

SOT-23 Precision Wide Supply High Output Drive Voltage Reference

FEATURES

- **Low Drift:**
 - A Grade: 10ppm/°C Max
 - B Grade: 20ppm/°C Max
- **High Accuracy:**
 - A Grade: ±0.05% Max
 - B Grade: ±0.10% Max
- **Low Noise: 1.6ppm_{p-p} (0.1Hz to 10Hz)**
- **Wide Supply Range to 36V**
- **Low Thermal Hysteresis**
- **Line Regulation (Up to 36V): 5ppm/V Max**
- **Low Dropout Voltage: 100mV Max**
- **Sinks and Sources ±10mA**
- **Load Regulation at 10mA: 8ppm/mA Max**
- **Easily Configured for Negative Voltage Output**
- **Fully Specified from -40°C to 125°C**
- **Available Output Voltage: 2.5V**
For 1.25V, 2.048V, 3V, 3.3V, 4.096V, 5V Versions, Consult LTC Marketing
- **Low Profile (1mm) ThinSOT™ Package**

APPLICATIONS

- Automotive Control and Monitoring
- High Temperature Industrial
- High Resolution Data Acquisition Systems
- Instrumentation and Process Control
- Precision Regulators
- Medical Equipment

DESCRIPTION

The LT®6654 is a small precision voltage reference that offers high accuracy, low noise, low drift, low dropout and low power. The LT6654 operates from voltages up to 36V and is fully specified from -40°C to 125°C. A buffered output ensures ±10mA of output drive with low output impedance and precise load regulation. These features, in combination, make the LT6654 ideal for portable equipment, industrial sensing and control, and automotive applications.

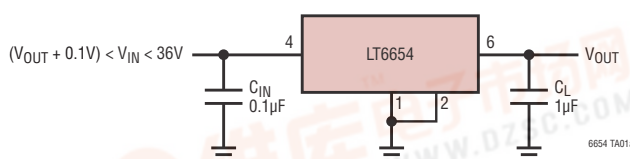
The LT6654 was designed with advanced manufacturing techniques and curvature compensation to provide 10ppm/°C temperature drift and 0.05% initial accuracy. Low thermal hysteresis ensures high accuracy and 1.6ppm_{p-p} noise minimizes measurement uncertainty. Since the LT6654 can also sink current, it can operate as a low power negative voltage reference with the same precision as a positive reference.

The LT6654 is offered in a 6-lead SOT-23 package.

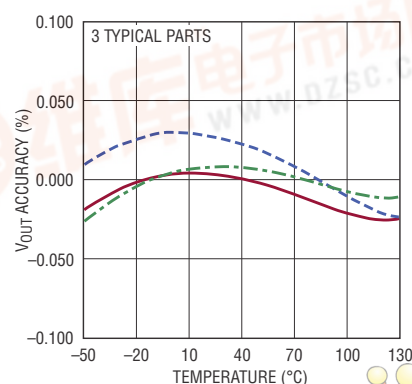
LT, LT, LTC, LTM, Linear Technology and the Linear logo are registered trademarks and ThinSOT is a trademark of Linear Technology Corporation. All other trademarks are the property of their respective owners.

TYPICAL APPLICATION

Basic Connection



Output Voltage Temperature Drift

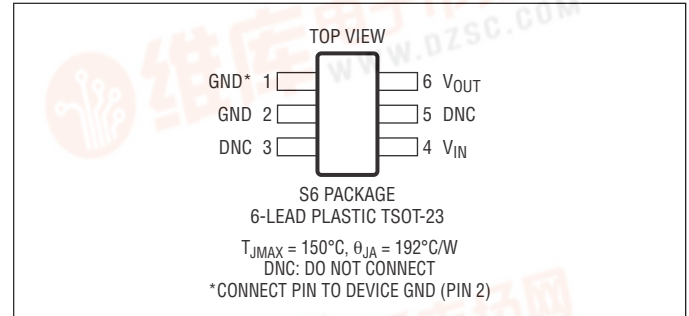


ABSOLUTE MAXIMUM RATINGS

(Note 1)

Input Voltage V_{IN} to GND -0.3V to 38V
 Output Voltage V_{OUT} -0.3V to $V_{IN} + 0.3V$
 Output Short Circuit Duration Indefinite
 Operating Temperature Range -40°C to 125°C
 Storage Temperature Range (Note 2) -65°C to 150°C
 Lead Temperature (Soldering, 10 sec.)
 (Note 9) 300°C

PIN CONFIGURATION



ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	SPECIFIED TEMPERATURE RANGE
LT6654AHS6-2.5#PBF	LT6654AHS6-2.5#TRPBF	LTFJY	6-Lead Plastic TSOT-23	-40°C to 125°C
LT6654BHS6-2.5#PBF	LT6654BHS6-2.5#TRPBF	LTFJY	6-Lead Plastic TSOT-23	-40°C to 125°C

Consult LTC Marketing for parts specified with wider operating temperature ranges. *The performance grade is identified by a label on the shipping container. Consult LTC Marketing for information on non-standard lead based finish parts.

For more information on lead free part marking, go to: <http://www.linear.com/leadfree/>

For more information on tape and reel specifications, go to: <http://www.linear.com/tapeandreel/>

AVAILABLE OPTIONS

OUTPUT VOLTAGE	INITIAL ACCURACY	TEMPERATURE COEFFICIENT	PART NUMBER
2.5V	0.05% 0.1%	10ppm/°C 20ppm/°C	LT6654AHS6-2.5 LT6654BHS6-2.5

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25^{\circ}\text{C}$, $C_L = 1\mu\text{F}$ and $V_{IN} = V_{OUT} + 0.5V$, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage Accuracy	LT6654A LT6654B	-0.05 -0.10		0.05 0.10	% %
Output Voltage Temperature Coefficient (Note 3)	LT6654A LT6654B	● ●	3 6	10 20	ppm/°C ppm/°C
Line Regulation	$V_{OUT} + 0.5V \leq V_{IN} \leq 36V$	●	1.2	5 10	ppm/V ppm/V

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25^\circ\text{C}$, $C_L = 1\mu\text{F}$ and $V_{IN} = V_{OUT} + 0.5\text{V}$, unless otherwise noted.

