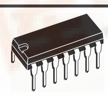
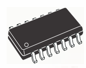
# TS924

## Rail-to-rail High Output Current Quad Operational Amplifier

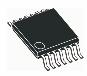
- Rail-to-rail input and output
- Low noise: 9nV/√Hz
- Low distortion
- High output current: 80mA (able to drive 32Ω loads)
- High-speed: 4MHz, 1.3V/µs
- Operating from 2.7V to 12V
- Low input offset voltage: 900µV max (TS924A)
- ESD Internal protection: 3kV
- Latch-up immunity
- Macromodel included in this specification



**N**
**DIP14**
(Plastic Package)

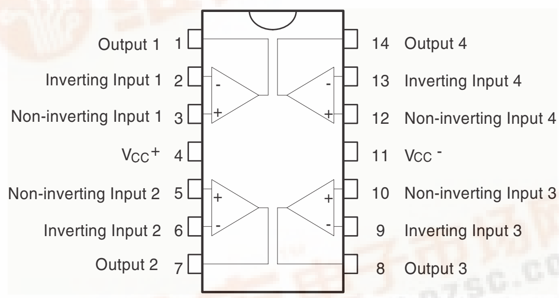


**D**
**SO-14**
(Plastic Micropackage)



**P**
**TSSOP14**
(Thin Shrink Small Outline Package)

Pin connection (top view)




## Description

The TS924 is a rail-to-rail quad BiCMOS operational amplifier optimized and fully specified for 3V and 5V operation.

High output current allows low load impedances to be driven.

The TS924 exhibits a very low noise, low distortion, low offset and high output current capability making this device an excellent choice for high quality, low voltage or battery operated audio systems.

The device is stable for capacitive loads up to 500pF.

## Applications

- Headphone amplifier
- Piezoelectric speaker driver
- Sound cards
- MPEG boards, multimedia systems,...
- Line driver, buffer
- Cordless telephones and portable communication equipment
- Instrumentation with low noise as key factor

## Order Codes

| Part Number | Temperature Range | Package | Packaging | Marking |
|---|---|---|---|---|
| TS924IN | -40°C, +125°C | DIP14 | Tube | TS924IN |
| TS924AIN | | | | TS924AIN |
| TS924ID/IDT | | SO-14 | Tube or Tape & Reel | 924I |
| TS924AID/AIDT | | | | 924AI |
| TS924IPT | | TSSOP14 (Thin Shrink Outline Package) | Tape & Reel | 924I |
| TS924AIPT | | | | 924AI |
| TS924IYD/IYDT | | SO-14 (automotive grade level) | Tube or Tape & Reel | 924IY |
| TS924AIYD/AIYDT | | | | 924AIY |
| TS924IYPT | | TSSOP14 (automotive grade level) | Tape & Reel | 924IY |
| TS924IAIYPT | | | | 924AIY |

# 1 Absolute Maximum Ratings

**Table 1. Key parameters and their absolute maximum ratings**

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| $V_{CC}$ | Supply voltage (1) | 14 | V |
| Vid | Differential Input Voltage (2) | ±1 | V |
| $V_i$ | Input Voltage (3) | $V_{DD}$ -0.3 to $V_{CC}$+0.3 | V |
| $T_{stg}$ | Storage Temperature | -65 to +150 | °C |
| $T_j$ | Maximum Junction Temperature | 150 | °C |
| $R_{thja}$ | Thermal Resistance Junction to Ambient<br>DIP14 | 103 | °C/W |
| | SO14 | 66 | |
| | TSSOP14 | 100 | |
| ESD | HBM: Human Body Model(4) | 3 | kV |
| | MM: Machine Model(5) | 100 | V |
| | CDM: Charged Device Model | 1 | kV |
| | Output Short Circuit Duration | see note(6) | |
| | Latch-up Immunity | 200 | mA |
| | Soldering Temperature (10sec), leaded version | 250 | °C |
| | Soldering Temperature (10sec), unleaded version | 260 | °C |

1. All voltages values, except differential voltage are with respect to network ground terminal.
2. Differential voltages are the non-inverting input terminal with respect to the inverting input terminal. If Vid > ±1V, the maximum input current must not exceed ±1mA. In this case (Vid > ±1V) an input serie resistor must be added to limit input current.
3. Do not exceed 14V.
4. Human body model, 100pF discharged through a 1.5kΩ resistor into pin of device.
5. Machine model ESD, a 200pF cap is charged to the specified voltage, then discharged directly into the IC with no external series resistor (internal resistor < 5Ω), into pin to pin of device.
6. There is no short-circuit protection inside the device: short-circuits from the output to $V_{cc}$ can cause excessive heating. The maximum output current is approximately 80mA, independent of the magnitude of $V_{cc}$. Destructive dissipation can result from simultaneous short-circuits on all amplifiers.

