MICROTECHNOLOGY
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PA02R

Radiation Tolerant Power Operational Amplifier

RoHS COMPLIANT

FEATURES

- High Power Bandwidth — 350 kHz
- High Slew Rate — 20V/µs
- Fast Settling Time — 600ns
- Low Internal Losses — 1.2V at 2A
- High Output Current — ±5A Peak
- Single Event Effect (SEE) Testing - 62.5 MeV.cm^2/mg
- Total Ionizing Dose (TID) Testing - 50krad (Si)

APPLICATIONS

- Motor, Valve, Actuator, and Gimbal Control
- Magnetic Deflection Circuits up to 5A
- Fine steering & deformable mirrors
- Voice coils & solenoids

DESCRIPTION

The PA02R is a wide-band, high output current operational amplifiers designed to drive resistive, inductive and capacitive loads. Their complementary "collector output" stage can swing close to the supply rails and is protected against inductive kickback. For optimum linearity, the output stage is biased for class A/B operation. The safe operating area (SOA) can be observed for all operating conditions by selection of user programmable, current limiting resistors (down to 10mA). The amplifier is internally compensated but are not recommended for use as unity gain followers. For continuous operation under load, mounting on a heatsink of proper rating is recommended.

These hybrid integrated circuits utilize thick film (cermet) resistors, ceramic capacitors and semiconductor chips to maximize reliability, minimize size and give top performance. Ultrasonically bonded aluminum wires provide reliable interconnections at all operating temperatures. The 8-pin TO-3 package is hermetically sealed and electrically isolated. Isolation washers are not recommended. The use of compressible thermal washers and/or improper mounting torque will void the product warranty. Please see Application Note 1 "General Operating Considerations."

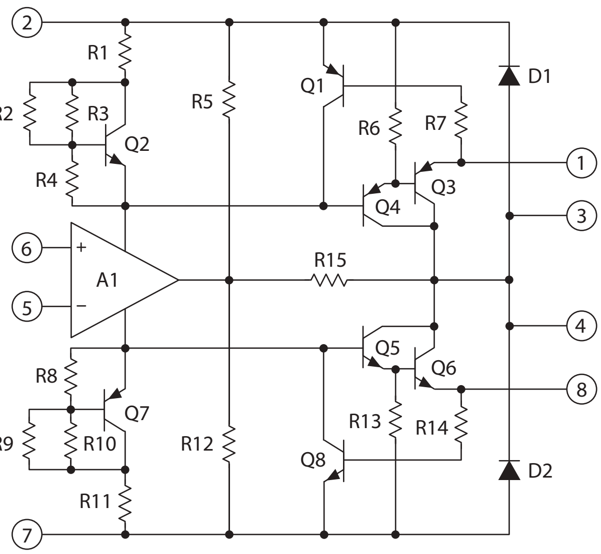
APEX RAD TOLERANT OVERVIEW

As an Apex radiation tolerant device, PA02R has been tested to "M/883" compliance. Additional testing for radiation tolerance includes:

- Particle Impact Noise Detection (PIND) Testing
- Single Event Effect (SEE) Testing: 62.5 MeV.cm^2/mg, Xenon heavy ion
- Enhanced Low Dose Rate Sensitivity (ELDRS) Testing: Dosage: 50 krad (Si)
- High-Dosage Radiation (HDR) Testing: Dosage: 50 krad (Si)

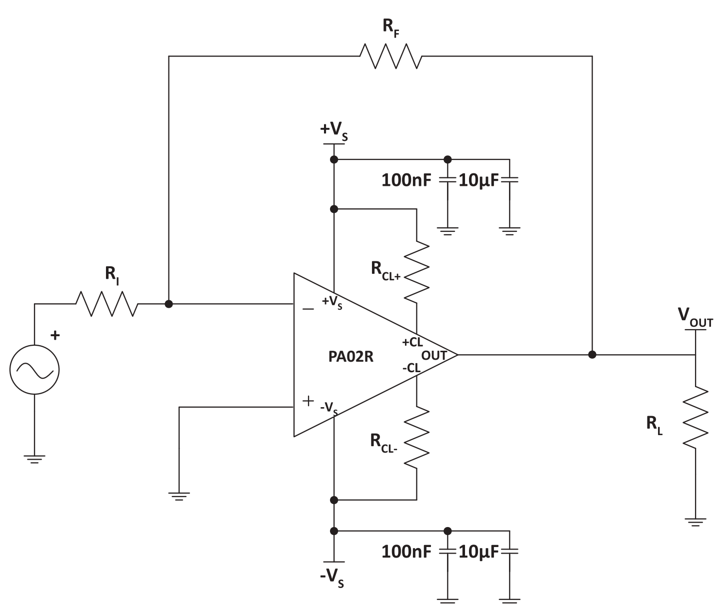
Apex radiation tolerant devices are considered "Class-H", or radiation-tolerant. These devices do not satisfy the requirements for "Class-K" or radiation-hardened devices.

Figure 1: Equivalent Schematic



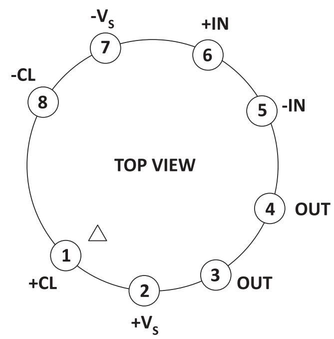
TYPICAL CONNECTIONS

Figure 2: Typical Connections



PINOUT AND DESCRIPTION TABLE

Figure 3: External Connections



Pin Number	Name	Description
1	+CL	Connect to the sourcing current limit resistor, and then the $+V_S$ pin. Power supply current flows into this pin through R_{CL+}.
2	$+V_S$	The positive supply rail.
3, 4	OUT	The output. Connect this pin to load and to the feedback resistors. (Pins 3 and 4 are internally connected).
5	-IN	The inverting input.
6	+IN	The non-inverting input.
7	$-V_S$	The negative supply rail.
8	-CL	Connect to the sinking current limit resistor, and then the $-V_S$ pin. Power supply current flows out of this pin through R_{CL-}.

SPECIFICATIONS

The power supply voltage for all specifications is the TYP rating unless otherwise noted as a test condition. Full temperature specifications are guaranteed but not 100% tested.

