# Picoampere Input Current Quad Bipolar Op Amp

# AD704

## FEATURES

**High dc precision**
- **150 µV maximum offset voltage**
- **1.5 µV/°C maximum offset voltage drift**
- **270 pA maximum input bias current**
- **0.3 pA/°C typical $I_B$ drift**

**Low noise: 0.5 µV p-p**
**Typical noise: 0.1 Hz to 10 Hz**
**Low power: 600 µA maximum supply current per amplifier**
**Dual version: AD706**

## APPLICATIONS

**Industrial/process controls**
**Weigh scales**
**ECG/EKG instrumentation**
**Low frequency active filters**

## GENERAL DESCRIPTION

The AD704 is a quad, low power bipolar op amp that has the low input bias current of a BiFET amplifier and offers a significantly lower $I_B$ drift over temperature. It uses superbeta bipolar input transistors to achieve picoampere input bias current levels (similar to FET input amplifiers at room temperature), while its $I_B$ typically increases only by 5× at 125°C (unlike a BiFET amp, for which $I_B$ doubles every 10°C, resulting in a 1000× increase at 125°C). In addition, the AD704 achieves 150 µV offset voltage and the low noise characteristics of a precision bipolar input op amp.

Because it has only 1/20 the input bias current of an OP07, the AD704 does not require the commonly used balancing resistor. Furthermore, the current noise is 1/5 that of the OP07, which makes the AD704 usable with much higher source impedances. At 1/6 the supply current (per amplifier) of the OP07, the AD704 is better suited for today's higher density circuit boards and battery-powered applications.

The AD704 is an excellent choice for use in low frequency active filters in 12- and 14-bit data acquisition systems, in precision instrumentation, and as a high quality integrator. The AD704 is internally compensated for unity gain stability. The AD704J is rated over the commercial temperature range of 0°C to 70°C. The AD704A is rated over the industrial temperature of −40°C to +85°C. The AD704S is rated over the military temperature range of −55°C to +125°C, processed to MIL-STD-883B.

## CONNECTION DIAGRAMS

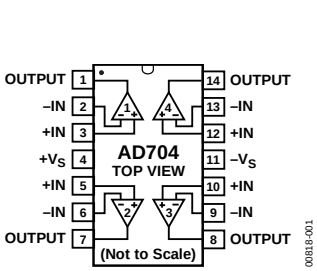



Figure 1. 14-Lead Plastic DIP (N)

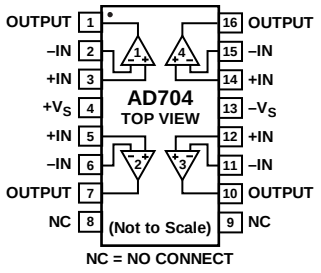



Figure 2. 16-Lead SOIC (R) Package

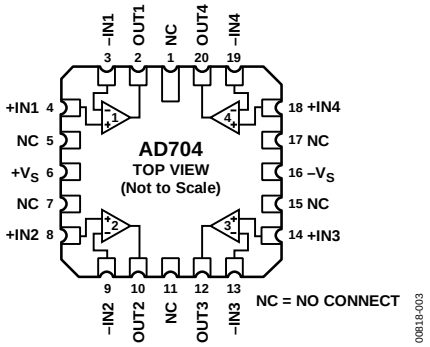



Figure 3. 20-Terminal LCC (E-20-1) Package

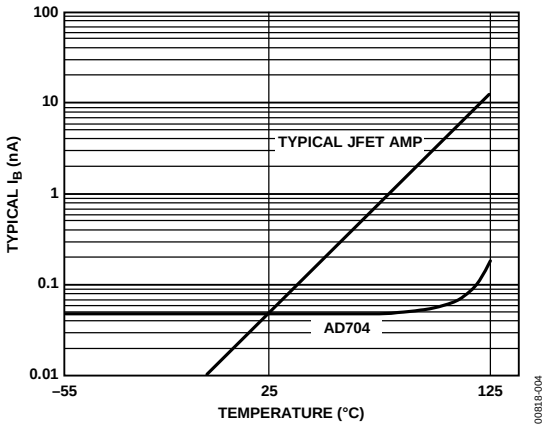



Figure 4. Input Bias Current Over Temperature

**Table 1. Low $I_B$ @ 125°C**

| Model | 30V | 16V | 1.3 to 5V | Next Generation |
|---|---|---|---|---|
| Single | N/A | AD8663 | AD8603 | N/A |
| Dual | AD706 | AD8667 | AD8607 | AD8622 |
| Quad | AD704 | AD8669 | AD8609 | AD8624 |

**Rev.** E

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## REVISION HISTORY

**1/10—Rev. D to Rev. E**

Updated Format ..... Universal
Changes to Features and General Description Section, Added Table 1, Renumbered Sequentially ..... 1
Changes to Table 2 ..... 3
Changes to Table 3 ..... 5
Updated Outline Dimensions ..... 13
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**12/09—Rev. C to Rev. D**

Updated Outline Dimensions ..... 10
Changes to Ordering Guide ..... 10

**11/01—Rev. B to Rev. C**

Edits to Features ..... 1
Edits to Product Description ..... 1
Edits to Absolute Maximum Ratings ..... 3
Deleted Metalization Photograph ..... 3
Edits to Ordering Guide ..... 4

# SPECIFICATIONS

$T_A$ = 25°C, $V_{CM}$ = 0 V, and $V_S$ =±15 V dc, unless otherwise noted.