Load Regulation (Note 4)	$I_{OUT(SOURCE)} = 10\text{mA}$	●	3	8 15	ppm/mA ppm/mA
	$I_{OUT(SINK)} = 10\text{mA}$	●	9	20 30	ppm/mA ppm/mA
Minimum Operating Voltage (Note 5)	$V_{IN} - V_{OUT}$, $\Delta V_{OUT} = 0.1\%$ $I_{OUT} = 0\text{mA}$		55	100 120	mV mV
	$I_{OUT(SOURCE)} = 10\text{mA}$	●		450	mV
	$I_{OUT(SINK)} = -10\text{mA}$	●		50	mV
Supply Current	No Load	●	350	550	μA μA
Output Short-Circuit Current	Short V_{OUT} to GND		40		mA
	Short V_{OUT} to V_{IN}		30		mA
Output Voltage Noise (Note 6)	$0.1\text{Hz} \leq f \leq 10\text{Hz}$		1.6		ppm _{P-P}
	$10\text{Hz} \leq f \leq 1\text{kHz}$		1.8		ppm _{RMS}
Turn-On Time	0.1% Settling, $C_{LOAD} = 1\mu\text{F}$		120		μs
Long-Term Drift of Output Voltage (Note 7)			60		ppm/ $\sqrt{\text{kHr}}$
Hysteresis (Note 8)	$\Delta T = 0^\circ\text{C}$ to 70°C		30		ppm
	$\Delta T = -40^\circ\text{C}$ to 85°C		40		ppm
	$\Delta T = -40^\circ\text{C}$ to 125°C		90		ppm

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

Note 2: If the parts are stored outside of the specified temperature range, the output may shift due to hysteresis.

Note 3: Temperature coefficient is measured by dividing the maximum change in output voltage by the specified temperature range.

Note 4: Load regulation is measured on a pulse basis from no load to the specified load current. Output changes due to die temperature change must be taken into account separately.

Note 5: Excludes load regulation errors.

Note 6: Peak-to-peak noise is measured with a 3-pole highpass at 0.1Hz and 4-pole lowpass filter at 10Hz. The unit is enclosed in a still-air environment to eliminate thermocouple effects on the leads. The test time is 10 seconds. RMS noise is measured on a spectrum analyzer in a shielded environment where the intrinsic noise of the instrument is removed to determine the actual noise of the device.

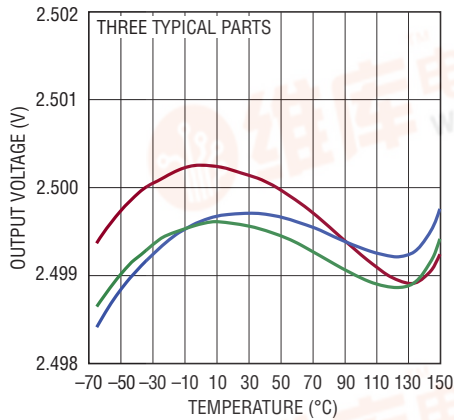
Note 7: Long-term stability typically has a logarithmic characteristic and therefore, changes after 1000 hours tend to be much smaller than before that time. Total drift in the second thousand hours is normally less than one third that of the first thousand hours with a continuing trend toward reduced drift with time. Long-term stability will also be affected by differential stresses between the IC and the board material created during board assembly.

Note 8: Hysteresis in output voltage is created by package stress that differs depending on whether the IC was previously at a higher or lower temperature. Output voltage is always measured at 25°C , but the IC is cycled to the hot or cold temperature limit before successive measurements. Hysteresis measures the maximum output change for the averages of three hot or cold temperature cycles. For instruments that are stored at well controlled temperatures (within 20 or 30 degrees of operational temperature), it's usually not a dominant error source.

Note 9: The stated temperature is typical for soldering of the leads during manual rework. For detailed IR reflow recommendations, refer to the Applications Information section.

