



# High Power Monolithic OPERATIONAL AMPLIFIER

## FEATURES

- POWER SUPPLIES TO  $\pm 40V$
- OUTPUT CURRENT TO 10A PEAK
- PROGRAMMABLE CURRENT LIMIT
- INDUSTRY-STANDARD PIN OUT
- FET INPUT
- TO-3 AND LOW-COST POWER PLASTIC PACKAGES

## APPLICATIONS

- MOTOR DRIVER
- SERVO AMPLIFIER
- SYNCHRO EXCITATION
- AUDIO AMPLIFIER
- PROGRAMMABLE POWER SUPPLY

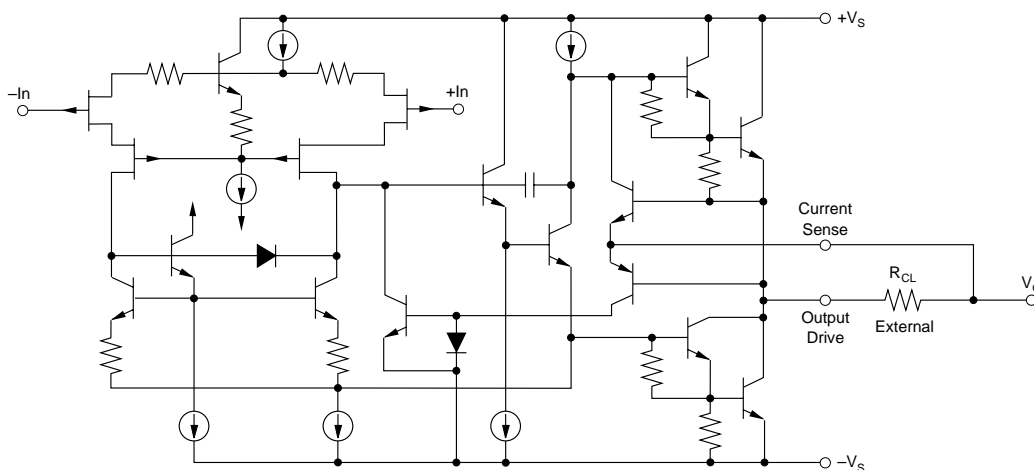
## DESCRIPTION

The OPA541 is a power operational amplifier capable of operation from power supplies up to  $\pm 40V$  and delivering continuous output currents up to 5A. Internal current limit circuitry can be user-programmed with a single external resistor, protecting the amplifier and load from fault conditions. The OPA541 is fabricated using a proprietary bipolar/FET process.

Pinout is compatible with popular hybrid power amplifiers such as the OPA511, OPA512 and the 3573. The OPA541 uses a single current-limit resistor to set both the positive and

negative current limits. Applications currently using hybrid power amplifiers requiring two current-limit resistors need not be modified.

The OPA541 is available in an 11-pin power plastic package and an industry-standard 8-pin TO-3 hermetic package. The power plastic package has a copper-lead frame to maximize heat transfer. The TO-3 package is isolated from all circuitry, allowing it to be mounted directly to a heat sink without special insulators.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

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## ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>