**Table 2.**

| | | AD704J/A | | | |
|---|---|---|---|---|---|
| **Parameters** | **Conditions** | **Min** | **Typ** | **Max** | **Unit** |
| INPUT OFFSET VOLTAGE | | | | | |
| Initial Offset | | | 50 | 150 | µV |
| Offset | $T_{MIN}$ – $T_{MAX}$ | | 100 | 250 | µV |
| vs. Temp, Average TC | | | 0.2 | 1.5 | µV/°C |
| vs. Supply (PSRR) | $V_S$ = ±2 V to ±18 V | 100 | 132 | | dB |
| $T_{MIN}$ – $T_{MAX}$ | $V_S$ = ±2.5 V to ±18 V | 100 | 126 | | dB |
| Long-Term Stability | | | 0.3 | | µV/month |
| INPUT BIAS CURRENT[1] | $V_{CM}$ = 0 V | | 100 | 270 | pA |
| | $V_{CM}$ = ±13.5 V | | | 300 | pA |
| vs. Temp, Average TC | | | 0.3 | | pA/°C |
| $T_{MIN}$ – $T_{MAX}$ | $V_{CM}$ = 0 V | | | 300 | pA |
| | $V_{CM}$ = ±13.5 V | | | 400 | pA |
| INPUT OFFSET CURRENT | $V_{CM}$ = 0 V | | 80 | 250 | pA |
| | $V_{CM}$ = ±13.5 V | | | 300 | pA |
| vs. Temp, Average TC | | | 0.6 | | pA/°C |
| $T_{MIN}$ – $T_{MAX}$ | $V_{CM}$ = 0 V | | 100 | 300 | pA |
| | $V_{CM}$ = ±13.5 V | | 100 | 400 | pA |
| MATCHING CHARACTERISTICS | | | | | |
| Offset Voltage | | | | 250 | µV |
| | $T_{MIN}$ – $T_{MAX}$ | | | 400 | µV |
| Input Bias Current[2] | | | | 500 | pA |
| | $T_{MIN}$ – $T_{MAX}$ | | | 600 | pA |
| Common-Mode Rejection[3] | | 94 | | | dB |
| | $T_{MIN}$ – $T_{MAX}$ | 94 | | | dB |
| Power Supply Rejection[4] | | 94 | | | dB |
| | $T_{MIN}$ – $T_{MAX}$ | 94 | | | dB |
| Crosstalk[5] | f = 10 Hz | | | | |
| | $R_{LOAD}$ = 2 kΩ | | 150 | | dB |
| FREQUENCY RESPONSE UNITY GAIN | | | | | |
| Crossover Frequency | | | 0.8 | | MHz |
| Slew Rate, Unity Gain | G = –1 | | 0.15 | | V/µs |
| Slew Rate | $T_{MIN}$ – $T_{MAX}$ | | 0.1 | | V/µs |
| INPUT IMPEDANCE | | | | | |
| Differential | | | 40\|\|2 | | MΩ\|\|pF |
| Common-Mode | | | 300\|\|2 | | GΩ\|\|pF |
| INPUT VOLTAGE RANGE | | | | | |
| Common-Mode Voltage | | ±13.5 | ±14 | | V |
| Common-Mode Rejection Ratio | $V_{CM}$ = ±13.5 V | 100 | 132 | | dB |
| | $T_{MIN}$ – $T_{MAX}$ | 98 | 128 | | dB |
| INPUT CURRENT NOISE | 0.1 Hz to 10 Hz | | 3 | | pA p-p |
| | f = 10 Hz | | 50 | | fA/√Hz |
| INPUT VOLTAGE NOISE | 0.1 Hz to 10 Hz | | 0.5 | | µV p-p |
| | f = 10 Hz | | 17 | | nV/√Hz |
| | f = 1 kHz | | 15 | 22 | nV/√Hz |

| Parameters | Conditions | AD704J/A Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| OPEN-LOOP GAIN | $V_O$ = ±12 V | | | | |
| | $R_{LOAD}$ = 10 kΩ | 200 | 2000 | | V/mV |
| | $T_{MIN}$ – $T_{MAX}$ | 150 | 1500 | | V/mV |
| | $V_O$ = ±10 V | | | | |
| | $R_{LOAD}$ = 2 kΩ | 200 | 1000 | | V/mV |
| | $T_{MIN}$ – $T_{MAX}$ | 150 | 1000 | | V/mV |
| OUTPUT CHARACTERISTICS | | | | | |
| Voltage Swing | $R_{LOAD}$ = 10 kΩ | | | | V |
| | $T_{MIN}$ – $T_{MAX}$ | ±13 | ±14 | | |
| Current | Short circuit | | ±15 | | mA |
| CAPACITIVE LOAD | | | | | |
| Drive Capability | Gain = 1 | | 10,000 | | pF |
| POWER SUPPLY | | | | | |
| Rated Performance | | | ±15 | | V |
| Operating Range | | ±2.0 | | ±18 | V |
| Quiescent Current | | | 1.5 | 2.4 | mA |
| | $T_{MIN}$ – $T_{MAX}$ | | 1.6 | 2.6 | mA |
| TRANSISTOR COUNT | Number of transistors | | 180 | | |

[1] Bias current specifications are guaranteed maximum at either input.
[2] Input bias current match is the maximum difference between corresponding inputs of all four amplifiers.
[3] CMRR match is the difference of $\Delta V_{OS}/\Delta V_{CM}$ between any two amplifiers, expressed in dB.
[4] PSRR match is the difference between $\Delta V_{OS}/\Delta V_{SUPPLY}$ for any two amplifiers, expressed in dB.
[5] See Figure 5 for test circuit.

# ABSOLUTE MAXIMUM RATINGS

**Table 3.**

| Parameter | Rating |
|---|---|
| Supply Voltage | ±18 V |
| Internal Power Dissipation (25°C)[1] | |
| Input Voltage | $\pm V_S$ |
| Differential Input Voltage[2] | ±0.7 V |
| Output Short-Circuit Duration (Single Input) | Indefinite |
| Storage Temperature Range | −65°C to +125°C |
| Operating Temperature Range | |
| AD704J | 0°C to 70°C |
| AD704A | −40°C to +85°C |
| Lead Temperature (Soldering, 10 sec) | 300°C |

[1] Specification is for the device in free air:
14-lead plastic package: $\theta_{JA}$ = 150°C/W.
16-lead SOIC package: $\theta_{JA}$ = 100°C/W.
20-terminal LCC package: $\theta_{JA}$ = 150°C/W.

[2] The input pins of this amplifier are protected by back-to-back diodes. If the differential voltage exceeds ±0.7 volts, external series protection resistors should be added to limit the input current to less than 25 mA.

