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 (Note 2)	T_J	150	°C
Thermal Resistance, Junction−to−Air (Note 3) Case 646 Case 751A Case 948G	$R_{\theta JA}$	118 156 190	°C/W
Storage Temperature Range	T_{stg}	−65 to +150	°C
ESD Protection at any Pin Human Body Model Machine Model	V_{esd}	 2000 200	V
Operating Ambient Temperature Range LM224 LM324, 324A LM2902 LM2902V, NCV2902 (Note 4)	T_A	 −25 to +85 0 to +70 −40 to +105 −40 to +125	°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

1. Split Power Supplies.
2. For supply voltages less than 32 V, the absolute maximum input voltage is equal to the supply voltage.
3. All $R_{\theta JA}$ measurements made on evaluation board with 1 oz. copper traces of minimum pad size. All device outputs were active.
4. *NCV2902 is qualified for automitive use.*

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

Characteristics	Symbol	LM224			LM324A			LM324			LM2902			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 5)		–	–	7.0	–	–	5.0	–	–	9.0	–	–	10	–	–	13	
T_A = T_{low} (Note 5)		–	–	7.0	–	–	5.0	–	–	9.0	–	–	10	–	–	10	
Average Temperature Coefficient of Input Offset Voltage T_A = T_{high} to T_{low} (Notes 5 and 7)	$\Delta V_{IO}/\Delta T$	–	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 5)		–	–	100	–	–	75	–	–	150	–	–	200	–	–	200	
Average Temperature Coefficient of Input Offset Current T_A = T_{high} to T_{low} (Notes 5 and 7)	$\Delta I_{IO}/\Delta T$	–	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 5)		–	–	−300	–	–	−200	–	–	−500	–	–	−500	–	–	−500	
Input Common Mode Voltage Range (Note 6) 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 5)		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	A_{VOL}																V/mV
R_L = 2.0 kΩ, V_{CC} = 15 V, for Large V_O Swing		50	100	–	25	100	–	25	100	–	25	100	–	25	100	–	
T_A = T_{high} to T_{low} (Note 5)		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

5. LM224: T_{low} = −25°C, T_{high} = +85°C
   LM324/LM324A: T_{low} = 0°C, T_{high} = +70°C
   LM2902: T_{low} = −40°C, T_{high} = +105°C
   LM2902V & NCV2902: T_{low} = −40°C, T_{high} = +125°C
   NCV2902 is qualified for automotive use.
6. 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}.
7. 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			LM2902			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 8)		26	–	–	26	–	–	26	–	–	26	–	–	26	–	–	
V_{CC} = 30 V, R_L = 10 kΩ (T_A = T_{high} to T_{low}) (Note 8)		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 8)	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 8)		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 8)		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 9)	I_{SC}	–	40	60	–	40	60	–	40	60	–	40	60	–	40	60	mA
Power Supply Current (T_A = T_{high} to T_{low}) (Note 8)	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	

8. LM224: T_{low} = −25°C, T_{high} = +85°C
   LM324/LM324A: T_{low} = 0°C, T_{high} = +70°C
   LM2902: T_{low} = −40°C, T_{high} = +105°C
   LM2902V & NCV2902: T_{low} = −40°C, T_{high} = +125°C
   NCV2902 is qualified for automotive use.
9. 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}.

