# 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
- NCV Prefix for Automotive and Other Applications Requiring Site and Control Changes
- These Devices are Pb−Free, Halogen Free/BFR Free and are RoHS Compliant

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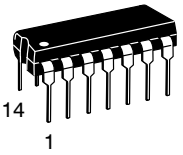
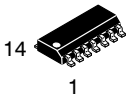
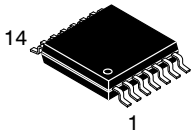



**PDIP−14**
**N SUFFIX**
**CASE 646**

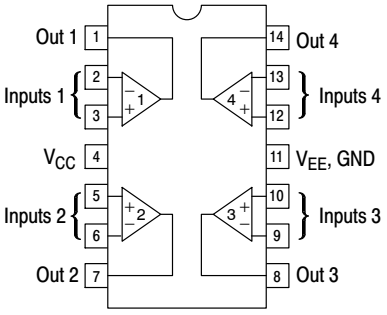



**SOIC−14**
**D SUFFIX**
**CASE 751A**




**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 11 of this data sheet.

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

| Rating | | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltages | | | | Vdc |
| Single Supply | | $V_{CC}$ | 32 | |
| Split Supplies | | $V_{CC}$, $V_{EE}$ | ±16 | |
| Input Differential Voltage Range (Note 1) | | $V_{IDR}$ | ±32 | Vdc |
| Input Common Mode Voltage Range (Note 2) | | $V_{ICR}$ | −0.3 to 32 | Vdc |
| Output Short Circuit Duration | | $t_{SC}$ | Continuous | |
| Junction Temperature | | $T_J$ | 150 | °C |
| Thermal Resistance, Junction−to−Air (Note 3) | Case 646 | $R_{\theta JA}$ | 118 | °C/W |
| | Case 751A | | 156 | |
| | Case 948G | | 190 | |
| Storage Temperature Range | | $T_{stg}$ | −65 to +150 | °C |
| ESD Protection at any Pin | | $V_{esd}$ | | V |
| Human Body Model | | | 2000 | |
| 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 (Note 4) | | −40 to +125 | |

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<br>$V_{CC}$ = 5.0 V to 30 V<br>$V_{ICR}$ = 0 V to $V_{CC}$ −1.7 V,<br>$V_O$ = 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<br>$T_A$ = $T_{high}$ 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<br>$T_A$ = $T_{high}$ to $T_{low}$ (Note 5) | $I_{IO}$ | –<br>– | 3.0<br>– | 30<br>100 | –<br>– | 5.0<br>– | 30<br>75 | –<br>– | 5.0<br>– | 50<br>150 | –<br>– | 5.0<br>– | 50<br>200 | –<br>– | 5.0<br>– | 50<br>200 | nA |
| Average Temperature Coefficient of Input Offset Current<br>$T_A$ = $T_{high}$ to $T_{low}$ (Notes 5 and 7) | $\Delta I_{IO}/\Delta T$ | – | 10 | – | – | 10 | 300 | – | 10 | – | – | 10 | – | – | 10 | – | pA/°C |
| Input Bias Current<br>$T_A$ = $T_{high}$ to $T_{low}$ (Note 5) | $I_{IB}$ | –<br>– | −90<br>– | −150<br>−300 | –<br>– | −45<br>– | −100<br>−200 | –<br>– | −90<br>– | −250<br>−500 | –<br>– | −90<br>– | −250<br>−500 | –<br>– | −90<br>– | −250<br>−500 | nA |
| Input Common Mode Voltage Range (Note 6)<br>$V_{CC}$ = 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<br>$R_L$ = 2.0 kΩ,<br>$V_{CC}$ = 15 V,<br>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 5) | | 25 | – | – | 15 | – | – | 15 | – | – | 15 | – | – | 15 | – | – | |
| Channel Separation<br>10 kHz ≤ f ≤ 20 kHz,<br>Input Referenced | CS | – | −120 | – | – | −120 | – | – | −120 | – | – | −120 | – | – | −120 | – | dB |
| Common Mode Rejection,<br>$R_S$ ≤ 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 $V_{CC}$.

