



**THE DATASHEET OF  
NCS2004SQ3T2G**



# NCS2004, NCS2004A

## 3.5 MHz, Wide Supply, Rail-to-Rail Output Operational Amplifier

The NCS2004 operational amplifier provides rail-to-rail output operation. The output can swing within 70 mV to the positive rail and 30 mV to the negative rail. This rail-to-rail operation enables the user to make optimal use of the entire supply voltage range while taking advantage of 3.5 MHz bandwidth. The NCS2004 can operate on supply voltage as low as 2.5 V over the temperature range of  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ . The high bandwidth provides a slew rate of  $2.4\text{ V}/\mu\text{s}$  while only consuming a typical  $390\ \mu\text{A}$  of quiescent current. Likewise the NCS2004 can run on a supply voltage as high as 16 V making it ideal for a broad range of battery operated applications. Since this is a CMOS device it has high input impedance and low bias currents making it ideal for interfacing to a wide variety of signal sensors. In addition it comes in either a small SC-88A or UDFN package allowing for use in high density PCB's.

### Features

- Rail-To-Rail Output
- Wide Bandwidth: 3.5 MHz
- High Slew Rate:  $2.4\text{ V}/\mu\text{s}$
- Wide Power Supply Range: 2.5 V to 16 V
- Low Supply Current:  $390\ \mu\text{A}$
- Low Input Bias Current: 45 pA
- Wide Temperature Range:  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$
- Small Packages: 5-Pin SC-88A and UDFN6 1.6x1.6
- These Devices are Pb-Free, Halogen Free/BFR Free and are RoHS Compliant

### Applications

- Notebook Computers
- Portable Instruments



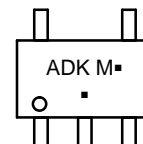
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### MARKING DIAGRAMS



**SC-88A  
(SC-70-5)  
SN SUFFIX  
CASE 419A**



ADK = Specific Device Code

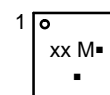
M = Date Code

▪ = Pb-Free Package

(Note: Microdot may be in either location)



**UDFN6  
CASE 517AP**



xx = Specific Device Code

AA for NCS2004

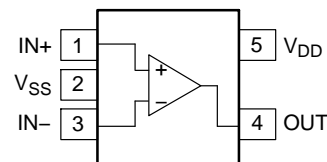
AC for NCS2004A

M = Date Code

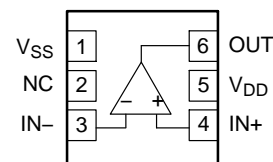
▪ = Pb-Free Package

(Note: Microdot may be in either location)

### PIN CONNECTIONS



SC-88A (Top View)



UDFN6 (Top View)

### ORDERING INFORMATION

Device	Package	Shipping†
NCS2004SQ3T2G	SC-88A (Pb-Free)	3000 / Tape & Reel
NCS2004MUTAG, NCS2004AMUTAG	UDFN6 (Pb-Free)	3000 / Tape & Reel

†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.

# NCS2004, NCS2004A

## MAXIMUM RATINGS

Symbol	Rating	Value	Unit
$V_{DD}$	Supply Voltage	16.5	V
$V_{ID}$	Input Differential Voltage	± Supply Voltage	V
$V_I$	Input Common Mode Voltage Range	-0.2 V to ( $V_{DD} + 0.2$ V)	V
$I_I$	Maximum Input Current	± 10	mA
$I_O$	Output Current Range	± 100	mA
	Continuous Total Power Dissipation (Note 1)	200	mW
$T_J$	Maximum Junction Temperature	150	°C
$\theta_{JA}$	Thermal Resistance	333	°C/W
$T_{stg}$	Operating Temperature Range (free-air)	-40 to 125	°C
$T_{stg}$	Storage Temperature	-65 to 150	°C
	Mounting Temperature (Infrared or Convection – 20 sec)	260	°C
$V_{ESD}$	Machine Model Human Body Model	300 2000	V

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

1. Continuous short circuit operation to ground at elevated ambient temperature can result in exceeding the maximum allowed junction temperature of 150°C. Output currents in excess of 45 mA over long term may adversely affect reliability. Shorting output to either  $V+$  or  $V-$  will adversely affect reliability.

## DC ELECTRICAL CHARACTERISTICS ( $V_{DD} = 2.5$ V, 3.3 V, 5 V and $\pm 5$ V, $T_A = 25^\circ\text{C}$ , $R_L \geq 10$ k $\Omega$ unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Offset Voltage (NCS2004)	$V_{IO}$	$V_{IC} = V_{DD}/2$ , $V_O = V_{DD}/2$ , $R_L = 10$ k $\Omega$ , $R_S = 50$ $\Omega$		0.5	5.0	mV
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			7.0	
Input Offset Voltage (NCS2004A)	$V_{IO}$	$V_{IC} = V_{DD}/2$ , $V_O = V_{DD}/2$ , $R_L = 10$ k $\Omega$ , $R_S = 50$ $\Omega$			3.0	mV
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			5.0	
Offset Voltage Drift	$ICV_{OS}$	$V_{IC} = V_{DD}/2$ , $V_O = V_{DD}/2$ , $R_L = 10$ k $\Omega$ , $R_S = 50$ $\Omega$		2.0		$\mu\text{V}/^\circ\text{C}$
Common Mode Rejection Ratio	CMRR	$0\text{ V} \leq V_{IC} \leq V_{DD} - 1.35\text{ V}$ , $R_S = 50$ $\Omega$	$V_{DD} = 2.5$ V	55	94	dB
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		52	
		$0\text{ V} \leq V_{IC} \leq V_{DD} - 1.35\text{ V}$ , $R_S = 50$ $\Omega$	$V_{DD} = 5$ V	65	130	
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		62	
		$0\text{ V} \leq V_{IC} \leq V_{DD} - 1.35\text{ V}$ , $R_S = 50$ $\Omega$	$V_{DD} = \pm 5$ V	69	140	
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		66	
Power Supply Rejection Ratio	PSRR	$V_{DD} = 2.5$ V to 16 V, $V_{IC} = V_{DD}/2$ , No Load		70	135	dB
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		65		
Large Signal Voltage Gain	$A_{VD}$	$V_{O(pp)} = V_{DD}/2$ , $R_L = 10$ k $\Omega$	$V_{DD} = 2.5$ V	90	130	dB
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		76	
		$V_{O(pp)} = V_{DD}/2$ , $R_L = 10$ k $\Omega$	$V_{DD} = 3.3$ V	92	123	
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		76	
		$V_{O(pp)} = V_{DD}/2$ , $R_L = 10$ k $\Omega$	$V_{DD} = 5$ V	95	127	
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		86	
		$V_{O(pp)} = V_{DD}/2$ , $R_L = 10$ k $\Omega$	$V_{DD} = \pm 5$ V	95	130	
			$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		90	

