TELEDYNE COMPONENTS

LOW POWER, CHOPPER-STABILIZED OPERATIONAL AMPLIFIER

FEATURES

- **Low Power Dissipation .... 2 mW**
- **Low Power Supply Current .... 140 μA**
- **Low-Input Offset Voltage .... 5 μV Max**
- **Low-Input Offset Voltage Drift .... 0.05 μV/°C Max**
- **High-Impedance Differential CMOS Inputs ... $10^{12}\Omega$**
- **High Open-Loop Voltage Gain .... 120 dB Min**
- **Low Input Noise Voltage .... 0.3 μV_{P-P}**
- **High Slew Rate .... 0.2 V/μs**
- **Unity-Gain Stable**
- **Available in 8-Pin DIP and SO**

GENERAL DESCRIPTION

The TC900 is a low power, precision operational amplifier. Its 200 μA maximum supply current reduces device power requirements over 15 times, compared to 7650 devices.

Offset voltage is a low 5 μV with drift at 0.05 μV/°C. Input offset voltage (V_{OS}) errors are removed and adjustment potentiometers are not necessary. The chopper-stabilized error-correction technique keeps offset voltage errors near zero throughout the device's operating temperature range.

The TC900 performance advantages are achieved without additional manufacturing complexity and costs incurred with laser or "zener zap" V_{OS} trim techniques. The TC900 is one of the lowest cost, low power, precision operational amplifiers available.

The TC900 nulling scheme corrects both DC V_{OS} errors and V_{OS} drift errors with temperature. A nulling amplifier alternately corrects its own V_{OS} errors and the main amplifier V_{OS} errors. Offset-nulling voltages are stored on two user-supplied external capacitors. The capacitors connect to the internal amplifier V_{OS} null points. The main amplifier input signal is never switched. The nulling scheme keeps V_{OS}

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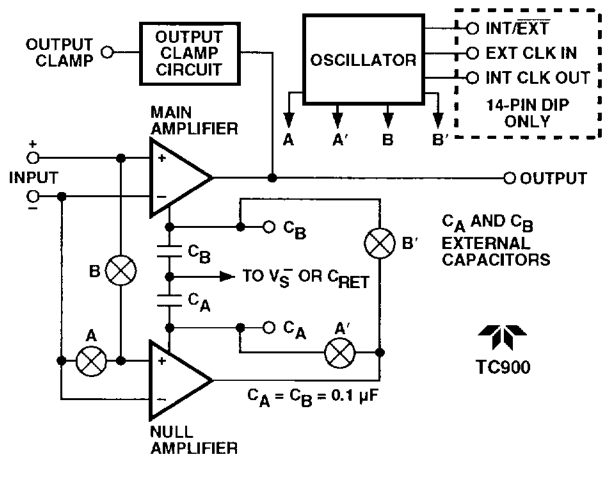
FUNCTIONAL DIAGRAM

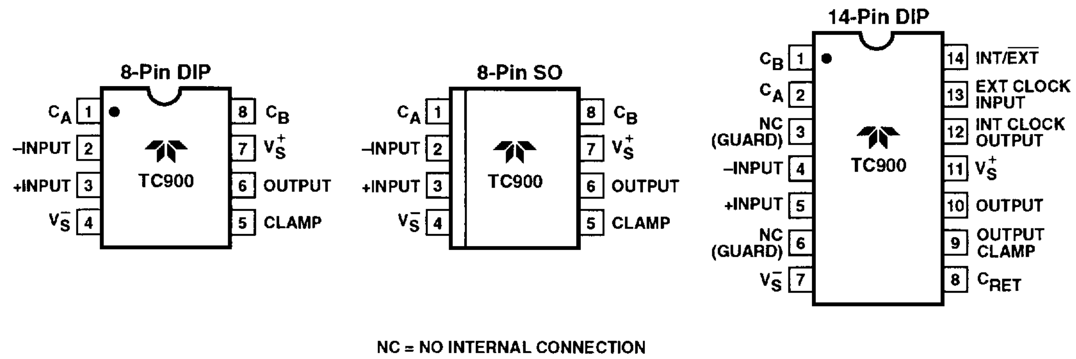


errors low throughout the operating temperature range. Laser and "zener zap" trimming can correct for V_{OS} at only one temperature.

