



## LM613A/LM613

### Dual Operational Amplifiers, Dual Comparators, and Adjustable Reference

#### General Description

The operational amplifiers are a versatile common-mode-to-the-negative-supply ("single supply") type similar to the LM124 series, but with improved slew rate, improved power bandwidth, reduced cross-over distortion, and low supply current even when driven beyond output swing limits. The comparators are also a common-mode-to-the-negative-supply type, similar to the LM139 series. The op amps and comparators have lateral PNP input transistors which enable low input currents for large differential input voltages and swings above  $V^+$ .

The voltage reference is a three-terminal shunt-type band-gap similar to the adjustable LM185 series, but with anode committed to the  $V^-$  terminal and improved voltage accuracy to  $\pm 0.4\%$ . Two resistors program the reference from 1.24V to 6.3V. The reference features operation over a shunt current range of 16  $\mu\text{A}$  to 20 mA, low dynamic impedance, broad capacitive load range, and cathode terminal voltage ranging from a diode-drop below  $V^-$  to above  $V^+$ .

As a member of National's new Super-Block™ family, the LM613 is a space-saving monolithic alternative to a multi-chip solution, offering a high level of integration without sacrificing performance.

#### Features (Guaranteed over temperature & supply)

##### OP AMPS AND COMPARATORS

- Low operating current 1000  $\mu\text{A}$   
(op amps & comparators)  
16  $\mu\text{A}$  (reference)
- Large supply voltage range 4V to 36V
- Large output swing (10 k $\Omega$  load) ( $V^- + 1\text{V}$ ) to ( $V^+ - 1.8\text{V}$ )
- Input common-mode range  $V^-$  to ( $V^+ - 1.4\text{V}$ )
- Wide differential input voltage  $\pm 36\text{V}$

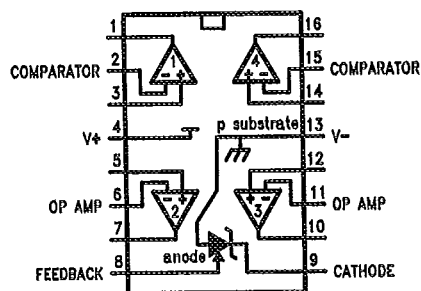
##### REFERENCE

- Adjustable output voltage 1.2V to 6.3V
- Tight initial tolerance available  $\pm 0.4\%$
- Tolerant of load capacitance

#### Applications

- Power supplies
- Signal conditioning

#### Connection Diagram



TL/H/9220-1

Top View

Order Number LM613IJ, LM613MJ, LM613CWM,  
LM613IWM, LM613AIN, LM613CN or LM613IN  
See NS Package Number J16A, M16B or N16A

#### Order Number

|                                                                                  |          |
|----------------------------------------------------------------------------------|----------|
| Prime Military                                                                   | LM613MJ  |
| Tested at $-55^\circ\text{C}$ , $+25^\circ\text{C}$ , $+125^\circ\text{C}$       |          |
| Drift tested at $-55^\circ\text{C}$ , $+25^\circ\text{C}$ , $+125^\circ\text{C}$ |          |
| Prime Industrial                                                                 | LM613AIN |
| Tested at $25^\circ\text{C}$                                                     |          |
| Drift tested at $-40^\circ\text{C}$ , $+25^\circ\text{C}$ , $+85^\circ\text{C}$  |          |
| Industrial                                                                       | LM613IN  |
| Tested at $+25^\circ\text{C}$                                                    |          |
|                                                                                  | LM613IJ  |
|                                                                                  | LM613IWM |
| Commercial                                                                       | LM613CN  |
| Tested at $+25^\circ\text{C}$                                                    |          |
|                                                                                  | LM613CWM |

#### Packages

|    |                                   |
|----|-----------------------------------|
| J  | Hermetic Dual-In-Line             |
| N  | Plastic Dual-In-Line              |
| WM | Plastic Surface Mount Wide (0.3") |

**Absolute Maximum Ratings** (Note 1)

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

Voltage on Any Pin Except Cathode Pin (referred to V<sup>-</sup> pin) (Note 2)

(Note 3) -0.3V (Min)

LM613M, LM613AI, LM613I 36V

LM613C 32V

Current through Any Input Pin & Cathode Pin ±20 mA

Differential Input Voltage

LM613M, LM613AI, LM613I ±36V

LM613C ±32V

Short Circuit Duration, Op Amp (Note 4) Continuous

Storage Temperature Range -65°C to +150°C

Maximum Junction Temperature 150°C

**Soldering Information**

J, N Packages

Soldering (10 seconds) 260°C

WM Package

Vapor Phase (60 seconds) 215°C

Infrared (15 seconds) 220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

**Thermal Resistance, Junction-to-Ambient** (Note 5)

LM613MJ, LM613IJ 100°C/W

LM613AIN, LM613IN, LM613CN 95°C/W

LM613IWM, LM613CWM 144°C/W

ESD Tolerance (Note 6) ±1 kV

Operating Junction Temperature Range T<sub>MIN</sub> to T<sub>MAX</sub>

LM613M -55°C to +125°C

LM613I -40°C to +85°C

LM613C 0°C to +70°C

**Electrical Characteristics** These specifications apply for V<sup>-</sup> = GND = 0V, V<sup>+</sup> = 5V, V<sub>CM</sub> = V<sub>OUT</sub> = V<sup>+</sup> / 2, I<sub>R</sub> = 100 μA, FEEDBACK pin shorted to GND, unless otherwise specified. Limits in standard typeface are for T<sub>J</sub> = 25°C; limits in boldface type apply for T<sub>MIN</sub> to T<sub>MAX</sub>.

| Parameter                           | Conditions                                                                                      | Typ<br>(Note 7) | LM613M                      |                             | LM613AI,<br>LM613I          |                             | LM613C                      |                             | Units                |
|-------------------------------------|-------------------------------------------------------------------------------------------------|-----------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------|
|                                     |                                                                                                 |                 | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) |                      |
| Total Supply Current                | V <sup>+</sup> Current, R <sub>LOAD</sub> = ∞,<br>4V ≤ V <sup>+</sup> ≤ 36V<br>(32V for LM613C) | 450<br>550      | 900<br>1000                 |                             | 940                         | 1000                        | 1000                        | 1070                        | μA (Max)<br>μA (Max) |
| Supply Voltage Range                | Total Supply Current Specification is Met                                                       | 2.2             | 2.8                         |                             | 2.8                         |                             | 2.8                         |                             | V (Min)              |
|                                     |                                                                                                 | 2.9             | 3                           |                             |                             | 3                           |                             | 3                           | V (Min)              |
|                                     |                                                                                                 | 46              | 36                          |                             | 36                          |                             | 32                          |                             | V (Max)              |
|                                     |                                                                                                 | 43              | 38                          |                             |                             | 36                          |                             | 32                          | V (Max)              |
| OPERATIONAL AMPLIFIERS              |                                                                                                 |                 |                             |                             |                             |                             |                             |                             |                      |
| Offset Voltage                      | 4V ≤ V <sup>+</sup> ≤ 36V<br>(32V for LM613C)                                                   | ±1.5<br>±2.0    | ±3.5<br>±5.0                |                             | ±3.5                        | ±6.0                        | ±5.0                        | ±7.0                        | mV (Max)<br>mV (Max) |
| Offset Voltage over V <sub>CM</sub> | 0V ≤ V <sub>CM</sub> ≤ (V <sup>+</sup> - 1.4V),<br>V <sup>+</sup> = 30V                         | ±1.0<br>±1.5    | ±3.5<br>±5.0                |                             | ±3.5                        | ±6.0                        | ±5.0                        | ±7.0                        | mV (Max)<br>mV (Max) |
| Average Offset Voltage Drift        | LM613M and LM613AI<br>Op Amp 3 Only, (Note 10)                                                  | 15<br>25        | 25                          |                             | 30                          |                             |                             |                             | μV/°C<br>(Max)       |
| Input Bias Current                  |                                                                                                 | -10<br>-11      | ±20<br>±25                  |                             | ±25                         | ±30                         | ±35                         | ±40                         | nA (Max)<br>nA (Max) |
| Input Offset Current                |                                                                                                 | ±0.2<br>±0.3    | ±4<br>±4                    |                             | ±4                          | ±5                          | ±4                          | ±5                          | nA (Max)<br>nA (Max) |
| Average Offset Current Drift        |                                                                                                 | ±4              |                             |                             |                             |                             |                             |                             | pA/°C                |
| Input Resistance                    |                                                                                                 | >1000           |                             |                             |                             |                             |                             |                             | MΩ                   |
| Input Capacitance                   | Differential<br>Non-Inv. Input to GND                                                           | 0.6<br>6        |                             |                             |                             |                             |                             |                             | pF<br>pF             |

