

### Features

(For  $V^+ = 5V$  and  $V^- = 0V$  typical unless otherwise noted)

- Guaranteed 2.7V and 5V performance
- Crossover distortion eliminated
- Operating temperature range (-40°C to +85°C)
- Gain-bandwidth 1 MHz
- Low supply current
  - APX321 110  $\mu A$  Typ
  - APX358 190  $\mu A$  Typ
  - APX324 340  $\mu A$  Typ
- Rail-to-rail output swing @ 10 k $\Omega$ 
  - $V^- - 10$  mV
  - $V^+ + 10$  mV
- Input Common Mode Voltage Range (0 to  $V^+ - 0.2V$ )
- Manufactured in standard CMOS process
- SOT353, SOT25, MSOP-8L, SOP-8L and TSSOP-14L:  
Available in "Green" Molding Compound (No Br, Sb)
- Lead-free Finish / RoHS Compliant (Note 4)

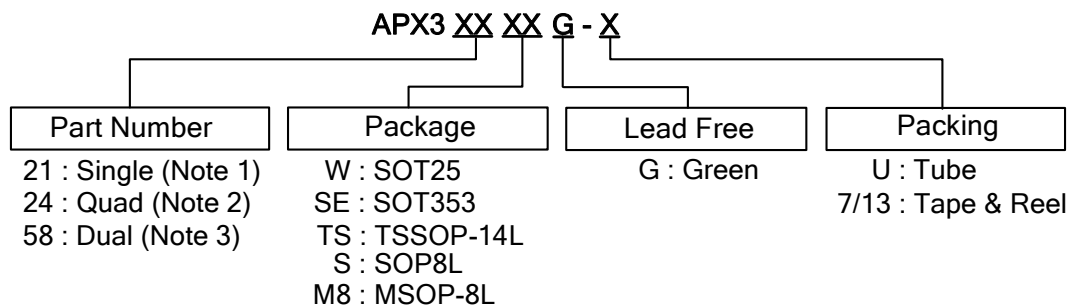
### General Description

The APX321/APX358/APX324 are low voltage (2.5V to 5.5V) single, dual and quad operational amplifiers. The APX321/APX358/APX324 are designed to effectively reduce cost and space at low voltage levels. These devices have the capability of rail-to-rail output swing and input common-mode voltage range. They can also achieve an efficient speed-to-power ratio, utilizing 1 MHz bandwidth and 1 V/ $\mu s$  slew rate at a low supply current. Reducing noise pickup and increasing signal integrity can be achieved by placing the device close to the signal source. The APX321 is available in 5-Pin SOT353/SOT25 packages that reduce space on pc boards and portable electronic devices. The APX324 is available in the TSSOP-14L package. The APX358 is available in the MSOP-8L and SOP-8L packages.

### Applications

- Active filters
- General purpose low voltage applications
- General purpose portable devices

### Ordering Information



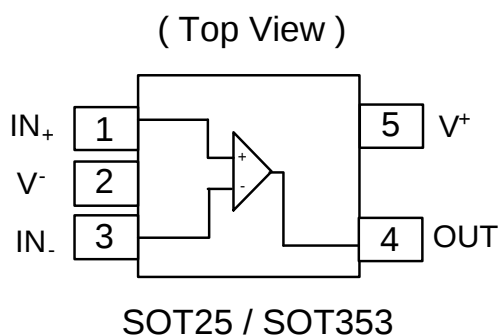
| Device       | Package Code | Packaging (Note 5) | Tube/Bulk |                    | 7"/13" Tape and Reel |                    |
|--------------|--------------|--------------------|-----------|--------------------|----------------------|--------------------|
|              |              |                    | Quantity  | Part Number Suffix | Quantity             | Part Number Suffix |
| APX321WG-7   | W            | SOT25              | NA        | NA                 | 3000/Tape & Reel     | -7                 |
| APX321SEG-7  | SE           | SOT353             | NA        | NA                 | 3000/Tape & Reel     | -7                 |
| APX324TSG-U  | TS           | TSSOP-14L          | 96        | -U                 | NA                   | NA                 |
| APX324TSG-13 | TS           | TSSOP-14L          | NA        | NA                 | 2500/Tape & Reel     | -13                |
| APX358SG-U   | S            | SOP-8L             | 100       | -U                 | NA                   | NA                 |
| APX358SG-13  | S            | SOP-8L             | NA        | NA                 | 2500/Tape & Reel     | -13                |
| APX358M8G-13 | M8           | MSOP-8L            | NA        | NA                 | 2500/Tape & Reel     | -13                |

Notes:

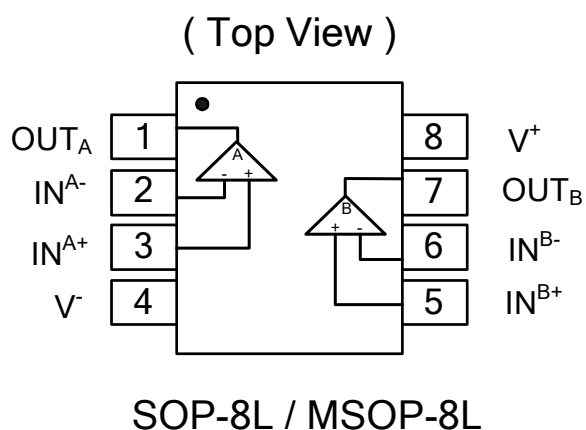
1. APX321 is only available for SOT25 and SOT353.
2. APX324 is only available for TSSOP-14L.
3. APX358 is only available for SOP-8L and MSOP-8L.
4. RoHS revision 13.2.2003. Glass and high temperature solder exemptions applied, see *EU Directive Annex Notes 5 and 7*
5. Pad layout as shown on Diodes Inc. suggested pad layout document AP02001, which can be found on our website at <http://www.diodes.com/datasheets/ap02001.pdf>.

## Pin Assignments

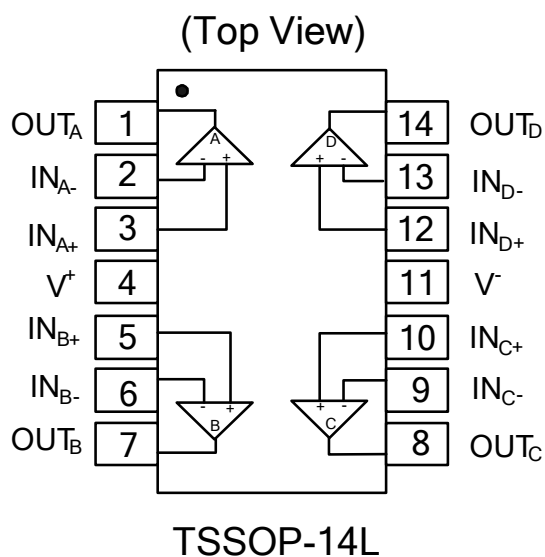
### (1) SOT25 / SOT353



### (2) SOP-8L / MSOP-8L



### (3) TSSOP-14L



### Absolute Maximum Ratings (Note 6)

| Symbol      | Description                     | Rating          | Unit |
|-------------|---------------------------------|-----------------|------|
| ESD HBM     | Human Body Model ESD Protection | APX321          | 4000 |
|             |                                 | APX358          | 4000 |
|             |                                 | APX324          | 4500 |
| ESD MM      | Machine Model ESD Protection    | APX321          | 350  |
|             |                                 | APX358          | 350  |
|             |                                 | APX324          | 250  |
|             | Differential Input Voltage      | ±Supply Voltage | V    |
| $V^+ - V^-$ | Supply Voltage                  | 5.5             | V    |
|             | Output Short Circuit to $V^+$   | (Note 7)        |      |
|             | Output Short Circuit to $V^-$   | (Note 8)        |      |
| $T_{ST}$    | Storage Temperature             | -65 to 150      | °C   |
| $T_J$       | Maximum Junction Temperature    | 150             | °C   |

### Operating Ratings (Note 6)

| Symbol      | Description                         | Rating     | Unit |
|-------------|-------------------------------------|------------|------|
| $V^+ - V^-$ | Supply Voltage                      | 2.5 to 5.5 | V    |
| $T_A$       | Operating Ambient Temperature Range | -40 to +85 | °C   |

Notes: 6. Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics.