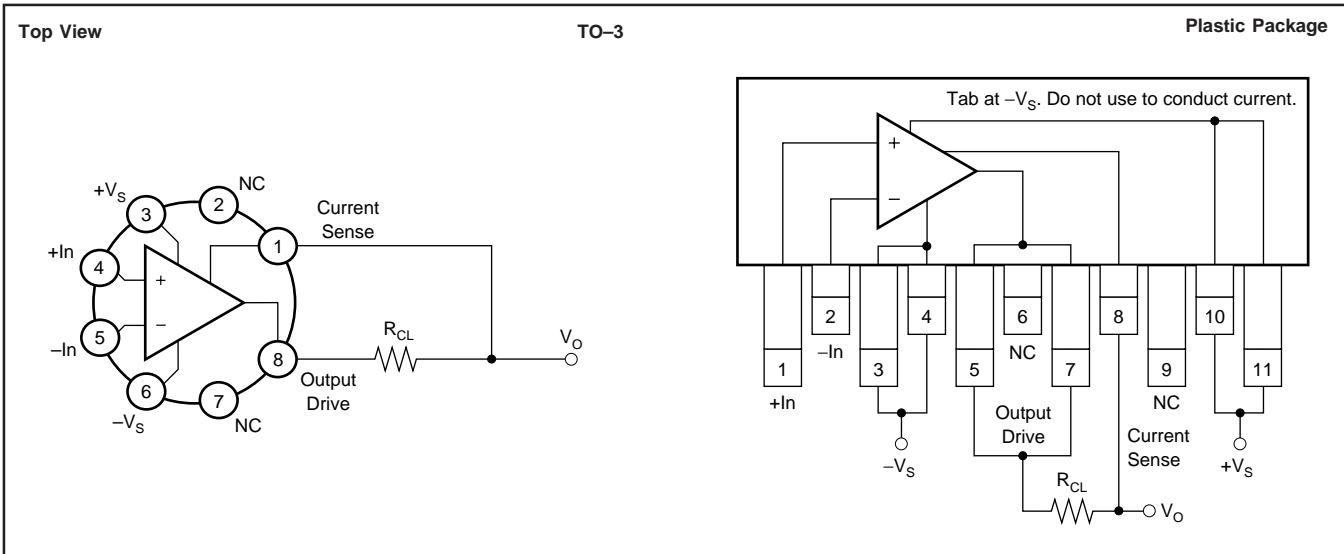
Supply Voltage, $+V_S$ to $-V_S$ .....	80V
Output Current .....	see SOA
Power Dissipation, Internal <sup>(2)</sup> .....	125W
Input Voltage: Differential .....	$\pm V_S$
Common-mode .....	$\pm V_S$
Temperature: Pin solder, 10s .....	+300°C
Junction <sup>(2)</sup> .....	+150°C
Temperature Range:	
AM, BM SM	
Storage .....	-65°C to +150°C
Operating (case) .....	-55°C to +125°C
AP	
Storage .....	-40°C to +85°C
Operating (case) .....	-25°C to +85°C

NOTE: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. (2) Long term operation at the maximum junction temperature will result in reduced product life. Derate internal power dissipation to achieve high MTTF.

## PACKAGE/ORDERING INFORMATION

For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at [www.ti.com](http://www.ti.com).

## CONNECTION DIAGRAMS



## ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

# ELECTRICAL CHARACTERISTICS

At  $T_C = +25^\circ\text{C}$  and  $V_S = \pm 35\text{VDC}$ , unless otherwise noted.

