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				Vdc
Single Supply	V_{CC}	32	26	
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
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.

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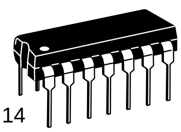
14



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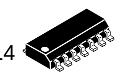
PDIP–14
N SUFFIX
CASE 646

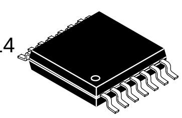
14



1

SO–14
D SUFFIX
CASE 751A

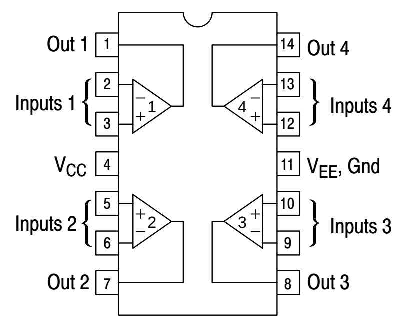
14



1

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 9 of this data sheet.

DEVICE MARKING INFORMATION

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

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 (26 V for LM2902, 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 2)		–	–	7.0	–	–	5.0	–	–	9.0	–	–	10	–	–	13	
$T_A = T_{low}$ (Note 2)		–	–	7.0	–	–	5.0	–	–	9.0	–	–	10	–	–	10	
Average Temperature Coefficient of Input Offset Voltage $T_A = T_{high}$ to T_{low} (Notes 2 and 4)	$\Delta V_{IO}/\Delta T$	–	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 2)		–	–	100	–	–	75	–	–	150	–	–	200	–	–	200	
Average Temperature Coefficient of Input Offset Current $T_A = T_{high}$ to T_{low} (Notes 2 and 4)	$\Delta I_{IO}/\Delta T$	–	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 2)		–	–	–300	–	–	–200	–	–	–500	–	–	–500	–	–	–500	
Input Common Mode Voltage Range (Note 3) V_{CC} = 30 V (26 V for LM2902, V)	V_{ICR}																V
T_A = +25°C		0	–	28.3	0	–	28.3	0	–	28.3	0	–	24.3	0	–	24.3	
$T_A = T_{high}$ to T_{low} (Note 2)		0	–	28	0	–	28	0	–	28	0	–	24	0	–	24	
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 2)		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

2. 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.
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 V.
4. 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 (T_A = $T_{high\ to}$ T_{low}) (Note 5)	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 (26 V for LM2902, V), R_L = 2.0 kΩ		26	–	–	26	–	–	26	–	–	22	–	–	22	–	–	
V_{CC} = 30 V (26 V for LM2902, V), R_L = 10 kΩ		27	28	–	27	28	–	27	28	–	23	24	–	23	24	–	
Output Voltage – Low Limit, V_{CC} = 5.0 V, R_L = 10 kΩ, T_A = T_{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 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 5)		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 5)		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 6)	I_{SC}	–	40	60	–	40	60	–	40	60	–	40	60	–	40	60	mA
Power Supply Current (T_A = T_{high} to T_{low}) (Note 5)	I_{CC}																mA
V_{CC} = 30 V (26 V for LM2902, 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	

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.

