LM614 Quad Operational Amplifier and Adjustable Reference

Check for Samples: **LM614**

FEATURES

Op Amp

- **Low Operating Current: 450µA**
- **Wide Supply Voltage Range: 4V to 36V**
- **Wide Common-Mode Range: V^- to (V^+ − 1.8V)**
- **Wide Differential Input Voltage: ±36V**
  Reference
- **Adjustable Output Voltage: 1.2V to 5.0V**
- **Initial Tolerance: ±2.0%**
- **Wide Operating Current Range: 17µA to 20mA**
- **Tolerant of Load Capacitance**

APPLICATIONS

- **Transducer Bridge Driver and Signal Processing**
- **Process and Mass Flow Control Systems**
- **Power Supply Voltage Monitor**
- **Buffered Voltage References for A/D's**

DESCRIPTION

The LM614 consists of four op-amps and a programmable voltage reference in a 16-pin package. The op-amp out-performs most single-supply op-amps by providing higher speed and bandwidth along with low supply current. This device was specifically designed to lower cost and board space requirements in transducer, test, measurement and data acquisition systems.

Combining a stable voltage reference with four wide output swing op-amps makes the LM614 ideal for single supply transducers, signal conditioning and bridge driving where large common-mode-signals are common. The voltage reference consists of a reliable band-gap design that maintains low dynamic output impedance (1Ω typical), initial tolerance (2.0%), and the ability to be programmed from 1.2V to 5.0V via two external resistors. The voltage reference is very stable even when driving large capacitive loads, as are commonly encountered in CMOS data acquisition systems.

As a member of TI's new Super-Block™ family, the LM614 is a space-saving monolithic alternative to a multichip solution, offering a high level of integration without sacrificing performance.

Connection Diagram
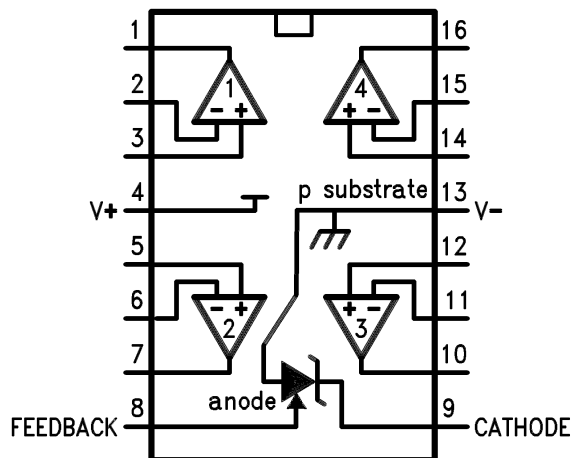
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Absolute Maximum Ratings[1][2]

Voltage on Any Pins except V_R (referred to V⁻ pin)		36V (Max)[3] −0.3V (Min)[4]
Current through Any Input Pin & V_R Pin		±20
Differential Input Voltage	LM614I	±36V
	LM614C	±32V
Storage Temperature Range		−65°C ≤ T_J ≤ +150°C
Maximum Junction Temperature		150°C
Thermal Resistance, Junction-to-Ambient[5]		150°C
Soldering Information (Soldering, 10 sec.)		220°C
ESD Tolerance[6]		±1kV

(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.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
(3) Input voltage above V+ is allowed.
(4) 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.
(5) Junction temperature may be calculated using TJ = TA + P DθjA. The given thermal resistance is worst-case for packages in sockets in still air. For packages soldered to copper-clad board with dissipation from one comparator or reference output transistor, nominal θjA is 90°C/W for the DW package.
(6) Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Operating Temperature Range

LM614I	−40°C ≤ T_J ≤ +85°C
LM614C	0°C ≤ T_J ≤ +70°C

Electrical Characteristics

These specifications apply for V⁻ = GND = 0V, V⁺ = 5V, V_{CM} = V_{OUT} = 2.5V, I_R = 100µA, FEEDBACK pin shorted to GND, unless otherwise specified. Limits in standard typeface are for T_J = 25°C; limits in **Boldface type** apply over the **Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ[1]	LM614I LM614C Limits[2]	Units
I_S	Total Supply Current	R_{LOAD} = ∞, 4V ≤ V⁺ ≤ 36V (32V for LM614C)	450 **550**	1000 **1070**	µA max µA max
V_S	Supply Voltage Range		2.2 **2.9**	2.8 **3**	V min V min
			46 **43**	32 **32**	V max V max
OPERATIONAL AMPLIFIER					
V_{OS1}	V_{OS} Over Supply	4V ≤ V⁺ ≤ 36V (4V ≤ V⁺ ≤ 32V for LM614C)	1.5 **2.0**	5.0 **7.0**	mV max mV max
V_{OS2}	V_{OS} Over V_{CM}	V_{CM} = 0V through V_{CM} = (V⁺ − 1.8V), V⁺ = 30V	1.0 **1.5**	5.0 **7.0**	mV max mV max
$\frac{V_{OS3}}{\Delta T}$	Average V_{OS} Drift	See [2]	**15**		µV/°C max
I_B	Input Bias Current		10 **11**	35 **40**	nA max nA max
I_{OS}	Input Offset Current		0.2 **0.3**	4 **5**	nA max nA max

(1) Typical values in standard typeface are for TJ = 25°C; values in boldface type apply for the full operating temperature range. These values represent the most likely parametric norm.
(2) All limits are ensured at room temperature (standard type face) or at operating temperature extremes **(bold type face)**.

Electrical Characteristics (continued)

These specifications apply for $V^- = GND = 0V$, $V^+ = 5V$, $V_{CM} = V_{OUT} = 2.5V$, $I_R = 100\mu A$, FEEDBACK pin shorted to GND, unless otherwise specified. Limits in standard typeface are for $T_J = 25°C$; limits in **Boldface type** apply over the **Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ[1]	LM614I LM614C Limits[2]	Units
$\dfrac{I_{OS1}}{\Delta T}$	Average Offset Drift Current		**4**		pA/°C
R_{IN}	Input Resistance	Differential	1800		MΩ
		Common-Mode	3800		MΩ
C_{IN}	Input Capacitance	Common-Mode Input	5.7		pF
e_n	Voltage Noise	f = 100 Hz, Input Referred	74		nV/√Hz
I_n	Current Noise	f = 100 Hz, Input Referred	58		fA/√Hz
CMRR	Common-Mode	$V^+ = 30V$, $0V \leq V_{CM} \leq (V^+ - 1.8V)$,	95	75	dB min
	Rejection Ratio	$CMRR = 20 \log (\Delta V_{CM}/\Delta V_{OS})$	**90**	**70**	dB min
PSRR	Power Supply	$4V \leq V^+ \leq 30V$, $V_{CM} = V^+/2$,	110	75	dB min
	Rejection Ratio	$PSRR = 20 \log (\Delta V^+/\Delta V_{OS})$	**100**	**70**	dB min
A_V	Open Loop Voltage Gain	$R_L = 10 k\Omega$ to GND, $V^+ = 30V$, $5V \leq V_{OUT} \leq 25V$	500 **50**	94 **40**	V/mV min
SR	Slew Rate	$V^+ = 30V$[3]	±0.70 **±0.65**	±0.50 **±0.45**	V/µs
GBW	Gain Bandwidth	$C_L = 50$ pF	0.8 **0.52**		MHz MHz
V_{O1}	Output Voltage Swing High	$R_L = 10 k\Omega$ to GND $V^+ = 36V$ (32V for LM614C)	$V^+ - 1.4$ **$V^+ - 1.6$**	$V^+ - 1.8$ **$V^+ - 1.9$**	V min V min
V_{O2}	Output Voltage Swing Low	$R_L = 10 k\Omega$ to V^+ $V^+ = 36V$ (32V for LM614C)	$V^- + 0.8$ **$V^- + 0.9$**	$V^- + 0.95$ **$V^- + 1.0$**	V max V max
I_{OUT}	Output Source	$V_{OUT} = 2.5V$, $V_{+IN} = 0V$, $V_{-IN} = -0.3V$	25 **15**	16 **13**	mA min mA min
I_{SINK}	Output Sink Current	$V_{OUT} = 1.6V$, $V_{+IN} = 0V$, $V_{-IN} = 0.3V$	17 **9**	13 **8**	mA min mA min
I_{SHORT}	Short Circuit Current	$V_{OUT} = 0V$, $V_{+IN} = 3V$, $V_{-IN} = 2V$, Source	30 **40**	50 **60**	mA max mA max
		$V_{OUT} = 5V$, $V_{+IN} = 2V$, $V_{-IN} = 3V$, Sink	30 **32**	70 **90**	mA max mA max
VOLTAGE REFERENCE					
V_R	Voltage Reference	See [4]	1.244	1.2191 1.2689 (±2.0%)	V min V max
$\dfrac{\Delta V_R}{\Delta T}$	Average Temperature Drift	See [5]	**10**	150	PPM/°C max
$\dfrac{\Delta V_R}{\Delta T_J}$	Hysteresis	See [6]	**3.2**		µV/°C
$\dfrac{\Delta V_R}{\Delta I_R}$	V_R Change with Current	$V_{R(100 \mu A)} - V_{R(17 \mu A)}$	0.05 **0.1**	1 **1.1**	mV max mV max
		$V_{R(10 mA)} - V_{R(100 \mu A)}$ [7]	1.5 **2.0**	5 **5.5**	mV max mV max

(3) Slew rate is measured with 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.