The nulling-circuit oscillator and control circuits are integrated on-chip. Only two external V_{OS} error storage capacitors are required. The TC900 operates as a conventional operational amplifier with vastly improved input specifications. The low V_{OS} and V_{OS} drift errors make the TC900 ideal for thermocouple, thermistor, and strain gauge applications. Low DC errors and high open-loop gain make the TC900 an excellent preamplifier for precision analog-to-digital converters, such as the TC7135, TC850 and TC7109A.

The 14-pin package has an external oscillator input to drive the nulling circuitry. Both the 8-pin and 14-pin packages have an output voltage clamp circuit to minimize overload recovery time.

PIN CONFIGURATIONS



ORDERING INFORMATION

Part No.	Package	Temperature Range	Maximum V_{OS}	Maximum Supply Current
TC900ACPA	8-Pin Plastic DIP	0°C to +70°C	5 µV	200 µA
TC900ACOA	8-Pin SO	0°C to +70°C	5 µV	200 µA
TC900AIJA	8-Pin CerDIP	–25°C to +85°C	5 µV	200 µA
TC900ACPD	14-Pin Plastic DIP	0°C to +70°C	5 µV	200 µA
TC900AIJD	14-Pin CerDIP	–25°C to +85°C	5 µV	200 µA
TC900BCPA	8-Pin Plastic DIP	0°C to +70°C	15 µV	400 µA
TC900BCOA	8-Pin SO	0°C to +70°C	15 µV	400 µA
TC900BIJA	8-Pin CerDIP	–25°C to +85°C	15 µV	400 µA
TC900BCPD	14-Pin Plastic DIP	0°C to +70°C	15 µV	400 µA
TC900BIJD	14-Pin CerDIP	–25°C to +85°C	15 µV	400 µA

LOW POWER, CHOPPER-STABILIZED OPERATIONAL AMPLIFIER

ABSOLUTE MAXIMUM RATINGS

Total Supply Voltage (V_S^+ to V_S^-) .... +18V
Input Voltage .... (V_S^+ +0.3V) to (V_S^- –0.3V)
Voltage on Oscillator Control Pins .... V_S^+ to V_S^-
Output Short-Circuit Duration .... Indefinite
Current Into Any Pin .... 10 mA
While Operating (Note 4) .... 100 µA
Storage Temperature Range .... –65°C to +150°C
Lead Temperature (Soldering, 10 sec) .... +300°C

Operating Temperature Range
C Device .... 0°C to +70°C
I Device .... –25°C to +85°C
Package Power Dissipation (T_A = 25°C) .... 500 mW

Static-sensitive device. Unused devices must be stored in conductive material to protect them from possible static damage. Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS: V_S^+ = +5V, V_S^- = –5V, $C_A = C_B$ = 0.1 µF, T_A = +25°C