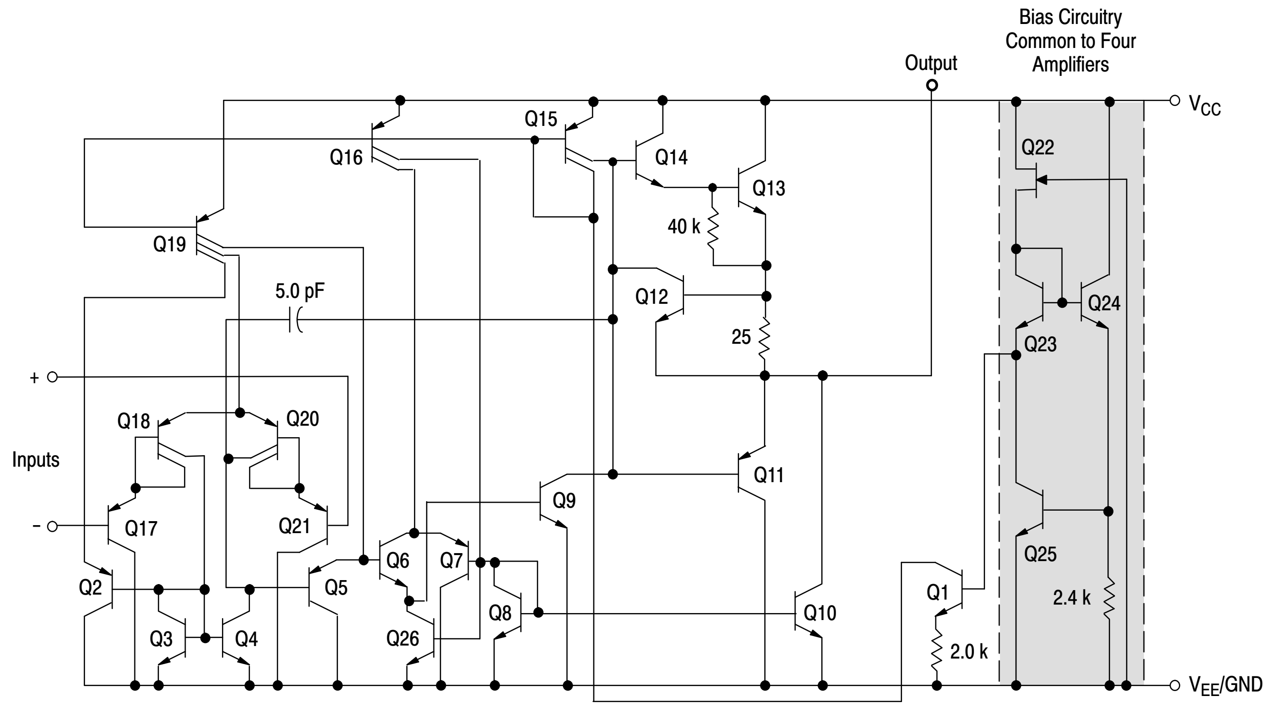


Figure 1. Representative Circuit Diagram
(One−Fourth of Circuit Shown)

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.

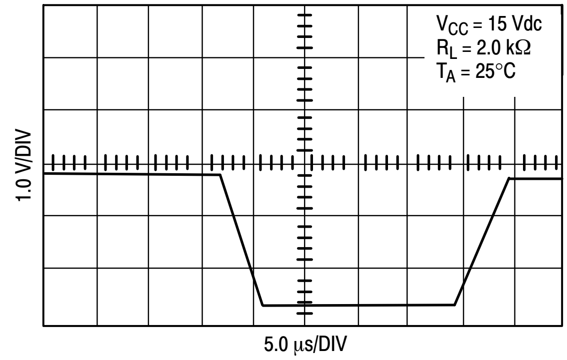


Figure 2. Large Signal Voltage Follower Response

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.

Figure 3.

