NL6000/NL6002/NL6004

Precision, Low Power, Rail-to-Rail Input/Output, High EMC performance Operational Amplifier

FEATURES

(V^+ = 3.3V, V^- = 0V, Typical value)

Low Input Offset Voltage	150μV max.
Low Input Offset Voltage Drift	0.9μV/°C max.
Operating Voltage	1.6V to 5.5V
Rail-to-Rail Input / Output	
Internal EMI filter	EMIRR = 96 dB at f = 1.8GHz
Low Supply Current	15μA/ch
Low Input Bias Current	1pA
CMOS Architecture	
Operating Temperature Range	-40°C to 125°C
Package	SOT-23-5-DC EMP-8-AN, VSP-8-AF, DFN3030-8-GF SSOP-14-BC

APPLICATIONS

Battery-Powered Equipment
Various Sensor Amplifiers
  Strain Gage, Thermopile, Flow, etc.
Photodiode Amplifier

GENERAL DESCRIPTION

NL6000(U.D.*)/NL6002/NL6004(U.D.*) is a high precision Rail-to-Rail Input/Output Single/Dual/Quad CMOS operational amplifier featuring a low supply current of 15μA typ., low input offset voltage of 150μV max., low temperature drift of 0.9μV/°C max. and low bias current of 1pA typ.

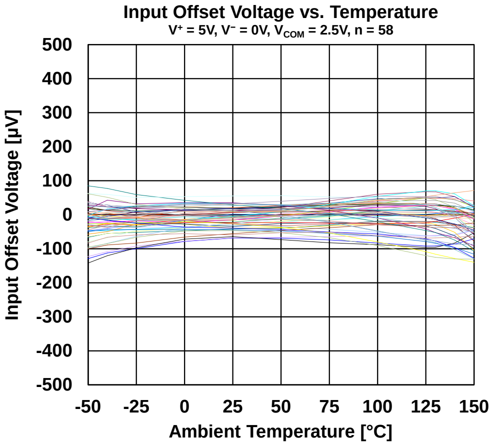
The NL600x series also has a high EMI noise immunity which can reduce malfunctions caused by RF noises from mobile phones and others.

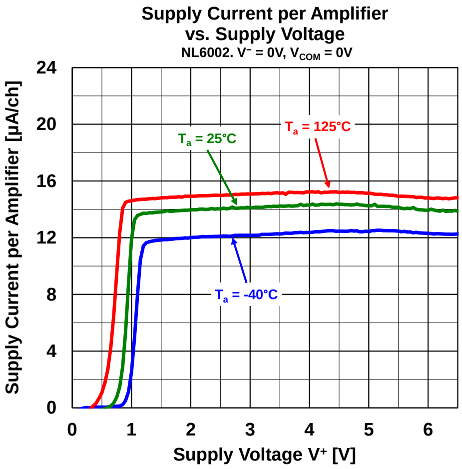
The combination of these specifications makes the NL600x series well-suited for sensor applications such as a temperature sensor, weight sensor and others, high precision current sensing amplifiers and current voltage converters.

*Preliminary specifications subject to change.

Precison Opamp Lineup

Description	Single	Dual	Quad
10μV, 0.05μV/°C, Zero-Drift	NL6010, NL6011	NL6012	
150μV, 5μV/°C, 10nV/√Hz	NJU7076	NJU7077	NJU7078
15μV, 0.05μV/°C, 10V, Zero-Drift	NJU7098AF1C		





■ PRODUCT NAME INFORMATION

NL600x aa A bb D

Description of configuration

Composition	Item	Description
x	Number of circuits	Indicates number of circuits. 0: 1ch 2: 2ch 4: 4ch
aa	Package code	Indicates the package. DC: SOT-23-5-DC AN: EMP-8-AN AF: VSP-8-AF GF: DFN3030-8-GF BC: SSOP-14-BC
A	Version	Product Version. Default is A.
bb	Packing	Refer to the packing specifications.
D	Grade	Indicates the quality grade. D: Industrial

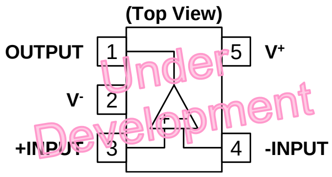
Grade

	Applications	Operating Temperature Range	Test Temperature
D	Indμstrial equipment and Social infrastructures	-40°C to 125°C	-40°C, 25°C, 125°C

■ ORDER INFORMATION

Product Name	Package	RoHS	Halogen-Free	Terminal Finish	Weight (mg)	Quantity (pcs/reel)
NL6000DCAE1D	SOT-23-5-DC	✓	✓	Sn2Bi	15	3000
NL6002ANAE2D	EMP-8-AN	✓	✓	Sn2Bi	76	2000
NL6002AFAE2D	VSP-8-AF	✓	✓	Sn2Bi	21	2000
NL6002GFAE4D	DFN3030-8-GF	✓	✓	Sn2Bi	18	1500
NL6004BCAE2D	SSOP-14-BC	✓	✓	Sn2Bi	65	2000

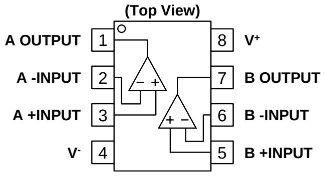
■ PIN DESCRIPTION (NL6000)



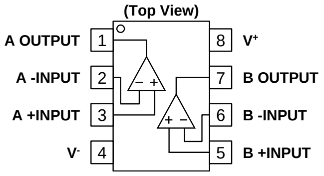
SOT-23-5-DC

Pin No.	Symbol	I/O	Description
1	OUTPUT	O	Output channel
2	V^-	-	Negative supply or GND (single supply)
3	+INPUT	I	Non-inverting input channel
4	−INPUT	I	Inverting input channel
5	V^+	-	Positive supply

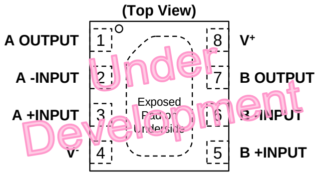
■ PIN DESCRIPTIONS (NL6002)



EMP-8-AN



VSP-8-AF

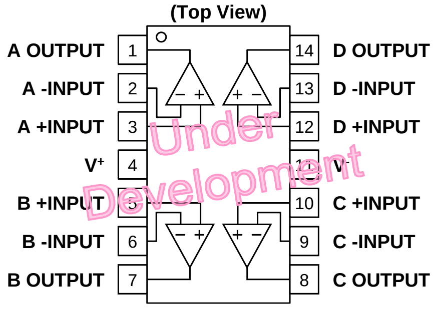


DFN3030-8-GF

Pin No.	Symbol	I/O	Description
1	A OUTPUT	O	Output channel A
2	A −INPUT	I	Inverting input channel A
3	A +INPUT	I	Non-inverting input channel A
4	V^-	-	Negative supply or GND (single supply)
5	B +INPUT	I	Non-inverting input channel B
6	B −INPUT	I	Inverting input channel B
7	B OUTPUT	O	Output channel B
8	V^+	-	Positive supply

*Connect exposed pad to V^-

■ PIN DESCRIPTION (NL6004)



SSOP-14-BC

Pin No.	Symbol	I/O	Description
1	A OUTPUT	O	Output channel A
2	A −INPUT	I	Inverting input channel A
3	A +INPUT	I	Non-inverting input channel A
4	V^+	-	Positive supply
5	B +INPUT	I	Non-inverting input channel B
6	B −INPUT	I	Inverting input channel B
7	B OUTPUT	O	Output channel B
8	C OUTPUT	O	Output channel C
9	C −INPUT	I	Inverting input channel C
10	C +INPUT	I	Non-inverting input channel C
11	V^-	-	Negative supply or GND (single supply)
12	D +INPUT	I	Non-inverting input channel D
13	D −INPUT	I	Inverting input channel D
14	D OUTPUT	O	Output channel D

■ ABSOLUTE MAXIMUM RATINGS

	Symbol	Rating	Unit
Supply Voltage $V_S = V^+ - V^-$	$V^+ - V^-$	6.5	V
Input Voltage[*1]	V_{IN}	V^- - 0.3 to V^+ + 0.3	V
Input Current[*1]	I_{IN}	-10	mA
Output Terminal Input Voltage[*2]	V_O	V^- - 0.3 to V^+ + 0.3	V
Differential Input Voltage[*3]	V_{ID}	±6.5	V
Output Short-Circuit Duration[*4]		Continuous	
Storage Temperature Range	T_{stg}	-55 to 150	°C
Junction Temperature [*5]	T_j	150	°C

[*1] Input voltages below the negative supply voltage will be clamped by ESD protection diodes. If the input voltage lower than V^- - 0.3V, the input current must be limited 10 mA or less by using a restriction resistance. Input current outflow is negative.

[*2] The output terminal input voltage is limited at 6.5V.

[*3] Differential voltage is the voltage difference between +INPUT and −INPUT.

[*4] Power loss increases when output is short-circuited; do not exceed T_j.

[*5] Calculate the power consumption of the IC from the operating conditions, and calculate the junction temperature with the thermal resistance.
Please refer to "Thermal characteristics" for the thermal resistance under our measurement board conditions.

ABSOLUTE MAXIMUM RATINGS
Electronic and mechanical stress momentarily exceeded absolute maximum ratings may cause permanent damage and may degrade the lifetime and safety for both device and system using the device in the field. The functional operation at or over these absolute maximum ratings is not assured.

■ THERMAL CHARACTERISTICS

Package	Measurement Result [*1]		Unit
	Thermal Resistance (Θja)	Thermal Characterization Parameter (ψjt)	
SOT-23-5-DC	192	58	°C/W
EMP-8-AN	125	27	
VSP-8-AF	189	53	
DFN3030-8-GF [*2]	69	18	
SSOP-14-BC	202	52	

θja: Junction-to-Ambient Thermal Resistance
ψjt: Junction-to-Top Thermal Characterization Parameter

[*1] Mounted on glass epoxy board (76.2 mm × 114.3 mm × 1.6 mm: based on EIA/JEDEC standard, 4-layer FR-4), internal Cu area: 74.2 mm × 74.2 mm.

[*2] Mounted on glass epoxy board (101.5 mm × 114.5 mm × 1.6 mm: based on EIA/JEDEC standard, 4-layer FR-4) with exposed pad. (For 4-layer, applying 99.5 mm × 99.5 mm inner Cu area and a thermal via hole to a board based on JEDEC standard JESD51-5.)

■ ELECTROSTATIC DISCHARGE (ESD) PROTECTION VOLTAGE

	Conditions	Protection Voltage
HBM	C = 100 pF, R = 1.5 kΩ	±2000V
CDM		±1000V

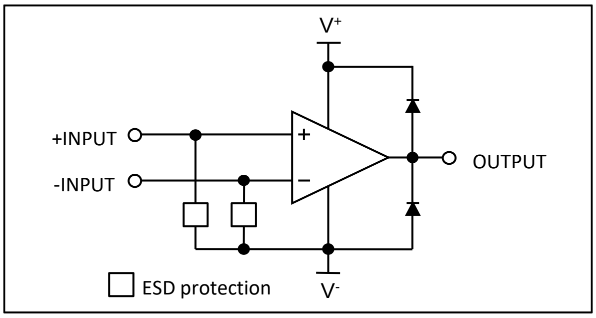
ELECTROSTATIC DISCHARGE RATINGS
The electrostatic discharge test is done based on JEDEC JS001, JS002. In the HBM method, ESD is applied using the power supply pin and GND pin as reference pins.

■ RECOMMENDED OPERATING CONDITIONS

	Symbol	Rating	Unit
Supply Voltage	$V^+ - V^-$	1.6 to 5.5	V
Operating Temperature Range	T_a	-40 to 125	°C

RECOMMENDED OPERATING CONDITIONS
All of electronic equipment should be designed that the mounted semiconductor devices operate within the recommended operating conditions. The semiconductor devices cannot operate normally over the recommended operating conditions, even if they are used over such conditions by momentary electronic noise or surge. And the semiconductor devices may receive serious damage when they continue to operate over the recommended operating conditions.

■ BLOCK DIAGRAM



■ ELECTRICAL CHARACTERISTICS (NL6002)

$V^+ = 5V, 3.3V, 1.8V, V^- = 0V, V_{COM} = V^+/2, R_L = 100k\Omega$ to $V^+/2$, $T_a = 25°C$, unless otherwise specified.