### Electrical Characteristics

#### 2.7V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 2.7\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = 1.0\text{V}$ ,  $V_O = V^+/2$  and  $R_L > 1\text{ M}\Omega$ .

| Symbol     | Parameter                             | Test Conditions                                            | Min<br>(Note 10) | Typ.<br>(Note 9) | Max<br>(Note 10) | Unit                         |
|------------|---------------------------------------|------------------------------------------------------------|------------------|------------------|------------------|------------------------------|
| $V_{OS}$   | Input Offset Voltage                  |                                                            |                  | 1.7              | 7                | mV                           |
| $TCV_{OS}$ | Input Offset Voltage<br>Average Drift |                                                            |                  | 5                |                  | $\mu\text{V}/^\circ\text{C}$ |
| $I_B$      | Input Bias Current                    |                                                            |                  | 10               |                  | nA                           |
| $I_{OS}$   | Input Offset Current                  |                                                            |                  | 5                | 50               | nA                           |
| CMRR       | Common Mode Rejection<br>Ratio        | $0\text{V} \leq V_{CM} \leq 2.4\text{V}$                   | 50               | 63               |                  | dB                           |
| PSRR       | Power Supply Rejection<br>Ratio       | $2.7\text{V} \leq V^+ \leq 5\text{V}$<br>$V_O = 1\text{V}$ | 50               | 60               |                  | dB                           |
| $V_{CMR}$  | Input Common-Mode<br>Voltage Range    | For CMRR $\geq 50\text{dB}$                                | 0                | -0.2             | 2.5              | V                            |
| $V_O$      | Output Swing                          | $R_L = 10\text{ k}\Omega$ to $1.35\text{V}$                | $V^+ - 100$      | $V^+ - 20$       | 100              | mV                           |
| $I_S$      | Supply Current                        | APX321<br>Single amplifier                                 |                  | 110              | 140              | $\mu\text{A}$                |
|            |                                       | APX358<br>Both amplifiers                                  |                  | 190              | 340              | $\mu\text{A}$                |
|            |                                       | APX324<br>All four amplifiers                              |                  | 340              | 680              | $\mu\text{A}$                |

#### 2.7V AC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 2.7\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = 1.0\text{V}$ ,  $V_O = V^+/2$  and  $R_L > 1\text{ M}\Omega$ .

| Symbol   | Parameter                       | Test Conditions       | Min<br>(Note 10) | Typ.<br>(Note 9) | Max<br>(Note 10) | Unit                                 |
|----------|---------------------------------|-----------------------|------------------|------------------|------------------|--------------------------------------|
| GBWP     | Gain-Bandwidth Product          | $C_L = 200\text{ pF}$ |                  | 1                |                  | MHz                                  |
| $\Phi_m$ | Phase Margin                    |                       |                  | 60               |                  | Deg                                  |
| Gm       | Gain Margin                     |                       |                  | 10               |                  | dB                                   |
| $e_n$    | Input-Referred Voltage<br>Noise | $f > 50\text{ KHz}$   |                  | 23               |                  | $\frac{\text{nV}}{\sqrt{\text{Hz}}}$ |

### Electrical Characteristics (Continued)

#### 5V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{\text{CM}} = 2.0\text{V}$ ,  $V_O = V^+/2$  and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol                   | Parameter                                 | Test Conditions                                                                          | Min<br>(Note 10)                             | Typ.<br>(Note 9) | Max<br>(Note 10)     | Unit                         |
|--------------------------|-------------------------------------------|------------------------------------------------------------------------------------------|----------------------------------------------|------------------|----------------------|------------------------------|
| $V_{\text{OS}}$          | Input Offset Voltage                      |                                                                                          |                                              | 1.7              | <b>7</b><br><b>9</b> | mV                           |
| $\text{TCV}_{\text{OS}}$ | Input Offset Voltage<br>Average Drift     |                                                                                          |                                              | 5                |                      | $\mu\text{V}/^\circ\text{C}$ |
| $I_B$                    | Input Bias Current                        |                                                                                          |                                              | 15               | 250<br><b>500</b>    | nA                           |
| $I_{\text{OS}}$          | Input Offset Current                      |                                                                                          |                                              | 5                | 50<br><b>150</b>     | nA                           |
| CMRR                     | Common Mode Rejection<br>Ratio            | $0\text{V} \leq V_{\text{CM}} \leq 4.7\text{V}$                                          | 50                                           | 65               |                      | dB                           |
| PSRR                     | Power Supply Rejection<br>Ratio           | $2.7\text{V} \leq V^+ \leq 5\text{V}$<br>$V_O = 1\text{V}$ , $V_{\text{CM}} = 1\text{V}$ | 50                                           | 60               |                      | dB                           |
| $V_{\text{CMR}}$         | Input Common-Mode<br>Voltage Range        | For CMRR $\geq 50\text{dB}$                                                              | 0                                            | -0.2             | 4.8                  | V                            |
| $A_v$                    | Large Signal Voltage Gain                 | $R_L = 2\text{k}\Omega$ (Note 11)                                                        | 15<br><b>10</b>                              | 100              |                      | V/mV                         |
| $V_O$                    | Output Swing                              | $R_L = 2\text{k}\Omega$ to 2.5V                                                          | $V^+ - 300$<br><b><math>V^+ - 400</math></b> | $V^+ - 50$       |                      | mV                           |
|                          |                                           |                                                                                          |                                              | 50               | 300<br><b>400</b>    | mV                           |
|                          |                                           | $R_L = 10\text{k}\Omega$ to 2.5V                                                         | $V^+ - 100$<br><b><math>V^+ - 200</math></b> | $V^+ - 10$       |                      | mV                           |
|                          |                                           |                                                                                          |                                              | 10               | 180<br><b>280</b>    | mV                           |
| $I_O$                    | Output Short Circuit<br>Current           | Sourcing, $V_O = 0\text{V}$                                                              | 5                                            | 60               |                      | mA                           |
|                          |                                           | Sinking, $V_O = 5\text{V}$                                                               | 10                                           | 90               |                      | mA                           |
| $I_S$                    | Supply Current                            | APX321<br>Single amplifier                                                               |                                              | 110              | 140                  | $\mu\text{A}$                |
|                          |                                           | APX358<br>Both amplifiers                                                                |                                              | 190              | 340<br><b>600</b>    | $\mu\text{A}$                |
|                          |                                           | APX324<br>All four amplifiers                                                            |                                              | 340              | 680<br><b>1100</b>   | $\mu\text{A}$                |
| $\theta_{\text{JA}}$     | Thermal Resistance<br>Junction-to-Ambient | SOT353 (Note 12)                                                                         |                                              | 330              |                      | $^\circ\text{C}/\text{W}$    |
|                          |                                           | SOT25 (Note 12)                                                                          |                                              | 250              |                      | $^\circ\text{C}/\text{W}$    |
|                          |                                           | TSSOP-14L<br>(Note 12)                                                                   |                                              | 100              |                      | $^\circ\text{C}/\text{W}$    |
|                          |                                           | MSOP-8L (Note 12)                                                                        |                                              | 203              |                      | $^\circ\text{C}/\text{W}$    |
|                          |                                           | SOP-8L (Note 12)                                                                         |                                              | 150              |                      | $^\circ\text{C}/\text{W}$    |

