National Semiconductor

December 1994

LM194/LM394 Supermatch Pair

General Description

The LM194 and LM394 are junction isolated ultra well-matched monolithic NPN transistor pairs with an order of magnitude improvement in matching over conventional transistor pairs. This was accomplished by advanced linear processing and a unique new device structure.

Electrical characteristics of these devices such as drift versus initial offset voltage, noise, and the exponential relationship of base-emitter voltage to collector current closely approach those of a theoretical transistor. Extrinsic emitter and base resistances are much lower than presently available pairs, either monolithic or discrete, giving extremely low noise and theoretical operation over a wide current range. Most parameters are guaranteed over a current range of 1 μA to 1 mA and 0V up to 40V collector-base voltage, ensuring superior performance in nearly all applications.

To guarantee long term stability of matching parameters, internal clamp diodes have been added across the emitter-base junction of each transistor. These prevent degradation due to reverse biased emitter current—the most common cause of field failures in matched devices. The parasitic isolation junction formed by the diodes also clamps the substrate region to the most negative emitter to ensure complete isolation between devices.

The LM194 and LM394 will provide a considerable improvement in performance in most applications requiring a closely matched transistor pair. In many cases, trimming can be eliminated entirely, improving reliability and decreasing costs. Additionally, the low noise and high gain make this device attractive even where matching is not critical.

The LM194 and LM394/LM394B/LM394C are available in an isolated header 6-lead TO-5 metal can package. The LM394/LM394B/LM394C are available in an 8-pin plastic dual-in-line package. The LM194 is identical to the LM394 except for tighter electrical specifications and wider temperature range.

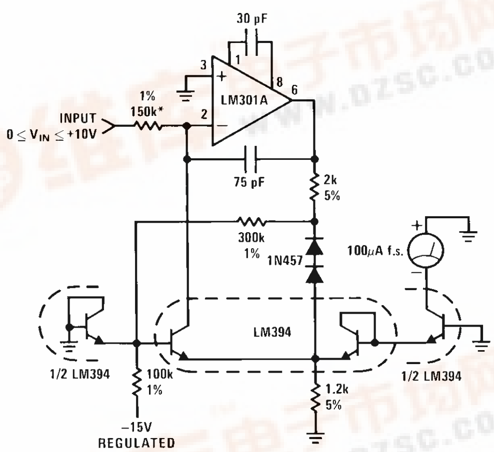
Features

- Emitter-base voltage matched to 50 μV
- Offset voltage drift less than 0.1 μV/°C
- Current gain (h_{FE}) matched to 2%
- Common-mode rejection ratio greater than 120 dB
- Parameters guaranteed over 1 μA to 1 mA collector current
- Extremely low noise
- Superior logging characteristics compared to conventional pairs
- Plug-in replacement for presently available devices

Typical Applications

Low Cost Accurate Square Root Circuit

$I_{OUT} = 10^{-5} \cdot \sqrt{10\, V_{IN}}$



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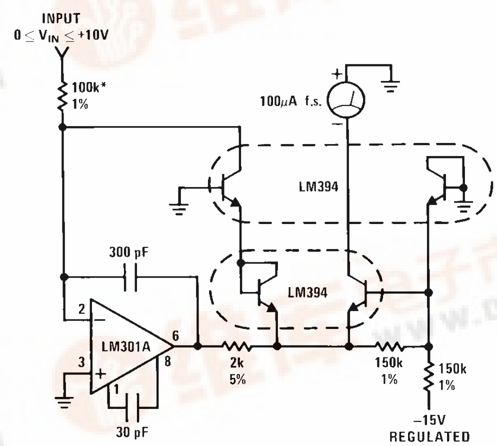
Low Cost Accurate Squaring Circuit

$I_{OUT} = 10^{-6} (V_{IN})^2$



TL/H/9241–2

*Trim for full scale accuracy

RRD-B30M115/Printed in U. S. A.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Collector Current	20 mA
Collector-Emitter Voltage	V_{MAX}
Collector-Emitter Voltage	35V
LM394C	20V
Collector-Base Voltage	35V
LM394C	20V
Collector-Substrate Voltage	35V
LM394C	20V
Collector-Collector Voltage	35V
LM394C	20V
Base-Emitter Current	±10 mA
Power Dissipation	500 mW
Junction Temperature	
LM194	−55°C to +125°C
LM394/LM394B/LM394C	−25°C to +85°C
Storage Temperature Range	−65°C to +150°C
Soldering Information	
Metal Can Package (10 sec.)	260°C
Dual-In-Line Package (10 sec.)	260°C
Small Outline Package	
Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C