**Electrical Characteristics** These specifications apply for  $V^- = \text{GND} = 0\text{V}$ ,  $V^+ = 5\text{V}$ ,  $V_{\text{CM}} = V_{\text{OUT}} = V^+ / 2$ ,  $I_{\text{R}} = 100\text{ }\mu\text{A}$ , FEEDBACK pin shorted to GND, unless otherwise specified. Limits in standard typeface are for  $T_{\text{J}} = 25^\circ\text{C}$ ; limits in boldface type apply for  $T_{\text{MIN}}$  to  $T_{\text{MAX}}$ . (Continued)

| Parameter                                      | Conditions                                                                                     | Typ<br>(Note 7)                              | LM613M                                        |                             | LM613AI,<br>LM613I          |                             | LM613C                      |                             | Units                |
|------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------|-----------------------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------|
|                                                |                                                                                                |                                              | Tested<br>Limit<br>(Note 8)                   | Design<br>Limit<br>(Note 9) | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) |                      |
| OPERATIONAL AMPLIFIERS (Continued)             |                                                                                                |                                              |                                               |                             |                             |                             |                             |                             |                      |
| Voltage Noise                                  | f = 100 Hz                                                                                     | 74                                           |                                               |                             |                             |                             |                             |                             | nV/√Hz               |
| Current Noise                                  | f = 100 Hz                                                                                     | 58                                           |                                               |                             |                             |                             |                             |                             | fA/√Hz               |
| Common-Mode<br>Rejection Ratio                 | 0V ≤ V <sub>CM</sub> ≤ (V <sup>+</sup> - 1.4V),<br>V <sup>+</sup> = 30V                        | 95<br>90                                     | 85<br>80                                      |                             | 80                          | 75                          | 75                          | 70                          | dB (Min)<br>dB (Min) |
| Power Supply<br>Rejection Ratio                | 4V ≤ V <sup>+</sup> ≤ 30V,<br>V <sub>CM</sub> = V <sup>+</sup> /2                              | 100<br>90                                    | 85<br>80                                      |                             | 80                          | 75                          | 75                          | 70                          | dB (Min)<br>dB (Min) |
| Voltage Gain,<br>Open Loop                     | R <sub>L</sub> = 10 kΩ to GND,<br>V <sup>+</sup> = 30V<br>5V ≤ V <sub>OUT</sub> ≤ 25V          | 500<br>50                                    | 100<br>40                                     |                             | 100                         | 40                          | 94                          | 40                          | V/mV<br>(Min)        |
| Slew Rate                                      | V <sup>+</sup> = 30V (Note 11)                                                                 | ±0.70<br>±0.65                               | ±0.55<br>±0.45                                |                             | ±0.55                       | ±0.45                       | ±0.50                       | ±0.45                       | V/μs<br>(Min)        |
| Gain-Bandwidth<br>Product                      | C <sub>L</sub> = 50 pF                                                                         | 0.8<br>0.5                                   |                                               |                             |                             |                             |                             |                             | MHz<br>MHz           |
| Output Voltage<br>Swing                        | R <sub>L</sub> = 10 kΩ to GND,<br>V <sup>+</sup> = 36V<br>(32V for LM613C)                     | V <sup>+</sup> - 1.4<br>V <sup>+</sup> - 1.6 | V <sup>+</sup> - 1.6<br>V <sup>+</sup> - 1.8  |                             | V <sup>+</sup> - 1.7        | V <sup>+</sup> - 1.9        | V <sup>+</sup> - 1.8        | V <sup>+</sup> - 1.9        | V (Min)<br>V (Min)   |
|                                                | R <sub>L</sub> = 10 kΩ to V <sup>+</sup> ,<br>V <sup>+</sup> = 36V<br>(32V for LM613C)         | V <sup>-</sup> + 0.8<br>V <sup>-</sup> + 0.9 | V <sup>-</sup> + 0.90<br>V <sup>-</sup> + 1.0 |                             | V <sup>-</sup> + 0.90       | V <sup>-</sup> + 1.0        | V <sup>-</sup> + 0.95       | V <sup>-</sup> + 1.0        | V (Max)<br>V (Max)   |
| Output Current<br>(Sourcing)                   | V <sub>OUT</sub> = V <sup>+</sup> - 2.5V,<br>V <sub>+IN</sub> = 0V<br>V <sub>-IN</sub> = -0.3V | -25<br>-15                                   | -20<br>-13                                    |                             | -20                         | -13                         | -16                         | -13                         | mA (Max)<br>mA (Max) |
| (Sinking)                                      | V <sub>OUT</sub> = 1.6V,<br>V <sub>+IN</sub> = 0V<br>V <sub>-IN</sub> = -0.3V                  | 17<br>9                                      | 15<br>8                                       |                             | 14                          | 11                          | 13                          | 11                          | mA (Min)<br>mA (Min) |
| Output Short-<br>Circuit Current<br>(Sourcing) | V <sub>OUT</sub> = 0V,<br>V <sub>+IN</sub> = 3V<br>V <sub>-IN</sub> = 2V                       | -30<br>-40                                   | -37<br>-46                                    |                             | -40                         | -48                         | -43                         | -50                         | mA (Min)<br>mA (Min) |
| (Sinking)                                      | V <sub>OUT</sub> = 5V,<br>V <sub>+IN</sub> = 2V<br>V <sub>-IN</sub> = 3V                       | 30<br>32                                     | 40<br>60                                      |                             | 60                          | 80                          | 70                          | 90                          | mA (Max)<br>mA (Max) |
| COMPARATORS                                    |                                                                                                |                                              |                                               |                             |                             |                             |                             |                             |                      |
| Offset Voltage                                 | 4V ≤ V <sup>+</sup> ≤ 36V<br>(32V for LM613C),<br>R <sub>L</sub> = 15 kΩ                       | ±1.0<br>±2.0                                 | ±2.5<br>±4.0                                  |                             | ±3.0                        | ±6.0                        | ±5.0                        | ±7.0                        | mV (Max)<br>mV (Max) |
| Offset Voltage<br>over V <sub>CM</sub>         | 0V ≤ V <sub>CM</sub> (V <sup>+</sup> - 1.4V),<br>V <sup>+</sup> = 30V, R <sub>L</sub> = 15 kΩ  | ±1.0<br>±1.5                                 | ±2.5<br>±4.0                                  |                             | ±3.0                        | ±6.0                        | ±5.0                        | ±7.0                        | mV (Max)<br>mV (Max) |
| Average Offset<br>Voltage Drift                |                                                                                                | 15                                           |                                               |                             |                             |                             |                             |                             | μV/°C<br>(Max)       |
| Input Bias<br>Current                          |                                                                                                | -5<br>-8                                     | ±20<br>±25                                    |                             | ±25                         | ±30                         | ±35                         | ±40                         | nA (Max)<br>nA (Max) |