# NCS2004, NCS2004A

**DC ELECTRICAL CHARACTERISTICS** ( $V_{DD} = 2.5\text{ V}, 3.3\text{ V}, 5\text{ V}$  and  $\pm 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $R_L \geq 10\text{ k}\Omega$  unless otherwise noted)

Parameter	Symbol	Conditions		Min	Typ	Max	Unit
Input Bias Current	$I_B$	$V_{DD} = 5\text{ V}, V_{IC} = V_{DD}/2, V_O = V_{DD}/2,$ $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$		45	150	pA
			$T_A = 125^\circ\text{C}$			1000	
Input Offset Current	$I_{IO}$	$V_{DD} = 5\text{ V}, V_{IC} = V_{DD}/2, V_O = V_{DD}/2,$ $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$		45	150	pA
			$T_A = 125^\circ\text{C}$			1000	
Differential Input Resistance	$r_{i(d)}$				1000		G $\Omega$
Common-mode Input Capacitance	$C_{IC}$	$f = 21\text{ kHz}$			8.0		pF
Output Swing (High-level)	$V_{OH}$	$V_{IC} = V_{DD}/2, I_{OH} = -1\text{ mA}$	$V_{DD} = 2.5\text{ V}$	2.35	2.43		V
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		2.28			
		$V_{IC} = V_{DD}/2, I_{OH} = -1\text{ mA}$	$V_{DD} = 3.3\text{ V}$	3.15	3.21		
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		3.00			
		$V_{IC} = V_{DD}/2, I_{OH} = -1\text{ mA}$	$V_{DD} = 5\text{ V}$	4.8	4.93		
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		4.75			
		$V_{IC} = V_{DD}/2, I_{OH} = -1\text{ mA}$	$V_{DD} = \pm 5\text{ V}$	4.92	4.96		
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		4.9			
		$V_{IC} = V_{DD}/2, I_{OH} = -5\text{ mA}$	$V_{DD} = 2.5\text{ V}$	1.7	2.14		
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		1.5			
		$V_{IC} = V_{DD}/2, I_{OH} = -5\text{ mA}$	$V_{DD} = 3.3\text{ V}$	2.5	2.89		
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		2.1			
		$V_{IC} = V_{DD}/2, I_{OH} = -5\text{ mA}$	$V_{DD} = 5\text{ V}$	4.5	4.68		
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		4.35			
		$V_{IC} = V_{DD}/2, I_{OH} = -5\text{ mA}$	$V_{DD} = \pm 5\text{ V}$	4.7	4.78		
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		4.65			
Output Swing (Low-level)	$V_{OL}$	$V_{IC} = V_{DD}/2, I_{OL} = -1\text{ mA}$	$V_{DD} = 2.5\text{ V}$		0.03	0.15	V
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				0.22	
		$V_{IC} = V_{DD}/2, I_{OL} = -1\text{ mA}$	$V_{DD} = 3.3\text{ V}$		0.03	0.15	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				0.22	
		$V_{IC} = V_{DD}/2, I_{OL} = -1\text{ mA}$	$V_{DD} = 5\text{ V}$		0.03	0.1	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				0.15	
		$V_{IC} = V_{DD}/2, I_{OL} = -1\text{ mA}$	$V_{DD} = \pm 5\text{ V}$		0.05	0.08	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				0.1	
		$V_{IC} = V_{DD}/2, I_{OL} = -5\text{ mA}$	$V_{DD} = 2.5\text{ V}$		0.15	0.7	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				1.1	
		$V_{IC} = V_{DD}/2, I_{OL} = -5\text{ mA}$	$V_{DD} = 3.3\text{ V}$		0.13	0.7	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				1.1	
		$V_{IC} = V_{DD}/2, I_{OL} = -5\text{ mA}$	$V_{DD} = 5\text{ V}$		0.13	0.4	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				0.5	
		$V_{IC} = V_{DD}/2, I_{OL} = -5\text{ mA}$	$V_{DD} = \pm 5\text{ V}$		0.16	0.3	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$				0.35	

# NCS2004, NCS2004A

## DC ELECTRICAL CHARACTERISTICS ( $V_{DD} = 2.5\text{ V}, 3.3\text{ V}, 5\text{ V}$ and $\pm 5\text{ V}$ , $T_A = 25^\circ\text{C}$ , $R_L \geq 10\text{ k}\Omega$ unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit	
Output Current	$I_O$	$V_O = 0.5\text{ V}$ from rail, $V_{DD} = 2.5\text{ V}$	Positive rail		4.0		mA
			Negative rail		5.0		
		$V_O = 0.5\text{ V}$ from rail, $V_{DD} = 5\text{ V}$	Positive rail		7.0		
			Negative rail		8.0		
		$V_O = 0.5\text{ V}$ from rail, $V_{DD} = 10\text{ V}$	Positive rail		13		
			Negative rail		12		
Power Supply Quiescent Current	$I_{DD}$	$V_O = V_{DD}/2$	$V_{DD} = 2.5\text{ V}$		380	560	$\mu\text{A}$
			$V_{DD} = 3.3\text{ V}$		385	620	
			$V_{DD} = 5\text{ V}$		390	660	
			$V_{DD} = 10\text{ V}$		400	800	
		$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$			1000		

## AC ELECTRICAL CHARACTERISTICS ( $V_{DD} = 2.5\text{ V}, 5\text{ V}$ , & $\pm 5\text{ V}$ , $T_A = 25^\circ\text{C}$ , and $R_L \geq 10\text{ k}\Omega$ unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit	
Unity Gain Bandwidth	UGBW	$R_L = 2\text{ k}\Omega$ , $C_L = 10\text{ pF}$	$V_{DD} = 2.5\text{ V}$		3.2		MHz
			$V_{DD} = 5\text{ V}$ to $10\text{ V}$		3.5		
Slew Rate at Unity Gain	SR	$V_{O(pp)} = V_{DD}/2$ , $R_L = 10\text{ k}\Omega$ , $C_L = 50\text{ pF}$	$V_{DD} = 2.5\text{ V}$		1.35	2.0	V/ $\mu\text{S}$
				$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		1	
		$V_{O(pp)} = V_{DD}/2$ , $R_L = 10\text{ k}\Omega$ , $C_L = 50\text{ pF}$	$V_{DD} = 5\text{ V}$		1.45	2.3	
				$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		1.2	
		$V_{O(pp)} = V_{DD}/2$ , $R_L = 10\text{ k}\Omega$ , $C_L = 50\text{ pF}$	$V_{DD} = \pm 5\text{ V}$		1.8	2.6	
$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$		1.3					
Phase Margin	$\theta_m$	$R_L = 2\text{ k}\Omega$ , $C_L = 10\text{ pF}$		45		$^\circ$	
Gain Margin		$R_L = 2\text{ k}\Omega$ , $C_L = 10\text{ pF}$		14		dB	
Settling Time to 0.1%	$t_S$	$V\text{-step}(pp) = 1\text{ V}$ , $AV = -1$ , $R_L = 2\text{ k}\Omega$ , $C_L = 10\text{ pF}$	$V_{DD} = 2.5\text{ V}$		2.9		$\mu\text{S}$
		$V\text{-step}(pp) = 1\text{ V}$ , $AV = -1$ , $R_L = 2\text{ k}\Omega$ , $C_L = 68\text{ pF}$	$V_{DD} = 5\text{ V}$ , $\pm 5\text{ V}$		2.0		
Total Harmonic Distortion plus Noise	THD+N	$V_{DD} = 2.5\text{ V}$ , $V_{O(pp)} = V_{DD}/2$ , $R_L = 2\text{ k}\Omega$ , $f = 10\text{ kHz}$	$AV = 1$		0.004		%
			$AV = 10$		0.04		
			$AV = 100$		0.3		
		$V_{DD} = 5\text{ V}$ , $\pm 5\text{ V}$ , $V_{O(pp)} = V_{DD}/2$ , $R_L = 2\text{ k}\Omega$ , $f = 10\text{ kHz}$	$AV = 1$		0.004		
			$AV = 10$		0.04		
			$AV = 100$		0.03		
Input-Referred Voltage Noise	$e_n$	$f = 1\text{ kHz}$		30		nV/ $\sqrt{\text{Hz}}$	
		$f = 10\text{ kHz}$		20			
Input-Referred Current Noise	$i_n$	$f = 1\text{ kHz}$		0.6		fA/ $\sqrt{\text{Hz}}$	