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

Electrical Characteristics (T_J = 25°C)

Parameter	Conditions	LM194			LM394			LM394B/394C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Current Gain (h_{FE})	V_{CB} = 0V to V_{MAX} (Note 1)										
	I_C = 1 mA	350	700		300	700		225	500		
	I_C = 100 μA	350	550		250	550		200	400		
	I_C = 10 μA	300	450		200	450		150	300		
	I_C = 1 μA	200	300		150	300		100	200		
Current Gain Match, (h_{FE} Match) $= \frac{100\,[\Delta I_B]\,[h_{FE(MIN)}]}{I_C}$	V_{CB} = 0V to V_{MAX}										
	I_C = 10 μA to 1 mA		0.5	2		0.5	4		1.0	5	%
	I_C = 1 μA		1.0			1.0			2.0		%
Emitter-Base Offset Voltage	V_{CB} = 0, I_C = 1 μA to 1 mA		25	100		25	150		50	200	μV
Change in Emitter-Base Offset Voltage vs Collector-Base Voltage (CMRR)	(Note 1) I_C = 1 μA to 1 mA, V_{CB} = 0V to V_{MAX}		10	25		10	50		10	100	μV
Change in Emitter-Base Offset Voltage vs Collector Current	V_{CB} = 0V, I_C = 1 μA to 0.3 mA		5	25		5	50		5	50	μV
Emitter-Base Offset Voltage Temperature Drift	I_C = 10 μA to 1 mA (Note 2) I_{C1} = I_{C2}		0.08	0.3		0.08	1.0		0.2	1.5	μV/°C
	V_{OS} Trimmed to 0 at 25°C		0.03	0.1		0.03	0.3		0.03	0.5	μV/°C
Logging Conformity	I_C = 3 nA to 300 μA, V_{CB} = 0, (Note 3)		150			150			150		μV
Collector-Base Leakage	V_{CB} = V_{MAX}		0.05	0.25		0.05	0.5		0.05	0.5	nA
Collector-Collector Leakage	V_{CC} = V_{MAX}		0.1	2.0		0.1	5.0		0.1	5.0	nA
Input Voltage Noise	I_C = 100 μA, V_{CB} = 0V, f = 100 Hz to 100 kHz		1.8			1.8			1.8		$nV/\sqrt{Hz}$
Collector to Emitter Saturation Voltage	I_C = 1 mA, I_B = 10 μA		0.2			0.2			0.2		V
	I_C = 1 mA, I_B = 100 μA		0.1			0.1			0.1		V

Note 1: Collector-base voltage is swept from 0 to V_{MAX} at a collector current of 1 μA, 10 μA, 100 μA, and 1 mA.

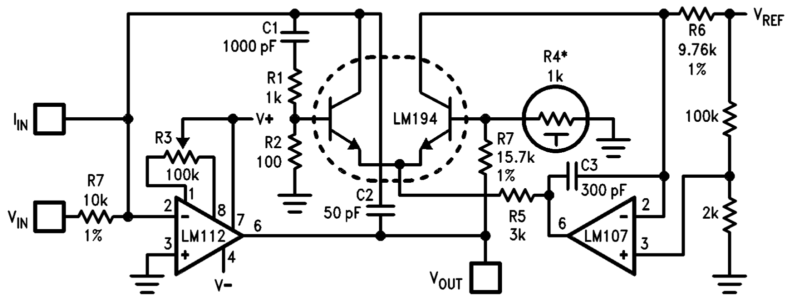
Note 2: Offset voltage drift with V_{OS} = 0 at T_A = 25°C is valid only when the ratio of I_{C1} to I_{C2} is adjusted to give the initial zero offset. This ratio must be held to within 0.003% over the entire temperature range. Measurements taken at +25°C and temperature extremes.

Note 3: Logging conformity is measured by computing the best fit to a true exponential and expressing the error as a base-emitter voltage deviation.

Note 4: Refer to RETS194X drawing of military LM194H version for specifications.