**Table 2. Operating conditions**

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| $V_{CC}$ | Supply voltage | 2.7 to 12 | V |
| $V_{icm}$ | Common Mode Input Voltage Range | $V_{DD}$ -0.2 to $V_{CC}$ +0.2 | V |
| $T_{oper}$ | Operating Free Air Temperature Range | -40 to +125 | °C |

# 2 Electrical Characteristics

**Table 3. $V_{CC}$ = +3V, $V_{DD}$ = 0V, $V_{icm}$ = $V_{CC}$/2, $T_{amb}$ = 25°C, $R_L$ connected to $V_{CC}$/2 (unless otherwise specified)**

| Symbol | Parameter | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|
| $V_{io}$ | Input Offset Voltage - TS924<br>TS924A<br>$T_{min.} \le T_{amb} \le T_{max.}$ - TS924<br>TS924A | | | 3<br>0.9<br>5<br>1.8 | mV |
| $DV_{io}$ | Input Offset Voltage Drift | | 2 | | µV/°C |
| $I_{io}$ | Input Offset Current<br>Vout = Vcc/2 | | 1 | 30 | nA |
| $I_{ib}$ | Input Bias Current<br>Vout = Vcc/2 | | 15 | 100 | nA |
| $V_{OH}$ | High Level Output Voltage<br>$R_L$= 100k<br>$R_L$ = 600Ω<br>$R_L$ = 32Ω | 2.90<br>2.87 | 2.63 | | V |
| $V_{OL}$ | Low Level Output Voltage<br>$R_L$= 10k<br>$R_L$ = 600Ω<br>$R_L$ = 32Ω | | 180 | 50<br>100 | mV |
| $A_{vd}$ | Large Signal Voltage Gain ($V_{out}$ = 2Vpk-pk)<br>$R_L$= 10k<br>$R_L$ = 600Ω<br>$R_L$ = 32Ω | | 200<br>35<br>16 | | V/mV |
| $I_{cc}$ | Total Supply Current<br>no load, $V_{out} = V_{cc/2}$ | | 4.5 | 7 | mA |
| GBP | Gain Bandwidth Product<br>$R_L$ = 600Ω | | 4 | | MHz |
| CMR | Common Mode Rejection Ratio | 60 | 80 | | dB |
| SVR | Supply Voltage Rejection Ratio - $V_{cc}$ = 2.7 to 3.3V | 60 | 85 | | dB |
| $I_o$ | Output Short Circuit Current | 50 | 80 | | mA |
| SR | Slew Rate | 0.7 | 1.3 | | V/µs |
| φm | Phase Margin at Unit Gain - $R_L$ = 600Ω, $C_L$ =100pF | | 68 | | Degrees |
| $G_m$ | Gain Margin - $R_L$ = 600Ω, $C_L$ =100pF | | 12 | | dB |
| $e_n$ | Equivalent Input Noise Voltage - f = 1kHz | | 9 | | $\frac{nV}{\sqrt{Hz}}$ |
| THD | Total Harmonic Distortion<br>$V_{out}$ = 2Vpk-pk, F = 1kHz, $A_v$ = 1, $R_L$ =600Ω | | 0.005 | | % |
| $C_s$ | Channel Separation | | 120 | | dB |

**Table 4. $V_{CC}$ = +5V, $V_{DD}$ = 0V, $V_{icm}$ = $V_{CC}/2$, $T_{amb}$ = 25°C, $R_L$ connected to $V_{CC}/2$ (unless otherwise specified)**