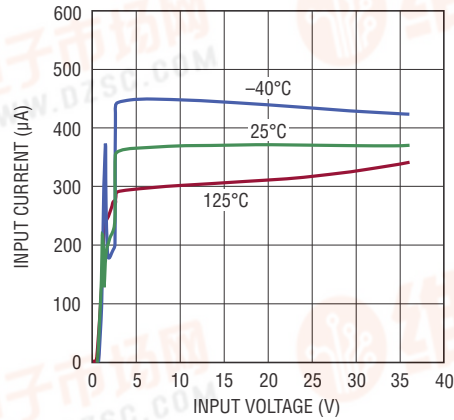
TYPICAL PERFORMANCE CHARACTERISTICS

Output Voltage Temperature Drift



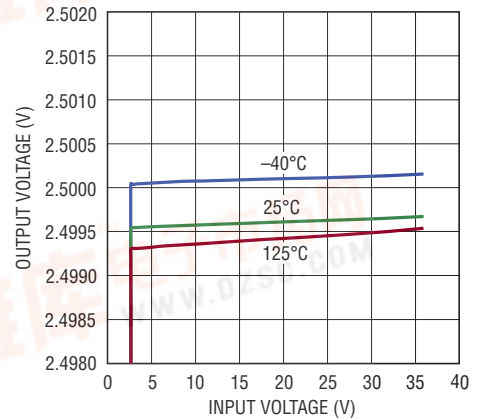
6654 G01

Supply Current vs Input Voltage



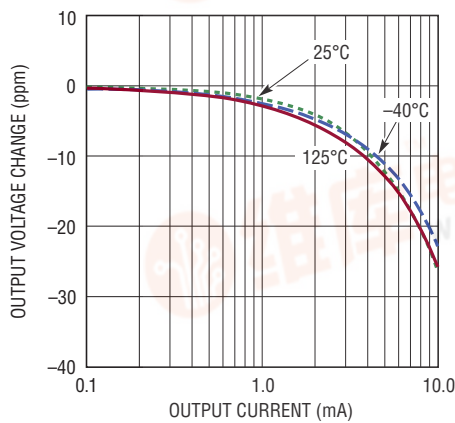
6654 G02

Line Regulation



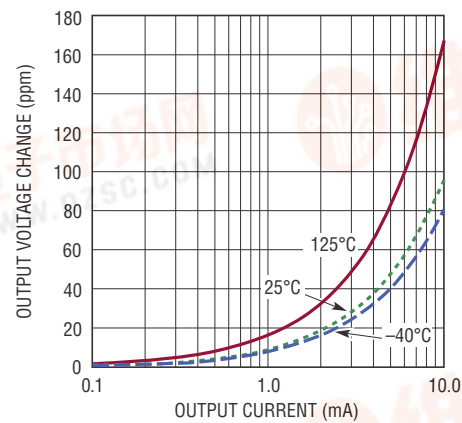
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Load Regulation (Sourcing)



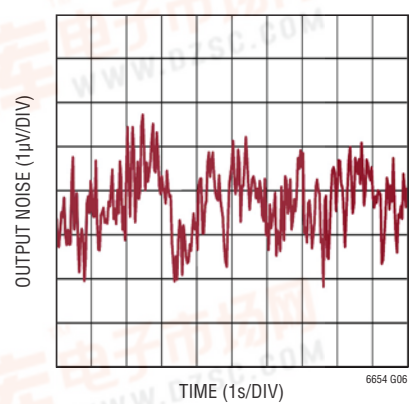
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Load Regulation (Sinking)



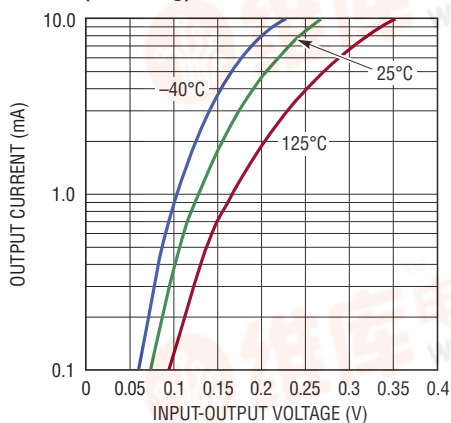
6654 G05

Output Noise 0.1Hz to 10Hz



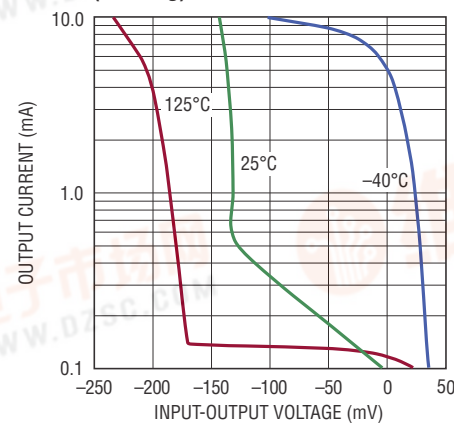
6654 G06

Minimum $V_{IN} - V_{OUT}$ Differential (Sourcing)



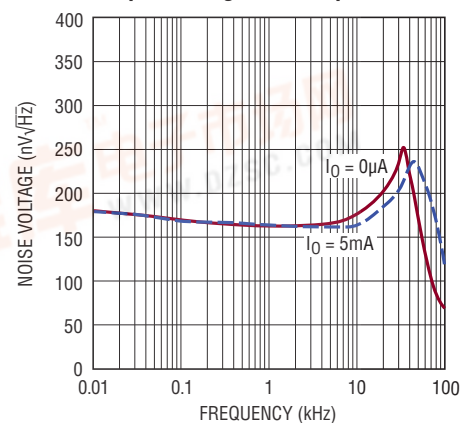
6654 G07

Minimum $V_{IN} - V_{OUT}$ Differential (Sinking)