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**Electrical Characteristics** These specifications apply for  $V^- = \text{GND} = 0\text{V}$ ,  $V^+ = 5\text{V}$ ,  $V_{\text{CM}} = V_{\text{OUT}} = V^+ / 2$ ,  $I_{\text{R}} = 100 \mu\text{A}$ , FEEDBACK pin shorted to GND, unless otherwise specified. Limits in standard typeface are for  $T_{\text{J}} = 25^\circ\text{C}$ ; limits in boldface type apply for  $T_{\text{MIN}}$  to  $T_{\text{MAX}}$ . (Continued)

| Parameter                                           | Conditions                                                                                                                            | Typ<br>(Note 7) | LM613M                      |                             | LM613AI,<br>LM613I          |                             | LM613C                      |                             | Units                |
|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------|
|                                                     |                                                                                                                                       |                 | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) | Tested<br>Limit<br>(Note 8) | Design<br>Limit<br>(Note 9) |                      |
| COMPARATORS (Continued)                             |                                                                                                                                       |                 |                             |                             |                             |                             |                             |                             |                      |
| Input Offset<br>Current                             |                                                                                                                                       | ±0.2<br>±0.3    | ±4<br>±4                    |                             | ±4                          | ±5                          | ±4                          | ±5                          | nA (Max)<br>nA (Max) |
| Voltage Gain                                        | R <sub>L</sub> = 10 kΩ to 36V<br>(32V for LM613C),<br>2V ≤ V <sub>OUT</sub> ≤ 27V                                                     | 500<br>100      |                             |                             |                             |                             |                             |                             | V/mV<br>V/mV         |
| Large Signal<br>Response Time                       | V <sub>+IN</sub> = 1.4V,<br>V <sub>-IN</sub> = TTL Swing,<br>R <sub>L</sub> = 5.1 kΩ                                                  | 1.5<br>2.0      |                             |                             |                             |                             |                             |                             | μs<br>μs             |
| Output Sink<br>Current                              | V <sub>+IN</sub> = 0V,<br>V <sub>-IN</sub> = 1V,<br>V <sub>OUT</sub> = 1.5V                                                           | 20<br>13        | 12<br>8                     |                             | 10                          | 8                           | 10                          | 8                           | mA (Min)<br>mA (Min) |
|                                                     | V <sub>OUT</sub> = 0.4V                                                                                                               | 2.8<br>2.4      | 1.0<br>0.8                  |                             | 1.0                         | 0.5                         | 0.8                         | 0.5                         | mA (Min)<br>mA (Min) |
| Output Leakage<br>Current                           | V <sub>+IN</sub> = 1V,<br>V <sub>-IN</sub> = 0V,<br>V <sub>OUT</sub> = 36V<br>(32V for LM613C)                                        | 0.1<br>0.2      | 10<br>10                    |                             | 10                          |                             | 10                          |                             | μA (Max)<br>μA (Max) |
| VOLTAGE REFERENCE (Note 12)                         |                                                                                                                                       |                 |                             |                             |                             |                             |                             |                             |                      |
| Reference<br>Voltage                                |                                                                                                                                       | 1.244           | 1.2390<br>1.2490<br>(±0.4%) |                             | 1.2365<br>1.2515<br>(±0.6%) |                             | 1.2191<br>1.2689<br>(±2%)   |                             | V (Min)<br>V (Max)   |
| Average Temp.<br>Drift                              | (Note 13)<br><br>LM613AI                                                                                                              | 10              | 20                          |                             | 20                          | 30                          |                             | 150                         | ppm/°C<br>(Max)      |
| Average Time<br>Drift                               | T <sub>J</sub> = 40°C<br>T <sub>J</sub> = 150°C                                                                                       | 400<br>1000     |                             |                             |                             |                             |                             |                             | ppm/kH<br>ppm/kH     |
| Hysteresis                                          | (Note 14)                                                                                                                             | ±3.2            |                             |                             |                             |                             |                             |                             | μV/°C                |
| V <sub>R</sub> Change with<br>Current               | V <sub>R</sub> [100 μA] - V <sub>R</sub> [16 μA]                                                                                      | 0.05<br>0.1     | ±1<br>±1                    |                             | ±1                          | ±1.1                        | ±1                          | ±1.1                        | mV (Max)<br>mV (Max) |
|                                                     | V <sub>R</sub> [10 mA] - V <sub>R</sub> [100 μA]<br>(Note 15)                                                                         | 1.5<br>2.0      | 5<br>5                      |                             | 5                           | 5.5                         | 5                           | 5.5                         | mV (Max)<br>mV (Max) |
| Resistance                                          | ΔV <sub>R</sub> [10 → 0.1 mA]/9.9 mA<br>ΔV <sub>R</sub> [100 → 16 μA]/84 μA                                                           | 0.2<br>0.6      |                             | 0.51<br>12                  |                             | 0.56<br>13                  |                             | 0.56<br>13                  | Ω (Max)<br>Ω (Max)   |
| V <sub>R</sub> Change with<br>High V <sub>RO</sub>  | V <sub>R</sub> [V <sub>ro</sub> = V <sub>R</sub> ] - V <sub>R</sub> [V <sub>ro</sub> = 6.3V]<br>(5.06V between Anode and<br>FEEDBACK) | 2.5<br>2.8      | 5<br>8                      |                             | 7                           | 10                          | 7                           | 10                          | mV (Max)<br>mV (Max) |
| V <sub>R</sub> Change with<br>V <sup>+</sup> Change | V <sub>R</sub> [V <sup>+</sup> = 5V] - V <sub>R</sub> [V <sup>+</sup> = 36V]<br>(V <sup>+</sup> = 32V for LM613C)                     | 0.1<br>0.1      | ±1.2<br>±1.2                |                             | ±1.2                        | ±1.3                        | ±1.2                        | ±1.3                        | mV (Max)<br>mV (Max) |
|                                                     | V <sub>R</sub> [V <sup>+</sup> = 5V] - V <sub>R</sub> [V <sup>+</sup> = 3V]                                                           | 0.01<br>0.01    | ±1<br>±1                    |                             | ±1                          | ±1.5                        | ±1                          | ±1.5                        | mV (Max)<br>mV (Max) |
| FEEDBACK Bias<br>Current                            | V <sub>ANODE</sub> ≤ V <sub>FB</sub> ≤ 5.06V                                                                                          | -22<br>-29      | -35<br>-40                  |                             | -35                         | -40                         | -50                         | -55                         | nA (Min)<br>nA (Min) |
| Voltage Noise                                       | BW = 10 Hz to 10 kHz,<br>V <sub>RO</sub> = V <sub>R</sub>                                                                             | 30              |                             |                             |                             |                             |                             |                             | μVRMS                |

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**Electrical Characteristics (Continued)**

**Note 1:** Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device beyond its rated operating conditions.

**Note 2:** Input voltage above  $V^+$  is allowed. As long as one input pin voltage remains inside the common-mode range, the comparator will deliver the correct output.

**Note 3:** More accurately, it is excessive current flow, with resulting excess heating, that limits the voltages on all pins. When any pin is pulled a diode drop below  $V^-$ , a parasitic NPN transistor turns ON. No latch-up will occur as long as the current through that pin remains below the Maximum Rating. Operation is undefined and unpredictable when any parasitic diode or transistor is conducting.

**Note 4:** Simultaneous short-circuit of multiple op amps or comparators while using high supply voltages may force junction temperature above maximum, and thus should not be continuous.

**Note 5:** Junction temperature may be calculated using  $T_J = T_A + P_D \theta_{JA}$ . The given thermal resistances are worst-case for packages in sockets in still air. Nominal  $\theta_{JA}$  are 85°C/W for LM613 in J package, 80°C/W for the N package, and 135°C/W for the WM package, for packages soldered to copper-clad board with dissipation from one op amp, comparator, or reference output transistor.

