![National Semiconductor]

LM11/LM11C/LM11CL Operational Amplifiers

General Description

The LM11 is a precision dc amplifier combining the best features of existing bipolar and FET op amps. It is similar to the LM108A, except that input currents have been reduced by more than a factor of ten. Offset voltage and drift have also been approved.

Compared to FETs, the device provides inherently lower offset voltage and offset voltage drift, along with at least an order of magnitude better long-term stability. Low frequency noise is also somewhat reduced. Bias current is significantly lower even under laboratory conditions, and its low drift makes compensation practical. Offset current is almost unmeasureable. Although not as fast as FETs, it does have a much lower power drain. This low dissipation has the added advantage of eliminating warm up time in critical applications.

Typical characteristics for 25°C (−55°C to 125°C) are:

- offset voltage: 100 μV (**200 μV**)
- bias current: 25 pA (**65 pA**)
- offset current: 0.5 pA (**3 pA**)
- temperature drift: 1 μV/°C
- long-term stability: 10 μV/year

The LM11 is internally compensated, but external compensation can be added for improved frequency stability, particularly with capacitive loads. Offset voltage balancing is also provided, with the balance range determined by a low-resistance potentiometer.

Otherwise, the device is the electrical equivalent of the LM108, except that the negative common-mode limit is 0.6V less, performance is specified down to ±2.5V and the guaranteed output drive has been increased to ±2 mA. The input noise is somewhat higher, but amplifier noise is obscured by resistor noise with higher source resistances.

This monolithic IC has obviously applications as electrometer amplifiers, charge integrators, analog memories, low frequency active filters or for frequency shaping in slow servo loops. It can be substituted for existing circuits to provide improved performance or eliminate trimming operations. The greater precision can also be used to extend the dynamic range of logarithmic amplifiers, light meters and solid-state particle detectors.

The LM11 is manufactured with standard bipolar processing using super-gain transistors.
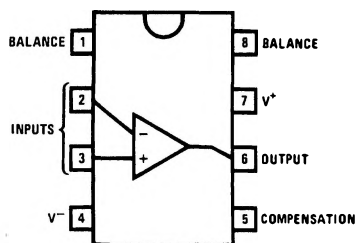
Connection Diagrams

Metal Can*
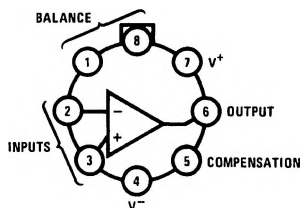
TL/H/5653–1

Top View

Order Number LM11H, LM11CH or LM11CLH
See NS Package H08C

*Case connected to V⁻

Mini-DIP

TL/H/5653–31

Top View

Order Number LM11CN or LM11CLN
See NS Package N08E

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

Total Supply Voltage	40V
Input Current (Note 1)	±10 mA
Power Dissipation (Note 2)	500 mW
Output Short-Circuit Duration (Note 3)	Indefinite
Storage Temperature Range	−65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	
(DIP)	260°C
(Metal Can)	300°C
ESD Tolerance	
(R_{ZAP} = 1.5k, C_{ZAP} = 100 pF)	1500V

Electrical Characteristics T_J = 25°C, $T_{MIN} \leq T_J \leq T_{MAX}$ (Note 4)
(Boldface type refers to limits over temperature range.)

Parameter	Conditions	LM11		LM11C		LM11CL		Units
		Typ	Lim	Typ	Lim	Typ	Lim	
Input Offset Voltage	(Note 4)	0.1	0.3	0.2	0.6	0.5	5	mV
			0.6		**0.8**		**6**	mV
Input Offset Current	(Note 4)	0.5	10	1	10	4	25	pA
			30		**20**		**50**	pA
Input Bias Current	(Note 4)	25	50	40	100	70	200	pA
			150		**150**		**300**	pA
Input Resistance	(Note 4)	10^{11}		10^{11}		10^{11}		Ω
Offset Voltage Drift	(Note 4)	1	**3**	2	**5**	3		μV/°C
Offset Current Drift	(Note 4)	20		10		50		fA/°C
Bias Current Drift	(Note 4)	0.5	**1.5**	0.8	**3**	1.4		pA/°C
Large Signal Voltage Gain	V_S ± 15V, I_{OUT} = ±2 mA	300	100	300	100	300	25	V/mV
	V_{OUT} = ±12V(**±11.5V**)		**50**		**50**		**15**	V/mV
	V_S = ±15V, I_{OUT} = ±0.5 mA	1200	250	1200	250	800	50	V/mV
	V_{OUT} ±12V		**100**		**100**		**30**	V/mV
Common-Mode Rejection	−13V (**−12.5V**) ≤ V_{CM} ≤ 14V	130	110	130	110	110	96	dB
	V_S = ±15V		**100**		**100**		**90**	dB
Power Supply Rejection Ratio	±2.5V ≤ V_S ≤ ±20V	118	100	118	100	100	84	dB
			96		**96**		**80**	dB
Supply Current	(Note 4)	0.3	0.6	0.3	0.8	0.3	0.8	mA
			0.8		**1**		**1**	mA
Output Short-Circuit Current	T_J = 150°C		±15					mA