| Symbol | Parameter | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|
| $V_{io}$ | Input Offset Voltage - TS924<br>TS924A<br>$T_{min.} \leq T_{amb} \leq T_{max.}$ - TS924<br>TS924A | | | 3<br>0.9<br>5<br>1.8 | mV |
| $DV_{io}$ | Input Offset Voltage Drift | | 2 | | µV/°C |
| $I_{io}$ | Input Offset Current<br>Vout = Vcc/2 | | 1 | 30 | nA |
| $I_{ib}$ | Input Bias Current<br>Vout = Vcc/2 | | 15 | 100 | nA |
| $V_{OH}$ | High Level Output Voltage<br>$R_L$= 100k<br>$R_L$ = 600Ω<br>$R_L$ = 32Ω | 4.90<br>4.85 | 4.4 | | V |
| $V_{OL}$ | Low Level Output Voltage<br>$R_L$= 10k<br>$R_L$ = 600Ω<br>$R_L$ = 32Ω | | 300 | 50<br>120 | mV |
| $A_{vd}$ | Large Signal Voltage Gain ($V_{out}$ = 2Vpk-pk)<br>$R_L$= 10k<br>$R_L$ = 600Ω<br>$R_L$ = 32Ω | | 200<br>40<br>17 | | V/mV |
| $I_{cc}$ | Total Supply Current<br>no load, $V_{out}$ = $V_{cc/2}$ | | 4.5 | 7 | mA |
| GBP | Gain Bandwidth Product<br>$R_L$ = 600Ω | | 4 | | MHz |
| CMR | Common Mode Rejection Ratio | 60 | 80 | | dB |
| SVR | Supply Voltage Rejection Ratio<br>$V_{cc}$ = 3V to 5V | 60 | 85 | | dB |
| $I_o$ | Output Short Circuit Current | 50 | 80 | | mA |
| SR | Slew Rate | 0.7 | 1.3 | | V/µs |
| φm | Phase Margin at Unit Gain<br>$R_L$ = 600Ω, $C_L$ =100pF | | 68 | | Degrees |
| $G_m$ | Gain Margin<br>$R_L$ = 600Ω, $C_L$ =100pF | | 12 | | dB |
| $e_n$ | Equivalent Input Noise Voltage<br>f = 1kHz | | 9 | | $\frac{nV}{\sqrt{Hz}}$ |
| THD | Total Harmonic Distortion<br>$V_{out}$ = 2Vpk-pk, F = 1kHz, $A_v$ = 1, $R_L$ =600Ω | | 0.005 | | % |
| $C_s$ | Channel Separation | | 120 | | dB |

