1-MHz, 80-μA, RRIO Operational Amplifier

Features

- Supply Voltage: 2.1 V to 6.0 V
- Low Supply Current: 80 μA per Channel
- Rail-to-Rail Input and Output
- Bandwidth: 1 MHz
- Slew Rate: 0.7 V/μs
- Excellent EMI Suppress Performance
- Offset Voltage: ±3 mV (Max)
- Offset Voltage Temperature Drift: 2 μV/°C
- Low Noise: 27 nV/√Hz at 1 kHz
- High Output Capability: 100 mA
- Operating Temperature Range: −40°C to 125°C

Applications

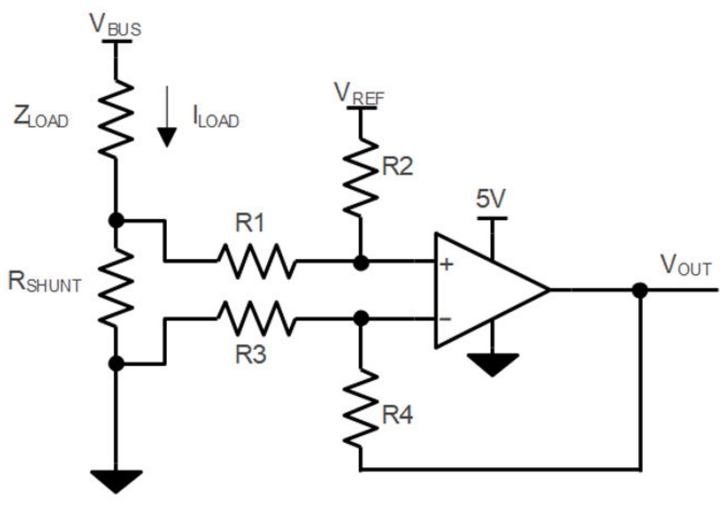
- Active Filters, ASIC Input or Output Amplifiers
- Sensor Interface
- Smoke/Gas/Environment Sensors
- Portable Instruments and Mobile Devices

Description

The TP600x is a series of CMOS single, dual, and quad op amps with RRIO, low offset, low power, and stable high-frequency response. The series incorporates 3PEAK's proprietary and patented design techniques to achieve excellent AC performance with 1-MHz bandwidth, 0.7-V/μs slew rate, and low distortion while drawing only 80 μA of quiescent current per amplifier. The common-mode input voltage range extends 100 mV beyond $-V_S$ and $+V_S$, and the outputs swing rail-to-rail. The TP600x series can be used as plug-in replacements for commercially available op amps to reduce power, extend the input/output ranges, and improve performance.

The combination of features makes the TP600x an ideal choice for motor control and portable audio amplification, sound ports, and other consumer audio. The TP600x op amps are very stable, and capable of driving heavy capacitive loads such as those found in LCDs. The ability to swing rail-to-rail at the inputs and outputs enables designers to buffer CMOS DACs, ASICs, or other wide-output swing devices in single-supply systems.

Typical Application Circuit



$$V_{OUT} = (I_{LOAD} \times R_{SHUNT}) \times (R2 / R1) + V_{REF}$$

When $R3 = R1$, $R2 = R4$, $R_{SHUNT} << R1$

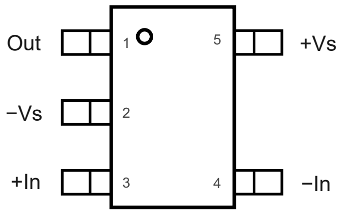
Table of Contents

Revision History

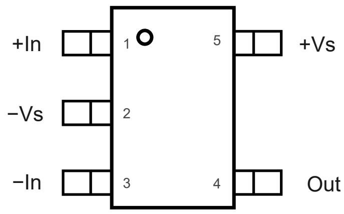
Date	Revision	Notes
2017-08-11	Rev.Pre.0	Released version. Confirmed the spec limit.
2017-10-28	Rev.Pre.1	Corrected the max of Common-Mode Input Voltage Range in Electrical Characteristics: from $(+V_S) - 0.1$ to $(+V_S) + 0.1$. Corrected Operating Temperature Range in Maximum Ratings: from −45 to 125°C to −40 to 125°C.
2017-12-07	Rev.Pre.2	Added package: TP6001U-CR.
2018-02-01	Rev.Pre.3	Corrected Pin Configuration of TP6001R. Corrected the quiescent current per amplifier in Description: from 500 µA to 80 µA.
2018-05-10	Rev.Pre.4	Added a new part number: TP6002-FR. Updated the Package Outline Dimensions data.
2021-03-21	Rev.A.0	Updated the document format. Updated the Marking Information of TP6002-FR: from 6002 to 602.
2024-12-18	Rev.A.1	The following updates are all about the new datasheet formats or typos, and the actual product remains unchanged. Updated to a new datasheet format. Updated to the Package Outline Dimensions. Updated the Tape and Reel Information.

Pin Configuration and Functions

TP6001
SOT23-5/SOT353 (SC70-5)
Top View



TP6001U
SOT23-5/SOT353 (SC70-5)
Top View



TP6001R
SOT23-5
Top View

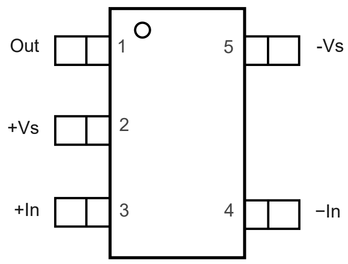


Table 1. Pin Functions: TP6001/TP6001U/TP6001R

Pin No.			Name	I/O	Description
TP6001	**TP6001U**	**TP6001R**			
1	4	1	Out	O	Output
2	2	5	$-V_S$	-	Negative power supply
3	1	3	+In	I	Non-inverting input
4	3	4	−In	I	Inverting input
5	5	2	$+V_S$	-	Positive power supply

TP6002
SOP8/TSSOP8/MSOP8
Top View

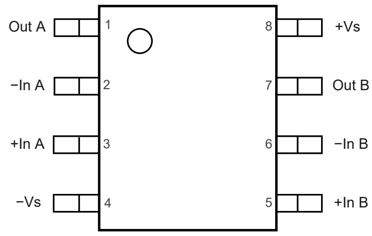
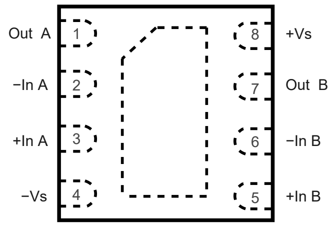


Table 2. Pin Functions: TP6002

Pin No.	Name	I/O	Description
1	Out A	O	Output
2	−In A	I	Inverting input
3	+In A	I	Non-inverting input
4	$-V_S$	-	Negative power supply
5	+In B	I	Non-inverting input
6	−In B	I	Inverting input
7	Out B	O	Output
8	$+V_S$	-	Positive power supply

TP6002
DFN2X2-8
Top View



The thermal pad of DFN2X2-8 package is recommended to be left float or connected to $-V_S$.