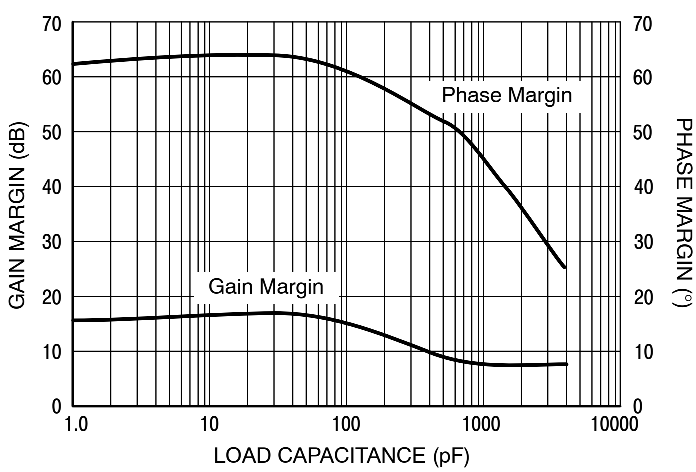


Figure 4. Gain and Phase Margin

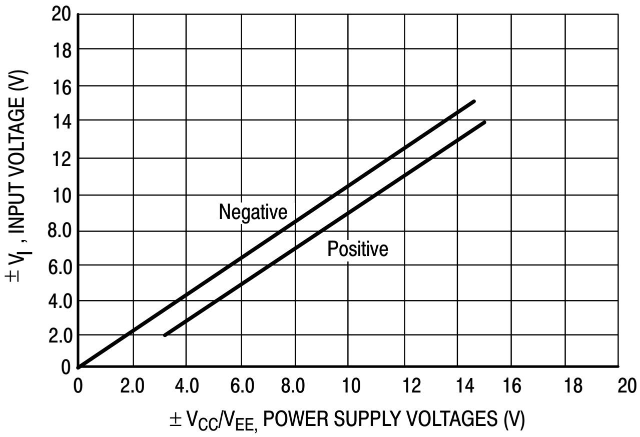


Figure 5. Input Voltage Range

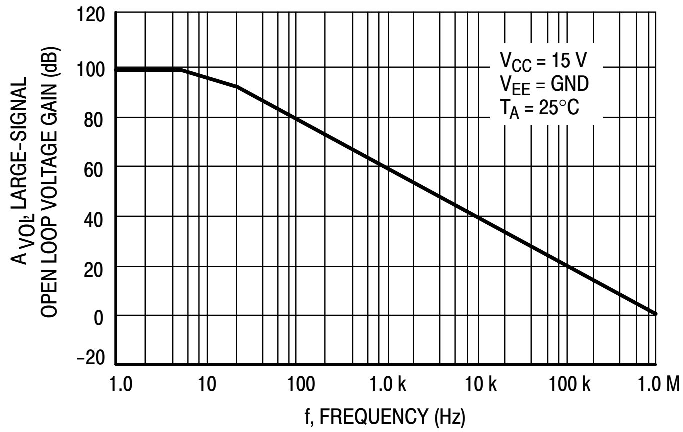


Figure 6. Open Loop Frequency

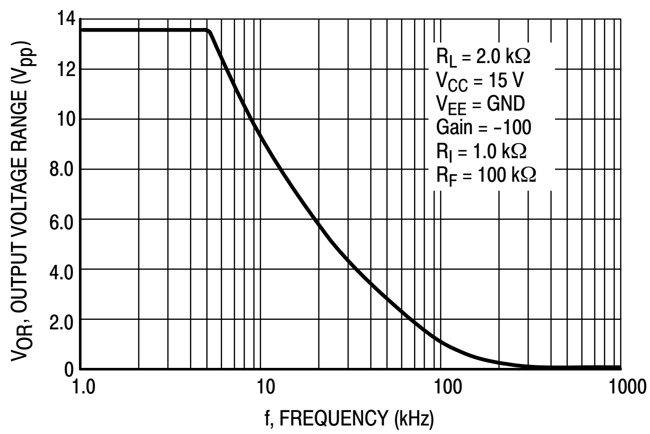


Figure 7. Large−Signal Frequency Response

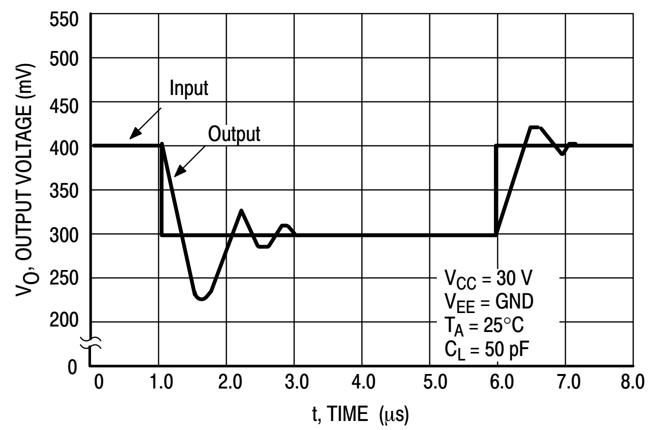


Figure 8. Small−Signal Voltage Follower Pulse Response (Noninverting)

