

LM324, LM324A, LM224, LM2902, 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.

- Short Circuited Protected Outputs
- True Differential Input Stage
- Single Supply Operation: 3.0 V to 32 V (LM224, LM324, LM324A)
- 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

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

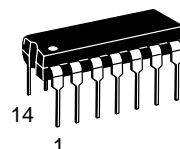
Rating	Symbol	LM224 LM324, LM324A	LM2902, LM2902V	Unit
Power Supply Voltages Single Supply	V _{CC}	32	26	Vdc
Split Supplies	V _{CC} , V _{EE}	±16	±13	
Input Differential Voltage Range (Note 1)	V _{IDR}	±32	±26	Vdc
Input Common Mode Voltage Range	V _{ICR}	-0.3 to 32	-0.3 to 26	Vdc
Output Short Circuit Duration	t _{SC}	Continuous		
Junction Temperature	T _J	150		°C
Storage Temperature Range	T _{stg}	-65 to +150		°C
ESD Protection at any Pin Human Body Model	V _{esd}	2000		V
Machine Model		200		
Operating Ambient Temperature Range	T _A			°C
LM224		-25 to +85		
LM324, 324A		0 to +70		
LM2902			-40 to +105	
LM2902V, NCV2902			-40 to +125	

1. Split Power Supplies.

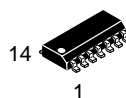


ON Semiconductor®

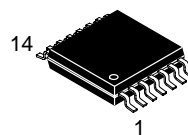
<http://onsemi.com>



PDIP-14
N SUFFIX
CASE 646

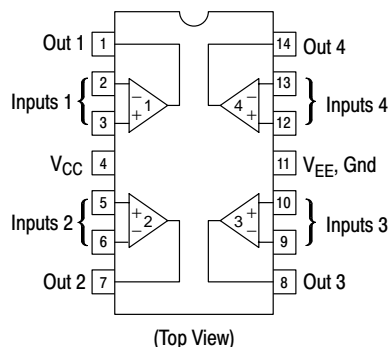


SO-14
D SUFFIX
CASE 751A



TSSOP-14
DTB SUFFIX
CASE 948G

PIN CONNECTIONS



ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 9 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 10 of this data sheet.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

ELECTRICAL CHARACTERISTICS ($V_{CC} = 5.0\text{ V}$, $V_{EE} = \text{Gnd}$, $T_A = 25^\circ\text{C}$, 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 $V_{CC} = 5.0\text{ V}$ to 30 V (26 V for LM2902, V), $V_{ICR} = 0\text{ V}$ to $V_{CC} - 1.7\text{ V}$, $V_O = 1.4\text{ V}$, $R_S = 0\ \Omega$ $T_A = 25^\circ\text{C}$ $T_A = T_{\text{high}}$ (Note 2) $T_A = T_{\text{low}}$ (Note 2)	V_{IO}	–	2.0	5.0	–	2.0	3.0	–	2.0	7.0	–	2.0	7.0	–	2.0	7.0	mV
Average Temperature Coefficient of Input Offset Voltage $T_A = T_{\text{high}}$ to T_{low} (Notes 2 and 4)	$\Delta V_{IO}/\Delta T$	–	7.0	–	–	7.0	30	–	7.0	–	–	7.0	–	–	7.0	–	$\mu\text{V}/^\circ\text{C}$
Input Offset Current $T_A = T_{\text{high}}$ to T_{low} (Note 2)	I_{IO}	–	3.0	30	–	5.0	30	–	5.0	50	–	5.0	50	–	5.0	50	nA
Average Temperature Coefficient of Input Offset Current $T_A = T_{\text{high}}$ to T_{low} (Notes 2 and 4)	$\Delta I_{IO}/\Delta T$	–	10	–	–	10	300	–	10	–	–	10	–	–	10	–	$\text{pA}/^\circ\text{C}$
Input Bias Current $T_A = T_{\text{high}}$ to T_{low} (Note 2)	I_{IB}	–	–90	–150	–	–45	–100	–	–90	–250	–	–90	–250	–	–90	–250	nA
Input Common Mode Voltage Range (Note 3) $V_{CC} = 30\text{ V}$ (26 V for LM2902, V) $T_A = +25^\circ\text{C}$ $T_A = T_{\text{high}}$ to T_{low} (Note 2)	V_{ICR}	0	–	28.3	0	–	28.3	0	–	28.3	0	–	24.3	0	–	24.3	V
Differential Input Voltage Range	V_{IDR}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	V
Large Signal Open Loop Voltage Gain $R_L = 2.0\text{ k}\Omega$, $V_{CC} = 15\text{ V}$, for Large V_O Swing $T_A = T_{\text{high}}$ to T_{low} (Note 2)	A_{VOL}	50	100	–	25	100	–	25	100	–	25	100	–	25	100	–	V/mV
Channel Separation $10\text{ kHz} \leq f \leq 20\text{ kHz}$, Input Referenced	CS	–	–120	–	–	–120	–	–	–120	–	–	–120	–	–	–120	–	dB
Common Mode Rejection, $R_S \leq 10\text{ k}\Omega$	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

