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LM324, LM324A, LM324E, LM224, LM2902, LM2902E, LM2902V, NCV2902

Single Supply Quad Operational Amplifiers

The LM324 series are low−cost, quad operational amplifiers with true differential inputs. They have several distinct advantages over standard operational amplifier types in single supply applications. The quad amplifier can operate at supply voltages as low as 3.0 V or as high as 32 V with quiescent currents about one−fifth of those associated with the MC1741 (on a per amplifier basis). The common mode input range includes the negative supply, thereby eliminating the necessity for external biasing components in many applications. The output voltage range also includes the negative power supply voltage.

Features

- Short Circuited Protected Outputs
- True Differential Input Stage
- Single Supply Operation: 3.0 V to 32 V
- Low Input Bias Currents: 100 nA Maximum (LM324A)
- Four Amplifiers Per Package
- Internally Compensated
- Common Mode Range Extends to Negative Supply
- Industry Standard Pinouts
- ESD Clamps on the Inputs Increase Ruggedness without Affecting Device Operation
- NCV Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC−Q100 Qualified and PPAP Capable
- These Devices are Pb−Free, Halogen Free/BFR Free and are RoHS Compliant

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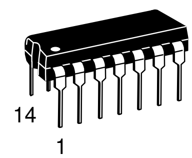
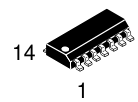
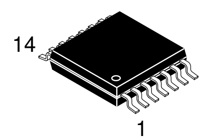


PDIP−14
N SUFFIX
CASE 646

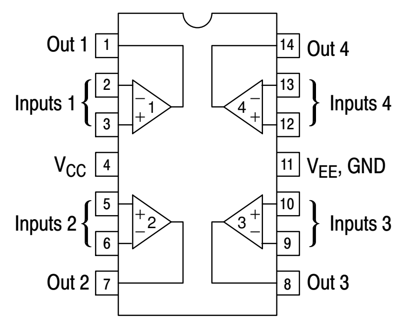


SOIC−14
D SUFFIX
CASE 751A



TSSOP−14
DTB SUFFIX
CASE 948G

PIN CONNECTIONS



(Top View)

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 10 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 11 of this data sheet.

October, 2016 − Rev. 29

Publication Order Number:
LM324/D

MAXIMUM RATINGS (T_A = +25°C, unless otherwise noted.)

Rating	Symbol	Value	Unit
Power Supply Voltages Single Supply Split Supplies	 V_{CC} V_{CC}, V_{EE}	 32 ±16	Vdc
Input Differential Voltage Range (Note 1)	V_{IDR}	±32	Vdc
Input Common Mode Voltage Range	V_{ICR}	−0.3 to 32	Vdc
Output Short Circuit Duration	t_{SC}	Continuous	
Junction Temperature	T_J	150	°C
Thermal Resistance, Junction−to−Air (Note 2) Case 646 Case 751A Case 948G	$R_{\theta JA}$	118 156 190	°C/W
Storage Temperature Range	T_{stg}	−65 to +150	°C
Operating Ambient Temperature Range LM224 LM324, LM324A, LM324E LM2902, LM2902E LM2902V, NCV2902 (Note 3)	T_A	 −25 to +85 0 to +70 −40 to +105 −40 to +125	°C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.
1. Split Power Supplies.
2. All $R_{\theta JA}$ measurements made on evaluation board with 1 oz. copper traces of minimum pad size. All device outputs were active.
3. *NCV2902 is qualified for automitive use.*

ESD RATINGS

Rating	HBM	MM	Unit
ESD Protection at any Pin (Human Body Model – HBM, Machine Model – MM)			
NCV2902 (Note 3)	2000	200	V
LM324E, LM2902E	2000	200	V
LM324DG/DR2G, LM2902DG/DR2G	200	100	V
All Other Devices	2000	200	V

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, V_{EE} = GND, T_A = 25°C, unless otherwise noted.)

Characteristics	Symbol	LM224			LM324A			LM324, LM324E			LM2902, LM2902E			LM2902V/NCV2902			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage V_{CC} = 5.0 V to 30 V V_{ICR} = 0 V to V_{CC} –1.7 V, V_O = 1.4 V, R_S = 0 Ω	V_{IO}																mV
T_A = 25°C		–	2.0	5.0	–	2.0	3.0	–	2.0	7.0	–	2.0	7.0	–	2.0	7.0	
T_A = T_{high} (Note 4)		–	–	7.0	–	–	5.0	–	–	9.0	–	–	10	–	–	13	
T_A = T_{low} (Note 4)		–	–	7.0	–	–	5.0	–	–	9.0	–	–	10	–	–	10	
Average Temperature Coefficient of Input Offset Voltage T_A = T_{high} to T_{low} (Notes 4 and 6)	$\Delta V_{IO}/\Delta T$	–	7.0	–	–	7.0	30	–	7.0	–	–	7.0	–	–	7.0	–	μV/°C
Input Offset Current	I_{IO}	–	3.0	30	–	5.0	30	–	5.0	50	–	5.0	50	–	5.0	50	nA
T_A = T_{high} to T_{low} (Note 4)		–	–	100	–	–	75	–	–	150	–	–	200	–	–	200	
Average Temperature Coefficient of Input Offset Current T_A = T_{high} to T_{low} (Notes 4 and 6)	$\Delta I_{IO}/\Delta T$	–	10	–	–	10	300	–	10	–	–	10	–	–	10	–	pA/°C
Input Bias Current	I_{IB}	–	–90	–150	–	–45	–100	–	–90	–250	–	–90	–250	–	–90	–250	nA
T_A = T_{high} to T_{low} (Note 4)		–	–	–300	–	–	–200	–	–	–500	–	–	–500	–	–	–500	
Input Common Mode Voltage Range (Note 5) V_{CC} = 30 V	V_{ICR}																V
T_A = +25°C		0	–	28.3	0	–	28.3	0	–	28.3	0	–	28.3	0	–	28.3	
T_A = T_{high} to T_{low} (Note 4)		0	–	28	0	–	28	0	–	28	0	–	28	0	–	28	
Differential Input Voltage Range	V_{IDR}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	V
Large Signal Open Loop Voltage Gain R_L = 2.0 kΩ, V_{CC} = 15 V, for Large V_O Swing	A_{VOL}	50	100	–	25	100	–	25	100	–	25	100	–	25	100	–	V/mV
T_A = T_{high} to T_{low} (Note 4)		25	–	–	15	–	–	15	–	–	15	–	–	15	–	–	
Channel Separation 10 kHz ≤ f ≤ 20 kHz, Input Referenced	CS	–	–120	–	–	–120	–	–	–120	–	–	–120	–	–	–120	–	dB
Common Mode Rejection, R_S ≤ 10 kΩ	CMR	70	85	–	65	70	–	65	70	–	50	70	–	50	70	–	dB
Power Supply Rejection	PSR	65	100	–	65	100	–	65	100	–	50	100	–	50	100	–	dB