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

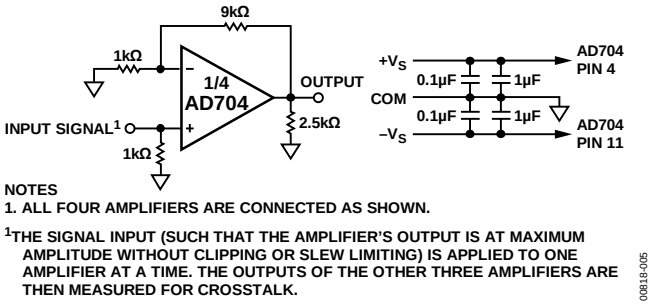



*Figure 5. Crosstalk Test Circuit*

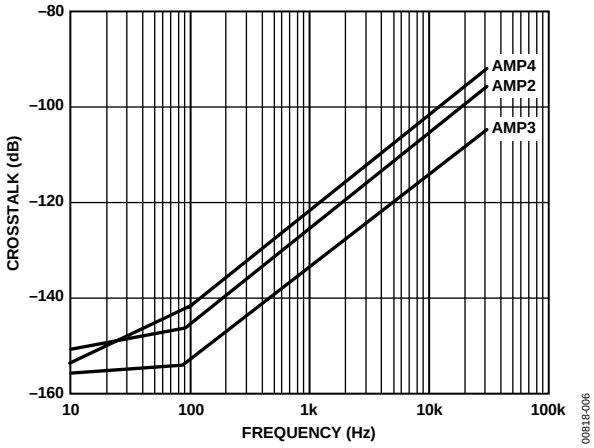



*Figure 6. Crosstalk vs. Frequency*

## ESD CAUTION



**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

# TYPICAL PERFORMANCE CHARACTERISTICS

$T_A$ = 25°C, $V_S$ = ±15 V dc, unless otherwise noted.