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Min	Max	Units
Supply Voltage, total	$+V_S$ to $-V_S$		38	V
Output Current, within SOA	I_{OUT}		5	A
Power Dissipation, internal [1]	P_D		48	W
Input Voltage, differential	$V_{IN\ (Diff)}$	-30	30	V
Input Voltage, common mode	V_{CM}	$-V_S + 2V$	$+V_S - 2V$	V
Temperature, pin solder, 10s max.			350	°C
Temperature, junction [1]	T_J		150	°C
Temperature Range, storage		-65	+150	°C
Operating Temperature Range, case	T_C	-55	+125	°C

1. Long term operation at the maximum junction temperature will result in reduced product life. Derate internal power dissipation to achieve high MTTF.

CAUTION The internal substrate contains beryllia (BeO). Do not break the seal. If accidentally broken, do not crush, machine, or subject to temperatures in excess of 850°C to avoid generating toxic fumes.

INPUT

Parameter	Test Conditions	PA02			PA02R			Units
		Min	Typ	Max	Min	Typ	Max	
Offset Voltage, initial	T_C = 25°C		±5	±10		±1		mV
Offset Voltage vs. temperature	Full temp range		±10	±50		*		µV/°C
Offset Voltage vs. supply	T_C = 25°C		±10			*		µV/V
Offset Voltage vs. power[2]	T_C = 25°C		±6			*		µV/W
Bias Current, initial[2]	T_C = 25°C		50	200		102		pA
Bias Current vs. temperature	T_C = 85°C			200			*	pA/°C
Bias Current vs. supply	T_C = 25°C		0.01			*		pA/V
Offset Current, initial[2]	T_C = 25°C		25	100		100		pA
Offset Current vs. temperature	T_C = 85°C			100			*	pA/°C
Input Impedance, DC	T_C = 25°C		1000			*		GΩ
Input Capacitance	T_C = 25°C		3			*		pF
Common Mode Voltage Range [1], Pos.	Full temp range	$+V_S$ −6	$+V_S$ −3		*	*		V
Common Mode Voltage Range [1], Neg.	Full temp range	$-V_S$ +6	$-V_S$ +5		*	*		V
Common Mode Rejection, DC[2]	Full temp range	70	100			106		dB

1. Exceeding CMV range can cause the output to latch.
2. Typical values are based on a sample of PA02Rs that underwent radiation testing, reflecting the average of the biased and unbiased HDR data at 50krad. These values provide a general overview of performance; however, the full PA02R Radiation Report should be consulted prior to flight.

GAIN

Parameter	Test Conditions	PA02			PA02R			Units
		Min	Typ	Max	Min	Typ	Max	
Open Loop Gain @ 10 Hz	T_C = 25°C, 1 kΩ load		103			*		dB
Open Loop Gain @ 10 Hz[1]	Full temp range, 10 kΩ load	86	100			112		dB
Gain Bandwidth Product @ 1 MHz	T_C = 25°C, 10 Ω load		4.5			*		MHz
Power Bandwidth	T_C = 25°C, 10 Ω load		350			*		kHz
Phase Margin	Full temp range, 10 Ω load		30			*		°

1. Typical values are based on a sample of PA02Rs that underwent radiation testing, reflecting the average of the biased and unbiased HDR data at 50krad. These values provide a general overview of performance; however, the full PA02R Radiation Report should be consulted prior to flight.

OUTPUT

Parameter	Test Conditions	PA02			PA02R			Units
		Min	Typ	Max	Min	Typ	Max	
Voltage Swing [1,2]	T_C=25°C, I_{OUT} = 5A, R_{CL} = 0.08 Ω	$\pm V_S -4$	$\pm V_S -3$		*	$\pm V_S -0.6$		V
Voltage Swing [1]	Full temp range, I_{OUT} = 2A	$\pm V_S -2$	$\pm V_S -1.2$		*	*		V
Current, peak	T_C = 25°C	5			*			A
Settling Time to 0.1%	T_C=25°C, 2V step		0.6			*		µs
Slew Rate[2]	T_C = 25°C	13	20			21		V/µs
Capacitive Load	Full temp range, A_V > 10		SOA			*		
Harmonic Distortion	P_O=0.5W, F = 1 kHz, R_L = 10 Ω		0.004			*		V
Small Signal rise/fall time	R_L = 10 Ω, A_V = 1		100			*		ns
Small Signal overshoot	R_L = 10 Ω, A_V = 1		10			*		%

1. $+V_S$ and $-V_S$ denote the positive and negative supply rail respectively. Total V_S is measured from $+V_S$ to $-V_S$.
2. Typical values are based on a sample of PA02Rs that underwent radiation testing, reflecting the average of the biased and unbiased HDR data at 50krad. These values provide a general overview of performance; however, the full PA02R Radiation Report should be consulted prior to flight.

POWER SUPPLY

Parameter	Test Conditions	PA02			PA02R			Units
		Min	Typ	Max	Min	Typ	Max	
Voltage	Full temp range	±7	±15	±19	*	*	*	V
Current, Quiescent[1]	T_C = 25°C		27	40		22	*	mA

1. Typical values are based on a sample of PA02Rs that underwent radiation testing, reflecting the average of the biased and unbiased HDR data at 50krad. These values provide a general overview of performance; however, the full PA02R Radiation Report should be consulted prior to flight.

THERMAL

Parameter	Test Conditions	PA02			PA02R			Units
		Min	Typ	Max	Min	Typ	Max	
Resistance, AC junction to case[1]	F > 60 Hz		1.9	2.1		*	*	°C/W
Resistance, DC junction to case	F < 60 Hz		2.4	2.6		*	*	°C/W
Resistance, junction to air			30			*		°C/W
Temperature Range, case	Meets full range specifications	-25		+85	-55		+125	°C

1. Rating applies if the output current alternates between both output transistors at a rate faster than 60 Hz.

Note: * The specifications were not measured under radiation. In a non-radiation environment, the PA02 parameters reflect the behavior of the PA02R. However, in a radiation environment, the PA02R specifications marked with an asterisk (excluding thermal specifications) may deviate from the PA02 specifications.