Symbol	Parameter	Test Conditions	TC900A Min	TC900A Typ	TC900A Max	TC900B Min	TC900B Typ	TC900B Max	Unit
Input									
V_{OS}	Input Offset Voltage		—	—	5	—	—	15	µV
TCV_{OS}	Input Offset Voltage vs Temperature Coefficient	Operating Temperature Range (Note 1)	—	0.02	0.05	—	0.1	0.3	µV/°C
I_{BIAS}	Average Input Bias Current (Note 5)	T_A = +25°C	—	—	50	—	—	80	pA
		0°C ≤ T_A ≤ +70°C	—	—	70	—	—	100	pA
		–25°C ≤ T_A ≤ +85°C	—	—	100	—	—	140	pA
I_{OS}	Input Offset Current	T_A = +25°C	—	0.5	—	—	0.5	—	pA
e_N	Input Noise Voltage	R_S = 100Ω, 0.1 Hz to 10 Hz	—	4	—	—	4	—	$µV_{P-P}$
		R_S = 100Ω, 0.1 to 1 Hz	—	0.3	—	—	0.3	—	$µV_{P-P}$
R_{IN}	Input Resistance		—	10^{12}	—	—	10^{12}	—	Ω
CMVR	Common-Mode Voltage Range		V_S^-	—	$V_S^+–2$	V_S^-	—	$V_S^+–2$	V
CMRR	Common-Mode Rejection Ratio	CMVR = –5V to +2V	110	130	—	100	—	—	dB
Output									
A_V	Large-Signal Voltage Gain	R_L = 10 kΩ	120	130	—	100	—	—	dB
V_{OUT}	Output Voltage Swing (Note 3)	R_L = 10 kΩ	–4.7	—	+3.5	–4.7	—	+3.5	V
		R_L = 100 kΩ	–4.9	—	+3.9	–4.9	—	+3.9	V
	Clamp ON Current (Note 2)	R_L = 100 kΩ	20	90	200	20	90	200	µA
	Clamp OFF Current (Note 2)	–4V < V_{OUT} < 4V	—	1	—	—	1	—	pA
Dynamic									
BW	Unity-Gain Bandwidth	Unity Gain (+1)	—	0.7	—	—	0.7	—	MHz
SR	Slew Rate	C = 50 pF, R_L = 100 kΩ	—	0.2	—	—	0.2	—	V/µs
	Rise Time		—	0.5	—	—	0.5	—	µs
	Overshoot		—	18	—	—	18	—	%
f_{CH}	Internal Chopping Frequency	Pins 12–14 Open (14-Pin DIP)	—	150	—	—	150	—	Hz
Supply									
V_S^+ to V_S^-	Operating Supply Range		4.5	—	16	4.5	—	16	V
I_S	Supply Current	No Load	—	140	200	—	—	400	µA
PSRR	Power Supply Rejection Ratio	V_S = ±3V to ±8V	120	—	—	100	—	—	dB

NOTES:
1. Operating temperature range is –25°C to +85°C for "I" grade and 0°C to +70°C for "C" grade.
2. See "Output Clamp" discussion.
3. Output clamp not connected.
4. Limiting input current to 100 µA is recommended to avoid latch-up problems.
5. Average current caused by switch charge transfer at input.

Chopper-Stabilized Operational Amplifiers

The TC900 is the first commercially-available, low-power, chopper-stabilized amplifer. Its maximum supply current is 15 times lower than the pin-compatible TC7650. Figure 1 shows how low supply current is achieved without sacrificing offset voltage or offset voltage drift performance.

Nulling-Capacitor Connection

The offset voltage correction capacitors are connected to C_A and C_B. The common capacitor connection is made to V_S^- (pin 4) on the 8-pin device and to capacitor return (C_{RET}, pin 8) on the 14-pin device. The common connection should be made through a separate PC trace or wire to avoid voltage drops. Internally, V_S^- is connected to C_{RET}. (See Figure 2.)

Clock Operation

The internal oscillator is set for a 150 Hz nominal chopping frequency. With the 14-pin device, the 150 Hz internal chopping frequency is available at the INTERNAL CLOCK OUTPUT (pin 12). A 300 Hz nominal signal will be present at the EXTERNAL CLOCK INPUT pin (pin 13) with INT/$\overline{\text{EXT}}$ high or open. This is the internal clock signal before a divide-by-two operation.

The 14-pin device can be driven by an external clock. The INT/$\overline{\text{EXT}}$ input (pin 14) has an internal pull-up and may be left open for internal clock operation. If an external clock is used, INT/$\overline{\text{EXT}}$ must be tied to V_S^- (pin 7) to disable the internal clock. The external clock signal is applied to the external clock input.