**Note 6:** Human body model, 100 pF discharged through a 1.5 kΩ resistor.

**Note 7:** Typical values in standard typeface are for  $T_J = 25^\circ\text{C}$ ; values in boldface type apply to the military temperature range. These values represent the most likely parametric norm.

**Note 8:** Tested limits are guaranteed and 100% tested.

**Note 9:** Design limits are guaranteed via correlation, but are not 100% tested.

**Note 10:** Offset voltage drift is calculated from the measurement of the offset voltage at 25°C and at the temperature extremes. The drift is  $\Delta V_{OS}/\Delta T$ , where  $\Delta V_{OS}$  is the lowest value subtracted from the highest, and  $\Delta T$  is the temperature range.

**Note 11:** Slew rate is measured with the op amp in a voltage follower configuration. For rising slew rate, the input voltage is driven from 5V to 25V, and the output voltage transition is sampled at 10V and 20V. For falling slew rate, the input voltage is driven from 25V to 5V, and the output voltage transition is sampled at 20V and 10V.

**Note 12:**  $V_{RO}$  is the Cathode-to-Anode voltage (i.e. the reference output voltage, 1.2V to 6.3V).  $V_R$  is the Cathode-to-FEEDBACK voltage (nominally 1.2V).

**Note 13:** Average reference drift is calculated from the measurement of the reference voltage at 25°C and at the temperature extremes. The drift, in ppm/°C, is  $10^6 \Delta V_R / V_R(25^\circ\text{C}) \Delta T_J$ , where  $\Delta V_R$  is the lowest value subtracted from the highest,  $V_R(25^\circ\text{C})$  is the value at 25°C, and  $\Delta T_J$  is the temperature range.

**Note 14:** Hysteresis is  $\Delta V_{RO}/\Delta T_J$ , where  $\Delta V_{RO}$  is the change in  $V_{RO}$  caused by a change in  $T_J$ , after the reference has been "dehystorized". To dehystorize the reference, its junction temperature should be cycled in the following pattern, spiraling in toward 25°C: 25°C, 125°C, -55°C, 85°C, -40°C, 70°C, 0°C, 25°C.

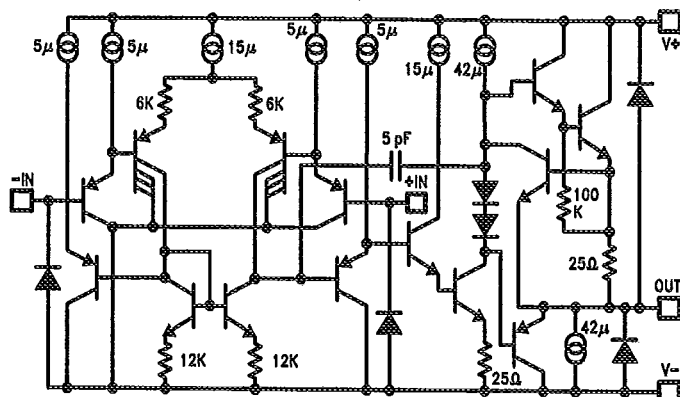
**Note 15:** Low contact resistance is required for accurate measurement.

## Simplified Schematic Diagrams

T-79-01

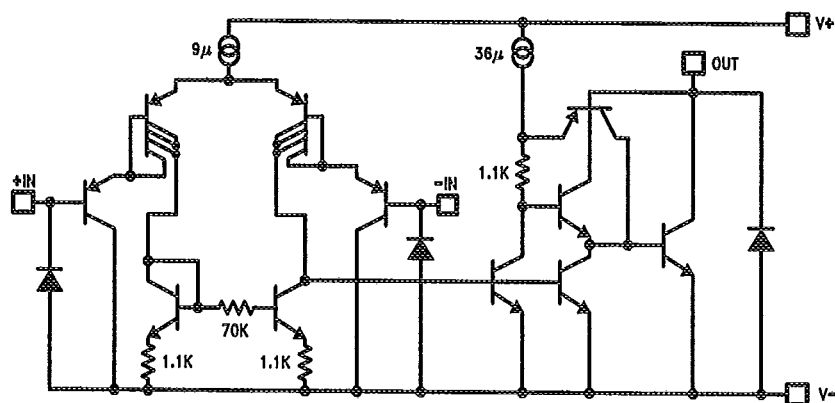
LM613A/LM613

Op Amp



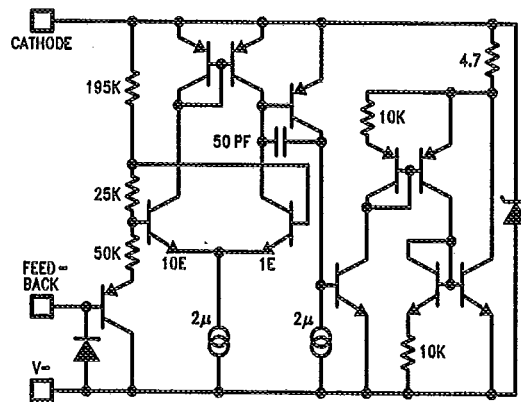
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Comparator

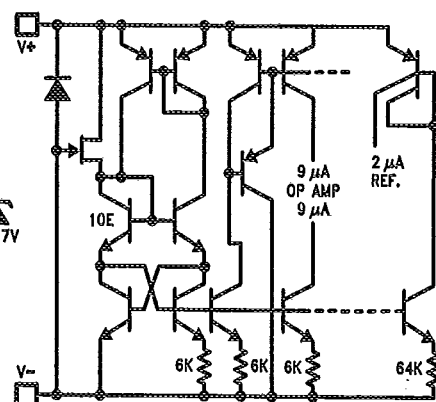


TL/H/9228-3

Reference



Bias



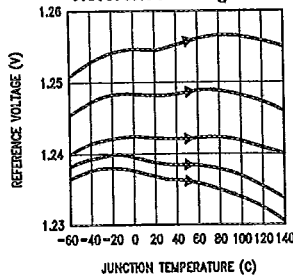
TL/H/9228-4

## Typical Performance Characteristics (Reference)

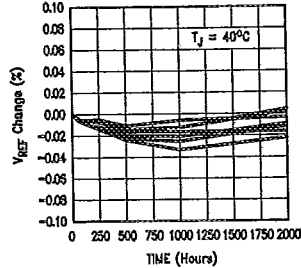
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T-79-01

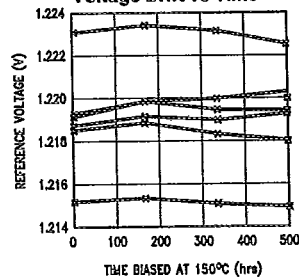
Reference Voltage vs Temp.