Table 3. Pin Functions: TP6002

Pin No.	Name	I/O	Description
1	Out A	O	Output
2	−In A	I	Inverting input
3	+In A	I	Non-inverting input
4	$-V_S$	-	Negative power supply
5	+In B	I	Non-inverting input
6	−In B	I	Inverting input
7	Out B	O	Output
8	$+V_S$	-	Positive power supply

TP6004
SOP14/TSSOP14
Top View

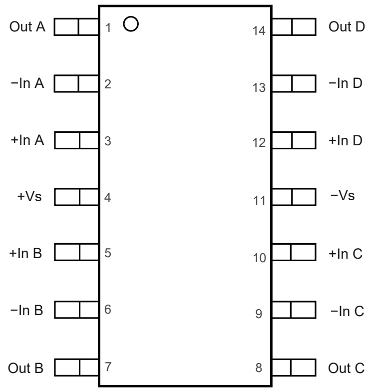


Table 4. Pin Functions: TP6004

Pin No.	Name	I/O	Description
1	Out A	O	Output
2	−In A	I	Inverting input
3	+In A	I	Non-inverting input
4	$+V_S$	-	Positive power supply
5	+In B	I	Non-inverting input
6	−In B	I	Inverting input
7	Out B	O	Output power supply
8	Out C	O	Output power supply
9	−In C	I	Inverting input
10	+In C	I	Non-inverting input
11	$-V_S$	-	Negative power supply
12	+In D	I	Noninverting input
13	−In D	I	Inverting input
14	Out D	O	Output

Specifications

Absolute Maximum Ratings (1)

Parameter		Min	Max	Unit
	Supply Voltage		7	V
	Input Voltage	$(-V_S) - 0.3$	$(+V_S) + 0.3$	V
	Input Current: +IN, −IN (2)		±10	mA
	Differential Input Voltage	$(-V_S) - (+V_S)$	$(+V_S) - (-V_S)$	mA
	Output Short-Circuit Duration (3)		Indefinite	
T_J	Maximum Junction Temperature		150	°C
T_A	Operating Temperature Range	−40	125	°C
T_{STG}	Storage Temperature Range	−65	150	°C
T_L	Lead Temperature (Soldering, 10 sec)		260	°C

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.
(2) The inputs are protected by ESD-protection diodes to each power supply. If the input extends more than 500 mV beyond the power supply, the input current should be limited to less than 10 mA.
(3) A heat sink may be required to keep the junction temperature below the absolute maximum. This depends on the power supply voltage and how many amplifiers are shorted. The thermal resistance varies with the amount of PC board metal connected to the package. The specified values are for short traces connected to the leads.

ESD, Electrostatic Discharge Protection

Symbol	Parameter	Condition	Minimum Level	Unit
HBM	Human Body Model ESD	ANSI/ESDA/JEDEC JS-001 (1)	8	kV
CDM	Charged Device Model ESD	ANSI/ESDA/JEDEC JS-002 (2)	2	kV

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

Thermal Information

Package Type	θ_{JA}	θ_{JC}	Unit
SOT353 (SC70-5)	400	150	°C/W
SOT23-5	250	81	°C/W
SOP8	158	43	°C/W
MSOP8	210	45	°C/W
TSSOP8	191	44	°C/W
DFN2X2-8	100	60	°C/W
SOP14	120	36	°C/W
TSSOP14	180	35	°C/W

Electrical Characteristics

All test conditions: V_S = 5 V, R_L = 10 kΩ, V_{CM} = V_{DD} / 2, T_A = +27°C, unless otherwise noted.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Power Supply						
V_S	Supply Voltage Range		2.1		6	V
I_Q	Quiescent Current per Amplifier			80	130	μA
PSRR	Power Supply Rejection Ratio		80	100		dB
Input Characteristics						
V_{OS}	Input Offset Voltage	V_{CM} = 0 V to 3 V	−3	0.5	3	mV
V_{OS} TC	Input Offset Voltage Drift	T_A = −40°C to 125°C		2		μV/°C
I_B	Input Bias Current	T_A = 25°C		1		pA
		T_A = 85°C		25		pA
I_{OS}	Input Offset Current			1		pA
C_{IN}	Input Capacitance	Differential mode		8		pF
		Common mode		7		pF
A_V	Open-Loop Voltage Gain	R_{LOAD} = 10 kΩ	85	110		dB
V_{CMR}	Common-Mode Input Voltage Range		(−V_S) − 0.1		(+V_S) + 0.1	V
CMRR	Common-Mode Rejection Ratio	V_{CM} = 0 V to 3 V	70	100		dB
Xtalk	Channel Separation	f = 1 kHz, R_L = 2 kΩ		110		dB
Output Characteristics						
V_{OH}, V_{OL}	Maximum Output Voltage Swing	R_{LOAD} = 10 kΩ		3	15	mV
I_{SC}	Output Short-Circuit Current			100		mA
AC Specifications						
GBW	Gain-Bandwidth Product			1		MHz
SR	Slew Rate	A_V = 1, V_{OUT} = 1.5 V to 3.5 V, C_{LOAD} = 60 pF, R_{LOAD} = 1 kΩ		0.7		V/μs
t_S	Settling Time, 0.1%	A_V = 1, 2-V step, C_{LOAD} = 60 pF, R_{LOAD} = 1 kΩ		3.5		μs
	Settling Time, 0.01%			4.8		μs
PM	Phase Margin	R_{LOAD} = 1 kΩ, C_{LOAD} = 60 pF		60		°
GM	Gain Margin	R_{LOAD} = 1 kΩ, C_{LOAD} = 60 pF		15		dB
Noise Performance						
E_N	Input Voltage Noise	f = 0.1 Hz to 10 Hz		8		$μV_{PP}$
e_N	Input Voltage Noise Density	f = 1 kHz		27		nV/√Hz
i_N	Input Current Noise	f = 1 kHz		2		fA/√Hz
THD+N	Total Harmonic Distortion and Noise	f = 1 kHz, A_V = 1, R_L = 2 kΩ, V_{OUT} = 1 Vp-p		0.003		%

Typical Performance Characteristics

All test conditions: V_S = 5 V, V_{CM} = 2.5 V, R_L = Open, unless otherwise noted.