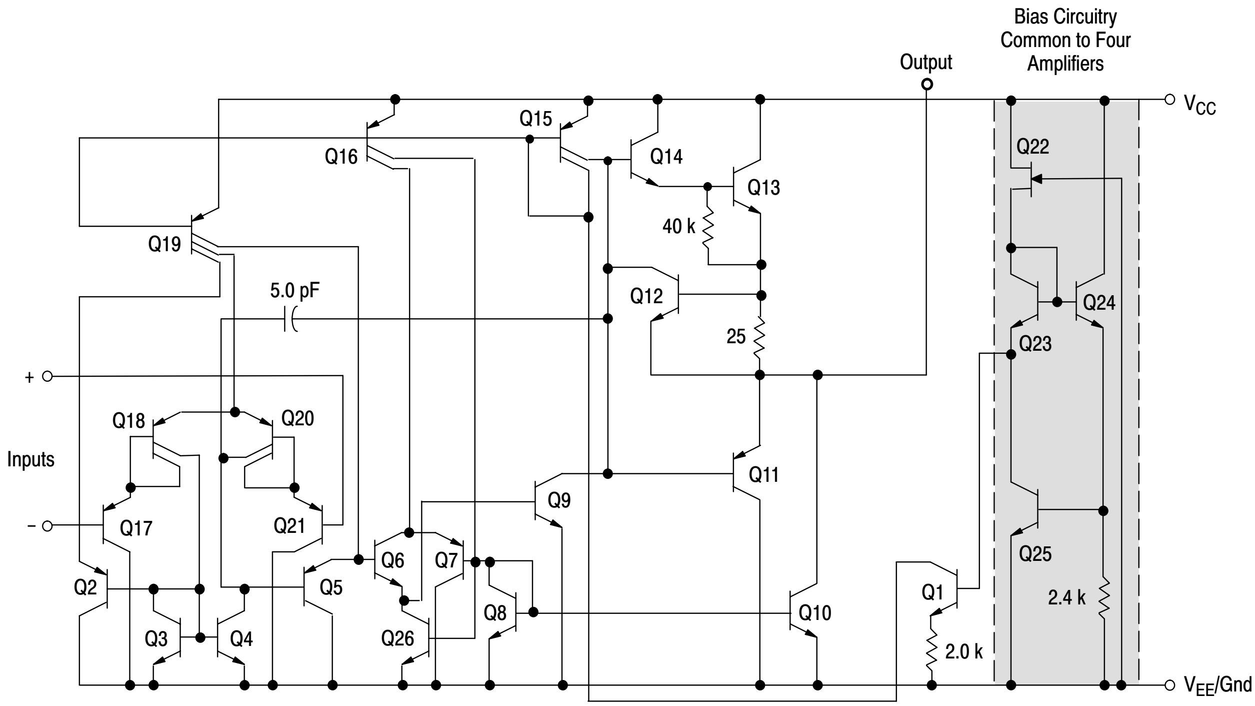


Figure 1. Representative Circuit Diagram
(One–Fourth of Circuit Shown)

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.

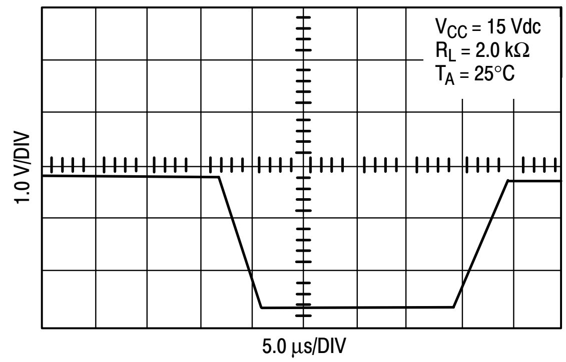
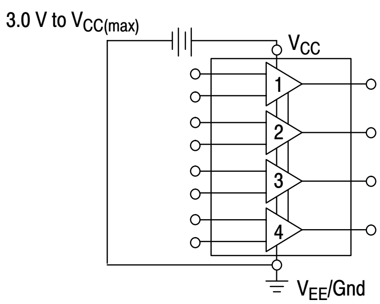
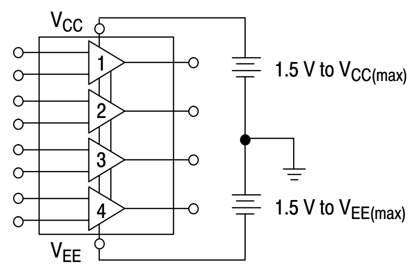


Figure 2. Large Signal Voltage Follower Response

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.