Parameter	Symbol	Conditions	MIN	TYP	MAX	Unit
INPUT CHARACTERISTICS *1						
Input Offset Voltage	V_{IO}	$V^+ = 5V$	-	10	200	μV
		$V^+ = 5V$, $T_a = -40°C$ to $125°C$	-	-	450	μV
		$V^+ = 3.3V$	-	10	150	μV
		$V^+ = 3.3V$, $T_a = -40°C$ to $125°C$	-	-	400	μV
		$V^+ = 1.8V$, $V_{COM} = 0V$	-	10	250	μV
		$V^+ = 1.8V$, $V_{COM} = 0V$, $T_a = -40°C$ to $125°C$	-	-	500	μV
Input Bias Current	I_B		-	1	-	pA
Input Offset Current	I_{IO}		-	1	-	pA
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	$V^+ = 5V, 3.3V$, $T_a = -40°C$ to $125°C$	-	0.3	0.9	μV/°C
		$V^+ = 1.8V$, $V_{COM} = 0V$, $T_a = -40°C$ to $125°C$	-	0.3	0.9	μV/°C
Input Resistance	R_{IC}		-	1000	-	GΩ
Input Capacitance	C_{IN}		-	10	-	pF
Open-Loop Voltage Gain	A_V	$V^+ = 5V$, $V_{COM} = 0V$, $V_O = 0.1V$ to $4.9V$	100	113	-	dB
		$V^+ = 3.3V$, $V_{COM} = 0V$, $V_O = 0.1V$ to $3.2V$	100	112	-	dB
		$V^+ = 1.8V$, $V_{COM} = 0V$, $V_O = 0.1V$ to $1.7V$	98	110	-	dB
Common-Mode Rejection Ratio	CMR	$V^+ = 5V, 3.3V$, $V_{COM} = V^- - 0.2V$ to $V^+ - 1.1V$	70	100	-	dB
		$V^+ = 5V, 3.3V$, $V_{COM} = V^- - 0.2V$ to $V^+ + 0.2V$	70	100	-	dB
		$V^+ = 1.8V$, $V_{COM} = V^- - 0.2V$ to $V^+ - 1.1V$	70	96	-	dB
		$V^+ - 1.8V$, $V_{COM} = V^- - 0.2V$ to $V^+ + 0.2V$	70	96	-	dB
Common-Mode Input Voltage Range	V_{ICM}	CMR ≥ CMR min	$V^- - 0.2$	-	$V^+ + 0.2$	V
OUTPUT CHARACTERISTICS						
High-level Output Voltage ($V^+ - V_O$)	V_{OH}	$R_L = 100k\Omega$ to $V^+/2$	-	10	25	mV
		$R_L = 10k\Omega$ to $V^+/2$	-	50	100	mV
Low-level Output Voltage	V_{OL}	$R_L = 100k\Omega$ to $V^+/2$	-	6	25	mV
		$R_L = 10k\Omega$ to $V^+/2$	-	50	100	mV
		$R_L = 100k\Omega$ to V^-	-	0.5	5	mV
		$R_L = 10k\Omega$ to V^-	-	0.5	5	mV
Output Short-Circuit Current	I_{SC}	$V^+ = 5V$, Source / Sink	-	20	-	mA
		$V^+ = 3.3V$, Source / Sink	-	10	-	mA
		$V^+ = 1.8V$, Source / Sink	-	1	-	mA

*1 Input offset voltage and drift, Input bias and offset current are positive or negative, its absolute values are listed in electrical characteristics.

■ ELECTRICAL CHARACTERISTICS (NL6002) (Continued)

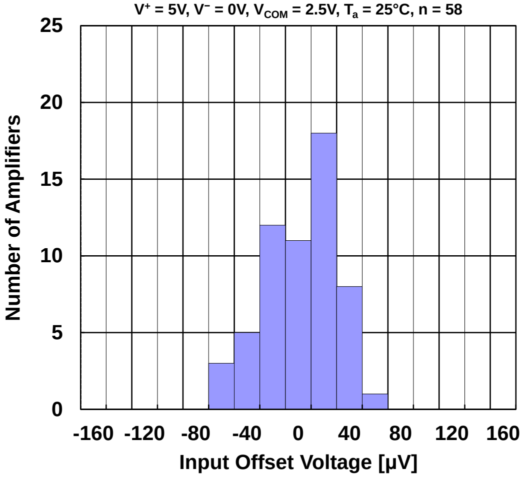
V^+ = 5V, 3.3V, 1.8V, V^- = 0V, V_{COM} = $V^+/2$, R_L = 100kΩ to $V^+/2$, T_a = 25°C, unless otherwise specified.

Parameter	Symbol	Conditions	MIN	TYP	MAX	Unit
POWER SUPPLY						
Supply Current per Amplifier	I_{SUPPLY}	No Signal, V_{COM} = 0V	-	15	21	μA
Supply Voltage Rejection Ratio	SVR	V^+ = 1.6V to 5.5V, V_{COM} = 0V	70	100	-	dB
AC CHARACTERISTICS						
Slew Rate	SR	C_L = 50pF, V_{IN} = 1V_{PP}, G_V = 1	-	0.04	-	V/μs
Gain Bandwidth Product	GBW	C_L = 50pF	-	120	-	kHz
Settling Time 0.1%	t_S	V^+ = 5V, C_L = 50pF, V_{IN} = 4V_{PP}	-	100	-	μs
		V^+ = 3.3V, C_L = 50pF, V_{IN} = 2.3V_{PP}	-	80	-	μs
		V^+ = 1.8V, C_L = 50pF, V_{IN} = 0.8V_{PP}	-	50	-	μs
Phase Margin	Φ_M	C_L = 50pF	-	50	-	Deg
Total Harmonic Distortion + Noise	THD+N	V^+ = 5V, Gain = 2, f = 1kHz, V_O = 1.5Vrms	-	0.05	-	%
		V^+ = 3.3V, Gain = 2, f = 1kHz, V_O = 0.9Vrms	-	0.05	-	%
		V^+ = 1.8V, Gain = 2, f = 1kHz, V_O = 0.4Vrms	-	0.5	-	%
Equivalent Input Noise Voltage	V_{NI}	f = 0.1Hz to 10Hz	-	1.4	-	μV_{PP}
Equivalent Input Noise Voltage	e_n	f = 100Hz	-	80	-	nV/√Hz
		f = 1kHz	-	65	-	nV/√Hz
Channel Separation	CS	f = 1kHz	-	-120	-	dB

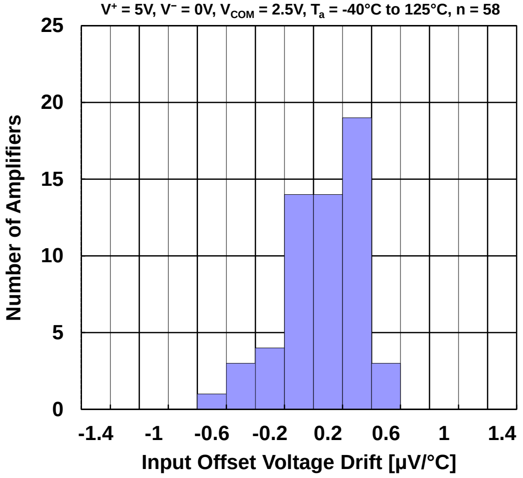
■ TYPICAL CHARACTERISTICS

Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

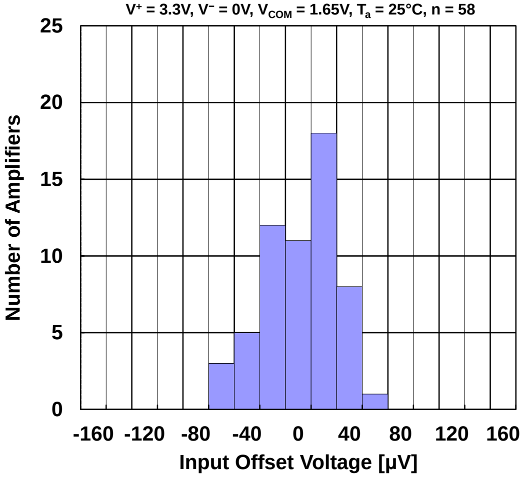
Input Offset Voltage Distribution
$V^+ = 5V, V^- = 0V, V_{COM} = 2.5V, T_a = 25°C, n = 58$



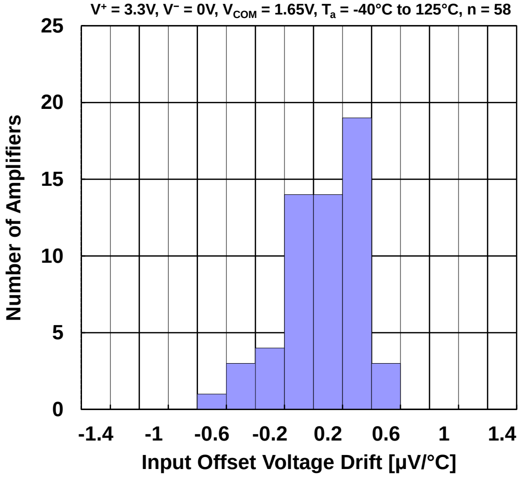
Input Offset Voltage Drift Distribution
$V^+ = 5V, V^- = 0V, V_{COM} = 2.5V, T_a = -40°C \text{ to } 125°C, n = 58$



Input Offset Voltage Distribution
$V^+ = 3.3V, V^- = 0V, V_{COM} = 1.65V, T_a = 25°C, n = 58$



Input Offset Voltage Drift Distribution
$V^+ = 3.3V, V^- = 0V, V_{COM} = 1.65V, T_a = -40°C \text{ to } 125°C, n = 58$



Input Offset Voltage Distribution
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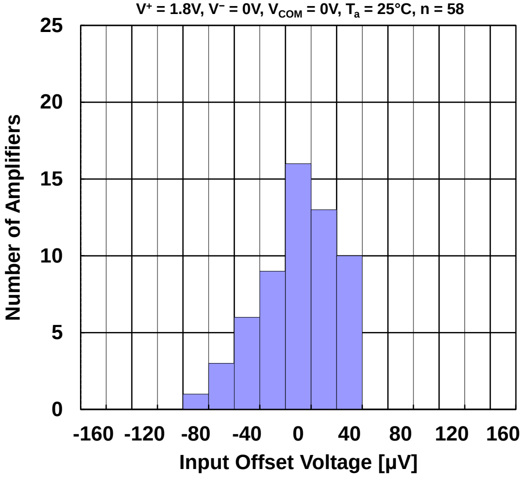
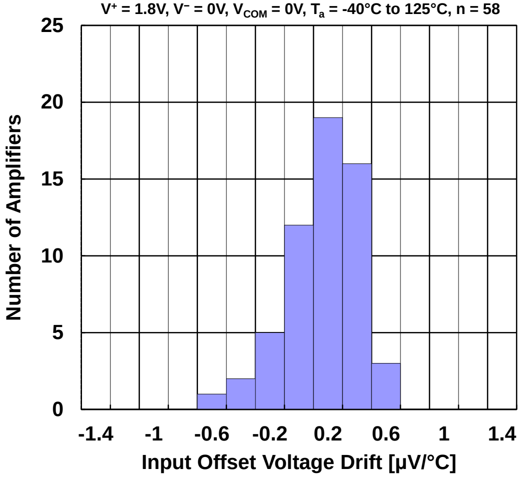
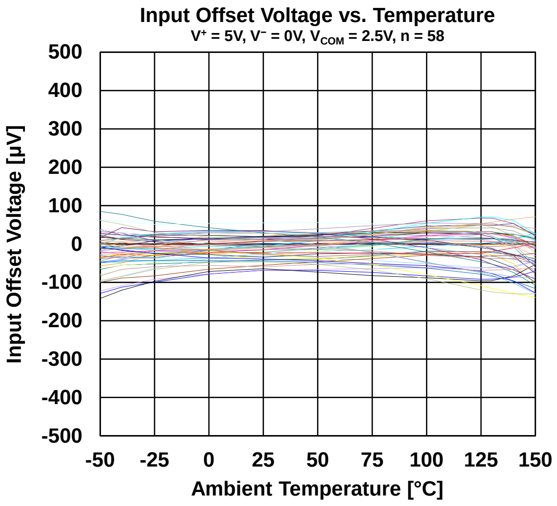


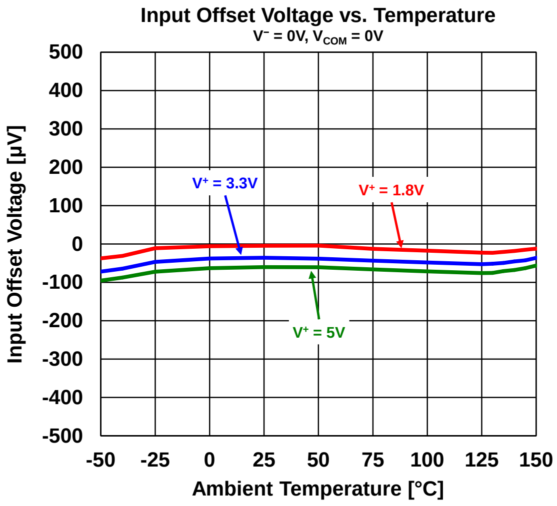
Input Offset Voltage Drift Distribution
$V^+ = 1.8V, V^- = 0V, V_{COM} = 0V, T_a = -40°C \text{ to } 125°C, n = 58$