TYPICAL PERFORMANCE GRAPHS (PA02)

Figure 4: Power Derating

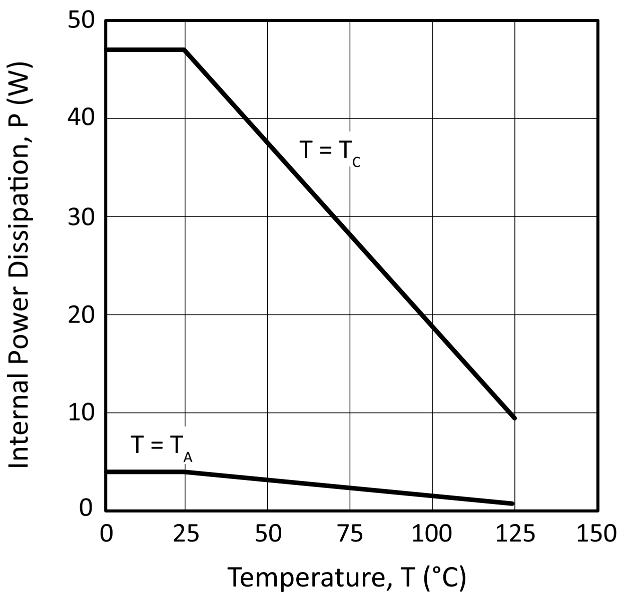


Figure 5: Output Voltage Swing

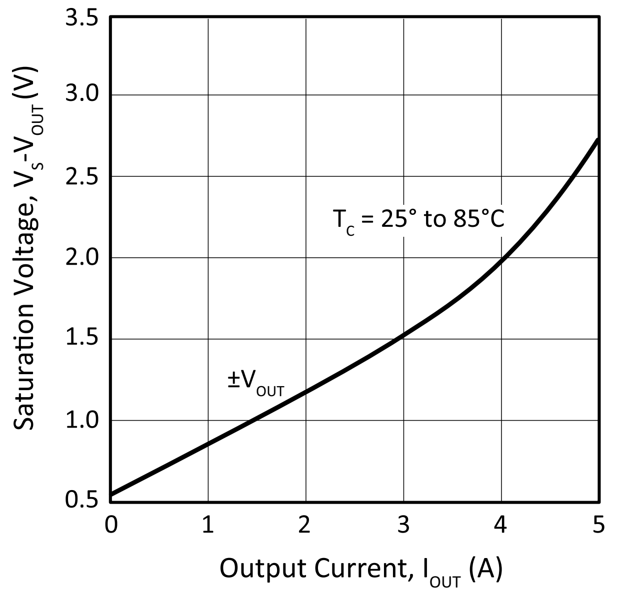


Figure 6: Small Signal Response

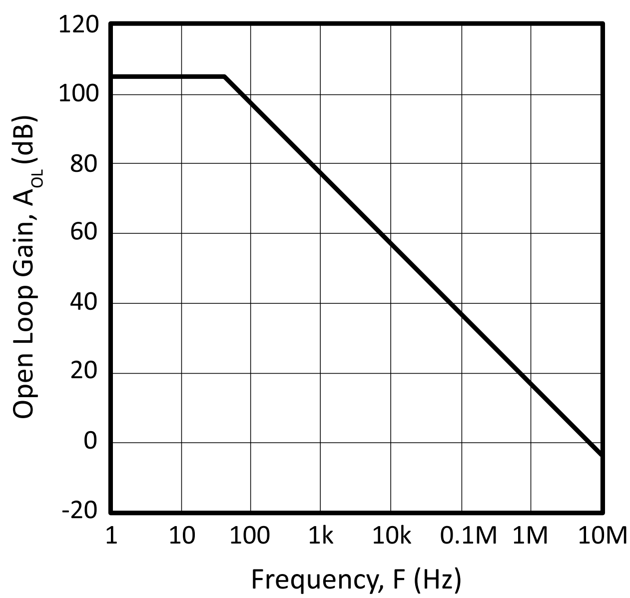


Figure 7: Phase Response

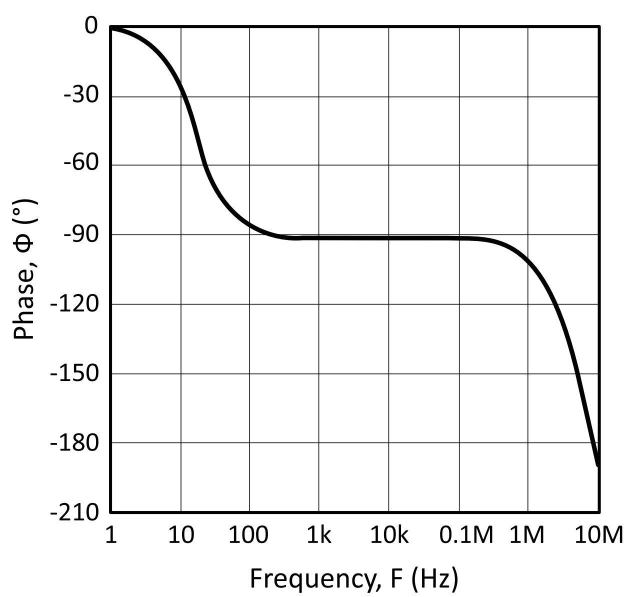


Figure 8: Current Limit

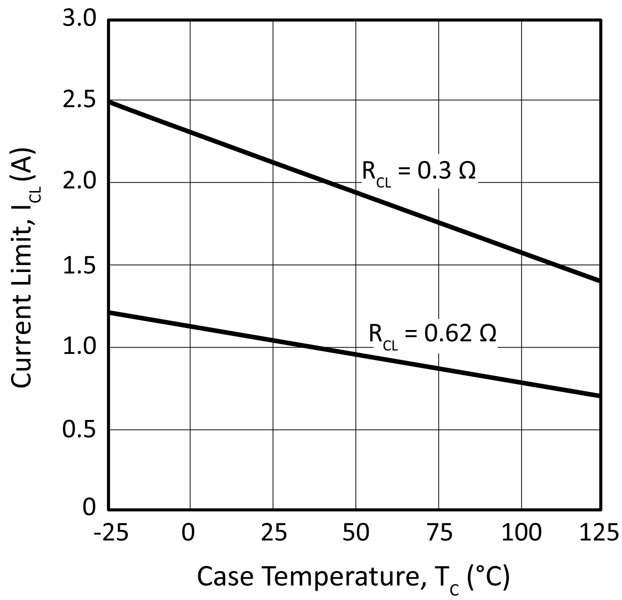