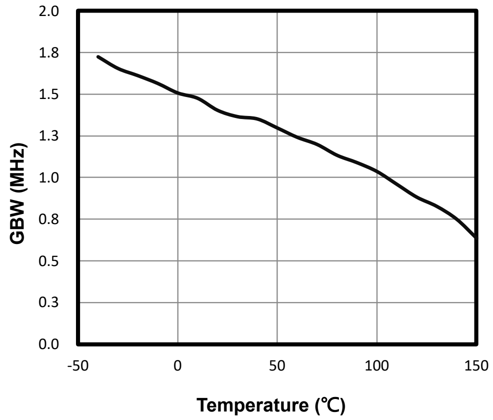


Figure 1. Unity Gain Bandwidth vs. Temperature

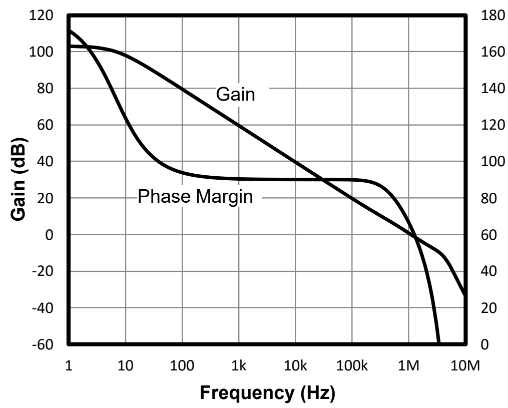


Figure 2. Open-Loop Gain and Phase

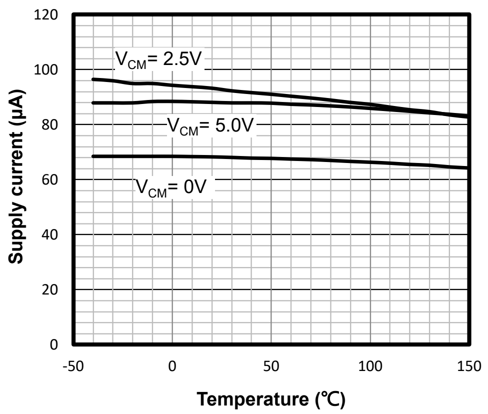


Figure 3. Supply Current vs. Temperature

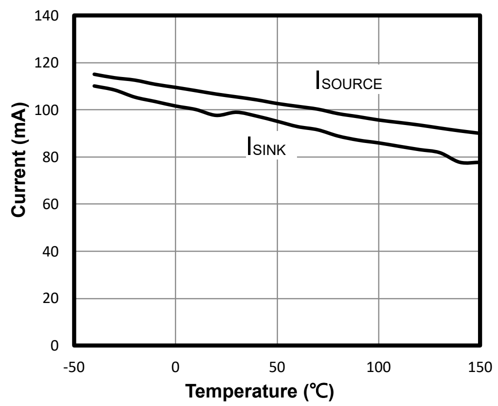


Figure 4. Short Circuit Current vs. Temperature

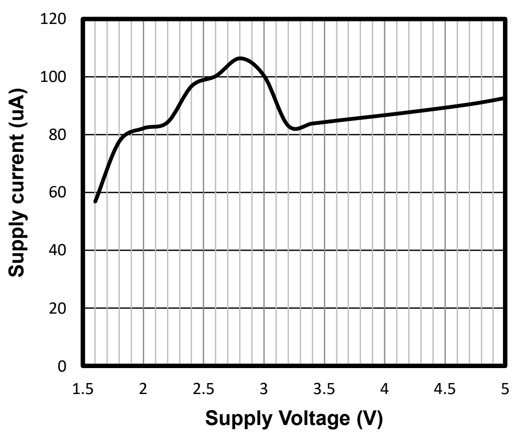


Figure 5. Quiescent Current vs. Supply Voltage

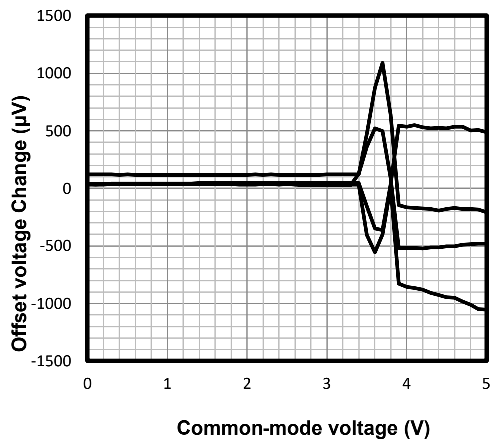


Figure 6. Offset Voltage vs. Common-Mode Voltage

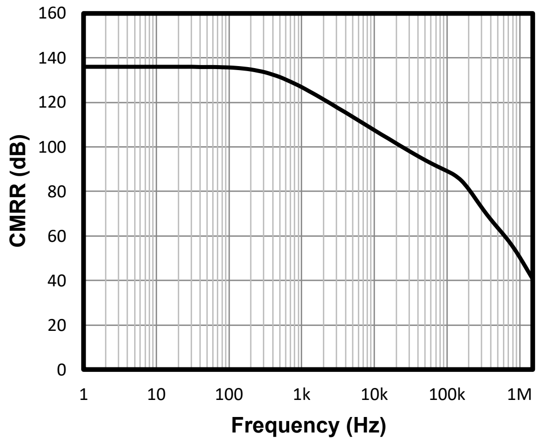


Figure 7. CMRR vs. Frequency

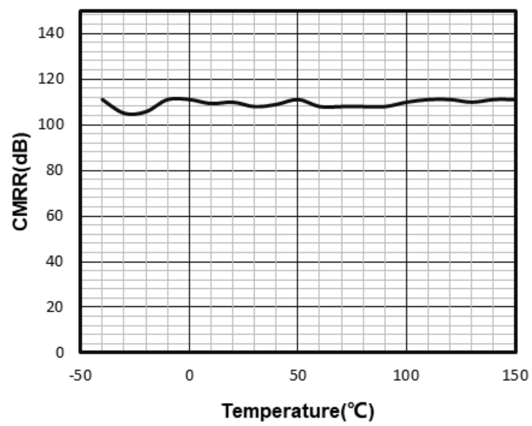


Figure 8. CMRR vs. Temperature

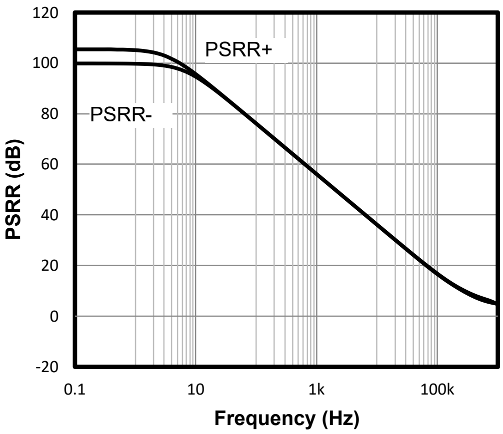


Figure 9. PSRR vs. Frequency

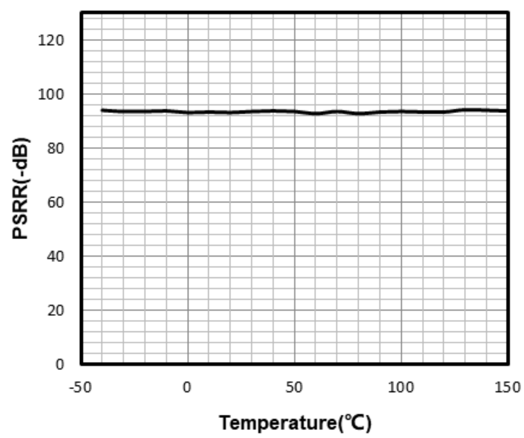


Figure 10. PSRR vs. Temperature

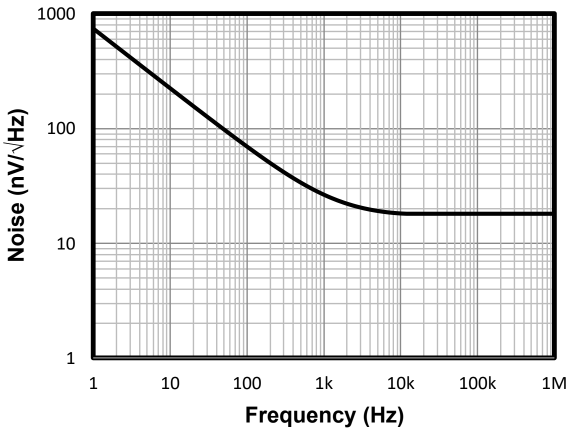


Figure 11. Input Voltage Noise Spectral Density

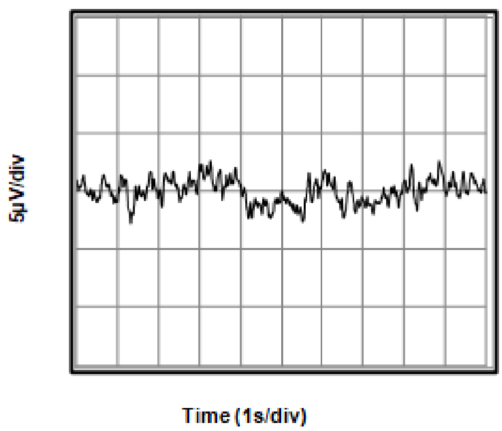


Figure 12. 0.1-Hz to 10-Hz Input Voltage Noise

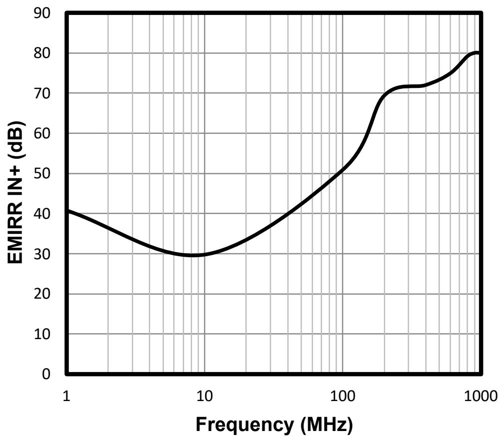


Figure 13. EMIRR IN+ vs. Frequency

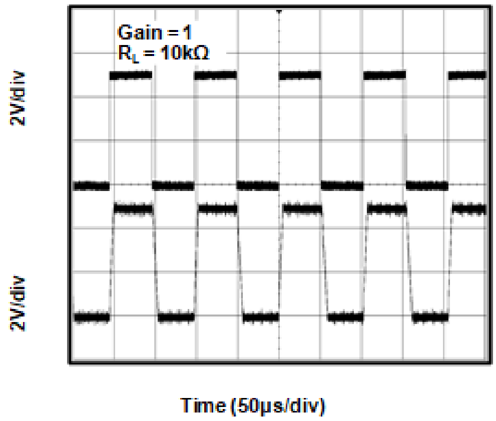


Figure 14. Large-Scale Step Response

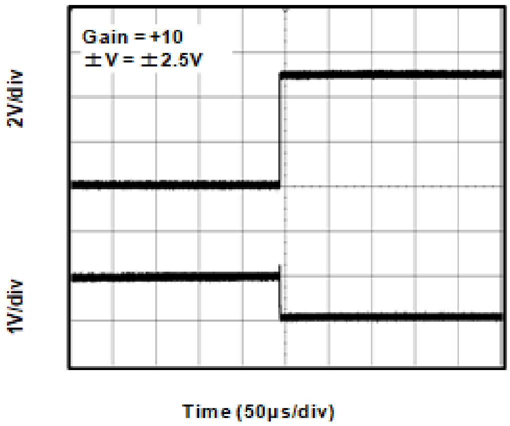


Figure 15. Negative Over-Voltage Recovery

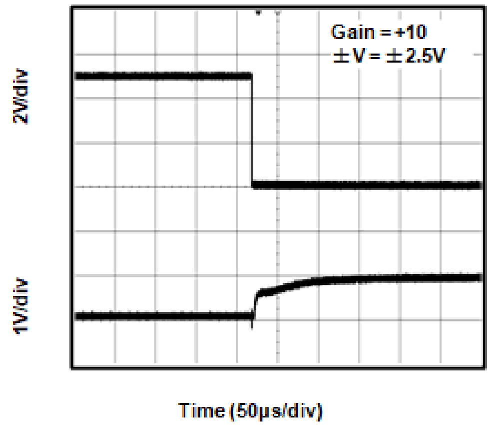


Figure 16. Positive Over-Voltage Recovery

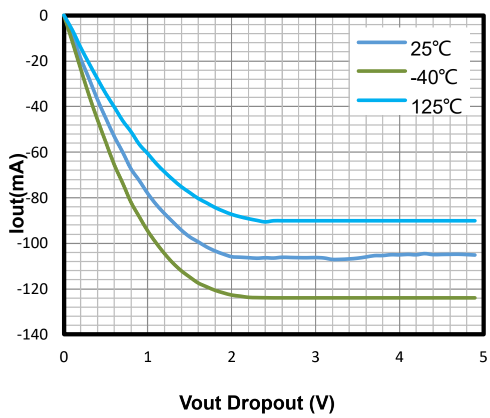


Figure 17. Negative Output Swing vs. Load Current

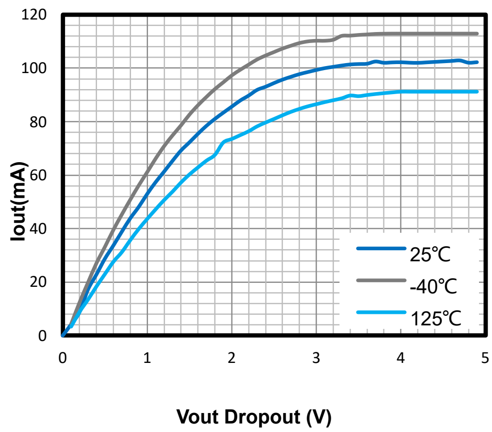


Figure 18. Positive Output Swing vs. Load Current

Application and Implementation

Note

Information in the following application sections is not part of the 3PEAK's component specification and 3PEAK does not warrant its accuracy or completeness. 3PEAK's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

Application Information

Low Supply Voltage and Low Power Consumption

The TP600x is a series of operational amplifiers that operate with power supply voltages from 2.1 V to 6.0 V. Each amplifier draws only 80-µA quiescent current. The low supply voltage capability and low supply current are ideal for portable applications demanding high capacitive-load driving capability and stable wide bandwidth. The TP600x series is optimized for wide-bandwidth and low-power applications. It has an industry-leading high