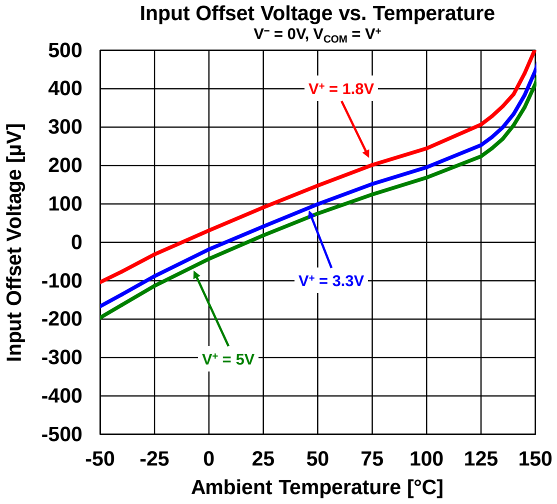


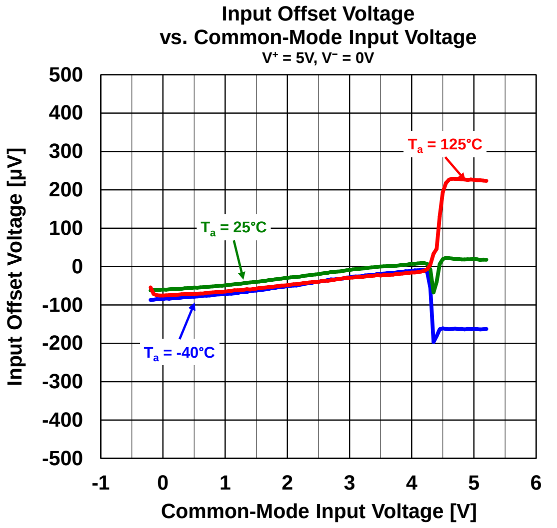
■ TYPICAL CHARACTERISTICS

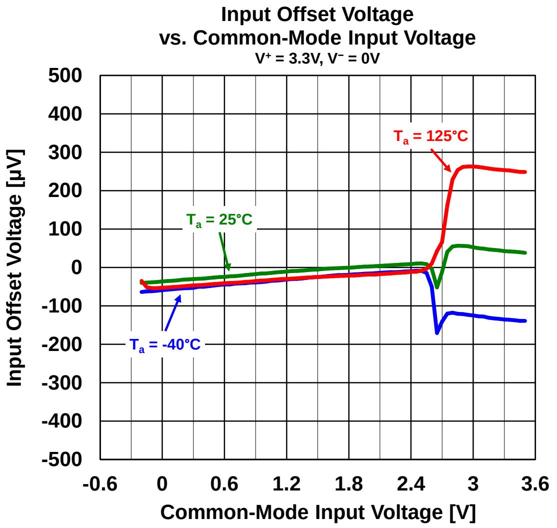
Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

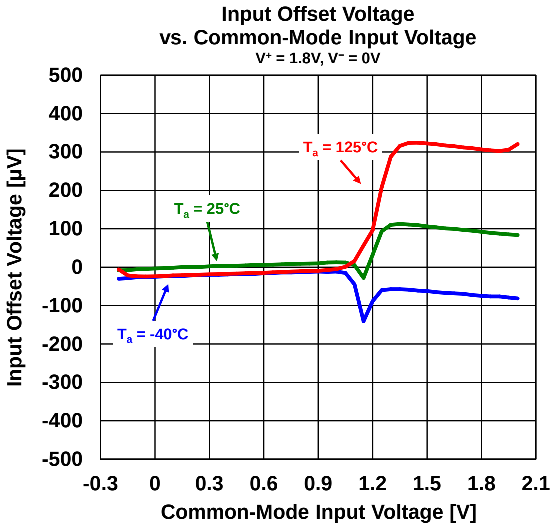

Input Offset Voltage vs. Temperature
$V^+ = 5V, V^- = 0V, V_{COM} = 2.5V$, n = 58


Input Offset Voltage vs. Temperature
$V^- = 0V, V_{COM} = 0V$


Input Offset Voltage vs. Temperature
$V^- = 0V, V_{COM} = V^+$

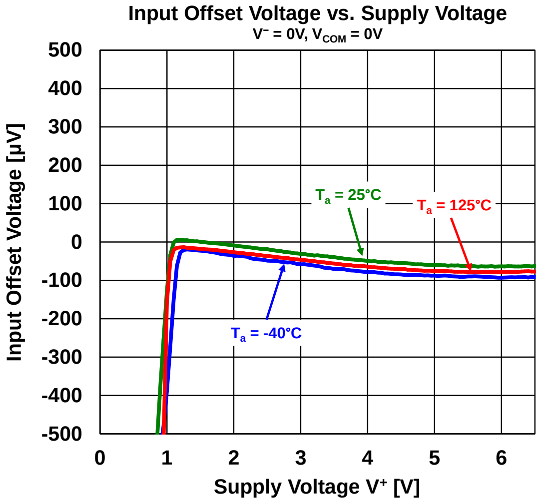

Input Offset Voltage
vs. Common-Mode Input Voltage
$V^+ = 5V, V^- = 0V$

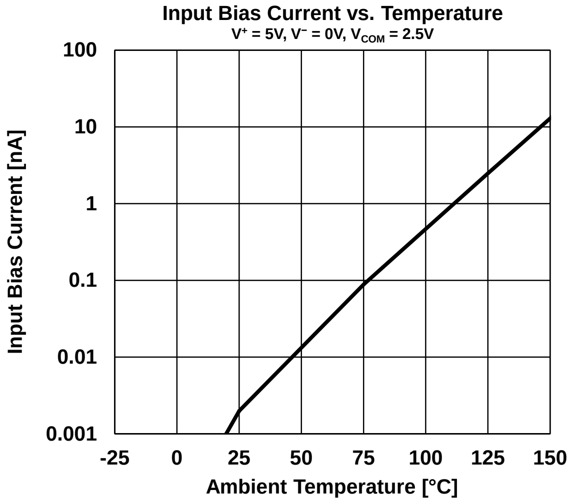

Input Offset Voltage
vs. Common-Mode Input Voltage
$V^+ = 3.3V, V^- = 0V$

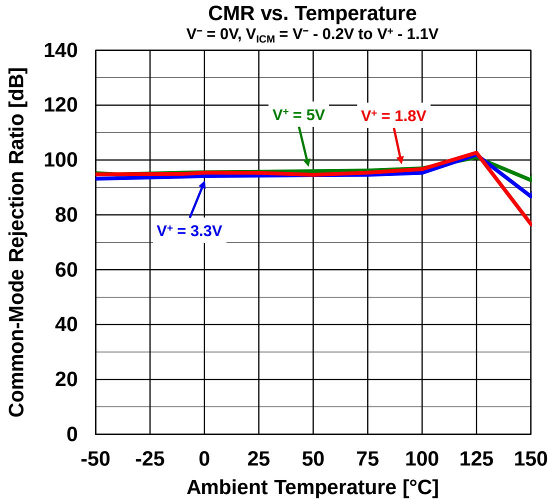

Input Offset Voltage
vs. Common-Mode Input Voltage
$V^+ = 1.8V, V^- = 0V$

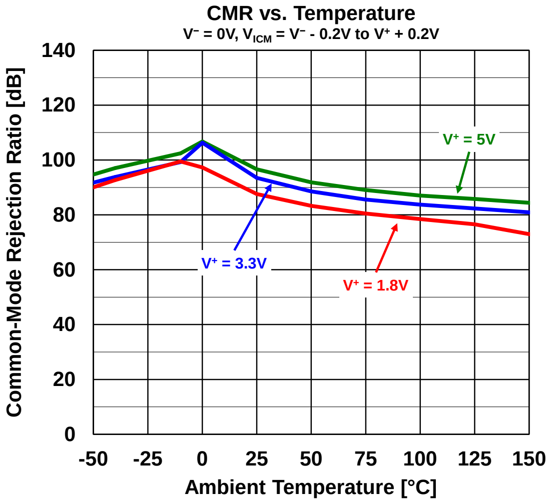
■ TYPICAL CHARACTERISTICS

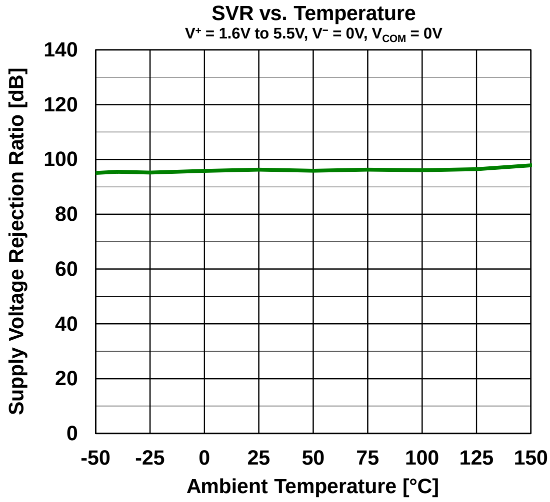
Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

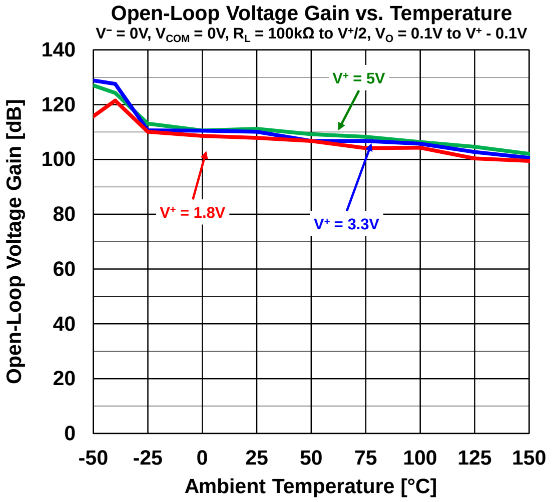








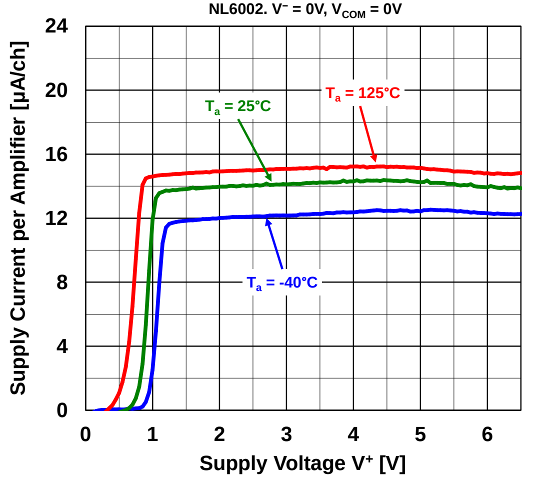




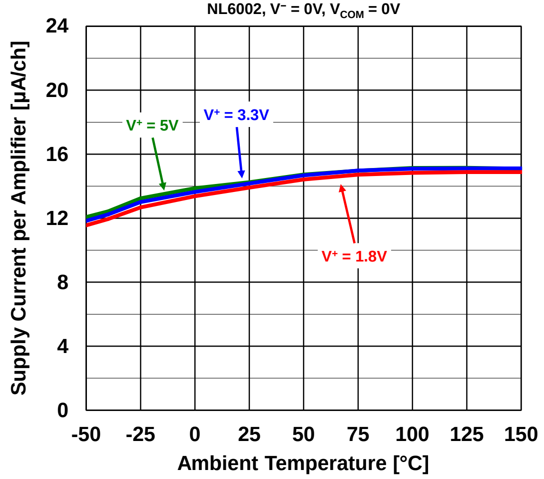
■ TYPICAL CHARACTERISTICS

Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

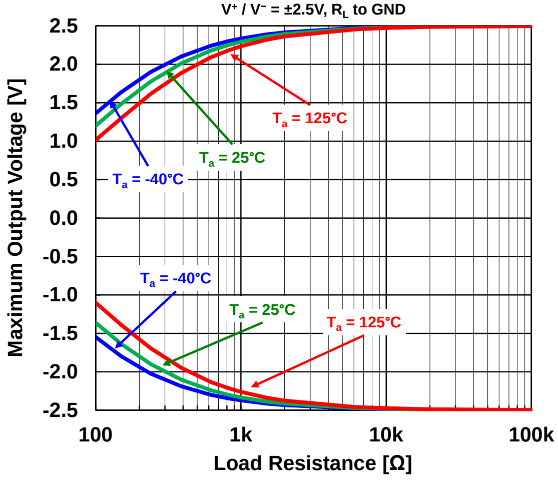
Supply Current per Amplifier vs. Supply Voltage
NL6002. $V^- = 0V$, $V_{COM} = 0V$



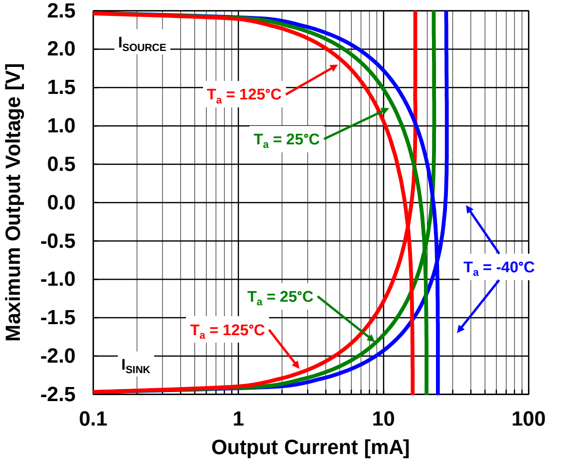
Supply Current per Amplifier vs. Temperature
NL6002, $V^- = 0V$, $V_{COM} = 0V$



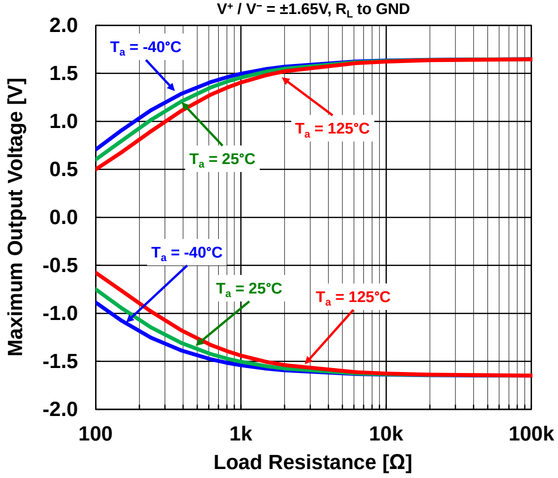
Maximum Output Voltage vs. Load Resistance
$V^+ / V^- = \pm 2.5V$, R_L to GND



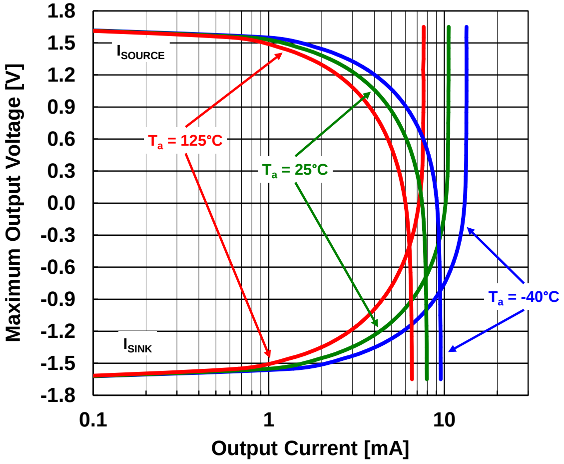
Maximum Output Voltage vs. Output Current
$V^+ / V^- = \pm 2.5V$



Maximum Output Voltage vs. Load Resistance
$V^+ / V^- = \pm 1.65V$, R_L to GND



Maximum Output Voltage vs. Output Current
$V^+ / V^- = \pm 1.65V$

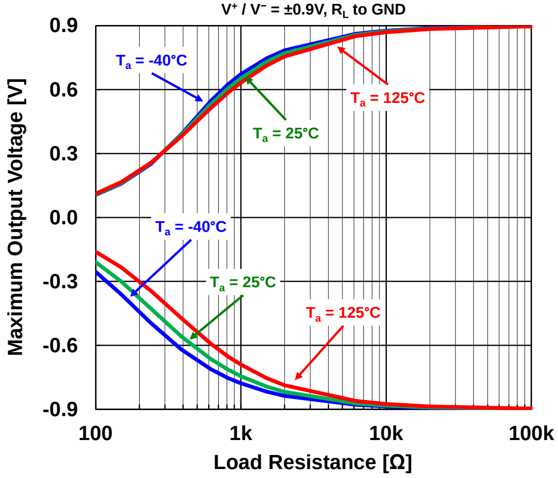


■ TYPICAL CHARACTERISTICS

Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.