2. LM224: $T_{\text{low}} = -25^\circ\text{C}$, $T_{\text{high}} = +85^\circ\text{C}$
 LM324/LM324A: $T_{\text{low}} = 0^\circ\text{C}$, $T_{\text{high}} = +70^\circ\text{C}$
 LM2902: $T_{\text{low}} = -40^\circ\text{C}$, $T_{\text{high}} = +105^\circ\text{C}$
 LM2902V & NCV2902: $T_{\text{low}} = -40^\circ\text{C}$, $T_{\text{high}} = +125^\circ\text{C}$
NCV2902 is qualified for automotive use.

3. 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 $V_{CC} - 1.7\text{ V}$.
4. Guaranteed by design.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

ELECTRICAL CHARACTERISTICS ($V_{CC} = 5.0\text{ V}$, $V_{EE} = \text{Gnd}$, $T_A = 25^\circ\text{C}$, 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 ($T_A = T_{\text{high}}$ to T_{low}) (Note 5) $V_{CC} = 5.0\text{ V}$, $R_L = 2.0\text{ k}\Omega$, $T_A = 25^\circ\text{C}$ $V_{CC} = 30\text{ V}$ (26 V for LM2902, V), $R_L = 2.0\text{ k}\Omega$ $V_{CC} = 30\text{ V}$ (26 V for LM2902, V), $R_L = 10\text{ k}\Omega$	V_{OH}	3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	V
Output Voltage – Low Limit, $V_{CC} = 5.0\text{ V}$, $R_L = 10\text{ k}\Omega$, $T_A = T_{\text{high}}$ to T_{low} (Note 5)	V_{OL}	–	5.0	20	–	5.0	20	–	5.0	20	–	5.0	100	–	5.0	100	mV
Output Source Current ($V_{ID} = +1.0\text{ V}$, $V_{CC} = 15\text{ V}$) $T_A = 25^\circ\text{C}$ $T_A = T_{\text{high}}$ to T_{low} (Note 5)	I_{O+}	20	40	–	20	40	–	20	40	–	20	40	–	20	40	–	mA
Output Sink Current ($V_{ID} = -1.0\text{ V}$, $V_{CC} = 15\text{ V}$) $T_A = 25^\circ\text{C}$ $T_A = T_{\text{high}}$ to T_{low} (Note 5)	I_{O-}	10	20	–	10	20	–	10	20	–	10	20	–	10	20	–	mA
($V_{ID} = -1.0\text{ V}$, $V_O = 200\text{ mV}$, $T_A = 25^\circ\text{C}$)		5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	μA
Output Short Circuit to Ground (Note 6)	I_{SC}	–	40	60	–	40	60	–	40	60	–	40	60	–	40	60	mA
Power Supply Current ($T_A = T_{\text{high}}$ to T_{low}) (Note 5) $V_{CC} = 30\text{ V}$ (26 V for LM2902, V), $V_O = 0\text{ V}$, $R_L = \infty$ $V_{CC} = 5.0\text{ V}$, $V_O = 0\text{ V}$, $R_L = \infty$	I_{CC}	–	–	3.0	–	1.4	3.0	–	–	3.0	–	–	3.0	–	–	3.0	mA
		–	–	1.2	–	0.7	1.2	–	–	1.2	–	–	1.2	–	–	1.2	

5. LM224: $T_{\text{low}} = -25^\circ\text{C}$, $T_{\text{high}} = +85^\circ\text{C}$
 LM324/LM324A: $T_{\text{low}} = 0^\circ\text{C}$, $T_{\text{high}} = +70^\circ\text{C}$
 LM2902: $T_{\text{low}} = -40^\circ\text{C}$, $T_{\text{high}} = +105^\circ\text{C}$
 LM2902V & NCV2902: $T_{\text{low}} = -40^\circ\text{C}$, $T_{\text{high}} = +125^\circ\text{C}$
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 $V_{CC} - 1.7\text{ V}$.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

