

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.

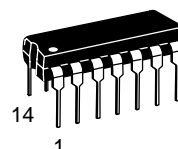
Features

- 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
- Pb-Free Packages are Available*
- NCV Prefix for Automotive and Other Applications Requiring Site and Control Changes

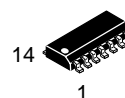


ON Semiconductor®

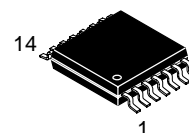
<http://onsemi.com>



**PDIP-14
N SUFFIX
CASE 646**

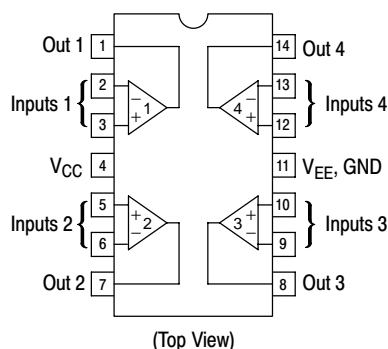


**SOIC-14
D SUFFIX
CASE 751A**



**TSSOP-14
DTB SUFFIX
CASE 948G**

PIN CONNECTIONS



ORDERING INFORMATION

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

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 12 of this data sheet.

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

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

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

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

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 automotive use.*

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 $V_{ICR} = 0\text{ V}$ 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 5) $T_A = T_{\text{low}}$ (Note 5)	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 5 and 7)	$\Delta V_{IO}/\Delta T$	-	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 5)	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 5 and 7)	$\Delta I_{IO}/\Delta T$	-	10	-	-	10	300	-	10	-	-	10	-	-	10	-	$\text{pA}/^\circ\text{C}$
Input Bias Current $T_A = T_{\text{high}}$ to T_{low} (Note 5)	I_{IB}	-	-90	-150	-	-45	-100	-	-90	-250	-	-90	-250	-	-90	-250	nA
Input Common Mode Voltage Range (Note 6) $V_{CC} = 30\text{ V}$ $T_A = +25^\circ\text{C}$ $T_A = T_{\text{high}}$ to T_{low} (Note 5)	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 5)	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

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 $V_{CC} - 1.7\text{ V}$, but either or both inputs can go to +32 V without damage, independent of the magnitude of V_{CC} .

7. Guaranteed by design.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

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 (T _A = T _{high} to T _{low}) (Note 8) V _{CC} = 5.0 V, R _L = 2.0 kΩ, T _A = 25°C V _{CC} = 30 V R _L = 2.0 kΩ V _{CC} = 30 V R _L = 10 kΩ	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 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) T _A = 25°C T _A = T _{high} to T _{low} (Note 8)	I _{O+}	20	40	–	20	40	–	20	40	–	20	40	–	20	40	–	mA
Output Sink Current (V _{ID} = –1.0 V, V _{CC} = 15 V) T _A = 25°C T _A = T _{high} to T _{low} (Note 8) (V _{ID} = –1.0 V, V _O = 200 mV, T _A = 25°C)	I _{O–}	10	20	–	10	20	–	10	20	–	10	20	–	10	20	–	mA
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) V _{CC} = 30 V V _O = 0 V, R _L = ∞ V _{CC} = 5.0 V, V _O = 0 V, R _L = ∞	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	mA

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}.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