Note 1: The inputs are shunted with back-to-back diodes for overvoltage protection. Therefore, excessive current will flow if a differential input voltage in excess of 1V is applied between the inputs unless some limiting resistance is used. In addition, a 2 kΩ minimum resistance in each input is advised to avoid possible latch up initiated by supply reversals.
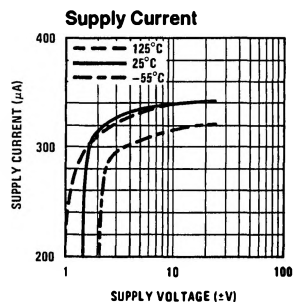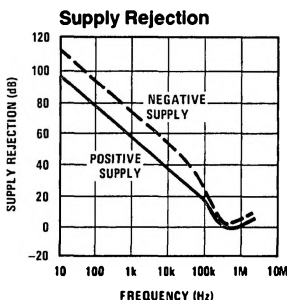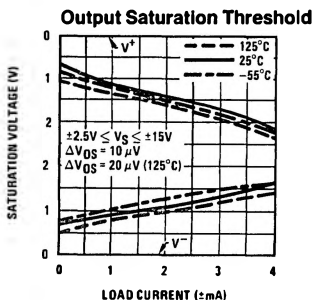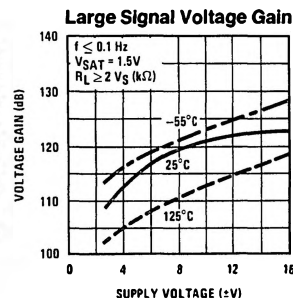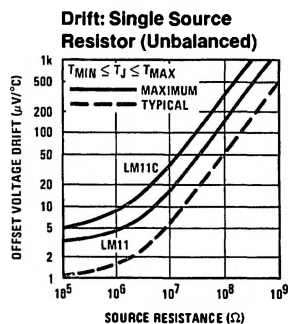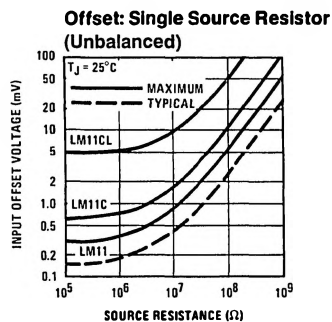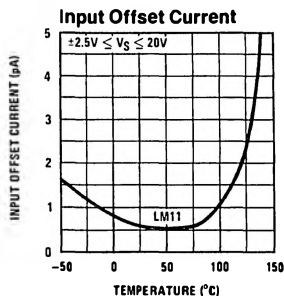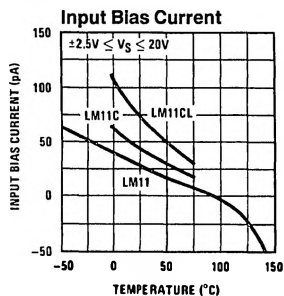
Note 2: The maximum operating-junction temperature is 150°C for the LM11 and 85°C for the LM11C(L). Devices must be derated at 150°C/W for the metal can and 155°C/W for the plastic DIP. The metal can has a thermal resistance of 45°C/W for the junction to case if a heat sink is used.

Note 3: Current limiting protects the output when it is shorted to ground or any voltage less than the supplies. With continuous overloads, package dissipation must be taken into account and heat sinking provided when necessary.

Note 4: These specifications apply for V^- + 2V (**2.5V**) ≤ V_{CM} ≤ V^+ − 1V and ±2.5V ≤ V_S ≤ ±20V, unless otherwise specified. Normal typeface indicates 25°C limits. **Boldface type indicates limits for full-temperature range operation.** This is −55°C ≤ T_J ≤ 125°C for the LM11 and 0°C ≤ T_J ≤ 70°C for the LM11C(L).

Note 5: Refer to RETS11X for LM11 military specifications.

Typical Characteristics

Input Bias Current

Input Offset Current

Offset: Single Source Resistor (Unbalanced)

Drift: Single Source Resistor (Unbalanced)

Input Noise

Input Noise

Common-Mode Limits

Common-Mode Rejection

Large Signal Voltage Gain

Output Saturation Threshold
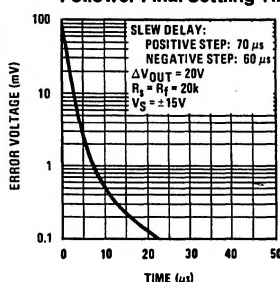
Supply Rejection

Supply Current
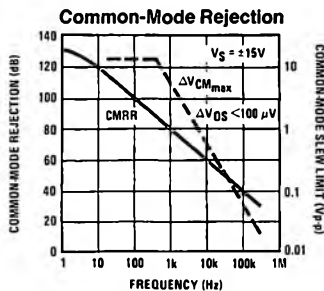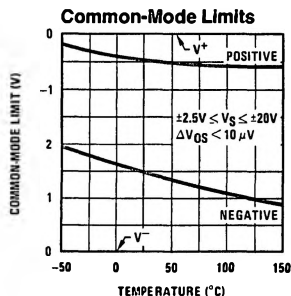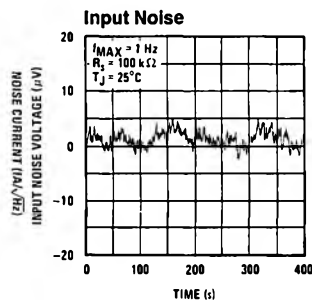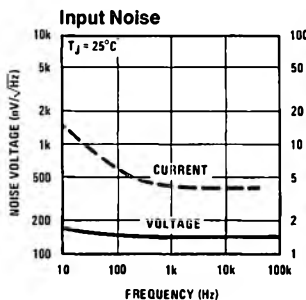
TL/H/5653–2

Typical Characteristics (Continued)
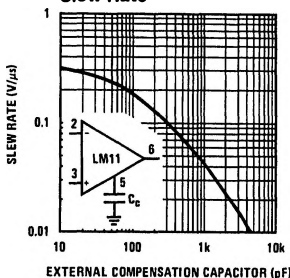
Open Loop Response
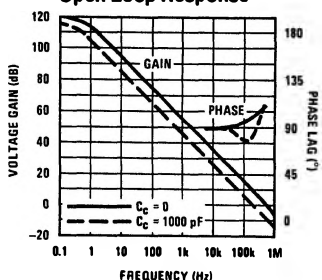
Follower Final Settling Time
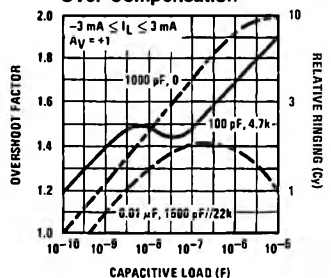