Figure 9: Power Response

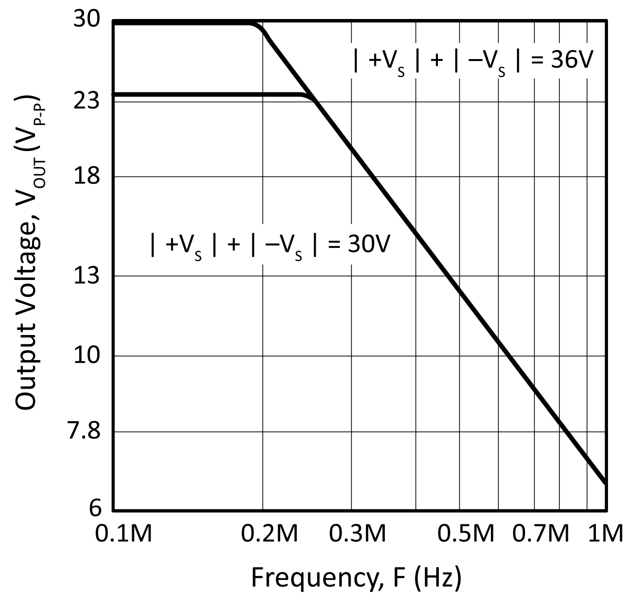


Figure 10: Bias Current

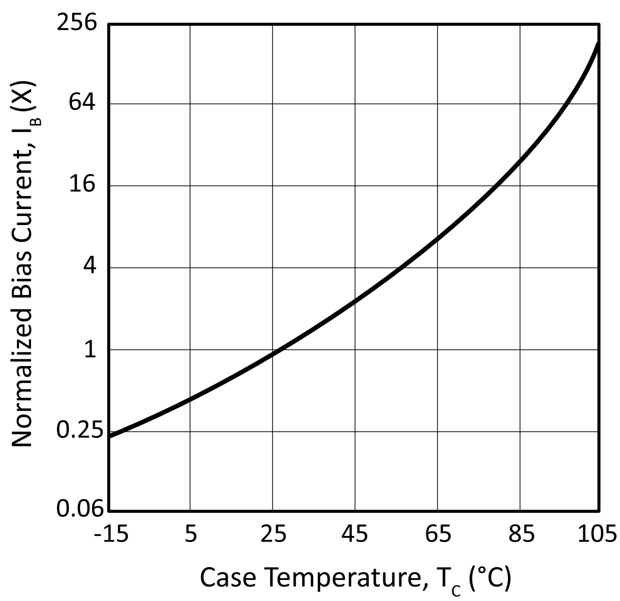


Figure 11: Common Mode Rejection

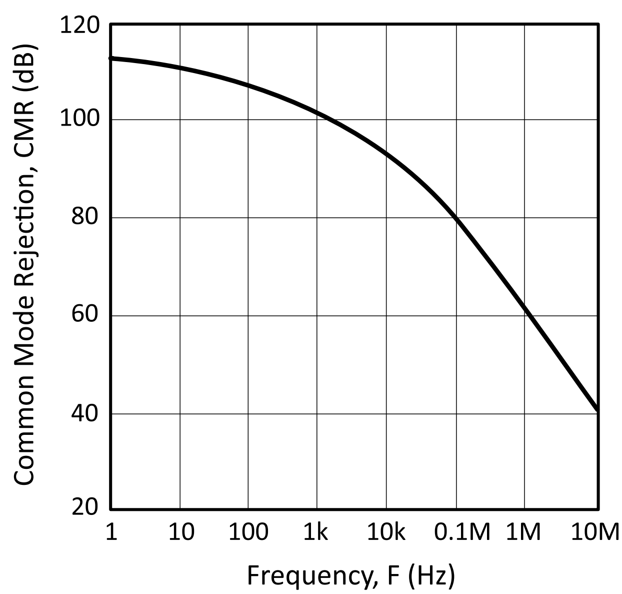


Figure 12: Power Supply Rejection

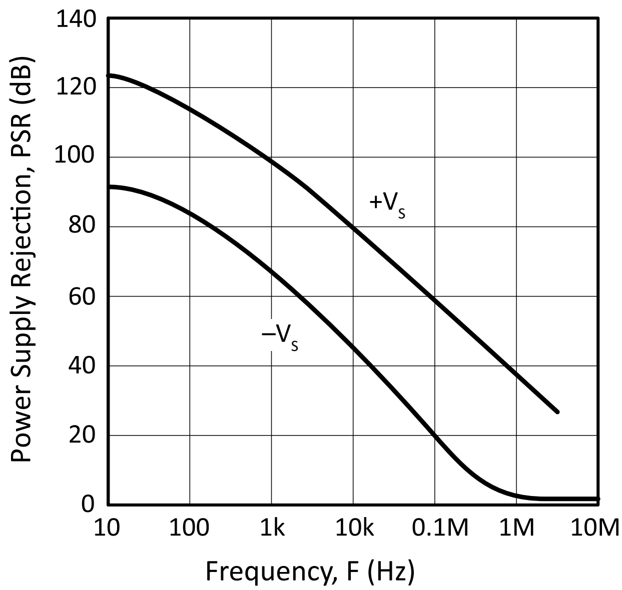


Figure 13: Input Noise

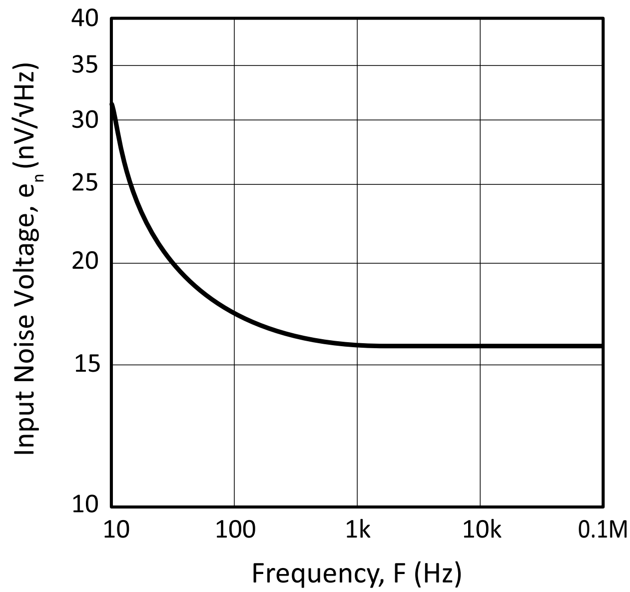