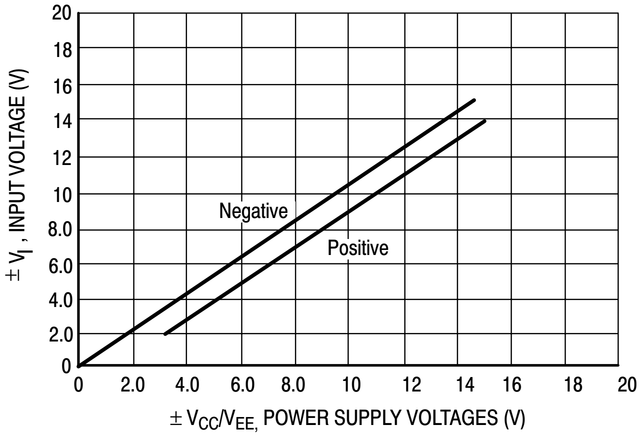


Figure 4. Input Voltage Range

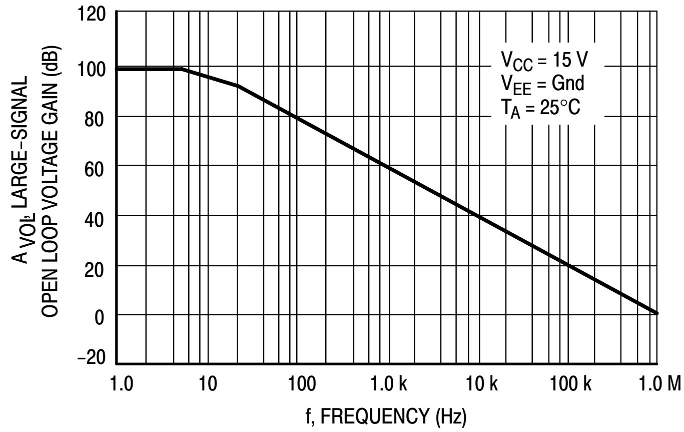


Figure 5. Open Loop Frequency

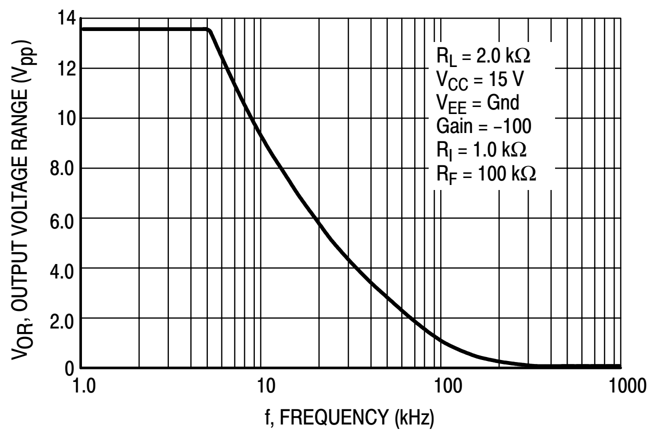


Figure 6. Large–Signal Frequency Response

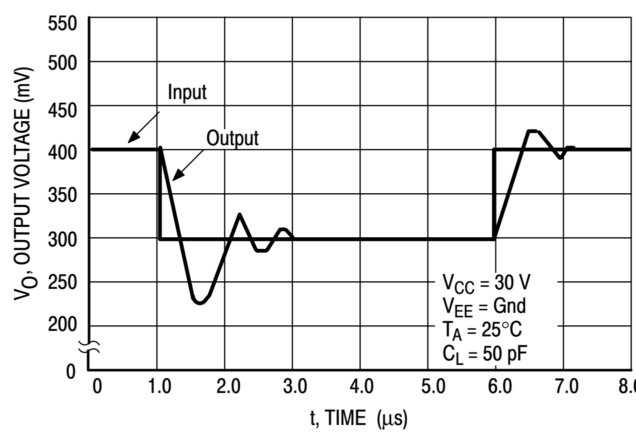


Figure 7. Small–Signal Voltage Follower Pulse Response (Noninverting)