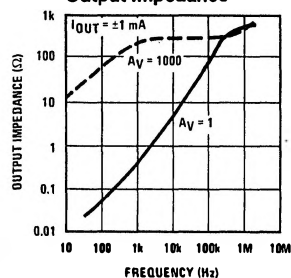### Inverter Final Settling Time
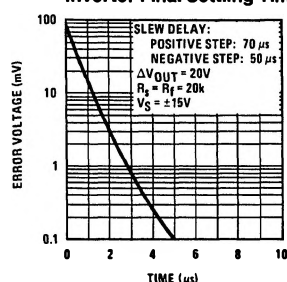
Slew Rate

Stability With Over-Compensation

Closed Loop Output Impedance

TL/H/5653–3

Application Hints

When working with circuitry capable of resolving picoampere level signals, leakage currents in circuitry external to the op amp can significantly degrade performance. High quality insulation is a must (Kel-F and Teflon rate high). Proper cleaning of all insulating surfaces to remove fluxes and other residues is also required. This includes the IC package as well as sockets and printed circuit boards. When operating in high humidity environments or near 0°C, some form of surface coating may be necessary to provide a moisture barrier.

The effects of board leakage can be minimized by encircling the input circuitry with a conductive guard ring operated at a potential close to that of the inputs. For critical applications, dual-in-line packages are available that include input guard pins.

Electrostatic shielding of high impedance circuitry is advisable.

Error voltages can also be generated in the external circuitry. Thermocouples formed between dissimilar metals can cause hundreds of microvolts of error in the presence of temperature gradients. The most troublesome thermocouples are the junction of the IC package and the printed circuit board (35 μV/°C for copper-kovar) and internal resistor connections. Problems can be avoided by keeping low level circuitry away from heat generating elements. Mounting the IC directly to the PC board while keeping package leads short and the input leads close together can also help.

With the LM11 there is a temptation to remove the bias-current-compensation resistor normally used on the noninverting input of a summing amplifier. Direct connection of the inputs to ground or a low-impedance voltage source is not recommended with supply voltages greater than about 3V. The potential problem involves reversal of one supply which can cause excessive current in the second supply. Destruction of the IC could result if the output current of the second supply is not limited to about 100 mA or if there is much more than 1 μF bypass on the supply buss.

Just disconnecting one supply will generally involve reversal because of loading to the other supply both within the IC and in external circuitry. Although difficulties can be largely avoided by installing clamp diodes across the supply lines on every PC board, a conservative design would include enough resistance in the input lead to limit current to 10 mA if the input lead is pulled to either supply by internal currents. This precaution is by no means limited to the LM11.

Application Hints (Continued)

Input Guarding

Input guarding can drastically reduce surface leakage. Layout for metal can is shown here. Guarding both sides of board is required. Bulk leakage reduction is less and depends on guard ring width.
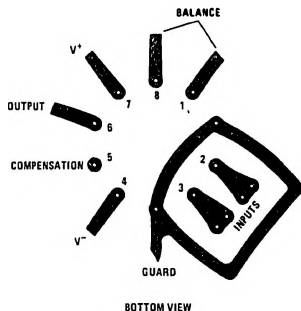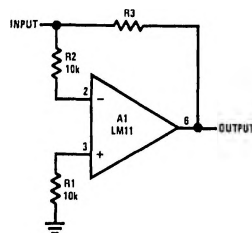

TL/H/5653–4

Guard ring is connected to low impedance point at same potential as sensitive input leads. Connections for various op amp configurations are here.
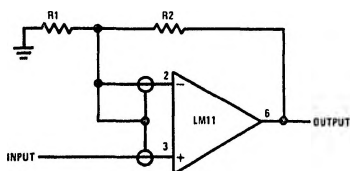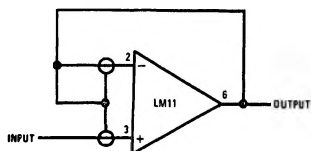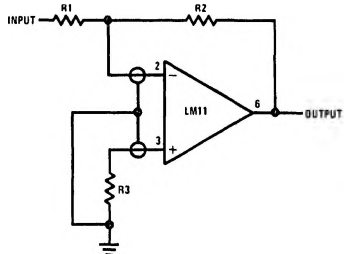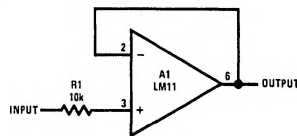

TL/H/5653–7

Input Protection

Current is limited by R2 even when input is connected to voltage source outside common mode range. If one supply reverses, current is controlled by R1. These resistors do not affect normal operation.
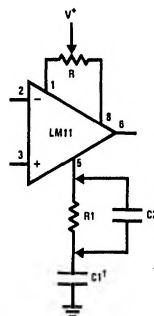

TL/H/5653–5

Input resistor controls current when input exceeds supply voltages, when power for op amp is turned off or when output is shorted.

TL/H/5653–6

Balancing And Over-Compensation

Over-compensation will improve stability with capacitive loading (see curves). Offset voltage adjustment range is determined by balance potentiometer resistance as indicated in the table.