(4) V_R is the Cathode-feedback voltage, nominally 1.244V.

(5) 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 $10^6 \cdot \Delta V_R/(V_{R[25°C]} \cdot \Delta T_J)$, where ΔV_R is the lowest value subtracted from the highest, $V_{R[25°C]}$ is the value at 25°C, and ΔT_J is the temperature range. This parameter is ensured by design and sample testing.

(6) Hysteresis is the change in V_R caused by a change in T_J, after the reference has been "dehysterized". To dehysterize the reference; that is minimize the hysteresis to the typical value, cycle its junction temperature in the following pattern, spiraling in toward 25°C: 25°C, 85°C, −40°C, 70°C, 0°C, 25°C.

(7) Low contact resistance is required for accurate measurement.

Electrical Characteristics (continued)

These specifications apply for $V^- =$ GND = 0V, $V^+ = 5V$, $V_{CM} = V_{OUT} = 2.5V$, $I_R = 100\mu A$, FEEDBACK pin shorted to GND, unless otherwise specified. Limits in standard typeface are for $T_J = 25°C$; limits in **Boldface type** apply over the **Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ[1]	LM614I LM614C Limits[2]	Units
R	Resistance	$\Delta V_{R(10 \to 0.1\ mA)}/9.9$ mA	**0.2**	**0.56**	Ω max
		$\Delta V_{R(100 \to 17\ \mu A)}/83$ µA	**0.6**	**13**	Ω max
ΔV_R $\overline{\Delta V}_{RO}$	V_R Change with High V_{RO}	$V_{R(Vro = Vr)} - V_{R(Vro = 5.0V)}$ (3.76V between Anode and FEEDBACK)	2.5 **2.8**	7 **10**	mV max mV max
$\dfrac{\Delta V_R}{\Delta V+}$	V_R Change with V^+ Change	$V_{R(V + = 5V)} - V_{R(V + = 36V)}$ ($V^+ = 32V$ for LM614C)	0.1 **0.1**	1.2 **1.3**	mV max mV max
		$V_{R(V + = 5V)} - V_{R(V + = 3V)}$	0.01 **0.01**	1 **1.5**	mV max mV max
I_{FB}	FEEDBACK Bias Current	$V_{ANODE} \leq V_{FB} \leq 5.06V$	22 **29**	50 **55**	nA max nA max
e_n	Voltage Noise	BW = 10 Hz to 10 kHz, $V_{RO} = V_R$	30		μV_{RMS}

Typical Performance Characteristics (Reference)

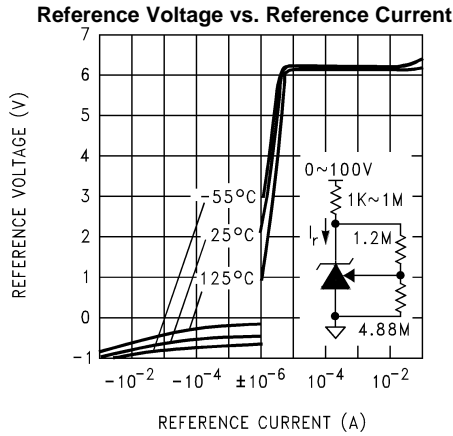T_J = 25°C, FEEDBACK pin shorted to V^- = 0V, unless otherwise noted

Reference Voltage vs Temperature on 5 Representative Units
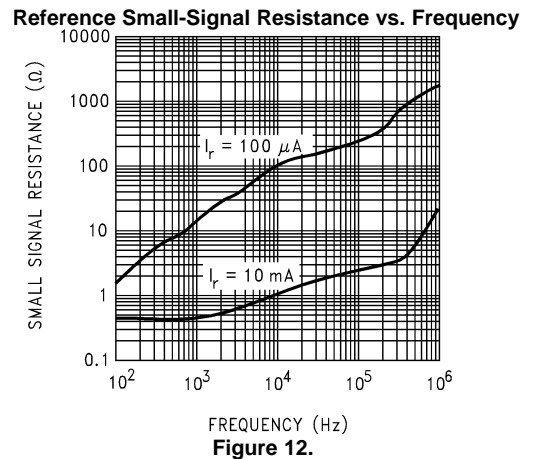

Figure 1.

Reference Voltage Drift

Figure 2.

Accelerated Reference Voltage Drift vs. Time

Figure 3.

Reference Voltage vs. Current and Temperature

Figure 4.

Reference Voltage vs. Current and Temperature
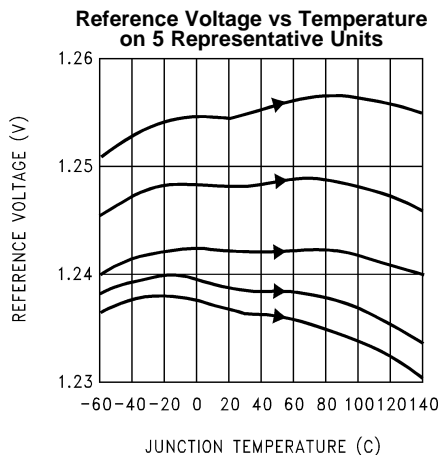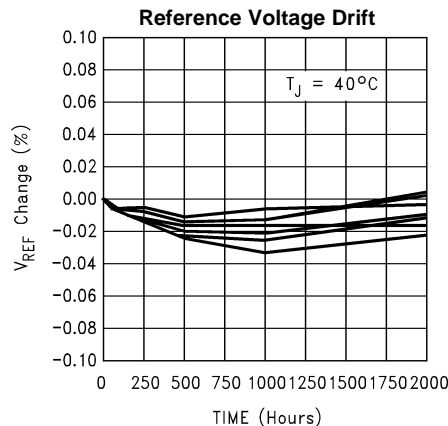
Figure 5.
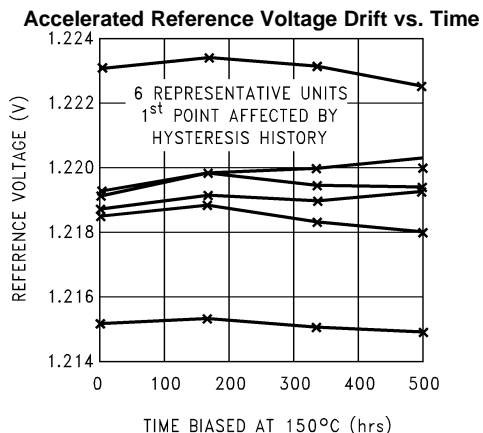
Reference Voltage vs. Reference Current
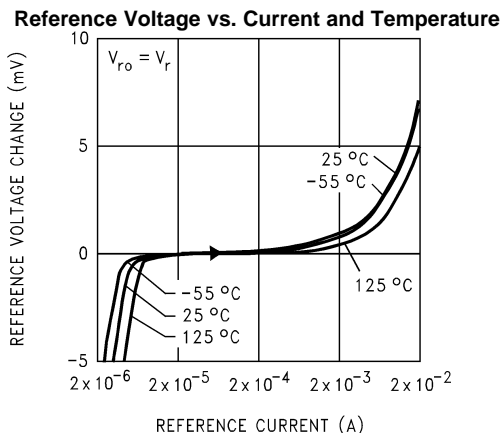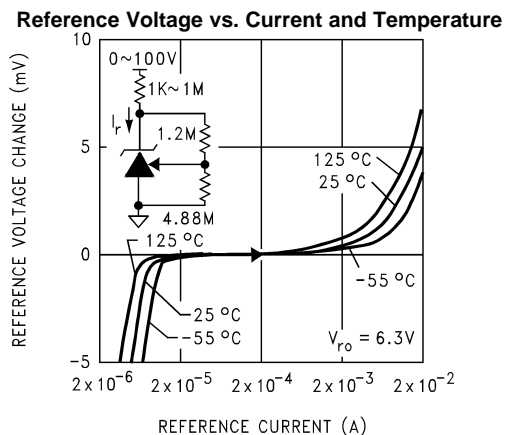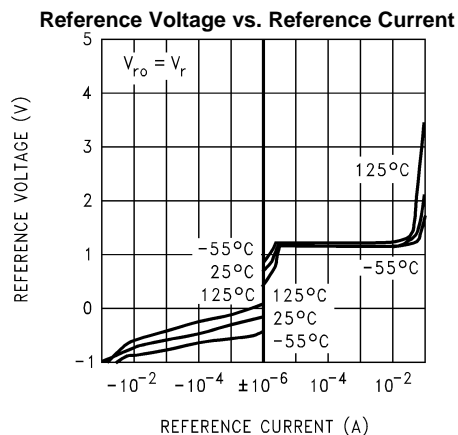
Figure 6.