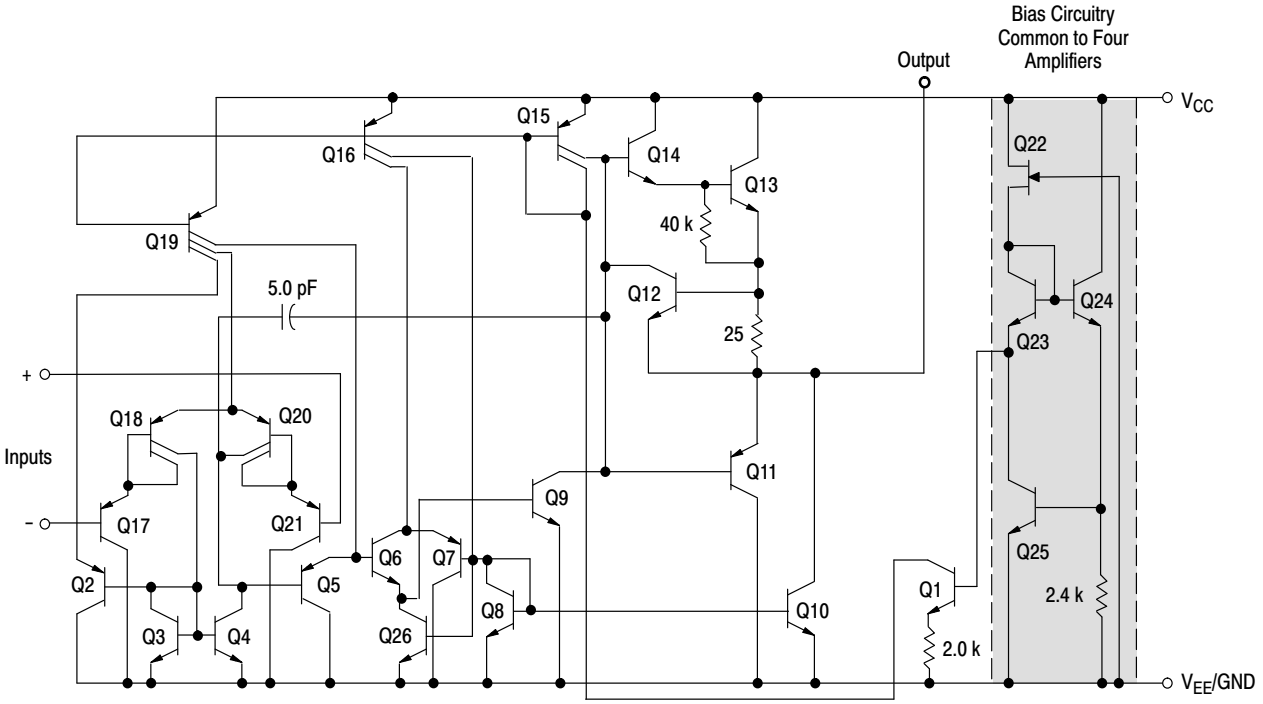



**Figure 1. Representative Circuit Diagram**
(One−Fourth of Circuit Shown)

## 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.

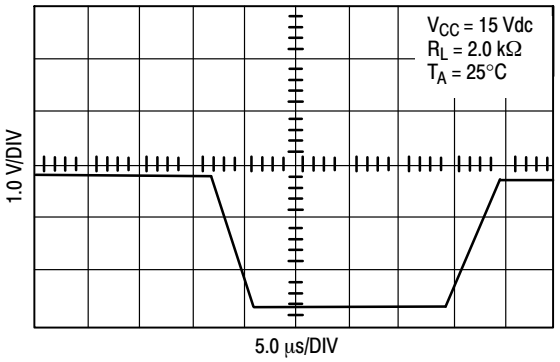



**Figure 2. Large Signal Voltage Follower Response**

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.**

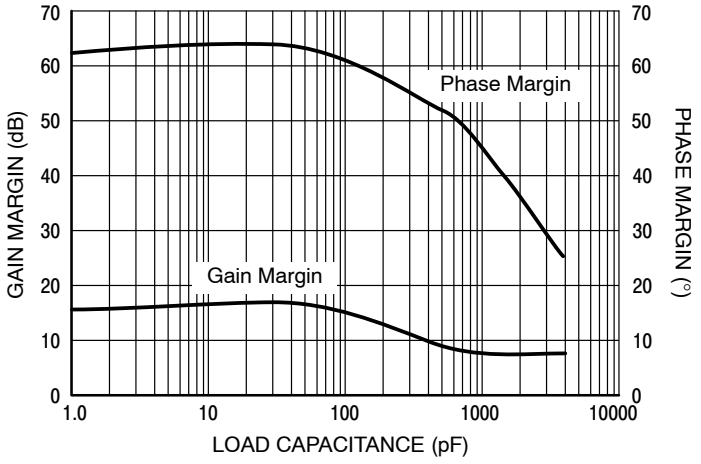



**Figure 4. Gain and Phase Margin**

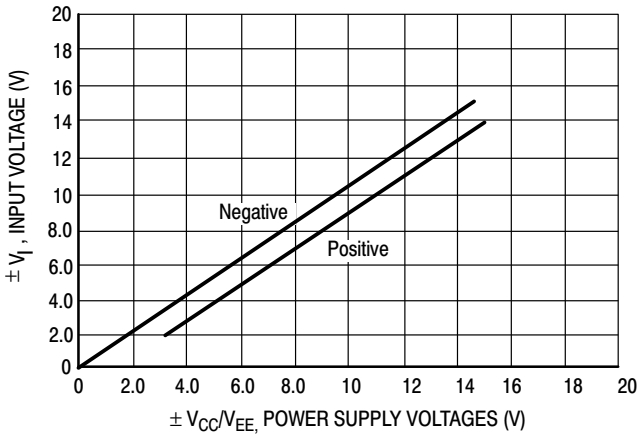



**Figure 5. Input Voltage Range**

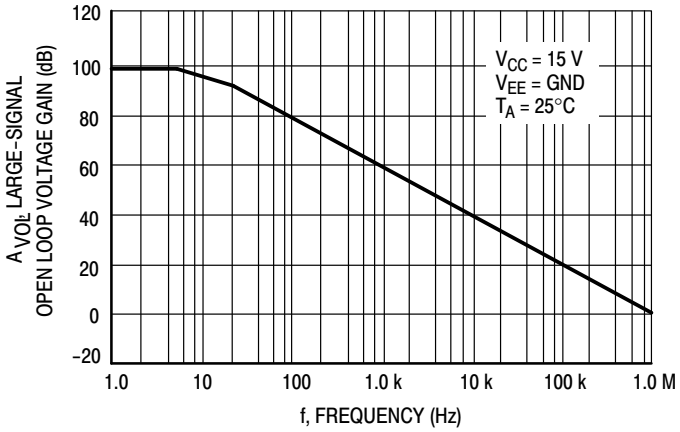



**Figure 6. Open Loop Frequency**

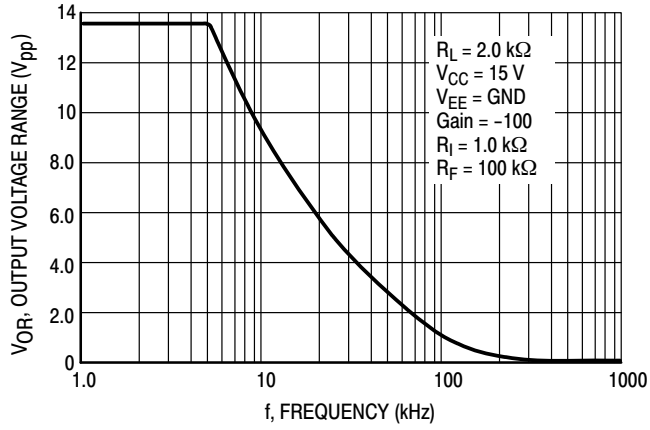