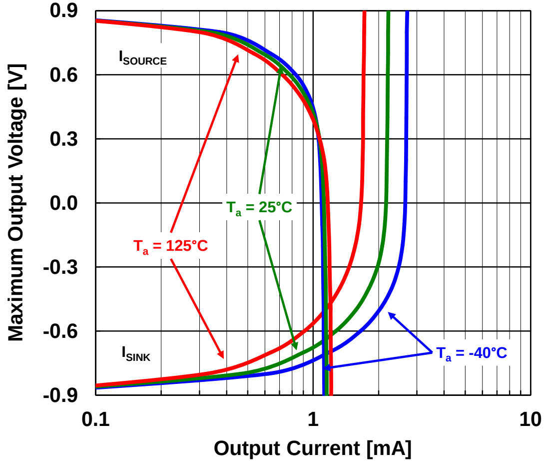
Maximum Output Voltage vs. Load Resistance

$V^+ / V^- = \pm0.9V$, R_L to GND



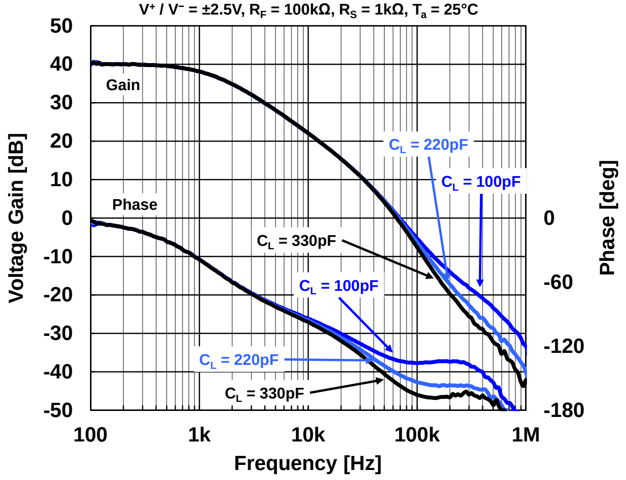
Maximum Output Voltage vs. Output Current

$V^+ / V^- = \pm0.9V$



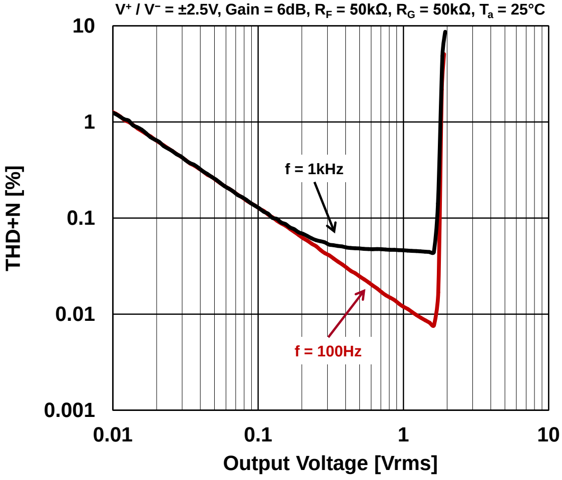
40dB Voltage Gain vs. Frequency

$V^+ / V^- = \pm2.5V$, $R_F = 100k\Omega$, $R_S = 1k\Omega$, $T_a = 25°C$



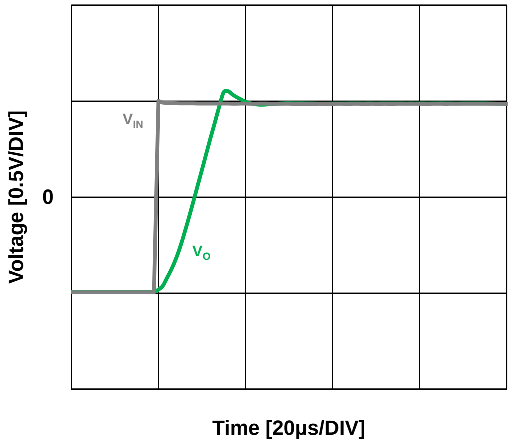
THD+N vs. Output Voltage

$V^+ / V^- = \pm2.5V$, Gain = 6dB, $R_F = 50k\Omega$, $R_G = 50k\Omega$, $T_a = 25°C$



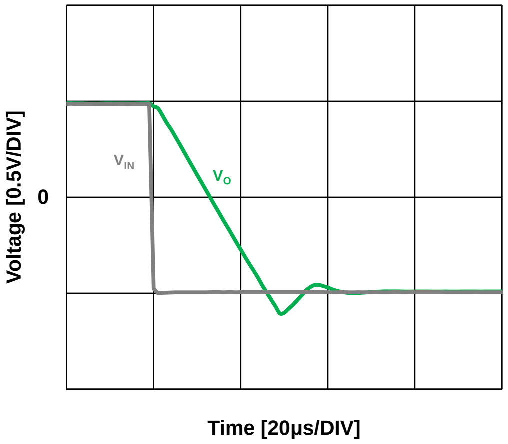
Pulse Response

$V^+ / V^- = \pm2.5V$, $R_L = 100k\Omega$ to GND, $C_L = 50pF$, $T_a = 25°C$



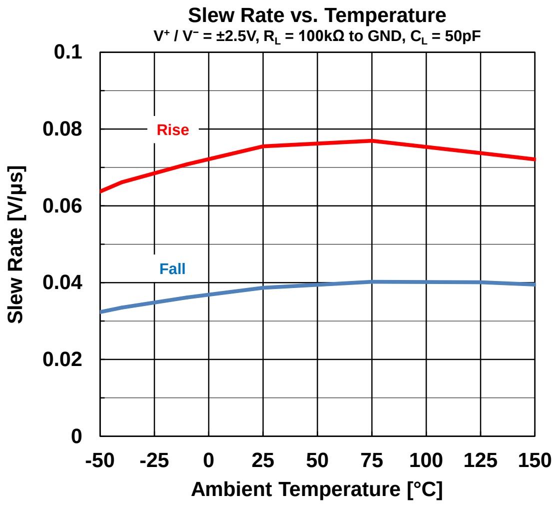
Pulse Response

$V^+ / V^- = \pm2.5V$, $R_L = 100k\Omega$ to GND, $C_L = 50pF$, $T_a = 25°C$



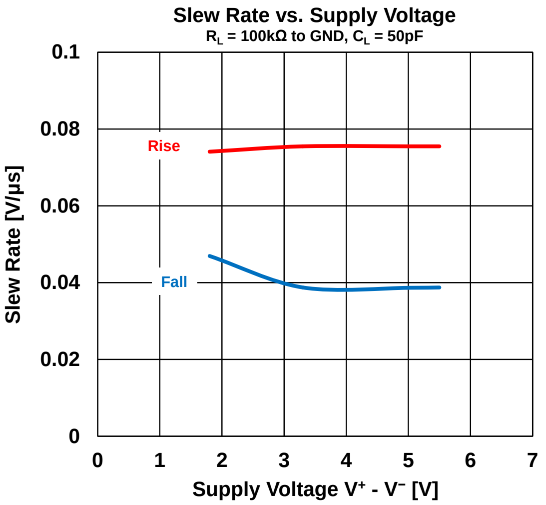
■ TYPICAL CHARACTERISTICS

Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.



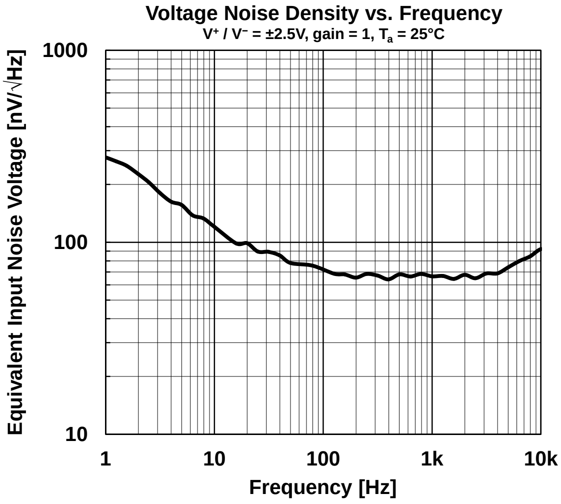
Slew Rate vs. Temperature

$V^+ / V^- = \pm 2.5V$, $R_L = 100k\Omega$ to GND, $C_L = 50pF$



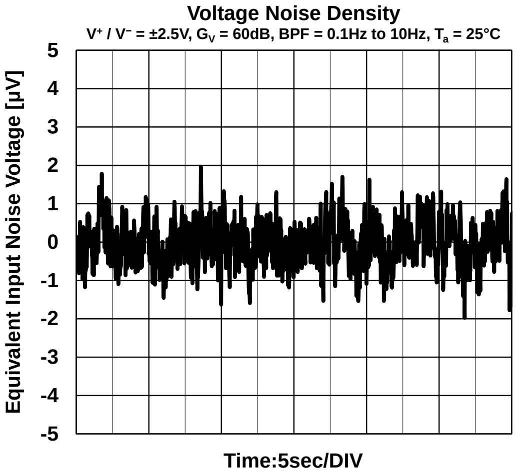
Slew Rate vs. Supply Voltage

$R_L = 100k\Omega$ to GND, $C_L = 50pF$



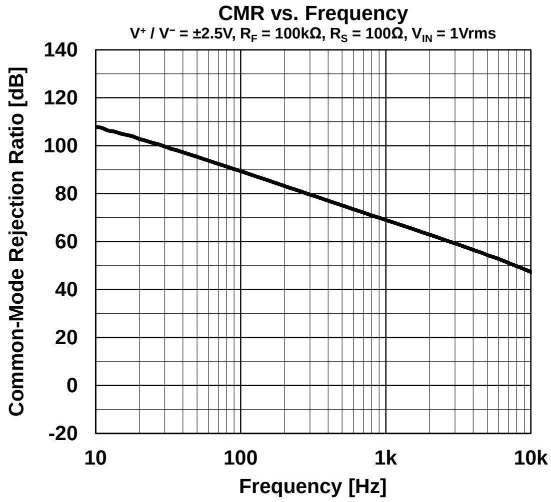
Voltage Noise Density vs. Frequency

$V^+ / V^- = \pm 2.5V$, gain = 1, $T_a = 25°C$



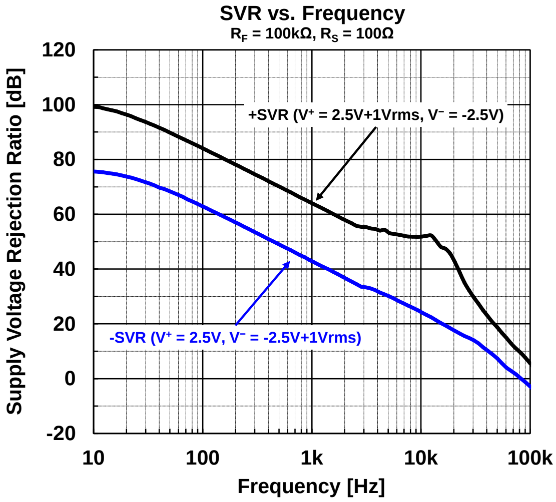
Voltage Noise Density

$V^+ / V^- = \pm 2.5V$, $G_V = 60dB$, BPF = 0.1Hz to 10Hz, $T_a = 25°C$



CMR vs. Frequency

$V^+ / V^- = \pm 2.5V$, $R_F = 100k\Omega$, $R_S = 100\Omega$, $V_{IN} = 1Vrms$

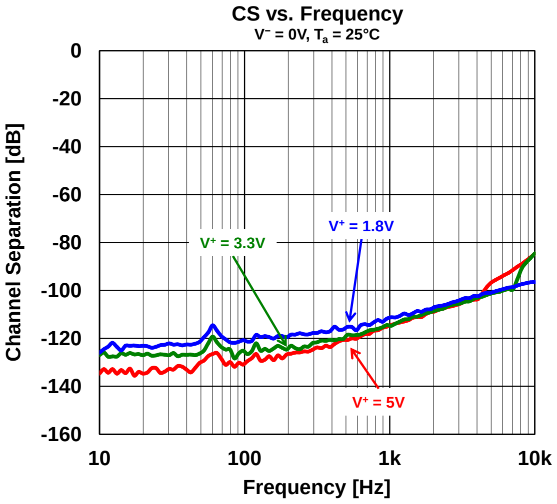


SVR vs. Frequency

$R_F = 100k\Omega$, $R_S = 100\Omega$

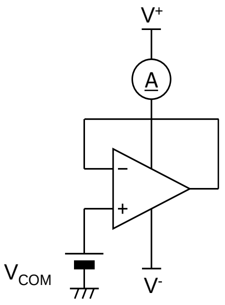
■ TYPICAL CHARACTERISTICS

Note: Typical Characteristics are intended to be used as reference data; they are not guaranteed.