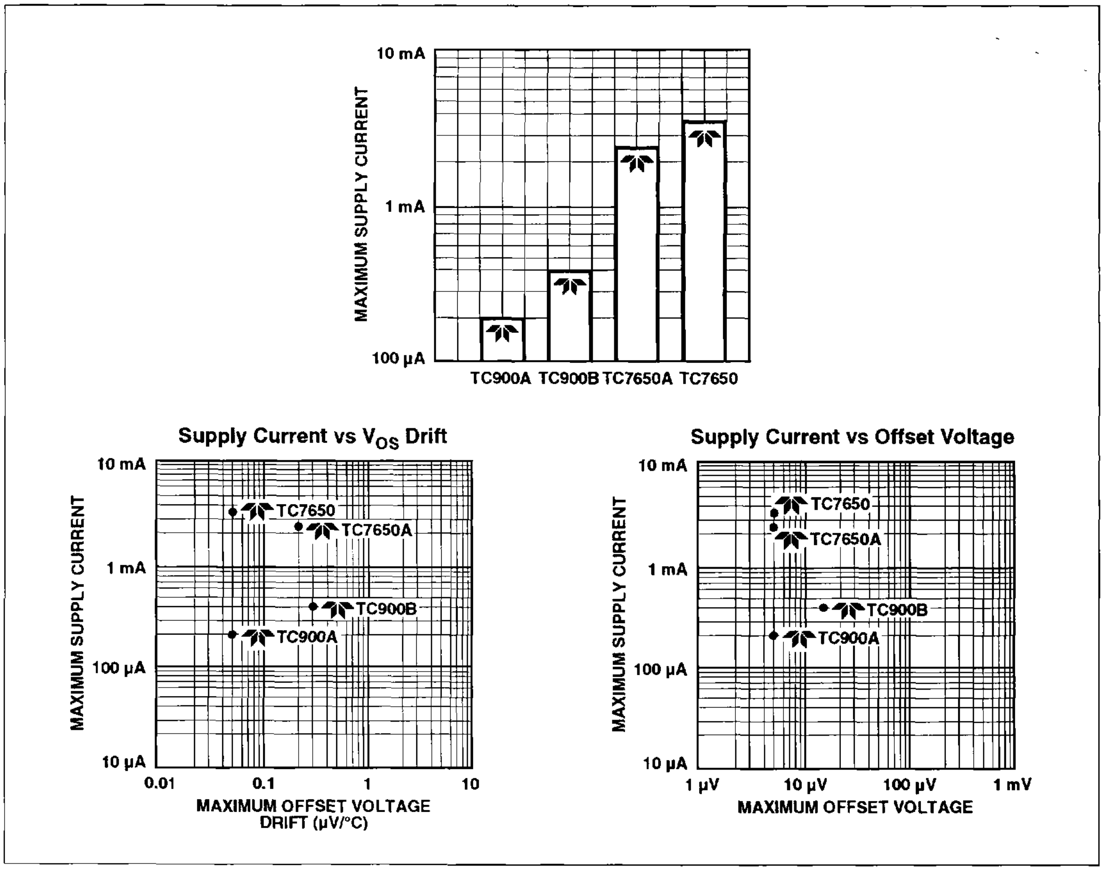


Figure 1

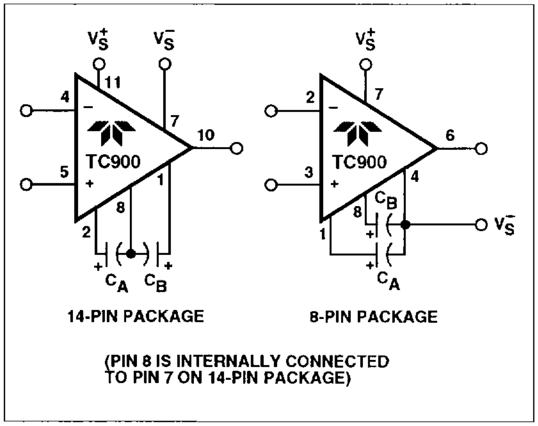


Figure 2. Nulling Capacitor Connection

The external clock amplitude should swing between V_S^+ and ground for power supplies up to ±6V, and between V_S^+ and V_S^+ –6V for higher supply voltages.