**Figure 7. Large−Signal Frequency Response**

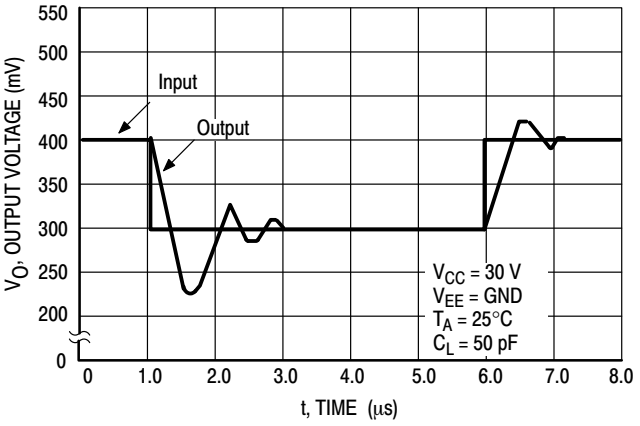



**Figure 8. Small−Signal Voltage Follower Pulse Response (Noninverting)**

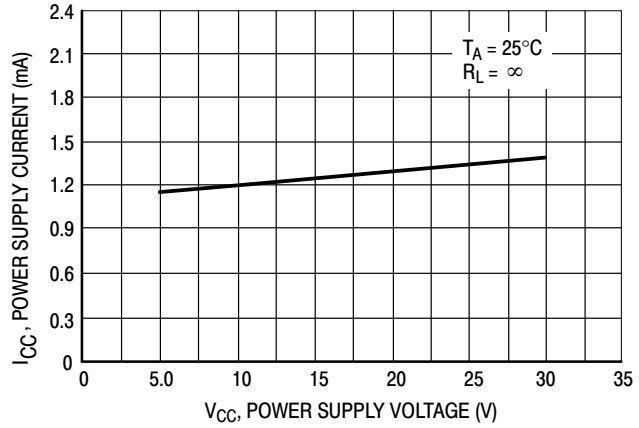



**Figure 9. Power Supply Current versus Power Supply Voltage**

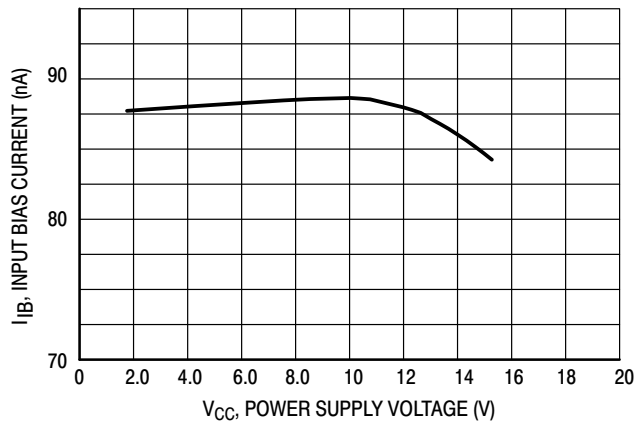



**Figure 10. Input Bias Current versus Power Supply Voltage**

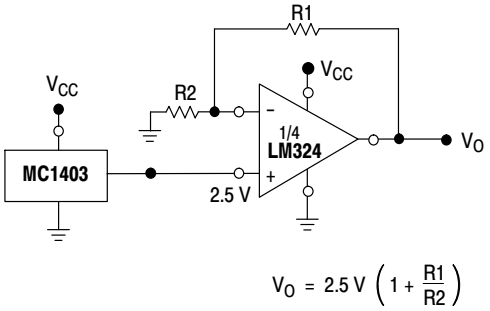



**Figure 11. Voltage Reference**

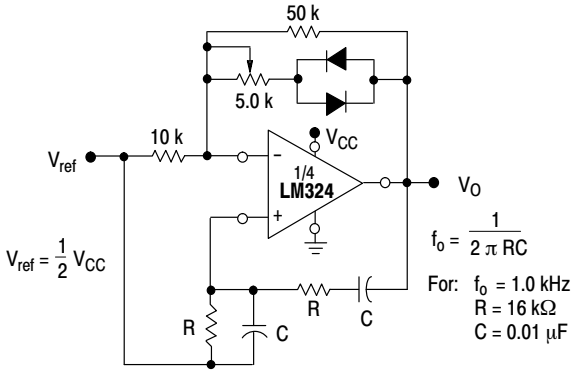



**Figure 12. Wien Bridge Oscillator**

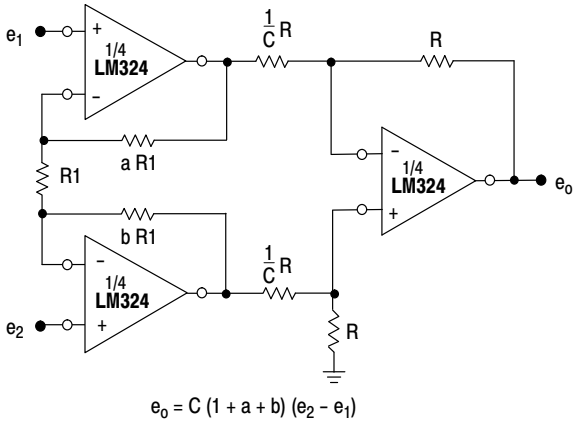