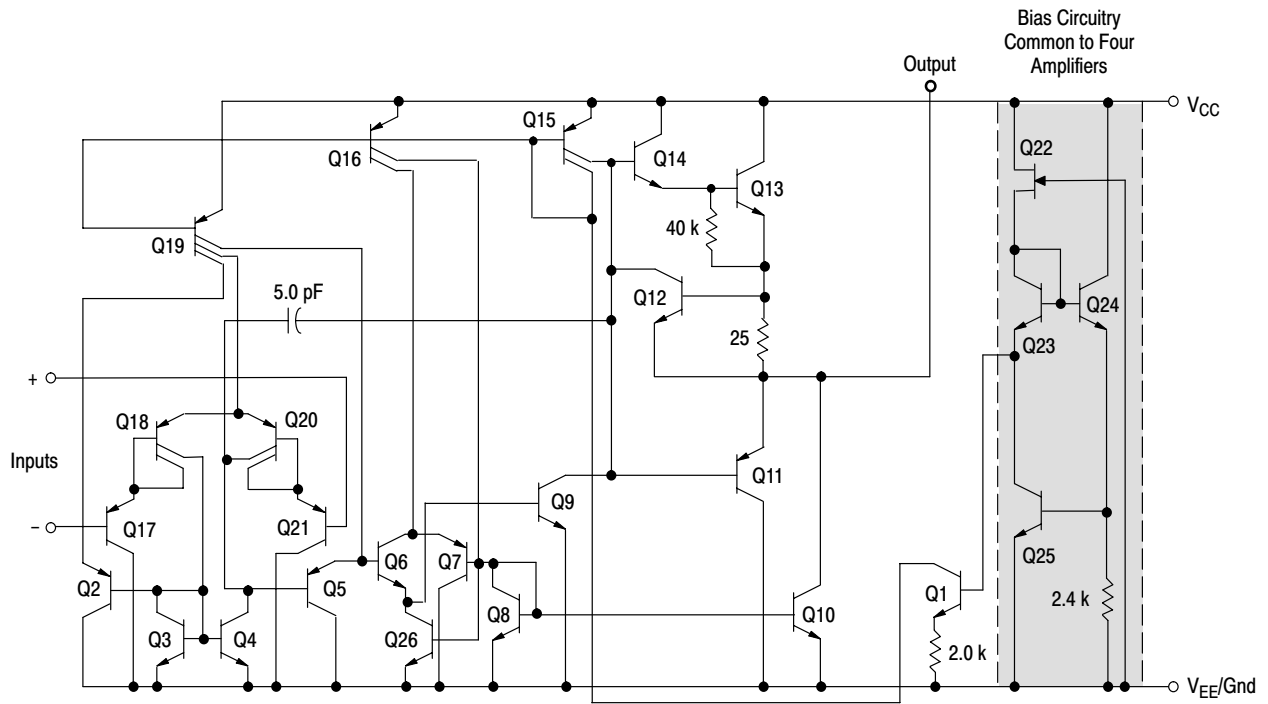


Figure 1. Representative Circuit Diagram
(One-Fourth of Circuit Shown)

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.

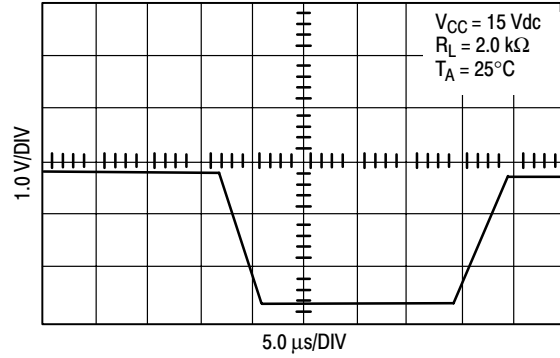


Figure 2. Large Signal Voltage Follower Response

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.

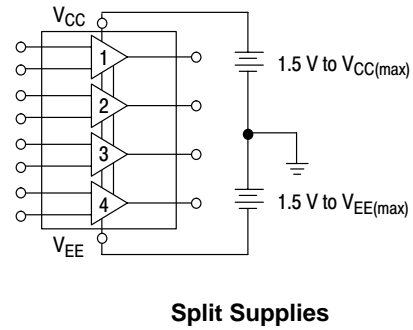
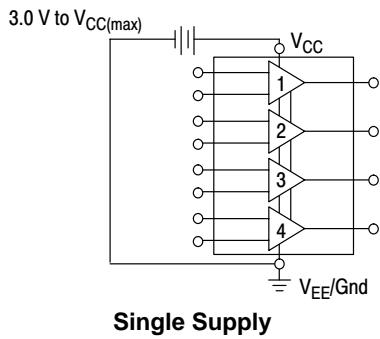


Figure 3.