Typical Performance Characteristics (Reference) (continued)

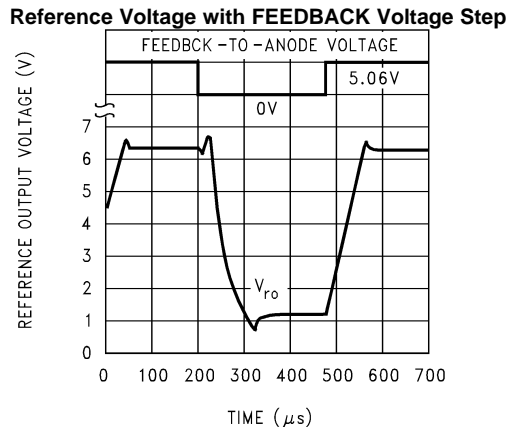T_J = 25°C, FEEDBACK pin shorted to V^- = 0V, unless otherwise noted

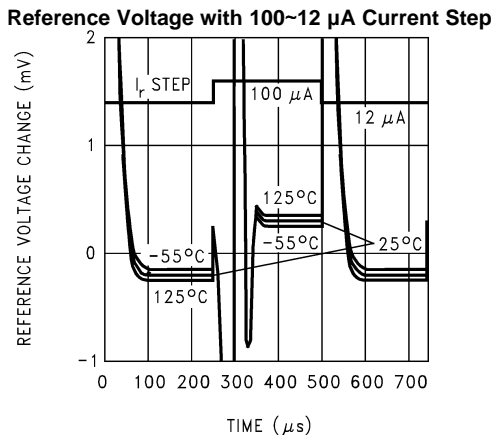**Reference Voltage vs. Reference Current**

Figure 7.

Reference AC Stability Range
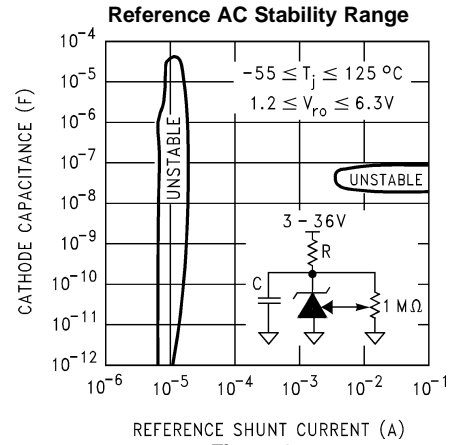
Figure 8.

FEEDBACK Current vs. FEEDBACK-to-Anode Voltage
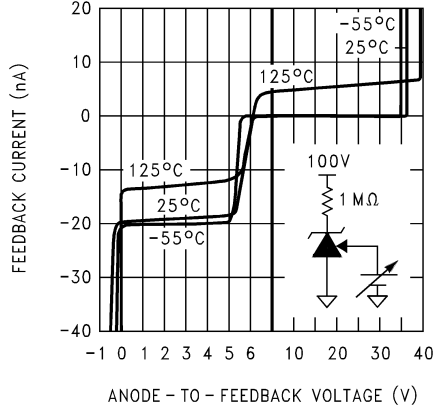
Figure 9.

FEEDBACK Current vs. FEEDBACK-to-Anode Voltage
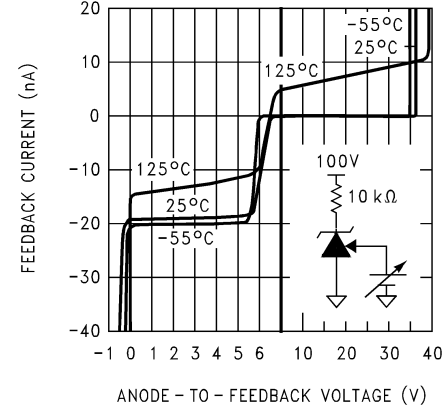
Figure 10.
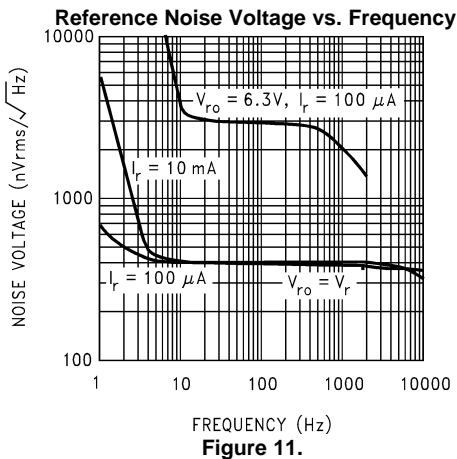
Reference Noise Voltage vs. Frequency

Figure 11.

Reference Small-Signal Resistance vs. Frequency

Figure 12.

Product Folder Links: *LM614*

Typical Performance Characteristics (Reference) (continued)

T_J = 25°C, FEEDBACK pin shorted to V^- = 0V, unless otherwise noted

Reference Power-Up Time

Figure 13.

Reference Voltage with FEEDBACK Voltage Step

Figure 14.

Reference Voltage with 100~12 µA Current Step

Figure 15.

Reference Step Response for 100 µA ~ 10 mA Current Step

Figure 16.

Reference Voltage Change with Supply Voltage Step

Figure 17.

Submit Documentation Feedback   7

Product Folder Links: *LM614*
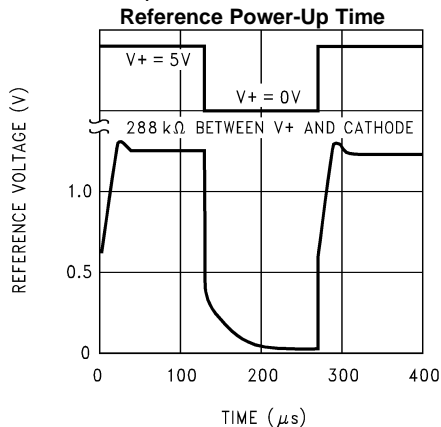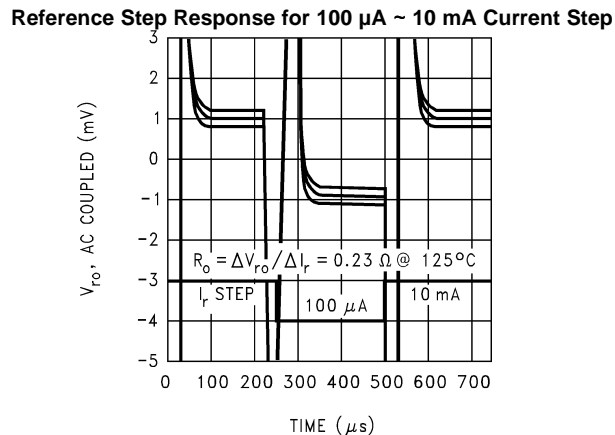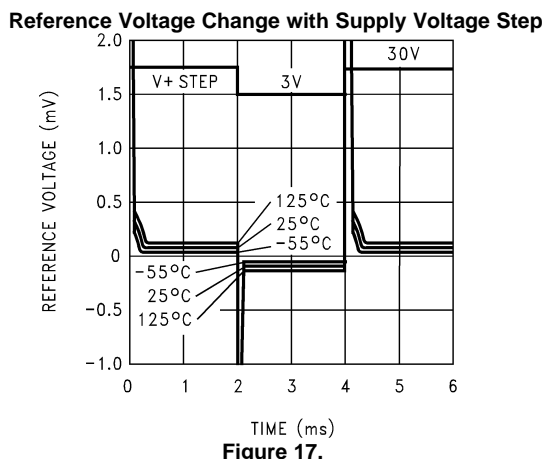
Typical Performance Characteristics (Op Amps)

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

Input Common-Mode Voltage Range vs. Temperature
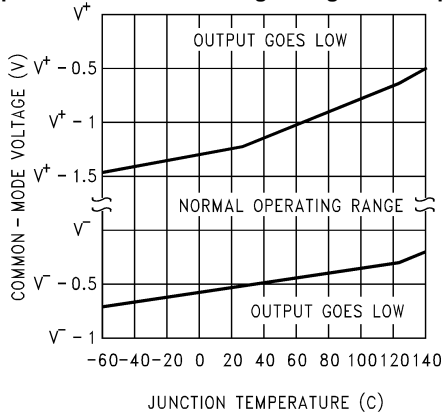
Figure 18.