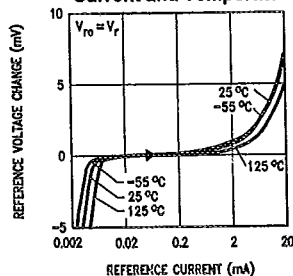
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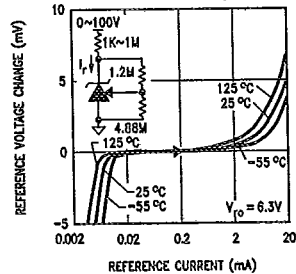
Accelerated Reference Voltage Drift vs Time



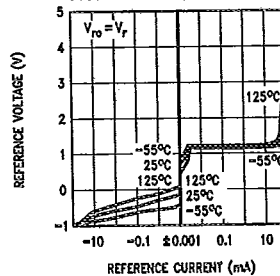
Reference Voltage vs Current and Temperature



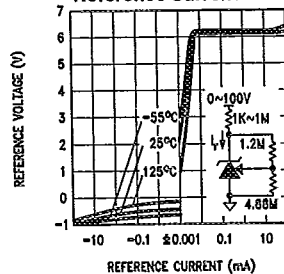
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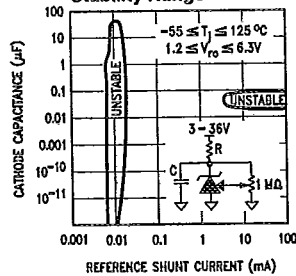
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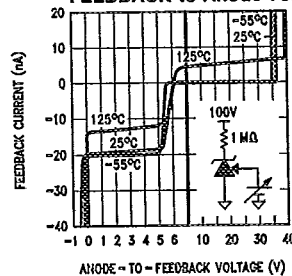
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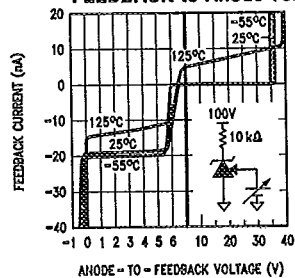
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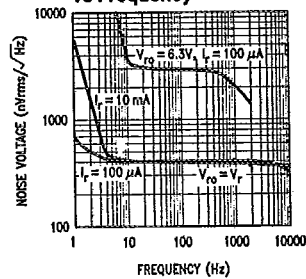
FEEDBACK Current vs FEEDBACK-to-Anode Voltage



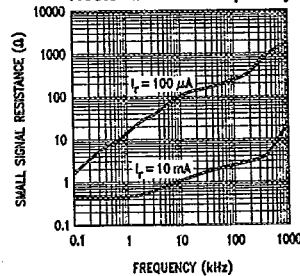
FEEDBACK Current vs FEEDBACK-to-Anode Voltage



Reference Noise Voltage vs Frequency



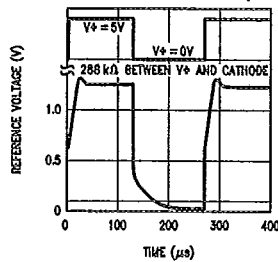
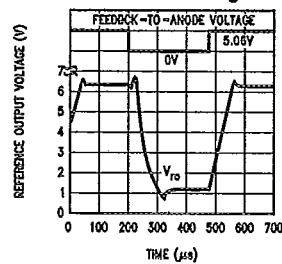
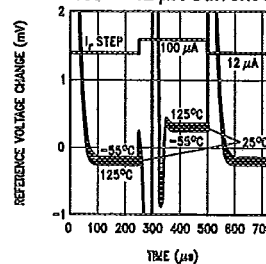
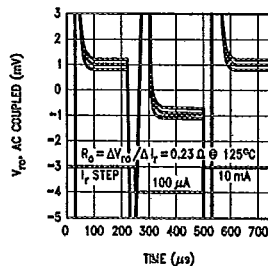
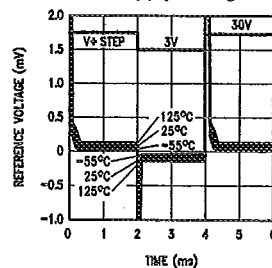
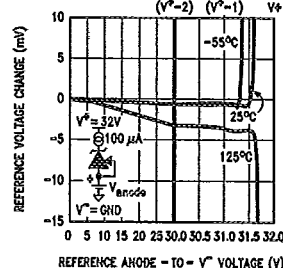
Reference Small-Signal Resistance vs Frequency



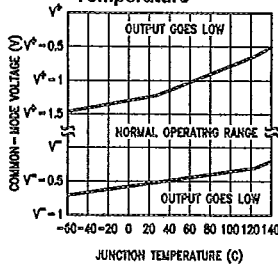
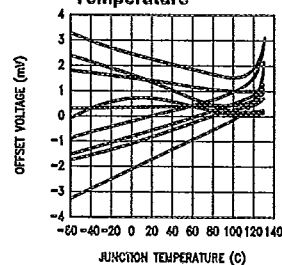
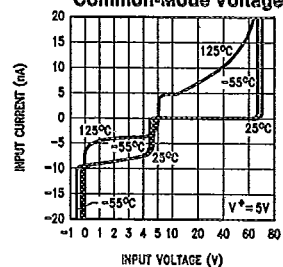
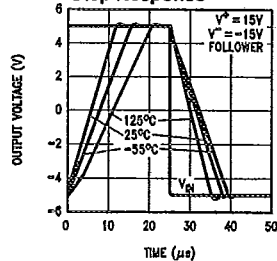
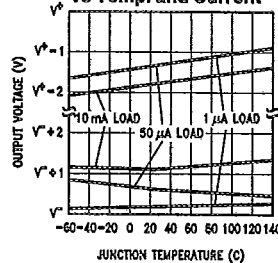
TL/H/9226-5

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LM613A/LM613

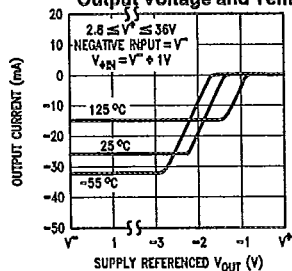
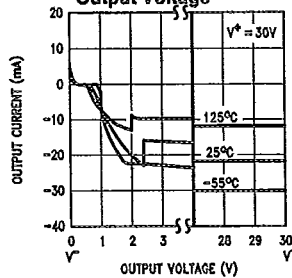
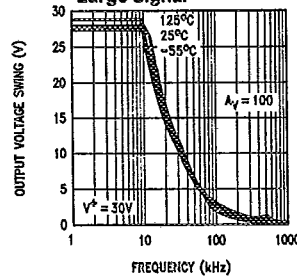
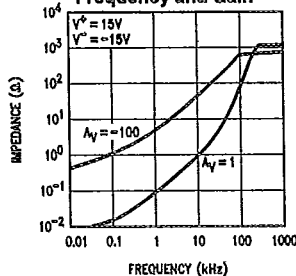
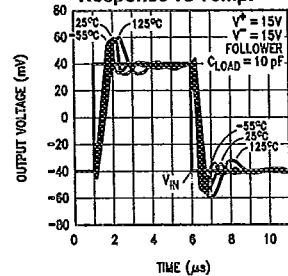
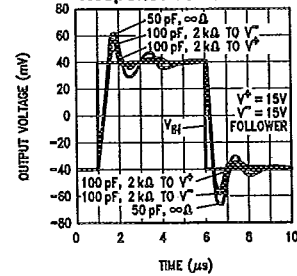
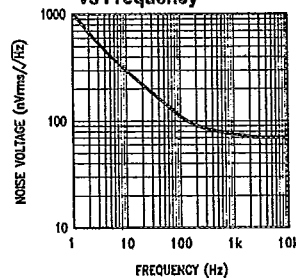
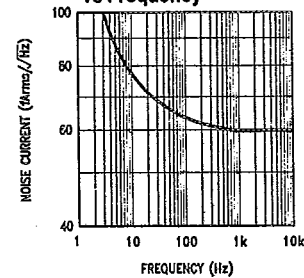
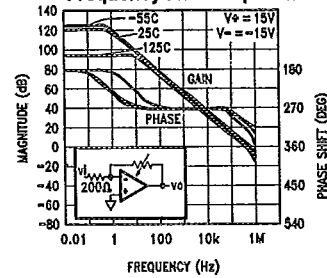
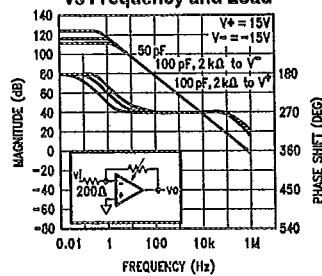
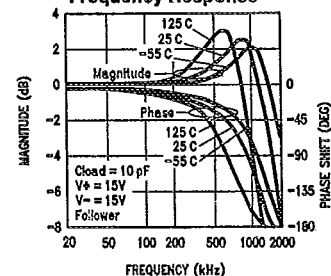
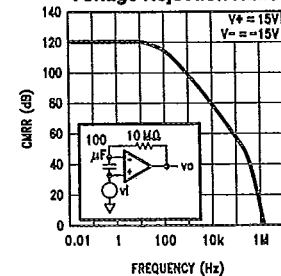
**Typical Performance Characteristics (Reference)** (Continued) $T_J = 25^\circ\text{C}$ , FEEDBACK pin shorted to  $V^- = 0\text{V}$ , unless otherwise noted**Reference Power-Up Time****Reference Voltage with FEEDBACK Voltage Step****Reference Voltage with 100 ~ 12 μA Current Step****Reference Step Response for 100 μA ~ 10 mA Current Step****Reference Voltage Change with Supply Voltage Step****Reference Change vs Common-Mode Voltage**

