V_{\text{OUT}} = -\frac{R_4}{R_1 + \frac{R_2}{R_1 + R_3} + \frac{R_3}{R_1 + R_4}} V_{\text{IN}} \]

\[ R_5 = R_1/R_2/R_3/R_4 \]

For minimum offset error due to input bias current
Section 1—Basic Circuits (Continued)

Non-Inverting Summing Amplifier

Inverting Amplifier with High Input Impedance

*RS = 1k for 1% accuracy

Source impedance less than 100k gives less than 1% gain error.

Fast Inverting Amplifier with High Input Impedance

Non-Inverting AC Amplifier

\[ V_{OUT} = \frac{R_1 + R_2}{R_1} V_{IN} \]

\[ R_{IN} = \frac{R_3}{R_1} \]

\[ R_3 = R_1 / R_2 \]
Section 1—Basic Circuits (Continued)

**Practical Differentiator**

![Differentiator Circuit Diagram](image1)

\[ f_c = \frac{1}{2\pi R_2 C_1} \]
\[ f_h = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi R_2 C_2} \]
\[ f_c < f_h < f_{\text{unity gain}} \]

**Integrator**

![Integrator Circuit Diagram](image2)

\[ V_{\text{OUT}} = -\frac{1}{R_1 C_1} \int_{t_1}^{t_2} V_{\text{IN}} \, dt \]
\[ f_c = \frac{1}{2\pi R_1 C_1} \]
\[ R_1 = R_2 \]

For minimum offset error due to input bias current

**Fast Integrator**

![Fast Integrator Circuit Diagram](image3)

**Current to Voltage Converter**

![Current to Voltage Converter Circuit Diagram](image4)

\[ V_{\text{OUT}} = \ln R_1 \]

*For minimum error due to bias current R2 = R1*
Section 1—Basic Circuits (Continued)

Circuit for Operating the LM101 without a Negative Supply

Neutralizing Input Capacitance to Optimize Response Time

Integrator with Bias Current Compensation

Voltage Comparator for Driving DTL or TTL Integrated Circuits

Threshold Detector for Photodiodes

*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**

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

**Multiple Aperture Window Discriminator**

\[ V_{\text{OUT}} = 4.6\text{V for } V_{\text{LT}} \leq V_{\text{IN}} \leq V_{\text{UT}} \]
\[ V_{\text{OUT}} = 0\text{V for } V_{\text{IN}} < V_{\text{LT}} \text{ or } V_{\text{IN}} > V_{\text{UT}} \]
Offset Voltage Adjustment for Inverting Amplifiers Using Any Type of Feedback Element

\[ \text{RANGE} = \pm V \left( \frac{R_2}{R_1} \right) \]

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

\[ \text{RANGE} = \pm V \left( \frac{R_2}{R_1} \right) \]
\[ \text{GAIN} = 1 + \frac{R_5}{R_4 + R_2} \]

Offset Voltage Adjustment for Voltage Followers

\[ \text{RANGE} = \pm V \left( \frac{R_3}{R_1} \right) \]

Offset Voltage Adjustment for Differential Amplifiers

\[ R_2 = R_3 + R_4 \]
\[ \text{RANGE} = \pm V \left( \frac{R_5}{R_4} \right) \left( \frac{R_1}{R_1 + R_3} \right) \]
\[ \text{GAIN} = \frac{R_2}{R_1} \]
Section 1—Basic Circuits

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

\[ R_1 = 2000 \frac{R_3}{R_4} \]
\[ R_4/R_3 \leq 10 \text{kΩ} \]
\[ \text{RANGE} = \pm V \left( \frac{R_3/R_4}{R_1} \right) \]

Section 2 — Signal Generation

Low Frequency Sine Wave Generator with Quadrature Output
Section 2 — Signal Generation (Continued)

High Frequency Sine Wave Generator with Quadrature Output

Free-Running Multivibrator

Wein Bridge Sine Wave Oscillator

*Chosen for oscillation at 100 Hz

Eldema 1869 10V, 14 mA Bulb
Section 2 — Signal Generation  (Continued)

Function Generator

Pulse Width Modulator
Bilateral Current Source

\[ I_{\text{OUT}} = \frac{R_3}{R_1 + R_5} V_{\text{IN}} \]

\[ R_3 = R_4 + R_5 \]

\[ R_1 = R_2 \]
Section 2 — Signal Generation (Continued)