6654 G08

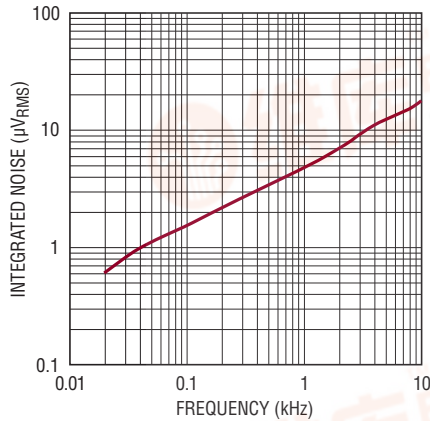
Output Voltage Noise Spectrum



6654 G09

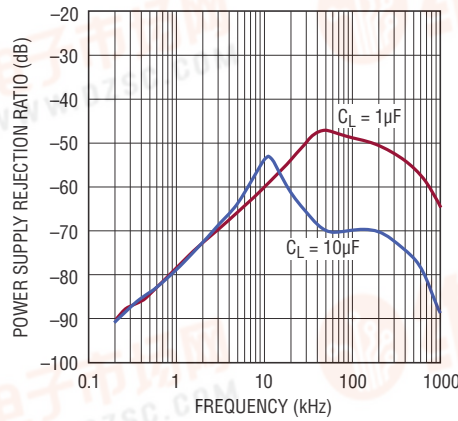
TYPICAL PERFORMANCE CHARACTERISTICS

Integrated Noise 10Hz to 10kHz



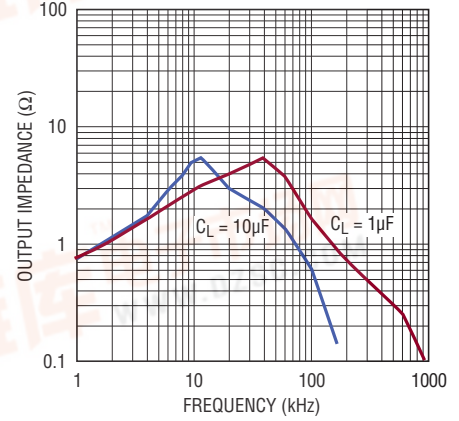
6654 G10

Power Supply Rejection Ratio vs Frequency



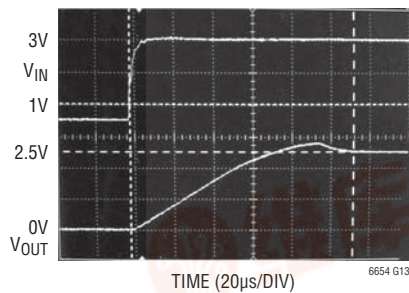
6654 G11

Output Impedance vs Frequency



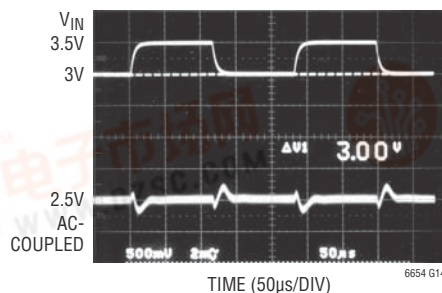
6654 G12

Turn-On Characteristics



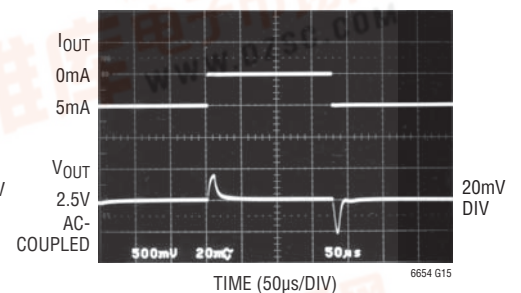
6654 G13

Line Transient Response



6654 G14

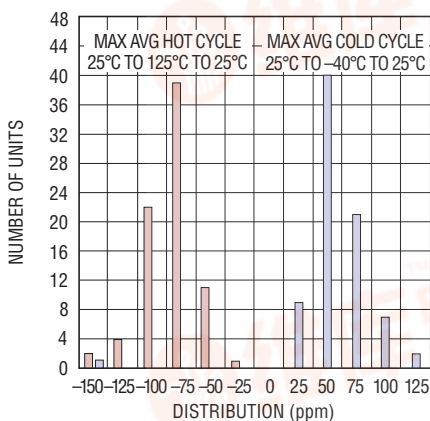
Load Transient Response (Sourcing)



6654 G15

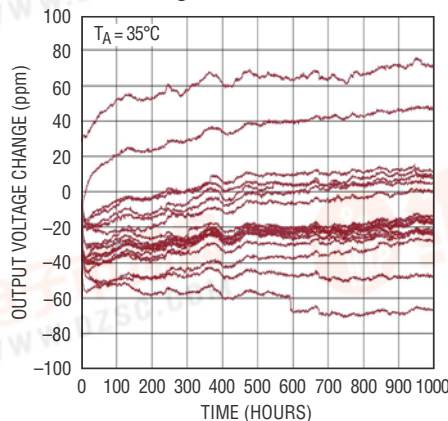
CL = 1µF

2.5V Hysteresis Plot for -40°C and 125°C



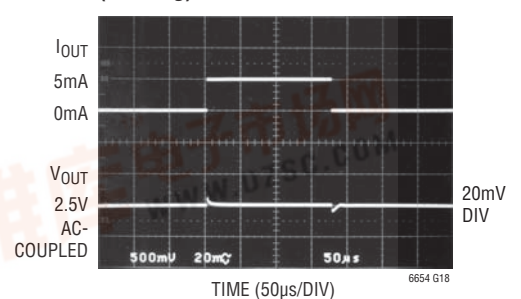
6654 G16

2.5V Long Term Drift



6654 G17

Load Transient Response (Sinking)



6654 G18

CL = 1µF

PIN FUNCTIONS

GND (Pin 1): Internal Function. This pin must be tied to ground.

GND (Pin 2): Primary Device Ground.

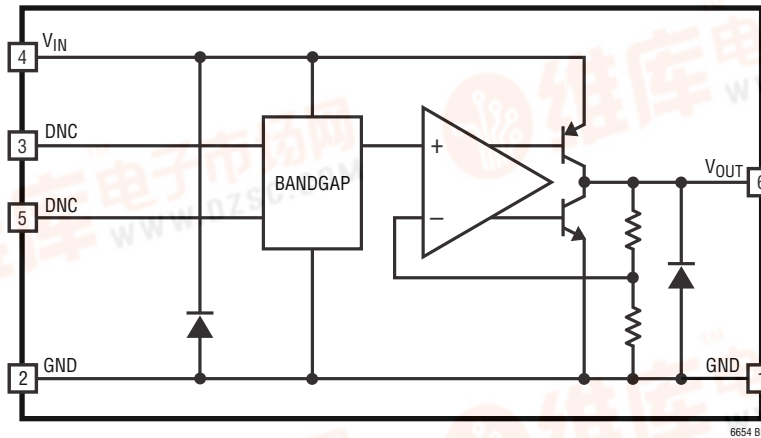
DNC (Pin 3): Do Not Connect. Keep leakage current from this pin to V_{IN} or GND to a minimum.

V_{IN} (Pin 4): Power Supply. Bypass V_{IN} with a 0.1 μ F capacitor to ground.