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**Typical Performance Characteristics (Op Amps)** $V^+ = 5\text{V}$ ,  $V^- = \text{GND} = 0\text{V}$ ,  $V_{\text{CM}} = V^+/2$ ,  $V_{\text{OUT}} = V^+/2$ ,  $T_J = 25^\circ\text{C}$ , unless otherwise noted**Input Common-Mode Voltage Range vs Temperature****Vos vs Junction Temperature****Input Bias Current vs Common-Mode Voltage****Large-Signal Step Response****Output Voltage Swing vs Temp. and Current**

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**Typical Performance Characteristics (Op Amps) (Continued)** $V^+ = 5V$ ,  $V^- = GND = 0V$ ,  $V_{CM} = V^+/2$ ,  $V_{OUT} = V^+/2$ ,  $T_J = 25^\circ C$ , unless otherwise noted**Output Source Current vs Output Voltage and Temp.****Output Sink Current vs Output Voltage****Output Swing, Large Signal****Output Impedance vs Frequency and Gain****Small Signal Pulse Response vs Temp.****Small-Signal Pulse Response vs Load****Op Amp Voltage Noise vs Frequency****Op Amp Current Noise vs Frequency****Small-Signal Voltage Gain vs Frequency and Temperature****Small-Signal Voltage Gain vs Frequency and Load****Follower Small-Signal Frequency Response****Common-Mode Input Voltage Rejection Ratio**

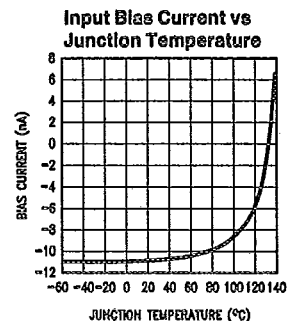
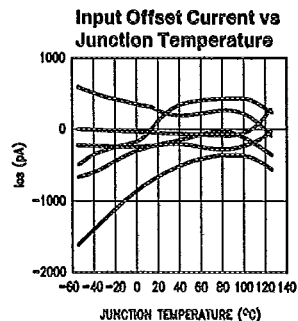
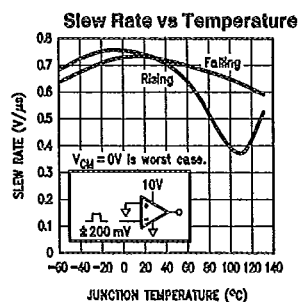
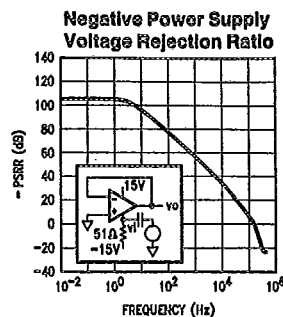
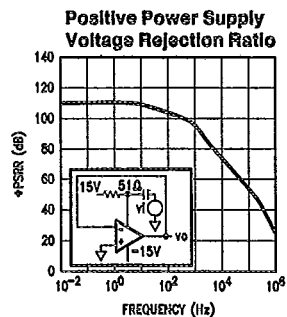
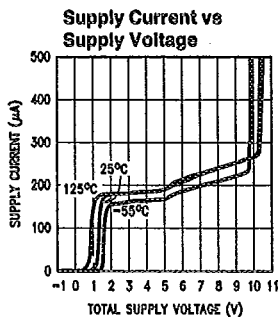
TL/H/9226-8

# Typical Performance Characteristics (Op Amps) (Continued)

$V^+ = 5V$ ,  $V^- = GND = 0V$ ,  $V_{CM} = V^+/2$ ,  $V_{OUT} = V^+/2$ ,  $T_J = 25^\circ C$ , unless otherwise noted

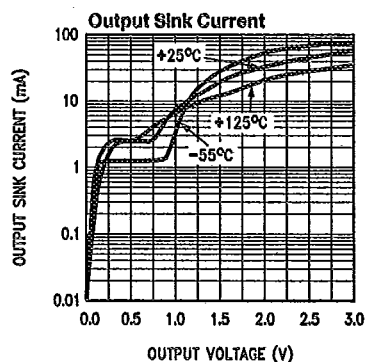
T-79-01

LM613A/LM613

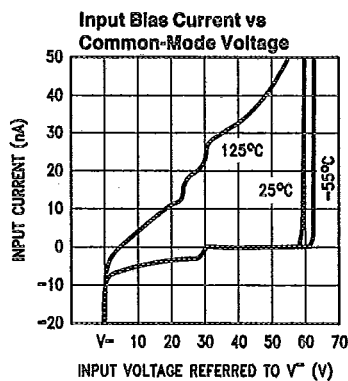


TL/H/9226-9

## Typical Performance Characteristics (Comparators)



TL/H/9226-10

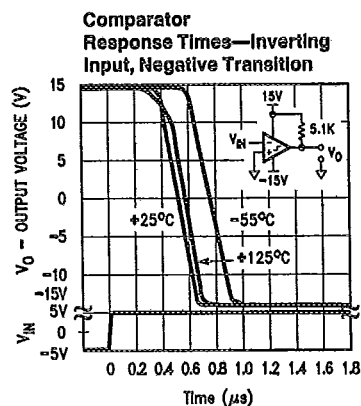
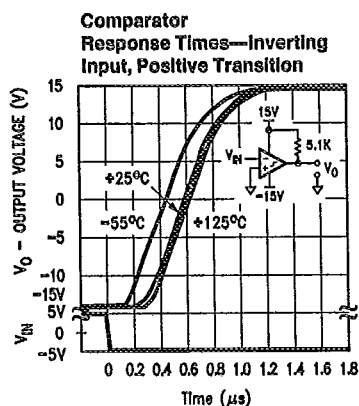
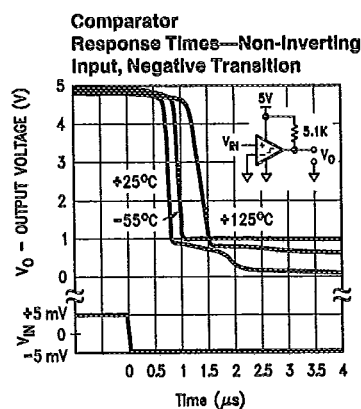
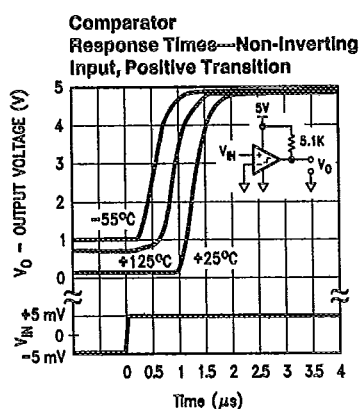
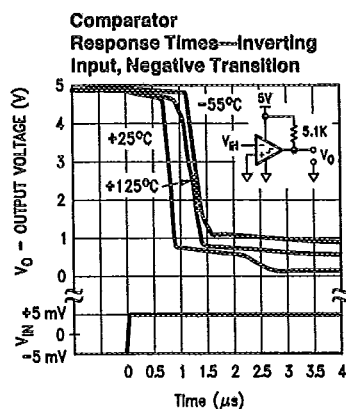
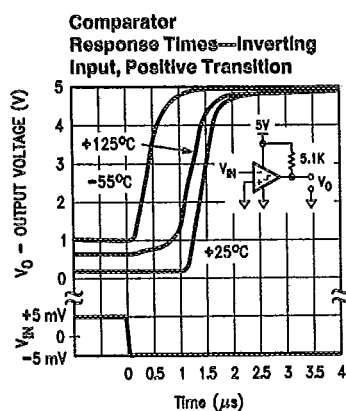