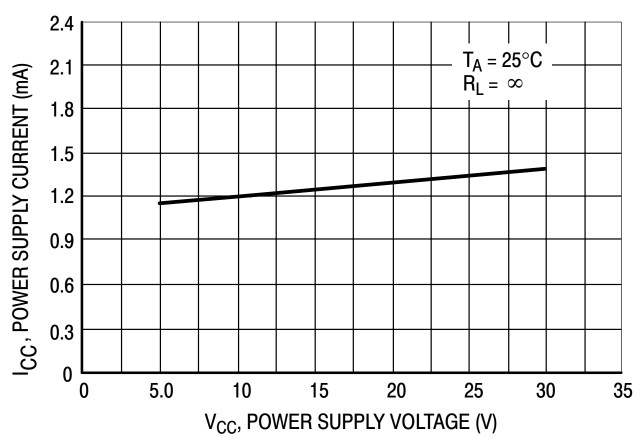


Figure 8. Power Supply Current versus Power Supply Voltage

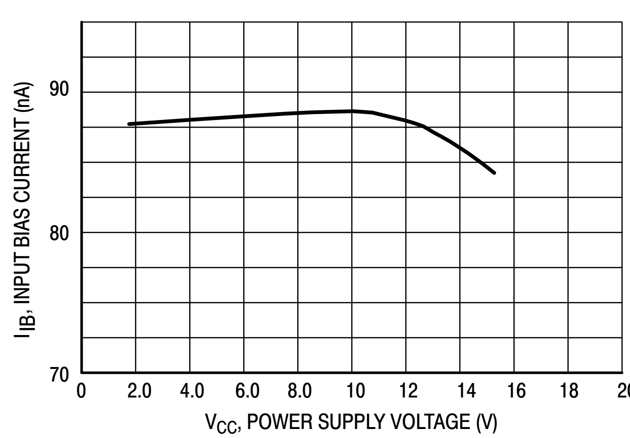
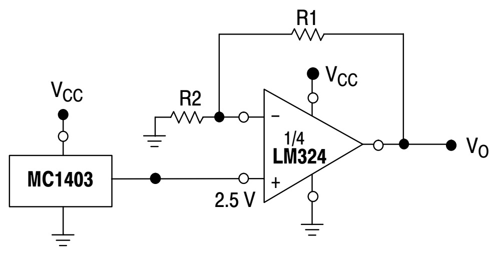


Figure 9. Input Bias Current versus Power Supply Voltage



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

Figure 10. Voltage Reference

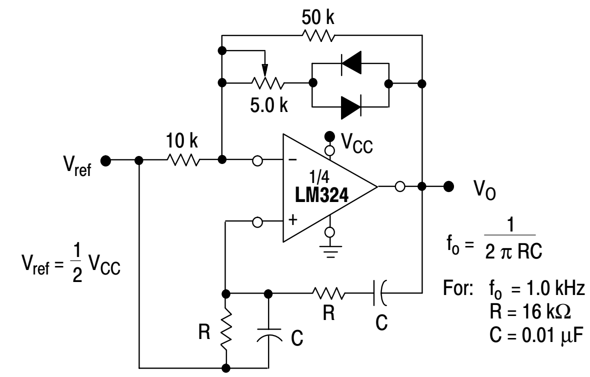
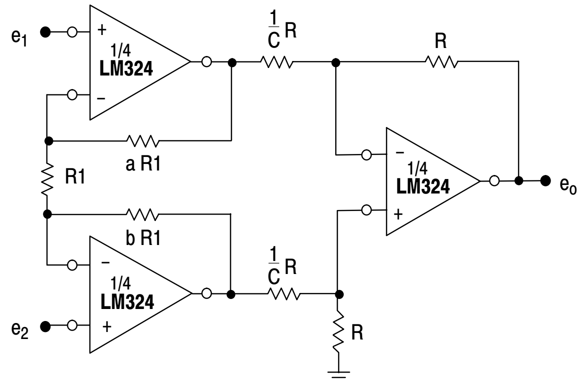
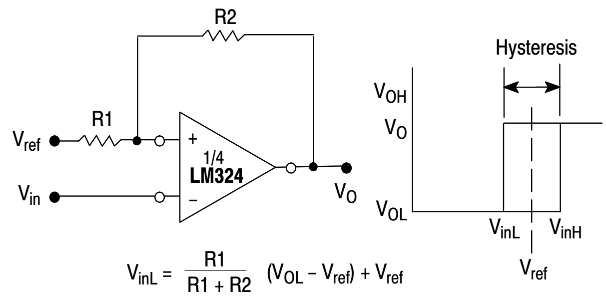