**Figure 13. High Impedance Differential Amplifier**

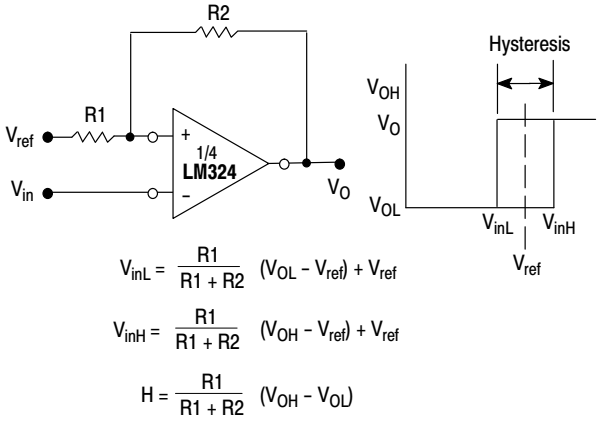



**Figure 14. Comparator with Hysteresis**

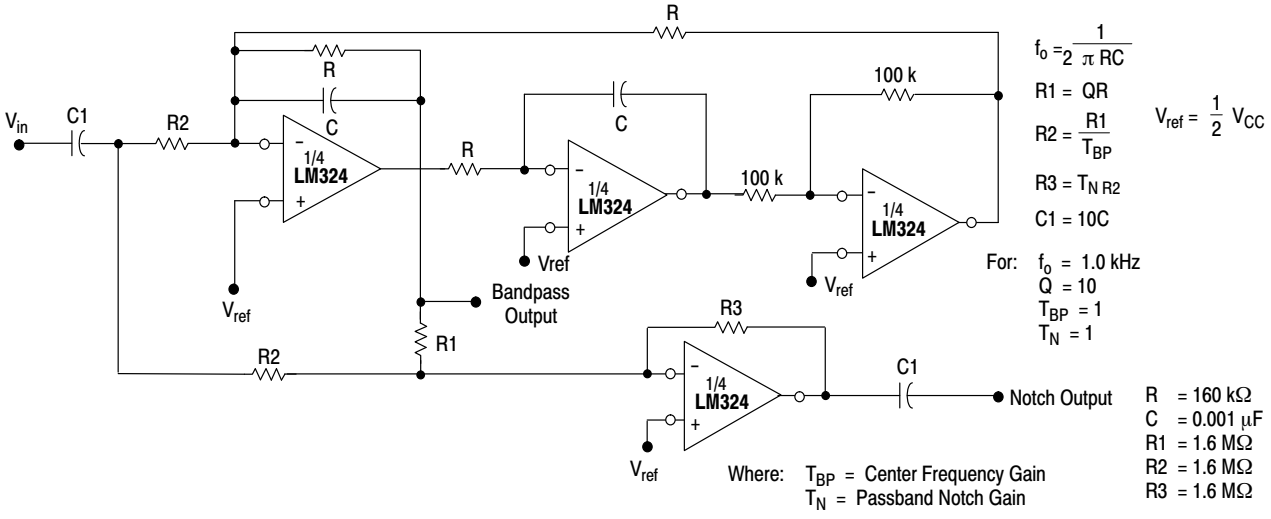



**Figure 15. Bi−Quad Filter**

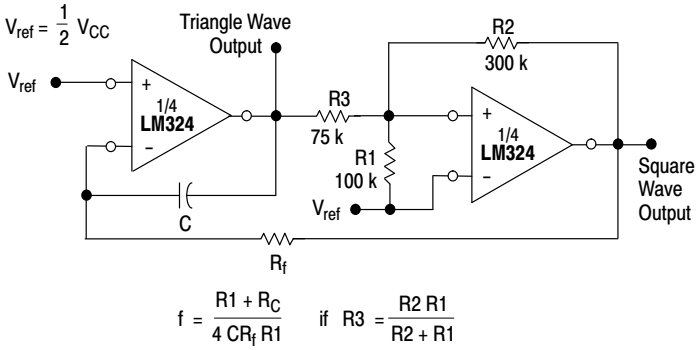



**Figure 16. Function Generator**

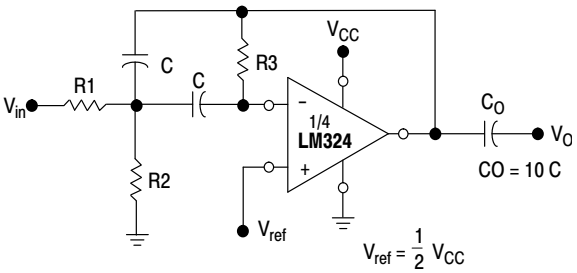



**Figure 17. Multiple Feedback Bandpass Filter**

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.

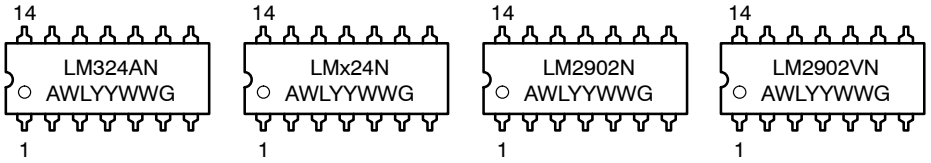
**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package | Shipping† |
|---|---|---|---|
| LM224DG | −25°C to +85°C | SOIC−14 | 55 Units/Rail |