DNC (Pin 5): Do Not Connect. Keep leakage current from this pin to V_{IN} or GND to a minimum.

V_{OUT} (Pin 6): Output Voltage. An output capacitor of 1 μ F minimum is required for stable operation.

BLOCK DIAGRAM



APPLICATIONS INFORMATION

Bypass and Load Capacitors

The LT6654 voltage references should have an input bypass capacitor of $0.1\mu\text{F}$ or larger, however the bypassing on other components nearby may be sufficient. These references also require an output capacitor for stability. The optimum output capacitance for most applications is $1\mu\text{F}$, although larger values work as well. This capacitor affects the turn-on and settling time for the output to reach its final value.

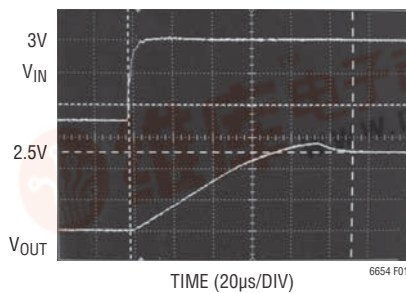


Figure 1. Turn-On Characteristics of LT6654-2.5

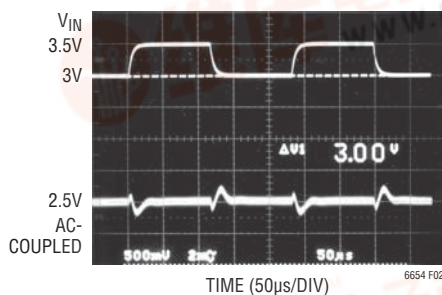


Figure 2. Output Response to 0.5V Ripple on V_{IN}

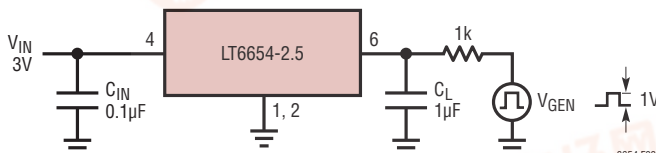


Figure 3. Response Time Test Circuit

Figure 1 shows the turn-on time for the LT6654-2.5 with a $0.1\mu\text{F}$ input bypass and $1\mu\text{F}$ load capacitor. Figure 2 shows the output response to a 0.5V transient on V_{IN} with the same capacitors.

The test circuit of Figure 3 is used to measure the stability with various load currents. With $R_L = 1\text{k}$, the 1V step produces a current step of 1mA . Figure 4 shows the response to a $\pm 0.5\text{mA}$ load. Figure 5 is the output response to a sourcing step from 4mA to 5mA , and Figure 6 is the output response of a sinking step from 4mA to 5mA .

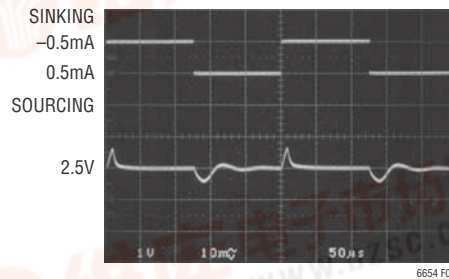


Figure 4. LT6654-2.5 Sourcing and Sinking 0.5mA

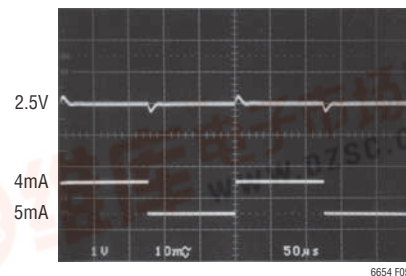


Figure 5. LT6654-2.5 Sourcing 4mA to 5mA

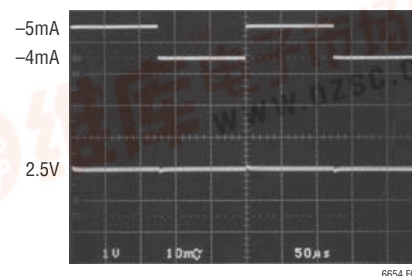


Figure 6. LT6654-2.5 Sinking 4mA to 5mA

APPLICATIONS INFORMATION

Positive or Negative Operation

The LT6654 can be operated in series mode or as a negative voltage reference. A typical series connection is shown on the front page of this data sheet.

The circuit in Figure 7 shows an LT6654 configured for negative operation. In this configuration, a positive voltage is required at V_{IN} (Pin 4) to bias the LT6654 internal circuitry. This voltage must be current limited with R1 to keep the output PNP transistor from turning on and driving the grounded output. C1 provides stability during load transients. This connection maintains nearly the same accuracy and temperature coefficient of the positive connected LT6654.

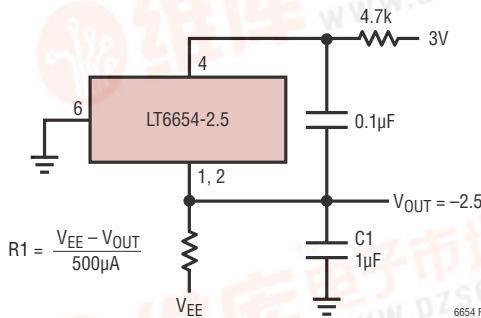


Figure 7. Using the LT6654-2.5 to Build a -2.5V Reference

Long-Term Drift

Long-term drift cannot be extrapolated from accelerated high temperature testing. This erroneous technique gives drift numbers that are wildly optimistic. The only way long-term drift can be determined is to measure it over the time interval of interest. The LT6654 drift data was taken on 40 parts that were soldered into PC boards similar to a real world application. The boards were then placed into a constant temperature oven with $T_A = 30^\circ\text{C}$, their outputs scanned regularly and measured with an 8.5 digit DVM. Long-term drift curves are shown in the Typical Performance Characteristics section.