Typical Applications (Continued)

Fast, Accurate Logging Amplifier, V_{IN} = 10V to 0.1 mV or I_{IN} = 1 mA to 10 nA

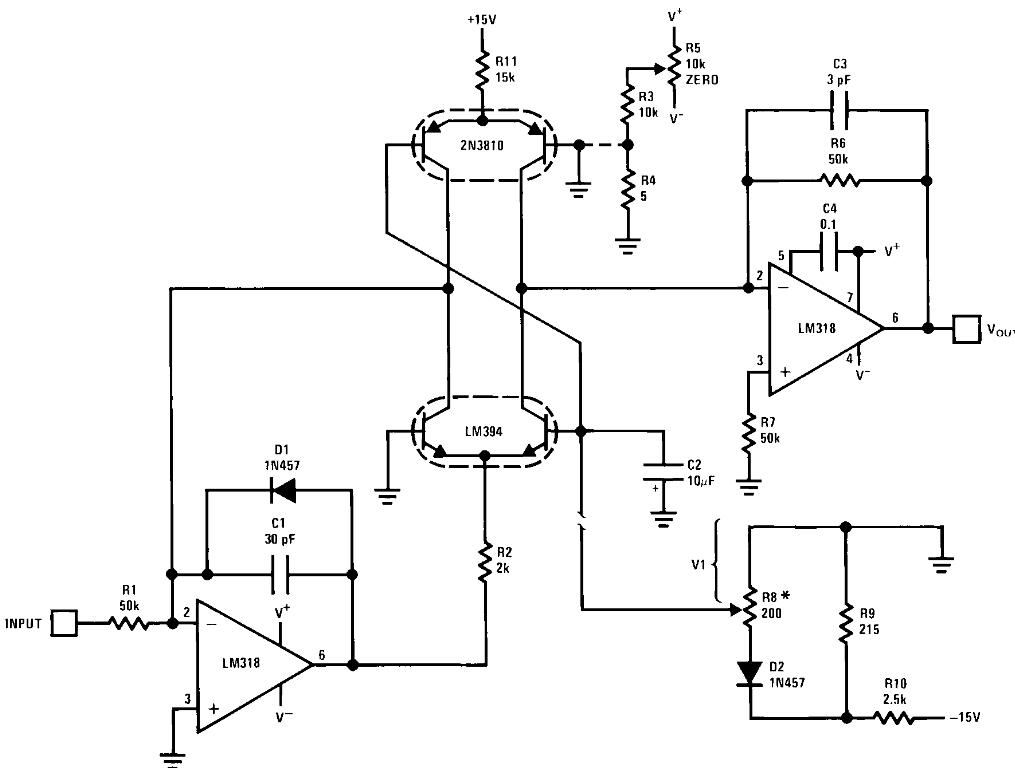


TL/H/9241–3

*1 kΩ (±1%) at 25°C, +3500 ppm/°C.
Available from Vishay Ultronix,
Grand Junction, CO, Q81 Series.

$$V_{OUT} = -\log_{10}\left(\frac{V_{IN}}{V_{REF}}\right)$$

Voltage Controlled Variable Gain Amplifier



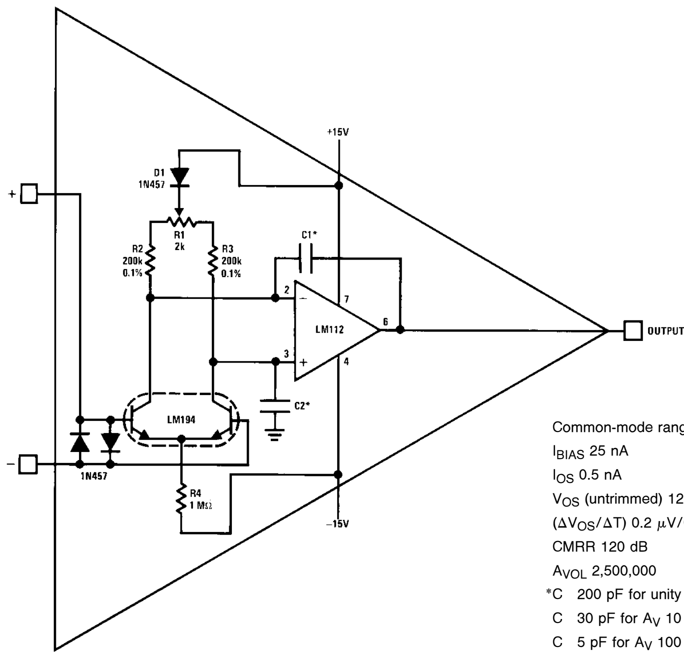
TL/H/9241–4

*R8–R10 and D2 provide a temperature independent gain control.
G = −336 V1 (dB)