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T-79-01

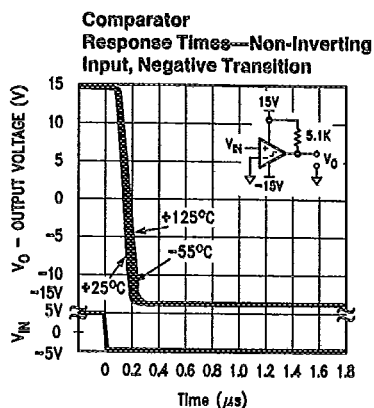
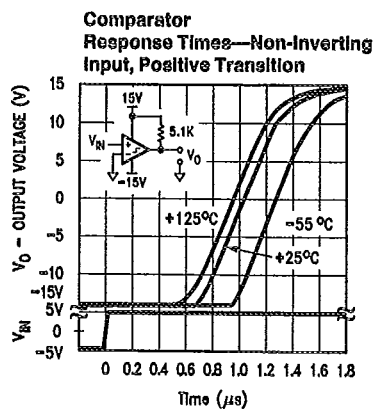
## Typical Performance Characteristics (Comparators) (Continued)



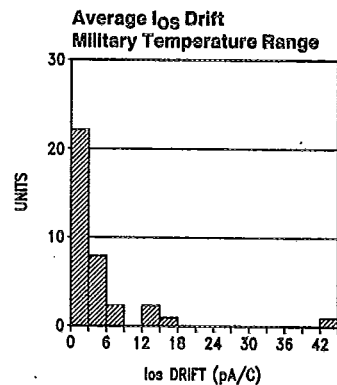
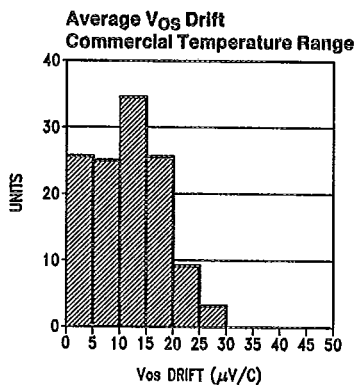
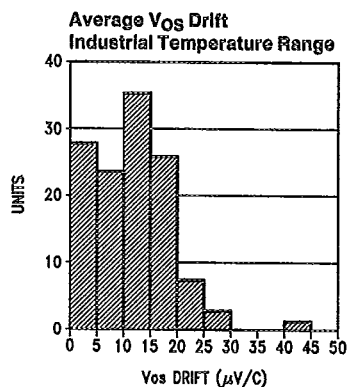
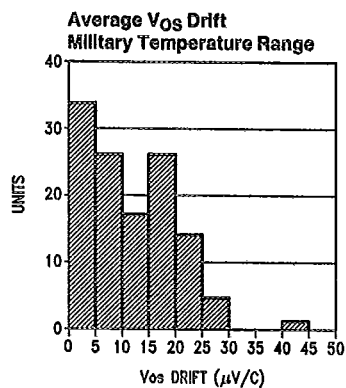
T-79-01

LM613A/LM613

## Typical Performance Characteristics (Comparators) (Continued)

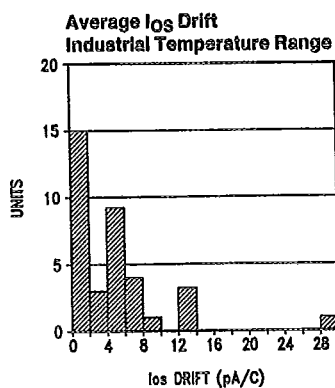


## Typical Performance Distributions

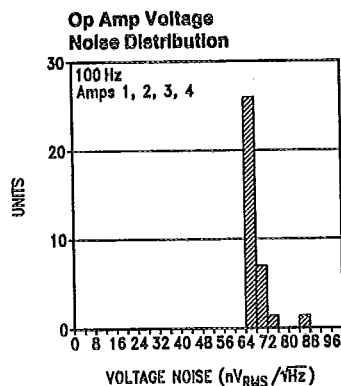


## Typical Performance Distributions (Continued)

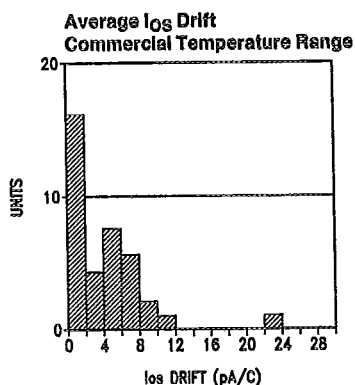
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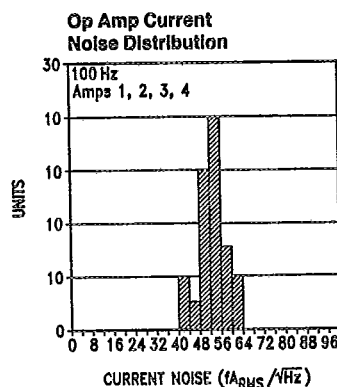
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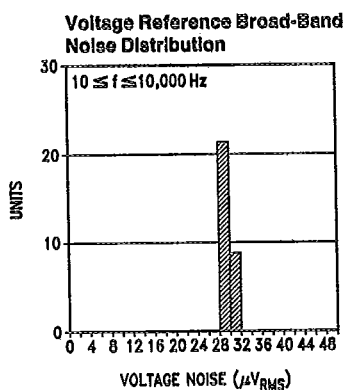
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TL/H/9226-25



TL/H/9226-26



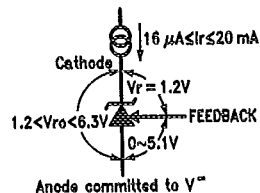
TL/H/9226-28

## Application Information

## VOLTAGE REFERENCE

## Reference Biasing

The voltage reference is of a shunt regulator topology that models as a simple zener diode. With current  $I_r$  flowing in the "forward" direction there is the familiar diode transfer function.  $I_r$  flowing in the reverse direction forces the reference voltage to be developed from cathode to anode. The cathode may swing from a diode drop below  $V^-$  to the reference voltage or to the avalanche voltage of the parallel protection diode, nominally 7V. A 6.3V reference with  $V^+ = 3V$  is allowed.



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FIGURE 1. Voltage Associated with Reference  
(current source  $I_r$  is external)

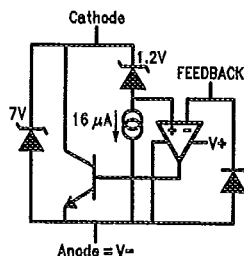
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LM613A/LM613

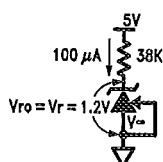
**Application Information (Continued)**

The reference equivalent circuit reveals how  $V_r$  is held at the constant 1.2V by feedback, and how the FEEDBACK pin passes little current.

To generate the required reverse current, typically a resistor is connected from a supply voltage higher than the reference voltage. Varying that voltage, and so varying  $I_r$ , has small effect with the equivalent series resistance of less than an ohm at the higher currents. Alternatively, an active current source, such as the LM134 series, may generate  $I_r$ .