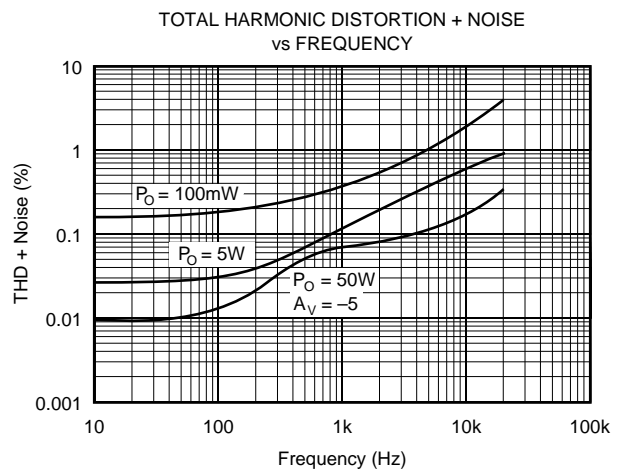
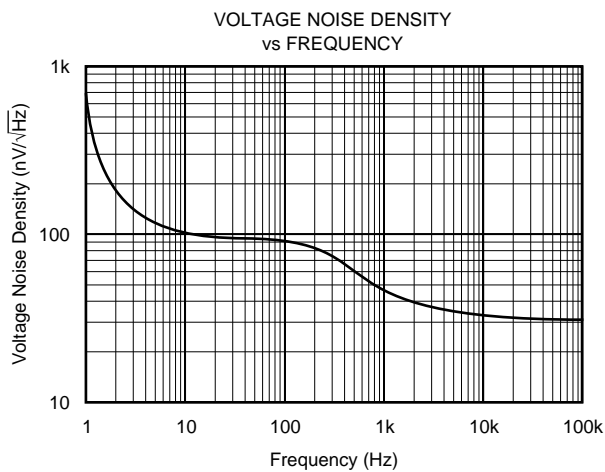
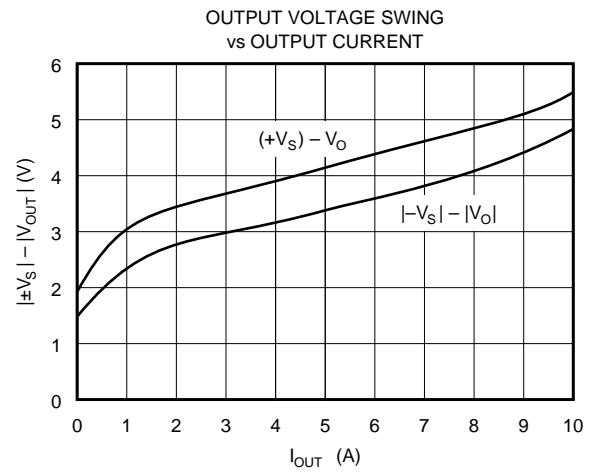
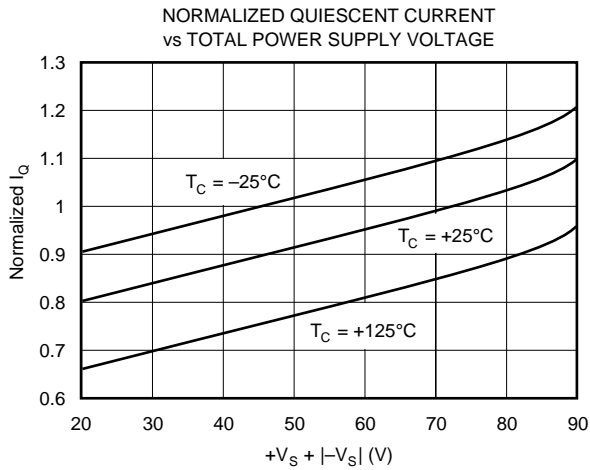
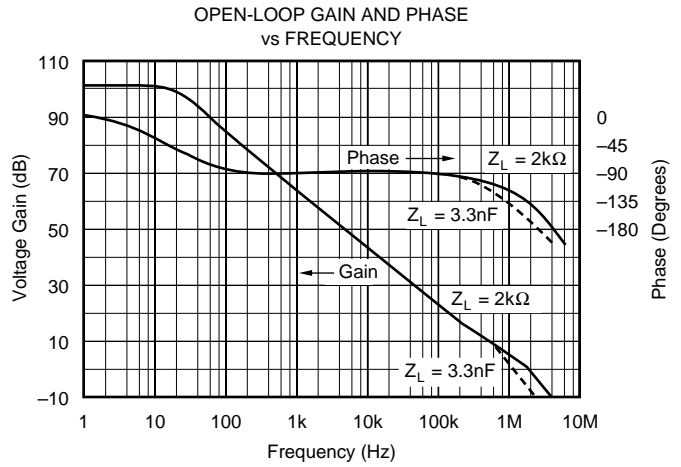
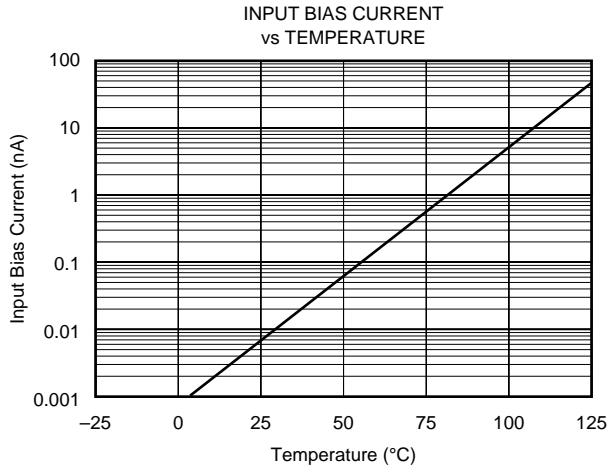
PARAMETER	CONDITIONS	OPA541AM/AP			OPA541BM/SM			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
<b>INPUT OFFSET VOLTAGE</b> $V_{OS}$ vs Temperature vs Supply Voltage vs Power	Specified Temperature Range $V_S = \pm 10\text{V}$ to $\pm V_{MAX}$		$\pm 2$ $\pm 20$ $\pm 2.5$ $\pm 20$	$\pm 10$ $\pm 40$ $\pm 10$ $\pm 60$		$\pm 0.1$ $\pm 15$ *	$\pm 1$ $\pm 30$ *	mV $\mu\text{V}/^\circ\text{C}$ $\mu\text{V}/\text{V}$ $\mu\text{V}/\text{W}$
<b>INPUT BIAS CURRENT</b> $I_B$			4	50		*	*	pA
<b>INPUT OFFSET CURRENT</b> $I_{OS}$	Specified Temperature Range		$\pm 1$	$\pm 30$ 5		*	*	pA nA
<b>INPUT CHARACTERISTICS</b> Common-Mode Voltage Range Common-Mode Rejection Input Capacitance Input Impedance, DC	Specified Temperature Range $V_{CM} = (\pm V_S) - 6\text{V}$	$\pm( V_S  - 6)$ 95	$\pm( V_S  - 3)$ 113 5 1		*	*		V dB pF T $\Omega$
<b>GAIN CHARACTERISTICS</b> Open Loop Gain at 10Hz Gain-Bandwidth Product	$R_L = 6\Omega$	90	97 1.6		*	*		dB MHz