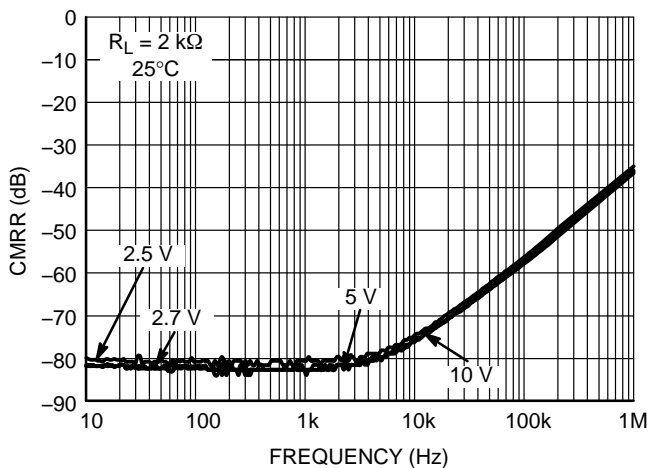


Figure 1. CMRR vs. Frequency

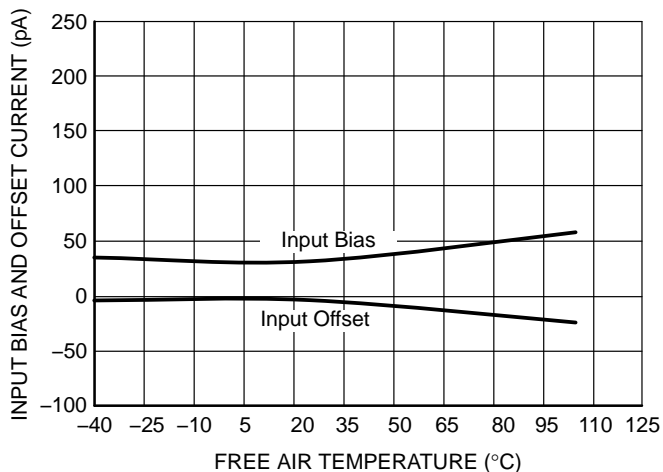


Figure 2. Input Bias and Offset Current vs. Temperature

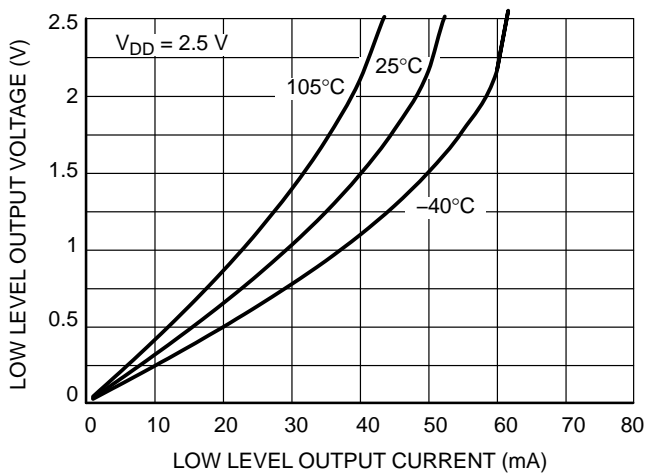


Figure 3. 2.5 V  $V_{OL}$  vs.  $I_{out}$

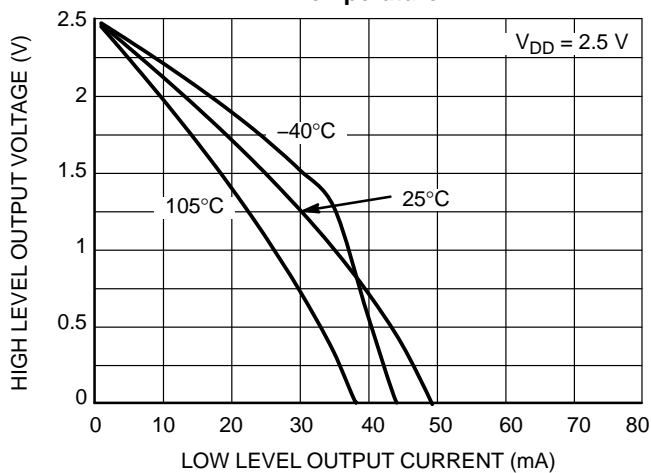


Figure 4. 2.5 V  $V_{OH}$  vs.  $I_{out}$

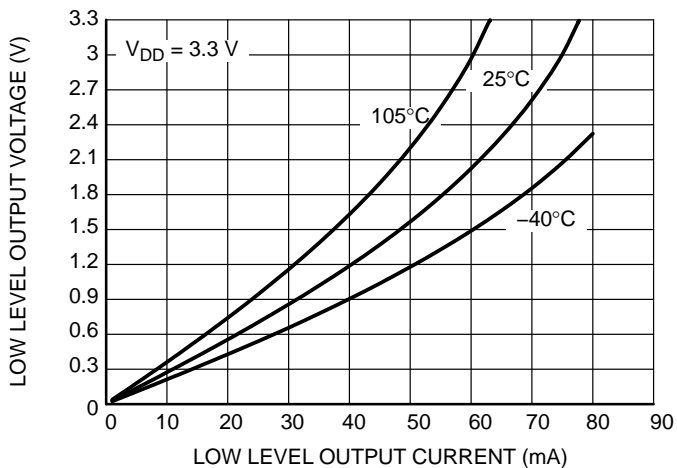


Figure 5. 3.3 V  $V_{OL}$  vs.  $I_{out}$

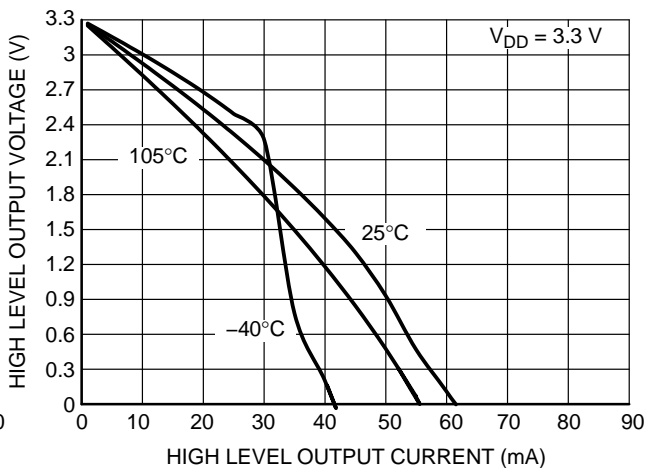


Figure 6. 3.3 V  $V_{OH}$  vs.  $I_{out}$

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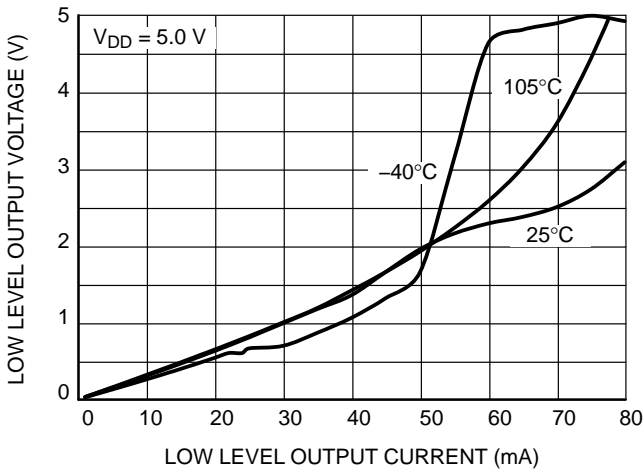