### Electrical Characteristics (Continued)

#### 5V AC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = 2.0\text{V}$ ,  $V_O = V^+/2$  and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

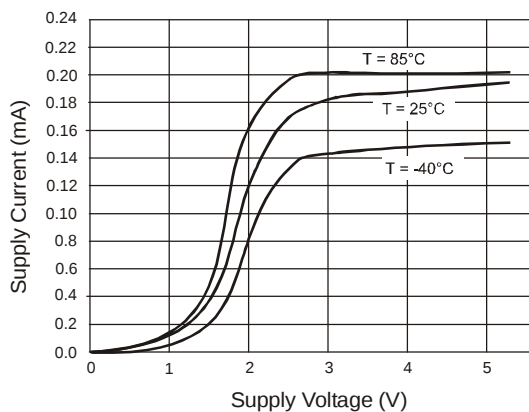
| Symbol   | Parameter                    | Test Conditions       | Min<br>(Note 10) | Typ.<br>(Note 9) | Max<br>(Note 10) | Unit                                 |
|----------|------------------------------|-----------------------|------------------|------------------|------------------|--------------------------------------|
| SR       | Slew Rate                    | (Note 13)             |                  | 1                |                  | V/ $\mu\text{s}$                     |
| GBWP     | Gain-Bandwidth Product       | $C_L = 200\text{ pF}$ |                  | 1                |                  | MHz                                  |
| $\Phi_m$ | Phase Margin                 |                       |                  | 60               |                  | Deg                                  |
| $G_m$    | Gain Margin                  |                       |                  | 10               |                  | dB                                   |
| $e_n$    | Input-Referred Voltage Noise | $f > 50\text{ KHz}$   |                  | 23               |                  | $\frac{\text{nV}}{\sqrt{\text{Hz}}}$ |

- Notes:
- Shorting output to  $V^+$  will adversely affect reliability.
  - Shorting output to  $V^-$  will adversely affect reliability.
  - Typical values represent the most likely parametric norm as determined at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not guaranteed on shipped production material.
  - All limits are guaranteed by testing or statistical analysis.
  - $R_L$  is connected to  $V^-$ . The output voltage is  $0.5\text{V} \leq V_O \leq 4.5\text{V}$ .
  - All numbers are typical, and apply for packages soldered directly onto a PC board in still air.
  - Connected as voltage follower with 3V step input. Number specified is the slower of the positive and negative slew rates.

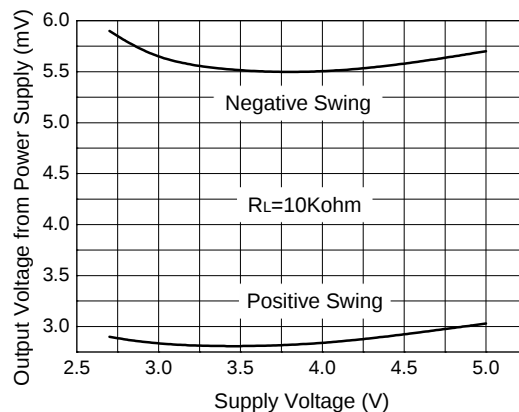
## Typical Performance Characteristics

Unless otherwise specified,  $V_s = +5V$ , single supply,  $T_A = 25^\circ C$

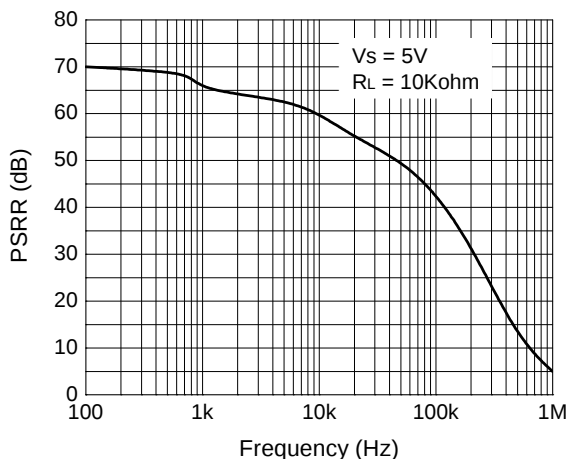
**Supply Current vs. Supply Voltage**



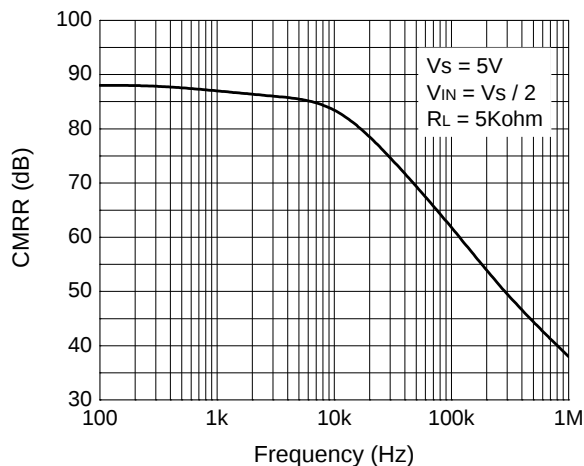
**Output Voltage Swing vs. Supply Voltage**