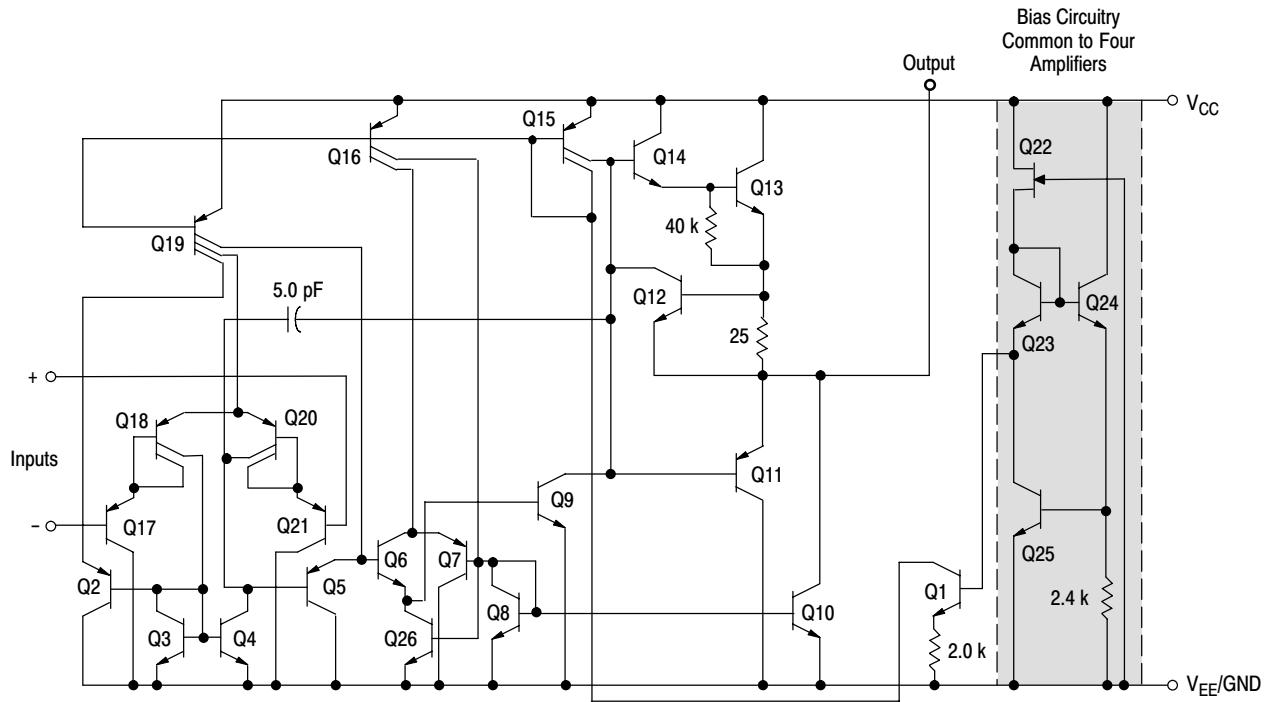


Figure 1. Representative Circuit Diagram
(One-Fourth of Circuit Shown)

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.

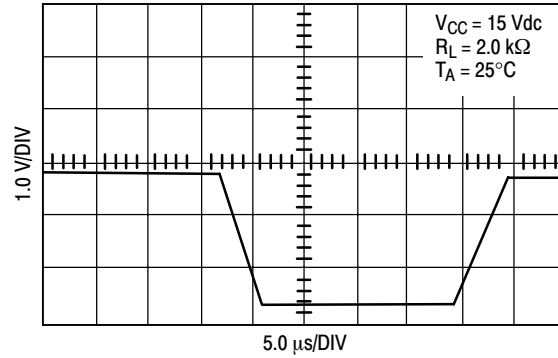


Figure 2. Large Signal Voltage Follower Response

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.

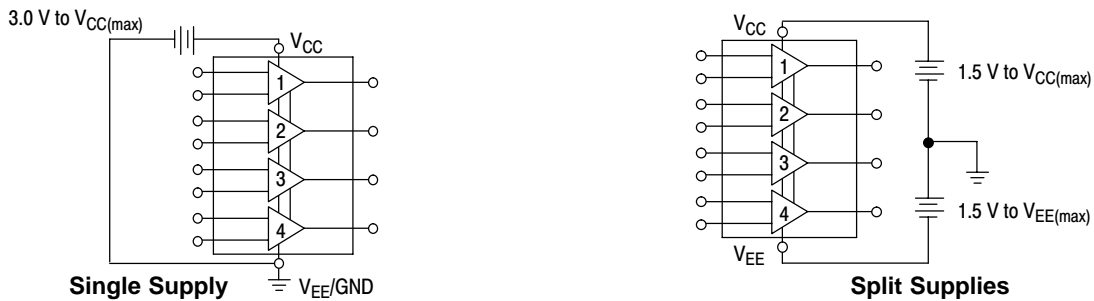


Figure 3.