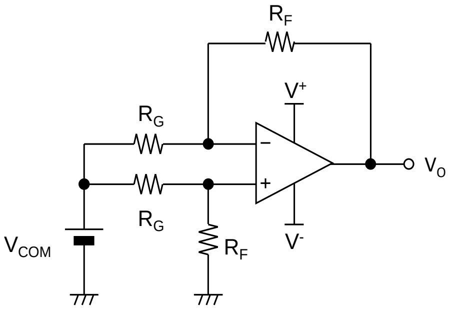
■ TEST CIRCUITS

- I_{SUPPLY}



- V_{IO}, CMR, SVR

$R_G = 50\Omega$, $R_F = 50k\Omega$



$$V_{IO} = \frac{R_G}{(R_G+R_F)} \times (V_O - V_{COM})$$

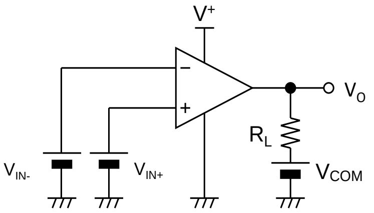
$$CMR = 20\log \frac{\Delta V_{COM}\left(1+\frac{R_F}{R_G}\right)}{\Delta V_O}$$

$$SVR = 20\log \frac{\Delta V_S\left(1+\frac{R_F}{R_G}\right)}{\Delta V_O}$$

$V_S = V^+ - V^-$

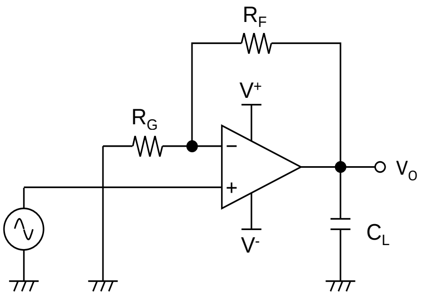
- V_{OH}, V_{OL}

V_{OH}; $V_{IN+} = V_{COM} + 1V$, $V_{IN-} = V_{COM}$, $V_{COM} = V^+ / 2$
V_{OL}; $V_{IN+} = V_{COM}$, $V_{IN-} = V_{COM} + 1V$, $V_{COM} = V^+ / 2$



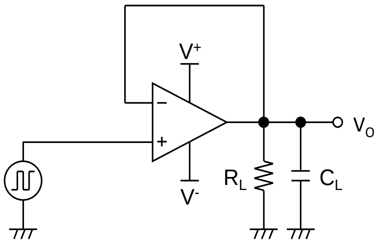
- GBW

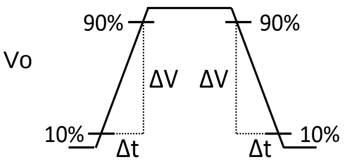
$R_G = 1k\Omega$, $R_F = 100k\Omega$



- SR

$R_L = 100k\Omega$





$$SR = \frac{\Delta V}{\Delta t}$$

■ APPLICATION NOTES

Single and Dual Supply Voltage Operation

The NL600x series works with both single supply and dual supply when the voltage supplied is between V^+ and V^-. These amplifiers operate from single 1.6V to 5.5V supply and dual ±0.8V to ±2.75V supply.

Bypassing power supply

To provide a stable supply voltage with low noise to the operational amplifier, connect the bias capacitor as close to the power supply pin as possible.

Input Offset Voltage Drift

The NL600x is a precision low power rail-to-rail input/output CMOS operational amplifier featuring low input offset voltage (150µV max.), low input offset voltage drift (0.9µV/°C max.) and low current consumption (15µA/ch).
The Xtended trimming high-precision trimming technology reduces the spread of offset voltage due to temperature drift compared to conventional trimming, achieving 0.9uV/°C max. in the -40°C to 125°C range. The offset change over this range is 149µV, which corresponds to 1LSB (200µV) of 3.3V, 14bit.

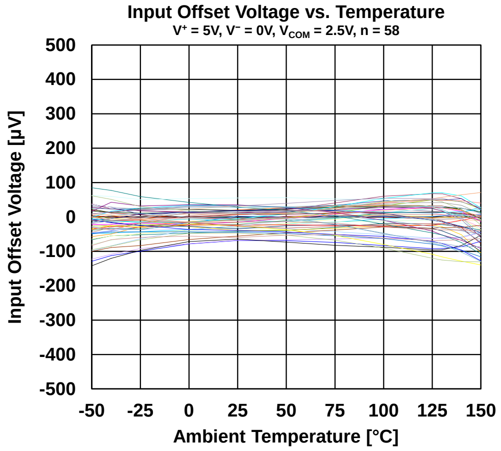
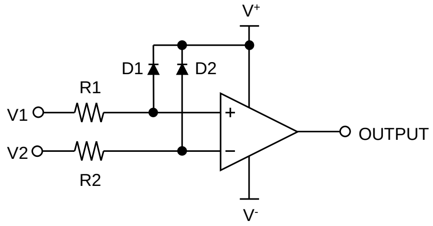


Figure1. Input Offset Voltage Drift

■ APPLICATION NOTES

Input Voltage Exceeding the Supply Voltage

For the input voltage below V^- - 0.3V, the ESD protection operates to protect the input terminal. At this moment, the current flowing in protection element is allowed up to 10 mA. Momentary voltages above V^+ + 0.3V, the ESD protection also activate, and clamp inputs, but cannot protect against overvoltage excepting ESD.
In some applications, it may be necessary to prevent excessive overvoltage. Figure 2 is example to protect input transistors. The external resistors R1, R2 limit the current through external diodes D1, D2.



$$(R1, R2) > \frac{V^- - (V1, V2)}{10mA}$$

$$(R1, R2) > \frac{(V1,\ V2) - V^+}{I_F}$$

I_F:Forward current of external diode.

Figure 2. Example of input protection

Capacitive Load

The NL600x series can use at unity gain follower, but the unity gain follower is the most sensitive configuration to capacitive loading. The combination of capacitive load placed directly on the output of an amplifier along with the output impedance of the amplifier creates a phase lag which in turn reduces the phase margin of the amplifier. If phase margin is significantly reduced, the response will cause overshoot and ringing in the step response.
The NL600x series is unity gain stable for capacitive loads of 220pF. To drive heavier capacitive loads, an isolation resistor, R_{ISO} as shown Figure 3, should be used. R_{ISO} improves the feedback loop's phase margin by making the output load resistive at higher frequencies. The larger the value of R_{ISO}, the more stable the output voltage will be. However, larger values of R_{ISO} result in reduced output swing, reduced output current drive and reduced frequency bandwidth.

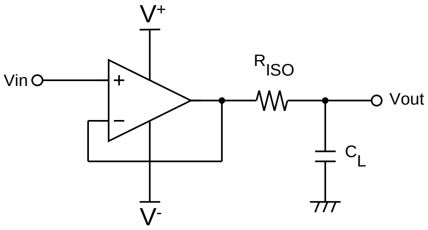


Figure 3. Isolating capacitive load

■ APPLICATION NOTES

Terminating unused OpAmps

Examples of common methods of terminating an uncommitted OpAmp are shown in Figure 4. Improper termination can be result increase supply current, heating and noise in OpAmps.

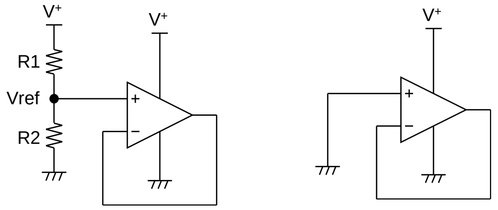
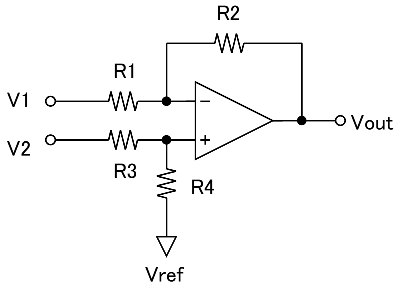


Figure 4. Terminating unused OpAmps

Differential Amplifier

Figure 5 shows a one OpAmp differential amplifier that consists of the single OpAmp and four external resistors. Differential amplifier amplifies the difference between its two input pins, and rejects the common- mode input voltage at both input pins. This is used in variety of applications including current sensing, differential to single-end converter, isolation amplifier to remove common-mode noise.



$$\mathrm{Vout}=\left(\frac{\mathrm{R1}+\mathrm{R2}}{\mathrm{R3}+\mathrm{R4}}\right)\frac{\mathrm{R4}}{\mathrm{R1}}\mathrm{V2}-\frac{\mathrm{R2}}{\mathrm{R1}}\mathrm{V1}+\left(\frac{\mathrm{R1}+\mathrm{R2}}{\mathrm{R3}+\mathrm{R4}}\right)\frac{\mathrm{R3}}{\mathrm{R1}}\mathrm{Vref}$$

$$\mathrm{R1}=\mathrm{R3},\ \mathrm{R2}=\mathrm{R4}$$

$$\mathrm{Vout}=\frac{\mathrm{R2}}{\mathrm{R1}}(\mathrm{V2}-\mathrm{V1})+\mathrm{Vref}$$

Figure 5. Differential Amplifier

The differential amplifier's common-mode rejection ratio (CMR) is primarily determined by resistor mismatches, not by the OpAmp's CMR. Ideally, the resistors are chosen such that R2/R1 = R4/R3.
The CMR due to the resistors in differential amplifier can be calculated using the below formula:

$$\mathrm{CMR}_{\mathrm{R\_error}} \approx 20\log\left(\frac{1+\frac{\mathrm{R2}}{\mathrm{R1}}}{4\mathrm{R}_{\mathrm{error}}}\right)$$

$$\mathrm{CMR}_{\mathrm{R\_error}} = \text{CMR due only to the resistors}$$

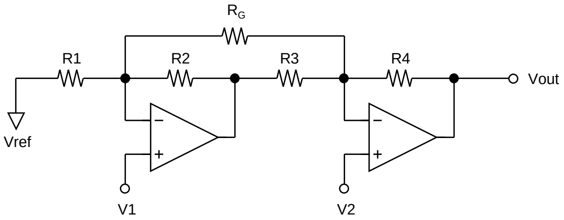
$$\mathrm{R}_{\mathrm{error}} = \text{Resistor's tolerance}$$

Example:
R2 / R1 = 1 and Rerror = 0.1%, then CMR = 54dB
R2 / R1 = 1 and Rerror = 1%, then CMR = 34dB
If using resistors with 1% tolerance and gain = 1, the CMR will only be 34dB.

■ APPLICATION NOTES

Instrumentation Amplifier

The instrumentation amplifier is suitable for requiring high input impedance and high CMR. Figure 6 and Figure 7 is instrumentation amplifier using two or three OpAmp. Supply the reference voltage (Vref) with a low impedance source to keep accuracy.

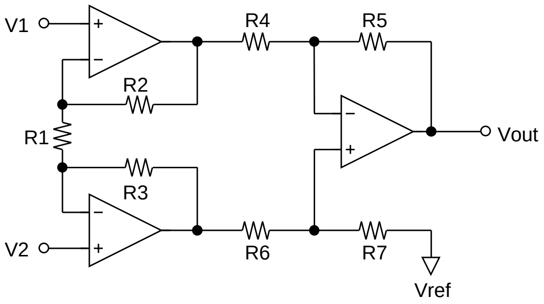


$$\mathrm{Vout}=\left(1+\frac{\mathrm{R4}}{\mathrm{R3}}+\frac{\mathrm{2R4}}{\mathrm{R_G}}\right)(\mathrm{V2}-\mathrm{V1})+\mathrm{Vref}$$

$$\mathrm{R1}=\mathrm{R4},\ \mathrm{R2}=\mathrm{R3}$$

$$\mathrm{CMR_{R\_error}}\approx 20\log\left(\frac{1+\frac{\mathrm{R4}}{\mathrm{R3}}+\frac{\mathrm{2R4}}{\mathrm{R_G}}}{\mathrm{4R_{error}}}\right)$$

Figure 6. Instrumentation Amplifier with two OpAmp



$$\mathrm{Vout}=\left(1+\frac{\mathrm{2R2}}{\mathrm{R1}}\right)\left(\frac{\mathrm{R5}}{\mathrm{R4}}\right)(\mathrm{V_2}-\mathrm{V_1})+\mathrm{Vref}$$

$$\mathrm{R2}=\mathrm{R3},\ \mathrm{R4}=\mathrm{R6},\ \mathrm{R5}=\mathrm{R7}$$

$$\mathrm{CMR_{R\_error}}\approx 20\log\left(\frac{\mathrm{R1}+\mathrm{2R2}}{\mathrm{R1}}\times\frac{1+\frac{\mathrm{R5}}{\mathrm{R4}}}{\mathrm{4R_{error}}}\right)$$

Figure 7. Instrumentation Amplifier with three OpAmp

■ APPLICATION NOTES

Current Sensing

Current sensing applications are one such application in a wide range of electronic applications and mostly used for feedback control systems, including power metering battery life indicators and chargers, over- current protection and supervising circuit, automotive, and medical equipment. In such applications, it is desirable to use a shunt with very low resistance to minimize the series voltage drop and minimizes wasted power, and allows the measurement of high current. The NL600x series is ideal for these current sensing applications.
Figure 8 shows a high-side current sensing circuit, and Figure 9 shows a low-side current sensing circuit. The NL600x series has rail-to-rail input and output characteristics, thus allows the both of high-side and low-side current sensing circuit.
The current detection circuit uses a differential amplifier consisting of an OpAmp and resistors R1/R2/R3/R4. The differential amplifier's common-mode rejection ratio (CMR) is primarily determined by resistor mismatches. For details, refer to "Differential Amplifier" in the application note.