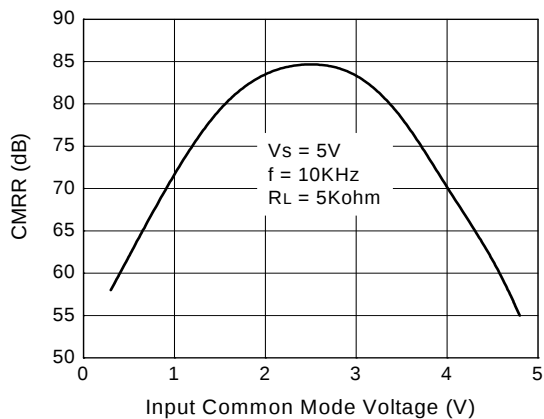
**PSRR vs. Frequency**



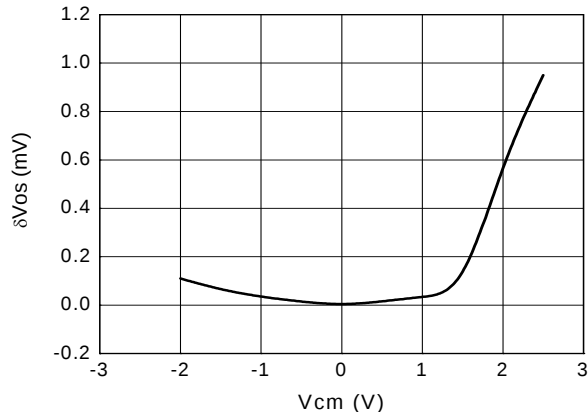
**CMRR vs. Frequency**



**CMRR vs. Input Common Mode Voltage**

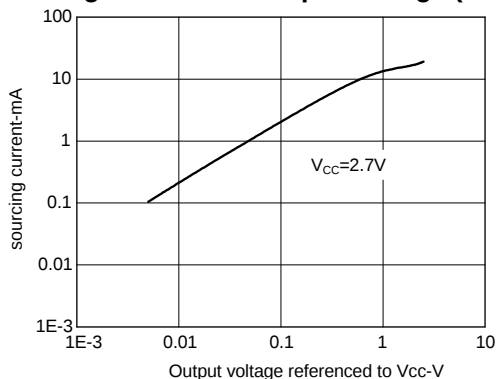


**$\Delta V_{os}$  vs. CMR**

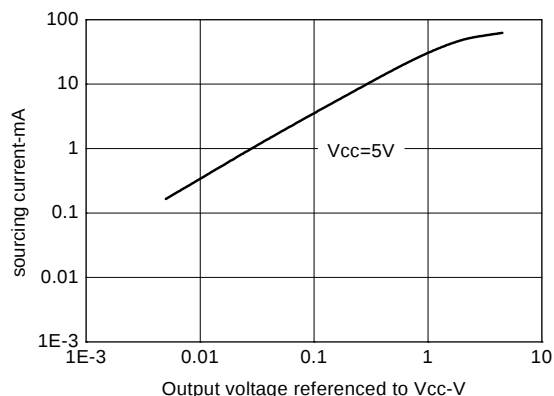


**Typical Performance Characteristics (Continued)**

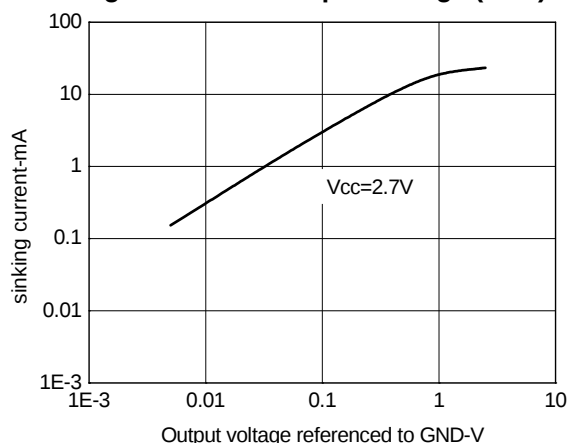
**Sourcing Current vs. Output Voltage (2.7V)**



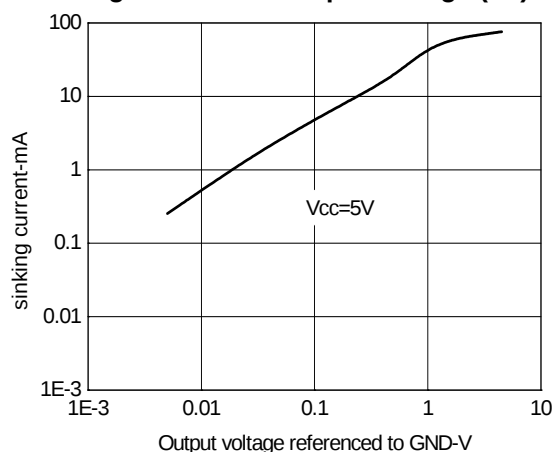
**Sourcing Current vs. Output Voltage (5V)**



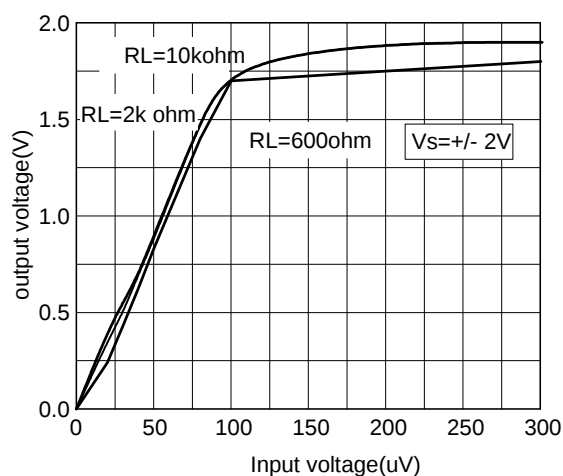
**Sinking Current vs. Output Voltage (2.7V)**



**Sinking Current vs. Output Voltage (5V)**

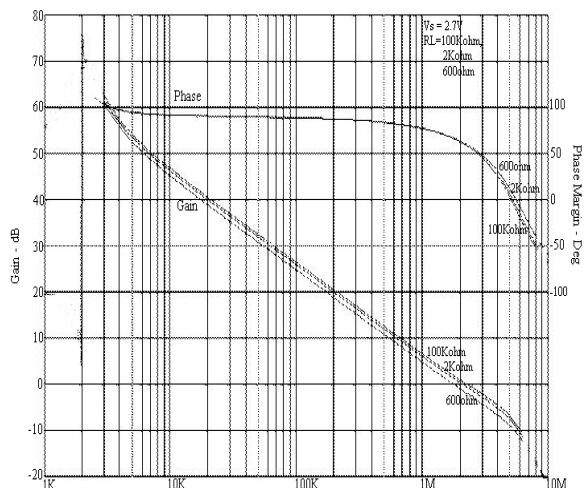


**Input Voltage vs. Output Voltage**

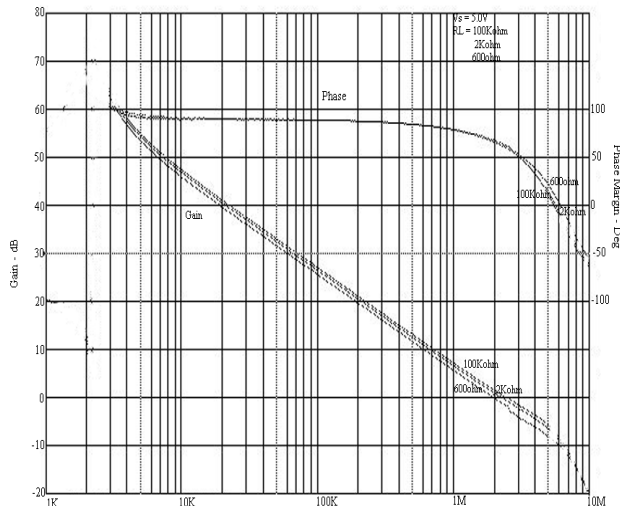


### Typical Performance Characteristics (Continued)

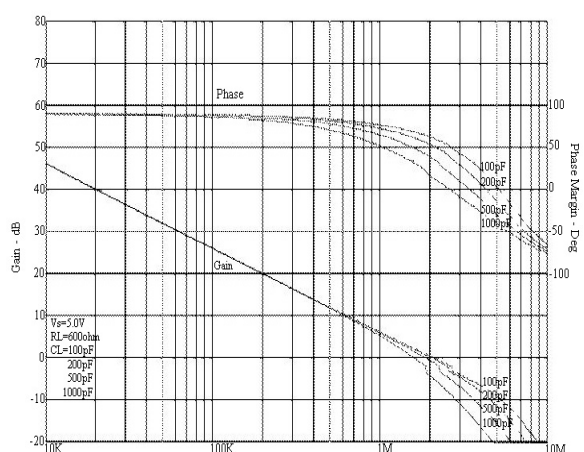
Frequency Response vs. Resistive Load (2.7V)



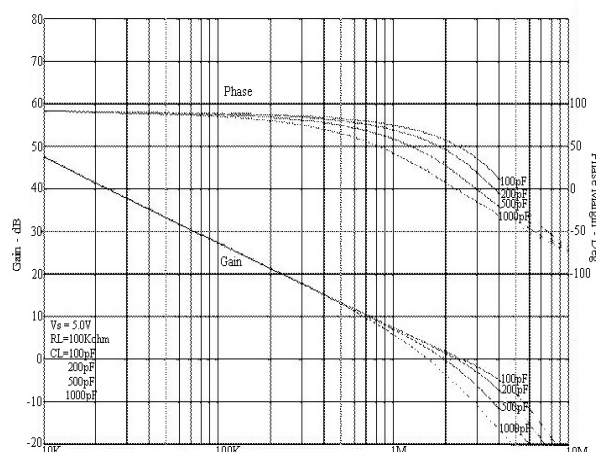
Frequency Response vs. Resistive Load (5V)