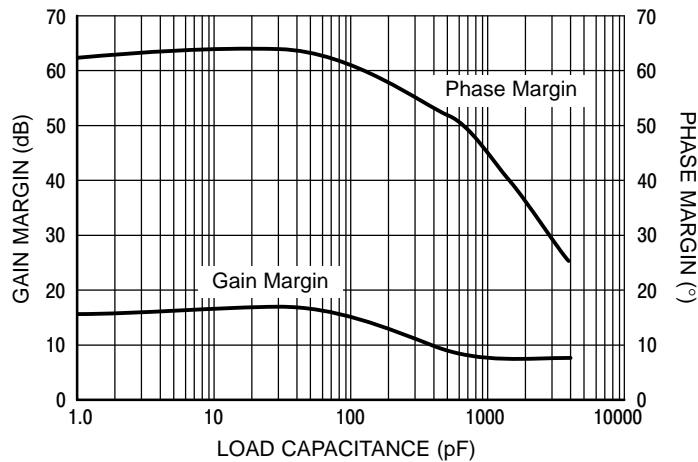


Figure 4. Gain and Phase Margin

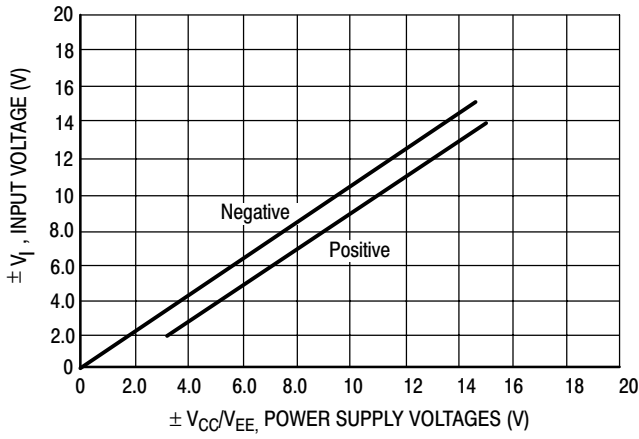


Figure 5. Input Voltage Range

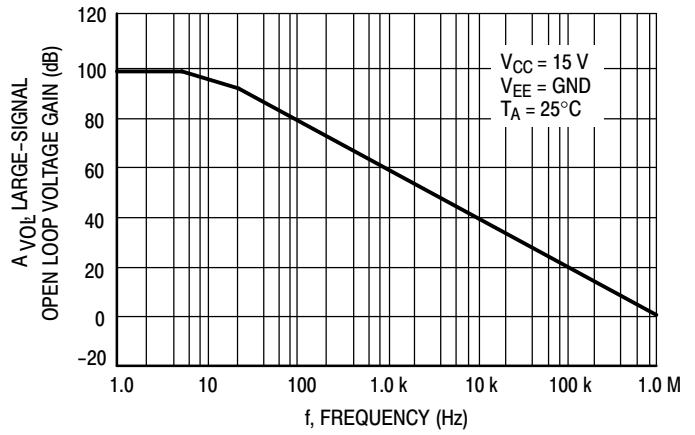


Figure 6. Open Loop Frequency

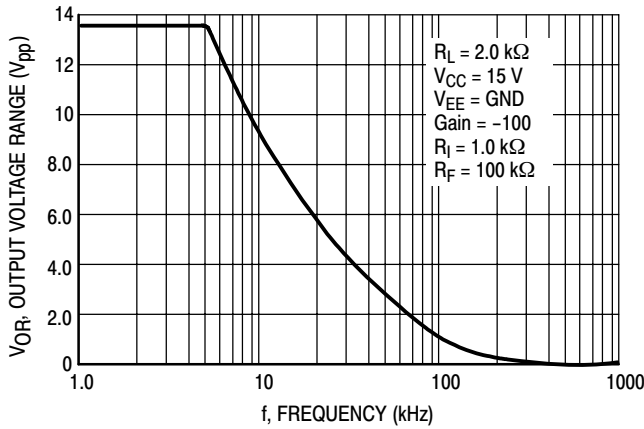


Figure 7. Large-Signal Frequency Response

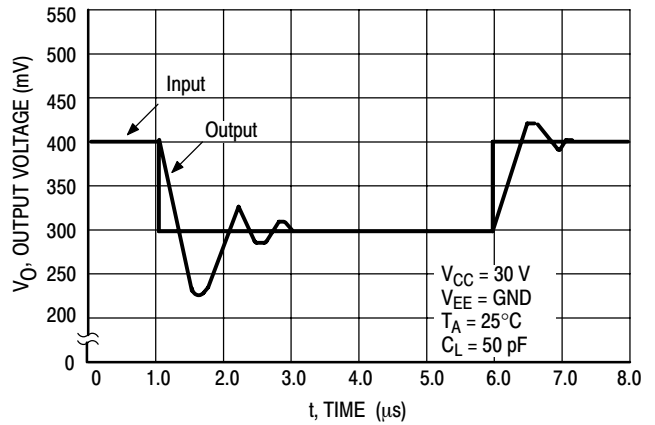


Figure 8. Small-Signal Voltage Follower Pulse Response (Noninverting)