At low frequencies, the external-clock duty cycle is not critical, since an internal divide-by-two gives the desired 50% switching duty cycle. The offset storage correction capacitors are charged only when the external clock input is high. A 50% to 80% external-clock positive duty cycle is desired for frequencies above 500 Hz to guarantee transients settle before the internal switches open.

The external clock input can also be used as a strobe input. If a strobe signal is connected at the external clock input, so that it is low during the time an overload signal is applied, neither capacitor will be charged. Leakage currents

Output Clamp

Chopper-stabilized systems can show long overload recovery times. If the output is driven to either supply rail, output saturation occurs; the inputs are no longer held at a "virtual ground." The V_{OS} null circuit treats the differential signal as an offset and tries to correct it by charging the external capacitors. The nulling circuit also saturates. Once the input signal returns to normal, the response time is lengthened by the long recovery time of the nulling amplifier and external capacitors.

Through an external clamp connection, the TC900 eliminates the overload recovery problem by reducing the feedback network gain before the output voltage reaches either supply rail.

The output clamp circuit is shown in Figure 3, with typical inverting and noninverting circuit connections shown in Figures 4 and 5. Output voltage versus clamp circuit current

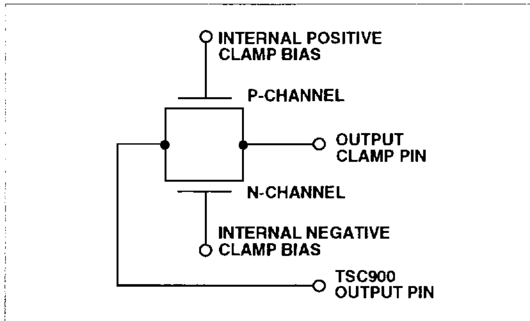


Figure 3. Internal Clamp Circuit

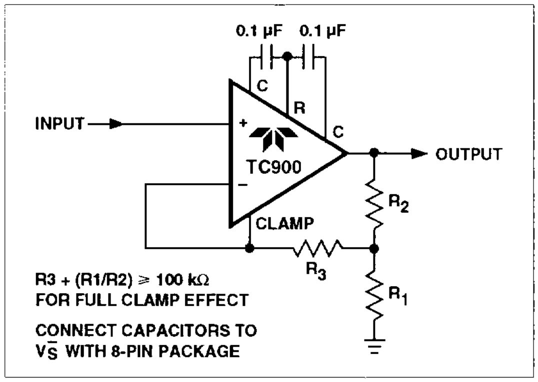


Figure 4. Noninverting Amplifier With Optional Clamp

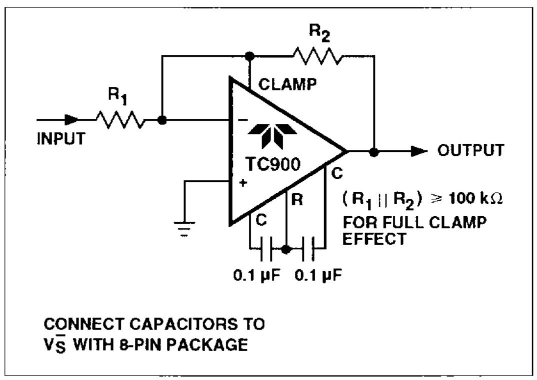


Figure 5. Inverting Amplifier With Optional Clamp

characteristics are shown in the typical operating curves. For the clamp to be fully effective, the impedance across the clamp output should be >100 kΩ.