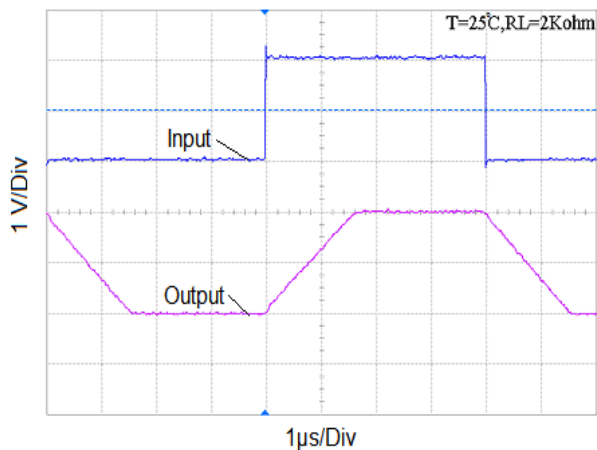
Frequency Response vs. Capacitive Load (2.7V)



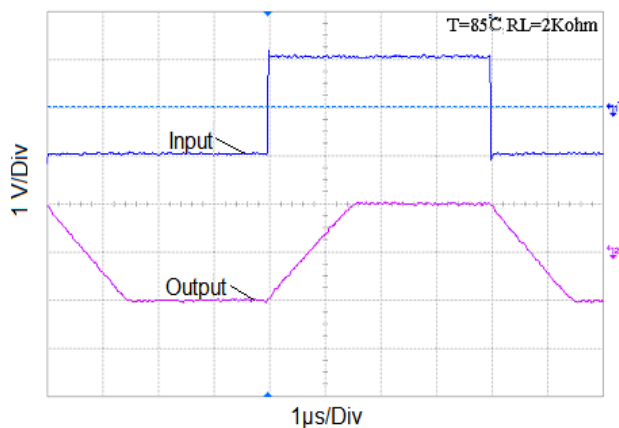
Frequency Response vs. Capacitive Load (5V)



Non-Inverting Large Signal Pulse Response

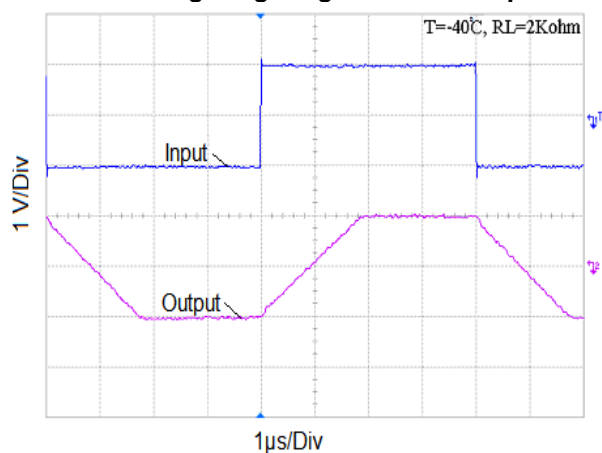


Non-Inverting Large Signal Pulse Response

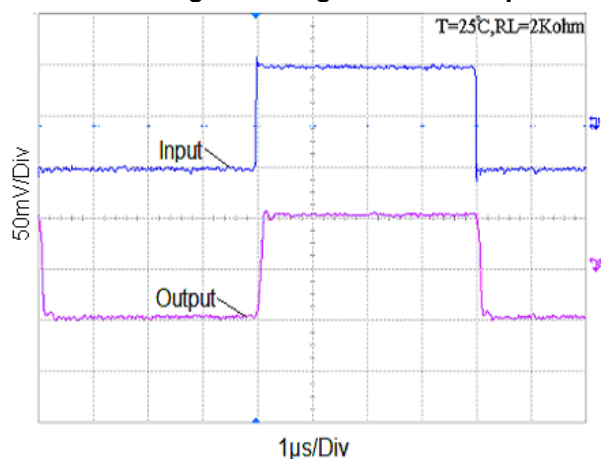


**Typical Performance Characteristics (Continued)**

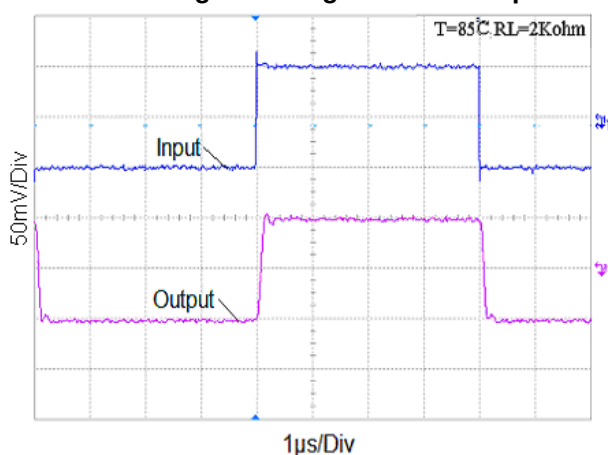
**Non-Inverting Large Signal Pulse Response**



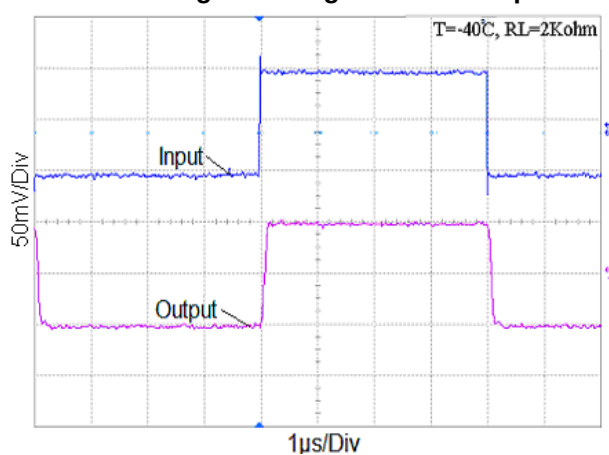
**Non-Inverting Small Signal Pulse Response**



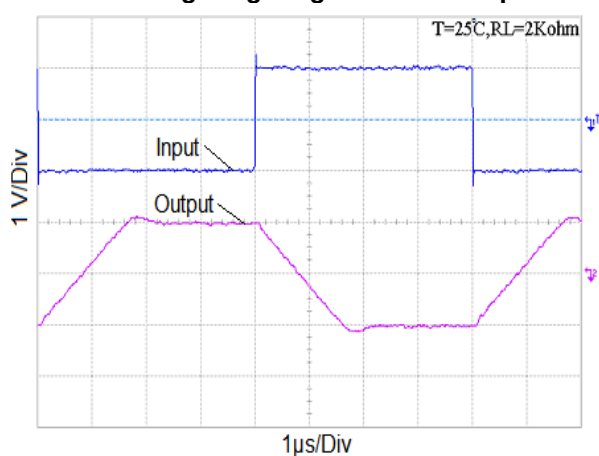
**Non-Inverting Small Signal Pulse Response**



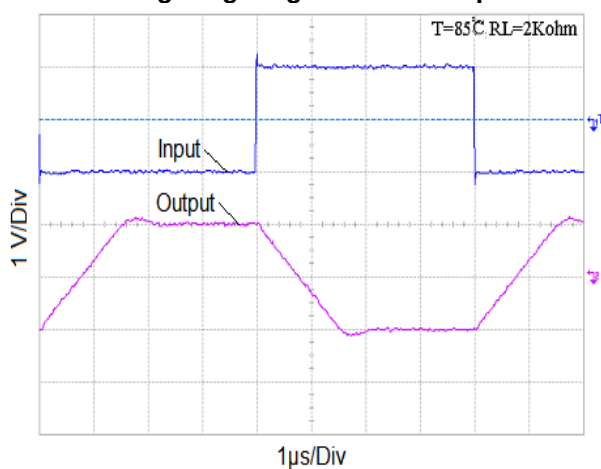
**Non-Inverting Small Signal Pulse Response**