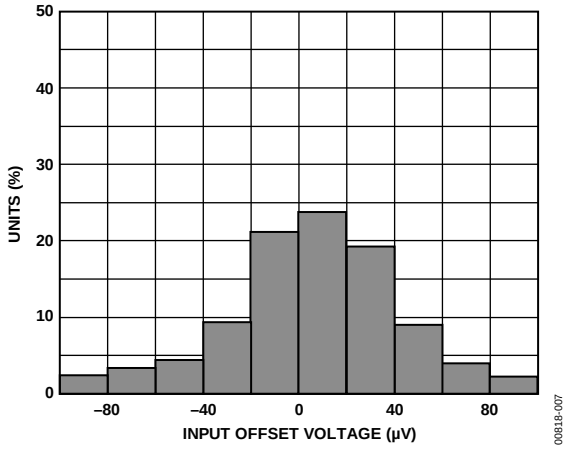



Figure 7. Typical Distribution of Input Offset Voltage

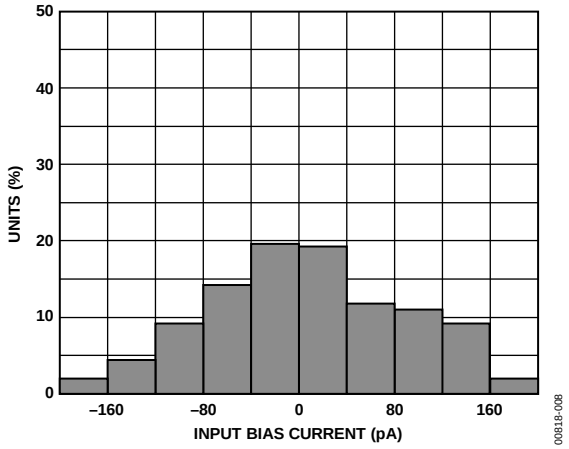



Figure 8. Typical Distribution of Input Bias Current

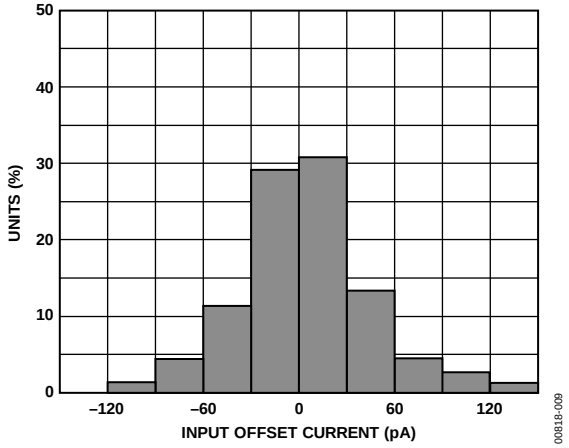



Figure 9. Typical Distribution of Input Offset Current

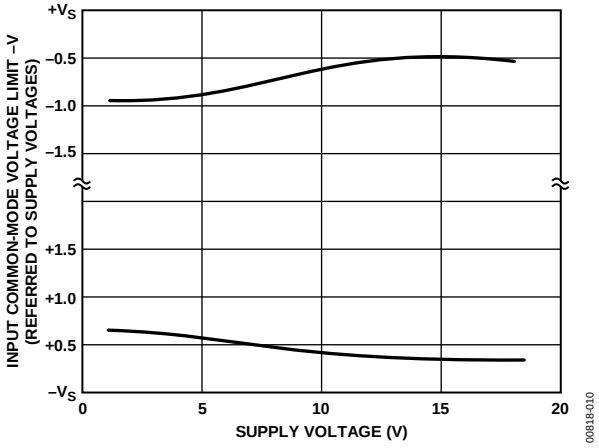



Figure 10. Input Common-Mode Voltage Range vs. Supply Voltage

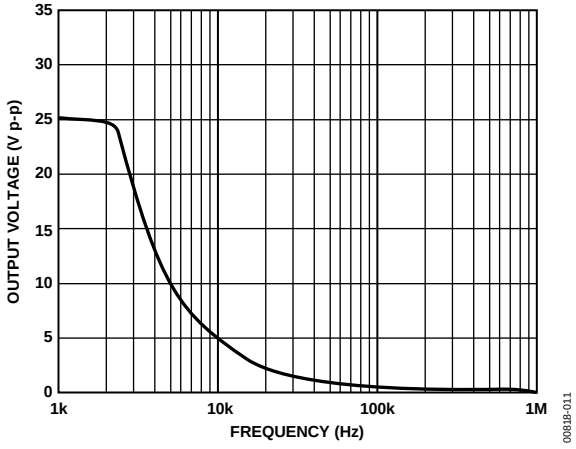



Figure 11. Large Signal Frequency Response

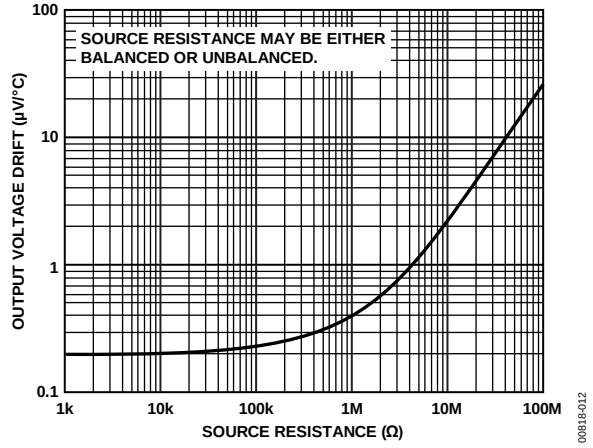



Figure 12. Offset Voltage Drift vs. Source Resistance

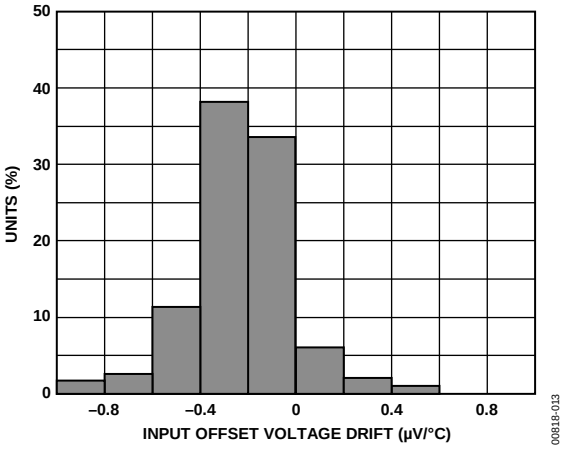



Figure 13. Typical Distribution of Input Offset Voltage Drift

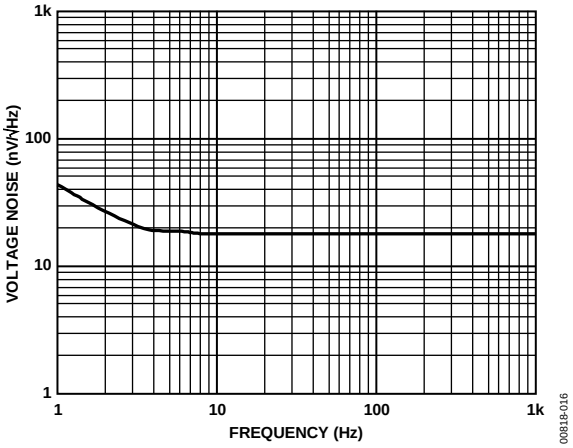



Figure 16. Input Noise Voltage Spectral Density

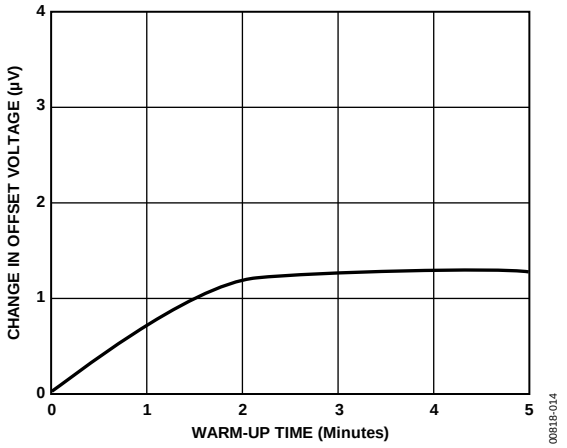



Figure 14. Change in Input Offset Voltage vs. Warm-Up Time

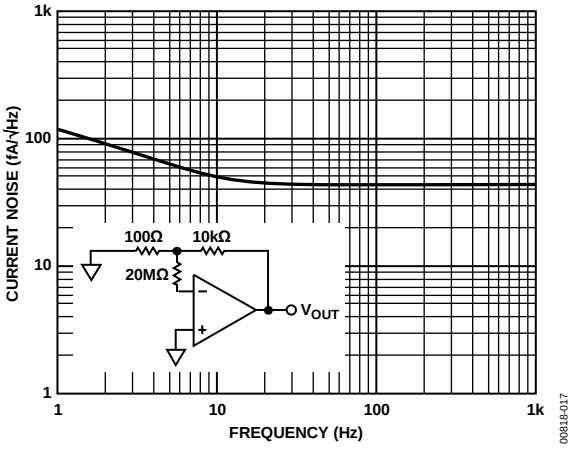



Figure 17. Input Noise Current Spectral Density

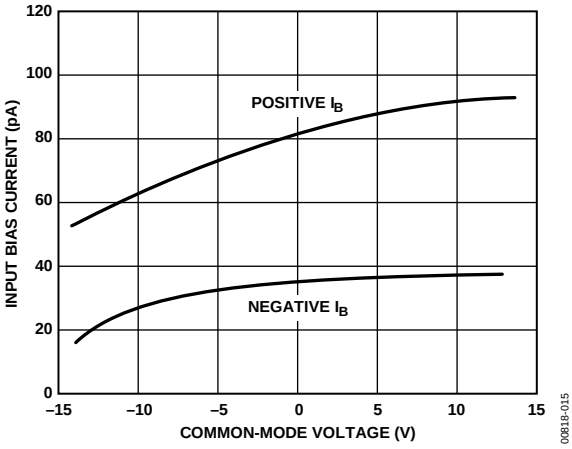



Figure 15. Input Bias Current vs. Common-Mode Voltage

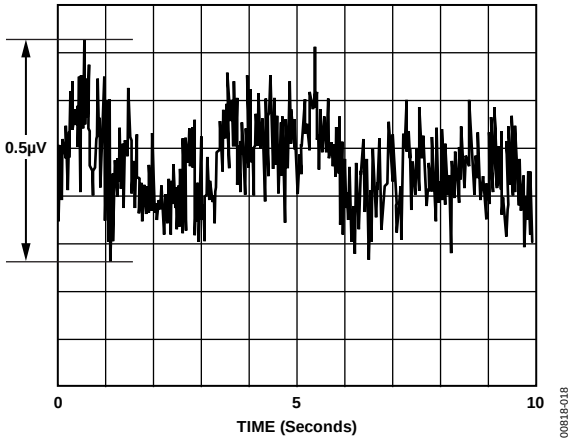



Figure 18. 0.1 Hz to 10 Hz Noise Voltage

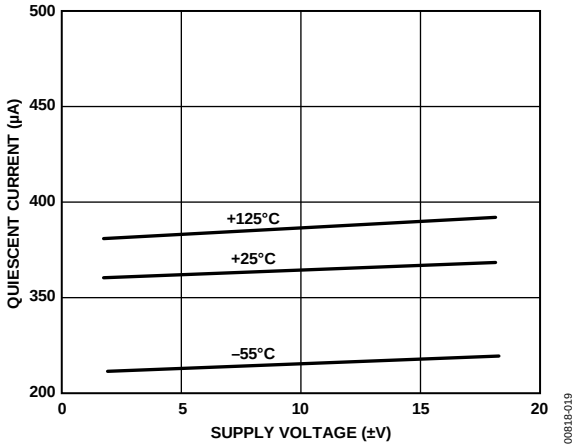



Figure 19. Quiescent Supply Current vs. Supply Voltage (per Amplifier)