<b>OUTPUT</b> Voltage Swing  Current, Peak	$I_O = 5\text{A}$ , Continuous $I_O = 2\text{A}$ $I_O = 0.5\text{A}$	$\pm( V_S  - 5.5)$ $\pm( V_S  - 4.5)$ $\pm( V_S  - 4)$ 9	$\pm( V_S  - 4.5)$ $\pm( V_S  - 3.6)$ $\pm( V_S  - 3.2)$ 10		*	*		V V V A
<b>AC PERFORMANCE</b> Slew Rate Power Bandwidth Settling Time to 0.1% Capacitive Load  Phase Margin	$R_L = 8\Omega$ , $V_O = 20\text{Vrms}$ 2V Step Specified Temperature Range, $G = 1$ Specified Temperature Range, $G > 10$ Specified Temperature Range, $R_L = 8\Omega$	6 45 3.3	10 55 2 40		*	*	*	V/ $\mu\text{s}$ kHz $\mu\text{s}$ nF Degrees
<b>POWER SUPPLY</b> Power Supply Voltage, $\pm V_S$ Current, Quiescent	Specified Temperature Range	$\pm 10$	$\pm 30$ 20	$\pm 35$ 25	*	$\pm 35$ *	$\pm 40$ *	V mA
<b>THERMAL RESISTANCE</b> $\theta_{JC}$ (Junction-to-Case) <sup>(2)</sup> $\theta_{JC}$ <sup>(2)</sup> $\theta_{JA}$ (Junction-to-Ambient) OPA541AP (Plastic)	AC Output $f > 60\text{Hz}$ DC Output No Heat Sink		2.5 3 40 40					$^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$
<b>TEMPERATURE RANGE</b> $T_{CASE}$	AM, BM, AP SM	-25		+85	*		*	$^\circ\text{C}$ $^\circ\text{C}$

