

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 ($T_A = +25^\circ\text{C}$, unless otherwise noted.)

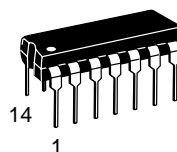
| Rating | Symbol | LM224 LM324, LM324A | LM2902, LM2902V | Unit |
|--|------------------|---------------------------|--------------------|------------------|
| Power Supply Voltages Single Supply | V_{CC} | 32 | 26 | Vdc |
| Split Supplies | V_{CC}, V_{EE} | ± 16 | ± 13 | |
| Input Differential Voltage 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 | | $^\circ\text{C}$ |
| Storage Temperature Range | T_{stg} | -65 to +150 | | $^\circ\text{C}$ |
| Operating Ambient Temperature Range | T_A | | | $^\circ\text{C}$ |
| 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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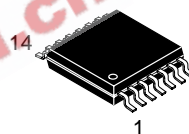
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PDIP-14
N SUFFIX
CASE 646

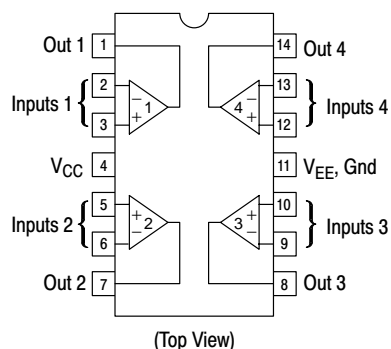


SO-14
D SUFFIX
CASE 751A



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 |

- 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.

- 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 $V_{CC} - 1.7\text{ V}$.
- 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) ($V_{ID} = -1.0\text{ V}$, $V_O = 200\text{ mV}$, $T_A = 25^\circ\text{C}$) | I_{O-} | 10 | 20 | — | 10 | 20 | — | 10 | 20 | — | 10 | 20 | — | 10 | 20 | — | mA |
| 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 |

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

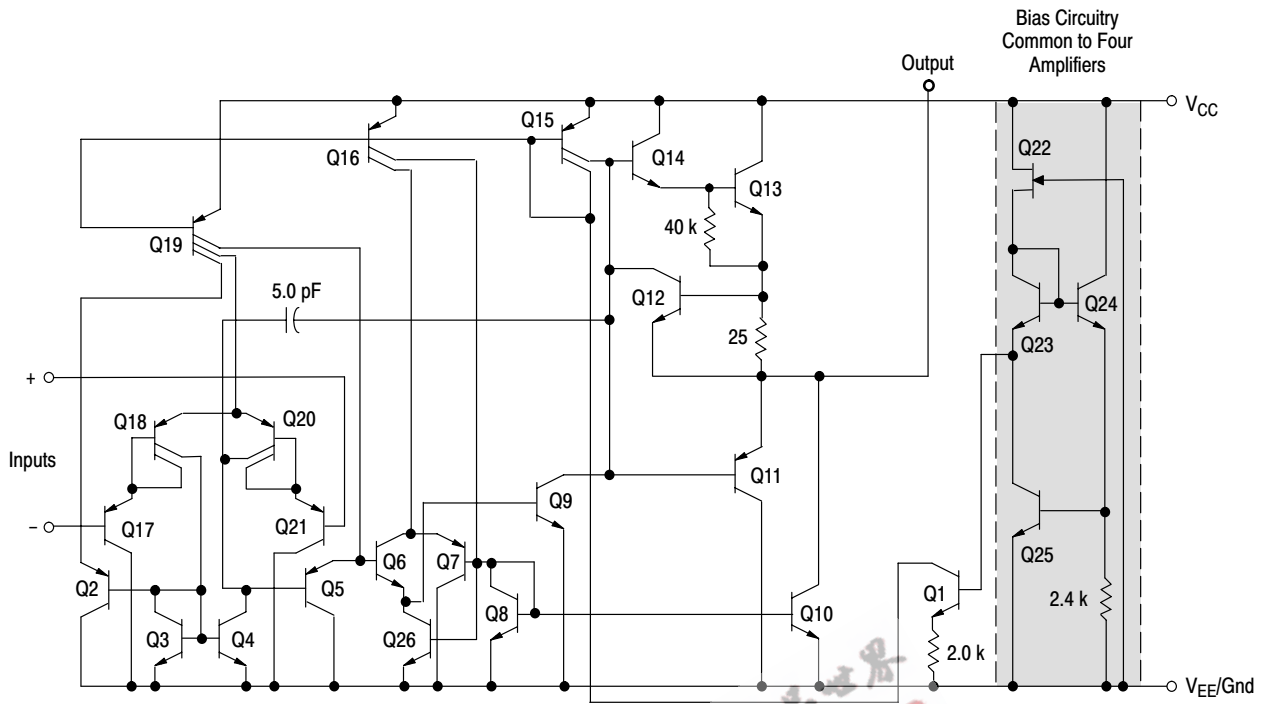


Figure 1. Representative Circuit Diagram
(One-Fourth of Circuit Shown)