4. LM224: T_{low} = –25°C, T_{high} = +85°C
   LM324/LM324A/LM324E: T_{low} = 0°C, T_{high} = +70°C
   LM2902/LM2902E: T_{low} = –40°C, T_{high} = +105°C
   LM2902V & NCV2902: T_{low} = –40°C, T_{high} = +125°C
   NCV2902 is qualified for automotive use.
5. The input common mode voltage or either input signal voltage should not be allowed to go negative by more than 0.3 V. The upper end of the common mode voltage range is V_{CC} –1.7 V, but either or both inputs can go to +32 V without damage, independent of the magnitude of V_{CC}.
6. Guaranteed by design.

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, V_{EE} = GND, T_A = 25°C, unless otherwise noted.)

Characteristics	Symbol	LM224			LM324A			LM324, LM324E			LM2902, LM2902E			LM2902V/NCV2902			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage – High Limit	V_{OH}																V
V_{CC} = 5.0 V, R_L = 2.0 kΩ, T_A = 25°C		3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	
V_{CC} = 30 V, R_L = 2.0 kΩ (T_A = T_{high} to T_{low}) (Note 7)		26	–	–	26	–	–	26	–	–	26	–	–	26	–	–	
V_{CC} = 30 V, R_L = 10 kΩ (T_A = T_{high} to T_{low}) (Note 7)		27	28	–	27	28	–	27	28	–	27	28	–	27	28	–	
Output Voltage – Low Limit, V_{CC} = 5.0 V, R_L = 10 kΩ, T_A = T_{high} to T_{low} (Note 7)	V_{OL}	–	5.0	20	–	5.0	20	–	5.0	20	–	5.0	100	–	5.0	100	mV
Output Source Current (V_{ID} = +1.0 V, V_{CC} = 15 V)	I_{O+}																mA
T_A = 25°C		20	40	–	20	40	–	20	40	–	20	40	–	20	40	–	
T_A = T_{high} to T_{low} (Note 7)		10	20	–	10	20	–	10	20	–	10	20	–	10	20	–	
Output Sink Current	I_{O-}																mA
(V_{ID} = –1.0 V, V_{CC} = 15 V) T_A = 25°C		10	20	–	10	20	–	10	20	–	10	20	–	10	20	–	
T_A = T_{high} to T_{low} (Note 7)		5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	
(V_{ID} = –1.0 V, V_O = 200 mV, T_A = 25°C)		12	50	–	12	50	–	12	50	–	–	–	–	–	–	–	μA
Output Short Circuit to Ground (Note 8)	I_{SC}	–	40	60	–	40	60	–	40	60	–	40	60	–	40	60	mA
Power Supply Current (T_A = T_{high} to T_{low}) (Note 7)	I_{CC}																mA
V_{CC} = 30 V, V_O = 0 V, R_L = ∞		–	–	3.0	–	1.4	3.0	–	–	3.0	–	–	3.0	–	–	3.0	
V_{CC} = 5.0 V, V_O = 0 V, R_L = ∞		–	–	1.2	–	0.7	1.2	–	–	1.2	–	–	1.2	–	–	1.2	

7. LM224: T_{low} = –25°C, T_{high} = +85°C
   LM324/LM324A/LM324E: T_{low} = 0°C, T_{high} = +70°C
   LM2902/LM2902E: T_{low} = –40°C, T_{high} = +105°C
   LM2902V & NCV2902: T_{low} = –40°C, T_{high} = +125°C
   NCV2902 is qualified for automotive use.
8. The input common mode voltage or either input signal voltage should not be allowed to go negative by more than 0.3 V. The upper end of the common mode voltage range is V_{CC} –1.7 V, but either or both inputs can go to +32 V without damage, independent of the magnitude of V_{CC}.