Figure 7.  $V_{OL}$  vs.  $I_{out}$

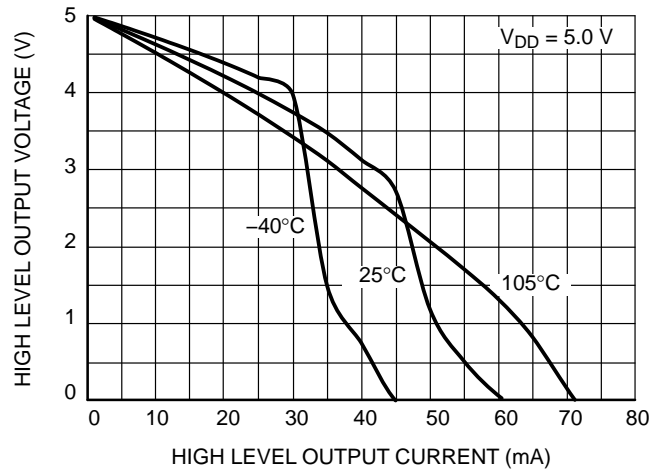


Figure 8.  $V_{OH}$  vs.  $I_{out}$

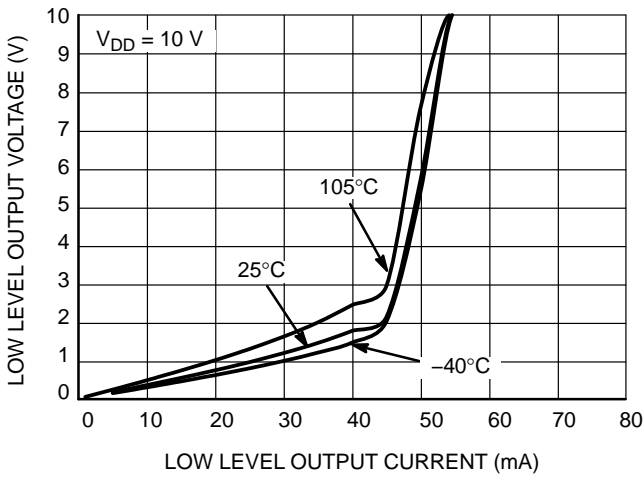


Figure 9. 10 V  $V_{OL}$  vs.  $I_{out}$

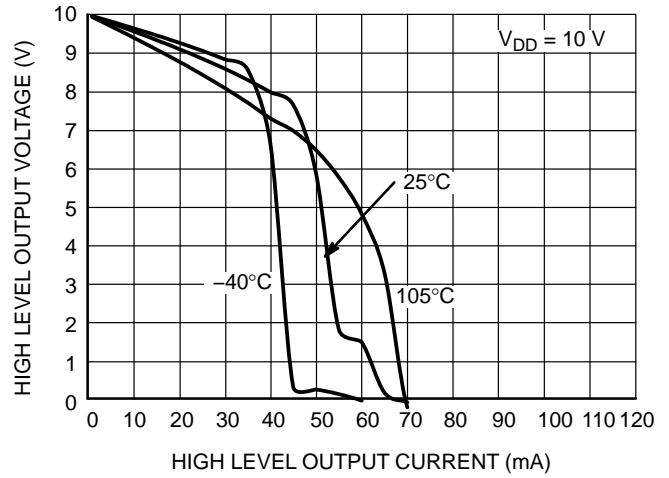


Figure 10. 10 V  $V_{OH}$  vs.  $I_{out}$

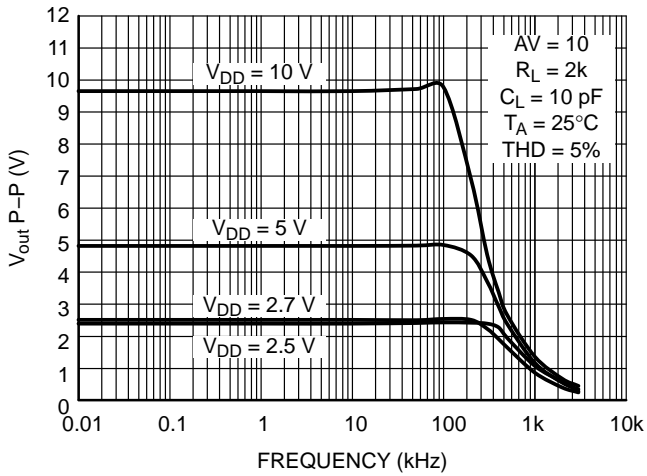


Figure 11. Peak-to-Peak Output vs. Supply vs. Frequency

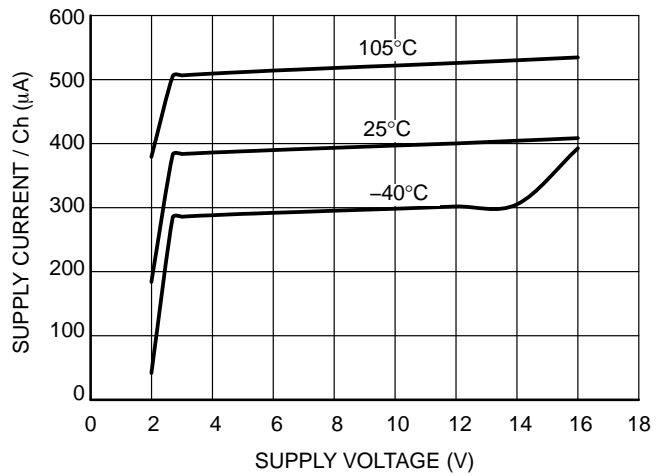


Figure 12. Supply Current vs. Supply Voltage