Distortion < 0.1%
Bandwidth > 1 MHz
100 dB gain range

Typical Applications (Continued)

Precision Low Drift Operational Amplifier



Common-mode range 10V

I_{BIAS} 25 nA

I_{OS} 0.5 nA

V_{OS} (untrimmed) 125 μV

($\Delta V_{OS}/\Delta T$) 0.2 μV/C

CMRR 120 dB

A_{VOL} 2,500,000

*C 200 pF for unity gain

C 30 pF for A_V 10

C 5 pF for A_V 100

C 0 pF for A_V 1000

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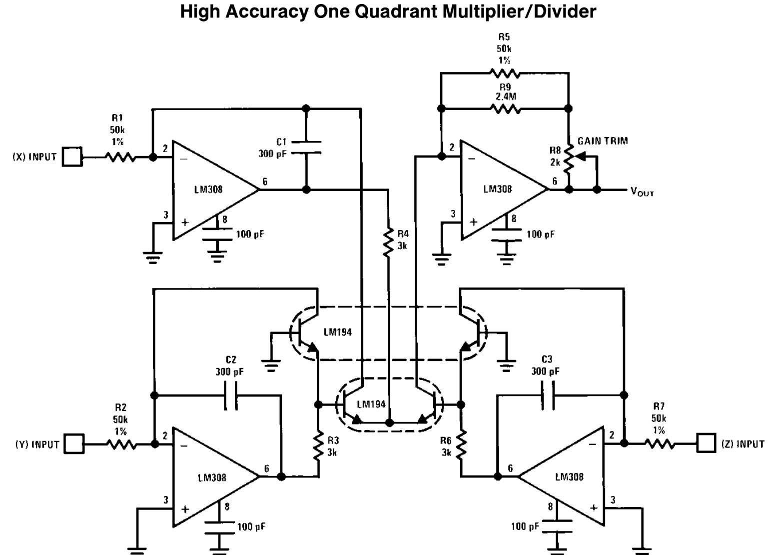
High Accuracy One Quadrant Multiplier/Divider



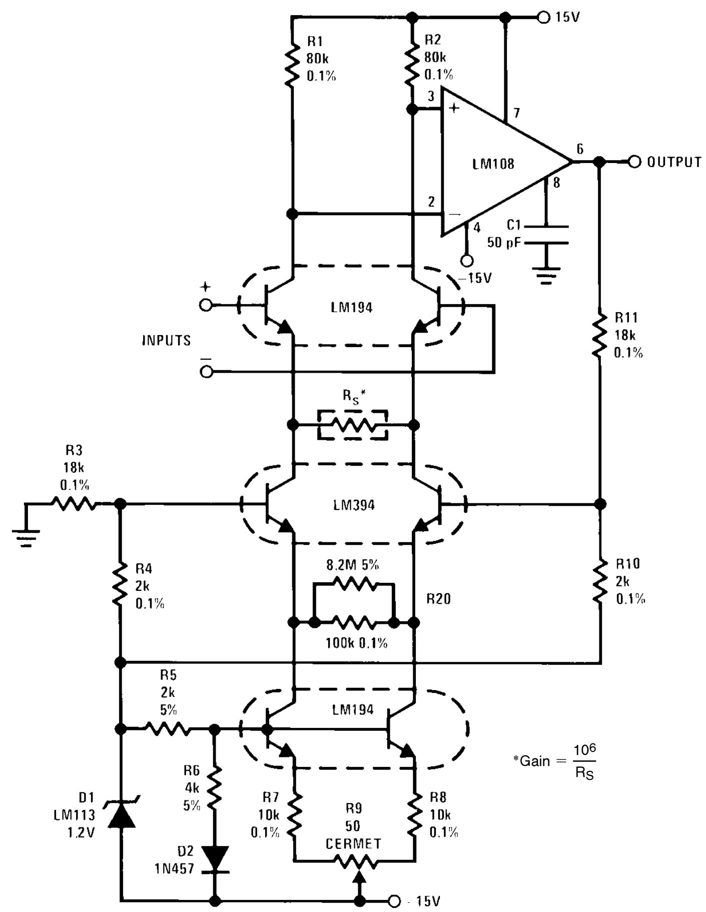
TL/H/9241–6

$V_{OUT} = \frac{(X)\,(Y)}{(Z)}$; positive inputs only.