GBWP to power ratio, and is unity-gain stable for any capacitive loads. When the load capacitance increases, the increased capacitance at the output pushes the non-dominant pole to lower the frequency in the open-loop frequency response, lowering the phase and the gain margin. Higher gain configurations tend to have better capacitive-load drive capability than lower gain configurations due to the lower closed-loop bandwidth and higher phase margin.

Ground Sensing and Rail-to-Rail Output

The TP600x series has excellent output drive capability, delivering over 100 mA of the output drive current. The output stage is a rail-to-rail topology that is capable of swinging to within 10 mV of either rail. Since the inputs can go 300 mV beyond either rail, the operational amplifiers can easily perform 'true ground' sensing.

The maximum output current is a function of the total supply voltage. As the supply voltage to the amplifier increases, the output current capability also increases. Attention must be paid to keeping the junction temperature of the IC below 150°C when the output is in a continuous short circuit. The output of the amplifier has reverse-biased ESD diodes connected to each supply. The output should not be forced more than 0.5 V beyond either supply, otherwise the current flows through these diodes.

Driving Large Capacitive Loads

Larger load capacitance decreases the overall phase margin in a feedback system where the internal frequency compensation is utilized. As the load capacitance increases, the phase margin of the feedback loop decreases, and the closed-loop bandwidth is reduced. This produces the gain peaking in the frequency response with the overshoot and ringing in the output step response. The unity-gain buffer (G = +1 V/V) is most sensitive to large capacitive loads.

When driving large capacitive loads with the TP600x OPA series (e.g., > 200 pF when G = +1 V/V), a small series resistor at the output (R_{ISO} in Figure 19) improves the phase margin and the stability of the feedback loop by making the output load resistive at higher frequencies.

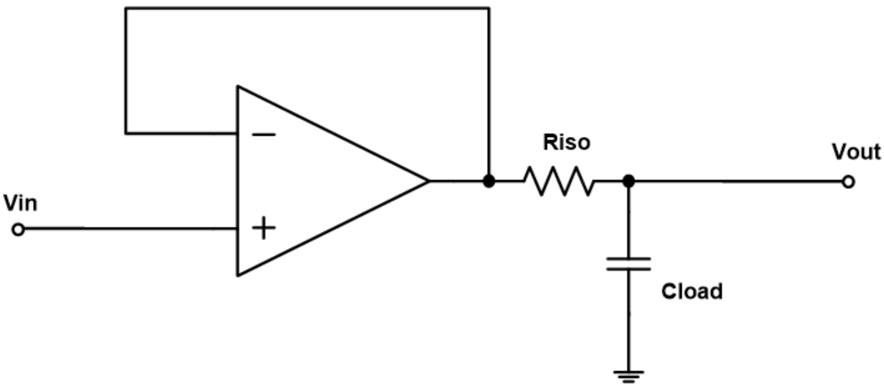
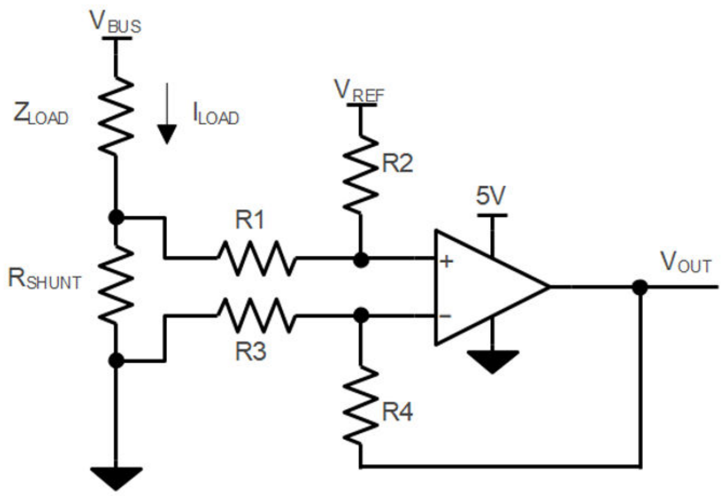


Figure 19. Driving Large Capacitive Loads

Typical Application

Figure 20 shows the typical application schematic.