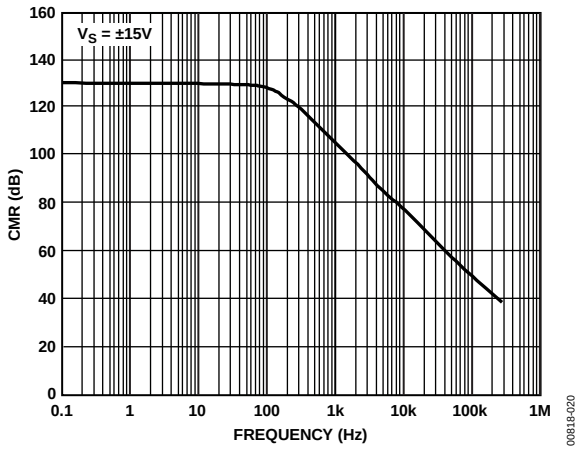



Figure 20. Common-Mode Rejection vs. Frequency

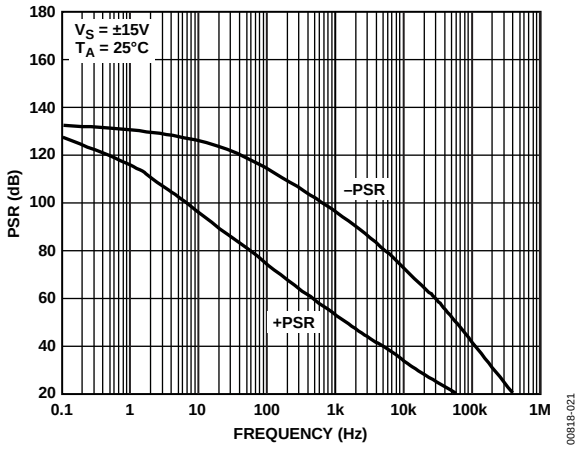



Figure 21. Power Supply Rejection vs. Frequency

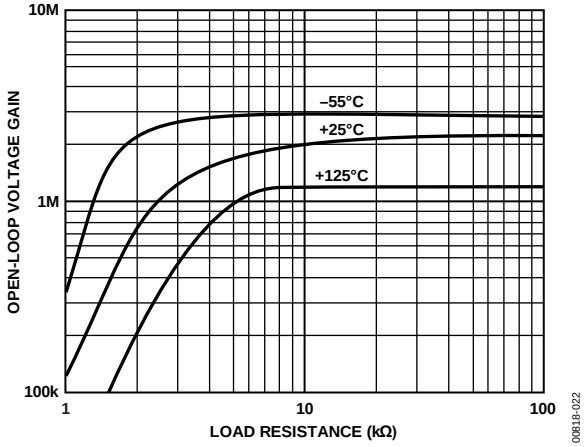



Figure 22. Open-Loop Gain vs. Load Resistance Over Temperature

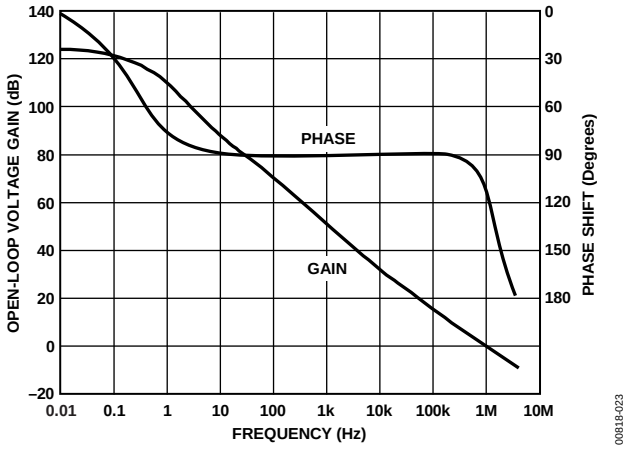



Figure 23. Open-Loop Gain and Phase vs. Frequency

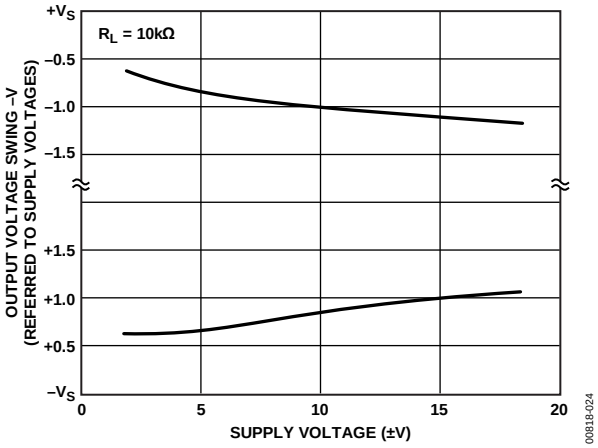



Figure 24. Output Voltage Swing vs. Supply Voltage

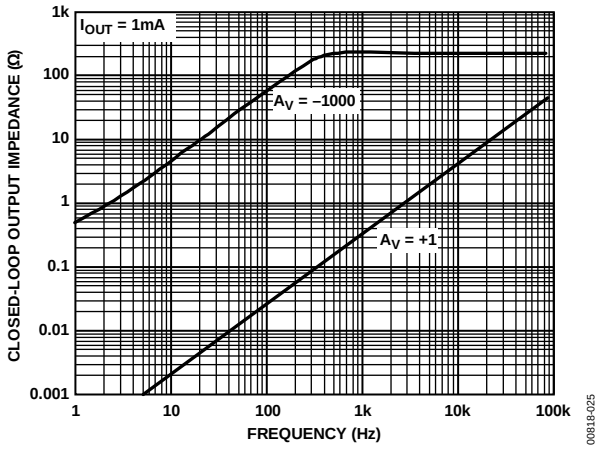



*Figure 25. Closed-Loop Output Impedance vs. Frequency*

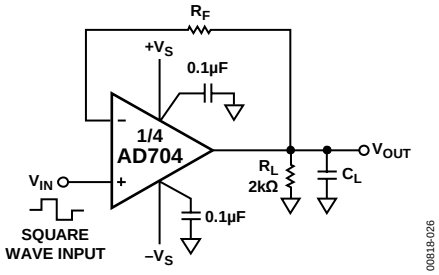



*Figure 26. Unity Gain Follower (for Large Signal Applications, Resistor $R_F$ Limits the Current Through the Input Protection Diodes)*