*Typical linearity 0.1%

Typical Applications (Continued)

High Performance Instrumentation Amplifier



$$\text{*Gain} = \frac{10^6}{R_S}$$

TL/H/9241–7

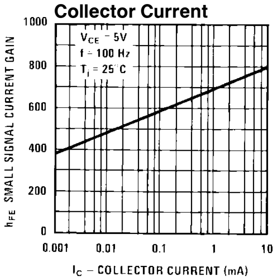
Performance Characteristics

	G = 10,000	G = 1,000	G = 100	G = 10	
Linearity of Gain (±10V Output)	≤0.01	≤0.01	≤0.02	≤0.05	%
Common-Mode Rejection Ratio (60 Hz)	≥120	≥120	≥110	≥90	dB
Common-Mode Rejection Ratio (1 kHz)	≥110	≥110	≥90	≥70	dB
Power Supply Rejection Ratio					
+ Supply	>110	>110	>110	>110	dB
− Supply	>110	>110	>90	>70	dB
Bandwidth (−3 dB)	50	50	50	50	kHz
Slew Rate	0.3	0.3	0.3	0.3	V/μs
Offset Voltage Drift**	≤0.25	≤0.4	2	≤10	μV/°C
Common-Mode Input Resistance	$>10^9$	$>10^9$	$>10^9$	$>10^9$	Ω
Differential Input Resistance	$>3 \times 10^8$	$>3 \times 10^8$	$>3 \times 10^8$	$>3 \times 10^8$	Ω
Input Referred Noise (100 Hz ≤ f ≤ 10 kHz)	5	6	12	70	$\frac{nV}{\sqrt{Hz}}$
Input Bias Current	75	75	75	75	nA
Input Offset Current	1.5	1.5	1.5	1.5	nA
Common-Mode Range	±11	±11	±11	±10	V
Output Swing (R_L = 10 kΩ)	±13	±13	±13	±13	V

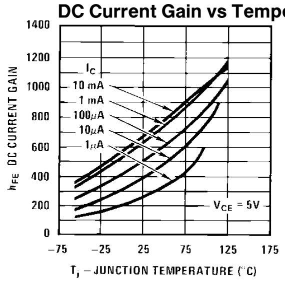
**Assumes ≤ 5 ppm/°C tracking of resistors

Typical Performance Characteristics

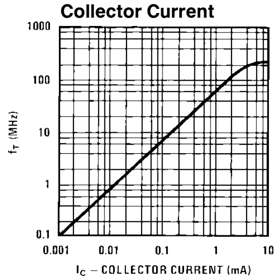
Small Signal Current Gain vs Collector Current



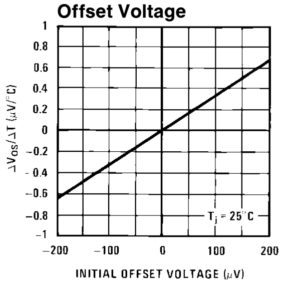
DC Current Gain vs Temperature



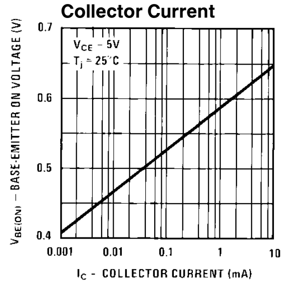
Unity Gain Frequency (f_t) vs Collector Current



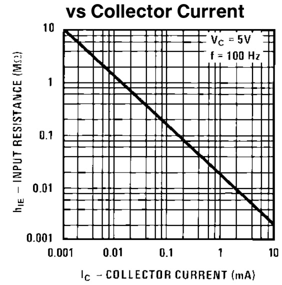
Offset Voltage Drift vs Initial Offset Voltage



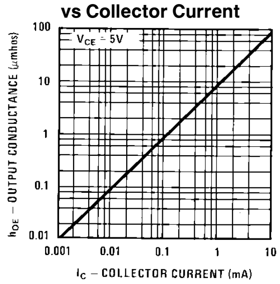
Base-Emitter On Voltage vs Collector Current



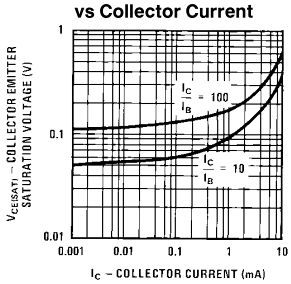
Small Signal Input Resistance (h_{ie}) vs Collector Current