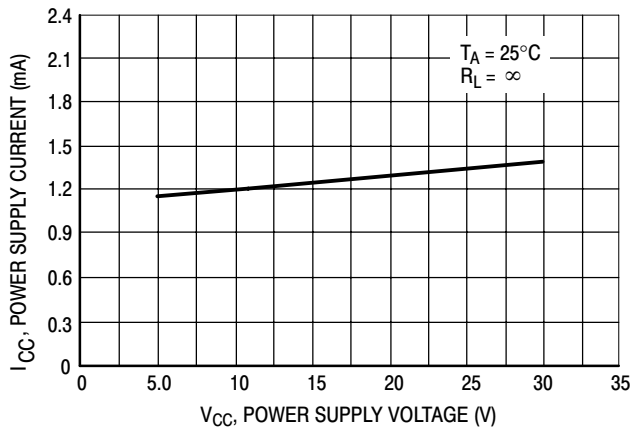


Figure 9. Power Supply Current versus Power Supply Voltage

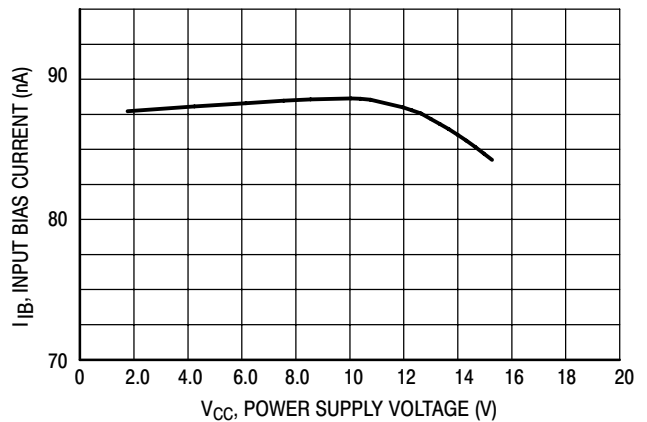


Figure 10. Input Bias Current versus Power Supply Voltage

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

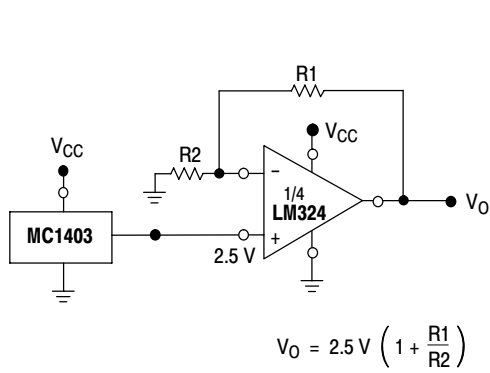


Figure 11. Voltage Reference

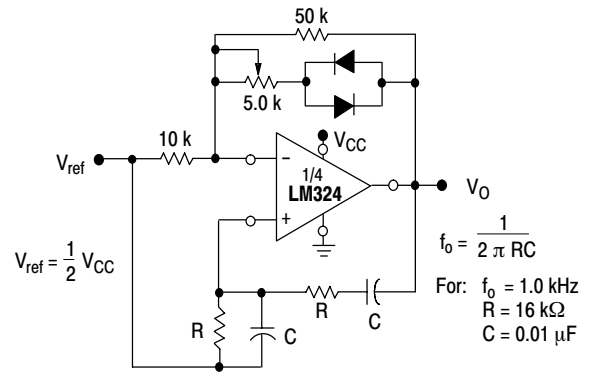


Figure 12. Wien Bridge Oscillator

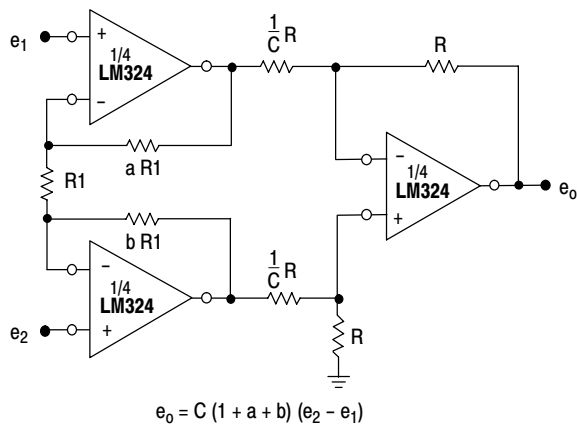


Figure 13. High Impedance Differential Amplifier

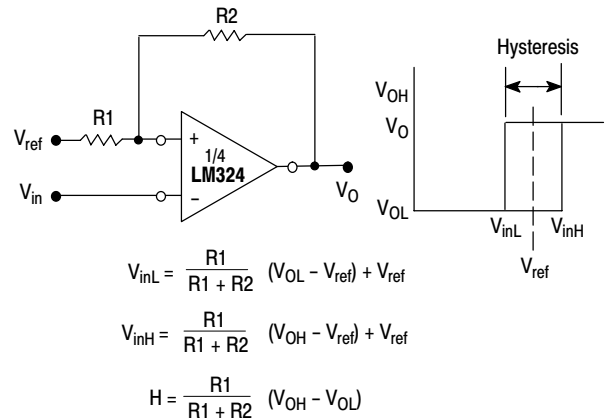


Figure 14. Comparator with Hysteresis

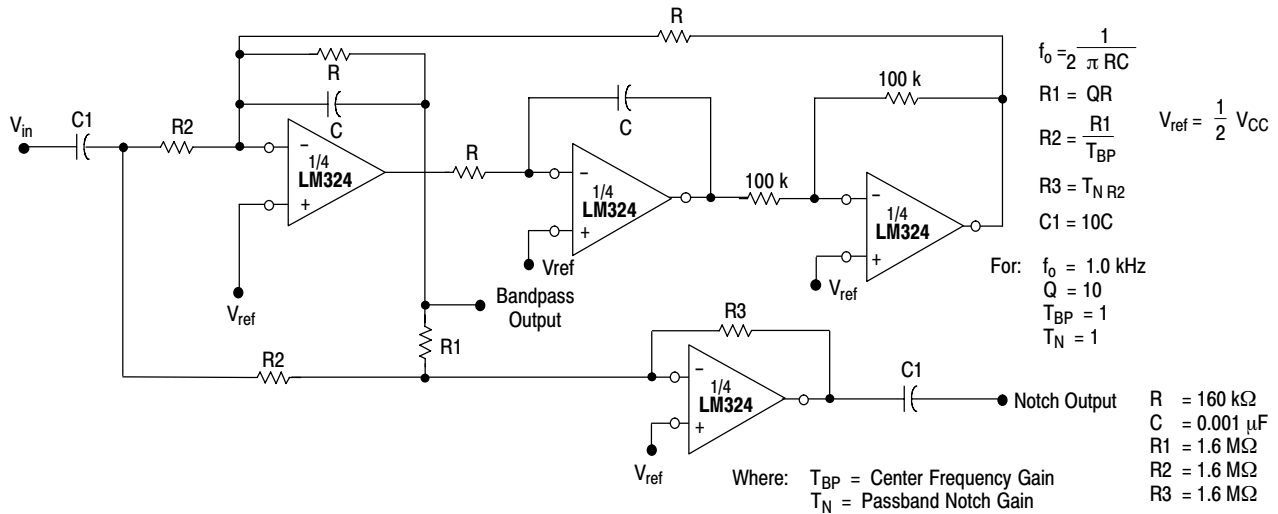


Figure 15. Bi-Quad Filter

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

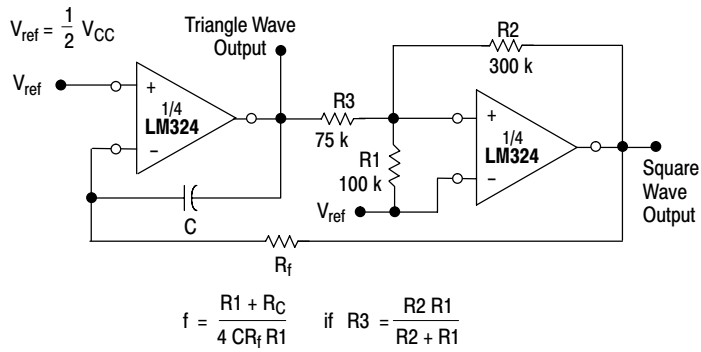