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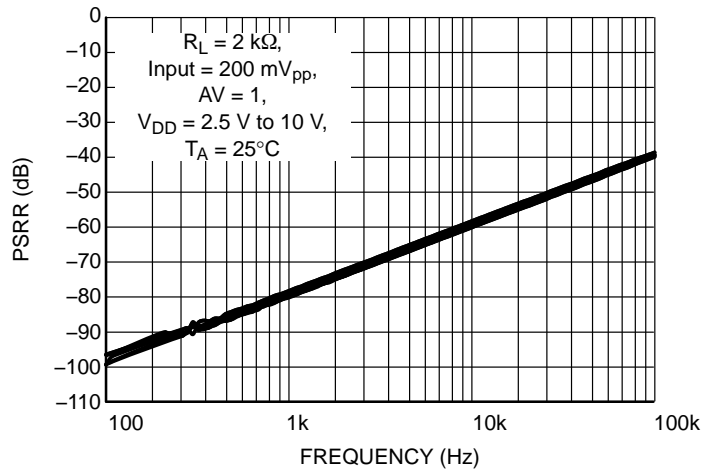


Figure 13. PSRR vs. Frequency

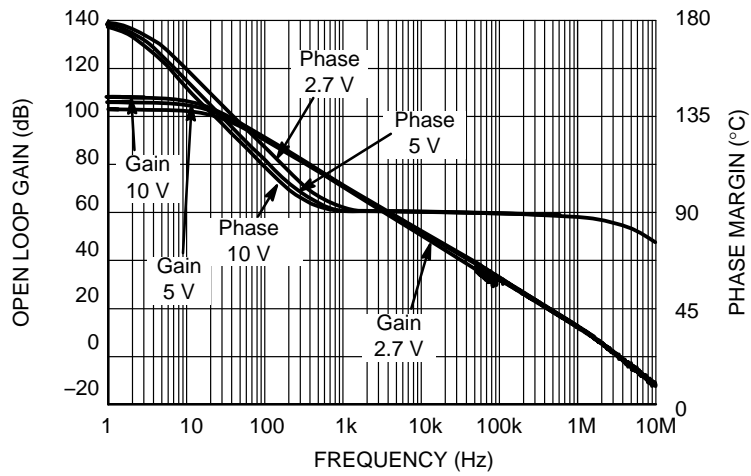


Figure 14. Open Loop Gain and Phase vs. Frequency

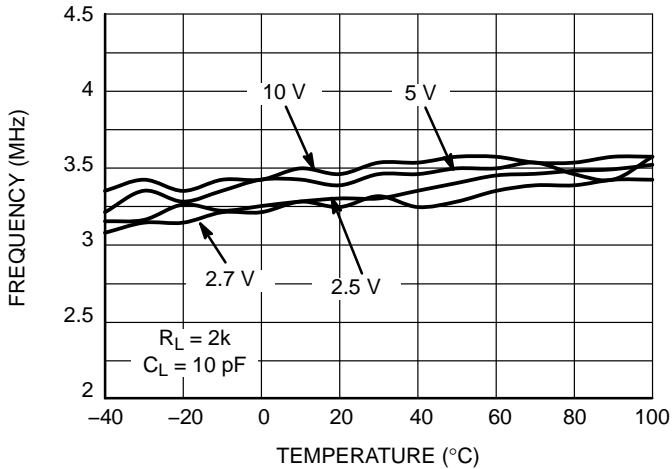


Figure 15. Gain Bandwidth Product vs. Temperature

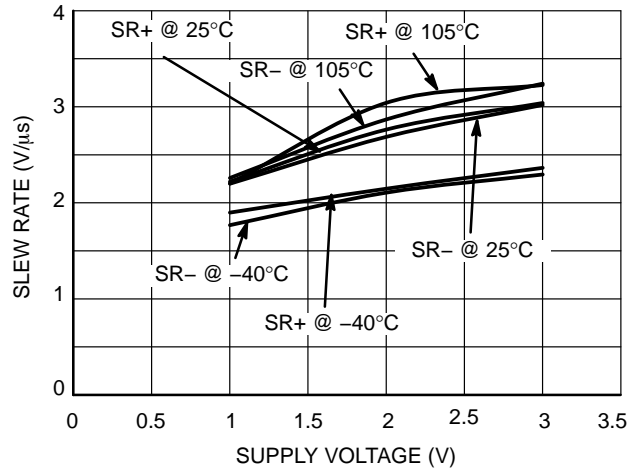


Figure 16. Slew Rate vs. Supply Voltage

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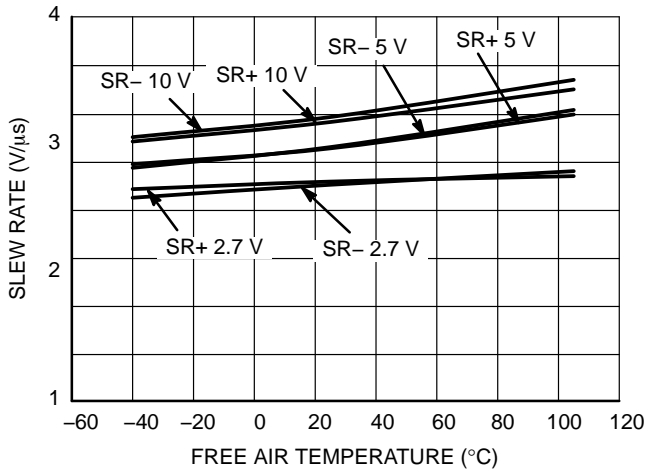