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LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

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.

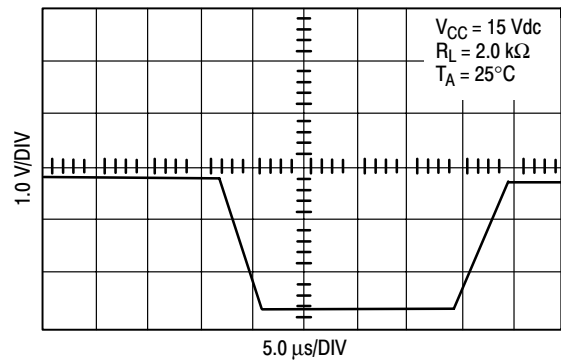


Figure 2. Large Signal Voltage Follower Response

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.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

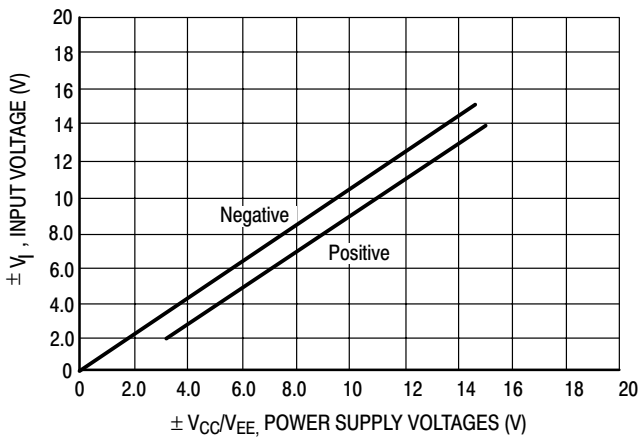


Figure 4. Input Voltage Range

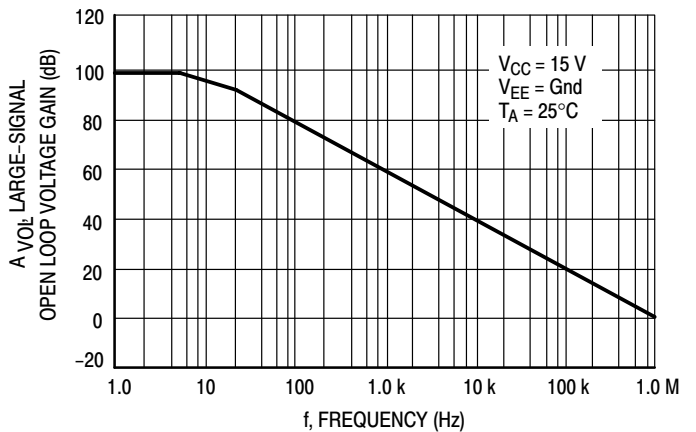


Figure 5. Open Loop Frequency

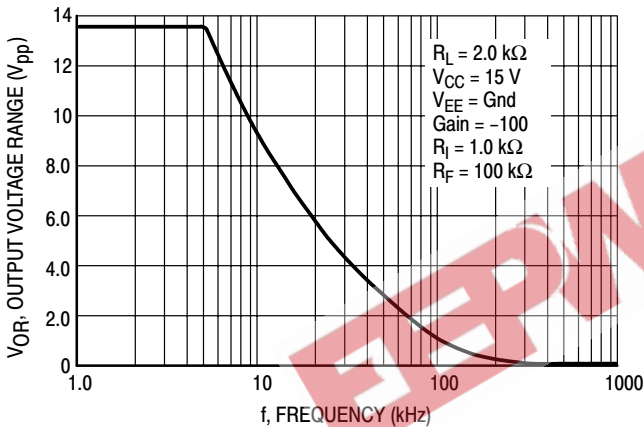


Figure 6. Large-Signal Frequency Response

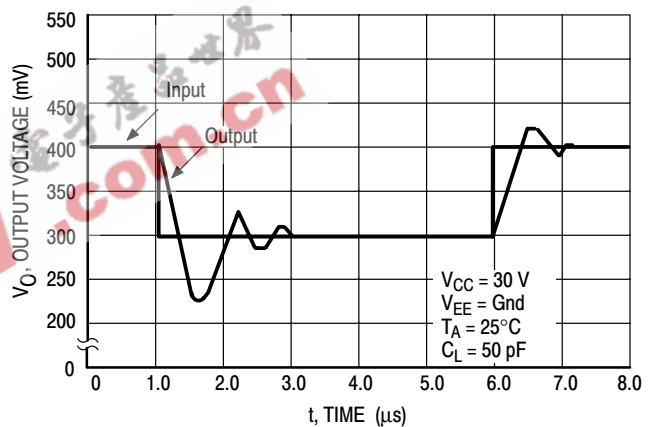


Figure 7. Small-Signal Voltage Follower Pulse Response (Noninverting)