**Figure 1. Output short circuit current vs. output voltage**

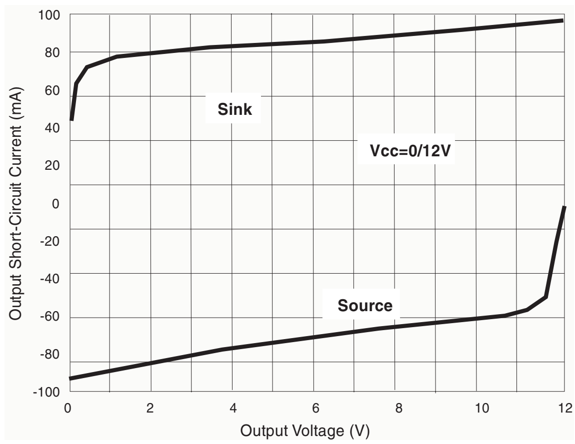



**Figure 2. Output short circuit current vs. output voltage**

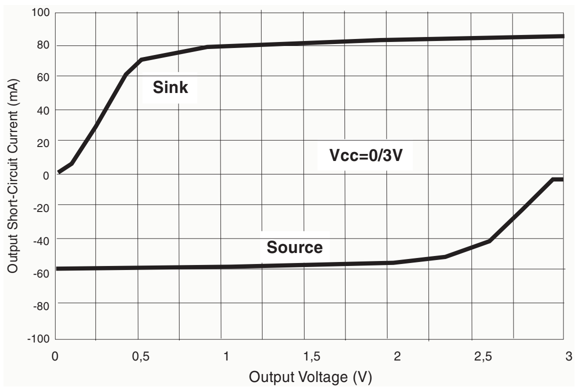



**Figure 3. Voltage gain and phase vs. frequency**

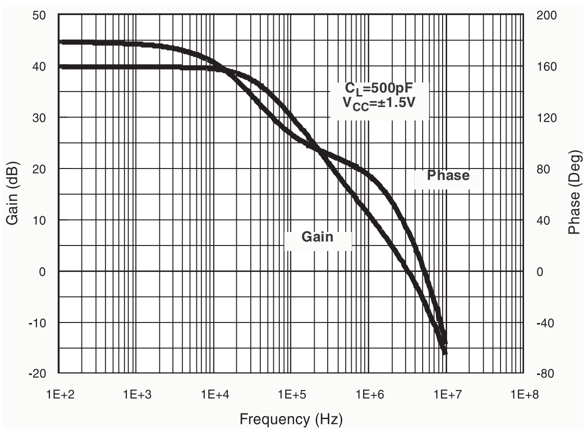



**Figure 4. Output short circuit current vs. output voltage**

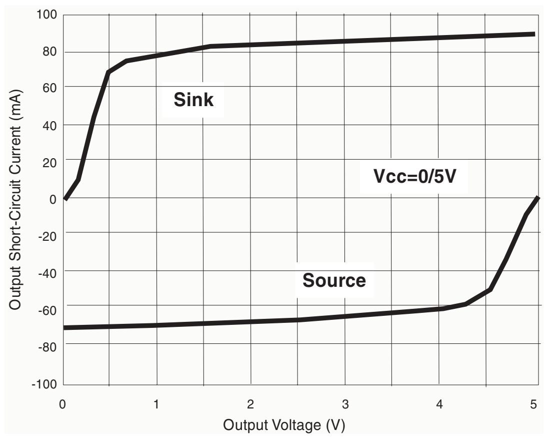



**Figure 5. Voltage gain & phase vs. frequency**

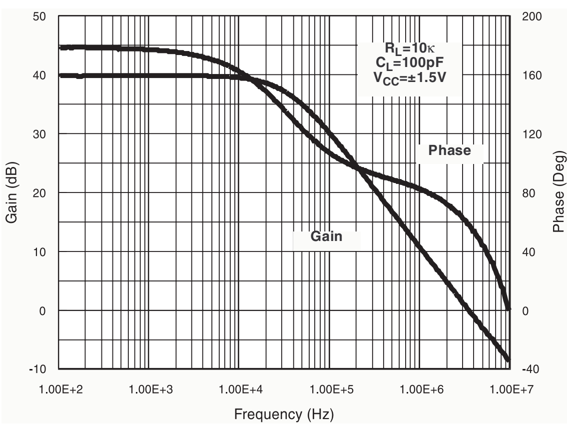



**Figure 6. THD + noise vs. frequency**

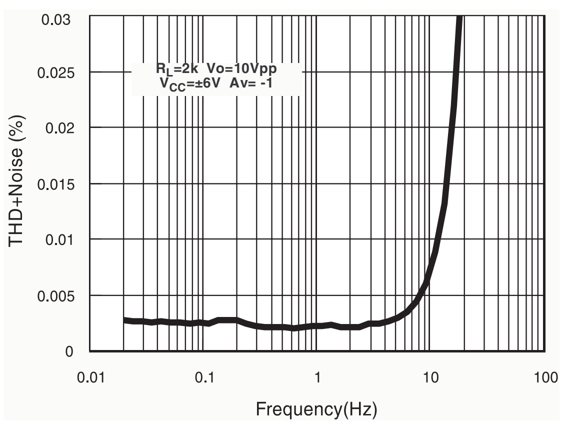


**Figure 7. THD + noise vs. frequency**

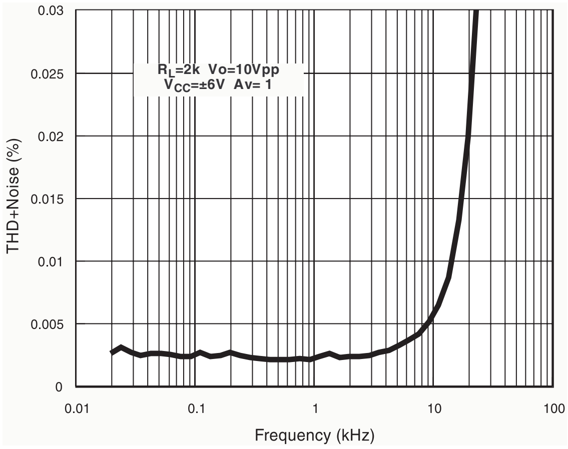



**Figure 8. THD + noise vs. frequency**

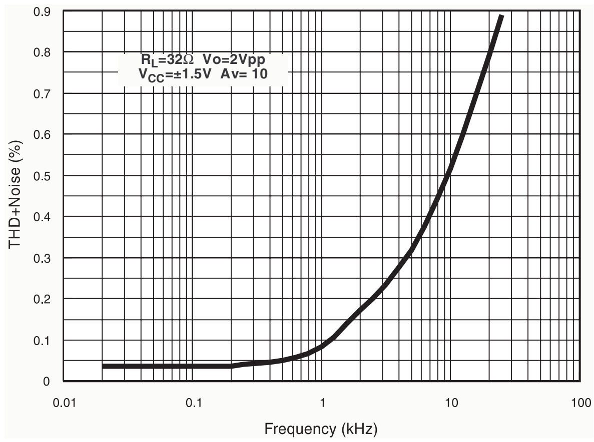



**Figure 9. THD + noise vs. Vout**

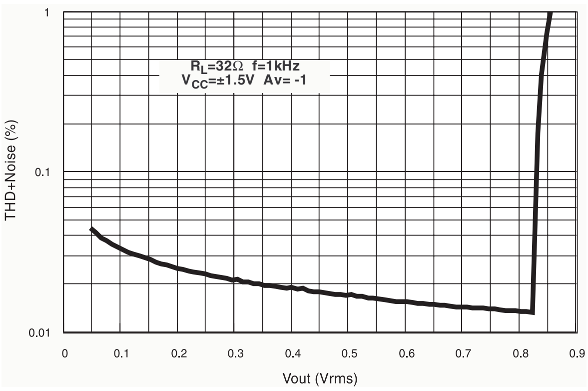



**Figure 10. THD + noise vs. frequency**

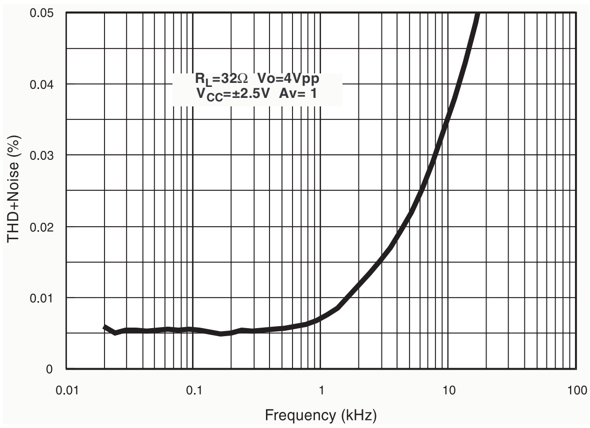



**Figure 11. THD + noise vs. Vout**

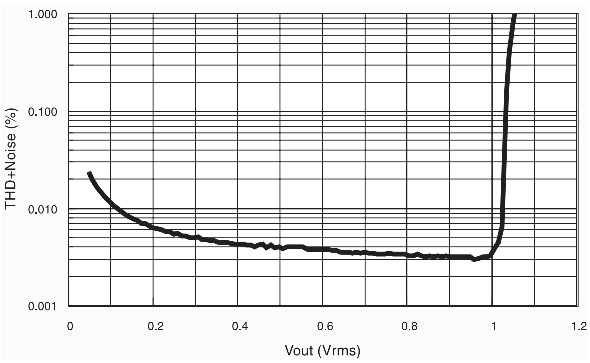