† See stability with over-compensation curve

TL/H/5653–8

| min. adj range	R
±4 mV	100 kΩ
±2	10k
±0.8	3k
±0.4	1k

Application Hints (Continued)

Resistance Multiplication

Equivalent feedback resistance is 10 GΩ, but only standard resistors are used. Even though the offset voltage is multiplied by 100, output offset is actually reduced because error is dependent on offset current rather than bias current. Voltage on summing junction is less than 5 mV.
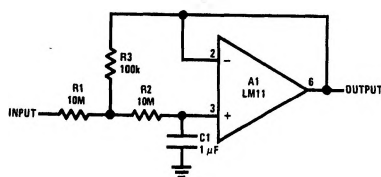

$$R_f = R2 \left(1 + \frac{R3}{R4}\right)$$

$$R2 >> R3\|R4$$

* gain trim
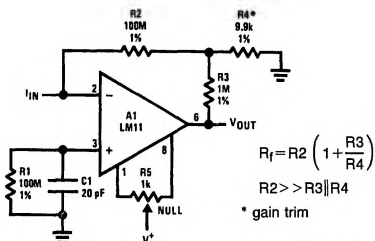
TL/H/5653–9

Follower input resistance is 1 GΩ. With the input open, offset voltage is multiplied by 100, but the added error is not great because the op amp offset is low.
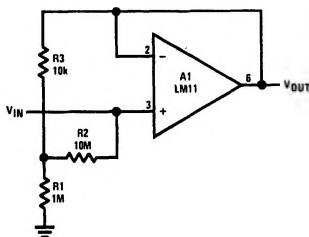
TL/H/5653–11

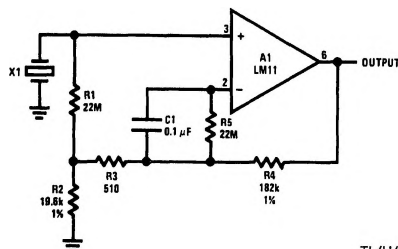This circuit multiplies RC time constant to 1000 seconds and provides low output impedance.

TL/H/5653–13

$$\tau = \frac{R1C}{R3}(R2 + R3)$$
$$\Delta V_{OUT} = \frac{R1 + R3}{R3}(I_B R2 + V_{OS})$$

A high-input-impedance ac amplifier for a piezoelectric transducer. Input resistance of 880 MΩ and gain of 10 is obtained.
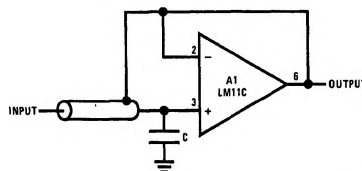

TL/H/5653–10

$$R_{IN} = R1\left(1 + \frac{R2}{R3}\right) \quad A_V = \frac{R2 + R3 + R4}{R2 + R3}$$
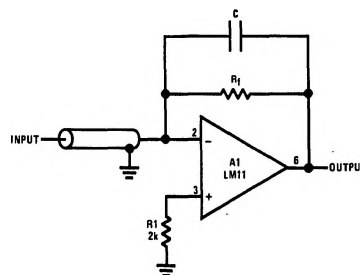
Cable Bootstrapping

Bootstrapping input shield for a follower reduces cable capacitance, leakage and spurious voltages from cable flexing. Instability can be avoided with small capacitor on input.

TL/H/5653–12

With summing amplifier, summing node is at virtual ground so input shield is best grounded. Small feedback capacitor insures stability.
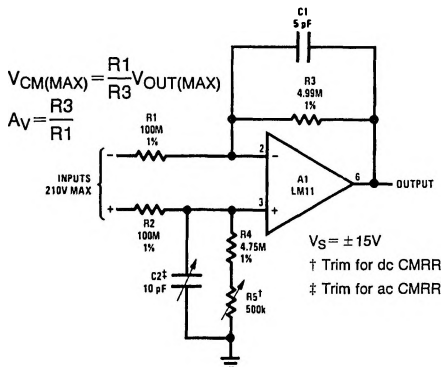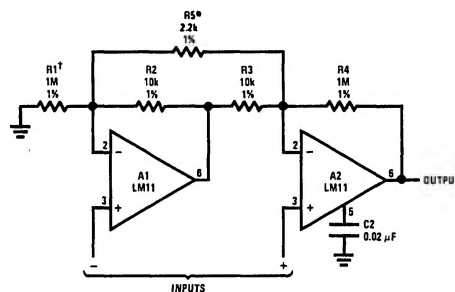

TL/H/5653–14

Application Hints (Continued)
Differential Amplifiers

This differential amplifier handles high input voltages. Resistor mismatches and stray capacitors should be balanced out for best common-mode rejection.

Two op-amp instrumentation amplifier has poor ac common mode rejection. This can be improved at the expense of differential bandwidth with C2.


$$V_{CM(MAX)} = \frac{R1}{R3} V_{OUT(MAX)}$$

$$A_V = \frac{R3}{R1}$$

$V_S = \pm 15V$
† Trim for dc CMRR
‡ Trim for ac CMRR

* Gain set
† Trim for dc CMRR
$f_0 = 10$ Hz

TL/H/5653–15

High gain differential instrumentation amplifier includes input guarding, cable bootstrapping and bias current compensation. Differential bandwidth is reduced by C1 which also makes common-mode rejection less dependent on matching of input amplifiers.

†† Current zero
‡ Voltage balance
*n Gain
† dc CMRR
** ac CMRR
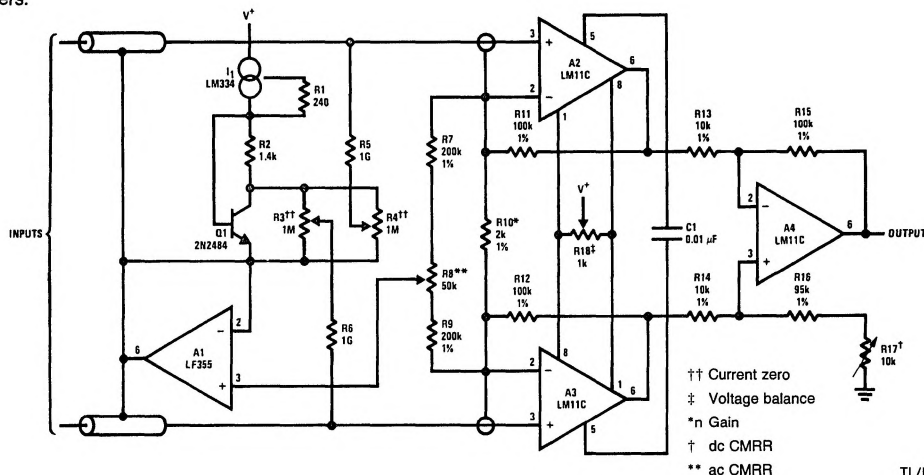
TL/H/5653–16