\* Specification same as OPA541AM/AP.

NOTE: (1) SOA is the Safe Operating Area shown in Figure 1. (2) Plastic package may require insulator which typically adds  $1^\circ\text{C}/\text{W}$ .

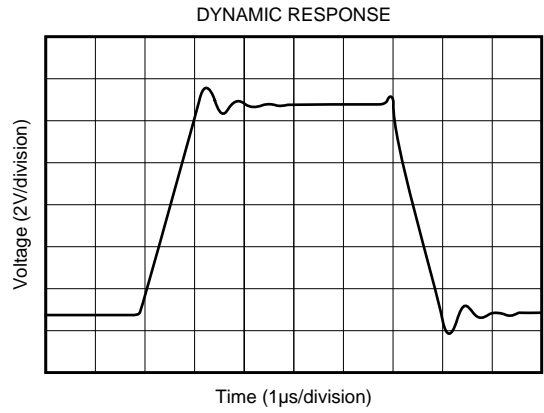
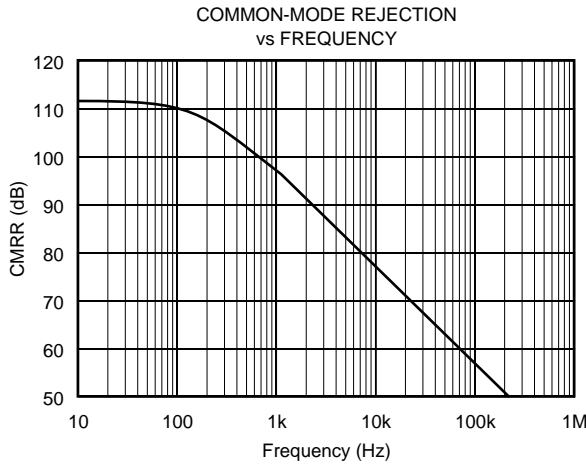
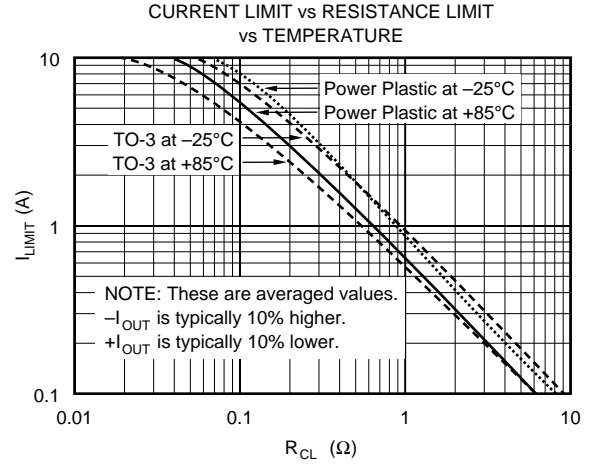
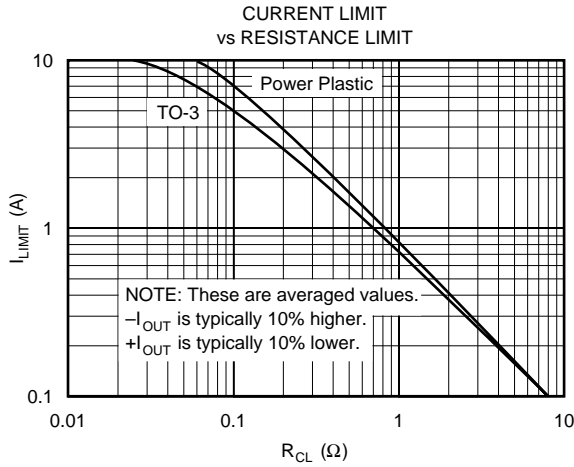
# TYPICAL CHARACTERISTICS

At  $T_A = +25^\circ\text{C}$ ,  $V_S = \pm 35\text{VDC}$ , unless otherwise noted.