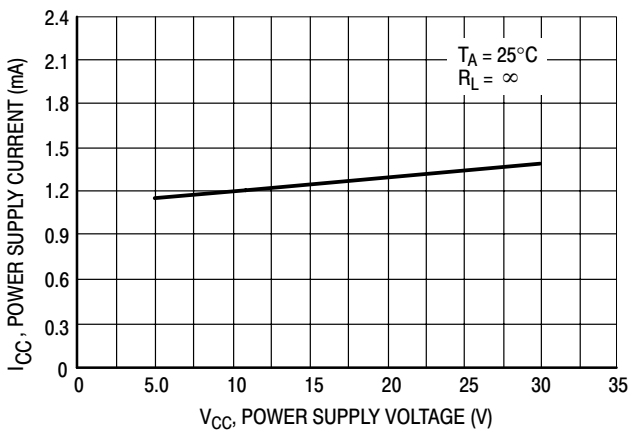


Figure 8. Power Supply Current versus Power Supply Voltage

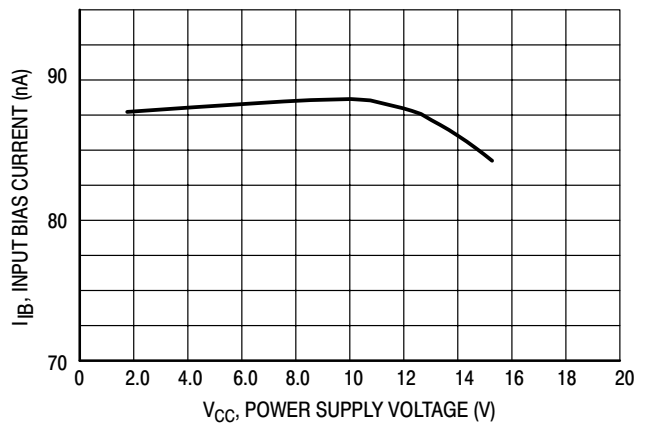


Figure 9. Input Bias Current versus Power Supply Voltage

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

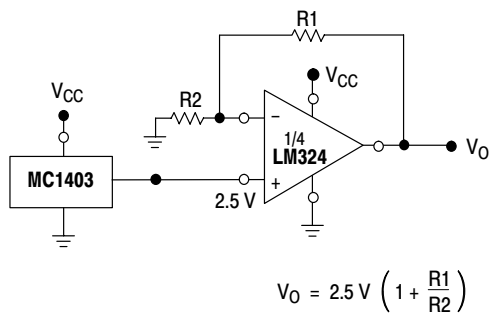


Figure 10. Voltage Reference

$$V_0 = 2.5V \left(1 + \frac{R1}{R2} \right)$$

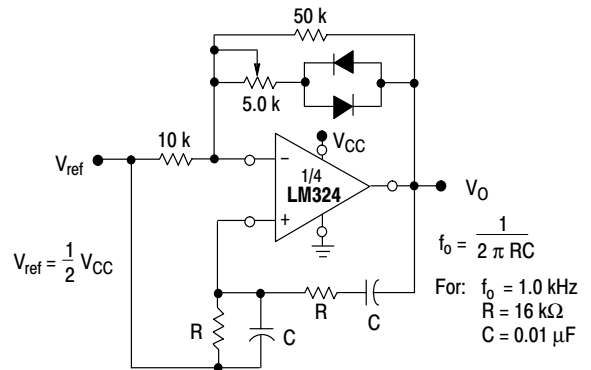


Figure 11. Wien Bridge Oscillator

$$f_0 = \frac{1}{2\pi RC}$$

For: $f_0 = 1.0 \text{ kHz}$
 $R = 16 \text{ k}\Omega$
 $C = 0.01 \mu\text{F}$

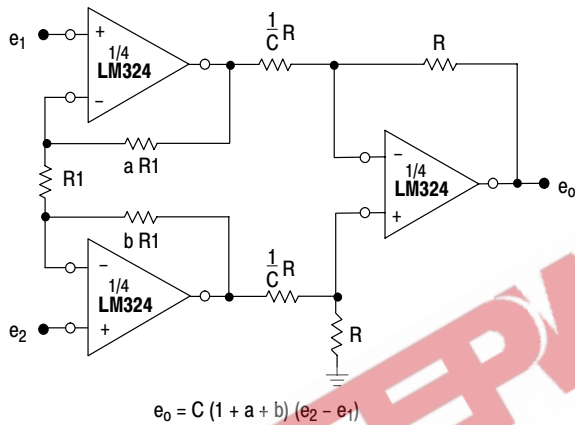