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**FIGURE 2. Reference Equivalent Circuit**

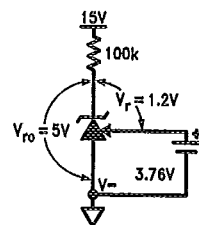
TL/H/9226-31

**FIGURE 3. 1.2V Reference**

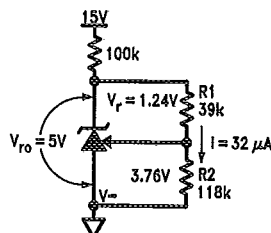
Capacitors in parallel with the reference are allowed. See the Reference AC Stability Range typical curve for capacitance values—from 20  $\mu$ A to 3 mA any capacitor value is stable. With the reference's wide stability range with resistive and capacitive loads, a wide range of RC filter values will perform noise filtering.

**Adjustable Reference**

The FEEDBACK pin allows the reference output voltage,  $V_{ro}$ , to vary from 1.24V to 6.3V. The reference attempts to hold  $V_r$  at 1.24V. If  $V_r$  is above 1.24V, the reference will conduct current from Cathode to Anode; FEEDBACK current always remains low. If FEEDBACK is connected to Anode, then  $V_{ro} = V_r = 1.24V$ . For higher voltages FEEDBACK is held at a constant voltage above Anode—say 3.76V for  $V_{ro} = 5V$ . Connecting a resistor across the constant  $V_r$  generates a current  $I = R1/V_r$  flowing from Cathode into FEEDBACK node. A Thevenin equivalent 3.76V is generated from FEEDBACK to Anode with  $R2 = 3.76/I$ . Keep  $I$  greater than one thousand times larger than FEEDBACK bias current for <0.1% error— $I \geq 32 \mu$ A for the military grade over the military temperature range ( $I \geq 5.5 \mu$ A for a 1% untrimmed error for a commercial part).



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**FIGURE 4. Thevenin Equivalent of Reference with 5V Output**

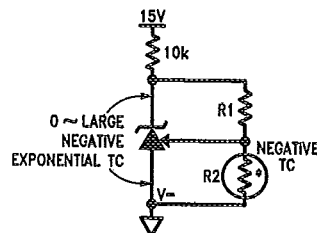
TL/H/9226-33

$$R1 = V_r/I = 1.24/32\mu = 39k$$

$$R2 = R1 [(V_{ro}/V_r) - 1] = 39k [(5/1.24) - 1] = 118k$$

**FIGURE 5. Resistors R1 and R2 Program Reference Output Voltage to be 5V**

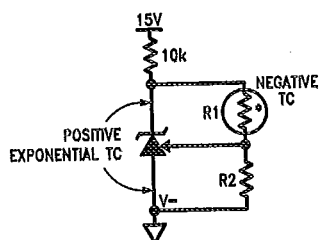
Understanding that  $V_r$  is fixed and that voltage sources, resistors, and capacitors may be tied to the FEEDBACK pin, a range of  $V_r$  temperature coefficients may be synthesized.



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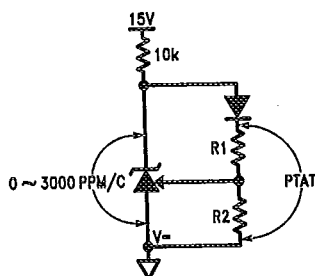
**FIGURE 6. Output Voltage has Negative Temperature Coefficient (TC) if R2 has Negative TC**

## Application Information (Continued)



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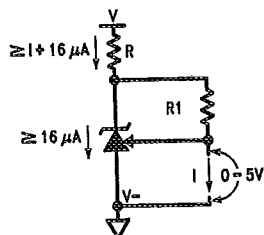
FIGURE 7. Output Voltage has Positive TC If R1 has Negative TC



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FIGURE 8. Diode in Series with R1 Causes Voltage Across R1 and R2 to be Proportional to Absolute Temperature (PTAT)

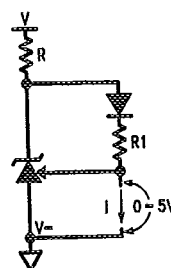
Connecting a resistor across Cathode-to-FEEDBACK creates a 0 TC current source, but a range of TCs may be synthesized.



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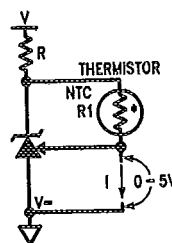
$$I = V_r/R_1 = 1.24/R_1$$

FIGURE 9. Current Source is Programmed by R1



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FIGURE 10. Proportional-to-Absolute-Temperature Current Source



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FIGURE 11. Negative-TC Current Source

## Reference Hysteresis

The reference voltage depends, slightly, on the thermal history of the die. Competitive micro-power products vary—always check the data sheet for any given device. Do not assume that no specification means no hysteresis.

## OPERATIONAL AMPLIFIERS AND COMPARATORS

Any amp, comparator, or the reference may be biased in any way with no effect on the other sections of the LM613, except when a substrate diode conducts (see Electrical Characteristics Note 1). For example, one amp input may be outside the common-mode range, another amp may be operating as a comparator, and all other sections may have all terminals floating with no effect on the others. Tying inverting input to output and non-inverting input to  $V^-$  on unused amps is preferred. Unused comparators should have non-inverting input and output tied to  $V^+$ , and inverting input tied to  $V^-$ . Choosing operating point that cause oscillation, such as driving too large a capacitive load, is best avoided.

## Op Amp Output Stage

These op amps, like the LM124 series, have flexible and relatively wide-swing output stages. There are simple rules to optimize output swing, reduce cross-over distortion, and optimize capacitive drive capability:

- 1) Output Swing: Unloaded, the 42  $\mu A$  pull-down will bring the output within 300 mV of  $V^-$  over the military temperature range. If more than 42  $\mu A$  is required, a resistor from output to  $V^-$  will help. Swing across any load may be improved slightly if the load can be tied to  $V^+$ , at the cost of poorer sinking open-loop voltage gain.

**Application Information** (Continued)

- 2) Cross-Over Distortion: The LM613 has lower cross-over distortion (a 1  $V_{BE}$  deadband versus 3  $V_{BE}$  for the LM124), and increased slew rate as shown in the characteristic curves. A resistor pull-up or pull-down will force class-A operation with only the PNP or NPN output transistor conducting, eliminating cross-over distortion.
- 3) Capacitive Drive: Limited by the output pole caused by the output resistance driving capacitive loads, a pull-down resistor conducting 1 mA or more reduces the output stage NPN  $r_o$  until the output resistance is that of the current limit 25 $\Omega$ . 200 pF may then be driven without oscillation.

**Comparator Output Stage**

The comparators, like the LM139 series, have open-collector output stages. A pull-up resistor must be added from each output pin to a positive voltage for the output transistor to switch properly. When the output transistor is OFF, the output voltage will be this external positive voltage.

For the output voltage to be under the TTL-low voltage threshold when the output transistor is ON, the output current must be less than 8 mA (over temperature). This impacts the minimum value of pull-up resistor.

The offset voltage may increase when the output voltage is low and the output current is less than 30  $\mu A$ . Thus, for best accuracy, the pull-up resistor value should be low enough to allow the output transistor to sink more than 30  $\mu A$ .

**Op Amp and Comparator Input Stage**

The lateral PNP input transistors, unlike those of most op amps, have  $BVEBO$  equal to the absolute maximum supply voltage. Also, they have no diode clamps to the positive supply nor across the inputs. These features make the inputs look like high impedances to input sources producing large differential and common-mode voltages.

**Typical Applications**

For typical applications, refer to the LM124 Op Amp, LM139 Comparator, and LM185 Adjustable Reference datasheets.

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