Figure 14: Quiescent Current

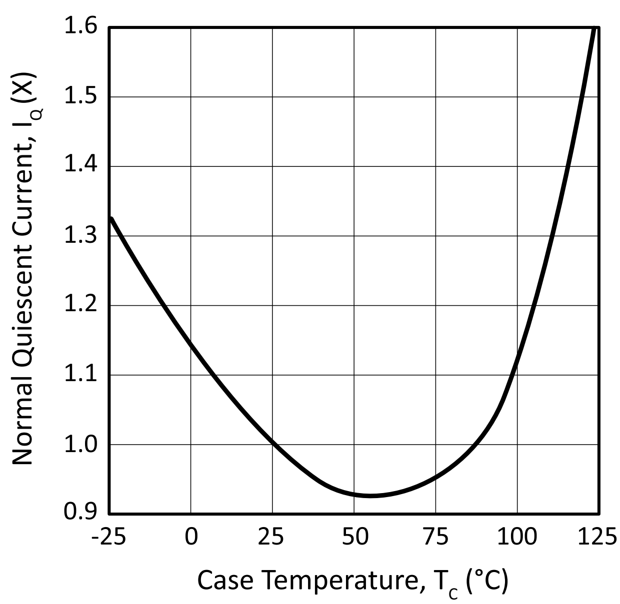


Figure 15: Settling Time

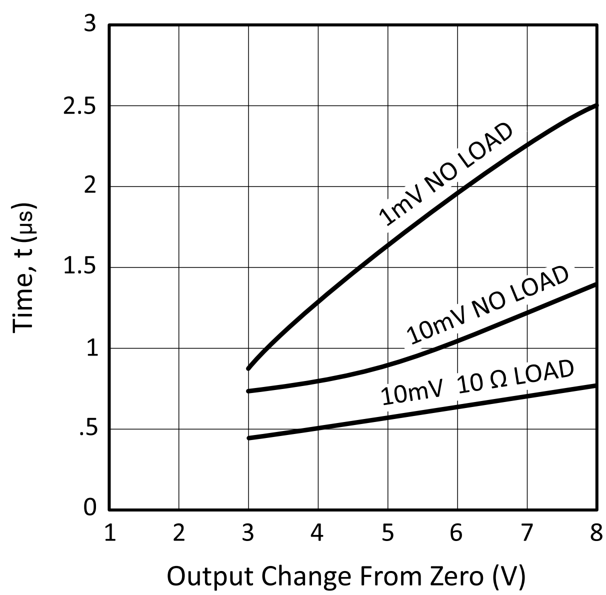


Figure 16: Harmonic Distortion

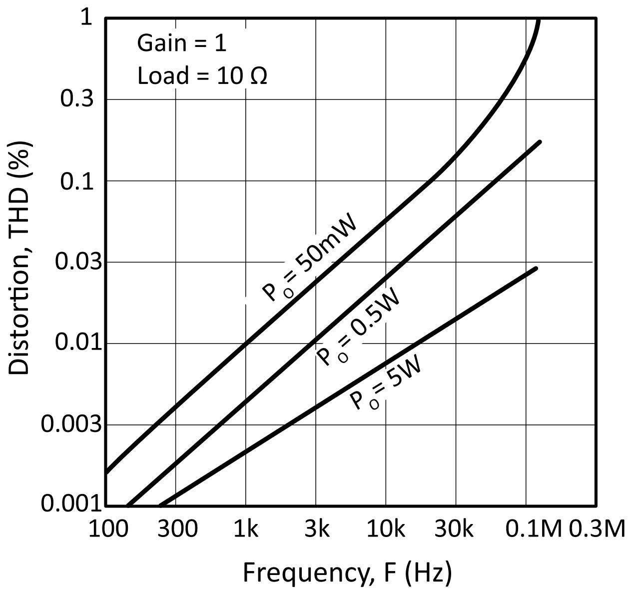


Figure 17: Pulse Response

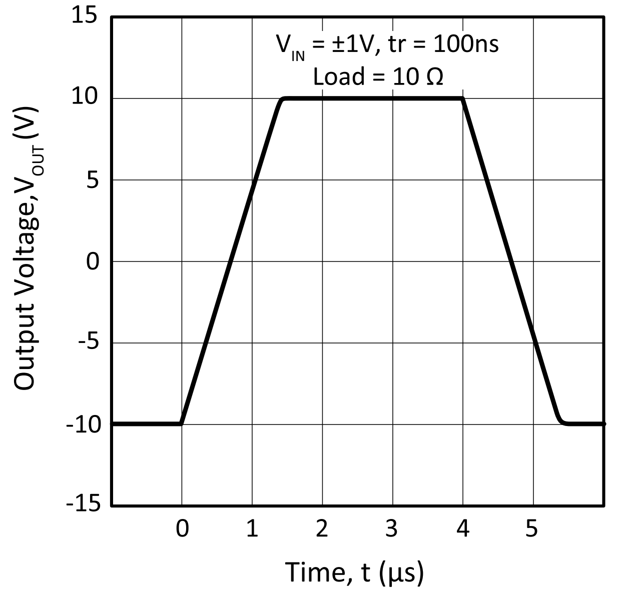


Figure 18: Pulse Response

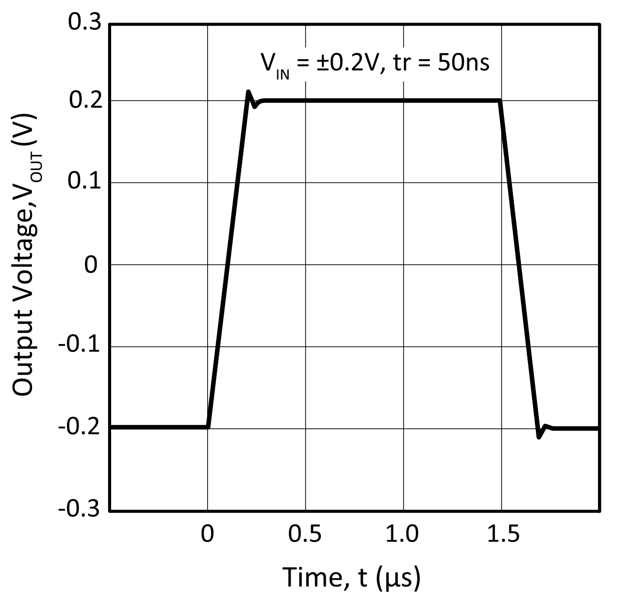
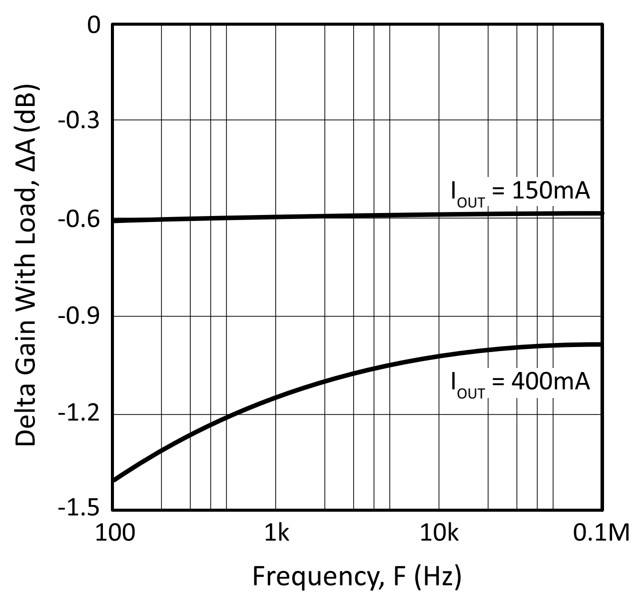