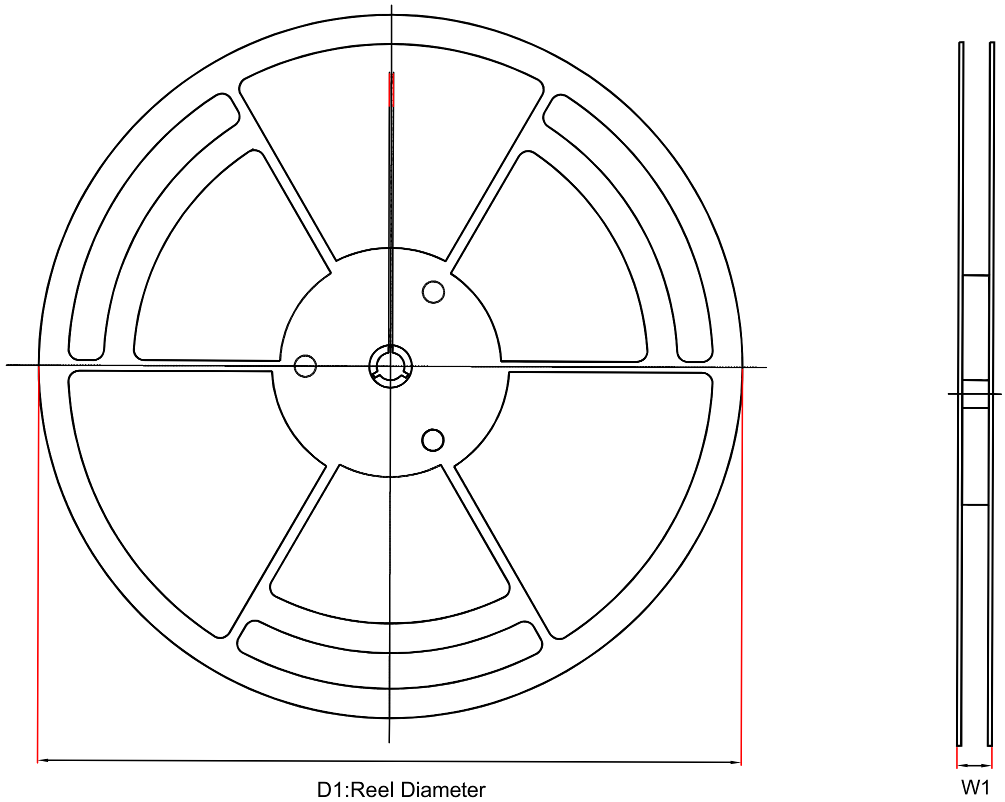


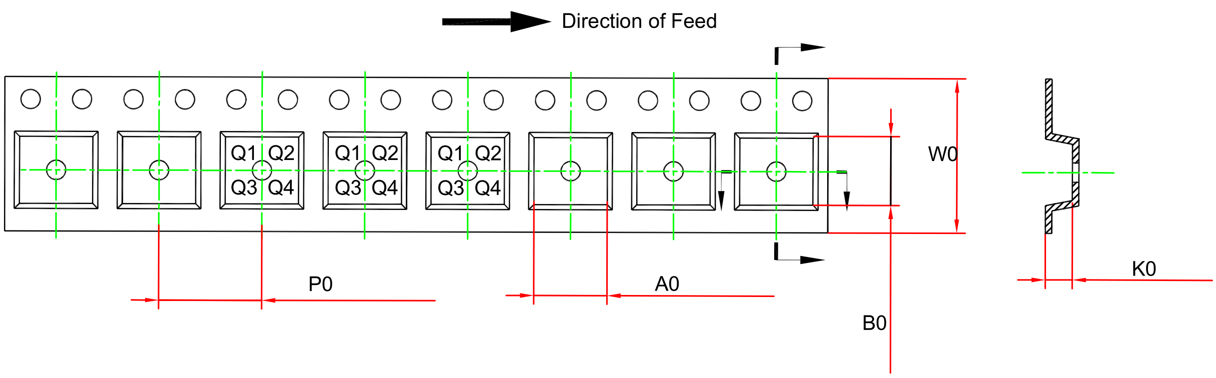
$$V_{OUT} = (I_{LOAD} \times R_{SHUNT}) \times (R2 / R1) + V_{REF}$$

When $R3 = R1$, $R2 = R4$, $R_{SHUNT} << R1$

Figure 20. Typical Application Circuit

Tape and Reel Information





Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm) (1)	B0 (mm) (1)	K0 (mm) (1)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TP6001-CR	SOT353 (SC70-5)	178	12.1	2.4	2.5	1.2	4	8	Q3
TP6001U-CR	SOT353 (SC70-5)	178	12.1	2.4	2.5	1.2	4	8	Q3
TP6001-TR	SOT23-5	180	12	3.3	3.25	1.4	4	8	Q3
TP6001R-TR	SOT23-5	180	12	3.3	3.25	1.4	4	8	Q3

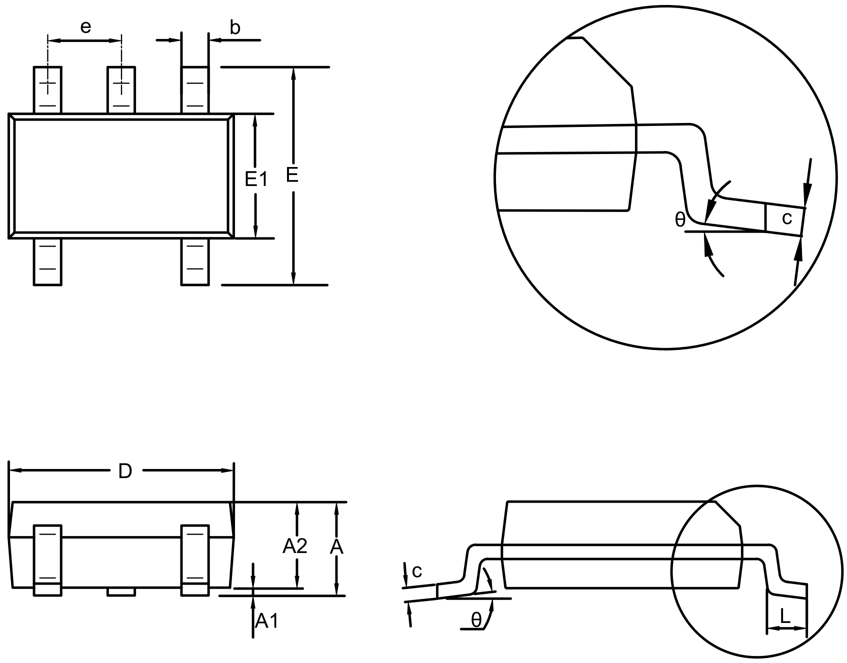
Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm) (1)	B0 (mm) (1)	K0 (mm) (1)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TP6002-SR	SOP8	330.0	17.6	6.4	5.4	2.1	8.0	12.0	Q1
TP6002-VR	MSOP8	330.0	17.6	5.2	3.3	1.5	8.0	12.0	Q1
TP6002-TSR	TSSOP8	330.0	17.6	6.8	3.3	1.2	8.0	12.0	Q1
TP6002-FR	DFN2X2-8	180.0	13.1	2.3	2.3	1.1	4.0	8.0	Q1
TP6004-SR	SOP14	330.0	21.6	6.5	9.0	2.1	8.0	16.0	Q1
TP6004-TR	TSSOP14	330.0	17.6	6.8	5.4	1.2	8.0	12.0	Q1

(1) The value is for reference only. Contact the 3PEAK factory for more information.