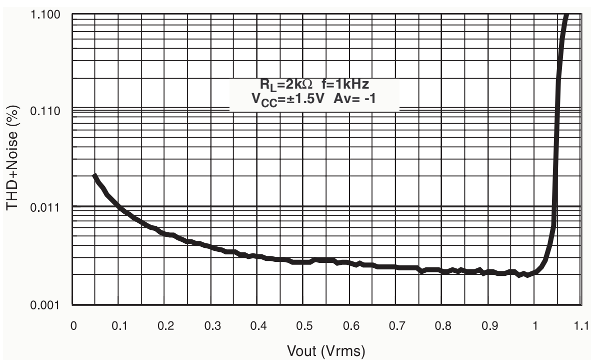



**Figure 12. THD + noise vs. Vout**



# 3 Macromodel

## 3.1 Important note concerning this macromodel

Please consider following remarks before using this macromodel.

- All models are a trade-off between accuracy and complexity (i.e. simulation time).
- Macromodels are not a substitute to breadboarding; rather, they confirm the validity of a design approach and help to select surrounding component values.
- A macromodel emulates the NOMINAL performance of a TYPICAL device within SPECIFIED OPERATING CONDITIONS (i.e. temperature, supply voltage, etc.). Thus the macromodel is often not as exhaustive as the datasheet, its goal is to illustrate the main parameters of the product.
- Data issued from macromodels used outside of its specified conditions (Vcc, Temperature, etc.) or even worse: outside of the device operating conditions (Vcc, Vicm, etc.) are not reliable in any way.

In *Section 3.3*, the electrical characteristics resulting from the use of these macromodels are presented.