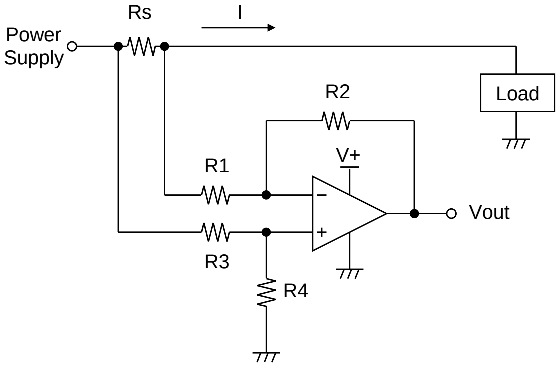


Figure 8. High-Side Current Sensing

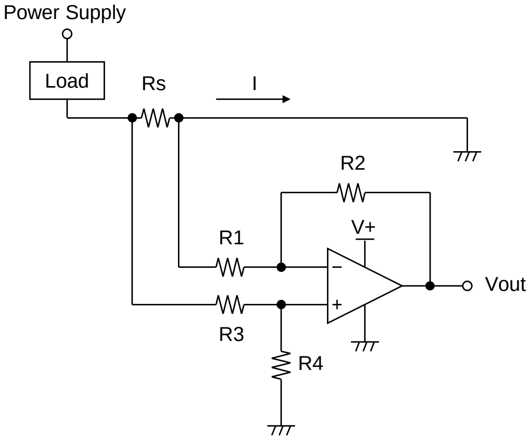


Figure 9. Low-Side Current Sensing

■ APPLICATION NOTES

Transimpedance Amplifier

The features high input impedance with CMOS input and low power can be used for transimpedance amplifier applications shown in Figure 10. The output voltage of amplifier is given by the equation VOUT = $I_{IN} \cdot R_F$. Since the output voltage swing of amplifier is limited, R_F should be selected such that all possible values of I_{IN} can be detected.

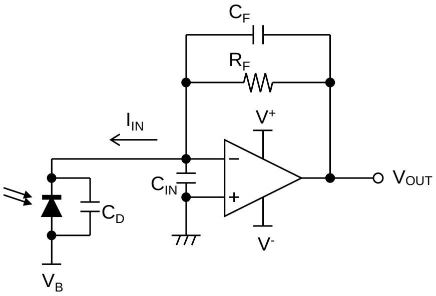


Figure 10. Transimpedance amplifier

The C_D, C_{IN} and R_F generate a phase lag which causes gain-peaking and can destabilized circuit. The essential component for obtaining a maximally flat response is a feedback capacitor C_F. C_F is usually added in parallel with R_F to maintain circuit stability and to control the frequency response. To maximally flat, 2nd order response, R_F and C_F should be chosen by using below equation.

$$C_F = \sqrt{\frac{C_{IN} + C_D}{GBW \times 2\pi \times R_F}}$$

Bridge Amplifier

Bridge sensors for measuring strain, pressure, and temperature are often used in the Wheatstone bridge circuit shown in Figure 11.
Since bridge output signals are typically small, amplifiers may need to operate with high gain, low offset voltage, drift, and low noise.
In addition, the bridge output signal is differential, so amplifier circuits are typically used with differential amplifiers or Instrumentation Amplifiers.

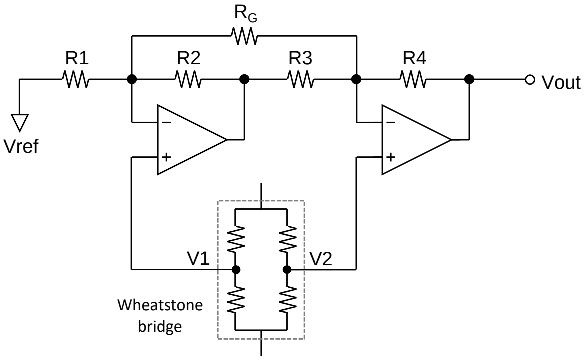


Figure 11. Bridge Amplifier

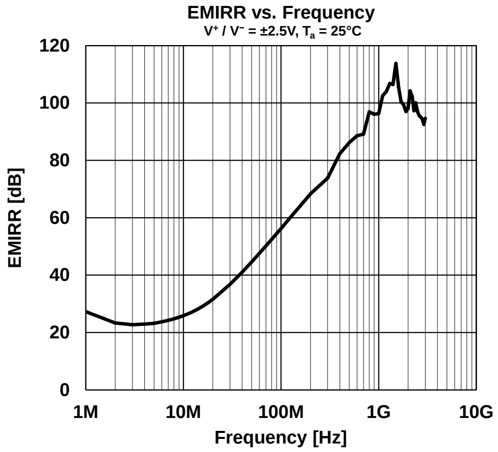
■ APPLICATION NOTES

EMIRR (EMI Rejection Ratio) Definition

EMIRR is a parameter indicating the EMI robustness of an OpAmp. The definition of EMIRR is given by the following equation1.
The tolerance of the RF signal can be grasped by measuring an RF signal and offset voltage shift quantity. Offset voltage shift is small so that a value of EMIRR is big. And it understands that the tolerance for the RF signal is high. In addition, about the input offset voltage shift with the RF signal, there is the thinking that influence applied to the input terminal is dominant. Therefore, generally the EMIRR becomes value that applied an RF signal to +INPUT terminal.

$$\mathrm{EMIRR} = 20 \cdot \log\left(\frac{V_{\mathrm{RF\_PEAK}}}{|\Delta V_{\mathrm{IO}}|}\right) \qquad \text{---eq.1}$$

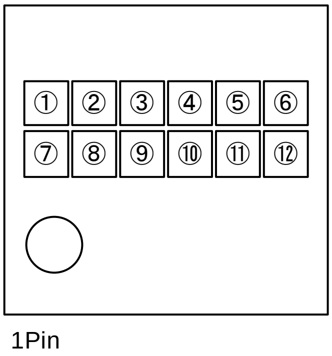
$V_{\mathrm{RF\_PEAK}}$: RF Signal Amplitude [VP]
ΔV_{IO}: Input offset voltage shift quantity [V]



*For details, refer to “Application Note for EMI Immunity" in our HP.

■ MARKING SPECIFICATION (EMP-8-AN, VSP-8-AF)

① to ⑦	Product Code	Refer to *Part Marking List*
⑧ to ⑫	Lot Number	Alphanumeric Serial Number



NOTICE
There can be variation in the marking when different AOI (Automated Optical Inspection) equipment is used. In the case of recognizing the marking characteristic with AOI, please contact our sales or distributor before attempting to use AOI.

Part Marking List

Product Name	①	②	③	④	⑤	⑥	⑦
NL6002ANAE2D	L	6	0	0	2	A	D
NL6002AFAE2D	L	6	0	0	2	A	D

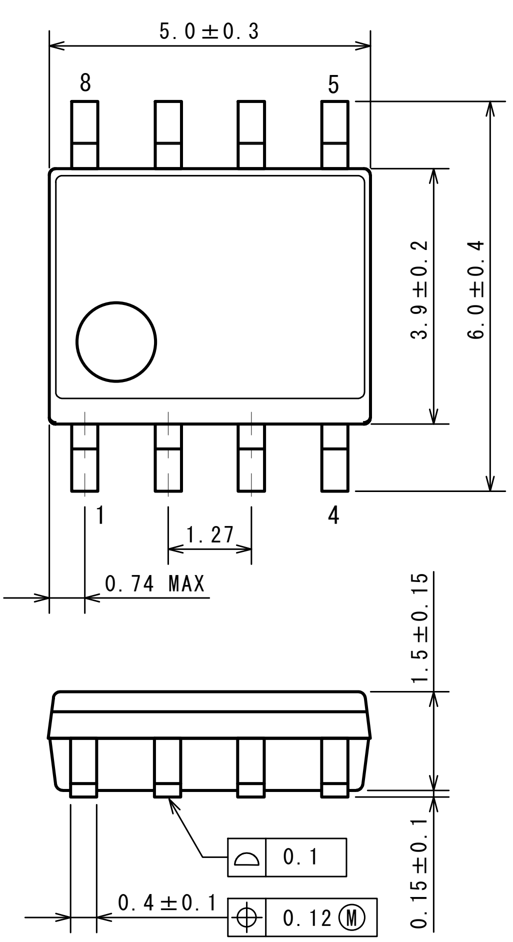
Nisshinbo Micro Devices Inc.