For moderate-gain instrumentation amplifiers, input amplifiers can be connected as followers. This simplifies circuitry, but A3 must also have low drift.
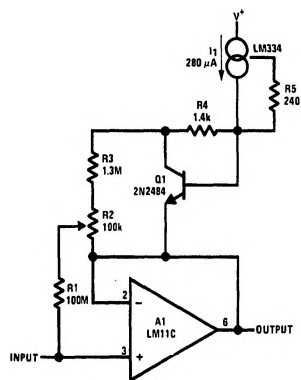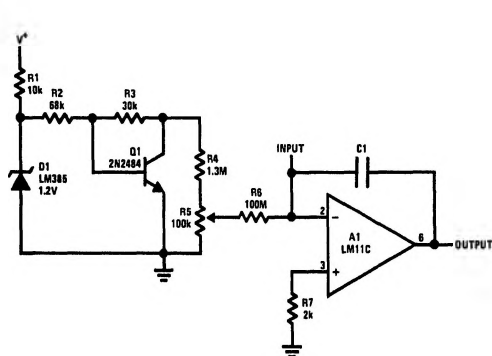

R1 = R3; R2 = R4

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

†Trim for dc CMRR
‡Set for ac CMRR
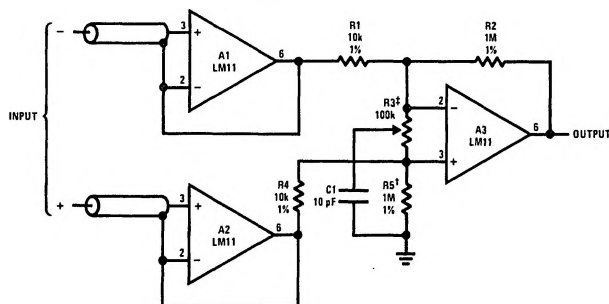
TL/H/5653–17

Application Hints (Continued)

Bias Current Compensation

Precise bias current compensation for use with unregulated supplies. Reference voltage is available for other circuitry.
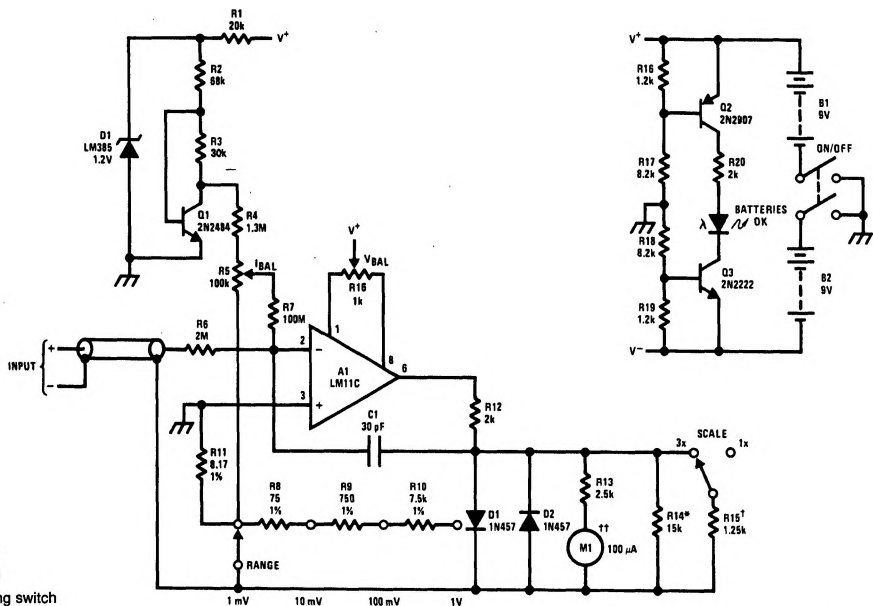
This circuit shows how bias current compensation can be used on a voltage follower.

TL/H/5653-18

Voltmeter

High input impedance millivoltmeter. Input current is proportional to input voltage, about 10 pA at full scale. Reference could be used to make direct reading linear ohmmeter.


* 1×scale calibrate

† 3×scale calibrate

†† Includes reversing switch

TL/H/5653-19

Application Hints (Continued)

Ammeter

Current meter ranges from 100 pA to 3 mA full scale. Voltage across input is 100 µV at lower ranges rising to 3 mV at 3 mA. Buffers on op amp are to remove ambiguity with high-current overload. Output can also drive DVM or DPM.