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

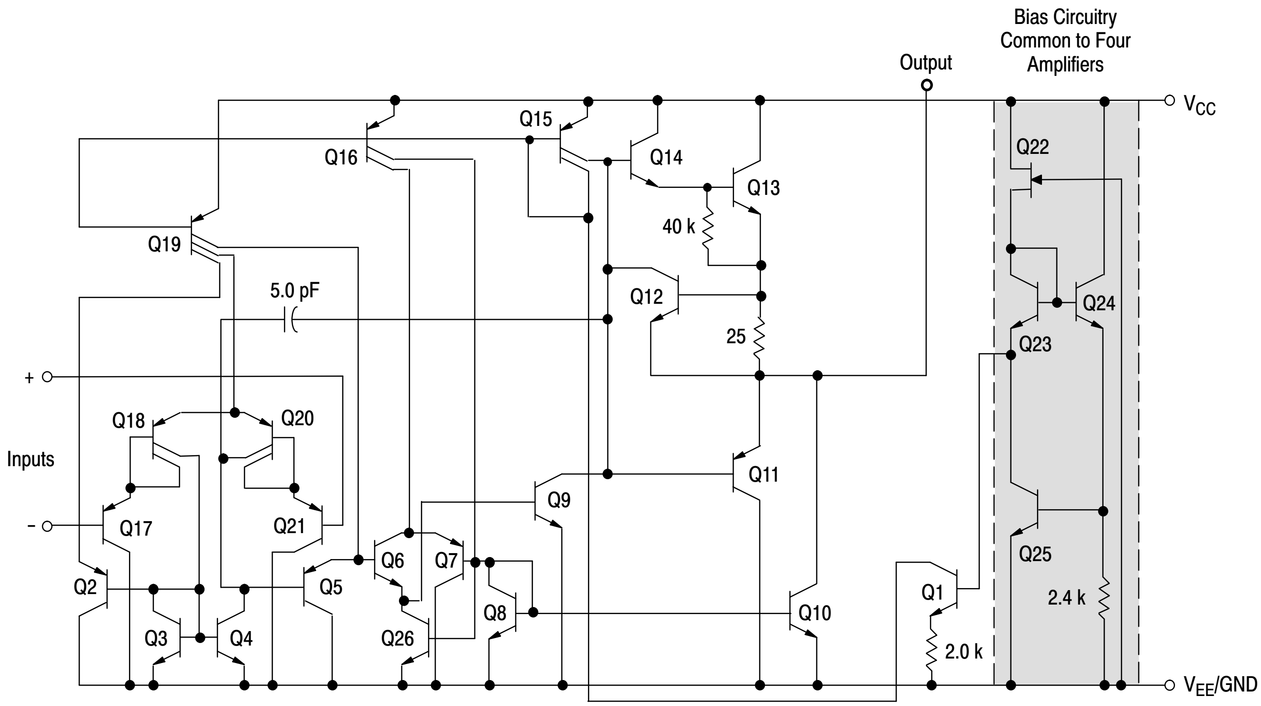


Figure 1. Representative Circuit Diagram
(One−Fourth of Circuit Shown)

CIRCUIT DESCRIPTION

The LM324 series is made using four internally compensated, two−stage operational amplifiers. The first stage of each consists of differential input devices Q20 and Q18 with input buffer transistors Q21 and Q17 and the differential to single ended converter Q3 and Q4. The first stage performs not only the first stage gain function but also performs the level shifting and transconductance reduction functions. By reducing the transconductance, a smaller compensation capacitor (only 5.0 pF) can be employed, thus saving chip area. The transconductance reduction is accomplished by splitting the collectors of Q20 and Q18. Another feature of this input stage is that the input common mode range can include the negative supply or ground, in single supply operation, without saturating either the input devices or the differential to single−ended converter. The second stage consists of a standard current source load amplifier stage.

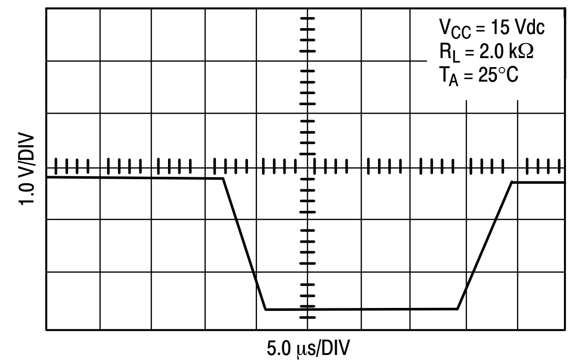
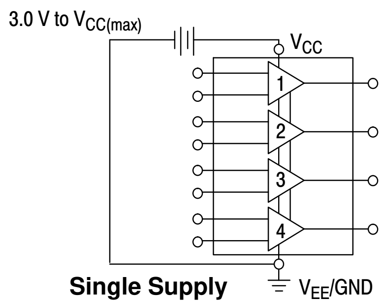
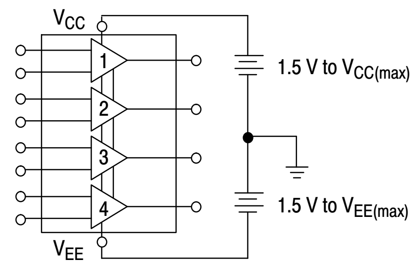


Figure 2. Large Signal Voltage Follower Response

Each amplifier is biased from an internal−voltage regulator which has a low temperature coefficient thus giving each amplifier good temperature characteristics as well as excellent power supply rejection.



Single Supply



Split Supplies

Figure 3.