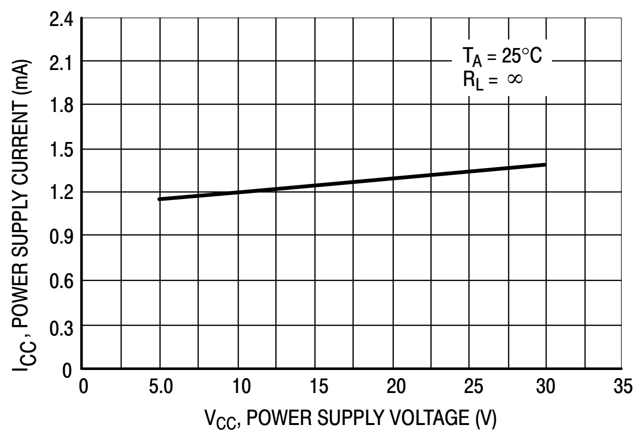


Figure 9. Power Supply Current versus Power Supply Voltage

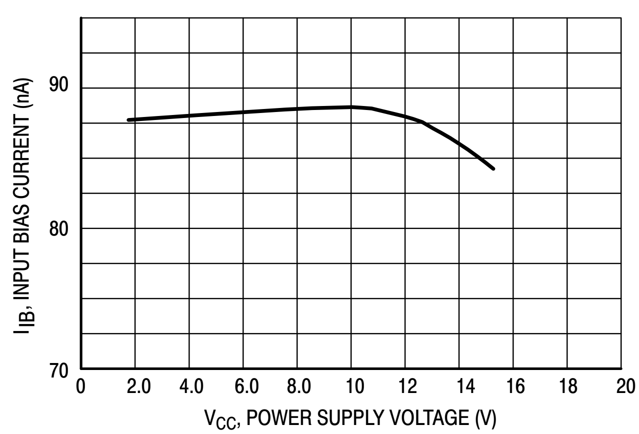
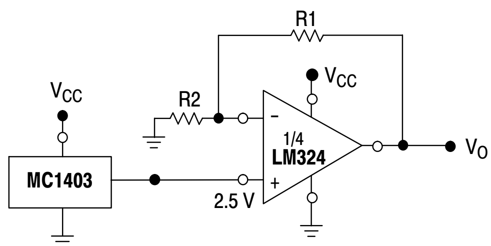


Figure 10. Input Bias Current versus Power Supply Voltage



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

Figure 11. Voltage Reference

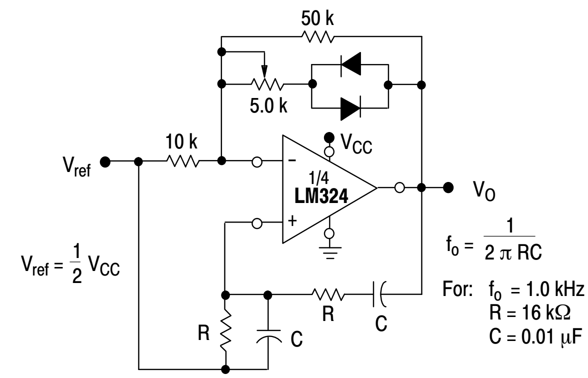
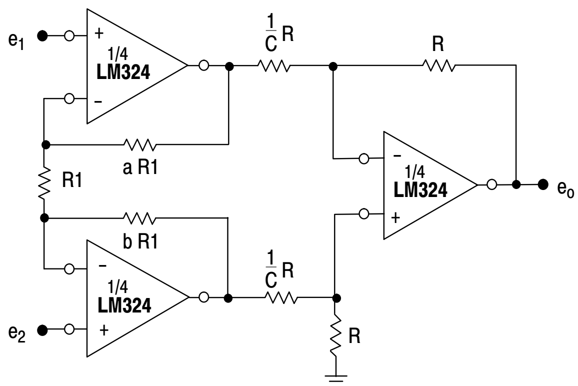
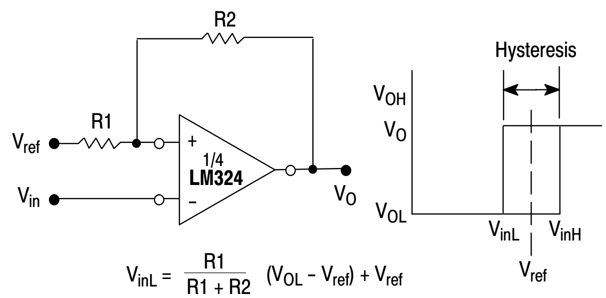