**Inverting Large Signal Pulse Response**

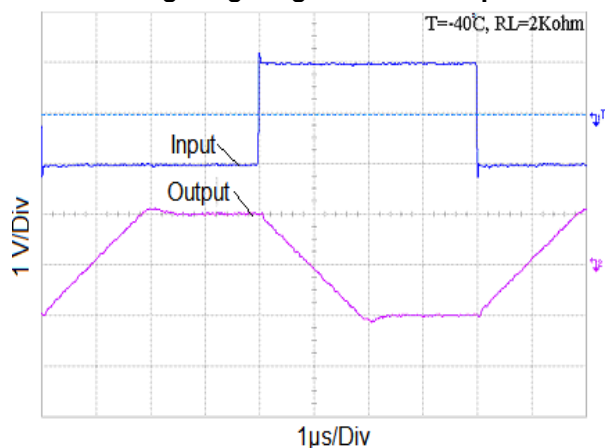


**Inverting Large Signal Pulse Response**

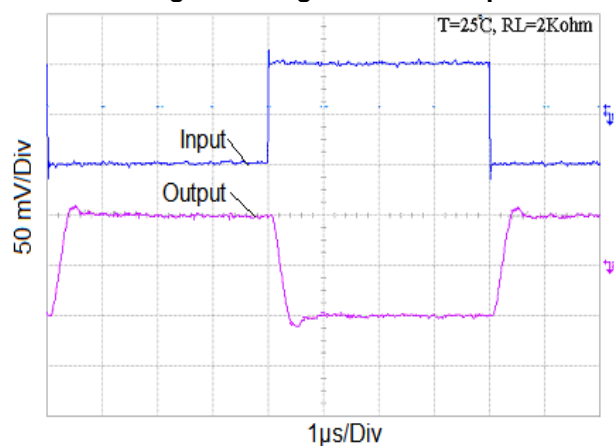


**Typical Performance Characteristics (Continued)**

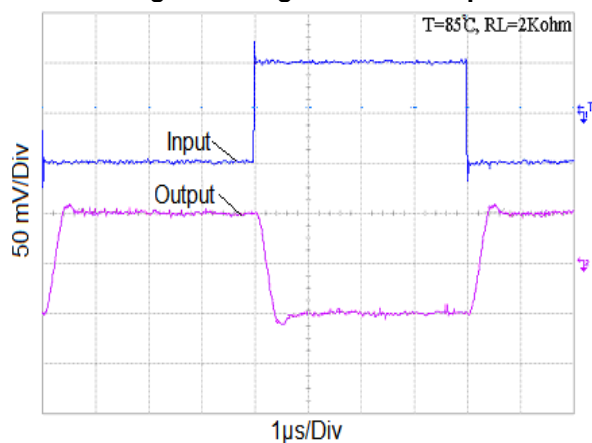
**Inverting Large Signal Pulse Response**



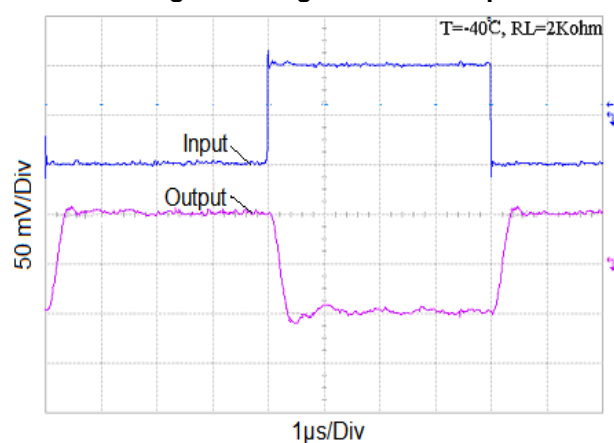
**Inverting Small Signal Pulse Response**



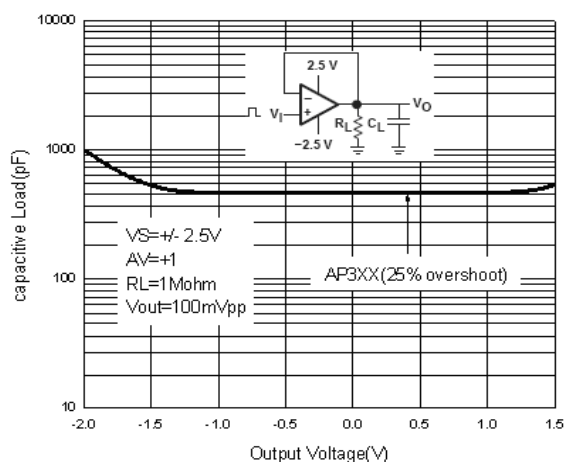
**Inverting Small Signal Pulse Response**



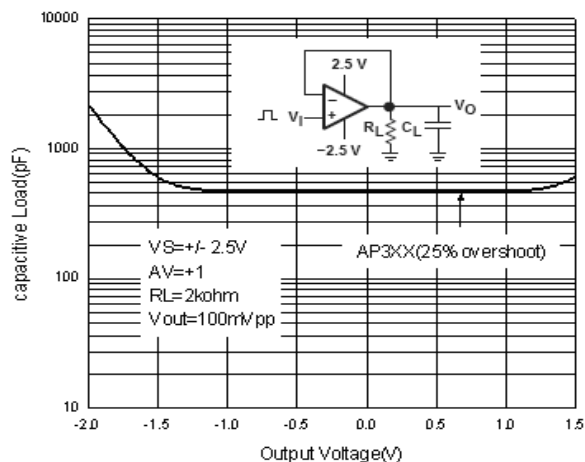
**Inverting Small Signal Pulse Response**