Static Protection

All device pins are static-protected. However, strong static fields and discharges should be avoided, as they can degrade diode junction characteristics and increase input-leakage currents.

Many companies are actively involved in providing services, educational materials, and supplies to aid electronic manufacturers in establishing "static safe" work areas where CMOS components are handled. Two such companies are:

- 3M
  Static Control Systems Division
  223-25W EM Center
  St. Paul, MN 55101
  (800) 792-1072

- Semtronics
  P.O. Box 592
  Martinsville, NJ 08836
  (210) 561-9520

Input Bias Current

The TC900 inputs are never disconnected from the main internal amplifier. The null amplifier samples the input offset voltage and corrects DC errors and drift by storing compensating voltages on external capacitors. However, the sampling causes charge transfer at the inputs. The charge transfer represents a peak impulse current of 200 nA to 290 nA at the inputs when the internal clock makes a transition.

Latch-Up Avoidance

Junction-isolated CMOS circuits inherently include a parasitic 4-layer (p-n-p-n) structure which has characteristics similar to an SCR. Under certain circumstances, this junction may be triggered into a low-impedance state, resulting in excessive supply current. To avoid this condition, voltages greater than 0.3V beyond the supply rails should not be applied to any pin. In general, the amplifier supplies must be established at the same time (or before) any input signals are applied. If this is not possible, the drive circuits must limit input current flow to under 0.1 mA to avoid latch-up.

Thermoelectric Potentials

Precision DC measurements are ultimately limited by thermoelectric potentials developed in thermocouple junctions of dissimilar metals, alloys, silicon, etc. Unless all junctions are at the same temperature, thermoelectric voltages, typically around 0.1 µV/°C, but up to tens of µV/°C for some materials, will be generated. In order to realize the benefits extremely low offset voltages provide, it is essential to take special precautions to avoid temperature gradients. All components should be enclosed to eliminate air movements, especially those caused by power-dissipating elements in the system. Low thermoelectric-coefficient connections should be used where possible, and power supply voltages and power dissipation should be kept to a minimum. High-impedance loads are preferable, and separation from surrounding heat-dissipating elements is advised.

Pin Compatibility

On the 8-pin TC900, the external null storage capacitors are connected to pins 1 and 8. On most other operational amplifiers these are left open, or are used for offset potentiometer or compensation capacitor connections.

For OP05 and OP07 operational amplifiers, the replacement of the offset null potentiometer between pins 1 and 8 by two capacitors from the pins to V_S^- will convert the OP05/07 pin configuration for TC900 operation. For LM108 devices, the compensation capacitor is replaced by the external nulling capacitors. The LM101/748/709 pinouts are modified similarly by removing any circuit connections to pin 5. On the TC900, pin 5 is the output clamp connection. Other operational amplifiers may use this pin as an offset or compensation point.

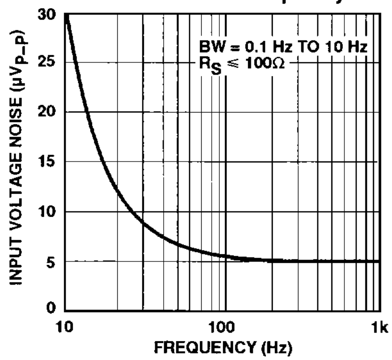
The minor modifications needed to retrofit a TC900 to existing sockets operating at reduced power supply voltages make prototyping and circuit verification straightforward.