Figure 19: Loading Effects



SAFE OPERATING AREA (SOA)

The SOA curves combine the effect of all limits for this Power Op Amp. For a given application, the direction and magnitude of the output current should be calculated or measured and checked against the SOA curves. This is simple for resistive loads but more complex for reactive and EMF generating loads. The following guidelines may save extensive analytical efforts:

1. Under transient conditions, capacitive and dynamic* loads up to the following maximums are safe:

$\pm V_S$	CAPACITIVE LOAD		INDUCTIVE LOAD	
	I_{CL} = 2A	I_{CL} = 5A	I_{CL} = 2A	I_{CL} = 5A
18V	2 mF	0.7 mF	0.2 H	10 mH
15V	10 mF	2.2 mF	0.7 H	25 mH
10V	25 mF	10 mF	5 H	50 mH

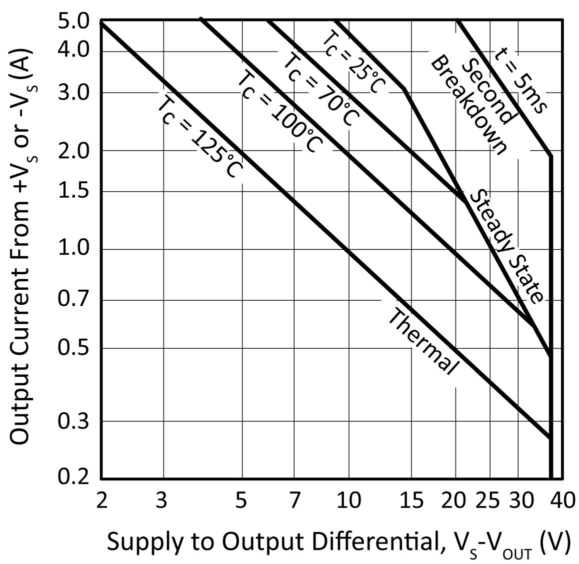
* If the inductive load is driven near steady state conditions, allowing the output voltage to drop more than 8V below the supply rail with I_{CL} = 5A, or 17V below the supply rail with I_{CL} = 2A while the amplifier is current limiting, the inductor should be capacitively coupled or the current limit must be lowered to meet SOA criteria.

2. The amplifier can handle any EMF generating or reactive load and short circuits to the supply rails or shorts to common if the current limits are set as follows at T_C = 85°C.

$\pm V_S$	Short to $\pm V_S$ C, L, or EMF Load	Short to Common
18V	0.5A	1.7A
15V	0.7A	2.8A
10V	1.6A	4.2A

These simplified limits may be exceeded with further analysis using the operating conditions for a specific application.

Figure 20: SOA



GENERAL

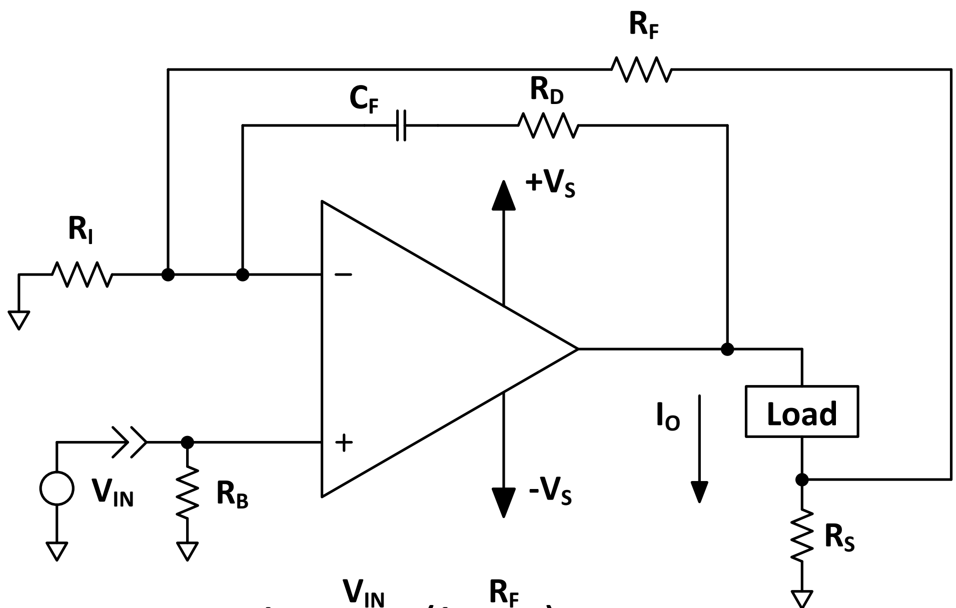
Please read Application Note 1 "General Operating Considerations" which covers stability, supplies, heat sinking, mounting, current limit, SOA interpretation, and specification interpretation. Visit www.apexanalog.com for Apex Microtechnology's complete Application Notes library, Technical Seminar Workbook, and Evaluation Kits.