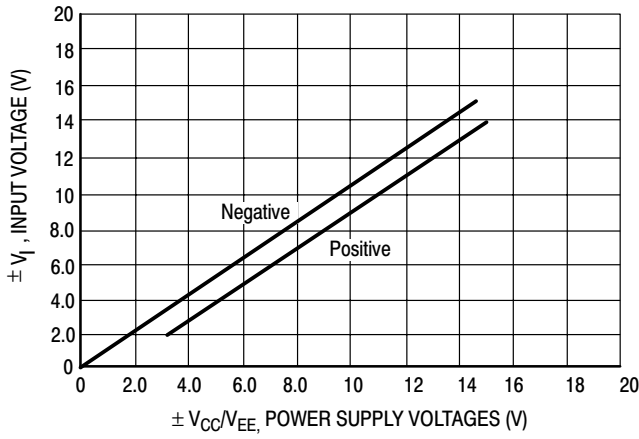


Figure 4. Input Voltage Range

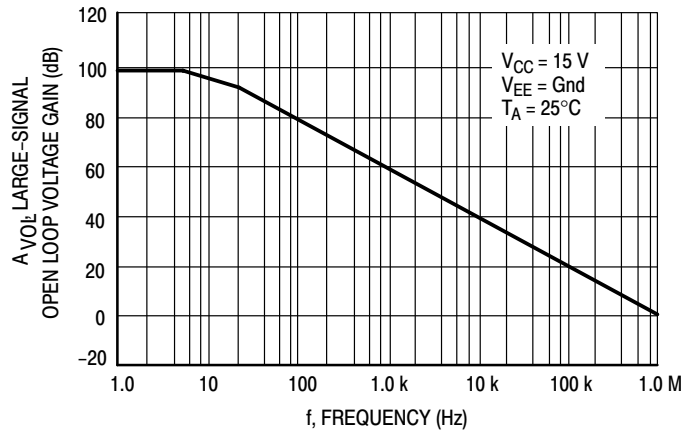


Figure 5. Open Loop Frequency

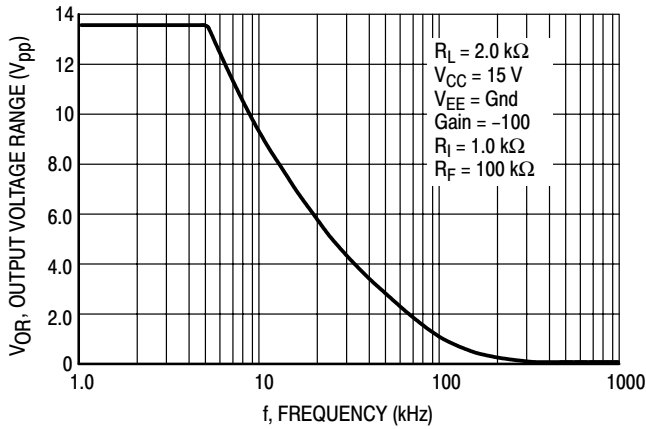


Figure 6. Large-Signal Frequency Response

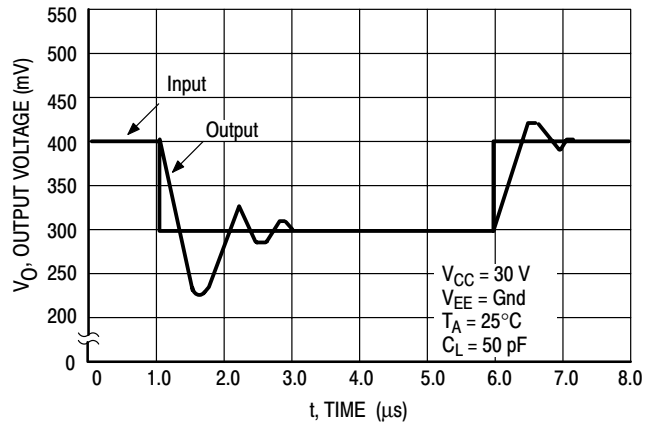


Figure 7. Small-Signal Voltage Follower Pulse Response (Noninverting)