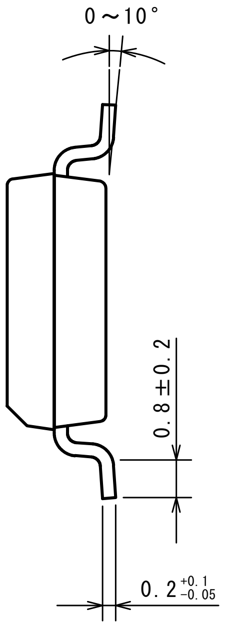
EMP-8-AN

PI-EMP-8-AN-E-A

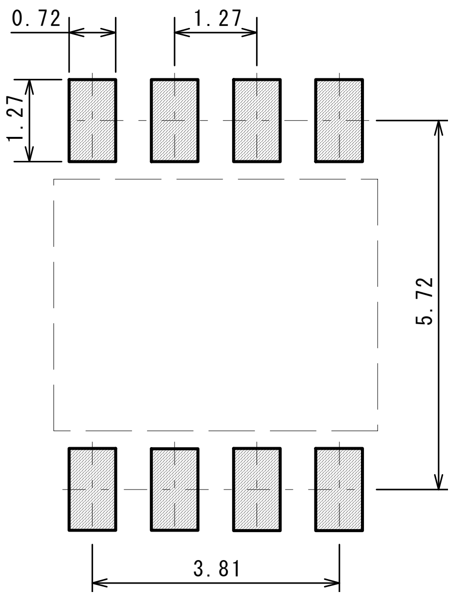
■ PACKAGE DIMENSIONS

UNIT: mm





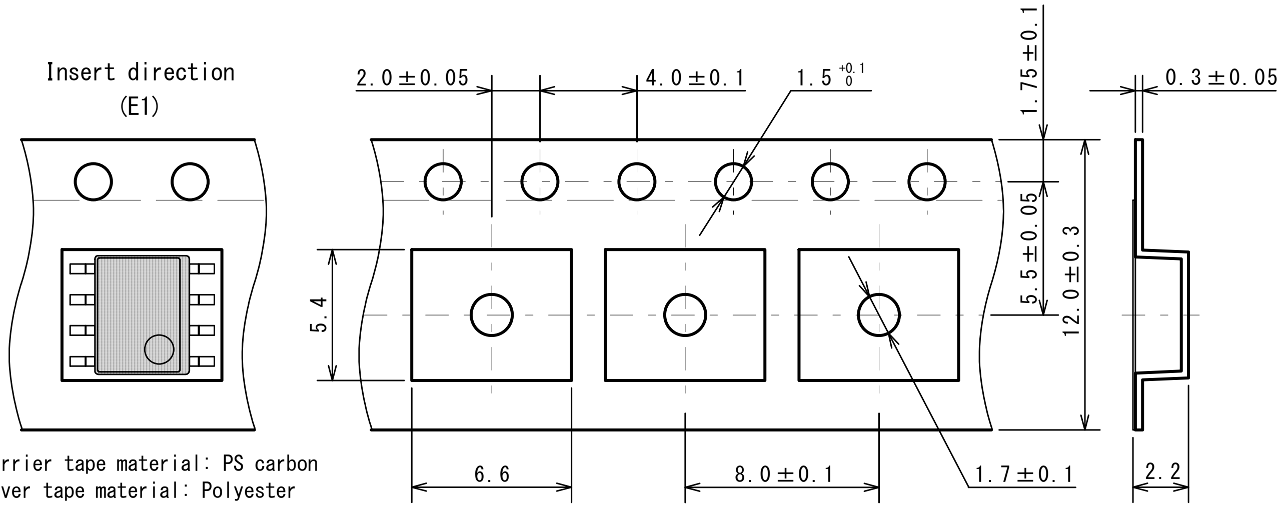
■ EXAMPLE OF SOLDER PADS DIMENSIONS



■ PACKING SPEC

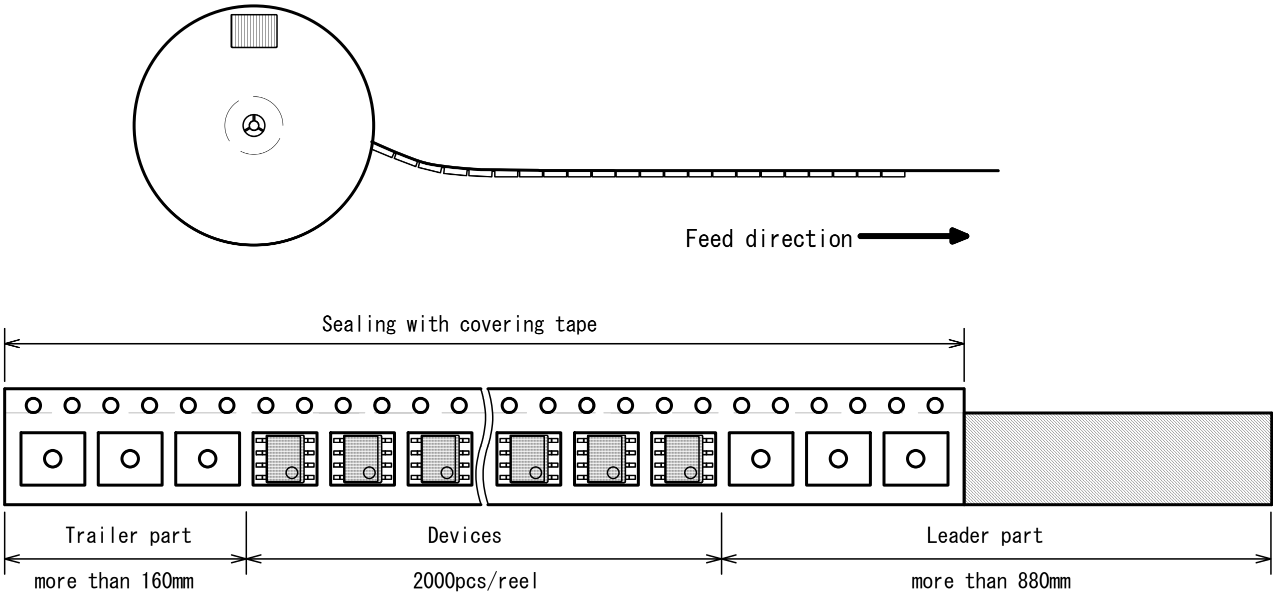
UNIT: mm

(1) Taping dimensions / Insert direction

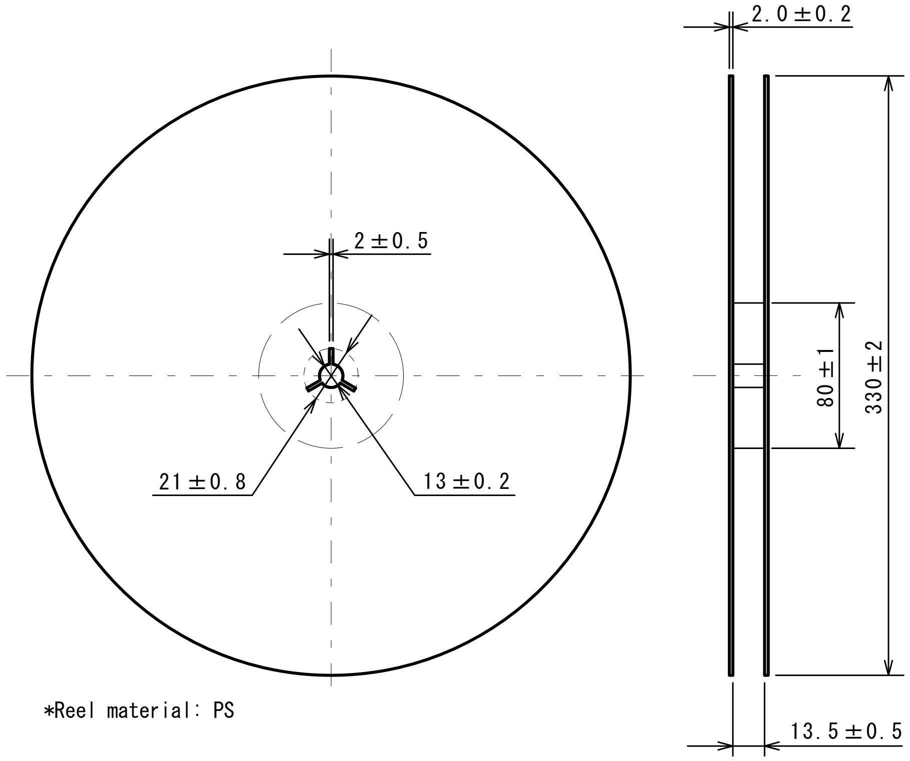


*Carrier tape material: PS carbon
*Cover tape material: Polyester

(2) Taping state



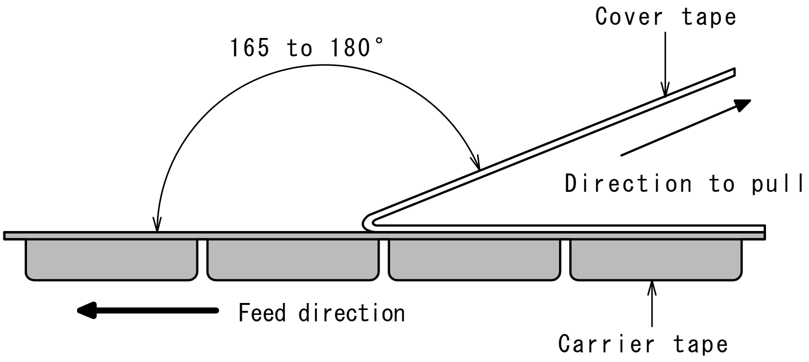
(3) Reel dimensions



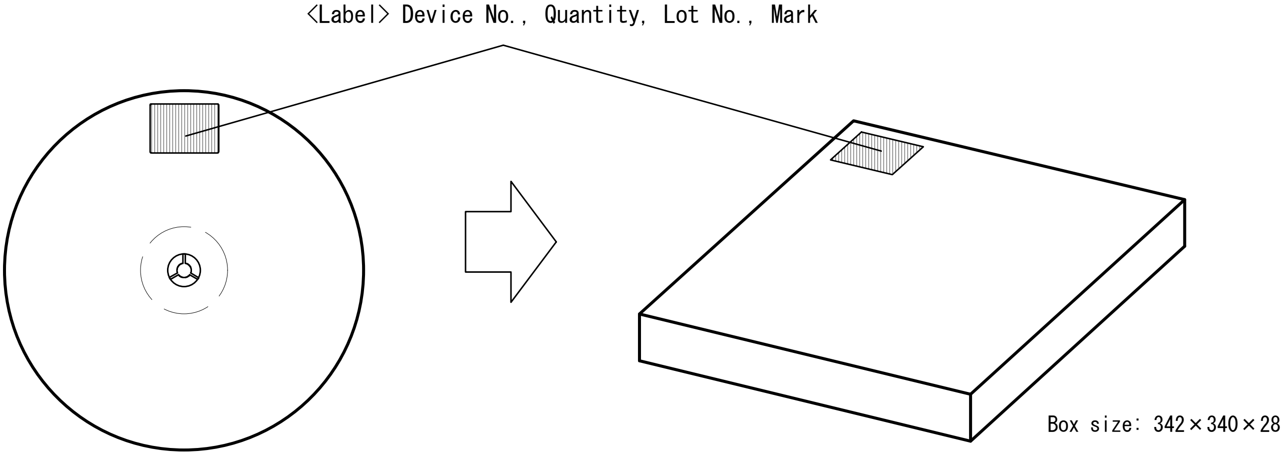
(4) Peeling strength

Peeling strength of cover tape

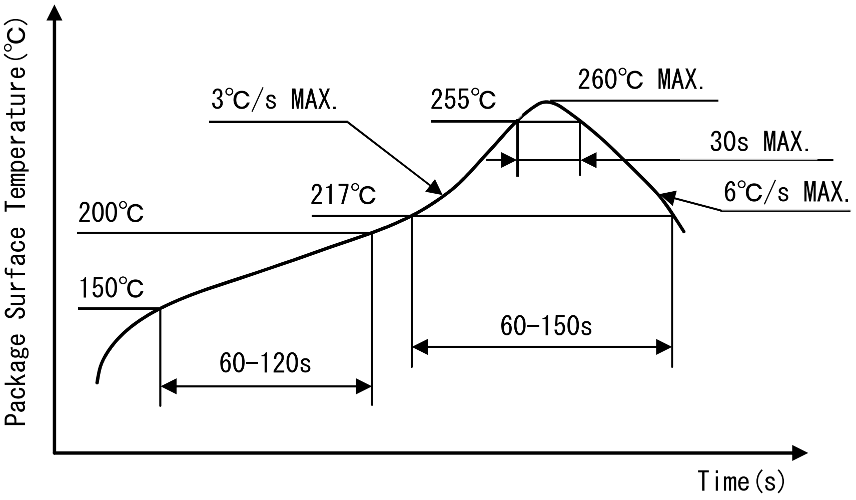
・Peeling angle	165 to 180° degrees to the taped surface.
・Peeling speed	300mm/min
・Peeling strength	0.1 to 1.3N