Package Outline Dimensions

SOT353 (SC70-5)

Package Outline Dimensions SC5(SOT353-5-A)



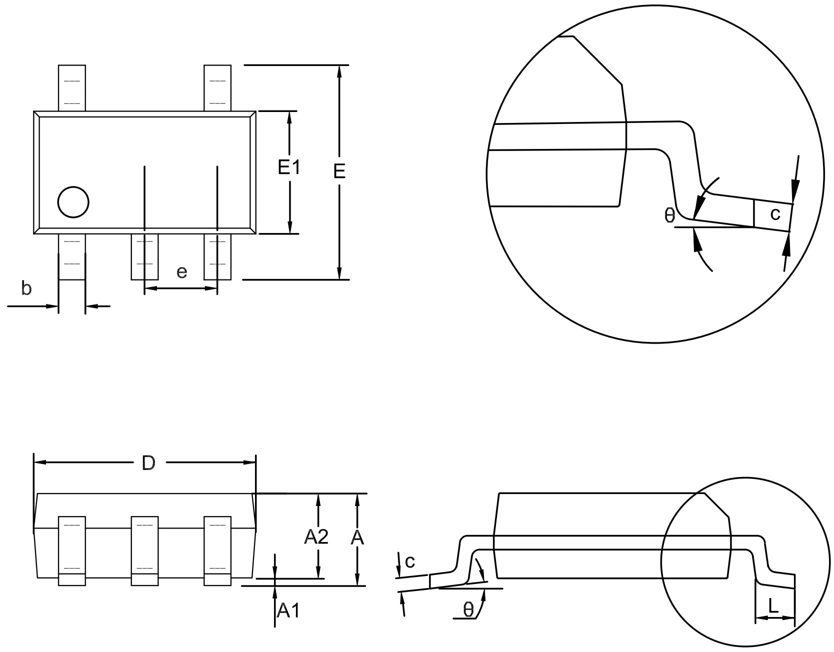
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.850	1.100	0.033	0.043
A1	0.000	0.100	0.000	0.004
A2	0.800	1.000	0.031	0.039
b	0.150	0.350	0.006	0.014
c	0.110	0.230	0.004	0.009
D	2.000	2.200	0.079	0.087
E	2.150	2.450	0.085	0.096
E1	1.150	1.350	0.045	0.053
e	0.650 BSC		0.026 BSC	
L	0.260	0.460	0.010	0.018
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

SOT23-5

Package Outline Dimensions S5T(SOT23-5-A)



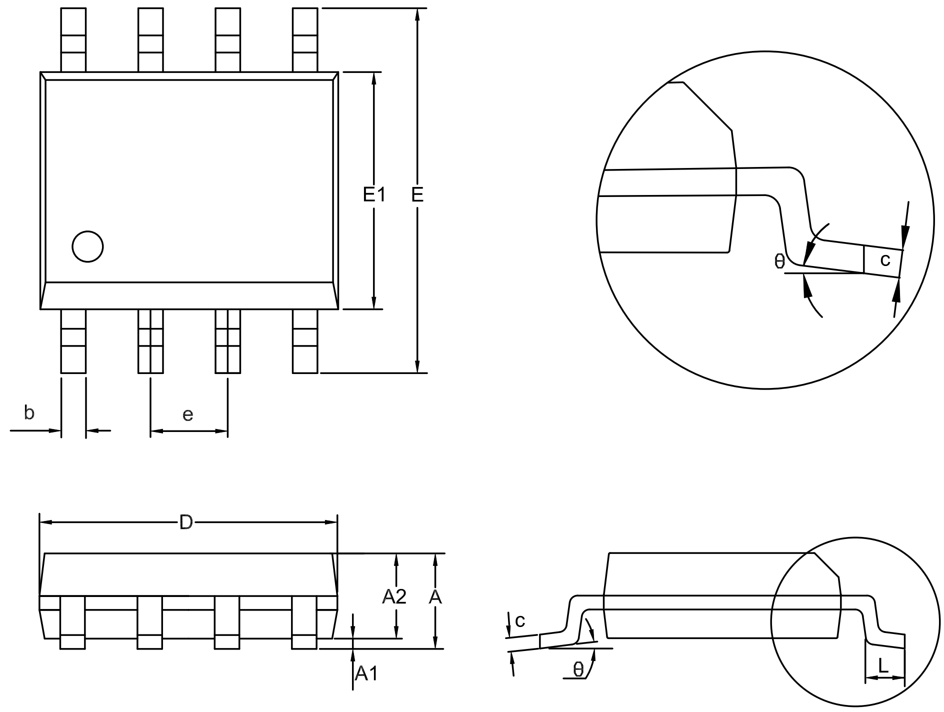
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	1.050	1.250	0.041	0.049
A1	0.000	0.150	0.000	0.006
A2	1.000	1.200	0.039	0.047
b	0.280	0.500	0.011	0.020
c	0.100	0.230	0.004	0.009
D	2.820	3.020	0.111	0.119
E	2.600	3.000	0.102	0.118
E1	1.500	1.720	0.059	0.068
e	0.950 BSC		0.037 BSC	
L	0.300	0.600	0.012	0.024
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

SOP8

Package Outline Dimensions SO1(SOP-8-A)



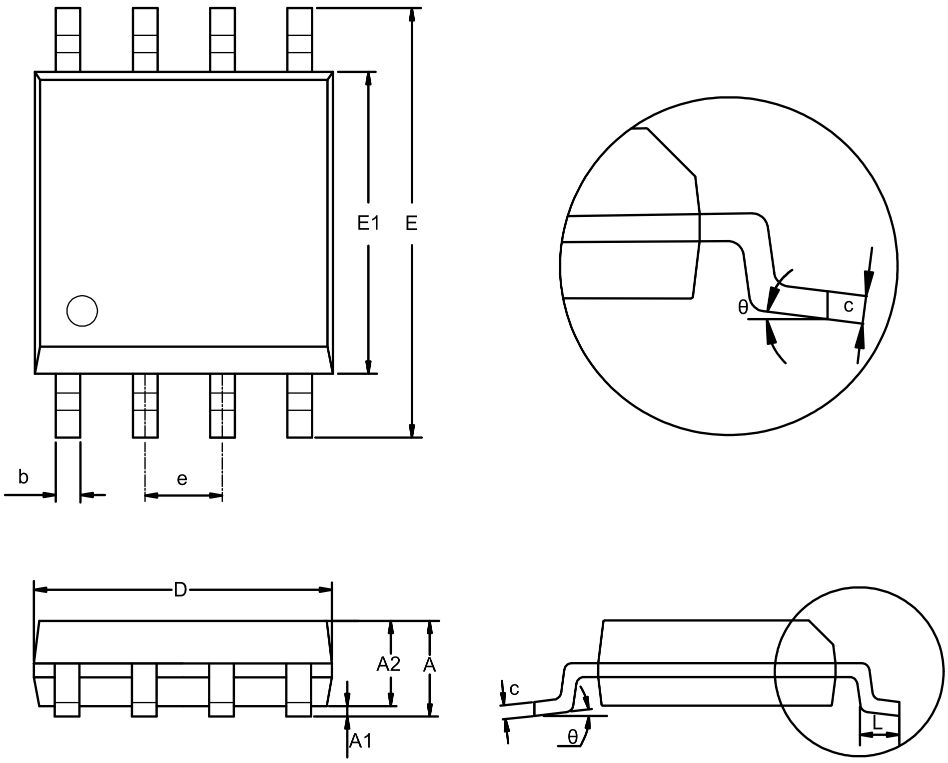
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	1.350	1.750	0.053	0.069
A1	0.050	0.250	0.002	0.010
A2	1.250	1.550	0.049	0.061
b	0.330	0.510	0.013	0.020
c	0.170	0.250	0.007	0.010
D	4.700	5.100	0.185	0.201
E	5.800	6.200	0.228	0.244
E1	3.800	4.000	0.150	0.157
e	1.270 BSC		0.050 BSC	
L	0.400	1.000	0.016	0.039
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