Figure 12. High Impedance Differential Amplifier

$$e_0 = C(1 + a + b)(e_2 - e_1)$$

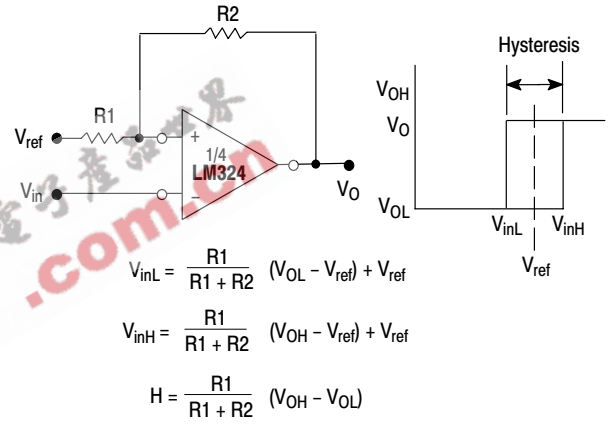


Figure 13. Comparator with Hysteresis

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

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

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

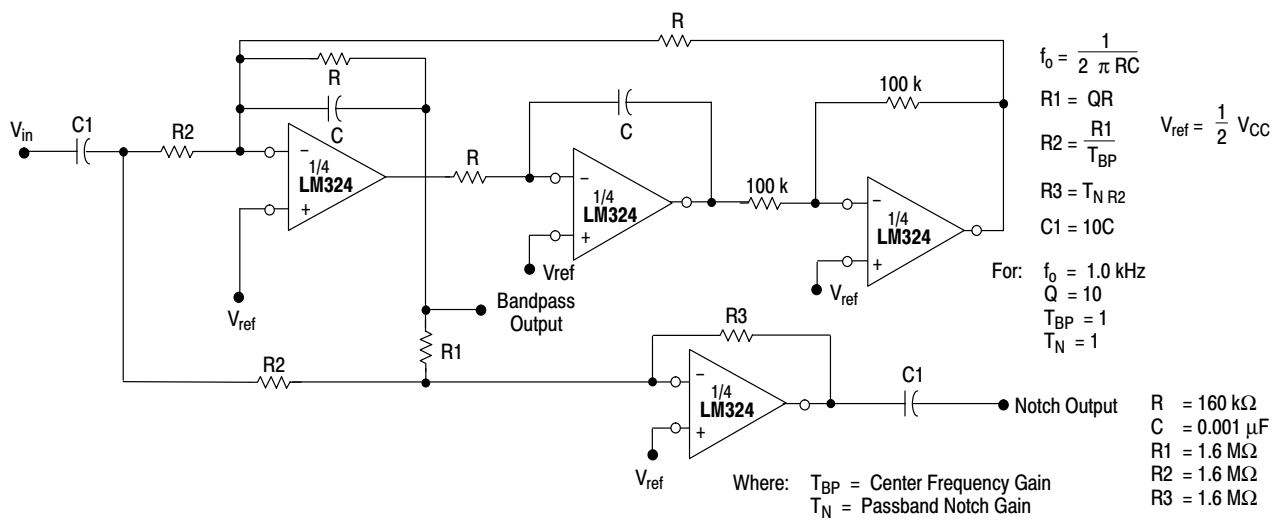


Figure 14. Bi-Quad Filter

$$f_0 = \frac{1}{2\pi RC}$$

$$V_{ref} = \frac{1}{2} V_{CC}$$

For: $f_0 = 1.0 \text{ kHz}$
 $Q = 10$
 $T_{BP} = 1$
 $T_N = 1$

Where: T_{BP} = Center Frequency Gain
 T_N = Passband Notch Gain

$R = 160 \text{ k}\Omega$
 $C = 0.001 \mu\text{F}$