## 3.2 Electrical characteristics from macromodelization

**Table 5. Electrical characteristics resulting from macromodel simulation at $V_{CC}$ = 3V, $V_{DD}$ = 0V, $R_L$, $C_L$ connected to $V_{CC/2}$, $T_{amb}$ = 25°C (unless otherwise specified)**

| Symbol | Conditions | Value | Unit |
|---|---|---|---|
| $V_{io}$ | | 0 | mV |
| $A_{vd}$ | $R_L$ = 10kΩ | 200 | V/mV |
| $I_{CC}$ | No load, per operator | 1.2 | mA |
| $V_{icm}$ | | -0.2 to 3.2 | V |
| $V_{OH}$ | $R_L$ = 10kΩ | 2.95 | V |
| $V_{OL}$ | $R_L$ = 10kΩ | 25 | mV |
| $I_{sink}$ | $V_O$ = 3V | 80 | mA |
| $I_{source}$ | $V_O$ = 0V | 80 | mA |
| GBP | $R_L$ = 600kΩ | 4 | MHz |
| SR | $R_L$ = 10kΩ, $C_L$ = 100pF | 1 | V/µs |
| ϕm | $R_L$ = 600kΩ | 68 | Degrees |

## 3.3 Macromodel code

```
** Standard Linear Ics Macromodels, 1996.
** CONNECTIONS:
* 1 INVERTING INPUT
* 2 NON-INVERTING INPUT
* 3 OUTPUT
* 4 POSITIVE POWER SUPPLY
* 5 NEGATIVE POWER SUPPLY

.SUBCKT TS92X 1 2 3 4 5
*
.MODEL MDTH D IS=1E-8 KF=2.664234E-16 CJO=10F
*
* INPUT STAGE
CIP 2 5 1.000000E-12
CIN 1 5 1.000000E-12
EIP 10 5 2 5 1
EIN 16 5 1 5 1
RIP 10 11 8.125000E+00
RIN 15 16 8.125000E+00
RIS 11 15 2.238465E+02
DIP 11 12 MDTH 400E-12
DIN 15 14 MDTH 400E-12
VOFP 12 13 DC 153.5u
VOFN 13 14 DC 0
IPOL 13 5 3.200000E-05
CPS 11 15 1e-9
DINN 17 13 MDTH 400E-12
VIN 17 5 -0.100000e+00
DINR 15 18 MDTH 400E-12
VIP 4 18 0.400000E+00
FCP 4 5 VOFP 1.865000E+02
FCN 5 4 VOFN 1.865000E+02
FIBP 2 5 VOFP 6.250000E-03
FIBN 5 1 VOFN 6.250000E-03
* GM1 STAGE ***************
FGM1P 119 5 VOFP 1.1
FGM1N 119 5 VOFN 1.1
RAP 119 4 2.6E+06
RAN 119 5 2.6E+06
* GM2 STAGE ***************
G2P 19 5 119 5 1.92E-02
G2N 19 5 119 4 1.92E-02
R2P 19 4 1E+07
R2N 19 5 1E+07
**************************
VINT1 500 0 5
GCONVP 500 501 119 4 19.38
VP 501 0 0
GCONVN 500 502 119 5 19.38
VN 502 0 0
```

```
********* orientation isink isource *******
VINT2 503 0 5
FCOPY 503 504 VOUT 1
DCOPYP 504 505 MDTH 400E-9
VCOPYP 505 0 0
DCOPYN 506 504 MDTH 400E-9
VCOPYN 0 506 0
***************************
F2PP 19 5 poly(2) VCOPYP VP 0 0 0 0 0.5
F2PN 19 5 poly(2) VCOPYP VN 0 0 0 0 0.5
F2NP 19 5 poly(2) VCOPYN VP 0 0 0 0 1.75
F2NN 19 5 poly(2) VCOPYN VN 0 0 0 0 1.75
* COMPENSATION ************
CC 19 119 25p
* OUTPUT ***********
DOPM 19 22 MDTH 400E-12
DONM 21 19 MDTH 400E-12
HOPM 22 28 VOUT 6.250000E+02
VIPM 28 4 5.000000E+01
HONM 21 27 VOUT 6.250000E+02
VINM 5 27 5.000000E+01
VOUT 3 23 0
ROUT 23 19 6
COUT 3 5 1.300000E-10
DOP 19 25 MDTH 400E-12
VOP 4 25 1.052
DON 24 19 MDTH 400E-12
VON 24 5 1.052
.ENDS ;TS92X
```