Wein Bridge Oscillator with FET Amplitude Stabilization

\[ f = \frac{1}{2\pi R_1 C_1} \]

- \( R_1 = R_2 \)
- \( C_1 = C_2 \)
Section 2 — Signal Generation (Continued)

Low Power Supply for Integrated Circuit Testing

![Circuit Diagram]
Section 2 — Signal Generation

Negative Voltage Reference

![Diagram of Negative Voltage Reference](image1)

Precision Current Sink

![Diagram of Precision Current Sink](image2)

Precision Current Source

![Diagram of Precision Current Source](image3)

\[ I_O = \frac{V_{IN}}{R1} \]

\[ V_{IN} \geq 0V \]
Section 3 — Signal Processing

Differential-Input Instrumentation Amplifier

\[ R_4 = R_5 \]
\[ R_2 = R_3 \]
\[ A_U = \frac{R_4}{R_2} \]

Variable Gain, Differential-Input Instrumentation Amplifier

*Gain adjust

\[ A_U = 10^{-4} R_6 \]
Instrumentation Amplifier with ±100 Volt Common Mode Range

Matching determines common mode rejection.

\[ R_1 = R_5 = 10R_2 \]
\[ R_2 = R_3 \]
\[ R_3 = R_4 \]
\[ R_1 = R_6 = 10R_3 \]
\[ A_v = \frac{R_7}{R_6} \]
Section 3 — Signal Processing  (Continued)

Instrumentation Amplifier with ±10 Volt Common Mode Range

![Instrumentation Amplifier Circuit Diagram]

- $R_1 = R_4$
- $R_2 = R_5$
- $R_6 = R_7$

$A_v = \frac{R_6}{R_2} \left(1 + \frac{2R_1}{R_3}\right)$

High Input Impedance Instrumentation Amplifier

![High Input Impedance Amplifier Circuit Diagram]

- $R_1 = R_4$, $R_2 = R_3$
- $A_v = 1 + \frac{R_1}{R_2}$

*†Matching Determines CMRR
‡May be deleted to maximize bandwidth
Bridge Amplifier with Low Noise Compensation

- 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**

\[ \frac{R_1}{R_{S1}} = \frac{R_2}{R_{S2}} \]

\[ V_{OUT} = V_+ \left( 1 - \frac{R_1}{R_{S1}} \right) \]

**Precision Diode**

**Precision Clamp Fast Half Wave Rectifier**

\[ E_{REF} \text{ must have a source impedance of less than } 200\Omega \text{ if } D_2 \text{ is used.} \]
*Feedforward compensation can be used to make a fast full wave rectifier without a filter.

---

**Low Drift Peak Detector**

![Diagram of a Low Drift Peak Detector](image)
Section 3 — Signal Processing (Continued)

Absolute Value Amplifier with Polarity Detector

\[
V_{\text{OUT}} = -|V_{\text{IN}}| \times \frac{R_2}{R_1}
\]

\[
R_2 = \frac{R_4 + R_3}{R_3}
\]

Sample and Hold

*Polycarbonate-dielectric capacitor*
Section 3 — Signal Processing  

(sample and hold figure)

- Worst case drift less than 2.5 mV/sec
- Teflon, Polyethylene or Polycarbonate Dielectric Capacitor

(low drift integrator figure)

- Q1 and Q3 should not have internal gate-protection diodes.
- Worst case drift less than 500 µV/sec over −55°C to +125°C.
Fast\textsuperscript{†} Summing Amplifier with Low Input Current

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

\textsuperscript{†}Power Bandwidth: 250 kHz
Small Signal Bandwidth: 3.5 MHz
Slew Rate: 10V/\mu s

\[ C_5 = \frac{6 \times 10^{-8}}{R_f} \]

Fast Integrator with Low Input Current
Section 3 — Signal Processing  (Continued)

Adjustable Q Notch Filter

\[ f_0 = \frac{1}{2\pi R_1 C_1} \]
\[ = 60 \text{ Hz} \]
\[ R_1 = R_2 = R_3 \]
\[ C_1 = C_2 = C_3 \]
Section 3 — Signal Processing (Continued)