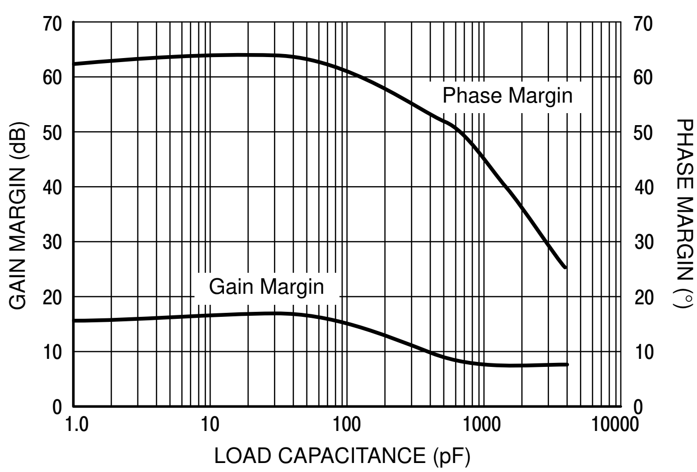


Figure 4. Gain and Phase Margin

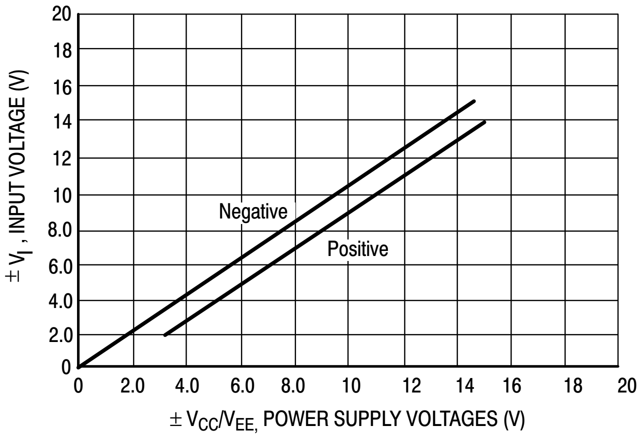


Figure 5. Input Voltage Range

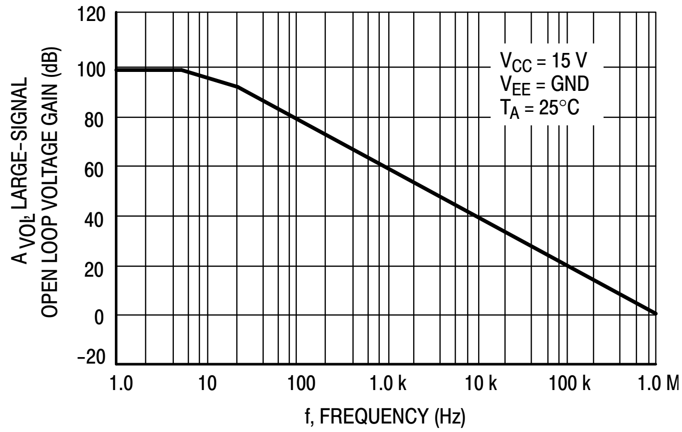


Figure 6. Open Loop Frequency

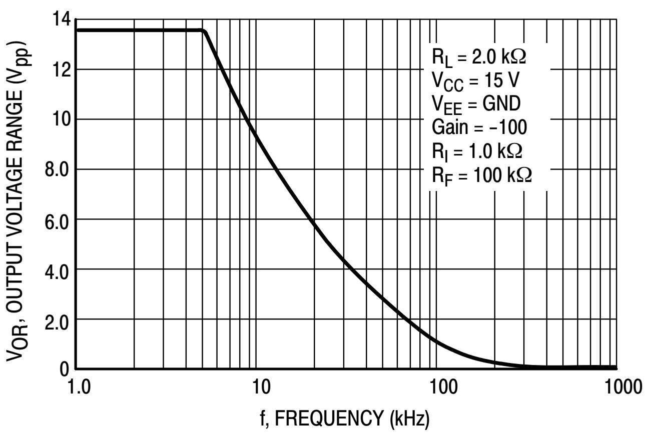


Figure 7. Large−Signal Frequency Response

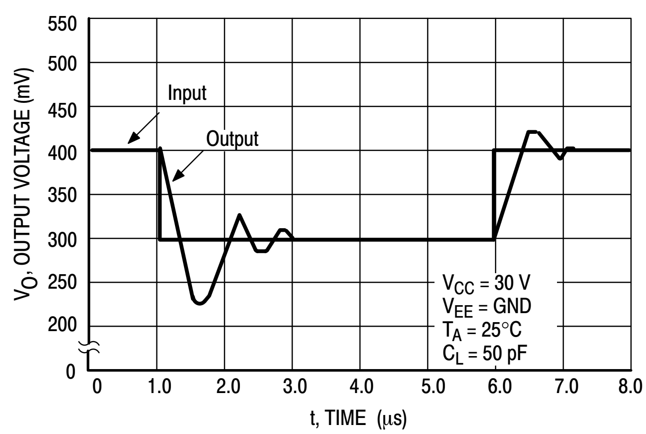


Figure 8. Small−Signal Voltage Follower Pulse Response (Noninverting)