Figure 12. Wien Bridge Oscillator



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

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

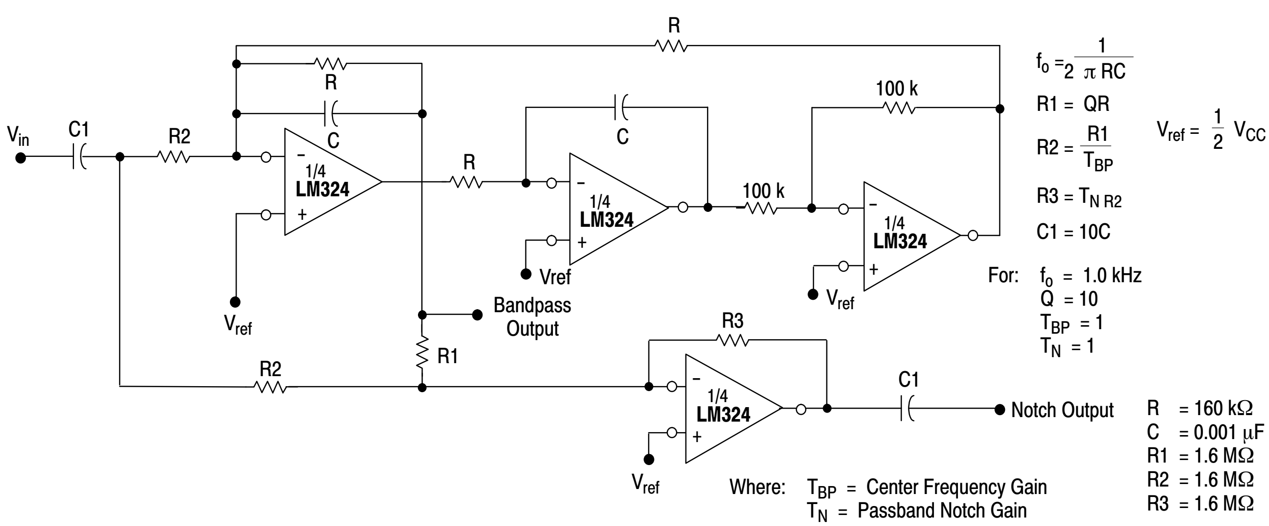
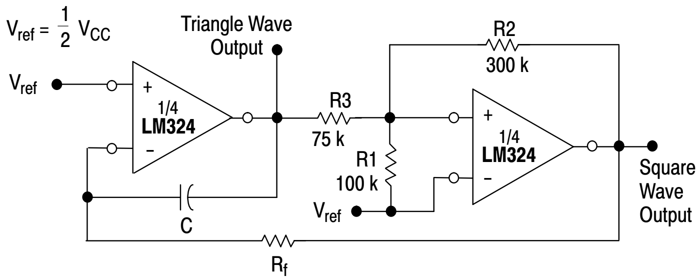