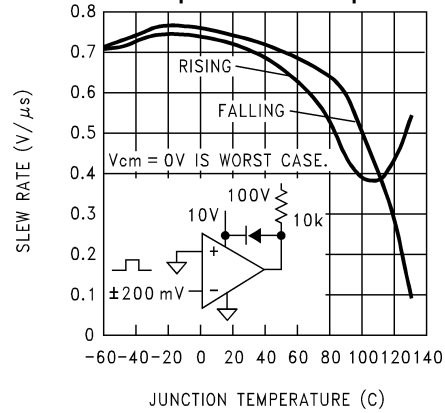**V_{OS} vs. Junction Temperature on 9 Representative Units**
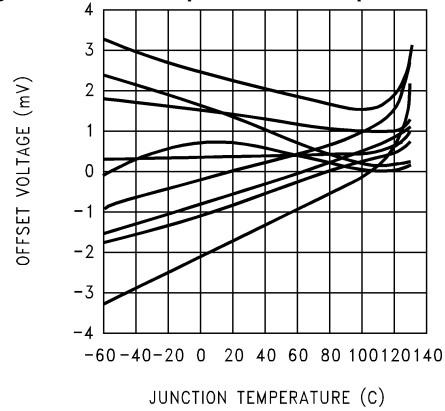
Figure 19.

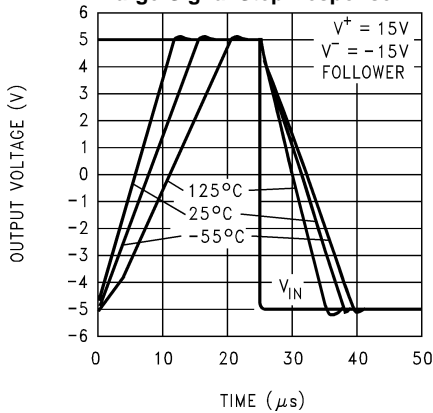**Input Bias Current vs. Common-Mode Voltage**
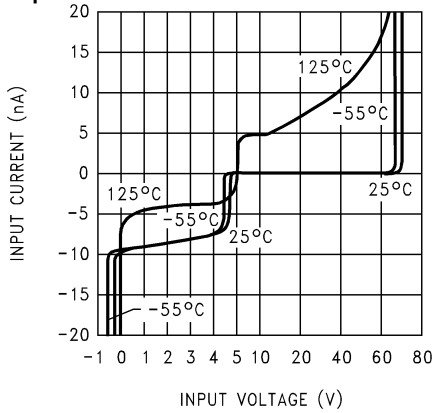
Figure 20.
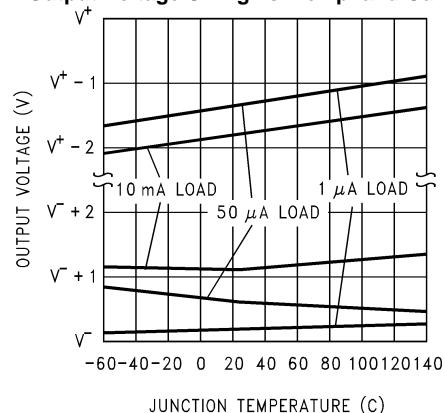
Slew Rate vs. Temperature and Output Sink Current

Figure 21.

Large-Signal Step Response

Figure 22.

Output Voltage Swing vs. Temp. and Current

Figure 23.

Product Folder Links: *LM614*

Typical Performance Characteristics (Op Amps) (continued)

V^+ = 5V, V^- = GND = 0V, V_{CM} = V^+/2, V_{OUT} = V^+/2, T_J = 25°C, unless otherwise noted
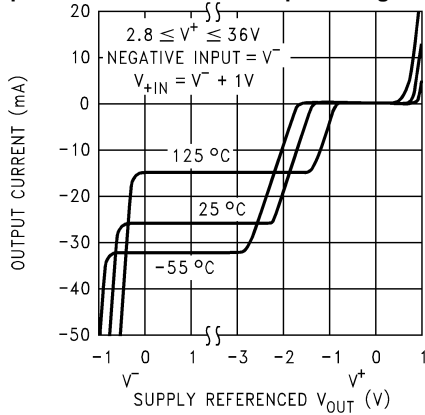
Output Source Current vs. Output Voltage and Temp.

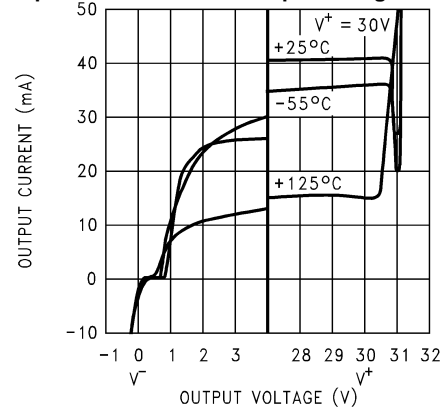**Figure 24.**

Output Sink Current vs. Output Voltage and Temp.
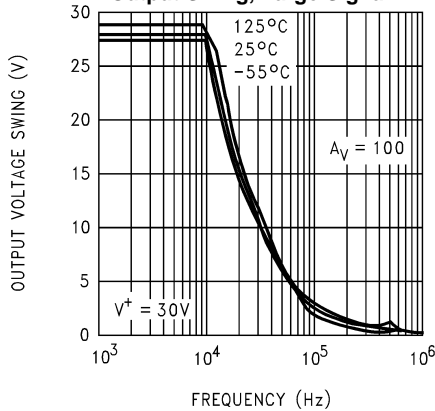
Figure 25.

Output Swing, Large Signal

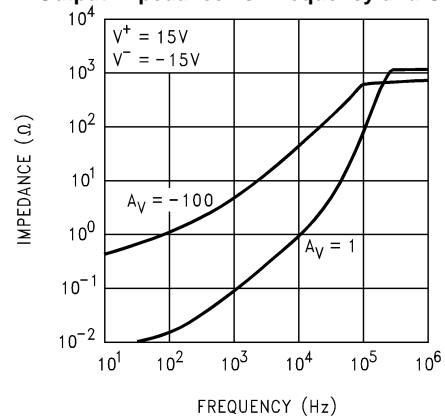**Figure 26.**

Output Impedance vs. Frequency and Gain

Figure 27.

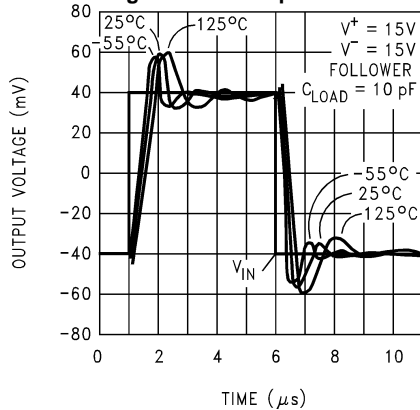**Small-Signal Pulse Response vs. Temp.**

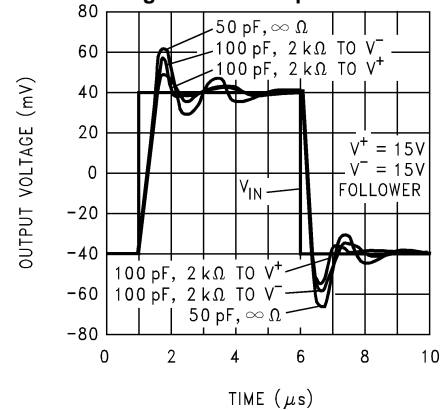**Figure 28.**

Small-Signal Pulse Response vs. Load

Figure 29.