 $R1 = 1.6 \text{ M}\Omega$
 $R2 = 1.6 \text{ M}\Omega$
 $R3 = 1.6 \text{ M}\Omega$

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

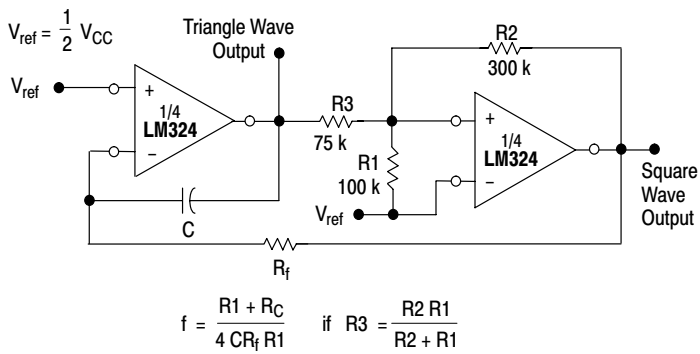


Figure 15. Function Generator

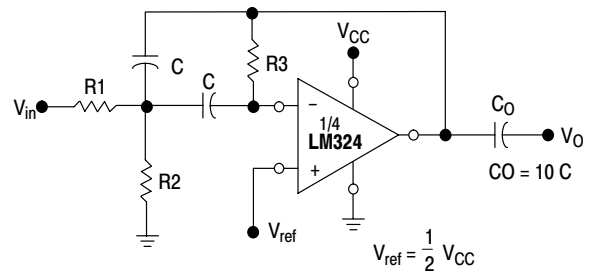


Figure 16. Multiple Feedback Bandpass Filter

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

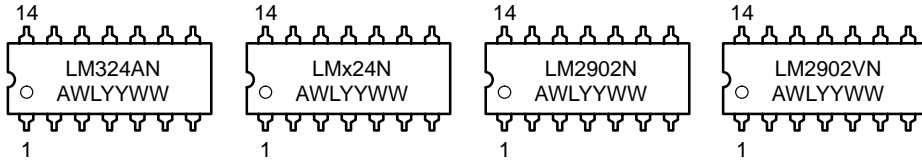
ORDERING INFORMATION

| 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 |
| 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 |

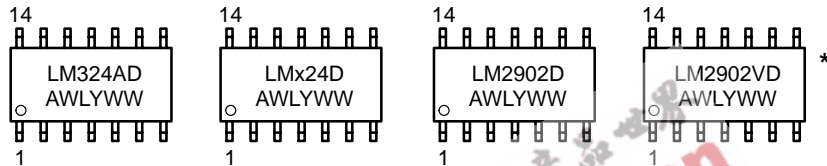
LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