† 1×scale calibrate
* 3×scale calibrate
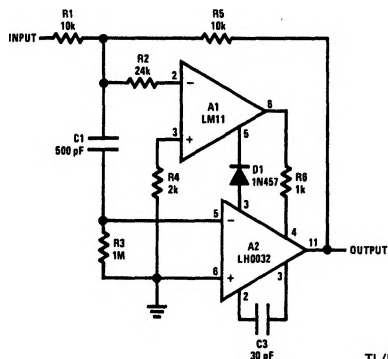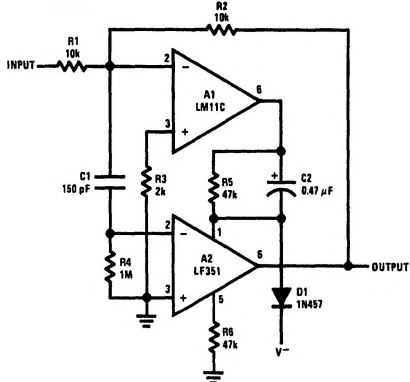†† Includes reversing switch

TL/H/5653-20
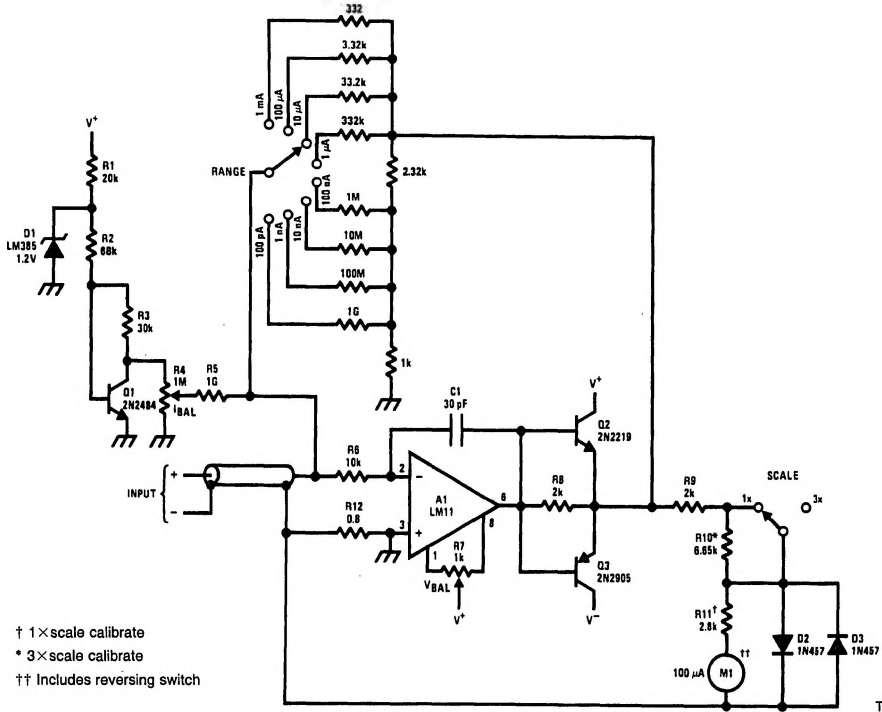
Current Source

Precision current source has 10 µA to 10 mA ranges with output compliance of 30V to −5V. Output current is fully adjustable on each range with a calibrated, ten-turn potentiometer. Error light indicates saturation.

*Calibrate range
†Select for $I_{CBO} \leq 100$ pA

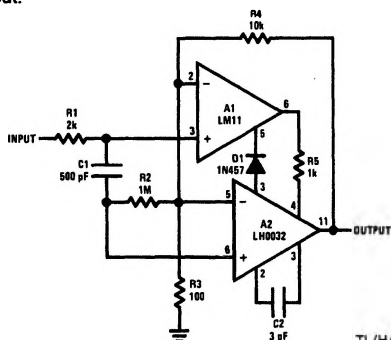TL/H/5653-21
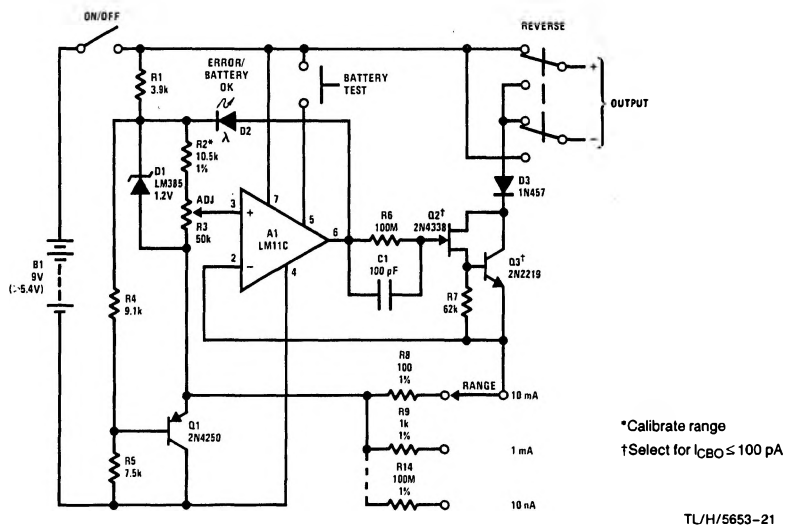
Application Hints (Continued)

Fast Amplifiers

These inverters have bias current and offset voltage of LM11 along with speed of the FET op amps. Open loop gain is about 140 dB and settling time to 1 mV about 8 μS. Over-load-recovery delay can be eliminated by direct coupling the FET amplifier to summing node.

Follower has 10 μS setting to 1 mV, but signal repetition frequency should not exceed 10 kHz if the FET amplifier is ac coupled to input. The circuit does not behave well if common-mode range is exceeded.
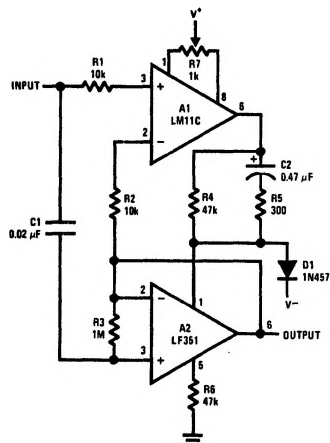

TL/H/5653–23

This 100× amplifier has small and large signal bandwidth of 1 MHz. The LM11 greatly reduces offset voltage, bias current and gain error. Eliminating long recovery delay for greater than 100% overload requires direct coupling of A2 to input.
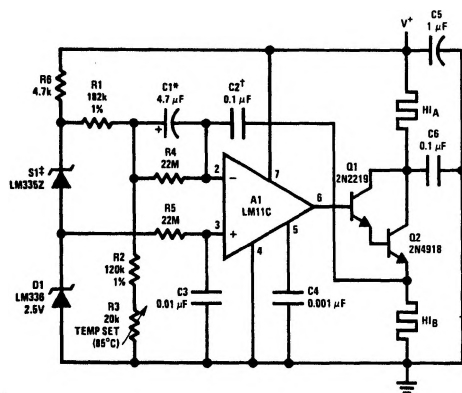
TL/H/5653–22

Heater Control

Proportional control crystal oven heater uses lead/lag compensation for fast settling. Time constant is changed with R4 and compensating resistor R5. If Q2 is inside oven, a regulated supply is recommended for 0.1°C control.