Typical Performance Characteristics (Op Amps) (continued)

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

Op Amp Voltage Noise vs. Frequency

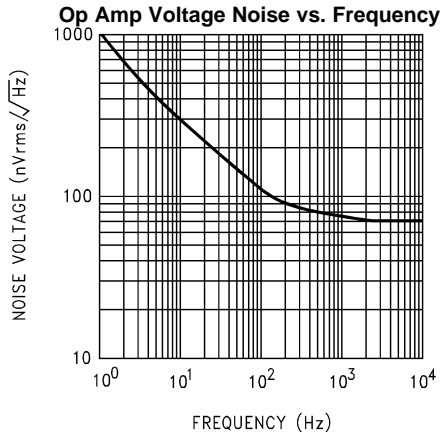**Figure 30.**

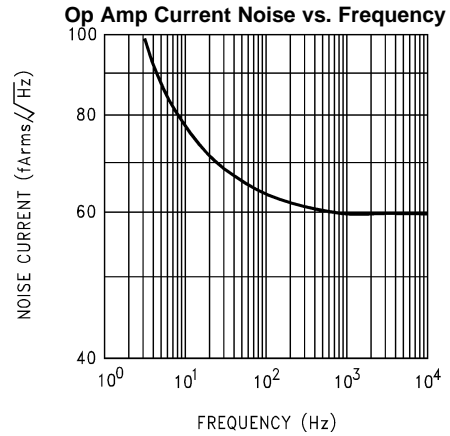**Op Amp Current Noise vs. Frequency**

Figure 31.

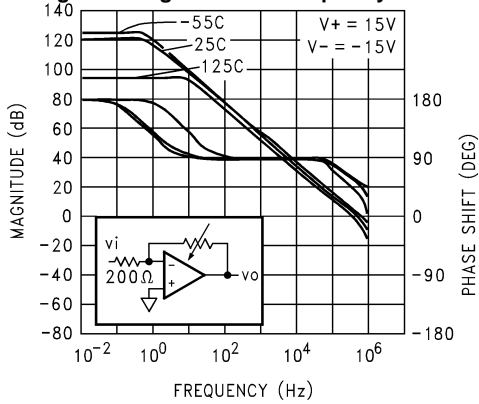**Small-Signal Voltage Gain vs. Frequency and Temperature**

Figure 32.
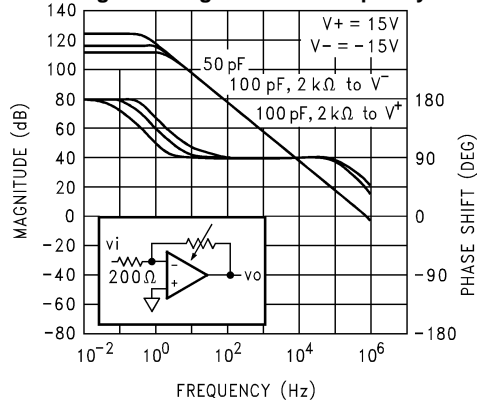
Small-Signal Voltage Gain vs. Frequency and Load

Figure 33.

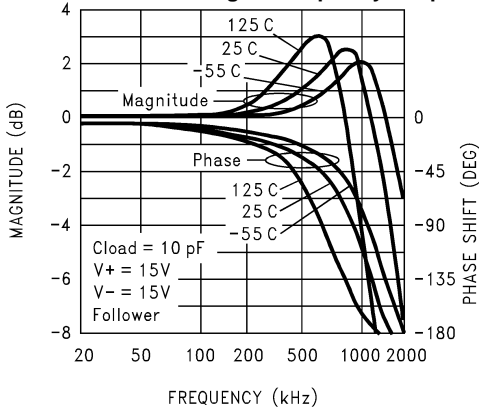**Follower Small-Signal Frequency Response**

Figure 34.
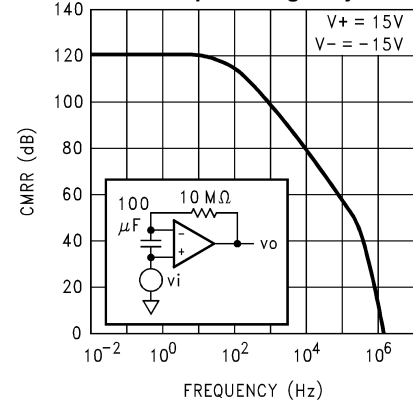
Common-Mode Input Voltage Rejection Ratio

Figure 35.

Product Folder Links: *LM614*

Typical Performance Characteristics (Op Amps) (continued)

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

Power Supply Current vs. Power Supply Voltage
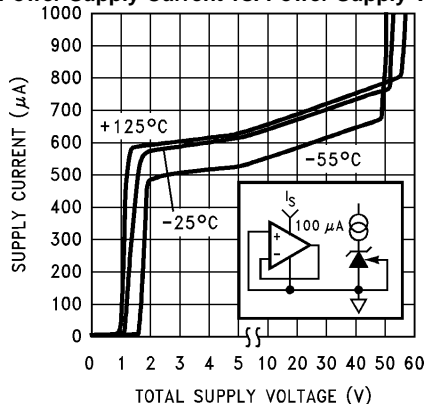

Figure 36.

Positive Power Supply Voltage Rejection Ratio
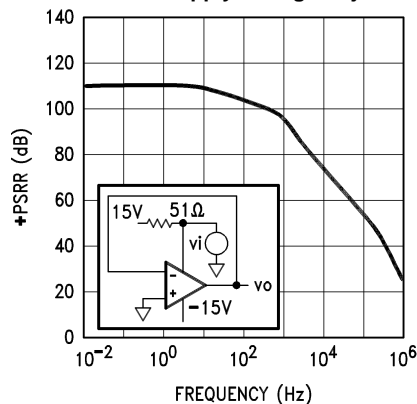

Figure 37.

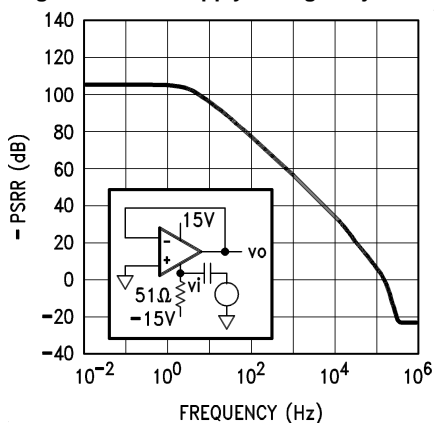**Negative Power Supply Voltage Rejection Ratio**

Figure 38.

Input Offset Current vs. Junction Temperature
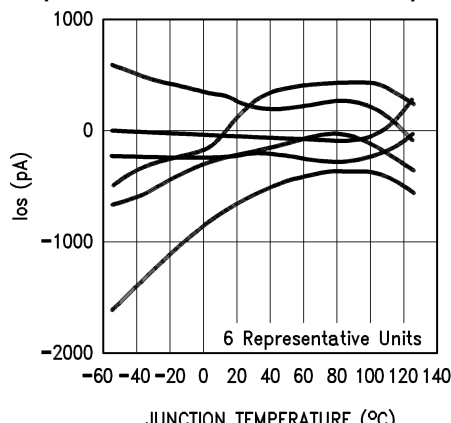
Figure 39.

Input Bias Current vs. Junction Temperature

Figure 40.

Product Folder Links: *LM614*
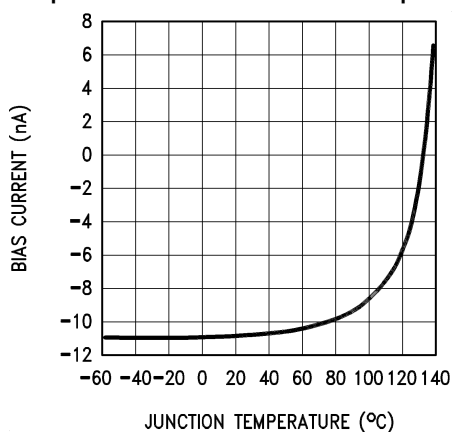
Typical Performance Distributions

Average V$_{OS}$ Drift Industrial Temperature Range
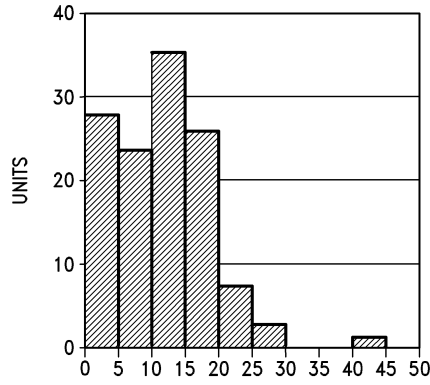
Figure 41.