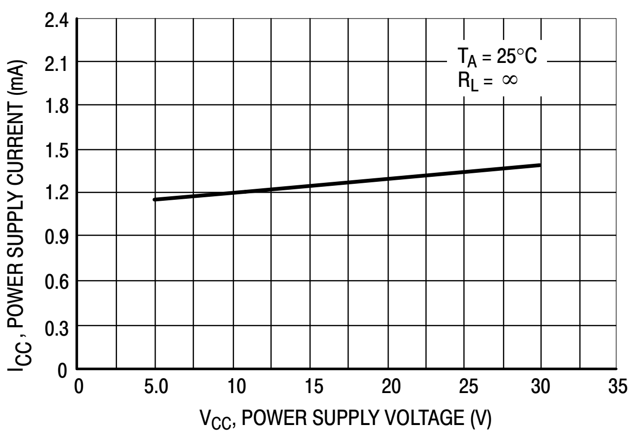


Figure 9. Power Supply Current versus Power Supply Voltage

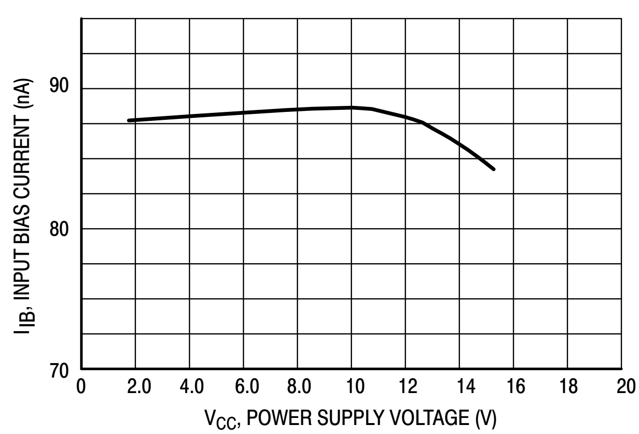
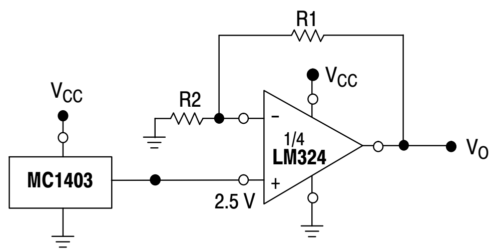


Figure 10. Input Bias Current versus Power Supply Voltage



$$V_O = 2.5\,V \left(1 + \frac{R1}{R2}\right)$$

Figure 11. Voltage Reference

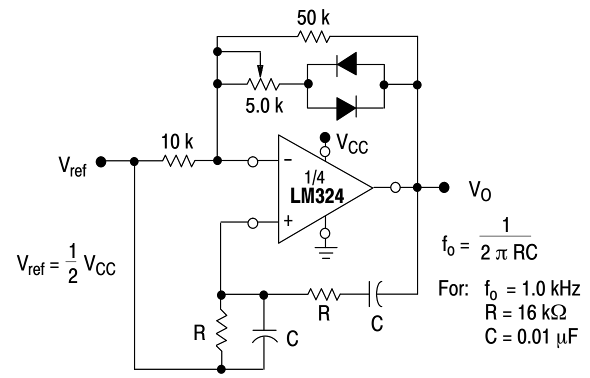
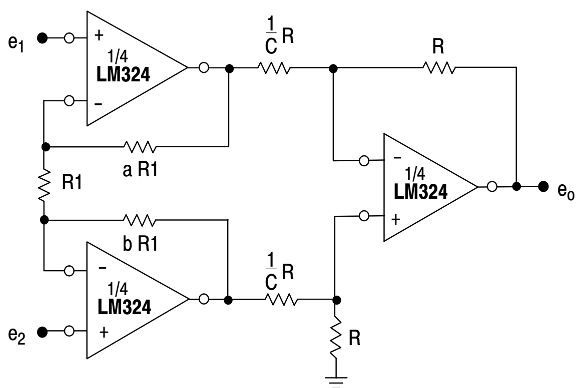
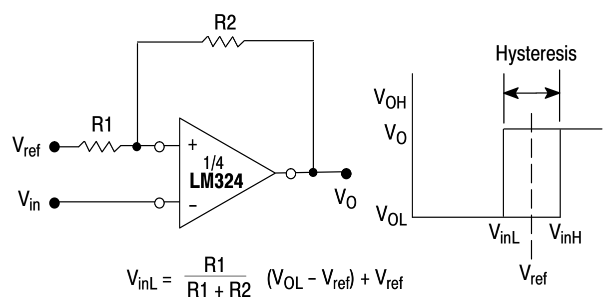


Figure 12. Wien Bridge Oscillator



$$e_o = C\,(1 + a + b)\,(e_2 - e_1)$$

Figure 13. High Impedance Differential Amplifier



$$V_{inL} = \frac{R1}{R1 + R2}\,(V_{OL} - V_{ref}) + V_{ref}$$

$$V_{inH} = \frac{R1}{R1 + R2}\,(V_{OH} - V_{ref}) + V_{ref}$$

$$H = \frac{R1}{R1 + R2}\,(V_{OH} - V_{OL})$$

Figure 14. Comparator with Hysteresis

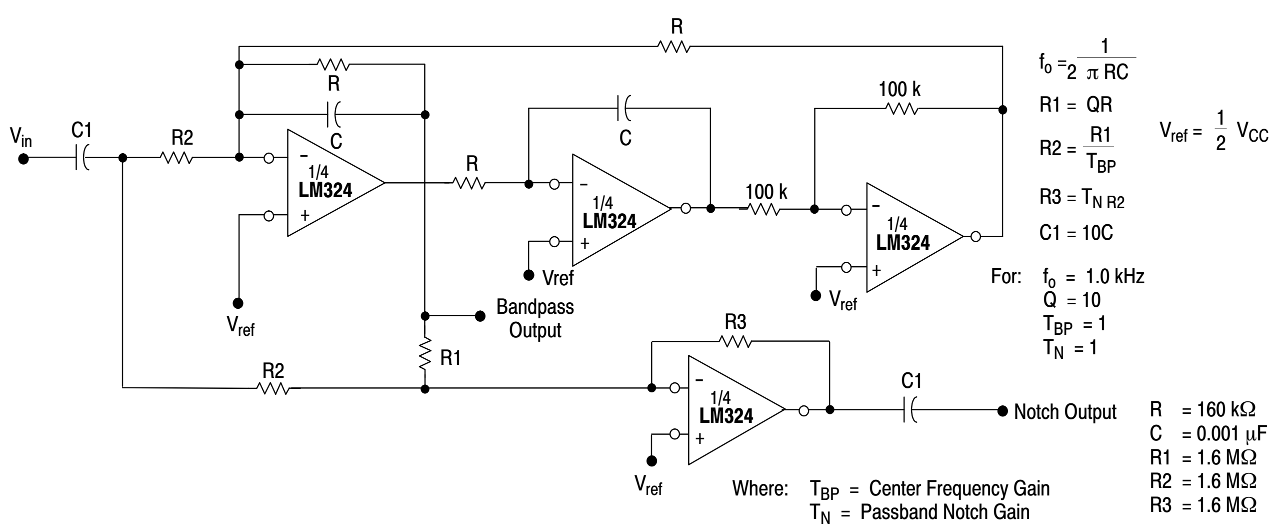
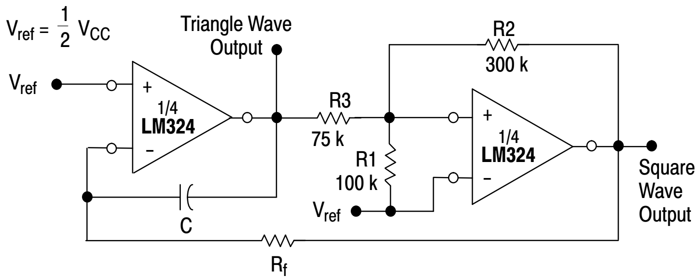