| LM224DR2G | | SOIC−14 | 2500/Tape & Reel |
| LM224DTBG | | TSSOP−14 | 96 Units/Tube |
| LM224DTBR2G | | TSSOP−14 | 2500/Tape & Reel |
| LM224NG | | PDIP−14 | 25 Units/Rail |
| LM324DG | 0°C to +70°C | SOIC−14 | 55 Units/Rail |
| LM324DR2G | | SOIC−14 | 2500/Tape & Reel |
| LM324DTBG | | TSSOP−14 | 96 Units/Tube |
| LM324DTBR2G | | TSSOP−14 | 2500/Tape & Reel |
| LM324NG | | PDIP−14 | 25 Units/Rail |
| LM324ADG | | SOIC−14 | 55 Units/Rail |
| LM324ADR2G | | SOIC−14 | 2500/Tape & Reel |
| LM324ADTBG | | TSSOP−14 | 96 Units/Tube |
| LM324ADTBR2G | | TSSOP−14 | 2500/Tape & Reel |
| LM324ANG | | PDIP−14 | 25 Units/Rail |
| LM2902DG | −40°C to +105°C | SOIC−14 | 55 Units/Rail |
| LM2902DR2G | | SOIC−14 | 2500/Tape & Reel |
| LM2902DTBG | | TSSOP−14 | 96 Units/Tube |
| LM2902DTBR2G | | TSSOP−14 | 2500/Tape & Reel |
| LM2902NG | | PDIP−14 | 25 Units/Rail |
| LM2902VDG | −40°C to +125°C | SOIC−14 | 55 Units/Rail |
| LM2902VDR2G | | SOIC−14 | 2500/Tape & Reel |
| LM2902VDTBG | | TSSOP−14 | 96 Units/Tube |
| LM2902VDTBR2G | | TSSOP−14 | 2500/Tape & Reel |
| LM2902VNG | | PDIP−14 | 25 Units/Rail |
| NCV2902DR2G | | SOIC−14 | 2500/Tape & Reel |
| NCV2902DTBR2G | | TSSOP−14 | |