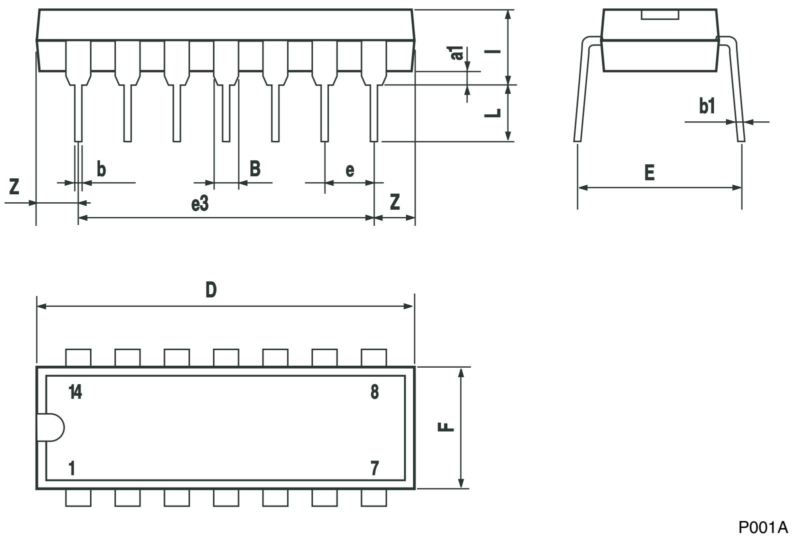
# 4 Package Mechanical Data

In order to meet environmental requirements, ST offers these devices in ECOPACK® packages. These packages have a Lead-free second level interconnect. The category of second level interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label. ECOPACK is an ST trademark. ECOPACK specifications are available at: www.st.com.

## 4.1 DIP14 Package

**Plastic DIP-14 MECHANICAL DATA**

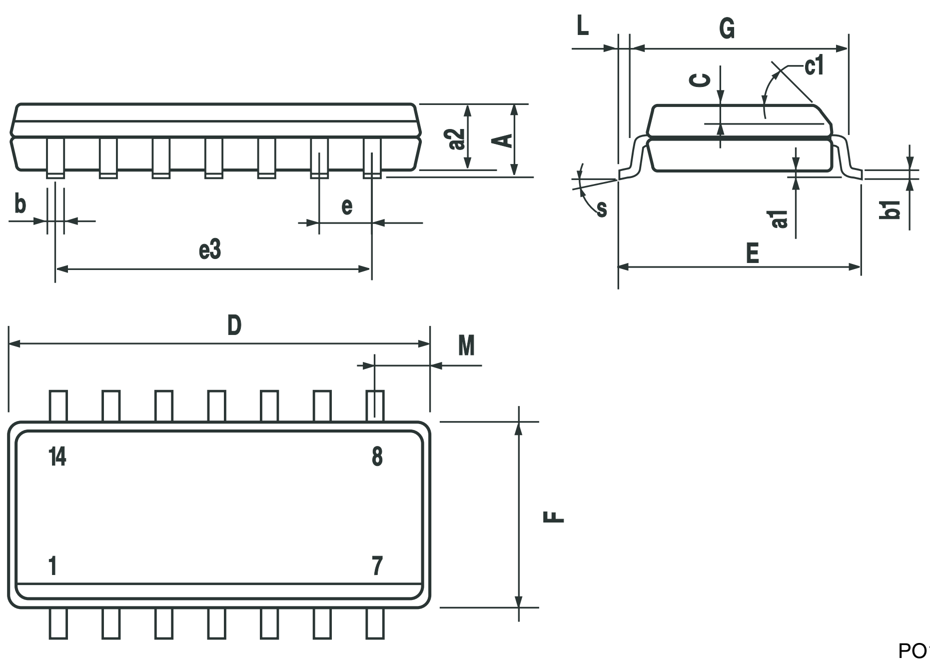
| DIM. | mm. | | | inch | | |
|---|---|---|---|---|---|---|
| | MIN. | TYP | MAX. | MIN. | TYP. | MAX. |
| a1 | 0.51 | | | 0.020 | | |
| B | 1.39 | | 1.65 | 0.055 | | 0.065 |
| b | | 0.5 | | | 0.020 | |
| b1 | | 0.25 | | | 0.010 | |
| D | | | 20 | | | 0.787 |
| E | | 8.5 | | | 0.335 | |
| e | | 2.54 | | | 0.100 | |
| e3 | | 15.24 | | | 0.600 | |
| F | | | 7.1 | | | 0.280 |
| I | | | 5.1 | | | 0.201 |
| L | | 3.3 | | | 0.130 | |
| Z | 1.27 | | 2.54 | 0.050 | | 0.100 |