TYPICAL APPLICATION

VOLTAGE CONTROLLED CURRENT SOURCE

Using the PA02R as a voltage controlled current source (VCCS) can be useful in wide array of applications. Precisely controlling the motor torque is simplified since torque is a direct function of current in the motor. The circuit in figure twenty-one allows for precise control of a solenoid or voice coil. The output current of the VCCS is a function of output voltage (determined by Vin, RF, & RI) and RS. The figure below utilized the PA02R in a non-inverting configuration. In many VCCS applications Cf and Rd are required to stabilize the op amp. More information regarding VCCS can be found in Apex Application Note 13: Voltage to Current Conversion.

Figure 21: Voltage Controlled Current Source



$$I_O = \frac{V_{IN}}{R_S}\left(1+\frac{R_F}{R_I}\right)$$

For: $R_S << R_F$ or R_I

CURRENT LIMIT

Proper operation requires the use of two current limit resistors, connected as shown in the external connection diagram. The minimum value for R_{CL} is 0.12 Ω, however for optimum reliability it should be set as high as possible.

$$R_{CL}(\Omega) = \frac{0.65V}{I_{CL}(A)}$$

Where:

I_{CL} is the current limit in Amperes.

R_{CL} is the current limit resistor value in Ohms.

Refer to Application Note 1 “General Operating Considerations” section of the handbook for current limit adjust details.

DEVICE MOUNTING

The case (mounting flange) is electrically isolated and should be mounted directly to a heatsink with thermal compound. Screws with Belville spring washers are recommended to maintain positive clamping pressure on heatsink mounting surfaces. Long periods of thermal cycling can loosen mounting screws and increase thermal resistance.

Since the case is electrically isolated (floating) with respect to the internal circuits it is recommended to connect it to common or other convenient AC ground potential.

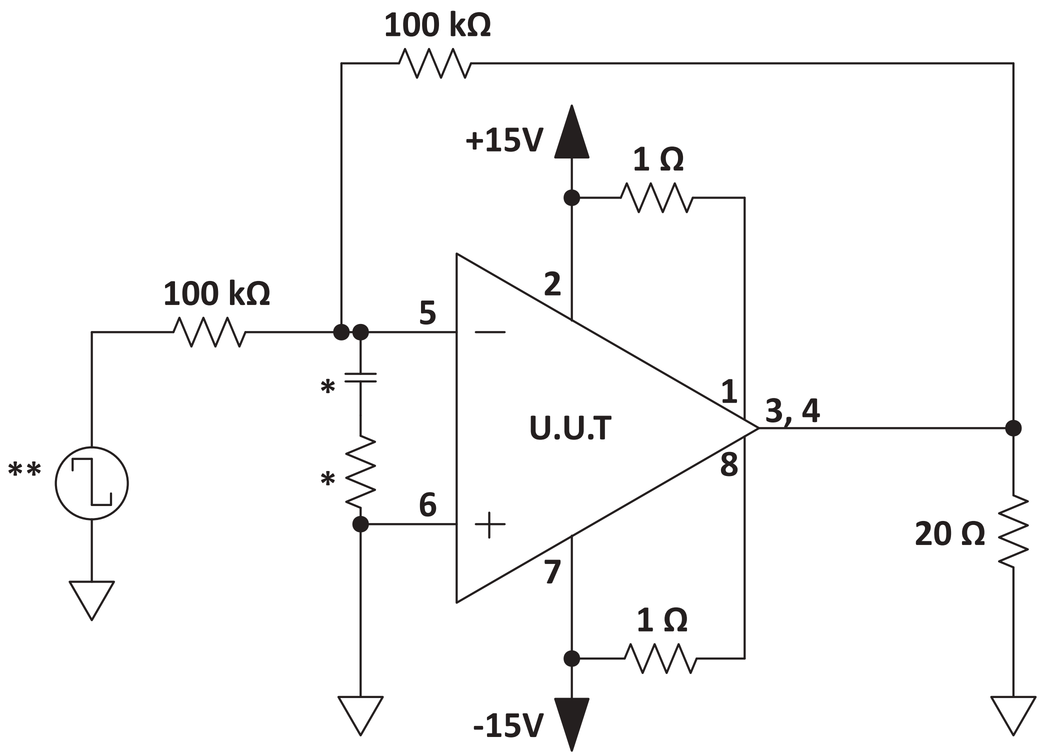
TABLE 4 GROUP A INSPECTION

SG	Parameter	Symbol	Temp.	Power	Test Conditions	Min	Max	Units
1	Quiescent Current	I_Q	25°C	±15V	V_{IN} =0, A_V=100, R_{CL}=0.2 Ω		40	mA
1	Input Offset Voltage	V_{OS}	25°C	±15V	V_{IN} = 0, A_V = 100		10	mV
1	Input Offset Voltage	V_{OS}	25°C	±7V	V_{IN} = 0, A_V = 100		11.6	mV
1	Input Offset Voltage	V_{OS}	25°C	±19V	V_{IN} = 0, A_V = 100		10.8	mV
1	Input Bias Current, +IN	$+I_B$	25°C	±15V	V_{IN} = 0		200	pA
1	Input Bias Current, –IN	$-I_B$	25°C	±15V	V_{IN} = 0		200	pA
1	Input Offset Current	I_{OS}	25°C	±15V	V_{IN} = 0		100	pA
3	Quiescent Current	I_Q	–55°C	±15V	V_{IN}=0, A_V=100, R_{CL} =0.2 Ω		60	mA
3	Input Offset Voltage	V_{OS}	–55°C	±15V	V_{IN} = 0, A_V = 100		14	mV
3	Input Offset Voltage	V_{OS}	–55°C	±7V	V_{IN} = 0, A_V = 100		15.6	mV
3	Input Offset Voltage	V_{OS}	–55°C	±19V	V_{IN} = 0, A_V = 100		14.8	mV
3	Input Bias Current, +IN	$+I_B$	–55°C	±15V	V_{IN} = 0		200	pA
3	Input Bias Current, –IN	$-I_B$	–55°C	±15V	V_{IN} = 0		200	pA
3	Input Offset Current	I_{OS}	–55°C	±15V	V_{IN} = 0		100	pA
2	Quiescent Current	I_Q	125°C	±15V	V_{IN}=0, A_V =100, R_{CL}=0.2 Ω		60	mA
2	Input Offset Voltage	V_{OS}	125°C	±15V	V_{IN} = 0, A_V = 100		15	mV
2	Input Offset Voltage	V_{OS}	125°C	±7V	V_{IN} = 0, A_V = 100		16.6	mV
2	Input Offset Voltage	V_{OS}	125°C	±19V	V_{IN} = 0, A_V = 100		15.8	mV
2	Input Bias Current, +IN	$+I_B$	125°C	±15V	V_{IN} = 0		30	nA
2	Input Bias Current, –IN	$-I_B$	125°C	±15V	V_{IN} = 0		30	nA
2	Input Offset Current	I_{OS}	125°C	±15V	V_{IN} = 0		10	nA
4	Output Voltage, I_O = 5A	V_O	25°C	±9V	R_L = 1 Ω, R_{CL} = 0 Ω	5		V
4	Output Voltage, I_O = 36mA	V_O	25°C	±19V	R_L = 500 Ω	18		V
4	Output Voltage, I_O = 2A	V_O	25°C	±12V	R_L = 5 Ω, R_{CL} = 0 Ω	10		V
4	Current Limits	I_{CL}	25°C	±9V	R_L = 5 Ω, R_{CL} = 1 Ω	0.54	0.86	A
4	Stability/Noise	E_N	25°C	±15V	R_L=500 Ω, A_V=1, C_L=1.5nF		1	mV
4	Slew Rate	SR	25°C	±18V	R_L = 500 Ω	13	100	V/µs
4	Open Loop Gain	A_{OL}	25°C	±15V	R_L = 500 Ω, F = 10 Hz	86		dB
4	Common Mode Rejection	CMR	25°C	±8.25V	R_L = 500 Ω, F = DC, V_{CM}= ±2.25V	70		dB