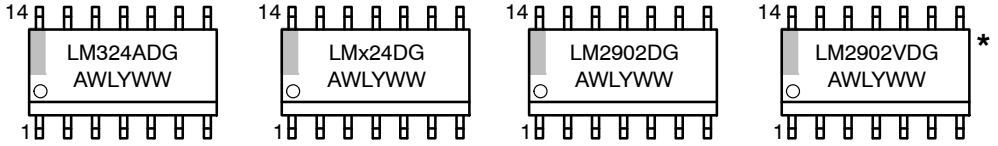
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

## MARKING DIAGRAMS

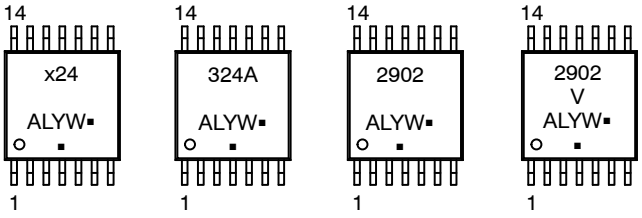
**PDIP−14**
**N SUFFIX**
**CASE 646**




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




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

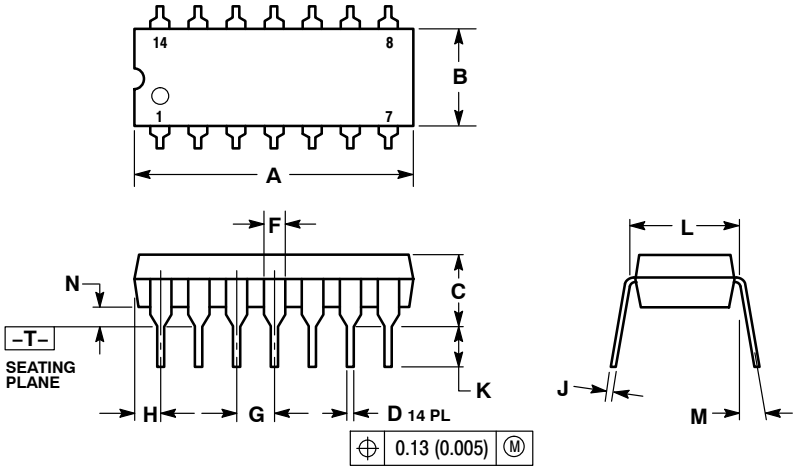



| | |
|---|---|
| x | = 2 or 3 |
| A | = Assembly Location |
| WL, L | = Wafer Lot |
| YY, Y | = Year |
| WW, W | = Work Week |
| G or ▪ | = Pb−Free Package |

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

## PACKAGE DIMENSIONS

**PDIP−14**
CASE 646−06
ISSUE P

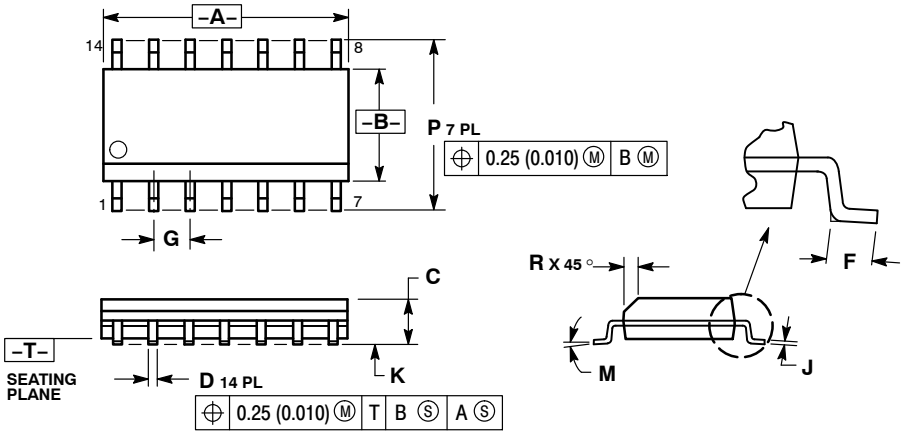



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
5. ROUNDED CORNERS OPTIONAL.