Figure 15. Bi−Quad Filter



$$f = \frac{R1 + R_C}{4\,CR_f\,R1} \quad \text{if} \quad R3 = \frac{R2\,R1}{R2 + R1}$$

Figure 16. Function Generator

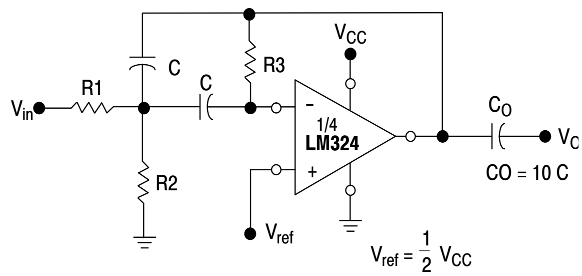


Figure 17. Multiple Feedback Bandpass Filter

Given: f_o = center frequency
$A(f_o)$ = gain at center frequency

Choose value f_o, C

Then: $R3 = \frac{Q}{\pi f_o C}$

$R1 = \frac{R3}{2 A(f_o)}$

$R2 = \frac{R1\,R3}{4Q^2 R1 - R3}$

For less than 10% error from operational amplifier, $\frac{Q_o f_o}{BW} < 0.1$

where f_o and BW are expressed in Hz.

If source impedance varies, filter may be preceded with voltage follower buffer to stabilize filter parameters.

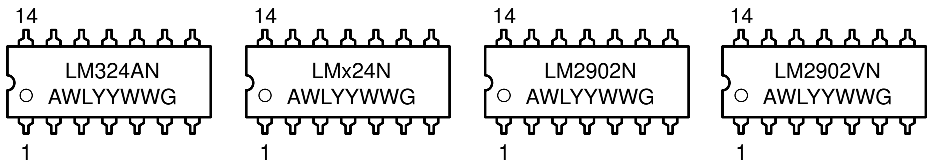
ORDERING INFORMATION

Device	Operating Temperature Range	Package	Shipping†
LM224DG	−25°C to +85°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM224DR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM224DTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM224DTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM224NG		PDIP−14 (Pb−Free)	25 Units/Rail
LM324DG	0°C to +70°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM324DR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM324EDR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM324DTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM324DTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM324NG		PDIP−14 (Pb−Free)	25 Units/Rail
LM324ADG		SOIC−14 (Pb−Free)	55 Units/Rail
LM324ADR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM324ADTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM324ADTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM324ANG		PDIP−14 (Pb−Free)	25 Units/Rail
LM2902DG	−40°C to +105°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM2902DR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM2902EDR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM2902DTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM2902DTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM2902NG		PDIP−14 (Pb−Free)	25 Units/Rail
LM2902VDG	−40°C to +125°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM2902VDR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM2902VDTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM2902VDTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM2902VNG		PDIP−14 (Pb−Free)	25 Units/Rail
NCV2902DR2G*		SOIC−14 (Pb−Free)	2500/Tape & Reel
NCV2902DTBR2G*		TSSOP−14 (Pb−Free)	

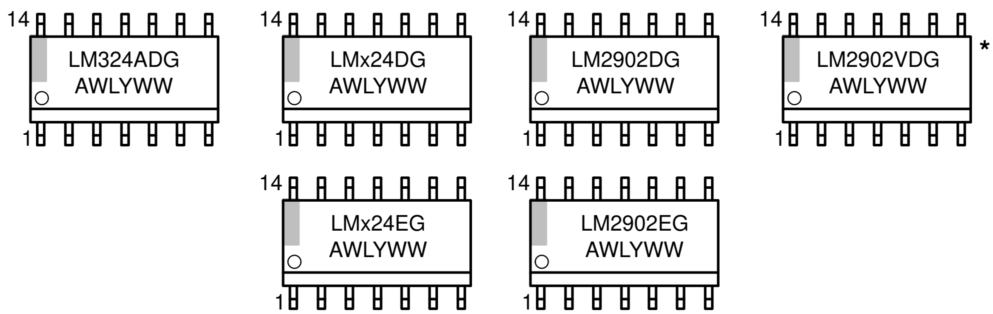
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.
*NCV Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC−Q100 Qualified and PPAP Capable.