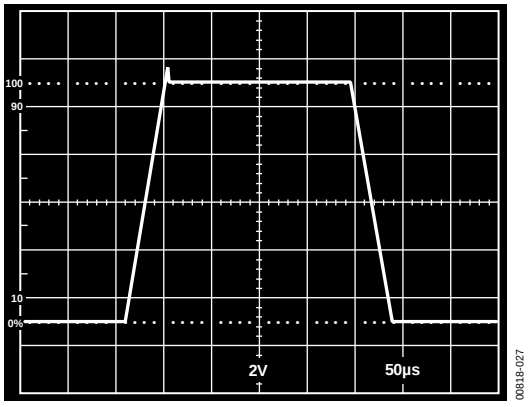



*Figure 27. Unity Gain Follower Large Signal Pulse Response $R_F$ = 10 kΩ, $C_L$ = 1000 pF*

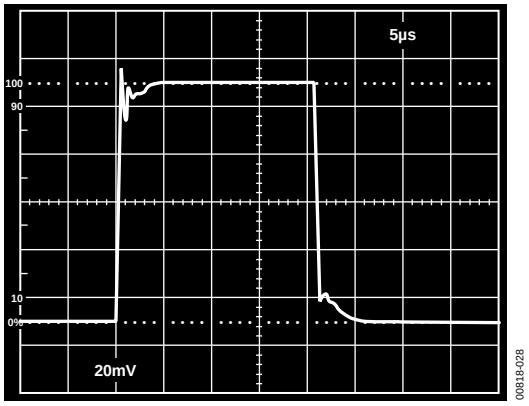



*Figure 28. Unity Gain Follower Small Signal Pulse Response $R_F$ = 0 Ω, $C_L$ = 100 pF*

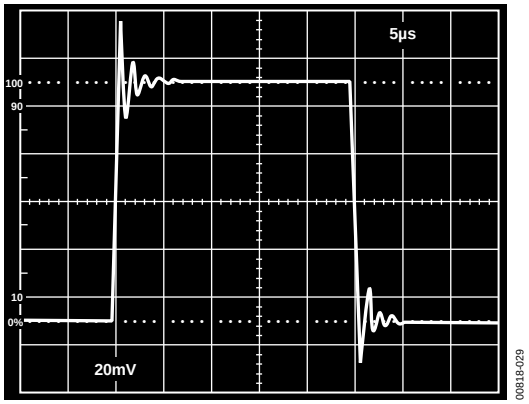



*Figure 29. Unity Gain Follower Small Signal Pulse Response $R_F$ = 0 Ω, $C_L$ = 1000 pF*