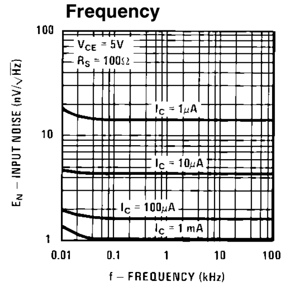
Small Signal Output Conductance vs Collector Current



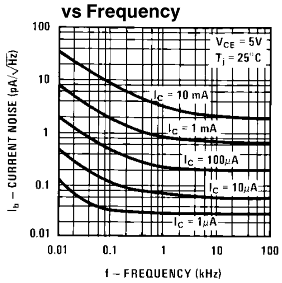
Collector-Emitter Saturation Voltage vs Collector Current



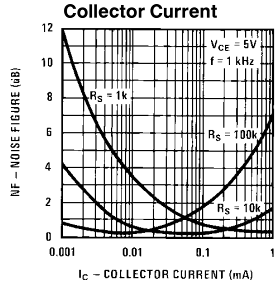
Input Voltage Noise vs Frequency



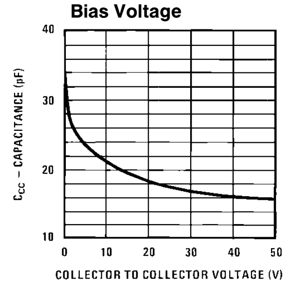
Base Current Noise vs Frequency



Noise Figure vs Collector Current



Collector to Collector Capacitance vs Reverse Bias Voltage



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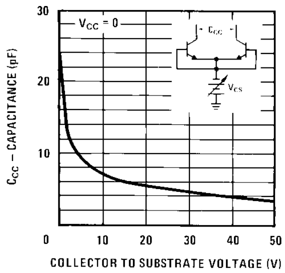
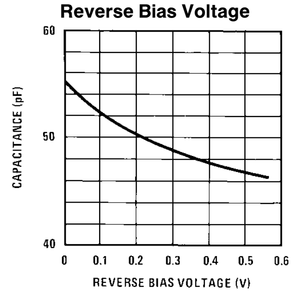
Typical Performance Characteristics (Continued)

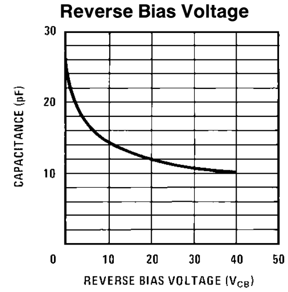
Collector to Collector Capacitance vs Collector-Substrate Voltage



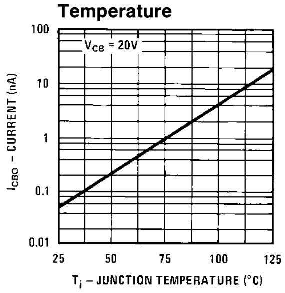
Emitter-Base Capacitance vs Reverse Bias Voltage



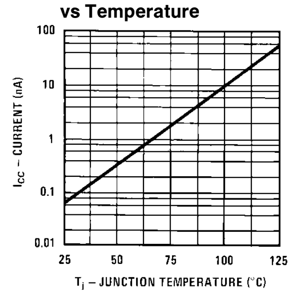
Collector-Base Capacitance vs Reverse Bias Voltage



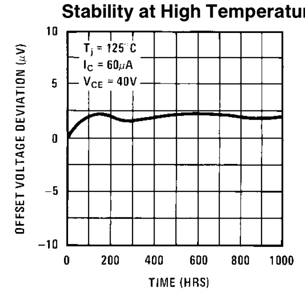
Collector-Base Leakage vs Temperature



Collector to Collector Leakage vs Temperature



Offset Voltage Long Term Stability at High Temperature



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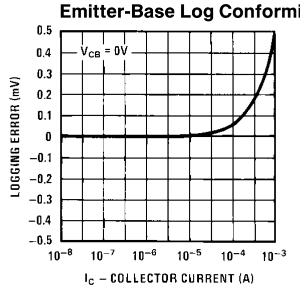
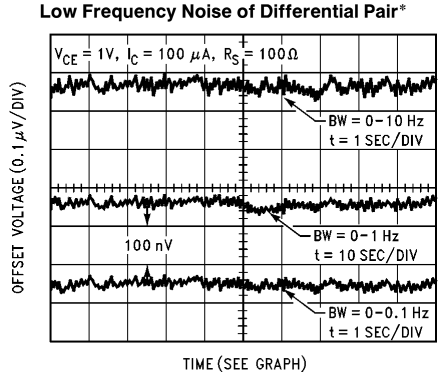
Emitter-Base Log Conformity



TL/H/9241–10

Low Frequency Noise of Differential Pair*

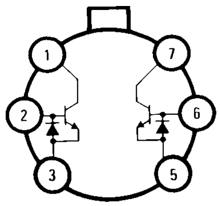


TL/H/9241–11

*Unit must be in still air environment so that differential lead temperature is held to less than 0.0003°C.