Figure 17. Slew Rate vs. Temperature

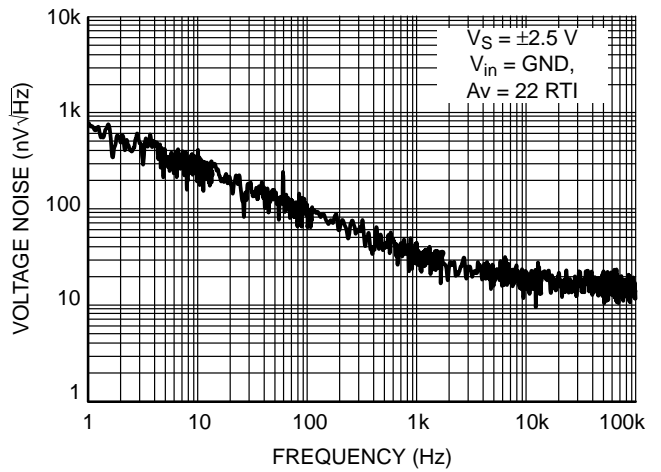


Figure 18. Voltage Noise vs. Frequency

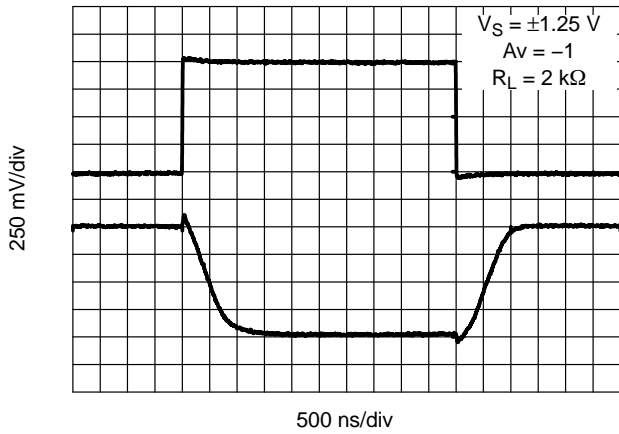


Figure 19. 2.5 V Inverting Large Signal Pulse Response

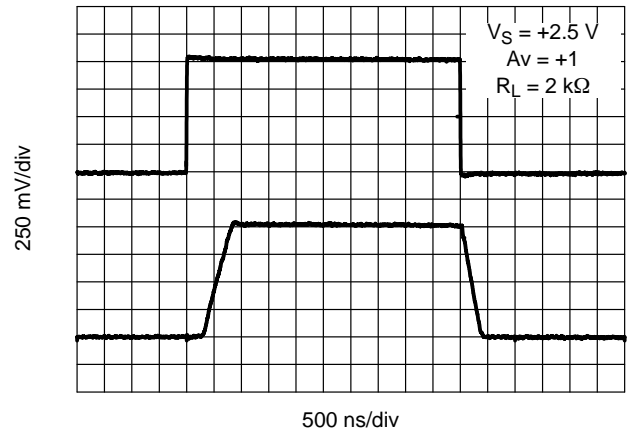


Figure 20. 2.5 V Non-Inverting Large Signal Pulse Response

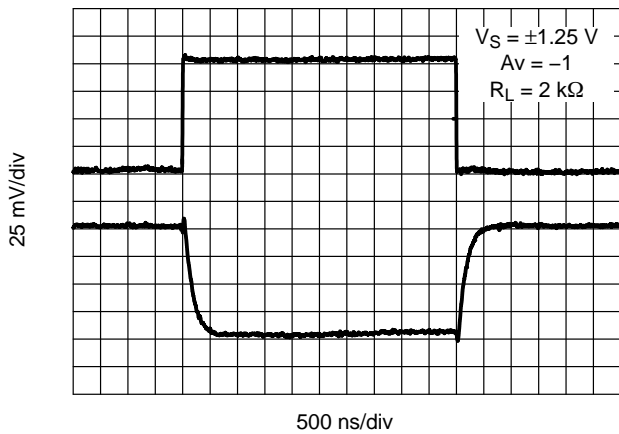


Figure 21. 2.5 V Inverting Small Signal Pulse Response

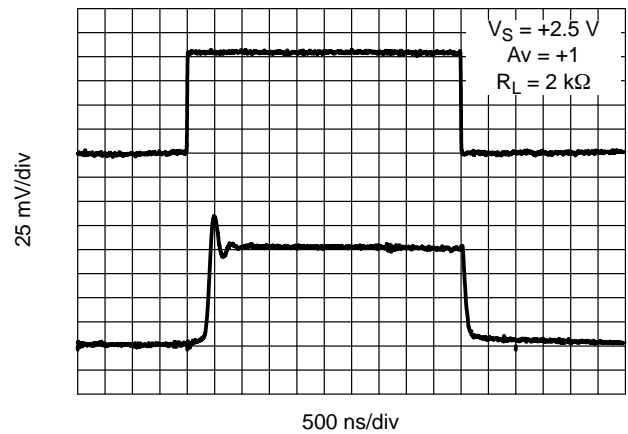
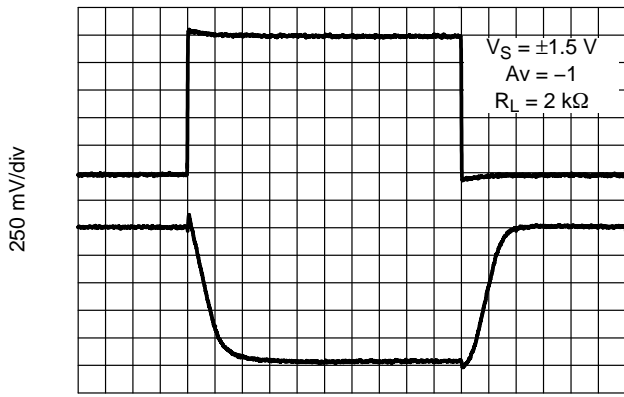


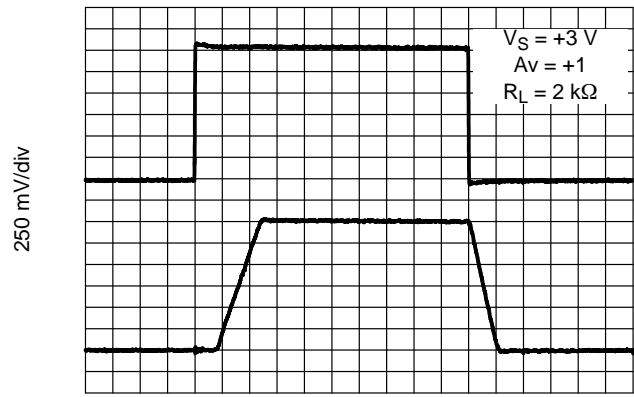
Figure 22. 2.5 V Non-Inverting Small Signal Pulse Response