Figure 15. Bi−Quad Filter



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

Figure 16. Function Generator

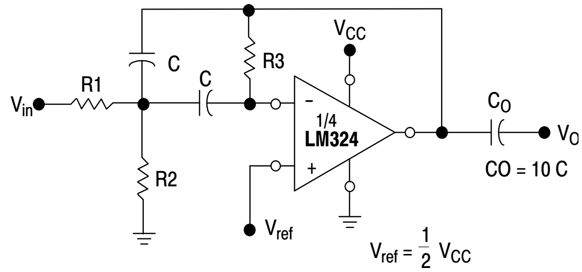


Figure 17. Multiple Feedback Bandpass Filter

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†
LM224D	−25°C to +85°C	SOIC−14	55 Units/Rail
LM224DG		SOIC−14 (Pb−Free)	
LM224DR2		SOIC−14	2500/Tape & Reel
LM224DR2G		SOIC−14 (Pb−Free)	
LM224DTB		TSSOP−14*	96 Units/Tube
LM224DTBG		TSSOP−14*	
LM224DTBR2		TSSOP−14*	2500/Tape & Reel
LM224DTBR2G		TSSOP−14*	
LM224N		PDIP−14	25 Units/Rail
LM224NG		PDIP−14 (Pb−Free)	
LM324D	0°C to +70°C	SOIC−14	55 Units/Rail
LM324DG		SOIC−14 (Pb−Free)	
LM324DR2		SOIC−14	2500/Tape & Reel
LM324DR2G		SOIC−14 (Pb−Free)	
LM324DTB		TSSOP−14*	96 Units/Tube
LM324DTBG		TSSOP−14*	
LM324DTBR2		TSSOP−14*	2500/Tape & Reel
LM324DTBR2G		TSSOP−14*	
LM324N		PDIP−14	25 Units/Rail
LM324NG		PDIP−14 (Pb−Free)	
LM324AD		SOIC−14	55 Units/Rail
LM324ADG		SOIC−14 (Pb−Free)	
LM324ADR2		SOIC−14	2500/Tape & Reel
LM324ADR2G		SOIC−14 (Pb−Free)	
LM324ADTB		TSSOP−14*	96 Units/Tube
LM324ADTBG		TSSOP−14*	
LM324ADTBR2		TSSOP−14*	2500/Tape & Reel
LM324ADTBR2G		TSSOP−14*	
LM324AN		PDIP−14	25 Units/Rail
LM324ANG		PDIP−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.
*This package is inherently Pb−Free.

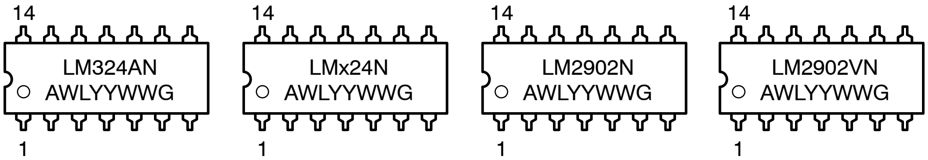
ORDERING INFORMATION (continued)

Device	Operating Temperature Range	Package	Shipping†
LM2902D	−40°C to +105°C	SOIC−14	55 Units/Rail
LM2902DG		SOIC−14 (Pb−Free)	
LM2902DR2		SOIC−14	2500/Tape & Reel
LM2902DR2G		SOIC−14 (Pb−Free)	
LM2902DTB		TSSOP−14*	96 Units/Tube
LM2902DTBG		TSSOP−14*	
LM2902DTBR2		TSSOP−14*	2500/Tape & Reel
LM2902DTBR2G		TSSOP−14*	
LM2902N		PDIP−14	25 Units/Rail
LM2902NG		PDIP−14 (Pb−Free)	
LM2902VD	−40°C to +125°C	SOIC−14	55 Units/Rail
LM2902VDG		SOIC−14 (Pb−Free)	
LM2902VDR2		SOIC−14	2500/Tape & Reel
LM2902VDR2G		SOIC−14 (Pb−Free)	
LM2902VDTB		TSSOP−14*	96 Units/Tube
LM2902VDTBG		TSSOP−14*	
LM2902VDTBR2		TSSOP−14*	2500/Tape & Reel
LM2902VDTBR2G		TSSOP−14*	
LM2902VN		PDIP−14	25 Units/Rail
LM2902VNG		PDIP−14 (Pb−Free)	
NCV2902DR2		SOIC−14	2500/Tape & Reel
NCV2902DR2G		SOIC−14 (Pb−Free)	
NCV2902DTBR2G		TSSOP−14*	

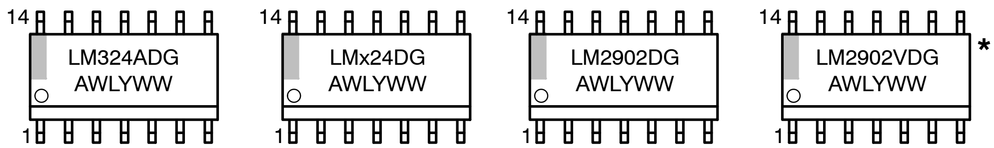
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.
*This package is inherently Pb−Free.