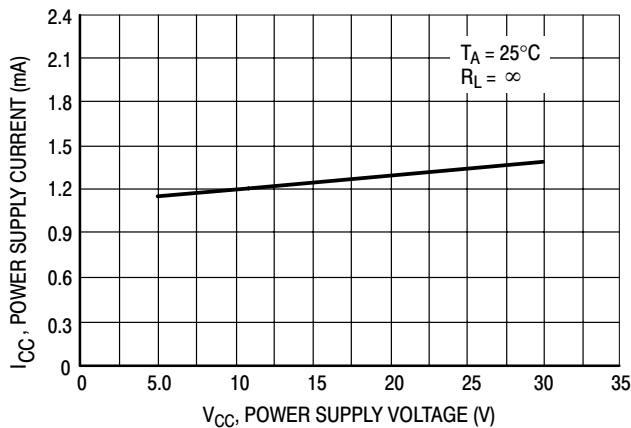


Figure 8. Power Supply Current versus Power Supply Voltage

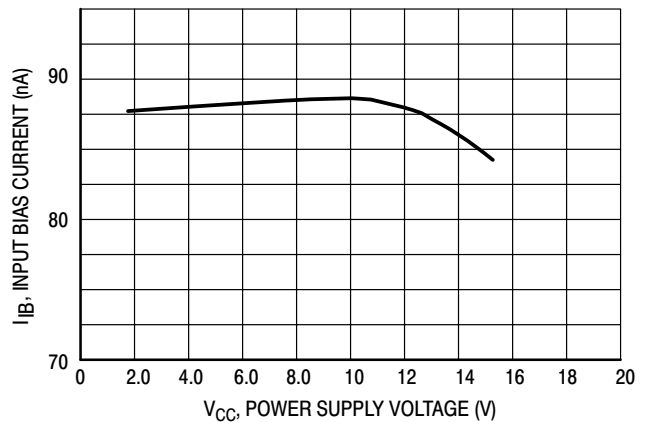


Figure 9. Input Bias Current versus Power Supply Voltage

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

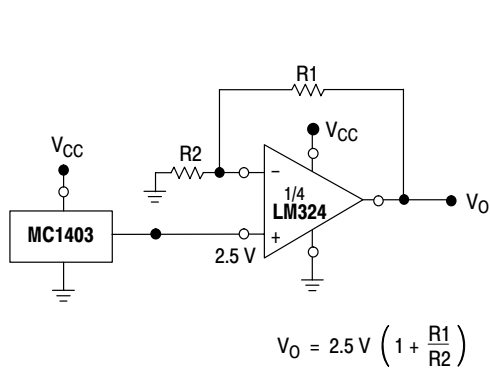


Figure 10. Voltage Reference

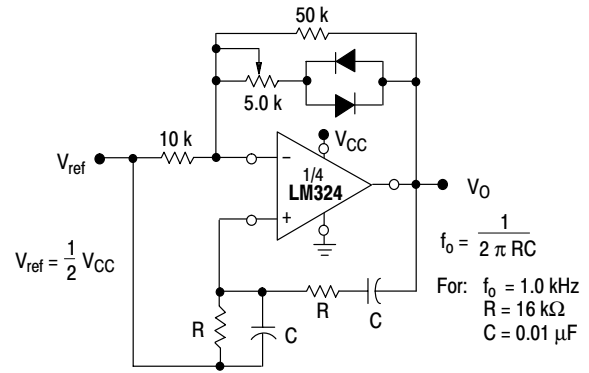


Figure 11. Wien Bridge Oscillator

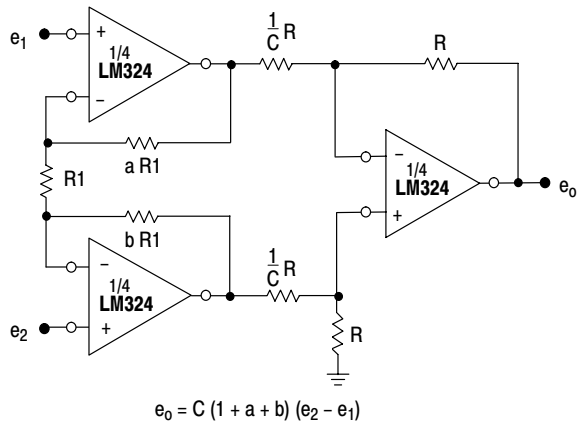


Figure 12. High Impedance Differential Amplifier

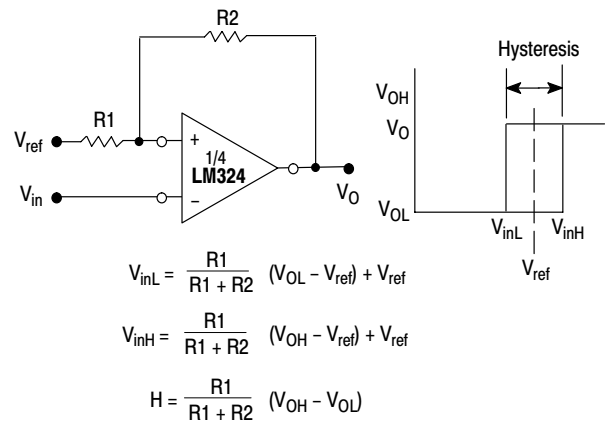


Figure 13. Comparator with Hysteresis