Figure 16. Function Generator

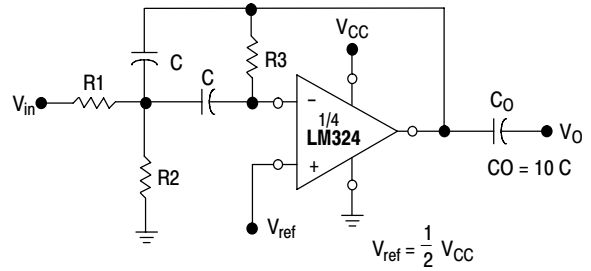


Figure 17. Multiple Feedback Bandpass Filter

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	Operating Temperature Range	Package	Shipping [†]
LM224D	-25°C to +85°C	SOIC-14	55 Units/Rail
LM224DG		SOIC-14 (Pb-Free)	55 Units/Rail
LM224DR2		SOIC-14	2500 Tape & Reel
LM224DR2G		SOIC-14 (Pb-Free)	2500 Tape & Reel
LM224DTB		TSSOP-14*	96 Units/Rail
LM224DTBG		TSSOP-14*	96 Units/Rail
LM224DTBR2		TSSOP-14*	2500 Tape & Reel
LM224DTBR2G		TSSOP-14*	2500 Tape & Reel
LM224N		PDIP-14	25 Units/Rail
LM224NG		PDIP-14 (Pb-Free)	25 Units/Rail
LM324D		0°C to +70°C	SOIC-14
LM324DG	SOIC-14 (Pb-Free)		55 Units/Rail
LM324DR2	SOIC-14		2500 Tape & Reel
LM324DR2G	SOIC-14 (Pb-Free)		2500 Tape & Reel
LM324DTB	TSSOP-14*		96 Units/Rail
LM324DTBG	TSSOP-14*		96 Units/Rail
LM324DTBR2	TSSOP-14*		2500 Tape & Reel
LM324DTBR2G	TSSOP-14*		2500 Tape & Reel
LM324N	PDIP-14		25 Units/Rail
LM324NG	PDIP-14 (Pb-Free)		25 Units/Rail
LM324AD	SOIC-14		55 Units/Rail
LM324ADG	SOIC-14 (Pb-Free)		55 Units/Rail
LM324ADR2	SOIC-14		2500 Tape & Reel
LM324ADR2G	SOIC-14 (Pb-Free)		2500 Tape & Reel
LM324ADTB	TSSOP-14*		96 Units/Rail
LM324ADTBG	TSSOP-14*		96 Units/Rail
LM324ADTBR2	TSSOP-14*		2500 Tape & Reel
LM324ADTBR2G	TSSOP-14*		2500 Tape & Reel
LM324AN	PDIP-14		25 Units/Rail
LM324ANG	PDIP-14 (Pb-Free)		25 Units/Rail

[†]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.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