Connection Diagrams

Metal Can Package

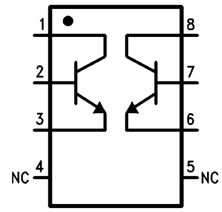


TL/H/9241–12

Top View

Order Number LM194H/883*,
LM394H, LM394BH or LM394CH
See NS Package Number H06C

Dual-In-Line and Small Outline Packages



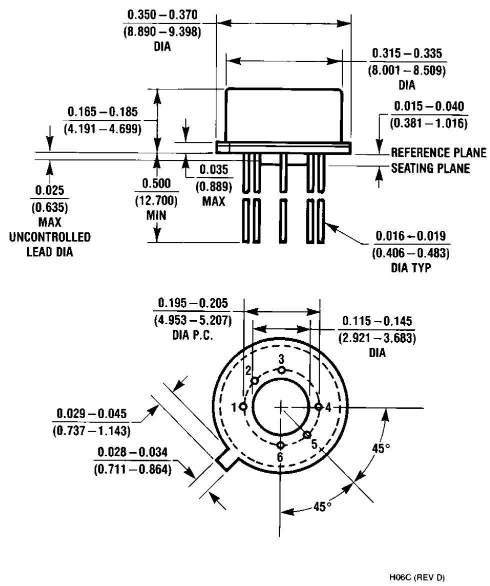
TL/H/9241–13

Top View

Order Number LM394N or LM394CN
See NS Package Number N08E

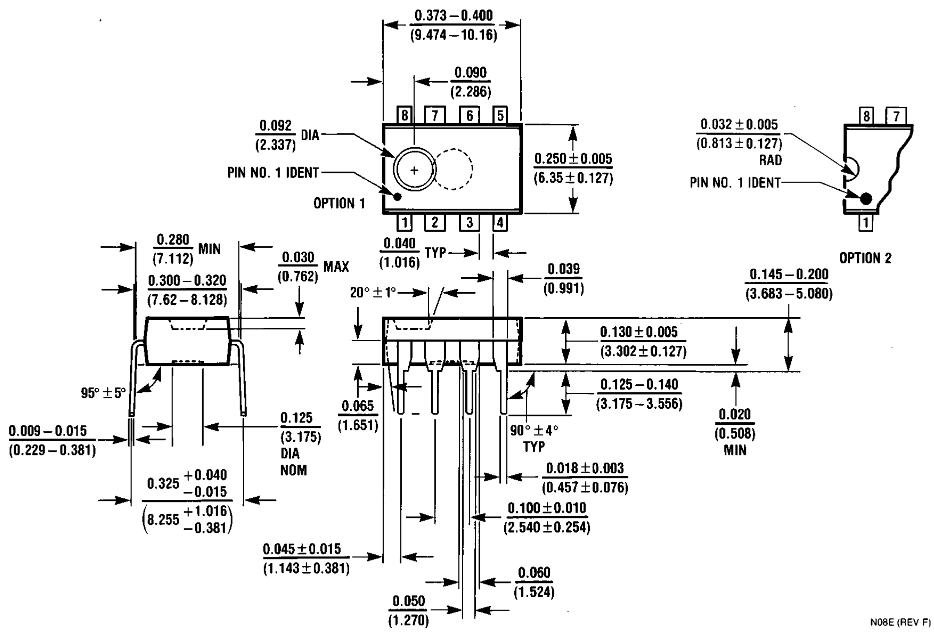
*Available per SMD #5962-8777701

Physical Dimensions inches (millimeters)



Metal Can Package (H)
Order Number LM194H/883, LM394H, LM394BH or LM394CH
NS Package Number H06C

Physical Dimensions inches (millimeters) (Continued)



Molded Dual-In-Line Package (N)
Order Number LM394CN or LM394N
NS Package Number N08E

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