# TYPICAL CHARACTERISTICS (Cont)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = \pm 35\text{VDC}$ , unless otherwise noted.



# INSTALLATION INSTRUCTIONS

## POWER SUPPLIES

The OPA541 is specified for operation from power supplies up to  $\pm 40\text{V}$ . It can also be operated from unbalanced power supplies or a single power supply, as long as the total power supply voltage does not exceed  $80\text{V}$ . The power supplies should be bypassed with low series impedance capacitors such as ceramic or tantalum. These should be located as near as practical to the amplifier's power supply pins. Good power amplifier circuit layout is, in general, like good high frequency layout. Consider the path of large power supply and output currents. Avoid routing these connections near low-level input circuitry to avoid waveform distortion and oscillations.

## CURRENT LIMIT

Internal current limit circuitry is controlled by a single external resistor,  $R_{CL}$ . Output load current flows through this external resistor. The current limit is activated when the voltage across this resistor is approximately a base-emitter turn-on voltage. The value of the current limit resistor is approximately:

$$\begin{aligned} \text{(AM, BM, SM)} \quad R_{CL} &= \frac{0.809}{|I_{LIM}|} - 0.057 \\ \text{(AP)} \quad R_{CL} &= \frac{0.813}{|I_{LIM}|} - 0.02 \end{aligned}$$

Because of the internal structure of the OPA541, the actual current limit depends on whether current is positive or negative. The above  $R_{CL}$  gives an average value. For a given  $R_{CL}$ ,  $+I_{OUT}$  will actually be limited at about 10% below the expected level, while  $-I_{OUT}$  will be limited about 10% above the expected level.

The current limit value decreases with increasing temperature due to the temperature coefficient of a base-emitter junction voltage. Similarly, the current limit value increases at low temperatures. Current limit versus resistor value and temperature effects are shown in the Typical Performance Curves. Approximate values for  $R_{CL}$  at other temperatures may be calculated by adjusting  $R_{CL}$  as follows:

$$\Delta R_{CL} = \frac{-2\text{mV}}{|I_{LIM}|} \times (T - 25)$$

The adjustable current limit can be set to provide protection from short circuits. The safe short-circuit current depends on power supply voltage. See the discussion on Safe Operating Area to determine the proper current limit value.

Since the full load current flows through  $R_{CL}$ , it must be selected for sufficient power dissipation. For a 5A current limit on the TO-3 package, the formula yields an  $R_{CL}$  of  $0.105\Omega$  ( $0.143\Omega$  on the power plastic package due to different internal resistances). A continuous 5A through  $0.105\Omega$  would require an  $R_{CL}$  that can dissipate  $2.625\text{W}$ .

Sinusoidal outputs create dissipation according to rms load current. For the same  $R_{CL}$ , AC peaks would still be limited to 5A, but rms current would be 3.5A, and a current limiting resistor with a lower power rating could be used. Some applications (such as voice amplification) are assured of signals with much lower duty cycles, allowing a current resistor with a low power rating. Wire-wound resistors may be used for  $R_{CL}$ . Some wire-wound resistors, however, have excessive inductance and may cause loop-stability problems. Be sure to evaluate circuit performance with the resistor type planned for production to assure proper circuit operation.

## HEAT SINKING

Power amplifiers are rated by case temperature, not ambient temperature as with signal op amps. Sufficient heat sinking must be provided to keep the case temperature within rated limits for the maximum ambient temperature and power dissipation. The thermal resistance of the heat sink required may be calculated by:

$$\theta_{HS} = \frac{T_{CASE} - T_{AMBIENT}}{P_D \text{ (max)}}$$

Commercially available heat sinks often specify their thermal resistance. These ratings are often suspect, however, since they depend greatly on the mounting environment and air flow conditions. Actual thermal performance should be verified by measurement of case temperature under the required load and environmental conditions.