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)	55 Units/Rail
LM2902DR2		SOIC-14	2500 Tape & Reel
LM2902DR2G		SOIC-14 (Pb-Free)	2500 Tape & Reel
LM2902DTB		TSSOP-14*	96 Units/Rail
LM2902DTBG		TSSOP-14*	96 Units/Rail
LM2902DTBR2		TSSOP-14*	2500 Tape & Reel
LM2902DTBR2G		TSSOP-14*	2500 Tape & Reel
LM2902N		PDIP-14	25 Units/Rail
LM2902NG		PDIP-14 (Pb-Free)	25 Units/Rail
LM2902VD		-40°C to +125°C	SOIC-14
LM2902VDG	SOIC-14 (Pb-Free)		55 Units/Rail
LM2902VDR2	SOIC-14		2500 Tape & Reel
LM2902VDR2G	SOIC-14 (Pb-Free)		2500 Tape & Reel
LM2902VDTB	TSSOP-14*		96 Units/Rail
LM2902VDTBG	TSSOP-14*		96 Units/Rail
LM2902VDTBR2	TSSOP-14*		2500 Tape & Reel
LM2902VDTBR2G	TSSOP-14*		2500 Tape & Reel
LM2902VN	PDIP-14		25 Units/Rail
LM2902VNG	PDIP-14 (Pb-Free)		25 Units/Rail
NCV2902DR2	SOIC-14		2500 Tape & Reel
NCV2902DR2G	SOIC-14 (Pb-Free)		2500 Tape & Reel
NCV2902DTBR2G	TSSOP-14*		2500 Tape & Reel

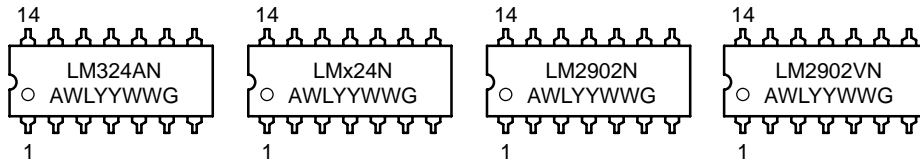
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

*This package is inherently Pb-Free.

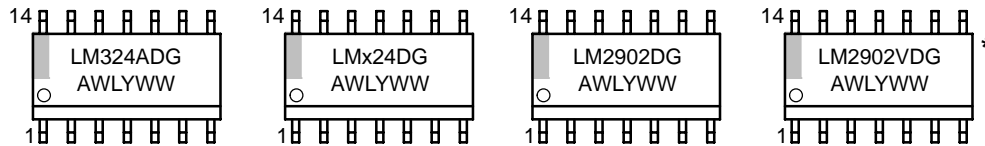
LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

MARKING DIAGRAMS

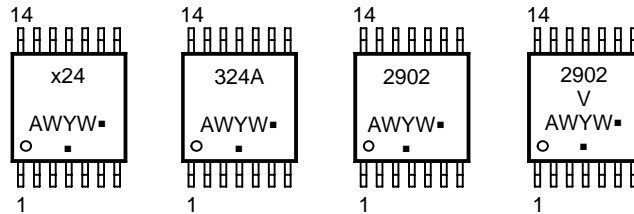
PDIP-14 N SUFFIX CASE 646



SOIC-14 D SUFFIX CASE 751A



TSSOP-14 DTB SUFFIX CASE 948G



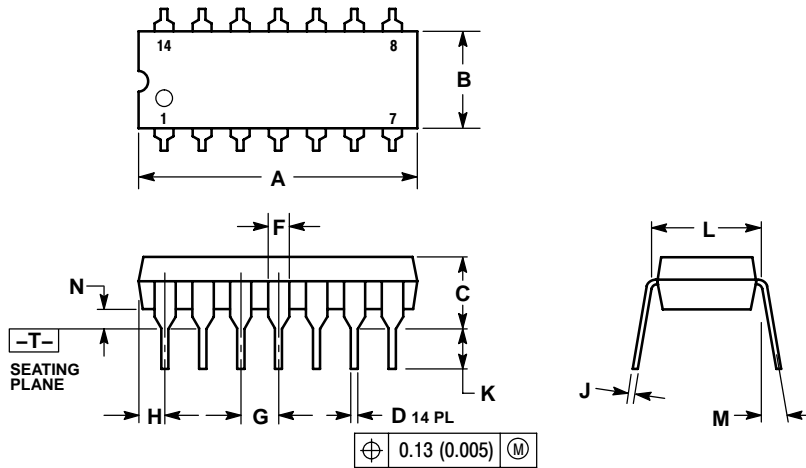
- x = 2 or 3
- A = Assembly Location
- WL = Wafer Lot
- YY, Y = Year
- WW, W = Work Week
- G = Pb-Free Package
- = Pb-Free Package – (Note: Microdot may be in either location)