Figure 11. Wien Bridge Oscillator



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

Figure 12. 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 13. Comparator with Hysteresis

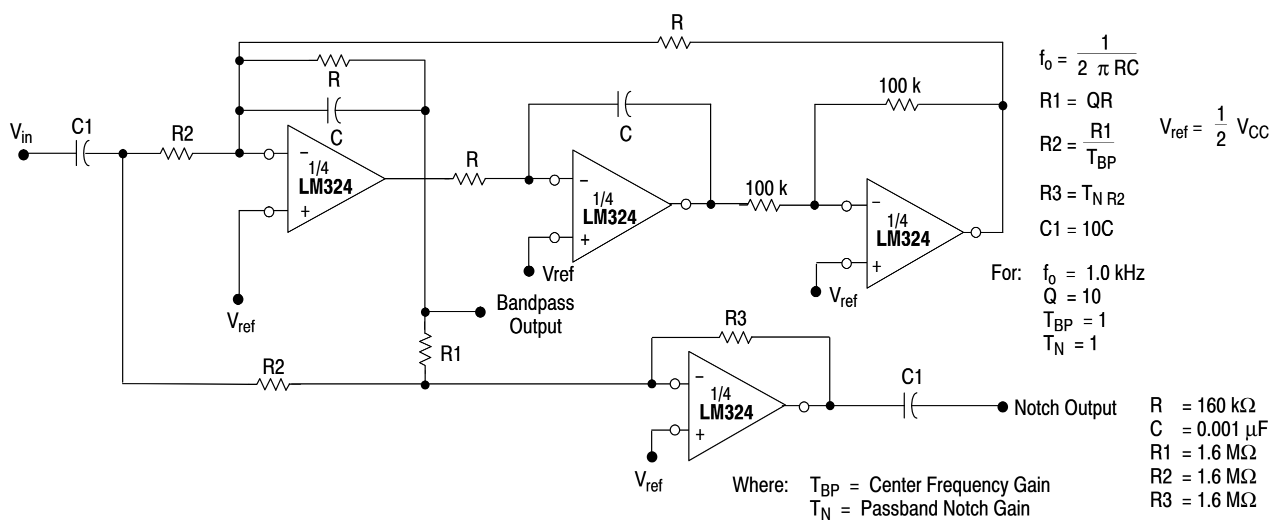
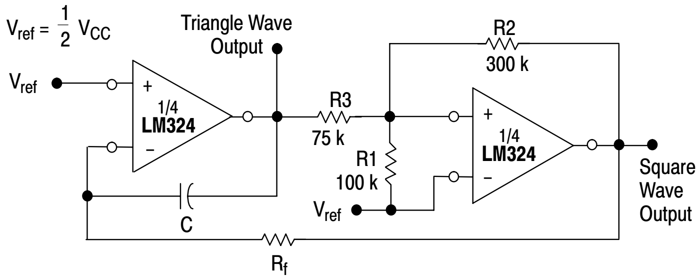


Figure 14. Bi–Quad Filter



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

Figure 15. Function Generator

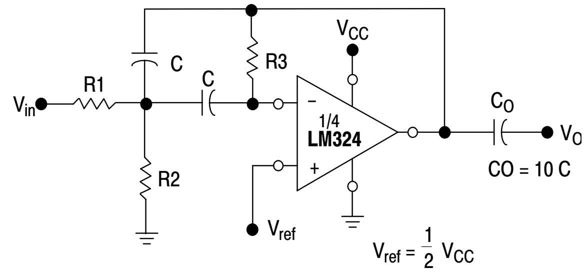


Figure 16. Multiple Feedback Bandpass Filter

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.