(5) Packing state



■ **HEAT-RESISTANCE PROFILES**

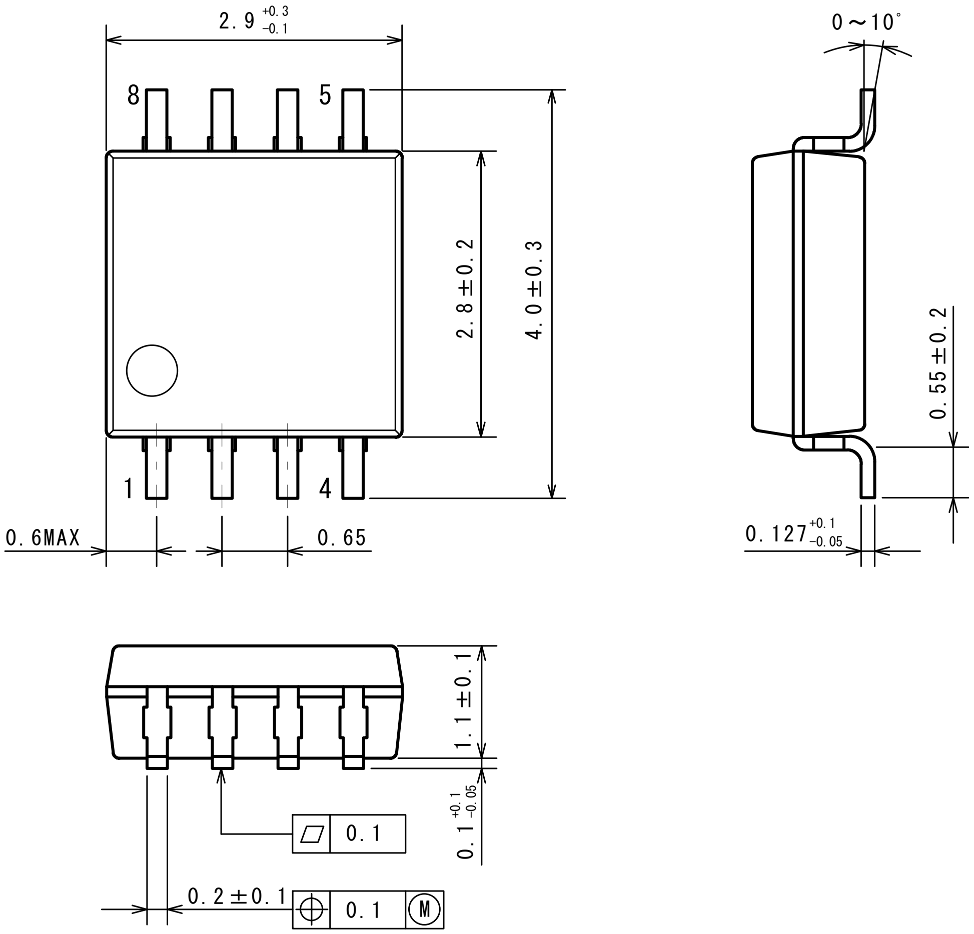


Reflow profile

VSP-8-AF

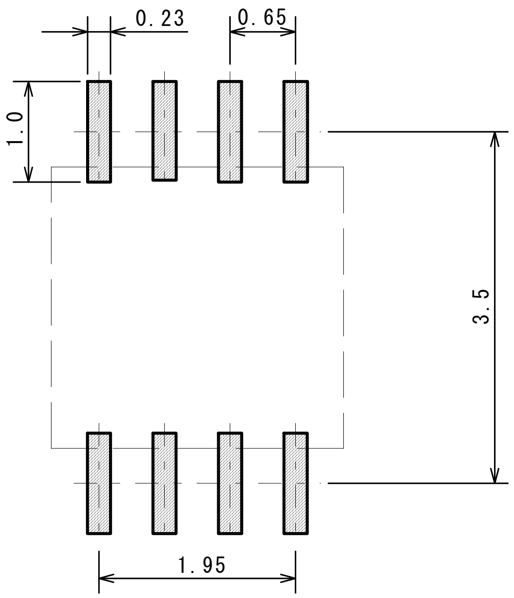
■ PACKAGE DIMENSIONS

UNIT: mm



■ EXAMPLE OF SOLDER PADS DIMENSIONS

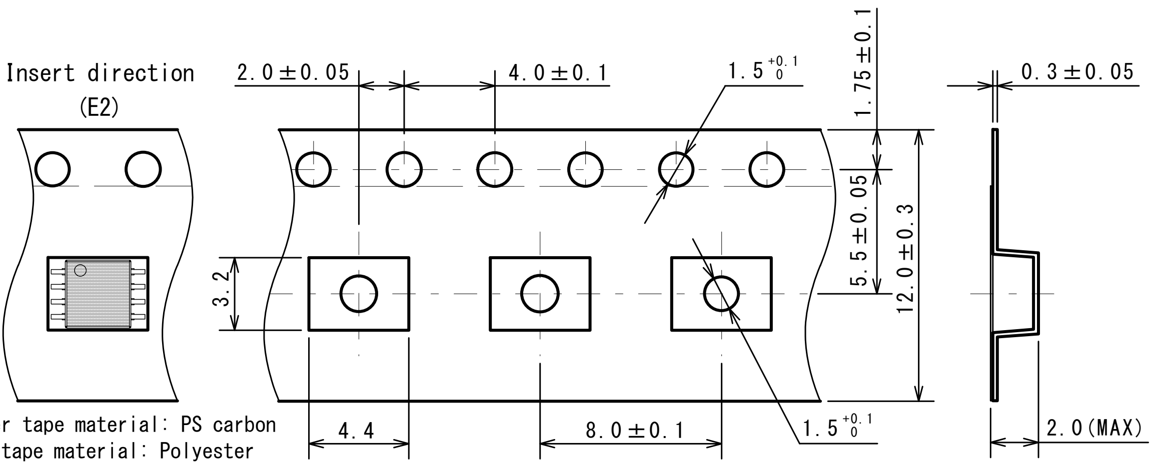
UNIT: mm



■ PACKING SPEC

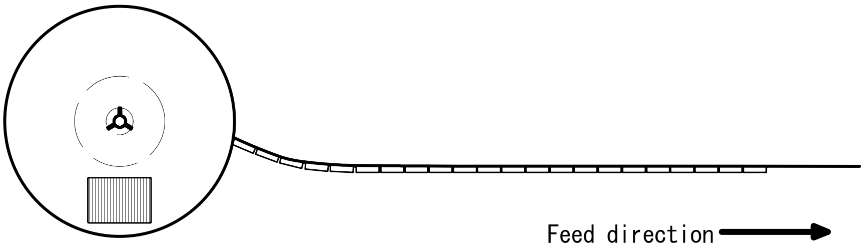
UNIT: mm

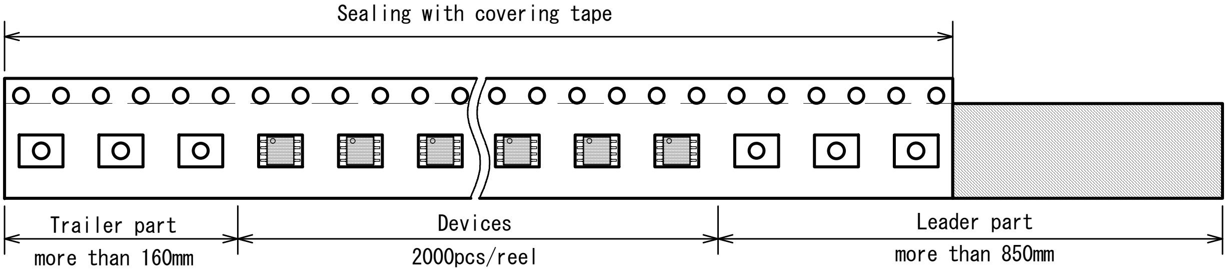
(1) Taping dimensions / Insert direction



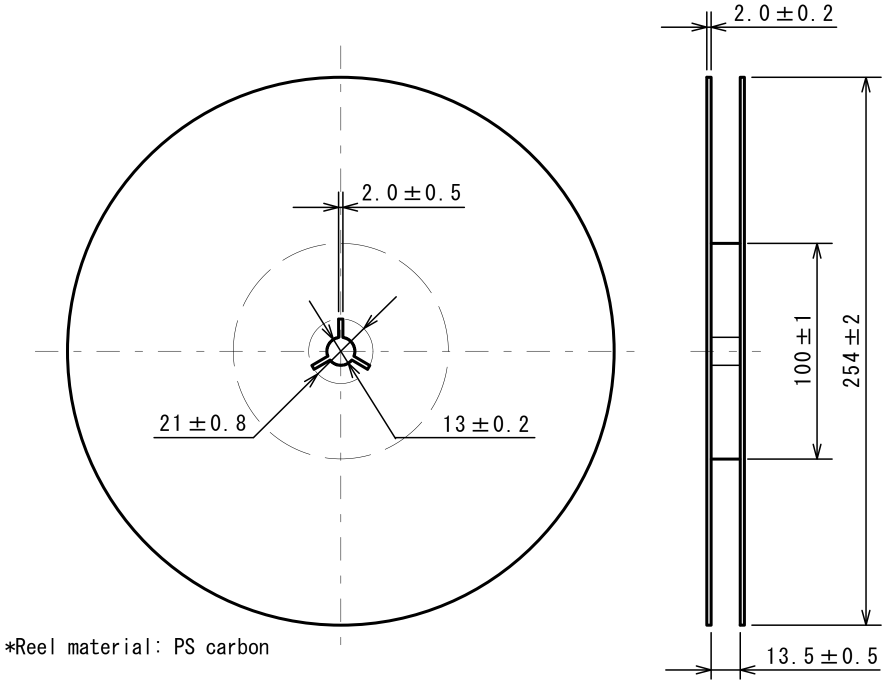
*Carrier tape material: PS carbon
*Cover tape material: Polyester

(2) Taping state





(3) Reel dimensions

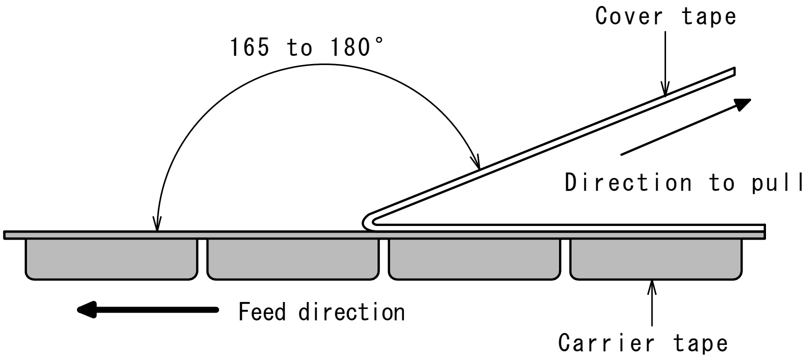


*Reel material: PS carbon

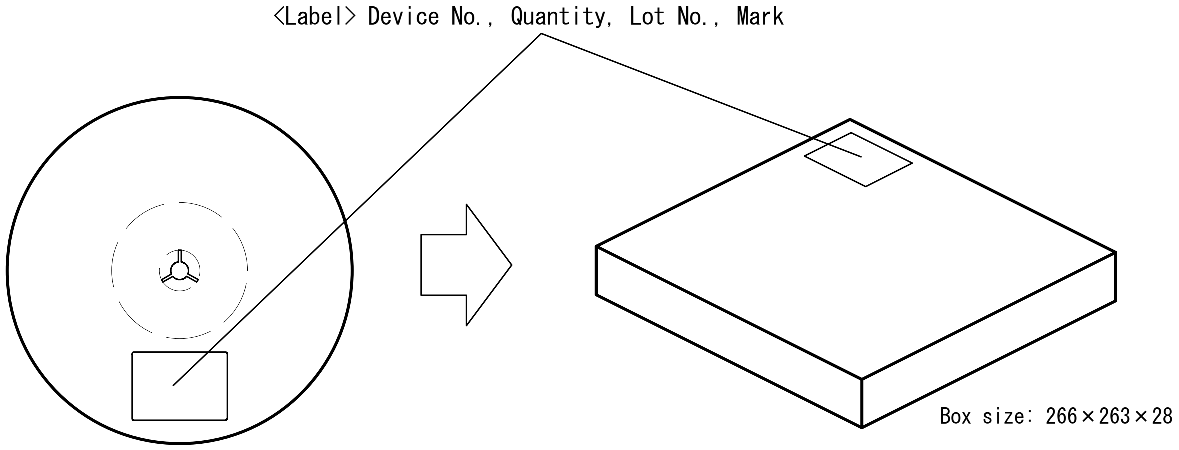
(4) Peeling strength

Peeling strength of cover tape

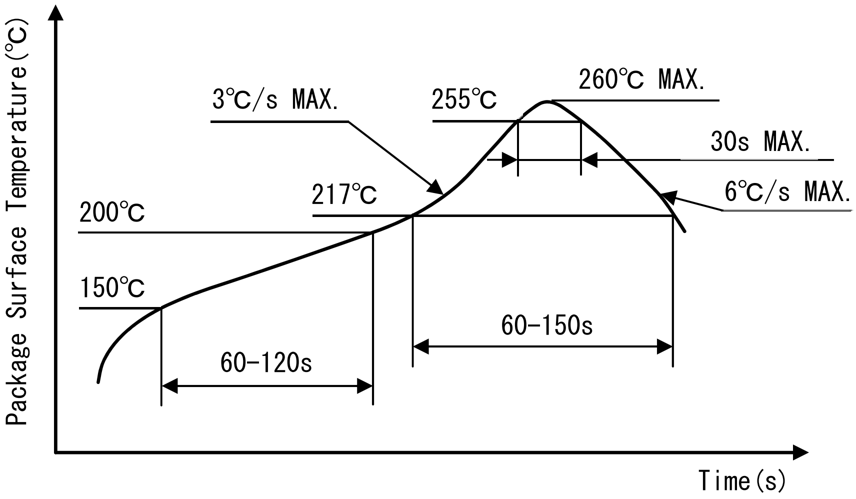
・Peeling angle	165 to 180° degrees to the taped surface.
・Peeling speed	300mm/min
・Peeling strength	0.1 to 1.3N



(5) Packing state



■ **HEAT-RESISTANCE PROFILES**



Reflow profile

■ REVISION HISTORY

Date	Revision	Contents of Changes
June 7, 2024	Ver.1.0	Initial Release

1. The products and the product specifications described in this document are subject to change or discontinuation of production without notice for reasons such as improvement. Therefore, before deciding to use the products, please refer to our sales representatives for the latest information thereon.
2. The materials in this document may not be copied or otherwise reproduced in whole or in part without the prior written consent of us.
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5. The products listed in this document are intended and designed for use as general electronic components in standard applications (office equipment, telecommunication equipment, measuring instruments, consumer electronic products, amusement equipment etc.). Those customers intending to use a product in an application requiring extreme quality and reliability, for example, in a highly specific application where the failure or misoperation of the product could result in human injury or death should first contact us.
    - Aerospace Equipment
    - Equipment Used in the Deep Sea
    - Power Generator Control Equipment (nuclear, steam, hydraulic, etc.)
    - Life Maintenance Medical Equipment
    - Fire Alarms / Intruder Detectors
    - Vehicle Control Equipment (automotive, airplane, railroad, ship, etc.)
    - Various Safety Devices
    - Traffic control system
    - Combustion equipment

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6. We are making our continuous effort to improve the quality and reliability of our products, but semiconductor products are likely to fail with certain probability. In order to prevent any injury to persons or damages to property resulting from such failure, customers should be careful enough to incorporate safety measures in their design, such as redundancy feature, fire containment feature and fail-safe feature. We do not assume any liability or responsibility for any loss or damage arising from misuse or inappropriate use of the products.
7. The products have been designed and tested to function within controlled environmental conditions. Do not use products under conditions that deviate from methods or applications specified in this datasheet. Failure to employ the products in the proper applications can lead to deterioration, destruction or failure of the products. We shall not be responsible for any bodily injury, fires or accident, property damage or any consequential damages resulting from misuse or misapplication of the products.
8. Quality Warranty

    8-1. Quality Warranty Period

    In the case of a product purchased through an authorized distributor or directly from us, the warranty period for this product shall be one (1) year after delivery to your company. For defective products that occurred during this period, we will take the quality warranty measures described in section 8-2. However, if there is an agreement on the warranty period in the basic transaction agreement, quality assurance agreement, delivery specifications, etc., it shall be followed.

    8-2. Quality Warranty Remedies

    When it has been proved defective due to manufacturing factors as a result of defect analysis by us, we will either deliver a substitute for the defective product or refund the purchase price of the defective product.

    Note that such delivery or refund is sole and exclusive remedies to your company for the defective product.

    8-3. Remedies after Quality Warranty Period

    With respect to any defect of this product found after the quality warranty period, the defect will be analyzed by us. On the basis of the defect analysis results, the scope and amounts of damage shall be determined by mutual agreement of both parties. Then we will deal with upper limit in Section 8-2. This provision is not intended to limit any legal rights of your company.
9. Anti-radiation design is not implemented in the products described in this document.
10. The X-ray exposure can influence functions and characteristics of the products. Confirm the product functions and characteristics in the evaluation stage.
11. WLCSP products should be used in light shielded environments. The light exposure can influence functions and characteristics of the products under operation or storage.
12. Warning for handling Gallium and Arsenic (GaAs) products (Applying to GaAs MMIC, Photo Reflector). These products use Gallium (Ga) and Arsenic (As) which are specified as poisonous chemicals by law. For the prevention of a hazard, do not burn, destroy, or process chemically to make them as gas or power. When the product is disposed of, please follow the related regulation and do not mix this with general industrial waste or household waste.
13. Please contact our sales representatives should you have any questions or comments concerning the products or the technical information.

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