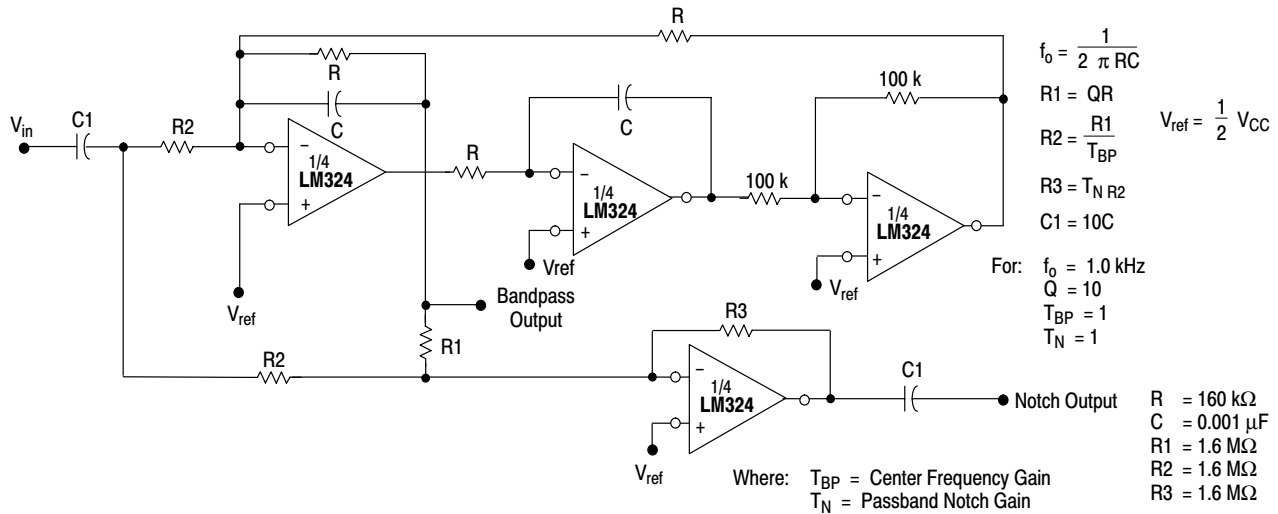


Figure 14. Bi-Quad Filter

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

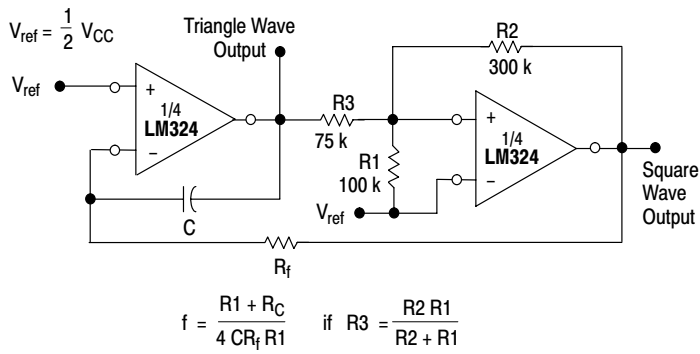


Figure 15. Function Generator

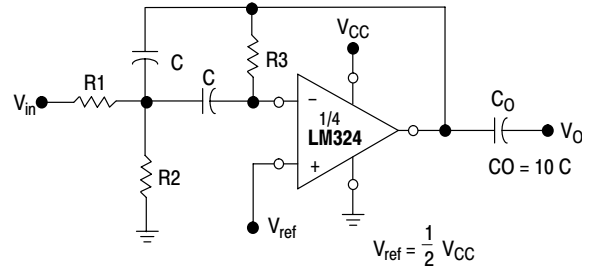


Figure 16. Multiple Feedback Bandpass Filter

Given: f_0 = center frequency
 $A(f_0)$ = gain at center frequency

Choose value f_0, C

$$\text{Then: } R3 = \frac{Q}{\pi f_0 C}$$

$$R1 = \frac{R3}{2 A(f_0)}$$

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

For less than 10% error from operational amplifier, $\frac{Q_0 f_0}{BW} < 0.1$

where f_0 and BW are expressed in Hz.