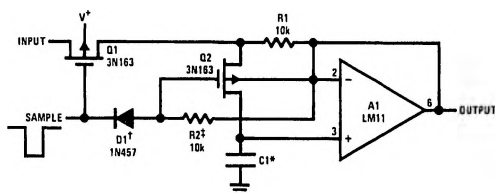
TL/H/5653–25

TL/H/5653–24

* Solid tantalum

† Mylar

‡ Close thermal coupling between sensor and oven shell is recommended.

Application Hints (Continued)

Leakage Isolation

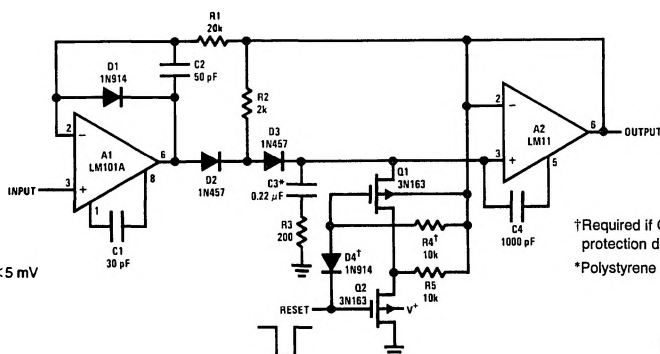Switch leakage in this sample and hold does not reach storage capacitor.

*Polystyrene or Teflon
†Required if protected-gate switch is used

TL/H/5653-26

A peak detector designed for extended hold. Leakage currents of peak-detecting diodes and reset switch are absorbed before reaching storage capacitor.
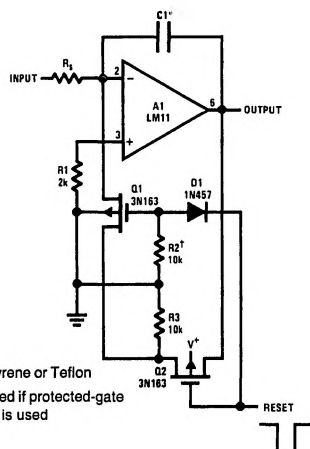

300 μS min single pulse
200 μS min repetitive pulse
300 Hz max sine wave error < 5 mV

†Required if Q1 has gate-protection diode
*Polystyrene or Teflon

TL/H/5653-27

Reset is provided for this integrater and switch leakage is isolated from the summing junction. Greater precision can be provided if bias-current compensation is included.
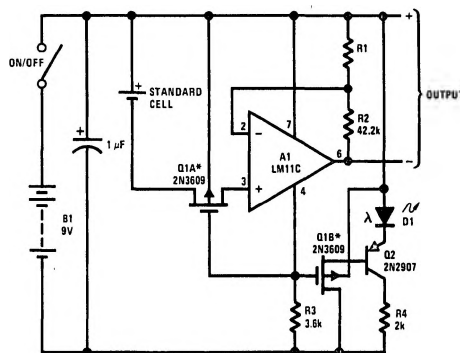

*Polystyrene or Teflon
†Required if protected-gate switch is used

Standard-Cell Buffer

Battery powered buffer amplifier for standard cell has negligible loading and disconnects cell for low supply voltage or overload on output. Indicator diode extinguishes as disconnect circuitry is activated.


TL/H/5653-28

*Cannot have gate protection diode; $V_{TH} > V_{OUT}$

Application Hints (Continued)

Logarithmic Amplifiers

Unusual frequency compensation gives this logarithmic converter a 100 μs, time constant from 1 mA down to 100 μA, increasing from 200 μs to 200 ms from 10 nA to 10 pA. Optional bias current compensation can give 10 pA resolution from $-55°C$ to 100°C. Scale factor is 1V/decade and temperature compensated.
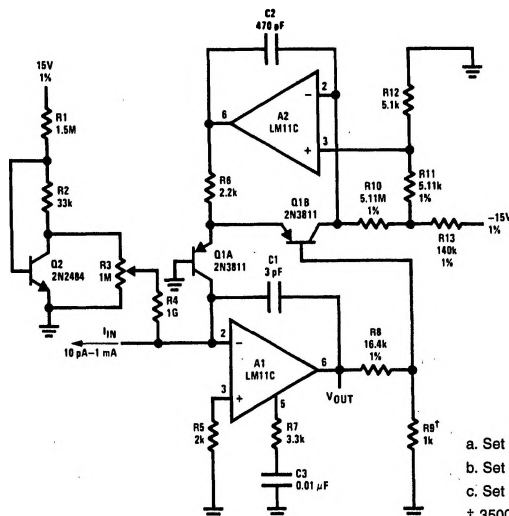
a. Set R11 for $V_{OUT} = 0$ at $I_{IN} = 100$ nA
b. Set R8 for $V_{OUT} = 3V$ at $I_{IN} = 100$ μA
c. Set R3 for $V_{OUT} = -4V$ at $I_{IN} = 10$ pA
† 3500 ppM/°C. Type Q81 available from Tel Labs Inc., Londonderry, N.H.