*This marking diagram also applies to NCV2902.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

PACKAGE DIMENSIONS

PDIP-14
N SUFFIX
CASE 646-06
ISSUE N

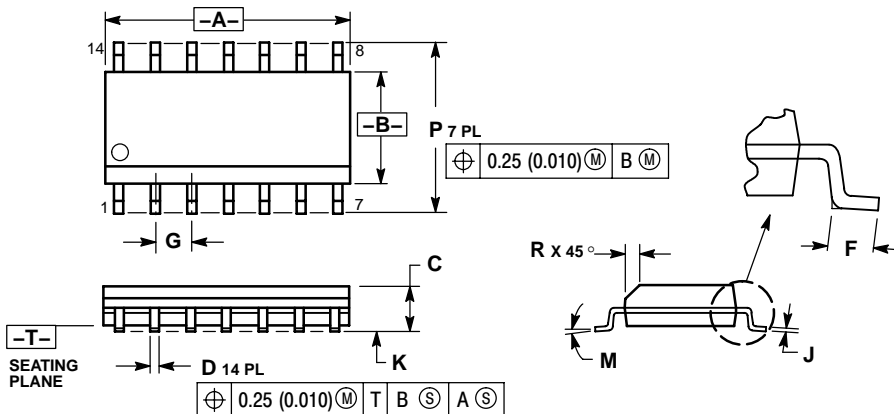


NOTES:

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

SOIC-14
D SUFFIX
CASE 751A-03
ISSUE G



NOTES:

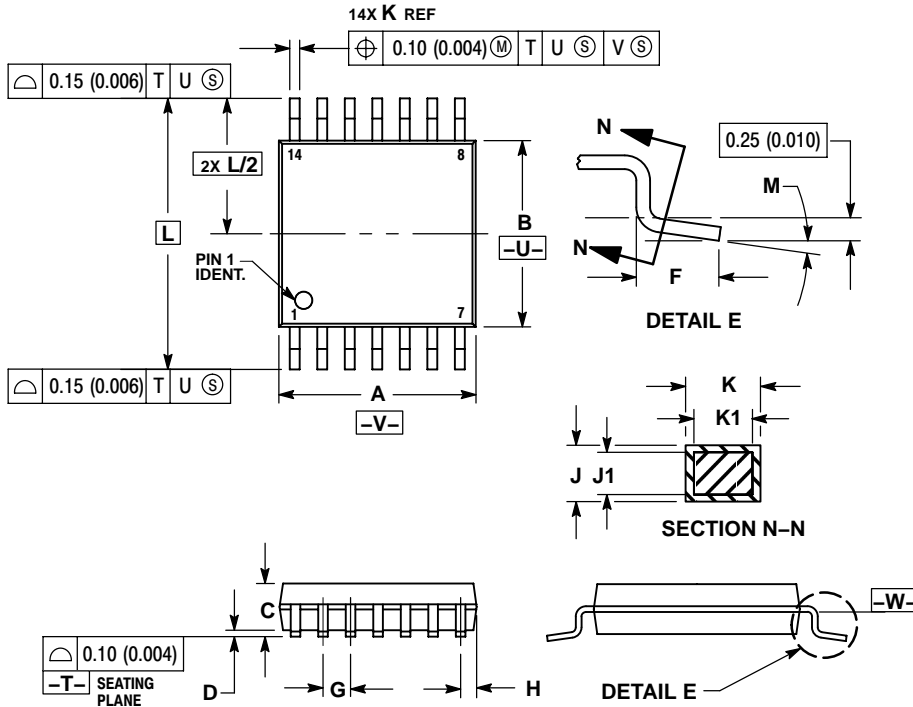
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL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



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-.

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°

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