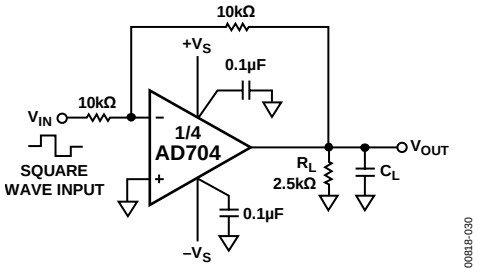



*Figure 30. Unity Gain Inverter Connection*

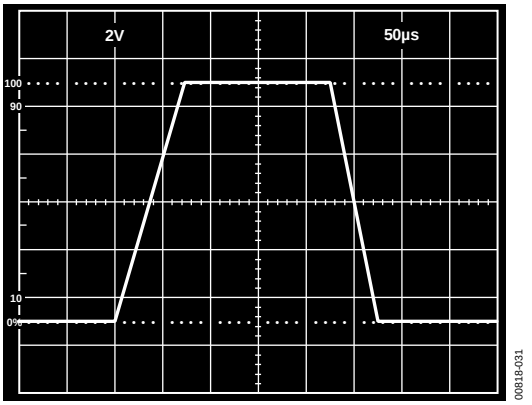



Figure 31. Unity Gain Inverter Large Signal Pulse Response, $C_L$ = 1000 pF

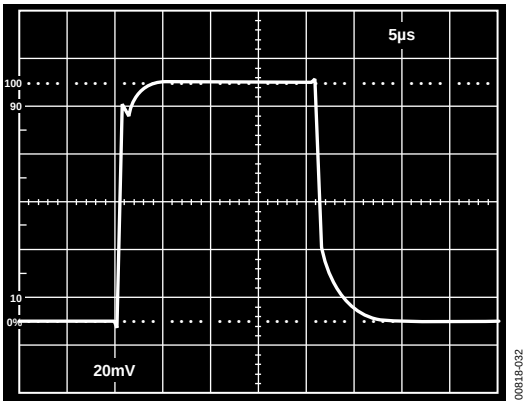



Figure 32. Unity Gain Inverter Small Signal Pulse Response, $C_L$ = 100 pF

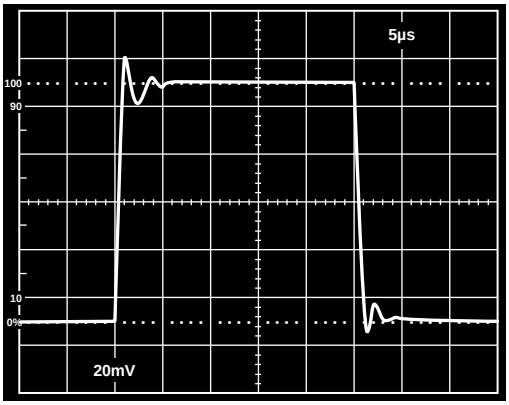
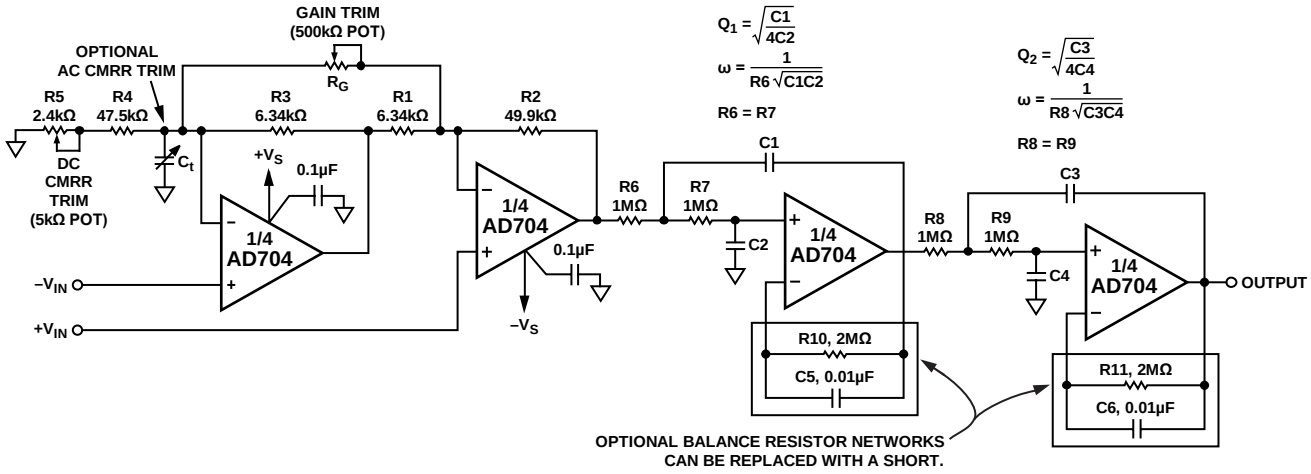



Figure 33. Unity Gain Inverter Small Signal Pulse Response, $C_L$ = 1000 pF

# THEORY OF OPERATION




NOTES
1. INSTRUMENTATION AMPLIFIER GAIN = $1 + \frac{R2}{R1} + \frac{2R2}{R_G}$ (FOR R1 = R3, R2 = R4 + R5).
2. CAPACITORS C2 AND C4 ARE SOUTHERN ELECTRONICS MPCC, POLYCARBONATE, ±5%, 50V.
3. ALL RESISTORS METAL FILM, 1%.

00818-034

*Figure 34. Gain-of-10 Instrumentation Amplifier with Post Filtering*

The instrumentation amplifier with post filtering (see Figure 34) combines two applications that benefit greatly from the AD704. This circuit achieves low power and dc precision over temperature with a minimum of components.

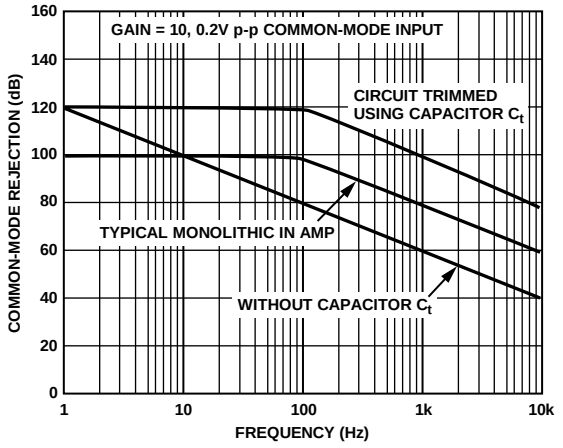
The instrumentation amplifier circuit offers many performance benefits, including BiFET level input bias currents, low input offset voltage drift, and only 1.2 mA quiescent current. It operates for gains that are G ≥ 2 and, at lower gains, it benefits from no output amplifier offset and no noise contribution as encountered in a 3-op-amp design. Good low frequency CMRR is achieved even without the optional ac CMRR trim (see Figure 35). Table 4 provides resistance values for three common circuit gains. For other gains, use the following equations:

$$R2 = R4 + R5 = 49.9\ \text{k}\Omega$$

$$R1 = R3 = \frac{49.9\ \text{k}\Omega}{0.9\,G - 1}$$

$$Max\ Value\ of\ R_G = \frac{99.8\ \text{k}\Omega}{0.06\,G}$$

$$C_t \approx \frac{1}{2\pi\,(R3)\,5 \times 10^5}$$




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*Figure 35. Common-Mode Rejection vs. Frequency with and Without Capacitor $C_t$*

**Table 4. Resistance Values for Various Gains**

| Circuit Gain (G) | R1 and R3 | $R_G$ (Max Value of Trim Potentiometer) | Bandwidth (–3 dB), Hz |
|---|---|---|---|
| 10 | 6.34 kΩ | 166 kΩ | 50 k |
| 100 | 526 Ω | 16.6 kΩ | 5k |
| 1000 | 56.2 Ω | 1.66 kΩ | 0.5 k |

The 1 Hz, four-pole active filter offers dc precision with a minimum of components and cost. The low current noise, $I_{OS}$, and $I_B$ allow the use of 1 MΩ resistors without sacrificing the 1 µV/°C drift of the AD704. This means that lower capacitor values can be used, reducing cost and space. Furthermore, because the AD704's $I_B$ is as low as its $I_{OS}$, over most of the MIL temperature range, most applications do not require the use of the normal balancing resistor (with its stability capacitor). Adding the optional balancing resistor enhances performance at high temperatures, as shown in Figure 36. Table 5 gives capacitor values for several common low pass responses.