# NCS2004, NCS2004A



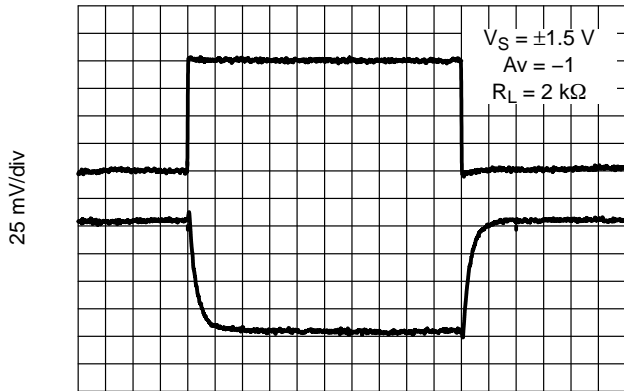
500 ns/div

**Figure 23. 3 V Inverting Large Signal Pulse Response**



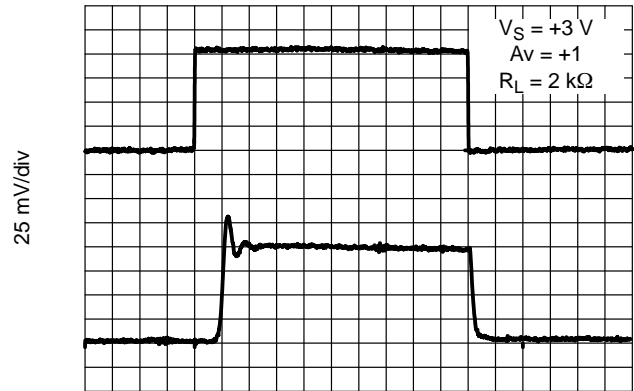
500 ns/div

**Figure 24. 3 V Non-Inverting Large Signal Pulse Response**



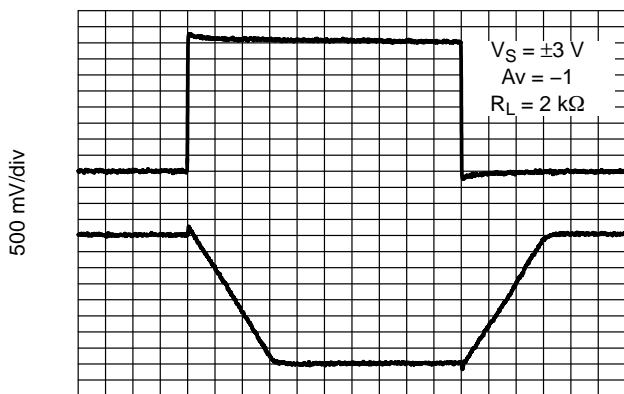
500 ns/div

**Figure 25. 3 V Inverting Small Signal Pulse Response**



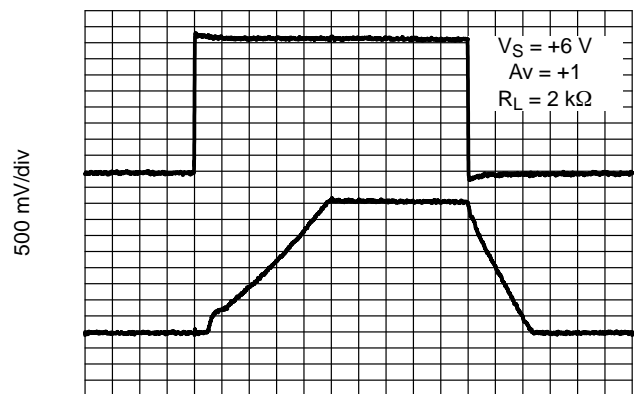
500 ns/div

**Figure 26. 3 V Non-Inverting Small Signal Pulse Response**



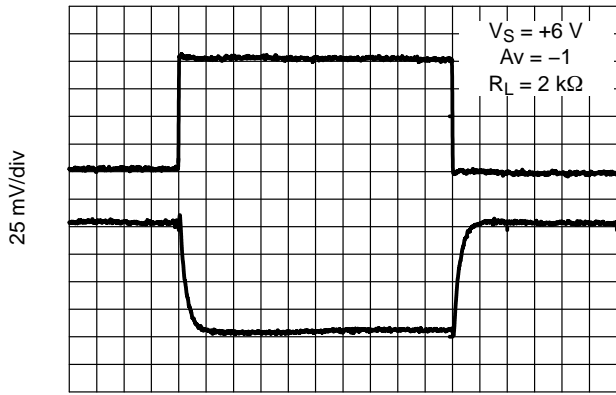
500 ns/div

**Figure 27. 6 V Inverting Large Signal Pulse Response**

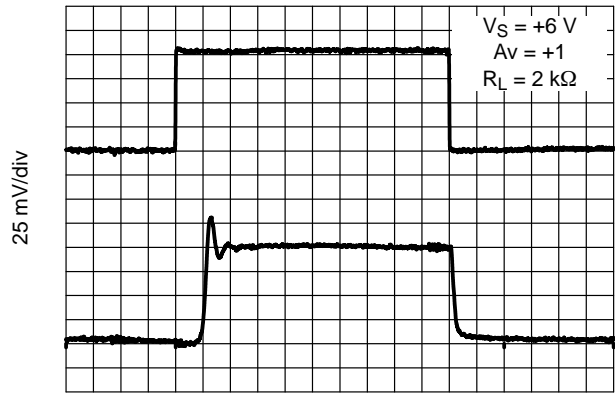


500 ns/div

**Figure 28. 6 V Non-Inverting Large Signal Pulse Response**



**Figure 29. 6 V Inverting Small Signal Pulse Response**



**Figure 30. 6 V Non-Inverting Small Signal Pulse Response**

APPLICATIONS

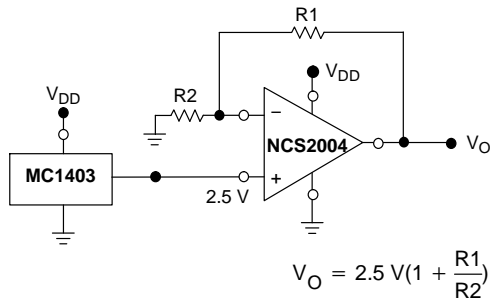


Figure 31. Voltage Reference

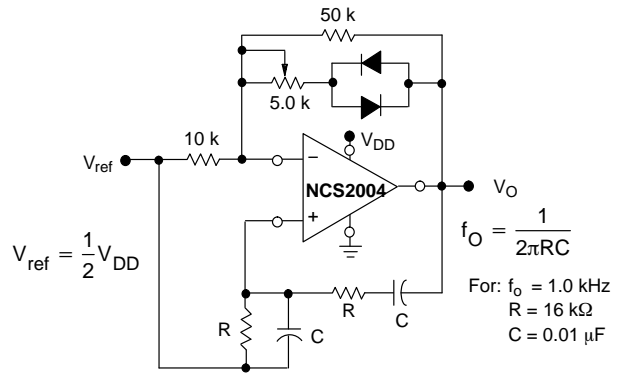


Figure 32. Wien Bridge Oscillator

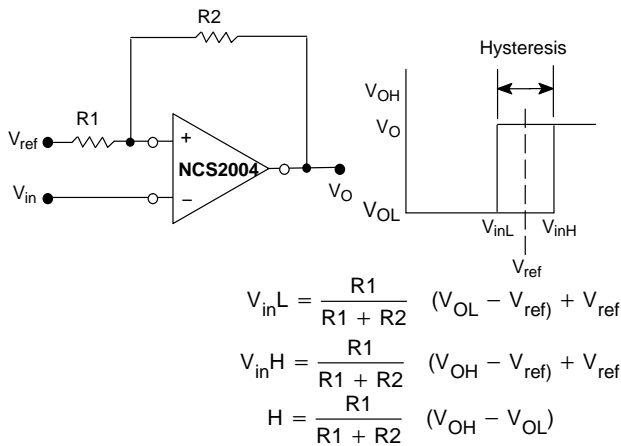
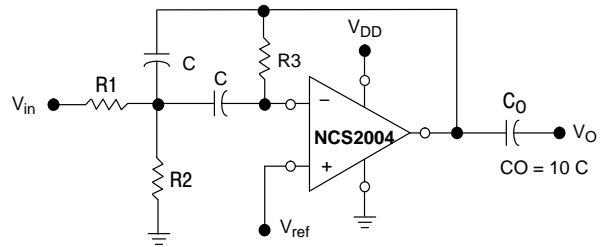