MSOP8

Package Outline Dimensions VS1(MSOP-8-A)



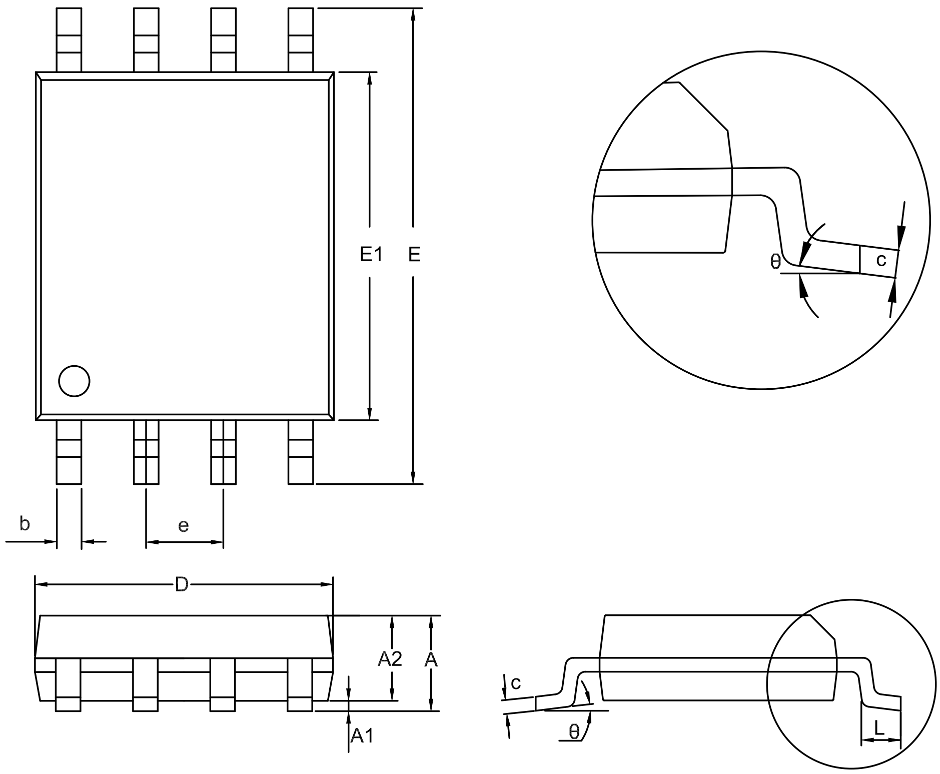
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.800	1.100	0.031	0.043
A1	0.020	0.150	0.001	0.006
A2	0.750	0.950	0.030	0.037
b	0.250	0.380	0.010	0.015
c	0.090	0.230	0.004	0.009
D	2.900	3.100	0.114	0.122
E	4.700	5.100	0.185	0.201
E1	2.900	3.100	0.114	0.122
e	0.650 BSC		0.026 BSC	
L	0.400	0.800	0.016	0.031
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

TSSOP8

Package Outline Dimensions TS1(TSSOP-8-A)



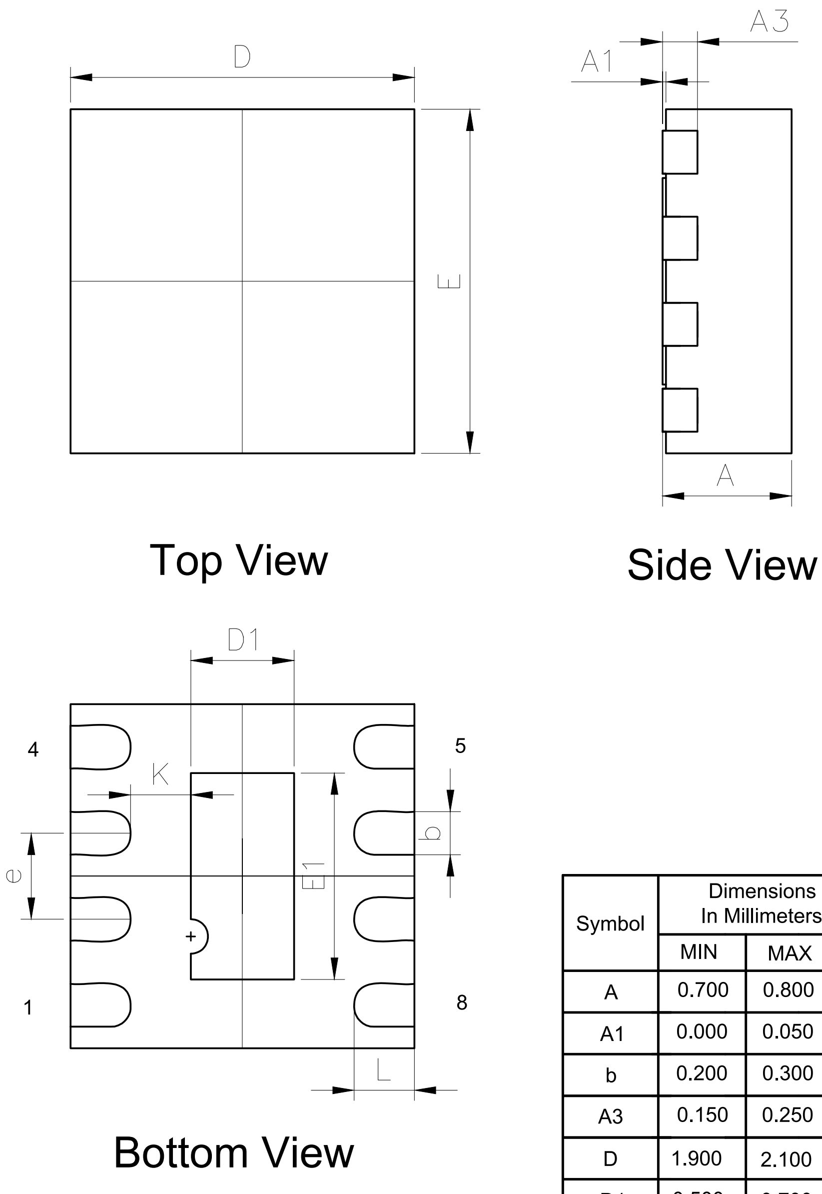
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.900	1.200	0.035	0.047
A1	0.050	0.150	0.002	0.006
A2	0.800	1.050	0.031	0.041
b	0.190	0.300	0.007	0.012
c	0.090	0.200	0.004	0.008
D	2.900	3.100	0.114	0.122
E	6.200	6.600	0.244	0.260
E1	4.300	4.500	0.169	0.177
e	0.650 BSC		0.026 BSC	
L	0.450	0.750	0.018	0.030
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

DFN2X2-8

Package Outline Dimensions DF4(DFN2X2-8-A)