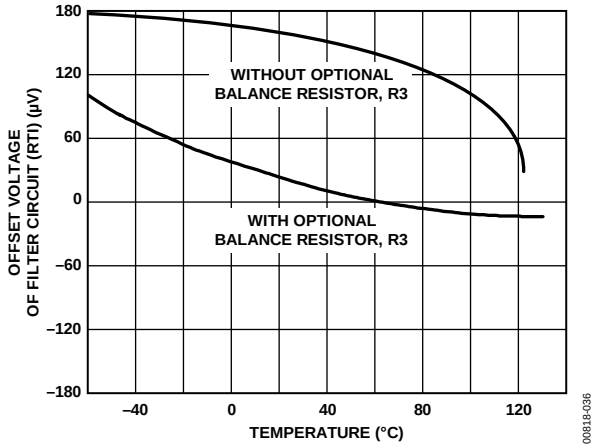


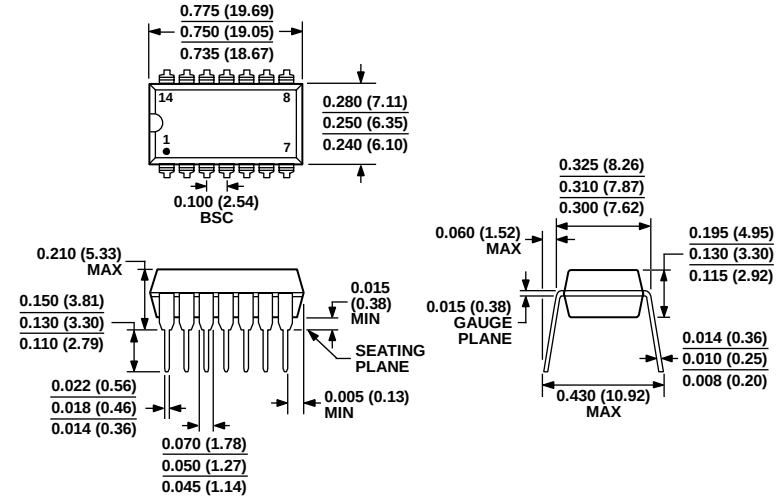

*Figure 36. $V_{OS}$ vs. Temperature Performance of the 1 Hz Filter Circuit*

**Table 5. 1 Hz, Four-Pole Low-Pass Filter Recommended Component Values[1]**

| Desired Low Pass Response | Section 1 Frequency (Hz) | Q | Section 2 Frequency (Hz) | Q | C1 ( µF) | C2 (µF) | C3 (µF) | C4 (µF) |
|---|---|---|---|---|---|---|---|---|
| Bessel | 1.43 | 0.522 | 1.60 | 0.806 | 0.116 | 0.107 | 0.160 | 0.0616 |
| Butterworth | 1.00 | 0.541 | 1.00 | 1.31 | 0.172 | 0.147 | 0.416 | 0.0609 |
| 0.1 dB Chebychev | 0.648 | 0.619 | 0.948 | 2.18 | 0.304 | 0.198 | 0.733 | 0.0385 |
| 0.2 dB Chebychev | 0.603 | 0.646 | 0.941 | 2.44 | 0.341 | 0.204 | 0.823 | 0.0347 |
| 0.5 dB Chebychev | 0.540 | 0.705 | 0.932 | 2.94 | 0.416 | 0.209 | 1.00 | 0.0290 |
| 1.0 dB Chebychev | 0.492 | 0.785 | 0.925 | 3.56 | 0.508 | 0.206 | 1.23 | 0.0242 |

[1] Specified values are for a −3 dB point of 1.0 Hz. For other frequencies, simply scale the C1 through C4 capacitors directly; that is, for a 3 Hz Bessel response, C1 = 0.0387 µF, C2 = 0.0357 µF, C3 = 0.0533 µF, and C4 = 0.0205 µF.

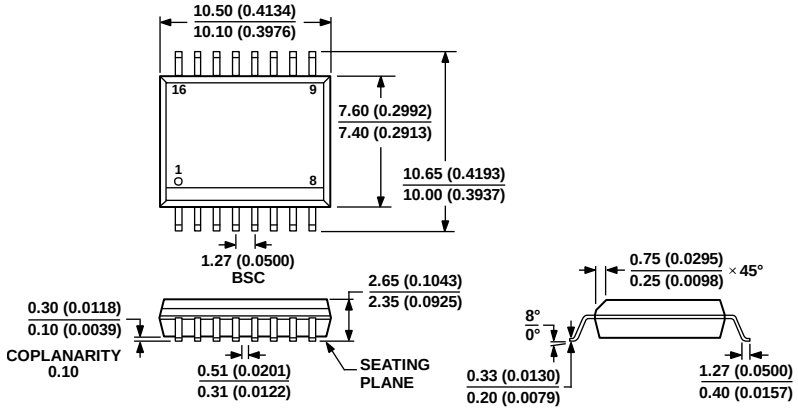
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CORNER LEADS MAY BE CONFIGURED AS WHOLE OR HALF LEADS.

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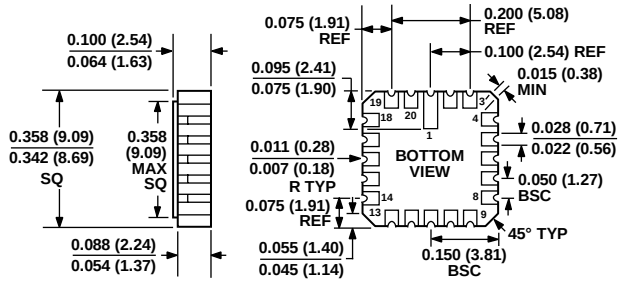
*Figure 37. 14-Lead Plastic Dual In-Line Package [PDIP]*
*Narrow Body (N-14)*
*Dimensions shown in inches and (millimeters)*




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032707-B

*Figure 38. 16-Lead Standard Small Outline Package [SOIC_W]*
*Wide Body (RW-16)*
*Dimensions shown in millimeters and (inches)*




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022106-A

*Figure 39. 20-Terminal Ceramic Leadless Chip Carrier [LCC]*
*(E-20-1)*
*Dimensions shown in inches and (millimeters)*

## ORDERING GUIDE

| Model[1] | Temperature Range | Package Description | Package Option |
|---|---|---|---|
| AD704AR-16 | −40°C to +85°C | 16-Lead SOIC_W | RW -16 |
| AD704AR-16-REEL | −40°C to +85°C | 16-Lead SOIC_W | RW -16 |
| AD704ARZ-16 | −40°C to +85°C | 16-Lead SOIC_W | RW -16 |
| AD704ARZ-16-REEL | −40°C to +85°C | 16-Lead SOIC_W | RW -16 |
| AD704JN | 0°C to 70°C | 14-Lead PDIP | N-14 |
| AD704JNZ | 0°C to 70°C | 14-Lead PDIP | N-14 |
| AD704JR-16 | 0°C to 70°C | 16-Lead SOIC_W | RW -16 |
| AD704JR-16-REEL | 0°C to 70°C | 16-Lead SOIC_W | RW -16 |
| AD704JRZ-16 | 0°C to 70°C | 16-Lead SOIC_W | RW -16 |
| AD704JRZ-16-REEL | 0°C to 70°C | 16-Lead SOIC_W | RW -16 |
| AD704SE/883B | −55°C to +125°C | 20-Terminal LCC | E-20-1 |

[1] Z = RoHS Compliant Part.

## NOTES

## NOTES

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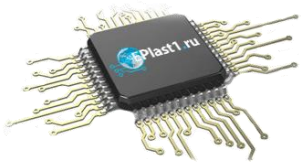
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