## 4.2 SO-14 package

**SO-14 MECHANICAL DATA**

| DIM. | mm. | | | inch | | |
|---|---|---|---|---|---|---|
| | MIN. | TYP | MAX. | MIN. | TYP. | MAX. |
| A | | | 1.75 | | | 0.068 |
| a1 | 0.1 | | 0.2 | 0.003 | | 0.007 |
| a2 | | | 1.65 | | | 0.064 |
| b | 0.35 | | 0.46 | 0.013 | | 0.018 |
| b1 | 0.19 | | 0.25 | 0.007 | | 0.010 |
| C | | 0.5 | | | 0.019 | |
| c1 | 45° (typ.) | | | | | |
| D | 8.55 | | 8.75 | 0.336 | | 0.344 |
| E | 5.8 | | 6.2 | 0.228 | | 0.244 |
| e | | 1.27 | | | 0.050 | |
| e3 | | 7.62 | | | 0.300 | |
| F | 3.8 | | 4.0 | 0.149 | | 0.157 |
| G | 4.6 | | 5.3 | 0.181 | | 0.208 |
| L | 0.5 | | 1.27 | 0.019 | | 0.050 |
| M | | | 0.68 | | | 0.026 |
| S | 8° (max.) | | | | | |

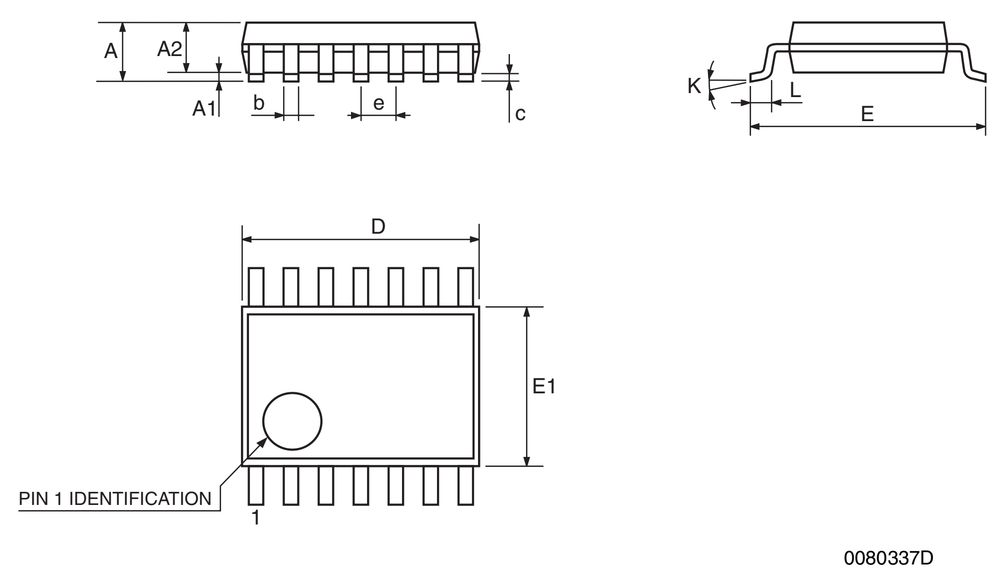



PO13G

## 4.3 TSSOP14 package

**TSSOP14 MECHANICAL DATA**

| DIM. | mm. | | | inch | | |
|---|---|---|---|---|---|---|
| | MIN. | TYP | MAX. | MIN. | TYP. | MAX. |
| A | | | 1.2 | | | 0.047 |
| A1 | 0.05 | | 0.15 | 0.002 | 0.004 | 0.006 |
| A2 | 0.8 | 1 | 1.05 | 0.031 | 0.039 | 0.041 |
| b | 0.19 | | 0.30 | 0.007 | | 0.012 |
| c | 0.09 | | 0.20 | 0.004 | | 0.0089 |
| D | 4.9 | 5 | 5.1 | 0.193 | 0.197 | 0.201 |
| E | 6.2 | 6.4 | 6.6 | 0.244 | 0.252 | 0.260 |
| E1 | 4.3 | 4.4 | 4.48 | 0.169 | 0.173 | 0.176 |
| e | | 0.65 BSC | | | 0.0256 BSC | |
| K | 0° | | 8° | 0° | | 8° |
| L | 0.45 | 0.60 | 0.75 | 0.018 | 0.024 | 0.030 |



# 5 Revision History

| Date | Revision | Changes |
|---|---|---|
| May 2001 | 1 | First Release |
| May 2005 | 2 | Modifications on AMR *Table 1 on page 3* (explanation of Vid and Vi limits, ESD MM and CDM values added, Rthja added) |
| July 2005 | 3 | PPAP references inserted in the datasheet see *Table  on page 2*. |
| Nov. 2005 | 4 | – Package mechanical data modified<br>– TS924IYPT/TS924AYIPT PPAP reference inserted in *Table  on page 2*.<br>– Macromodel modified |