Easily Tuned Notch Filter

![Circuit Diagram]

- **R1**: 4K ohm, 0.1%
- **R2**: 4K ohm, 0.1%
- **R3**: 4K ohm, 0.1%
- **C1**: 500 pF
- **LM107**

\[ f_0 = \frac{1}{2\pi R_4 C_1 C_2} \]

- **R4** = **R5**
- **R1** = **R3**
- **R4** = \( \frac{1}{2} R_1 \)

Tuned Circuit

![Circuit Diagram]

- **R2**: 100 ohm
- **R1**: 100K ohm
- **C1**: 0.1 \( \mu \)F
- **C2**: 0.33 \( \mu \)F
- **R3**: 10K ohm
- **C3**: 300 pF
- **C4**: 30 pF

\[ f_0 = \frac{1}{2\pi R_1 R_2 C_1 C_2} \]

Two-Stage Tuned Circuit

![Circuit Diagram]

- **R2**: 100K ohm
- **C1**: 1 \( \mu \)F
- **C2**: 1 \( \mu \)F
- **LM102**

\[ f_0 = \frac{1}{2\pi R_1 R_2 C_1 C_2} \]
Section 3 — Signal Processing  (Continued)

Negative Capacitance Multiplier

\[ C = \frac{R_2}{R_3} C_1 \]

\[ I_L = \frac{V_{os} + R_2 I_{os}}{R_3} \]

\[ R_S = \frac{R_3(R_1 + R_{IN})}{R_{IN} A_{VO}} \]

Variable Capacitance Multiplier

\[ C = \left( 1 + \frac{R_S}{R_a} \right) C_1 \]
Section 3 — Signal Processing (Continued)

Simulated Inductor

\[ L \geq R_1 R_2 C_1 \]

\[ R_S = R_2 \]

\[ R_P = R_1 \]

Capacitance Multiplier

\[ C = \frac{R_1 C_1}{R_3} \]

\[ I_L = \frac{V_{os} + I_{os} R_1}{R_3} \]

\[ R_S = R_3 \]

High Pass Active Filter

\[ R_1 = 110K \]

\[ C_1^\ast = 0.02 \mu F \]

\[ C_2^\ast = 0.01 \mu F \]

Low Pass Active Filter

\[ C_1^\ast = 940 \mu F \]

\[ C_2^\ast = 470 \mu F \]

*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

![Circuit Diagram]

Current Monitor

![Current Monitor Circuit Diagram]

\[ V_{OUT} = \frac{R_1 R_3}{R_2} \]
Section 3 — Signal Processing  (Continued)

Saturating Servo Preamplifier with Rate Feedback

Power Booster

www.national.com
Section 3 — Signal Processing

Analog Multiplier

\[ R_5 = R_1 \left( \frac{V^-}{10} \right) \]
\[ V_1 > 0 \]
\[ V_{OUT} = \frac{V_1 V_2}{10} \]

Long Interval Timer

*Low leakage ~0.017 \( \mu F \) per second delay

Fast Zero Crossing Detector

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**

Low frequency cutoff = R1 C1

**Temperature Probe**

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

**Photodiode Amplifier**

\[ V_{OUT} = R1 I_D \]

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

**High Input Impedance AC Follower**
**Section 3 — Signal Processing** (Continued)

**Temperature Compensated Logarithmic Converter**

10 nA < I_{IN} < 1 mA
Sensitivity is 1V per decade

\(1 \text{k}\Omega \pm 1\%\) 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**

\(1/2N3728\) matched pairs
Section 3 — Signal Processing (Continued)

Multiplier/Divider

Cube Generator

\[ E_{\text{OUT}} = -\frac{E_1}{E_2} \]
for
\[ E_1 \geq 0 \text{ and } E_2 \geq 0 \]
Section 3 — Signal Processing (Continued)

Fast Log Generator

![Fast Log Generator Circuit Diagram]

†1 kΩ (±1%) at 25°C, +3500 ppm/°C.
Available from Vishay Ultronix, Grand Junction, CO, Q81 Series.

Anti-Log Generator

![Anti-Log Generator Circuit Diagram]

†1 kΩ (±1%) at 25°C, +3500 ppm/°C.
Available from Vishay Ultronix, Grand Junction, CO, Q81 Series.
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