Light meter has eight-decade range. Bias current compensation can give input current resolution of better than ± 2 pA over 15°C to 55°C.
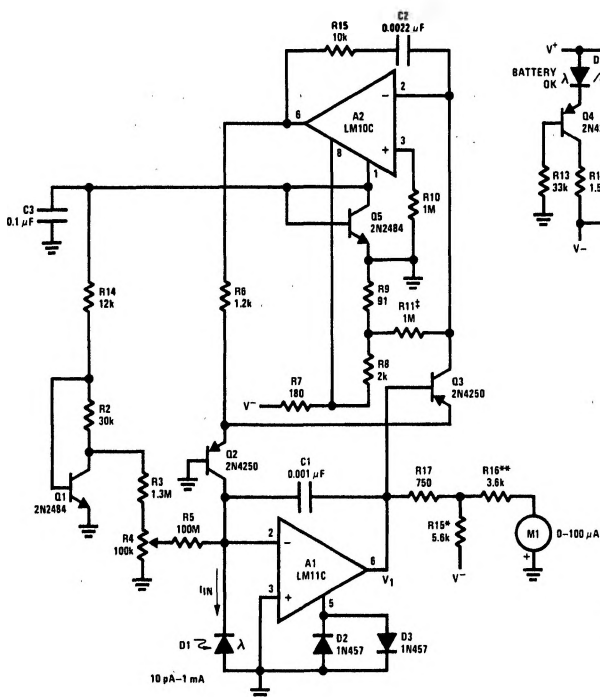
‡ $V1 = 0$ @ $I_{IN} = 100$ nA
† $V1 = -0.24V$ @ $I_{IN} = 10$ pA
* $M1 = 0$ @ $I_{IN} = 10$ pA
** $M1 = f_S$ @ $I_{IN} = 1$ mA

TL/H/5653–29

Schematic Diagram
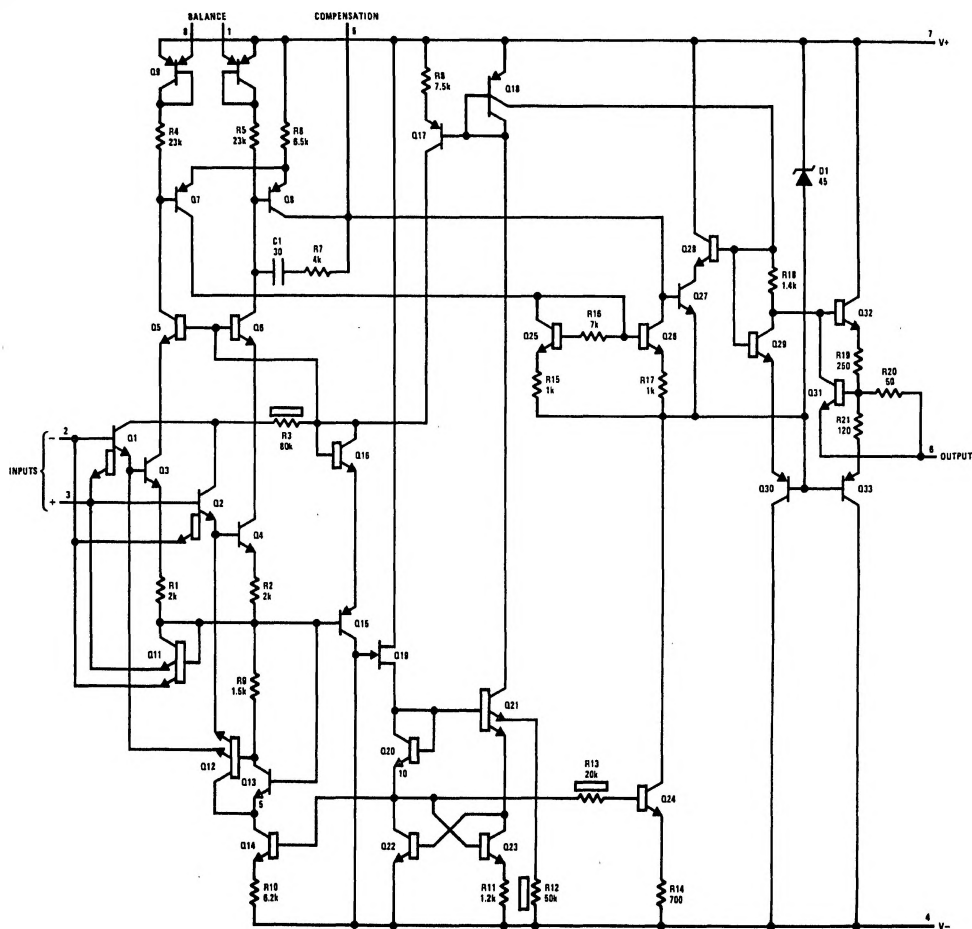
TL/H/5653-30

Definition of Terms

Input offset voltage: That voltage which must be applied between the input terminals to bias the unloaded output in the linear region.

Input offset current: The difference in the currents at the input terminals when the output is unloaded in the linear region.

Input bias current: The absolute value of the average of the two input currents.

Input resistance: The ratio of the change in input voltage to the change in input current on either input with the other grounded.

Large signal voltage gain: The ratio of the specified output voltage swing to the change in differential input voltage required to produce it.

Common-mode rejection: The ratio of the input voltage range to the change in offset voltage between the extremes.

Temperature drift: The change of a parameter measured at 25°C and either temperature extreme divided by the temperature change.

Power Supply Rejection Ratio: The ratio of the specified supply-voltage change (either or both supplies) to the change in offset voltage between the extremes.

Supply current: The current required from the power source to operate the amplifier with the output unloaded and operating in the linear range.