Hysteresis

The hysteresis data is shown in the Typical Performance Characteristics. The LT6654 is capable of dissipating relatively high power. With a maximum input voltage and 10mA load current applied to the LT6654-2.5 the power

dissipation is approximately $P_D = 33.5\text{V} \cdot 10\text{mA} = 335\text{mW}$, which causes an increase in the die temperature of 64°C . This could increase the junction temperature above 125°C ($T_{J\text{MAX}}$ is 150°C) and may cause the output to shift due to thermal hysteresis.

PC Board Layout

The mechanical stress of soldering a surface mount voltage reference to a PC board can cause the output voltage to shift and temperature coefficient to change. These two changes are not correlated. For example, the voltage may shift but the temperature coefficient may not.

To reduce the effects of stress-related shifts, mount the reference near the short edge of the PC board or in a corner. In addition, slots can be cut into the board on two sides of the device.

The capacitors should be mounted close to the LT6654. The GND and V_{OUT} traces should be as short as possible to minimize $I \cdot R$ drops. High trace resistance directly impacts load regulation.

IR Reflow Shift

The different expansion and contraction rates of the materials that make up the LT6654 package may cause the output voltage to shift after undergoing IR reflow. Lead free solder reflow profiles reach over 250°C , considerably more than with lead based solder. A typical lead free IR reflow profile is shown in Figure 8. Similar profiles are found using a convection reflow oven. LT6654 devices run up

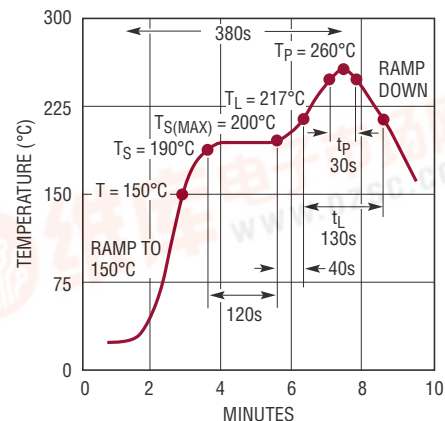


Figure 8. Lead Free Reflow Profile

APPLICATIONS INFORMATION

to three times through this reflow process show that the standard deviation of the output voltage increases with a slight negative mean shift of 0.003% as shown in Figure 9. While there can be up to 0.014% of output voltage shift, the overall drift of the LT6654 after IR reflow does not vary significantly.

Power Dissipation

The power dissipation in the LT6654 is dependent on V_{IN} , load current and the package. The LT6654 package has a thermal resistance, or θ_{JA} , of 230°C/W. A curve that illustrates allowed power dissipation versus temperature for the 6-lead SOT-23 package is shown in Figure 10. The power dissipation of the LT6654-2.5 as a function of input voltage is shown in Figure 11. The top curve shows

power dissipation with a 10mA load and the bottom curve shows power dissipation with no load. When operated within its specified limits of $V_{IN} = 36V$ and sourcing 10mA, the LT6654-2.5 consumes about 335mW at room temperature. The power-detrating curve in Figure 10 shows the LT6654-2.5 can only safely dissipate 108mW at 125°C, which is less than its maximum power output. Care must be taken when designing the circuit so that the maximum junction temperature is not exceeded.

The LT6654 includes output current limit circuitry, as well as thermal limit circuitry, to protect the reference from damage in the event of excessive power dissipation. The LT6654 is protected from damage by a thermal shutdown circuit. However, changes in performance may occur as a result of operation at high temperature.

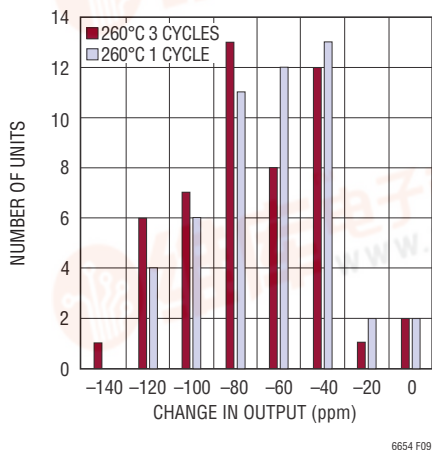


Figure 9. Output Voltage Shift Due to IR Reflow (%)

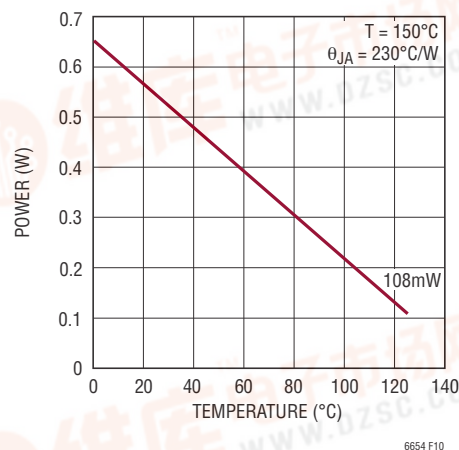


Figure 10. Maximum Allowed Dissipation for LT6654

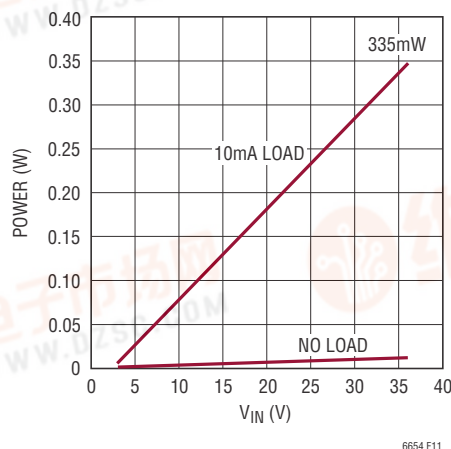
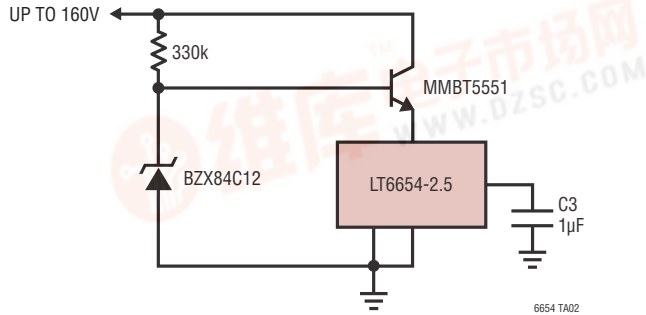