Average V$_{OS}$ Drift Commercial Temperature Range
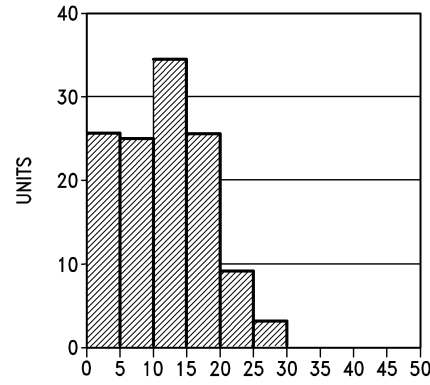
Figure 42.

Average I$_{OS}$ Drift Industrial Temperature Range
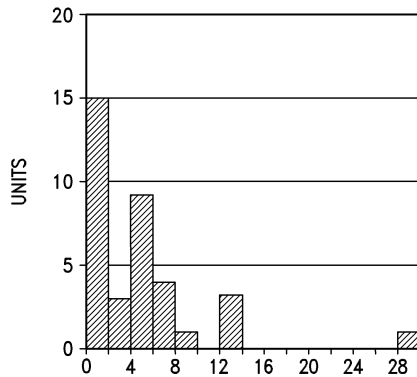
Figure 43.

Average I$_{OS}$ Drift Commercial Temperature Range
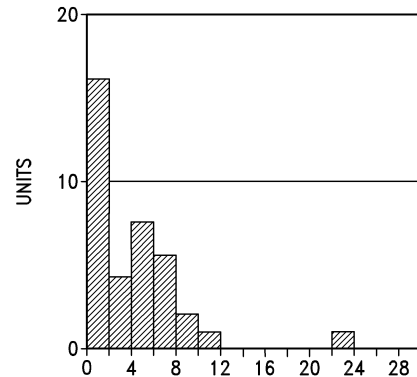
Figure 44.

Voltage Reference Broad-BandNoise Distribution
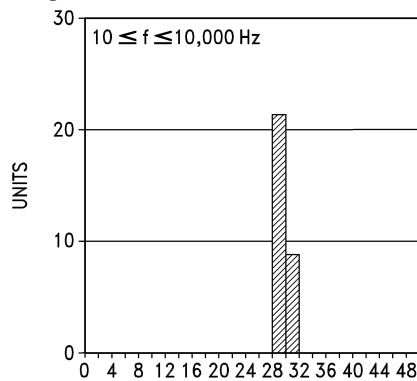
Figure 45.

Op Amp Voltage Noise Distribution

Figure 46.

Product Folder Links: *LM614*
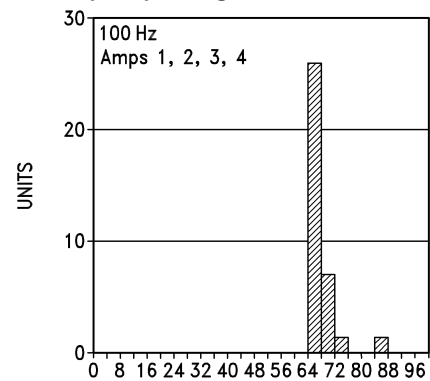
Typical Performance Distributions (continued)

Op Amp Current Noise Distribution

Figure 47.

Product Folder Links: *LM614*
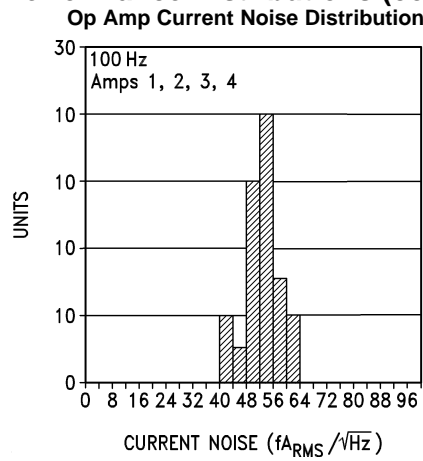
APPLICATION INFORMATION

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 5.0V reference with V⁺ = 3V is allowed.
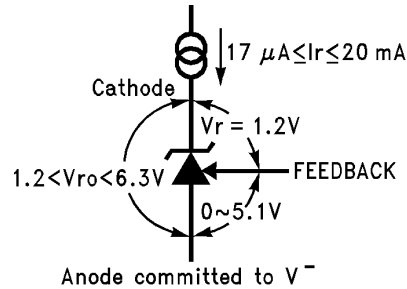
**Figure 48. Voltages Associated with Reference
(Current Source I_r is External)**

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.
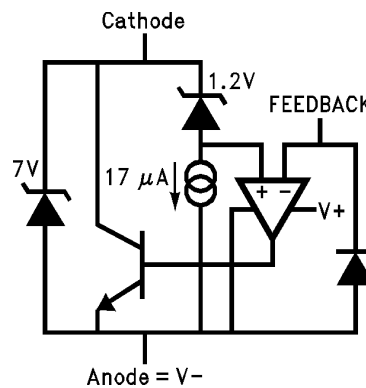
Figure 49. Reference Equivalent Circuit

Figure 50. 1.2V Reference

Product Folder Links: *LM614*
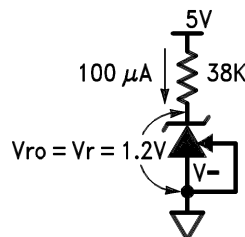
Capacitors in parallel with the reference are allowed. See Reference AC Stability Range typical curve for capacitance values—from 20 µA to 3 mA any capacitor value is stable. With the reference's wide stability range with resistive and capacitive loads, a wide range of RC filter values will perform noise filtering.

Adjustable Reference

The FEEDBACK pin allows the reference output voltage, V_{ro}, to vary from 1.24V to 5.0V. 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 $V_{ro} = V_r = 1.24$V. For higher voltages FEEDBACK is held at a constant voltage above Anode—say 3.76V for $V_{ro} = 5$V. Connecting a resistor across the constant V_r generates a current $I = V_r/R1$ flowing from Cathode into FEEDBACK node. A Thevenin equivalent 3.76V is generated from FEEDBACK to Anode with R2=3.76/I. For a 1% error, use R1 such that I is greater than one hundred times the FEEDBACK bias current. For example, keep $I \geq 5.5\mu$A.
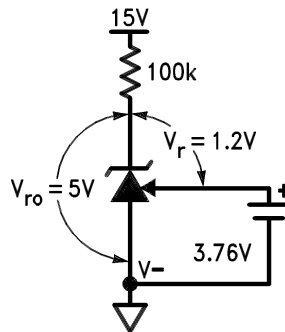
**Figure 51. Thevenin Equivalent
of Reference with 5V Output**
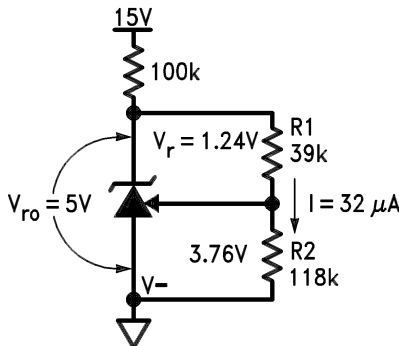
R1 = Vr/I = 1.24/32µ = 39k
R2 = R1 {(Vro/Vr) − 1} = 39k {(5/1.24) − 1)} = 118k

**Figure 52. 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.

Product Folder Links: *LM614*
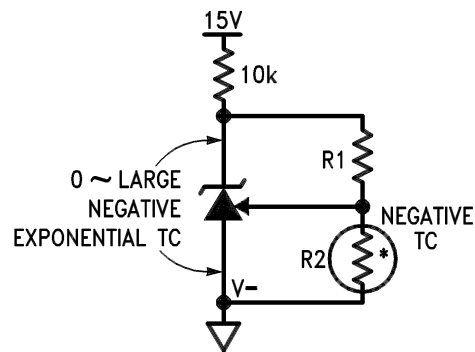
Figure 53. Output Voltage has Negative Temperature Coefficient (TC) if R2 has Negative TC
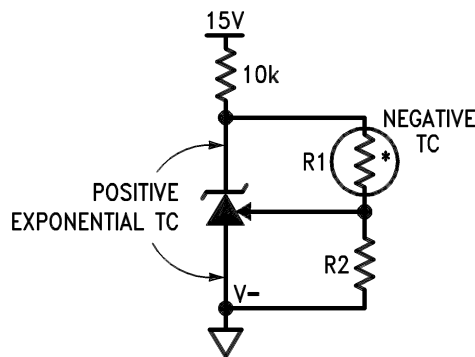
Figure 54. Output Voltage has Positive TC if R1 has Negative TC
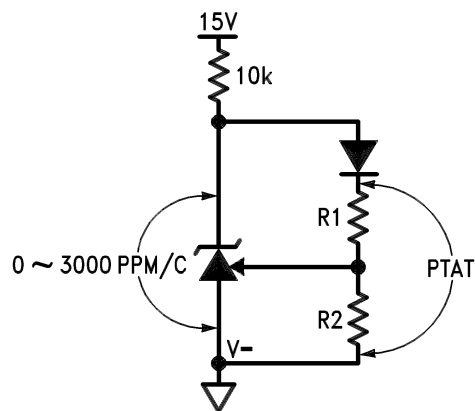
Figure 55. Diode in Series with R1 Causes Voltage across R1 and R2 to be Proportional to Absolute Temperature (PTAT)