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

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

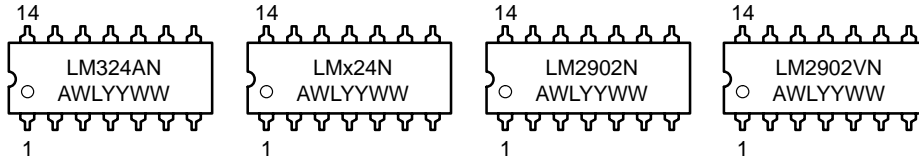
ORDERING INFORMATION

Device	Package	Operating Temperature Range	Shipping
LM224D	SO-14	-25° to +85°C	55 Units/Rail
LM224DR2	SO-14		2500 Tape & Reel
LM224DTB	TSSOP-14		96 Units/Rail
LM224DTBR2	TSSOP-14		2500 Tape & Reel
LM224N	PDIP-14		25 Units/Rail
LM324D	SO-14	0° to +70°C	55 Units/Rail
LM324DR2	SO-14		2500 Tape & Reel
LM324DTB	TSSOP-14		96 Units/Rail
LM324DTBR2	TSSOP-14		2500 Tape & Reel
LM324N	PDIP-14		25 Units/Rail
LM324AD	SO-14		55 Units/Rail
LM324ADR2	SO-14		2500 Tape & Reel
LM324ADTB	TSSOP-14		96 Units/Rail
LM324ADTBR2	TSSOP-14		2500 Tape & Reel
LM324AN	PDIP-14		25 Units/Rail
LM2902D	SO-14	-40° to +105°C	55 Units/Rail
LM2902DR2	SO-14		2500 Tape & Reel
LM2902DTB	TSSOP-14		96 Units/Rail
LM2902DTBR2	TSSOP-14		2500 Tape & Reel
LM2902N	PDIP-14		25 Units/Rail
LM2902VD	SO-14	-40° to +125°C	55 Units/Rail
LM2902VDR2	SO-14		2500 Tape & Reel
LM2902VDTB	TSSOP-14		96 Units/Rail
LM2902VDTBR2	TSSOP-14		2500 Tape & Reel
LM2902VN	PDIP-14		25 Units/Rail
NCV2902DR2	SO-14		2500 Tape & Reel

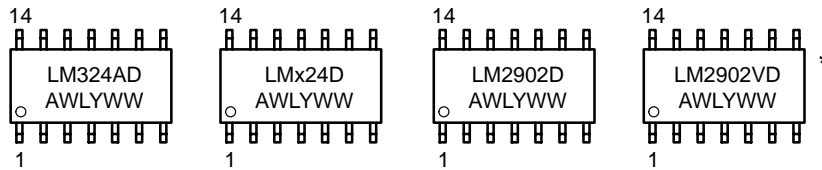
LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

MARKING DIAGRAMS

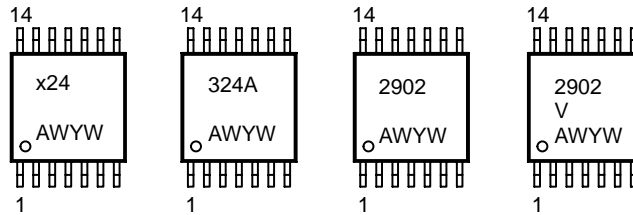
PDIP-14 N SUFFIX CASE 646



SO-14 D SUFFIX CASE 751A



TSSOP-14 DTB SUFFIX CASE 948G



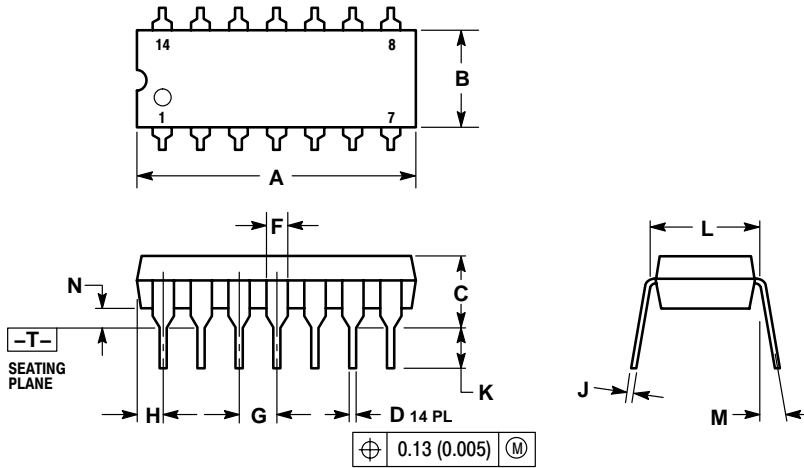
- x = 2 or 3
- A = Assembly Location
- WL = Wafer Lot
- YY, Y = Year
- WW, W = Work Week

*This marking diagram also applies to NCV2902.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