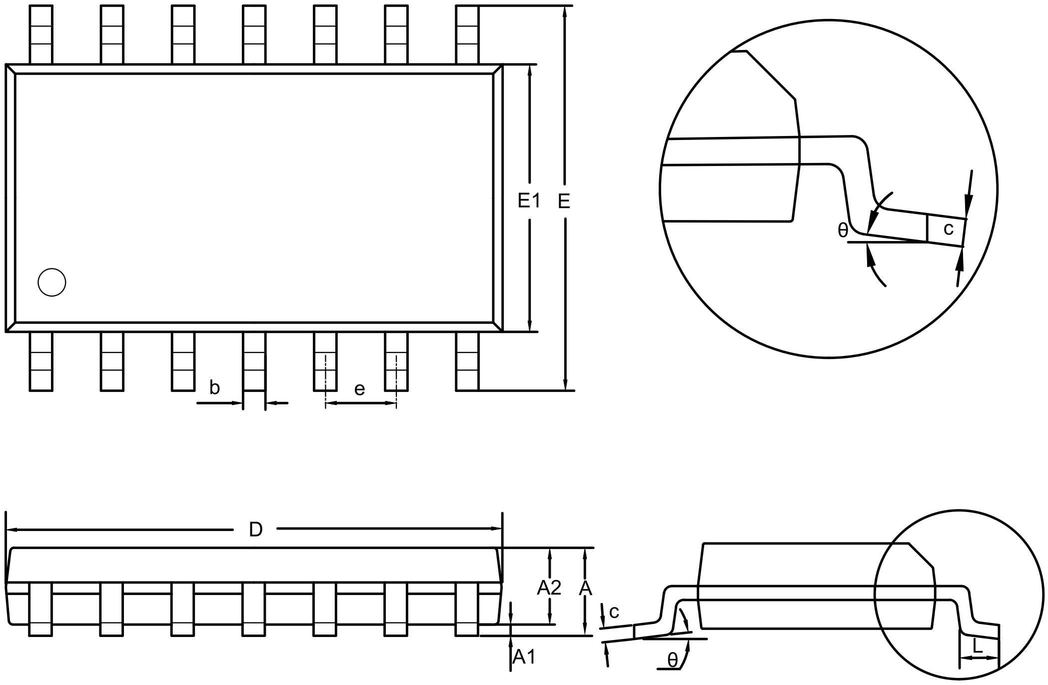
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
b	0.200	0.300	0.008	0.012
A3	0.150	0.250	0.006	0.010
D	1.900	2.100	0.075	0.083
D1	0.500	0.700	0.020	0.028
E	1.900	2.100	0.075	0.083
E1	1.100	1.300	0.043	0.051
e	0.500 BSC		0.020BSC	
L	0.274	0.426	0.011	0.017

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

SOP14

Package Outline Dimensions SO2(SOP-14-A)



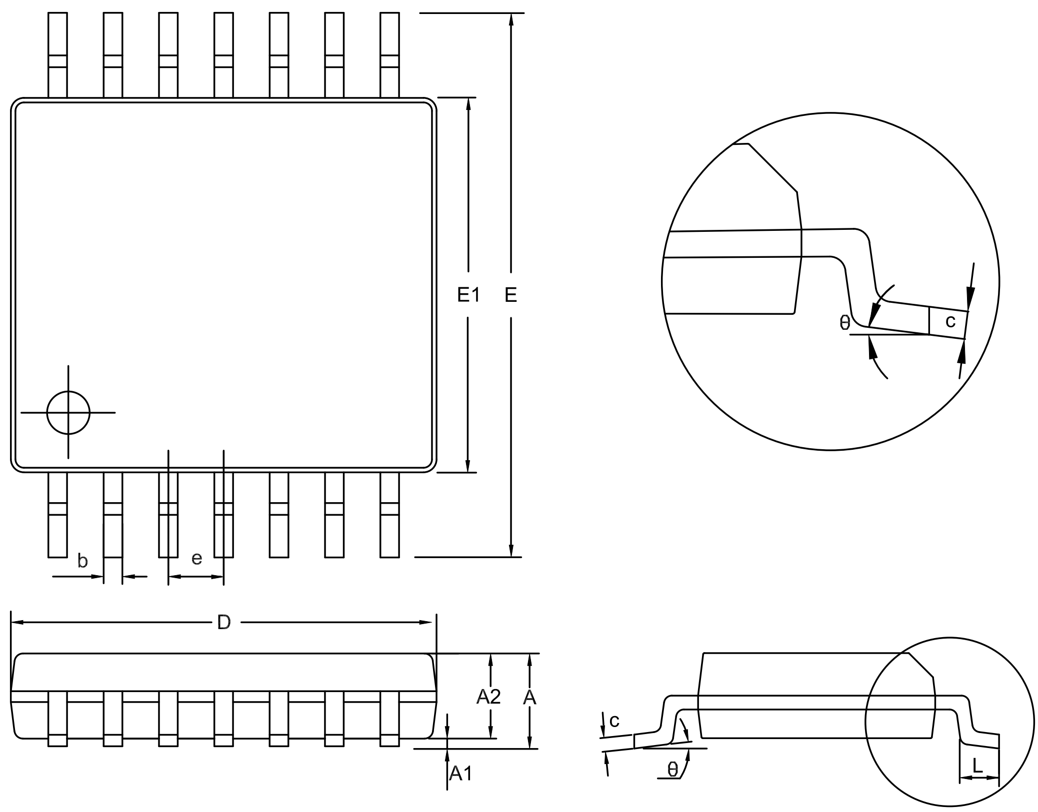
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	1.350	1.750	0.053	0.069
A1	0.050	0.250	0.002	0.010
A2	1.250	1.650	0.049	0.065
b	0.310	0.510	0.012	0.020
c	0.100	0.250	0.004	0.010
D	8.450	8.850	0.333	0.348
E	5.800	6.200	0.228	0.244
E1	3.800	4.000	0.150	0.157
e	1.270 BSC		0.050 BSC	
L	0.400	1.270	0.016	0.050
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

TSSOP14

Package Outline Dimensions TS2(TSSOP-14-A)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.900	1.200	0.035	0.047
A1	0.050	0.150	0.002	0.006
A2	0.800	1.050	0.031	0.041
b	0.190	0.300	0.007	0.012
c	0.090	0.200	0.004	0.008
D	4.900	5.100	0.193	0.201
E	6.200	6.600	0.244	0.260
E1	4.300	4.500	0.169	0.177
e	0.650 BSC		0.026 BSC	
L	0.450	0.750	0.018	0.030
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

Order Information

Order Number	Operating Temperature Range	Package	Marking Information	MSL	Transport Media, Quantity	Eco Plan
TP6001-CR	−40 to 125°C	SOT353 (SC70-5)	601	1	Tape and Reel, 3000	Green
TP6001U-CR	−40 to 125°C	SOT353 (SC70-5)	60U	1	Tape and Reel, 3000	Green
TP6001-TR	−40 to 125°C	SOT23-5	601	3	Tape and Reel, 3000	Green
TP6001R-TR	−40 to 125°C	SOT23-5	60R	3	Tape and Reel, 3000	Green
TP6002-SR	−40 to 125°C	SOP8	6002	3	Tape and Reel, 4000	Green
TP6002-TSR	−40 to 125°C	TSSOP8	6002	3	Tape and Reel, 3000	Green
TP6002-VR	−40 to 125°C	MSOP8	6002	3	Tape and Reel, 3000	Green
TP6002-FR	−40 to 125°C	DFN2X2-8	602	3	Tape and Reel, 3000	Green
TP6004-SR	−40 to 125°C	SOP14	6004	3	Tape and Reel, 2500	Green
TP6004-TR	−40 to 125°C	TSSOP14	6004	3	Tape and Reel, 3000	Green

Green: 3PEAK defines "Green" to mean RoHS compatible and free of halogen substances.

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