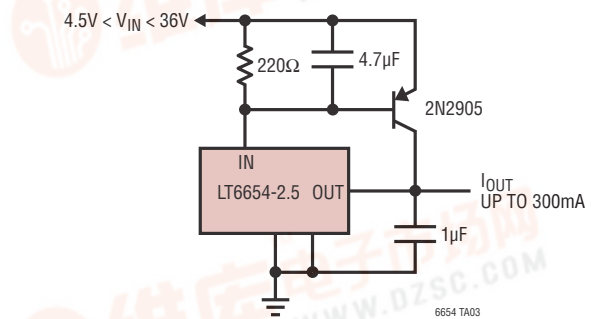
Figure 11. Typical Power Dissipation of the LT6654

TYPICAL APPLICATIONS

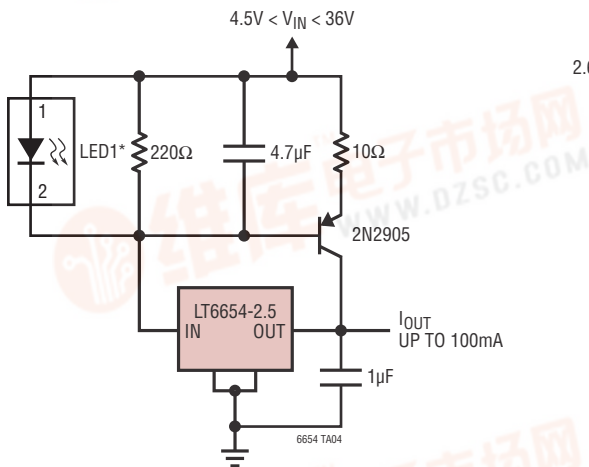
Extended Supply Range Reference



Boosted Output Current Reference

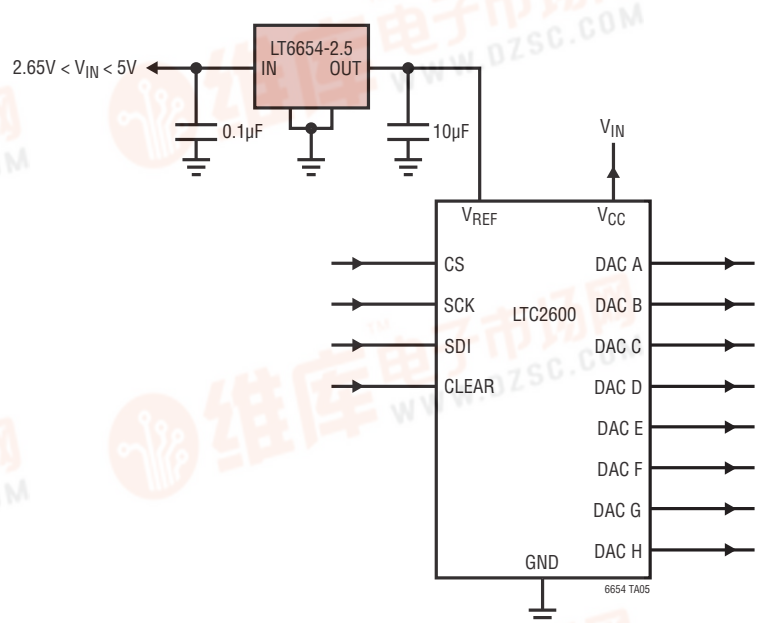


Boosted Output Current with Current Limit



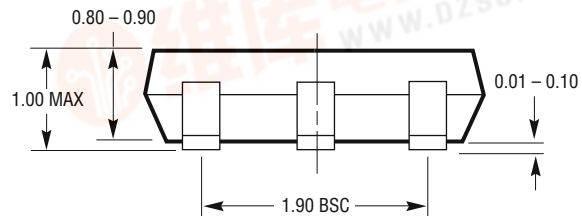
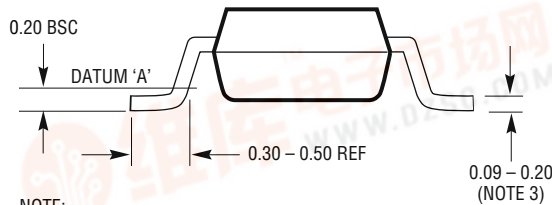
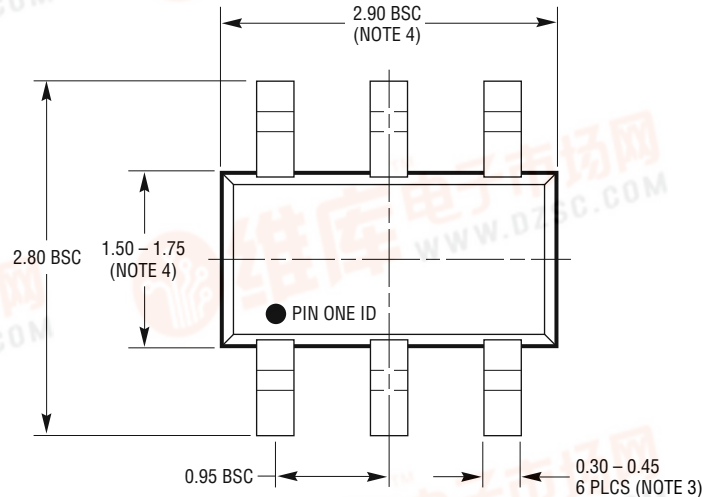
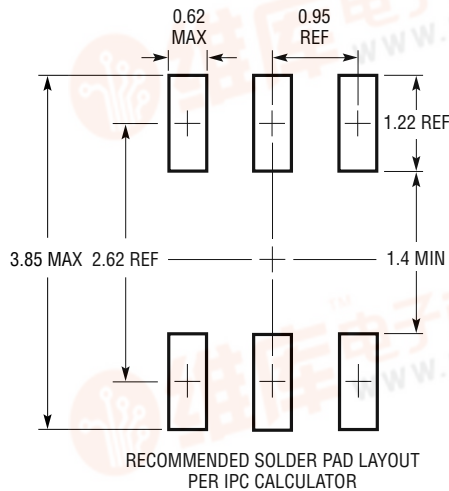
* LED CANNOT BE OMITTED
 THE LED CLAMPS THE VOLTAGE
 DROP ACROSS THE 220Ω AND
 LIMITS OUTPUT CURRENT