MARKING DIAGRAMS

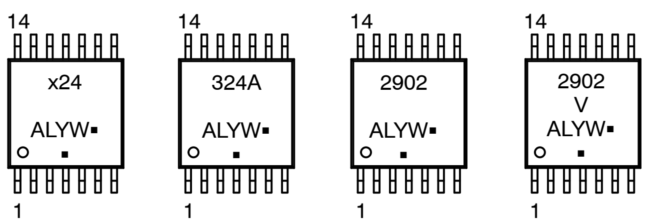
PDIP−14
N SUFFIX
CASE 646



SOIC−14
D SUFFIX
CASE 751A



TSSOP−14
DTB SUFFIX
CASE 948G

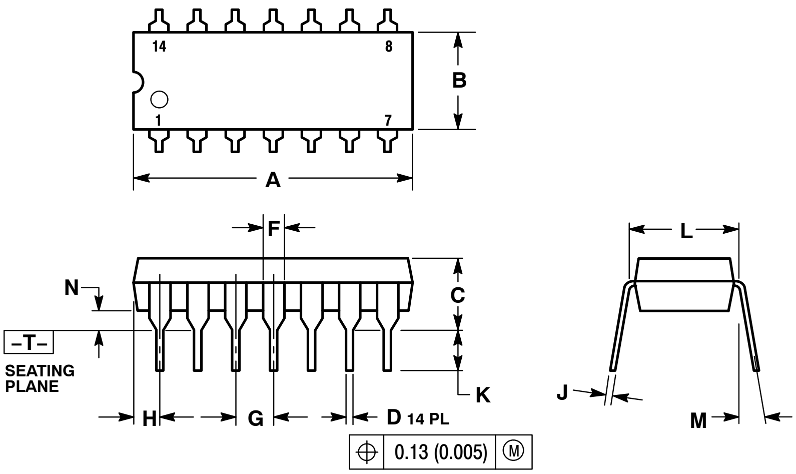


x	=	2 or 3
A	=	Assembly Location
WL, L	=	Wafer Lot
YY, Y	=	Year
WW, W	=	Work Week
G or ▪	=	Pb−Free Package

(Note: Microdot may be in either location)
*This marking diagram also applies to NCV2902.

PACKAGE DIMENSIONS

PDIP−14
CASE 646−06
ISSUE P

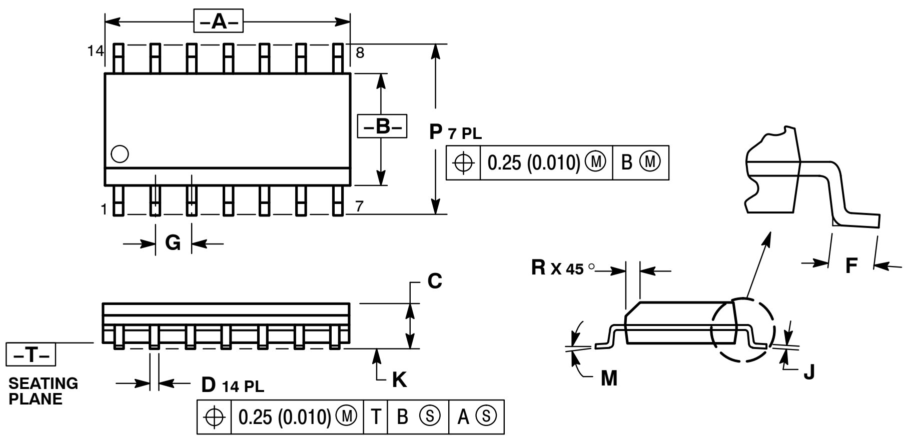


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
5. ROUNDED CORNERS OPTIONAL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.715	0.770	18.16	19.56
B	0.240	0.260	6.10	6.60
C	0.145	0.185	3.69	4.69
D	0.015	0.021	0.38	0.53
F	0.040	0.070	1.02	1.78
G	0.100 BSC		2.54 BSC	
H	0.052	0.095	1.32	2.41
J	0.008	0.015	0.20	0.38
K	0.115	0.135	2.92	3.43
L	0.290	0.310	7.37	7.87
M	---	10 °	---	10 °
N	0.015	0.039	0.38	1.01