SG	Parameter	Symbol	Temp.	Power	Test Conditions	Min	Max	Units
6	Output Voltage, I_O = 5A	V_O	–55°C	±9V	R_L = 1 Ω, R_{CL} = 0 Ω	5		V
6	Output Voltage, I_O = 36mA	V_O	–55°C	±19V	R_L = 500 Ω	18		V
6	Output Voltage, I_O = 2A	V_O	–55°C	±12V	R_L = 5 Ω, R_{CL} = 0 Ω	10		V
6	Stability/Noise	E_N	–55°C	±15V	R_L=500 Ω, A_V=1, C_L=1.5nF		1	mV
6	Slew Rate	SR	–55°C	±18V	R_L = 500 Ω	13	100	V/µs
6	Open Loop Gain	A_{OL}	–55°C	±15V	R_L = 500 Ω, F = 10 Hz	86		dB
6	Common Mode Rejection	CMR	–55°C	±8.25V	R_L = 500 Ω, F = DC, V_{CM}= ±2.25V	70		dB
5	Output Voltage, I_O = 3A	V_O	125°C	±7V	R_L = 1 Ω, R_{CL} = 0 Ω	3		V
5	Output Voltage, I_O = 36mA	V_O	125°C	±19V	R_L = 500 Ω	18		V
5	Output Voltage, I_O = 2A	V_O	125°C	±12V	R_L = 5 Ω, R_{CL} = 0 Ω	10		V
5	Stability/Noise	E_N	125°C	±15V	R_L=500 Ω, A_V=1, C_L=1.5nF		1	mV
5	Slew Rate	SR	125°C	±18V	R_L = 500 Ω	8.5	100	V/µs
5	Open Loop Gain	A_{OL}	125°C	±15V	R_L = 500 Ω, F = 10 Hz	86		dB
5	Common Mode Rejection	CMR	125°C	±8.25V	R_L = 500 Ω, F = DC, V_{CM}= ±2.25V	70		dB

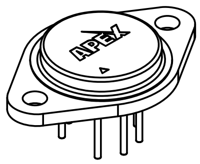
BURN IN CIRCUIT

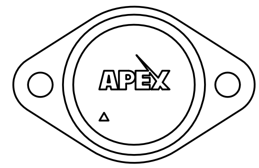
Figure 22: Burn In Circuit

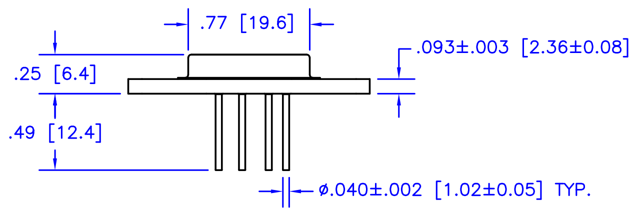


*These components are used to stabilize device due to poor high frequency characteristics of burn in board.
** Input signals are calculated to result in internal power dissipation of approximately 2.1W at case temperature = 125°C.

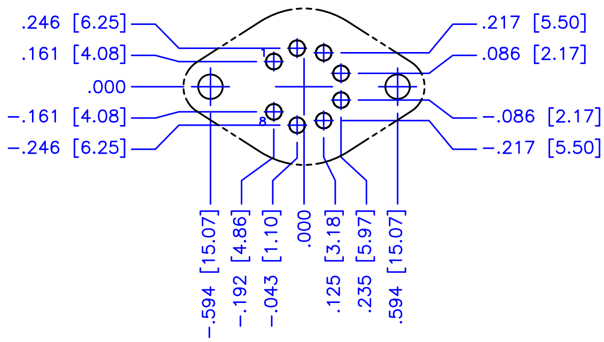
PACKAGE STYLE CE

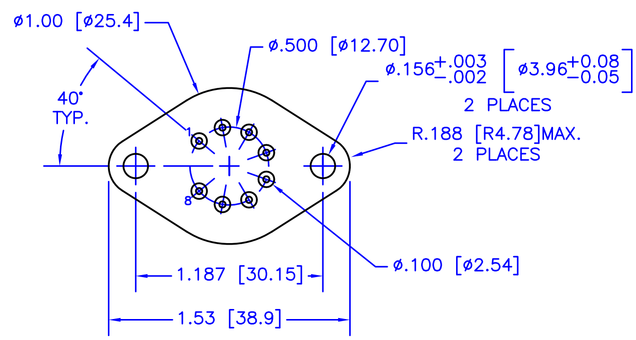






Ordinate dimensions for CAD layout





NOTES:

1. Dimensions are inches & [mm].
2. Triangle printed on lid denotes pin 1.
3. Header flatness within pin circle is .0005" TIR, max.
4. Header flatness between mounting holes is .0015" TIR, max.
5. Standard pin material: Solderable nickel−plated Alloy 52.
6. Header material: Nickel−plated cold−rolled steel.
7. Welded hermetic package seal
8. Isolation: 500 VDC any pin to case.
9. Package weight: .53 oz [15 g]

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