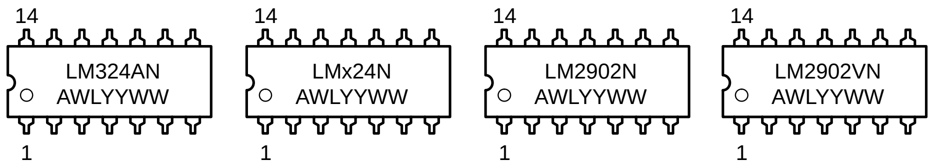
If source impedance varies, filter may be preceded with voltage follower buffer to stabilize filter parameters.

ORDERING INFORMATION

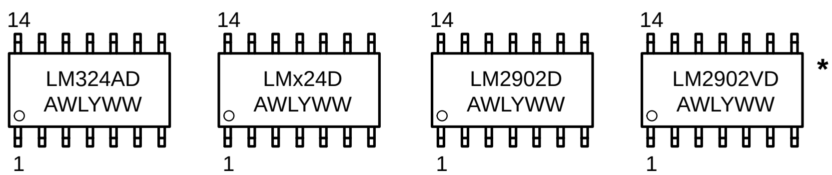
Device	Package	Operating Temperature Range	Shipping
LM224D	SO–14	–25° to +85°C	55 Units/Rail
LM224DR2	SO–14		2500 Tape & Reel
LM224DTB	TSSOP–14		96 Units/Rail
LM224DTBR2	TSSOP–14		2500 Tape & Reel
LM224N	PDIP–14		25 Units/Rail
LM324D	SO–14	0° to +70°C	55 Units/Rail
LM324DR2	SO–14		2500 Tape & Reel
LM324DTB	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

MARKING DIAGRAMS

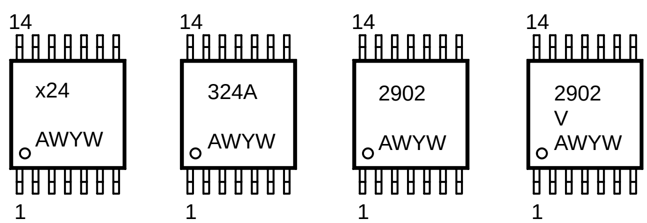
PDIP–14
N SUFFIX
CASE 646



SO–14
D SUFFIX
CASE 751A



TSSOP–14
DTB SUFFIX
CASE 948G

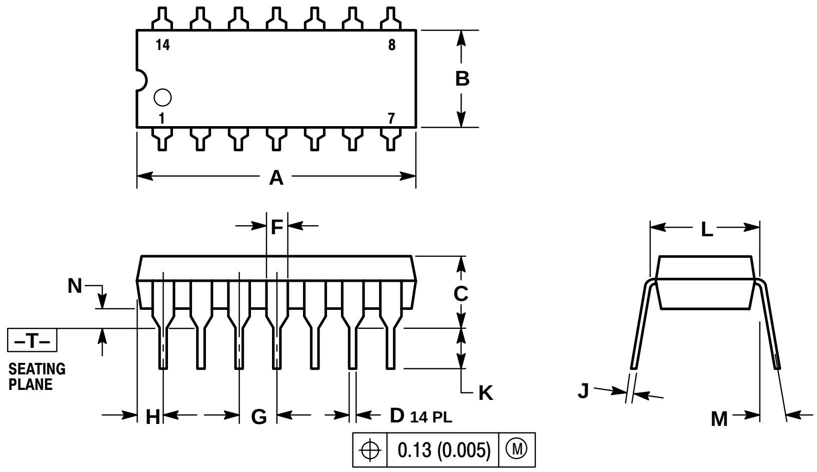


x = 2 or 3
A = Assembly Location
WL = Wafer Lot
YY, Y = Year
WW, W = Work Week

*This marking diagram also applies to NCV2902.