Connecting a resistor across Cathode-to-FEEDBACK creates a 0 TC current source, but a range of TCs may be synthesized.
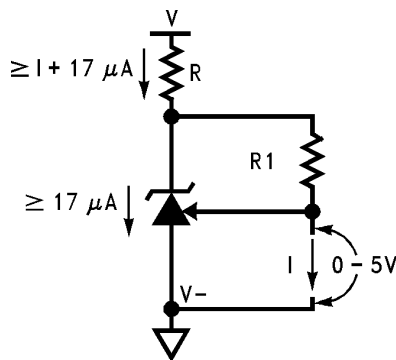
I = Vr/R1 = 1.24/R1

Figure 56. Current Source is Programmed by R1
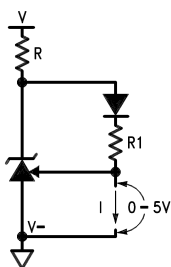
Figure 57. Proportional-to-Absolute-Temperature Current Source
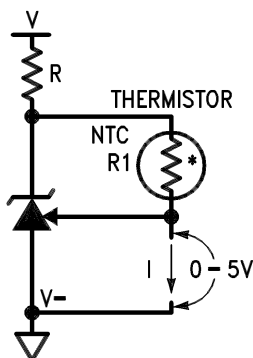
Figure 58. Negative-TC Current Source

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

Any amp or the reference may be biased in any way with no effect on the other amps or reference, except when a substrate diode conducts (see Electrical Characteristics). One amp input may be outside the common-mode range, another amp may be operated as a comparator, another with 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). Choosing operating points that cause oscillation, such as driving too large a capacitive load, is best avoided.

Op Amp Output Stage

These op amps, like their 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 42µA pull-down will bring the output within 300 mV of V⁻ over the military temperature range. If more than 42µA 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

2. Cross-over Distortion: The LM614 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_e until the output resistance is that of the current limit 25Ω. 200pF may then be driven without oscillation.

Op Amp Input Stage

The lateral PNP input transistors, unlike most op amps, have BV_{EBO} 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
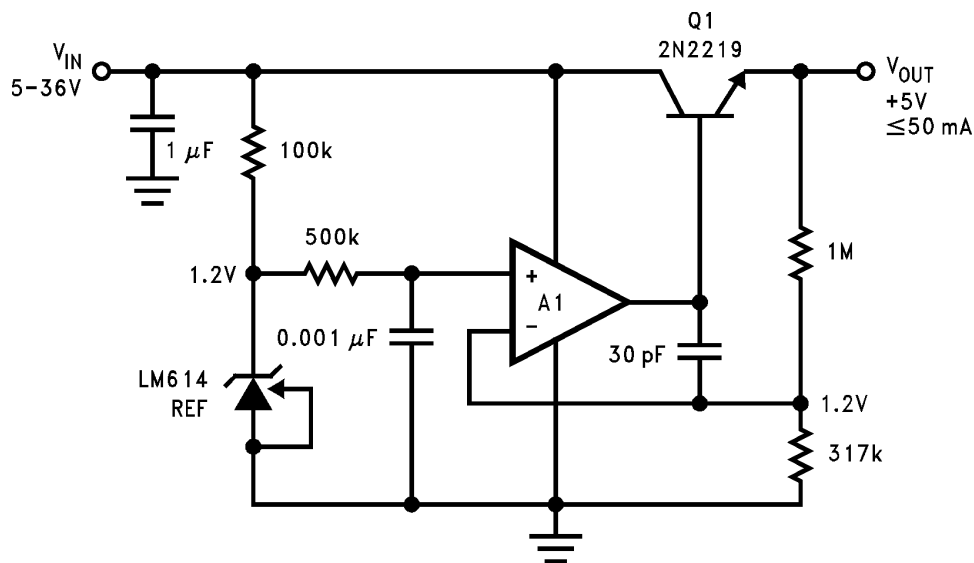
Figure 59. Simple Low Quiescent Drain Voltage Regulator.
Total supply current approximately 320µA, when V$_{IN}$ = +5V.

Product Folder Links: *LM614*
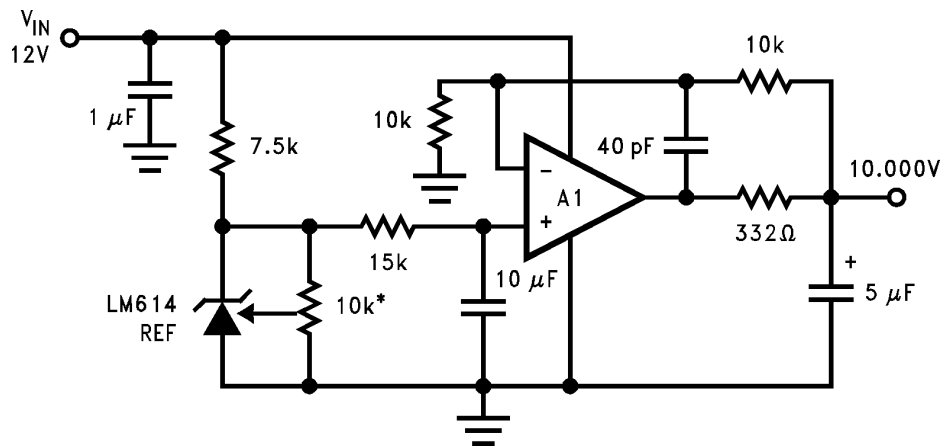
*10k must be low
t.c. trimpot.

**Figure 60. Ultra Low Noise 10.00V Reference.
Total output noise is typically 14µV$_{RMS}$.**
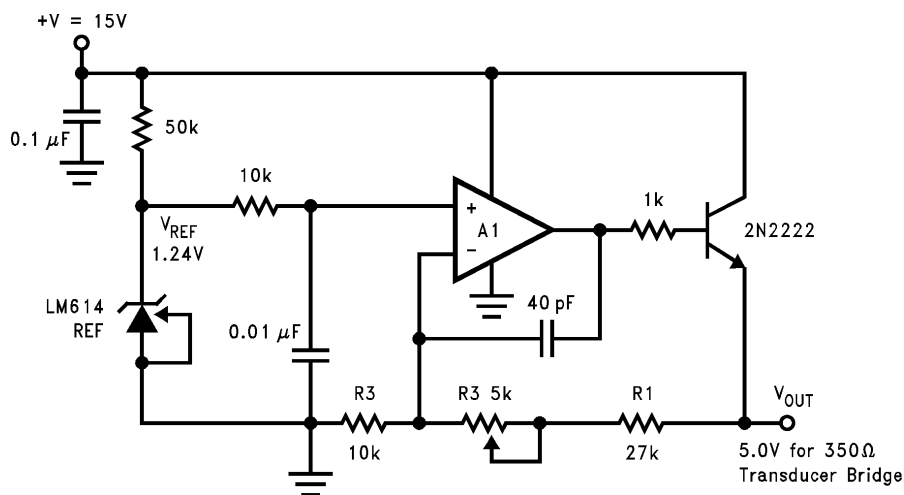
$V_{OUT} = (R_1 /Pe + 1) V_{REF}$
R_1, R_2 should be 1% metal film
P_β should be low T.C. trim pot