No insulating hardware is required when using the TO-3 package. Since mica and other similar insulators typically add approximately  $0.7^\circ\text{C/W}$  thermal resistance, their elimination significantly improves thermal performance. See Application Bulletin SBOA021, available for download at [www.ti.com](http://www.ti.com), for further details on heat sinking. On the power plastic package, the metal tab may have a high or low impedance connection to  $-V_S$ . The case should be allowed to float and will likely assume the potential of  $-V_S$ . Current should **NOT** be conducted through the case.

## SAFE OPERATING AREA

The safe operating area (SOA) plot provides comprehensive information on the power handling abilities of the OPA541. It shows the allowable output current as a function of the voltage across the conducting output transistor (see Figure 1). This voltage is equal to the power supply voltage minus the output voltage. For example, as the amplifier output swings near the positive power supply voltage, the voltage

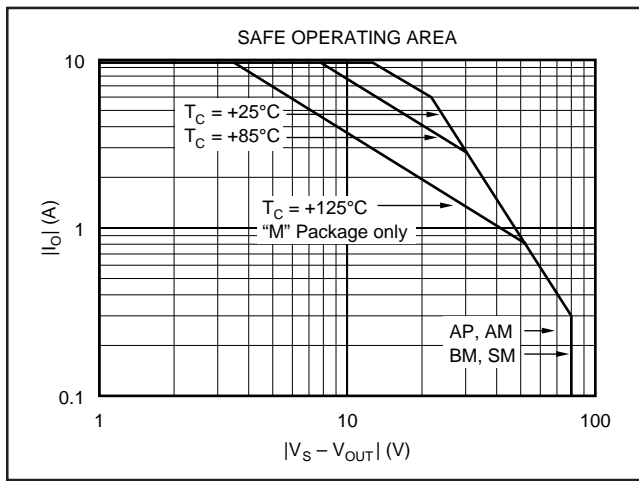


FIGURE 1. Safe Operating Area.

across the output transistor decreases and the device can safely provide large output currents demanded by the load.

Short circuit protection requires evaluation of the SOA. When the amplifier output is shorted to ground, the full power supply voltage is impressed across the conducting output transistor. The current limit must be set to a value which is safe for the power supply voltage used. For instance, with  $V_S \pm 35V$ , a short to ground would force 35V across the conducting power transistor. A current limit of 1.8A would be safe.

Reactive, or EMF-generating, loads such as DC motors can present difficult SOA requirements. With a purely reactive load, output voltage and load current are  $90^\circ$  out of phase. Thus, peak output current occurs when the output voltage is zero and the voltage across the conducting transistor is equal to the full power supply voltage. See Burr-Brown Application Bulletin SBOA022 (available at [www.ti.com](http://www.ti.com)) for further information on evaluating SOA.

### REPLACING HYBRID POWER AMPLIFIERS

The OPA541 can be used in applications currently using various hybrid power amplifiers, including the OPA501, OPA511, OPA512, and 3573. Of course, the application must be evaluated to assure that the output capability and other performance attributes of the OPA541 meet the necessary requirements. These hybrid power amplifiers use two current limit resistors to independently set the positive and negative current limit value. Since the OPA541 uses only one current limit resistor to set both the positive and negative current limit, only one resistor (see Figure 4) need be installed. If installed, the resistor connected to pin 2 (TO-3 package) is superfluous, but it does no harm.

Because one resistor carries the current previously carried by two, the resistor may require a higher power rating. Minor adjustments may be required in the resistor value to achieve the same current limit value. Often, however, the change in current limit value when changing models is small compared to its variation over temperature. Many applications can use the same current limit resistor.