PACKAGE DIMENSIONS

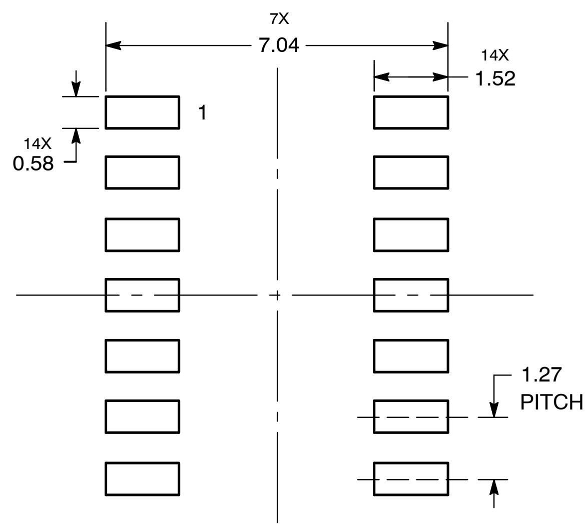
SOIC−14
CASE 751A−03
ISSUE H



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.55	8.75	0.337	0.344
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.054	0.068
D	0.35	0.49	0.014	0.019
F	0.40	1.25	0.016	0.049
G	1.27 BSC		0.050 BSC	
J	0.19	0.25	0.008	0.009
K	0.10	0.25	0.004	0.009
M	0 °	7 °	0 °	7 °
P	5.80	6.20	0.228	0.244
R	0.25	0.50	0.010	0.019

SOLDERING FOOTPRINT*

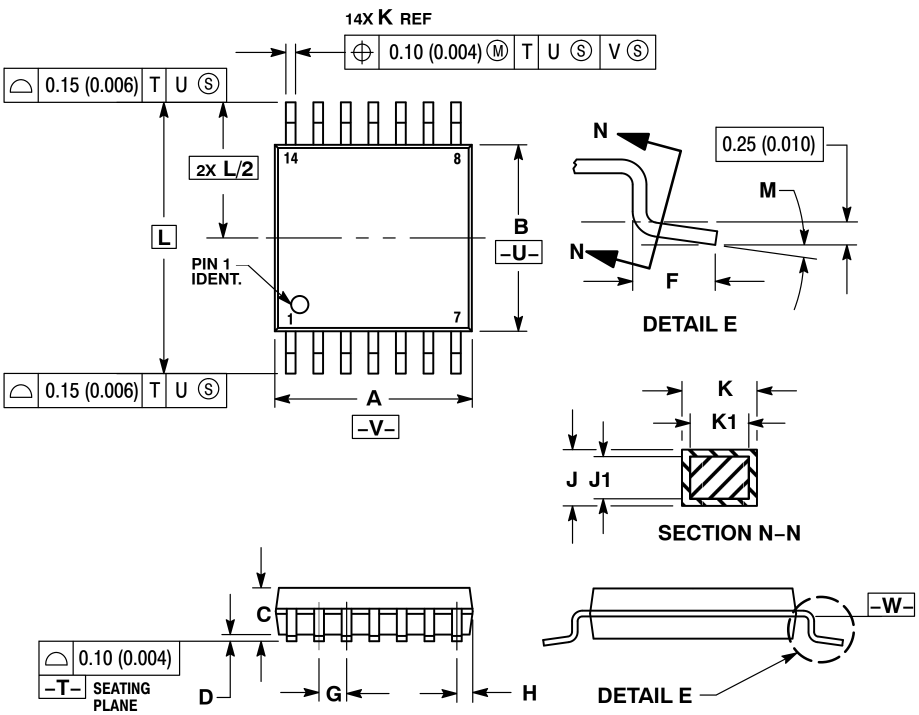


DIMENSIONS: MILLIMETERS

*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

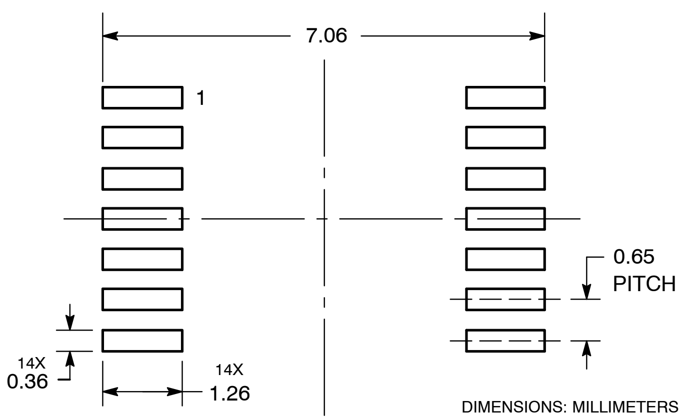
TSSOP−14
CASE 948G−01
ISSUE B



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*



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