Octal DAC Reference



PACKAGE DESCRIPTION

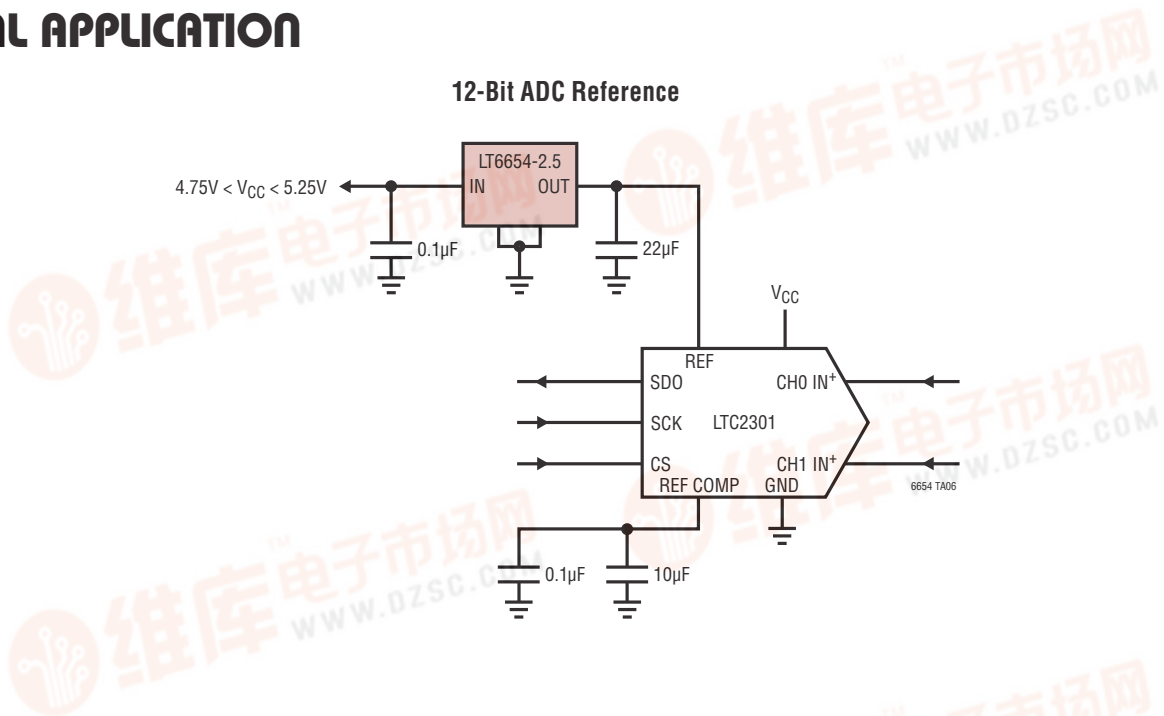
S6 Package
6-Lead Plastic TSOT-23
(Reference LTC DWG # 05-08-1636)



- NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
 2. DRAWING NOT TO SCALE
 3. DIMENSIONS ARE INCLUSIVE OF PLATING
 4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
 5. MOLD FLASH SHALL NOT EXCEED 0.254mm
 6. JEDEC PACKAGE REFERENCE IS MO-193

S6 TSOT-23 0302 REV B

TYPICAL APPLICATION



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1460	Micropower Series Reference	0.075% Max, 10ppm/°C Max Drift, 2.5V, 5V and 10V Versions, MSOP, PDIP, SO-8, SOT-23 and TO-92 Packages
LT1461	Micropower Precision LDO Series Reference	3ppm/°C Max Drift, 0°C to 70°C, -40°C to 85°C, -40°C to 125°C Options in SO-8
LT1790	Micropower Precision Series References	0.05% Max, 10ppm/°C Max, 60µA Supply, SOT-23 Package
LT6650	Micropower Reference with Buffer Amplifier	0.05% Max, 5.6µA Supply, SOT-23 Package
LTC6652	Precision Low Drift Low Noise Buffered Reference	0.5% Max, 5ppm/°C Max, 2.1ppm _{P-P} Noise (0.1Hz to 10Hz) 100% Tested at -40°C, 25°C and 125°C
LT6660	Tiny Micropower Series Reference	0.2% Max, 20ppm/°C Max, 20mA Output Current, 2mm × 2mm DFN
LTC6655	Precision Low Noise Reference	2ppm/°C Max, 650nV _{P-P} Noise (0.1Hz to 10Hz) 100% Tested at -40°C, 25°C and 125°C
LT6656	800nA Precision Voltage Reference	800nA, 10ppm/°C Max, 0.05% Max, SOT-23 Package