| | 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

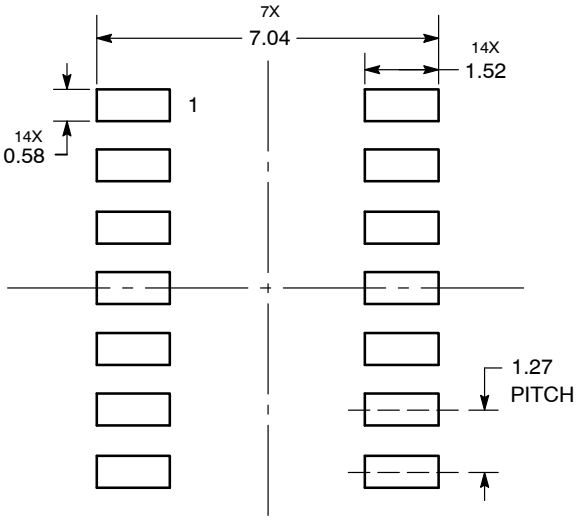
**SOIC−14**
CASE 751A−03
ISSUE H




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*

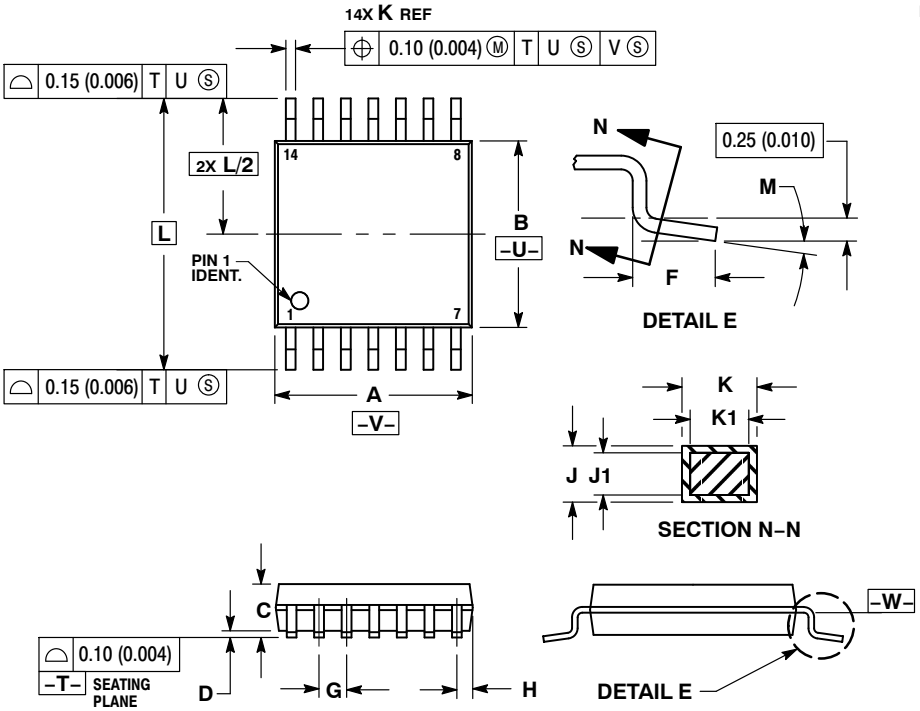



DIMENSIONS: MILLIMETERS

*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

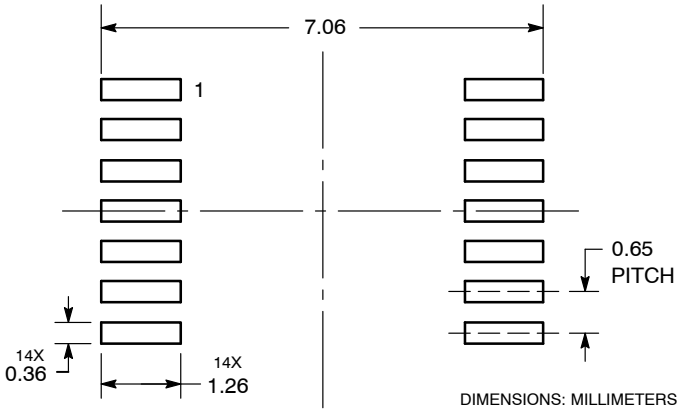
**TSSOP−14**
CASE 948G−01
ISSUE B




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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