**Stability vs. Capacitive Load**

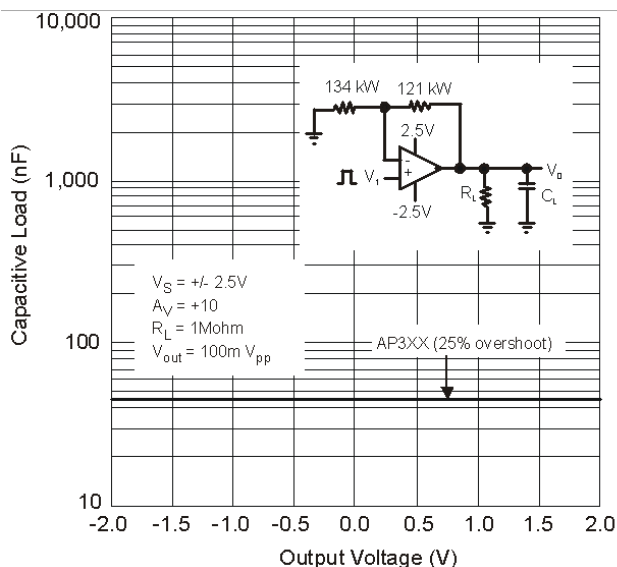


**Stability vs. Capacitive Load**

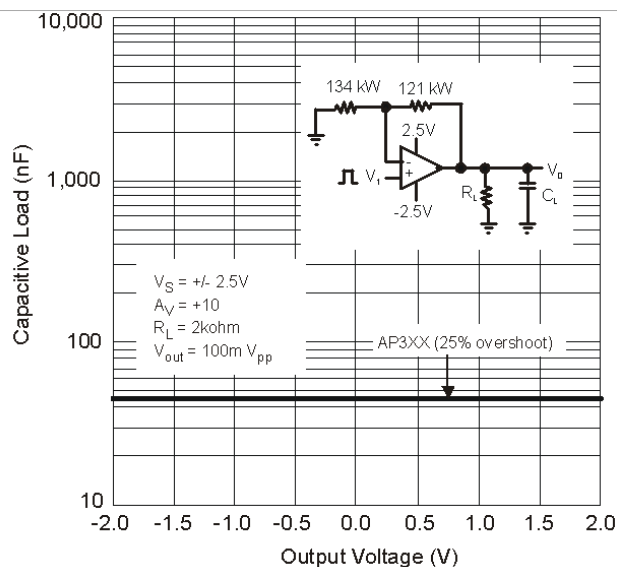


**Typical Performance Characteristics (Continued)**

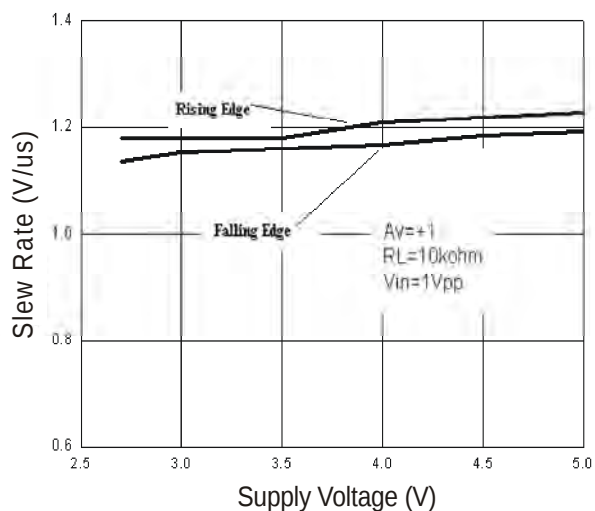
**Stability vs. Capacitive Load**



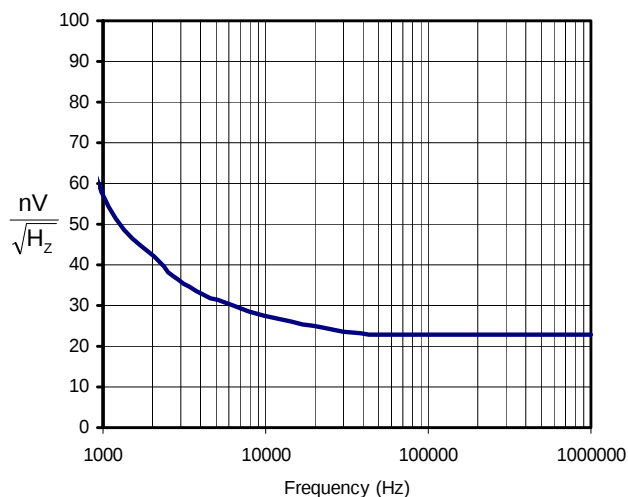
**Stability vs. Capacitive Load**

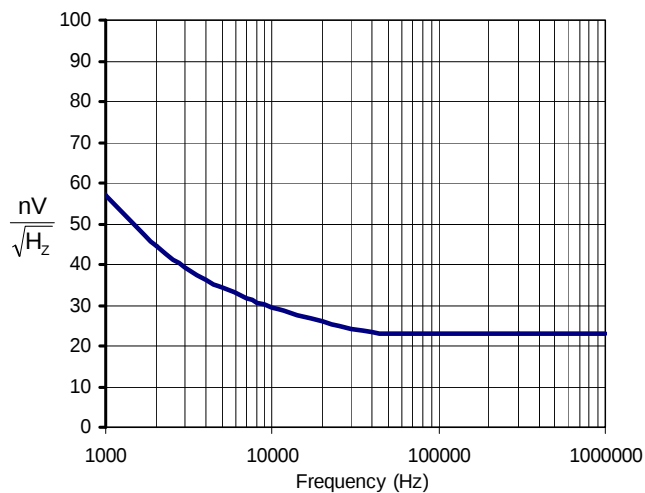


**Slew Rate vs. Supply Voltage**



**Input Voltage Noise**

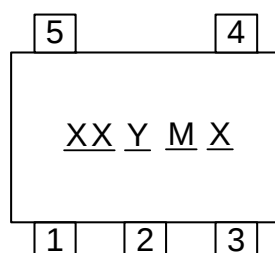


**Typical Performance Characteristics (Continued)****Input Voltage Noise (2.7V)**

### Marking Information

#### (1) SOT25 / SOT353

(Top View)



XX : Internal code

Y : Year 0~9

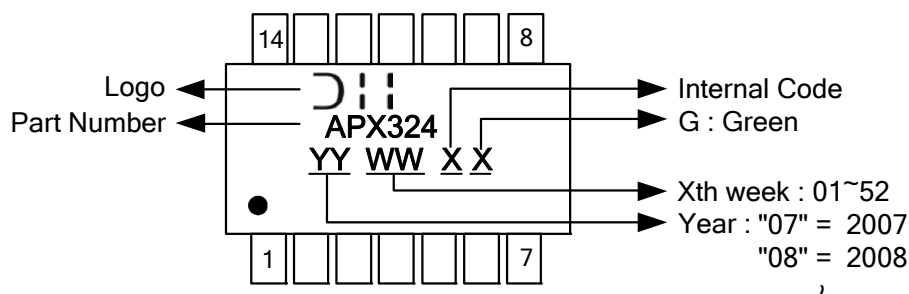
M : Month A~L

X : A~Z : Green

| Device   | Package type | Identification Code |
|----------|--------------|---------------------|
| APX321W  | SOT25        | V2                  |
| APX321SE | SOT353       | V3                  |

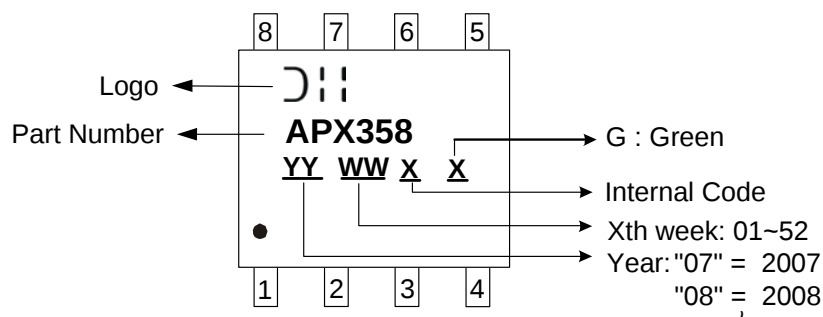
#### (2) TSSOP-14L

( Top View )



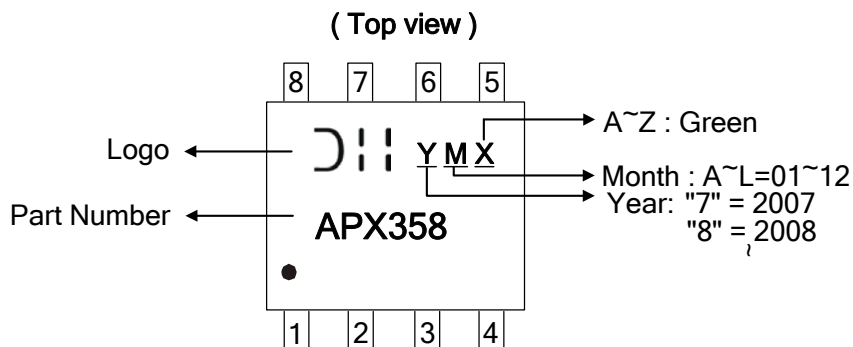
#### (3) SOP-8L

(Top view)