**Figure 61. Slow Rise Time Upon Power-Up, Adjustable Transducer Bridge Driver.
Rise time is approximately 1ms.**
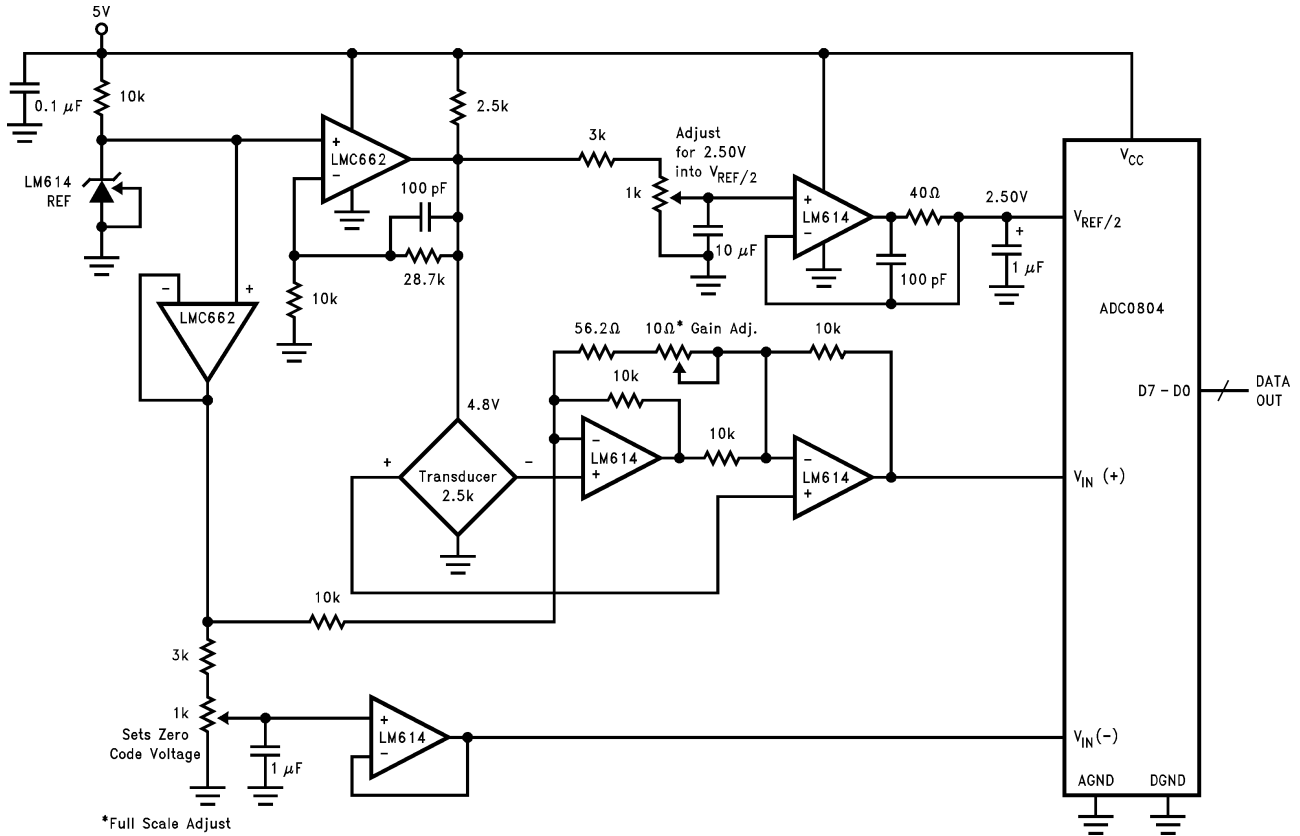
(1) Set zero code voltage, then adjust 10Ω gain adjust pot for full scale.

Figure 62. Transducer Data Acquisition System.

Product Folder Links: *LM614*

Simplified Schematic Diagrams
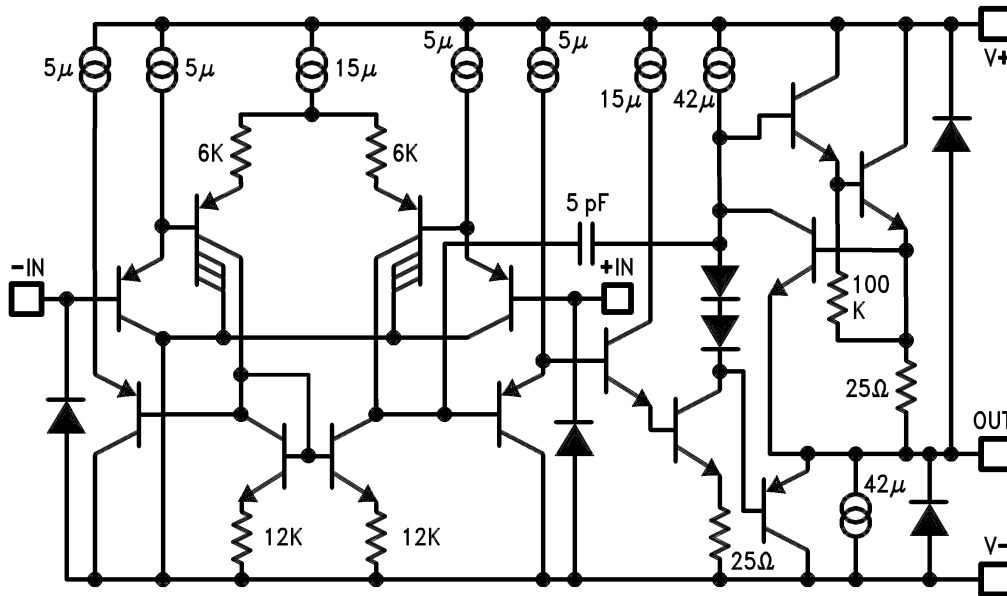
Figure 63. Op Amp
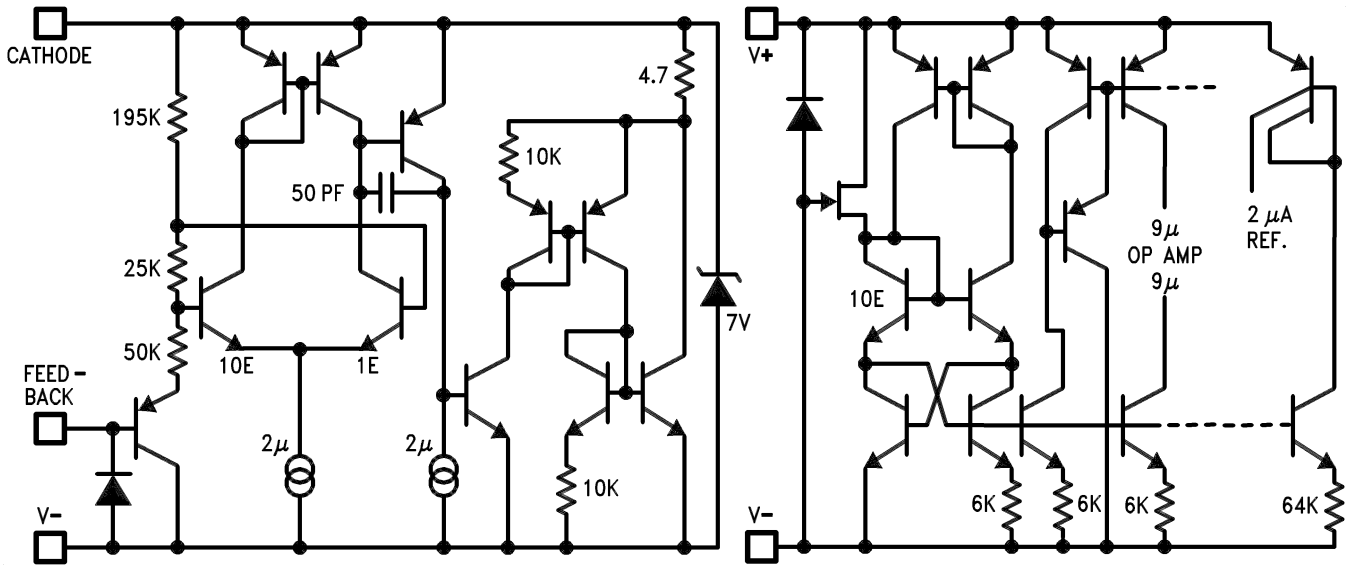
Figure 64. Reference / Bias

Product Folder Links: *LM614*

REVISION HISTORY

Changes from Revision B (March 2013) to Revision C   **Page**

Product Folder Links: *LM614*

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM614 MDC	ACTIVE	DIESALE	Y	0	100	RoHS & Green	Call TI	Level-1-NA-UNLIM	-40 to 85		Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) RoHS: TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2020, Texas Instruments Incorporated