MARKING DIAGRAMS

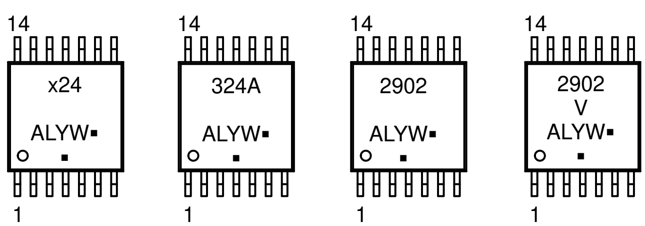
PDIP−14
N SUFFIX
CASE 646



SOIC−14
D SUFFIX
CASE 751A



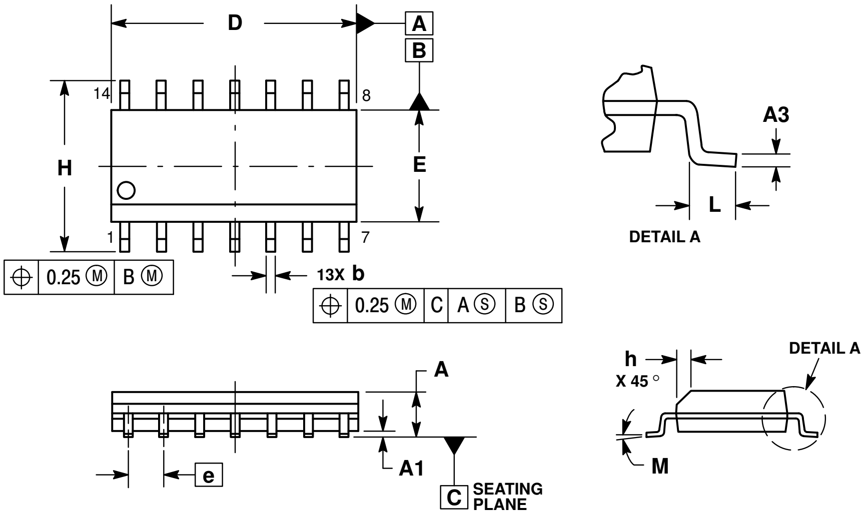
TSSOP−14
DTB SUFFIX
CASE 948G



x = 2 or 3
A = Assembly Location
WL, L = Wafer Lot
YY, Y = Year
WW, W = Work Week
G or ▪ = Pb−Free Package
(Note: Microdot may be in either location)
*This marking diagram also applies to NCV2902.

PACKAGE DIMENSIONS

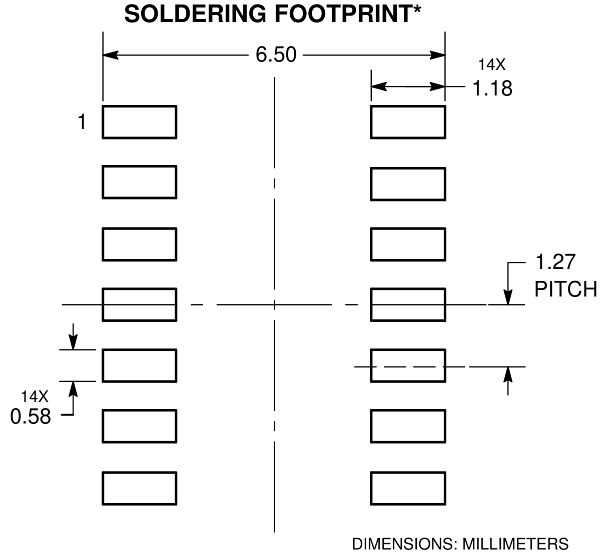
SOIC−14
CASE 751A−03
ISSUE K



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSION b DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE PROTRUSION SHALL BE 0.13 TOTAL IN EXCESS OF AT MAXIMUM MATERIAL CONDITION.
4. DIMENSIONS D AND E DO NOT INCLUDE MOLD PROTRUSIONS.
5. MAXIMUM MOLD PROTRUSION 0.15 PER SIDE.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	1.35	1.75	0.054	0.068
A1	0.10	0.25	0.004	0.010
A3	0.19	0.25	0.008	0.010
b	0.35	0.49	0.014	0.019
D	8.55	8.75	0.337	0.344
E	3.80	4.00	0.150	0.157
e	1.27 BSC		0.050 BSC	
H	5.80	6.20	0.228	0.244
h	0.25	0.50	0.010	0.019
L	0.40	1.25	0.016	0.049
M	0°	7°	0°	7°