MARKING DIAGRAMS

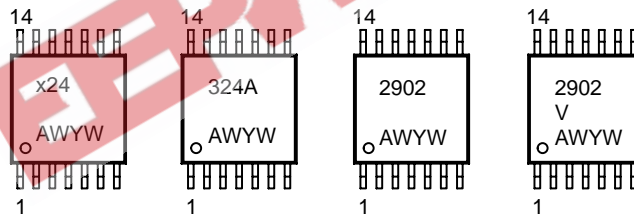
PDIP-14 N SUFFIX CASE 646



SO-14 D SUFFIX CASE 751A



TSSOP-14 DTB SUFFIX CASE 948G



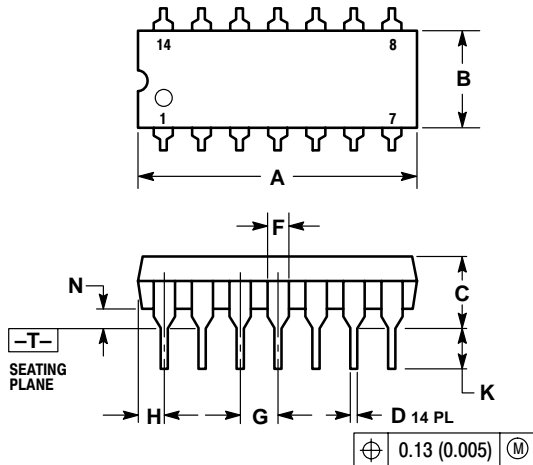
x = 2 or 3
A = Assembly Location
WL = Wafer Lot
YY, Y = Year
WW, W = Work Week

*This marking diagram also applies to NCV2902.

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

PACKAGE DIMENSIONS

PDIP-14
N SUFFIX
CASE 646-06
ISSUE M

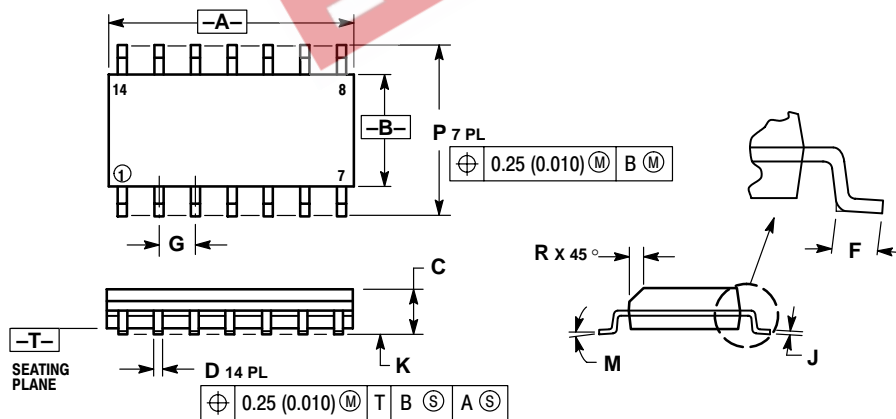


NOTES:

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:

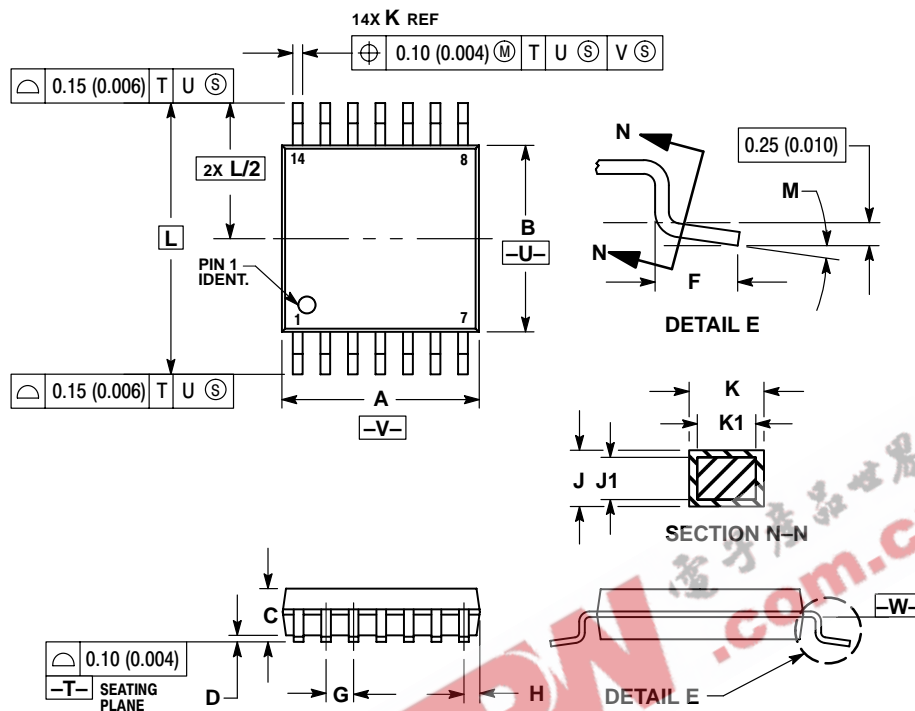
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL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

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