PACKAGE DIMENSIONS

PDIP-14
N SUFFIX
 CASE 646-06
 ISSUE M

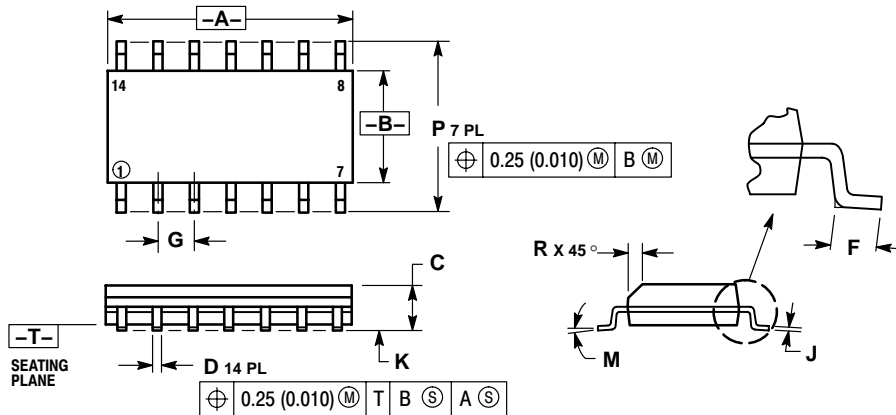


NOTES:

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.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.715	0.770	18.16	18.80
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

SO-14
D SUFFIX
 CASE 751A-03
 ISSUE F



NOTES:

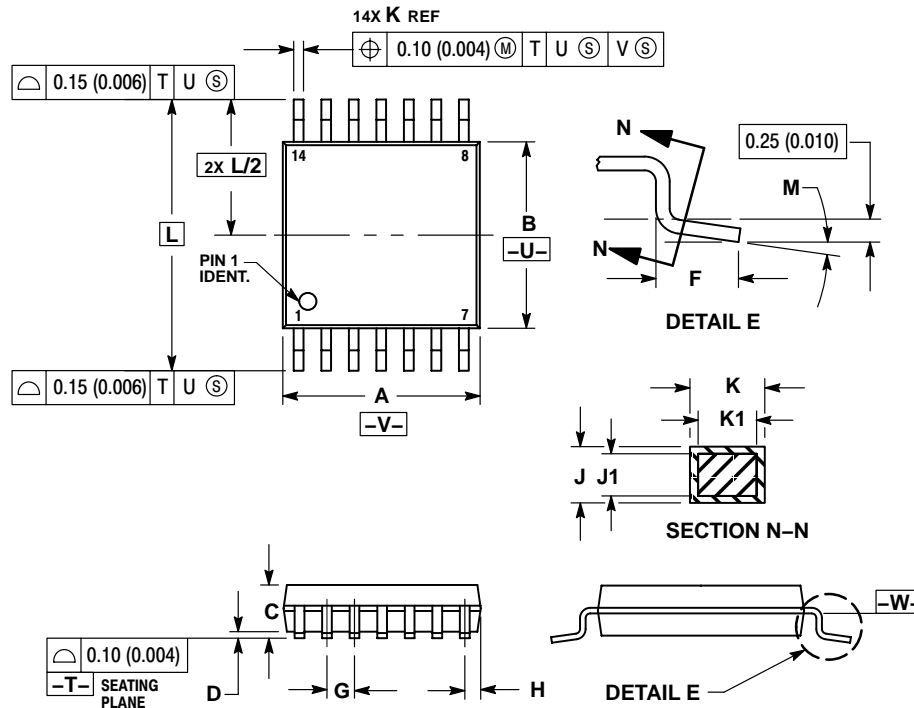
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL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

DIM	MILLIMETERS		INCHES	
	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

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

PACKAGE DIMENSIONS


TSSOP-14
DTB SUFFIX
CASE 948G-01
ISSUE O



NOTES:

- DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
- CONTROLLING DIMENSION: MILLIMETER.
- 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.
- DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
- 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.
- TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
- DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE -W-.

DIM	MILLIMETERS		INCHES	
	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°

ON Semiconductor and  are registered trademarks of Semiconductor Components Industries, LLC (SCILLC). SCILLC reserves the right to make changes without further notice to any products herein. SCILLC makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does SCILLC assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. "Typical" parameters which may be provided in SCILLC data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. SCILLC does not convey any license under its patent rights nor the rights of others. SCILLC products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the SCILLC product could create a situation where personal injury or death may occur. Should Buyer purchase or use SCILLC products for any such unintended or unauthorized application, Buyer shall indemnify and hold SCILLC and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that SCILLC was negligent regarding the design or manufacture of the part. SCILLC is an Equal Opportunity/Affirmative Action Employer.

PUBLICATION ORDERING INFORMATION

Literature Fulfillment:

Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303-675-2175 or 800-344-3860 Toll Free USA/Canada
Fax: 303-675-2176 or 800-344-3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800-282-9855 Toll Free USA/Canada

JAPAN: ON Semiconductor, Japan Customer Focus Center
2-9-1 Kamimeguro, Meguro-ku, Tokyo, Japan 153-0051
Phone: 81-3-5773-3850

ON Semiconductor Website: <http://onsemi.com>

For additional information, please contact your local Sales Representative.