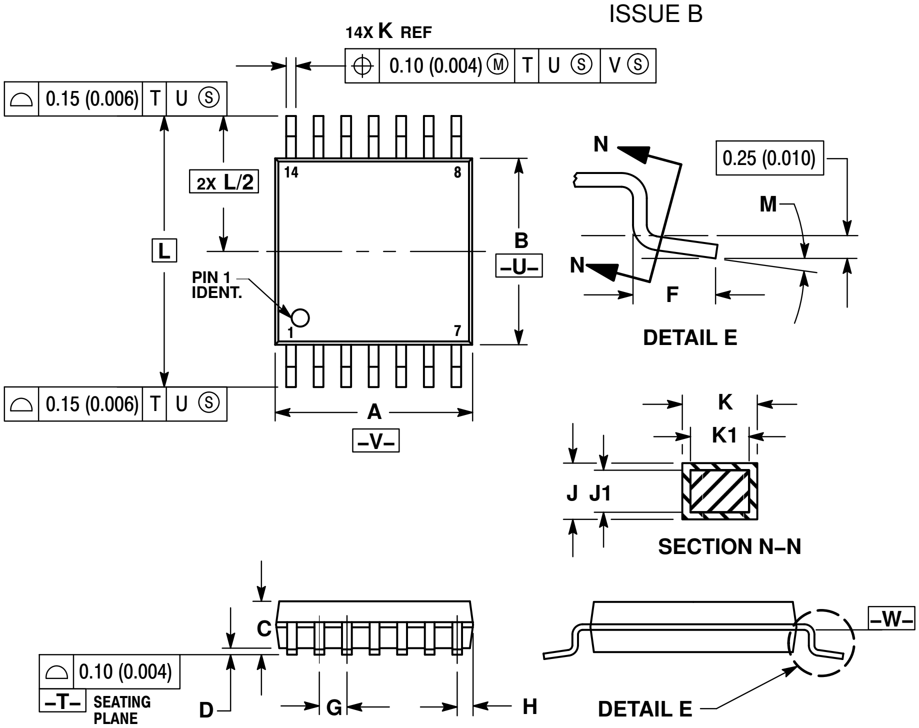
SOLDERING FOOTPRINT*



*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

PACKAGE DIMENSIONS

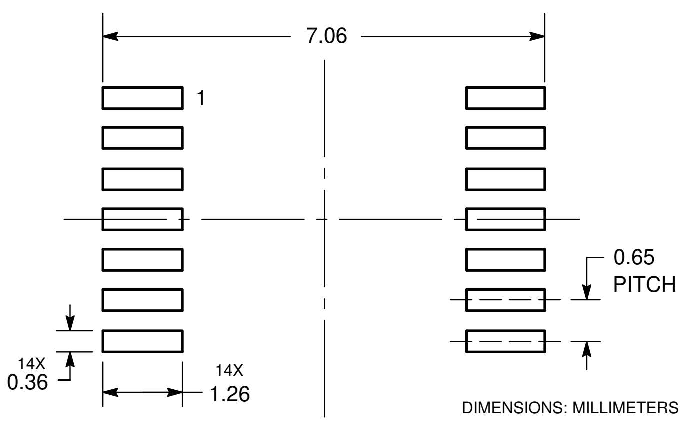
TSSOP−14
CASE 948G
ISSUE B



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4. DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5. DIMENSION K DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE K DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
7. DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE −W−.

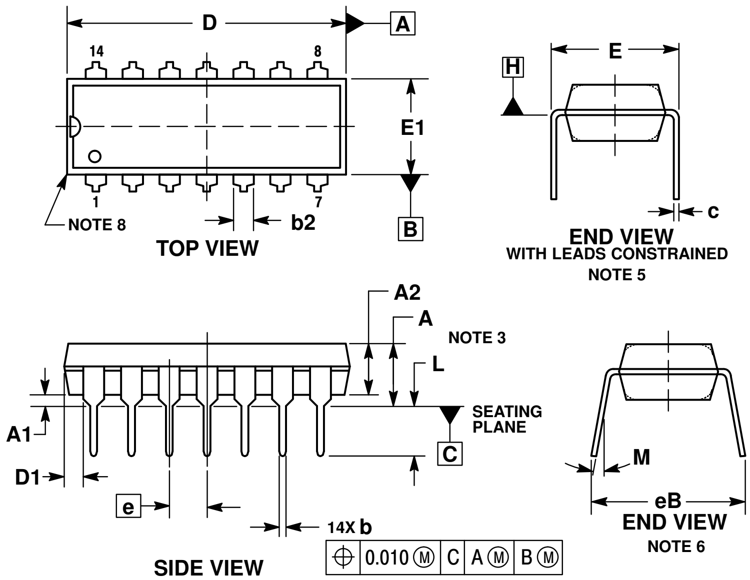
	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	4.90	5.10	0.193	0.200
B	4.30	4.50	0.169	0.177
C	−−−	1.20	−−−	0.047
D	0.05	0.15	0.002	0.006
F	0.50	0.75	0.020	0.030
G	0.65 BSC		0.026 BSC	
H	0.50	0.60	0.020	0.024
J	0.09	0.20	0.004	0.008
J1	0.09	0.16	0.004	0.006
K	0.19	0.30	0.007	0.012
K1	0.19	0.25	0.007	0.010
L	6.40 BSC		0.252 BSC	
M	0 °	8 °	0 °	8 °

SOLDERING FOOTPRINT



PACKAGE DIMENSIONS

PDIP−14
CASE 646−06
ISSUE S



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCHES.
3. DIMENSIONS A, A1 AND L ARE MEASURED WITH THE PACKAGE SEATED IN JEDEC SEATING PLANE GAUGE GS−3.
4. DIMENSIONS D, D1 AND E1 DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS ARE NOT TO EXCEED 0.10 INCH.
5. DIMENSION E IS MEASURED AT A POINT 0.015 BELOW DATUM PLANE H WITH THE LEADS CONSTRAINED PERPENDICULAR TO DATUM C.
6. DIMENSION eB IS MEASURED AT THE LEAD TIPS WITH THE LEADS UNCONSTRAINED.
7. DATUM PLANE H IS COINCIDENT WITH THE BOTTOM OF THE LEADS, WHERE THE LEADS EXIT THE BODY.
8. PACKAGE CONTOUR IS OPTIONAL (ROUNDED OR SQUARE CORNERS).

	INCHES		MILLIMETERS	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	−−−−	0.210	−−−	5.33
A1	0.015	−−−−	0.38	−−−
A2	0.115	0.195	2.92	4.95
b	0.014	0.022	0.35	0.56
b2	0.060 TYP		1.52 TYP	
C	0.008	0.014	0.20	0.36
D	0.735	0.775	18.67	19.69
D1	0.005	−−−−	0.13	−−−
E	0.300	0.325	7.62	8.26
E1	0.240	0.280	6.10	7.11
e	0.100 BSC		2.54 BSC	
eB	−−−−	0.430	−−−	10.92
L	0.115	0.150	2.92	3.81
M	−−−−	10°	−−−	10°

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