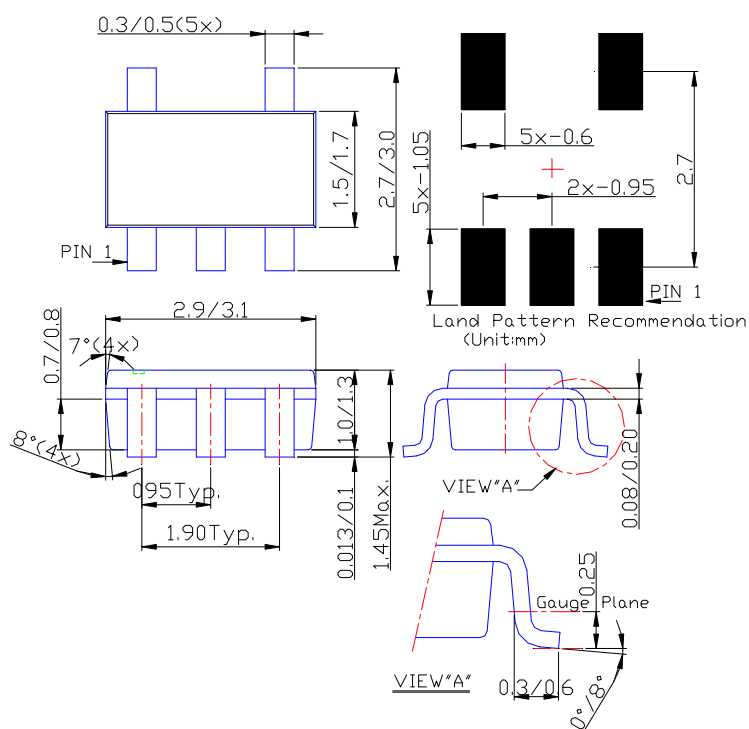
**Marking Information (Continued)**

**(4) MSOP-8L**



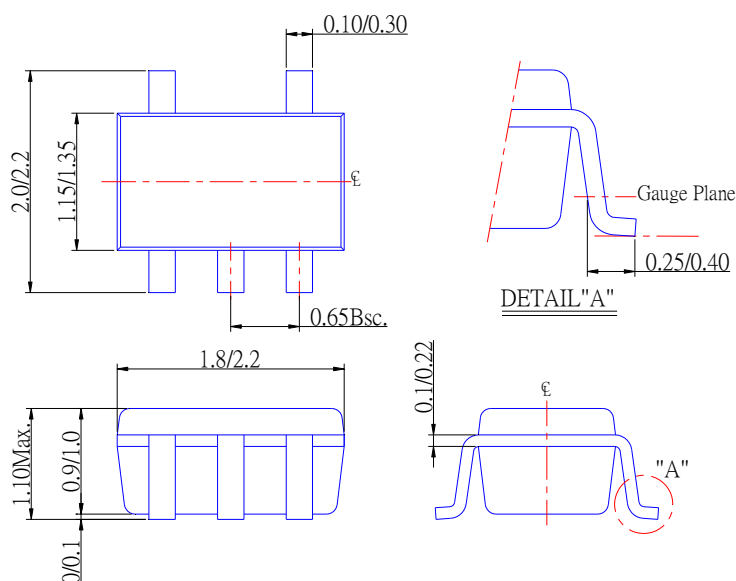
**Package Information (All Dimensions in mm)**

**(1) Package Type: SOT25**

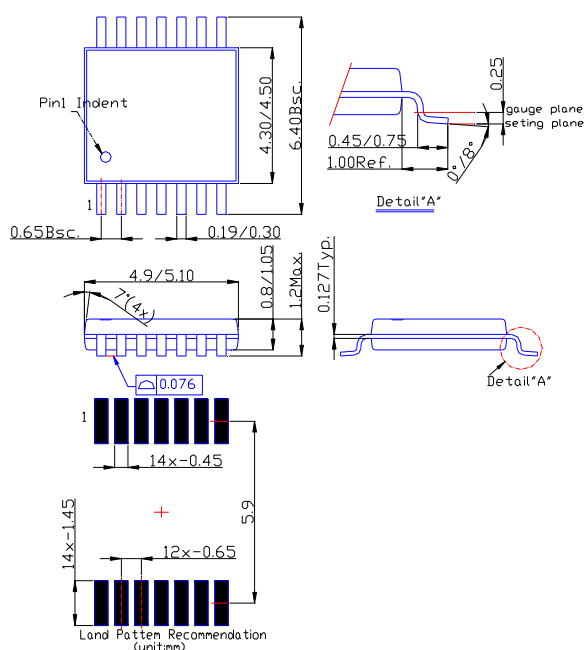


### Package Information (Continued)

**(2) Package Type: SOT353**

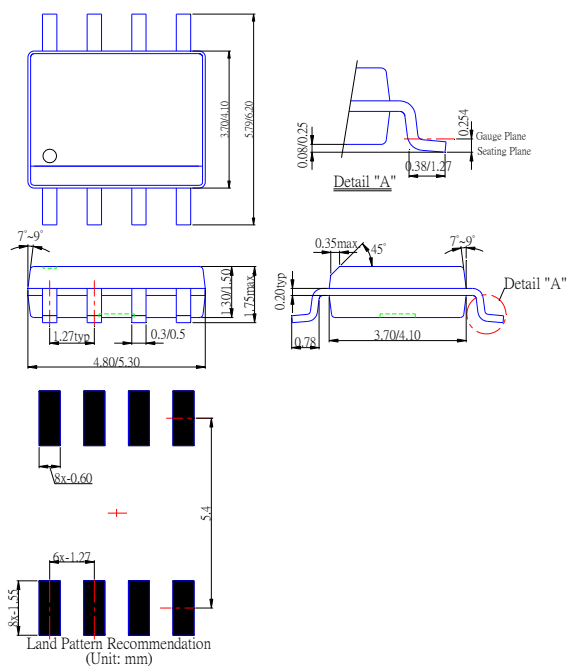


**(3) Package Type: TSSOP-14L**

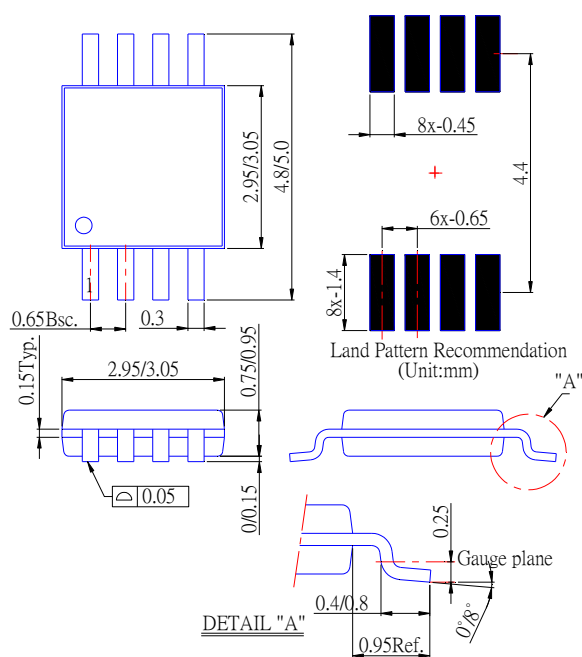


**Package Information (Continued)**

**(4) Package Type: SOP-8L**



**(5) Package Type: MSOP-8L**





# APX321/APX358/APX324

## LOW VOLTAGE, RAIL-TO-RAIL INPUT AND OUTPUT SINGLE/DUAL/QUAD OPERATIONAL AMPLIFIERS

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