Component Selection

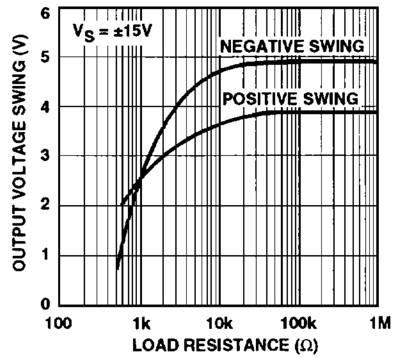
The two required capacitors, C_A and C_B, have optimum values, depending on the clock or chopping frequency. For the present internal clock, the correct value is 0.1 µF. To maintain the same relationship between the chopping frequency and the nulling time constant, the capacitor values should be scaled in proportion to the external clock, if used. High-quality, film-type capacitors (such as Mylar) are preferred. Ceramic or other lower-grade capacitors may be suitable in some applications. For fast settling on initial turn-on, low dielectric absorption capacitors (such as polypropylene) should be used. With ceramic capacitors, several seconds may be required to settle to microvolt levels.

TYPICAL CHARACTERISTICS CURVES

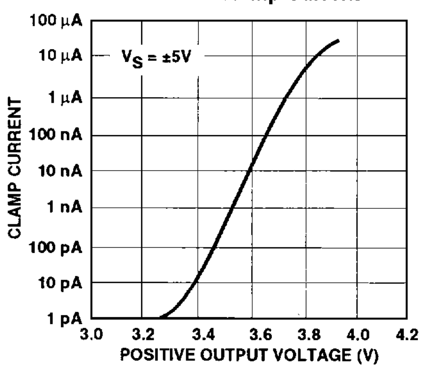
Input Voltage Noise vs External Clock Frequency



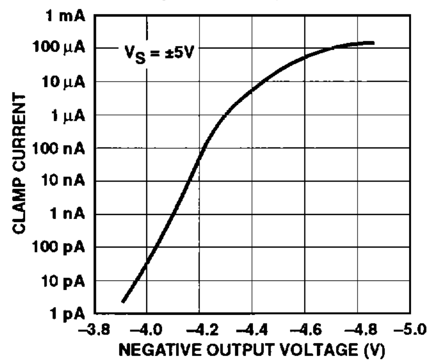
Output Voltage Swing vs Load Resistance



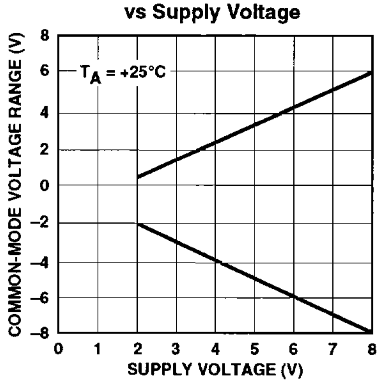
Positive Clamp Current



Negative Clamp Current

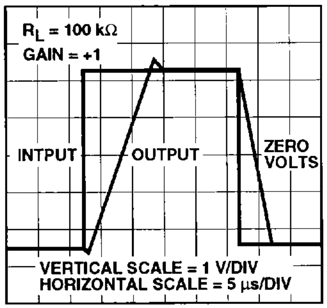


Input Common-Mode Voltage Range vs Supply Voltage

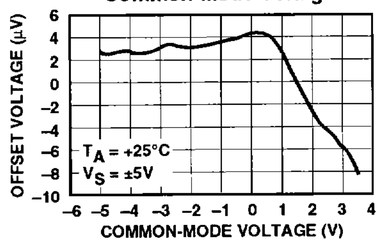


TYPICAL CHARACTERISTICS CURVES (Cont.)

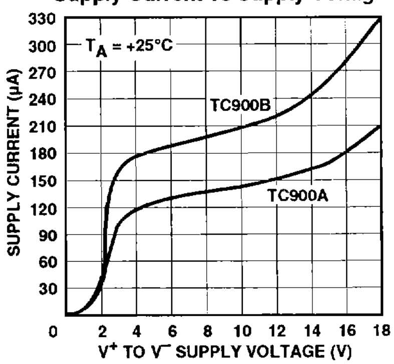
Slew Rate



Offset Voltage vs Common-Mode Voltage



Supply Current vs Supply Voltage



Gain and Phase vs Frequency