Figure 33. Comparator with Hysteresis



Given:  $f_o$  = center frequency  
 $A(f_o)$  = gain at center frequency

Choose value  $f_o, C$   
 Then:  $R_3 = \frac{Q}{\pi f_o C}$

$$R_1 = \frac{R_3}{2 A(f_o)}$$

$$R_2 = \frac{R_1 R_3}{4Q^2 R_1 - R_3}$$

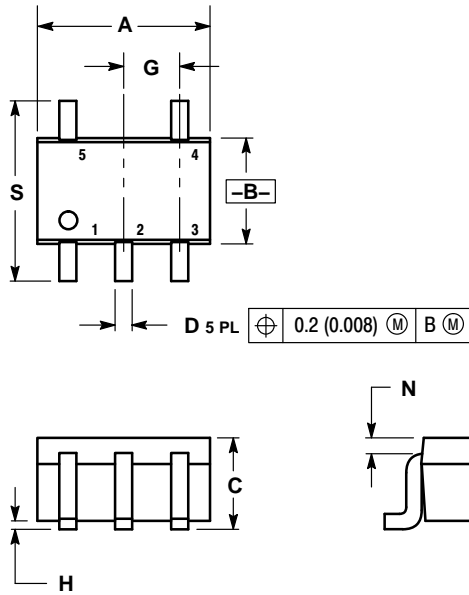
For less than 10% error from operational amplifier,  
 $((Q_o f_o)/BW) < 0.1$  where  $f_o$  and  $BW$  are expressed in Hz.  
 If source impedance varies, filter may be preceded with  
 voltage follower buffer to stabilize filter parameters.

Figure 34. Multiple Feedback Bandpass Filter

# NCS2004, NCS2004A

## PACKAGE DIMENSIONS

SC-88A (SC-70-5/SOT-353)  
CASE 419A-02  
ISSUE L

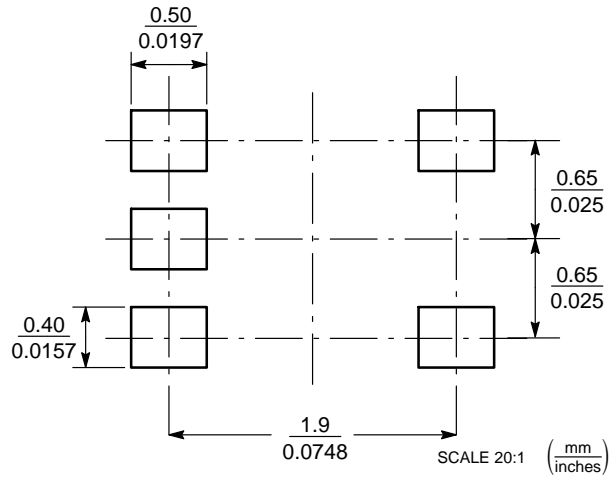


NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. 419A-01 OBSOLETE. NEW STANDARD 419A-02.
4. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH, PROTRUSIONS, OR GATE BURRS.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.071	0.087	1.80	2.20
B	0.045	0.053	1.15	1.35
C	0.031	0.043	0.80	1.10
D	0.004	0.012	0.10	0.30
G	0.026 BSC		0.65 BSC	
H	---	0.004	---	0.10
J	0.004	0.010	0.10	0.25
K	0.004	0.012	0.10	0.30
N	0.008 REF		0.20 REF	
S	0.079	0.087	2.00	2.20

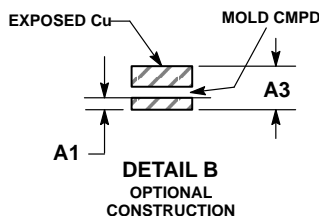
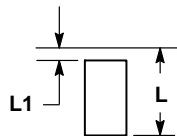
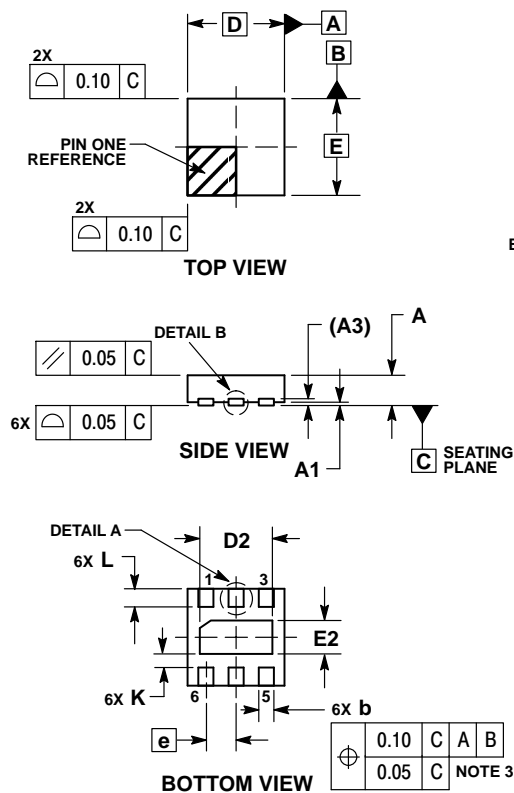
### SOLDER FOOTPRINT



# NCS2004, NCS2004A

## PACKAGE DIMENSIONS

### UDFN6 1.6x1.6, 0.5P CASE 517AP ISSUE O

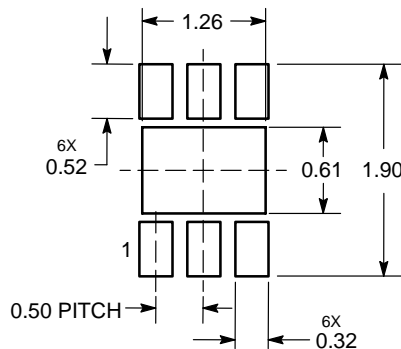


**NOTES:**

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.15 AND 0.30 mm FROM TERMINAL.
4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.

MILLIMETERS		
DIM	MIN	MAX
A	0.45	0.55
A1	0.00	0.05
A3	0.13	REF
b	0.20	0.30
D	1.60	BSC
E	1.60	BSC
e	0.50	BSC
D2	1.10	1.30
E2	0.45	0.65
K	0.20	---
L	0.20	0.40
L1	0.00	0.15

### SOLDERMASK DEFINED MOUNTING 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.

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