PACKAGE DIMENSIONS

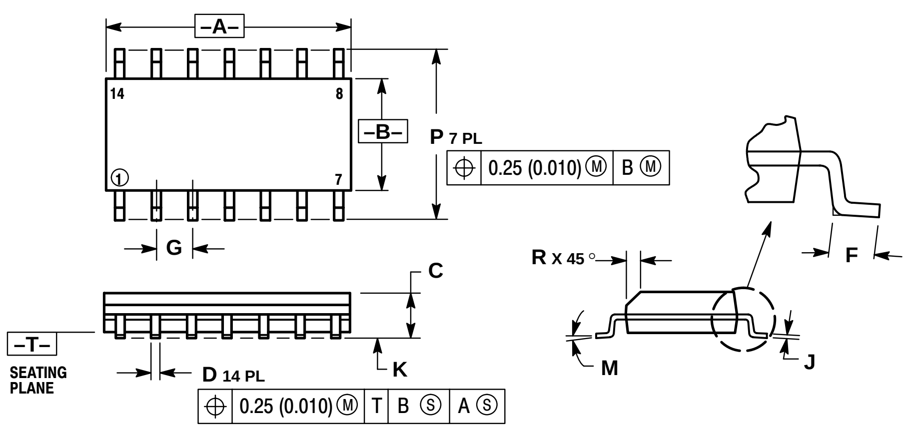
PDIP–14
N SUFFIX
CASE 646–06
ISSUE M



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.

	INCHES		MILLIMETERS	
DIM	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

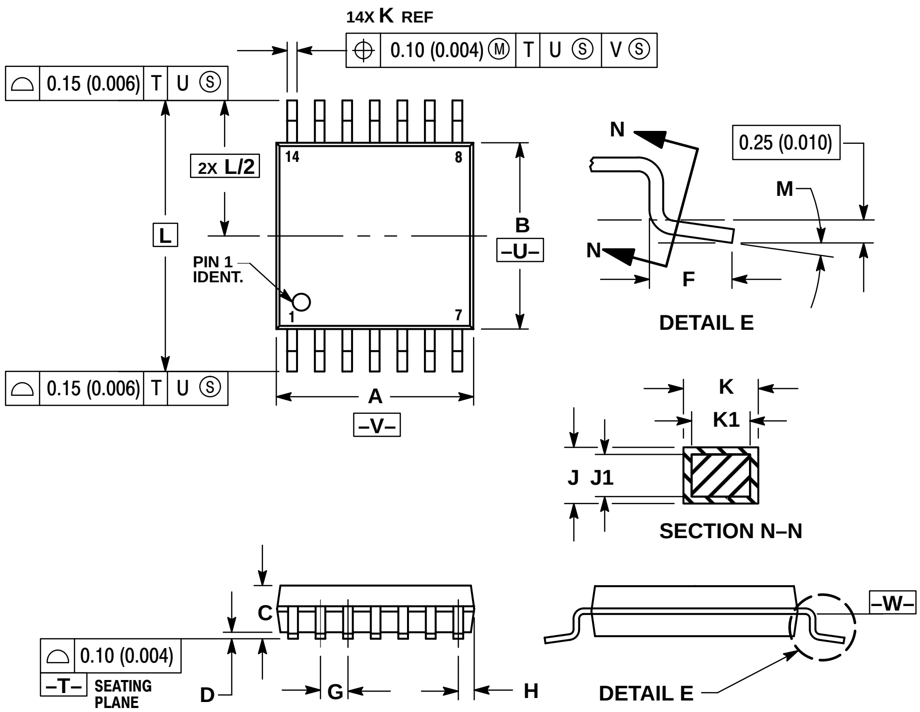


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005)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

	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

PACKAGE DIMENSIONS

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



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°

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