## APPLICATIONS CIRCUITS

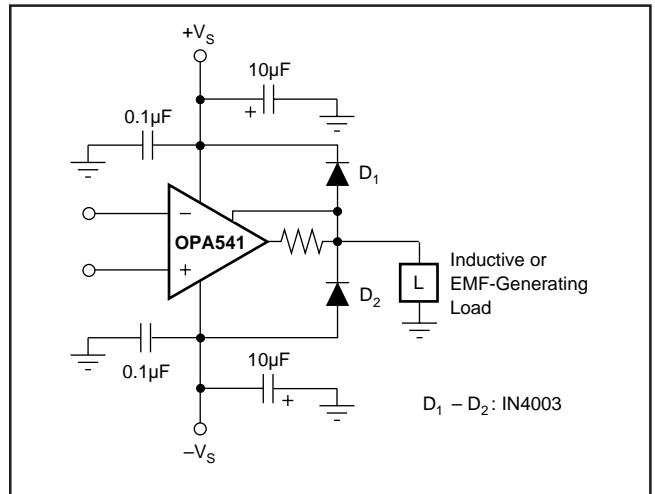


FIGURE 2. Clamping Output for EMF-Generating Loads.

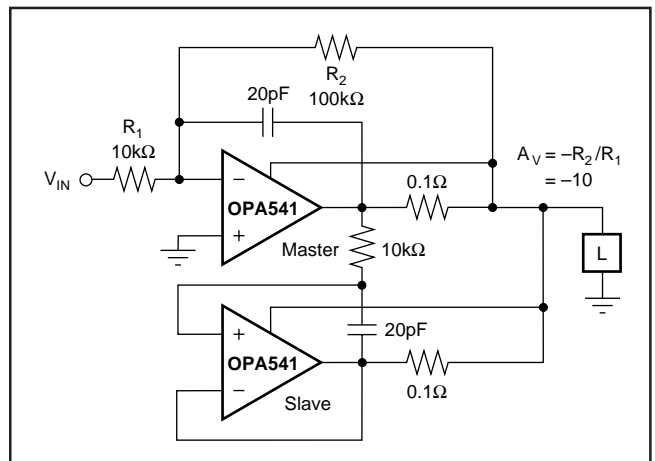


FIGURE 3. Isolating Capacitive Loads.

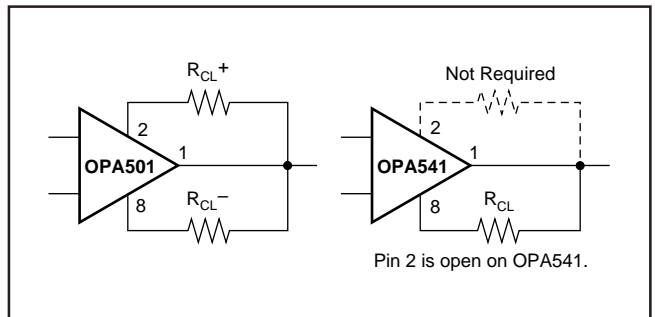


FIGURE 4. Replacing OPA501 with OPA541.

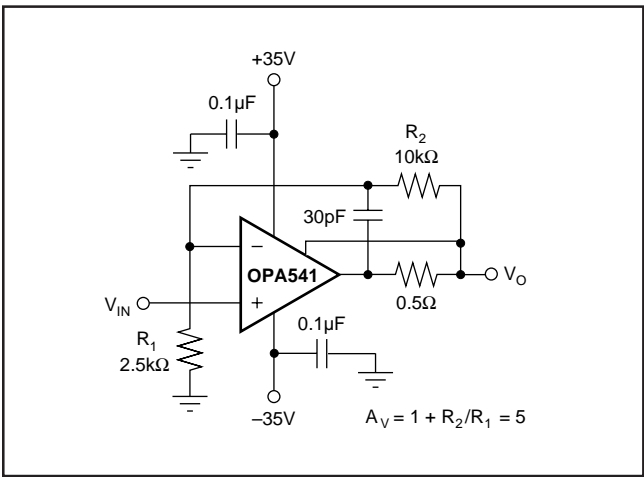


FIGURE 5. Paralleled Operation, Extended SOA.

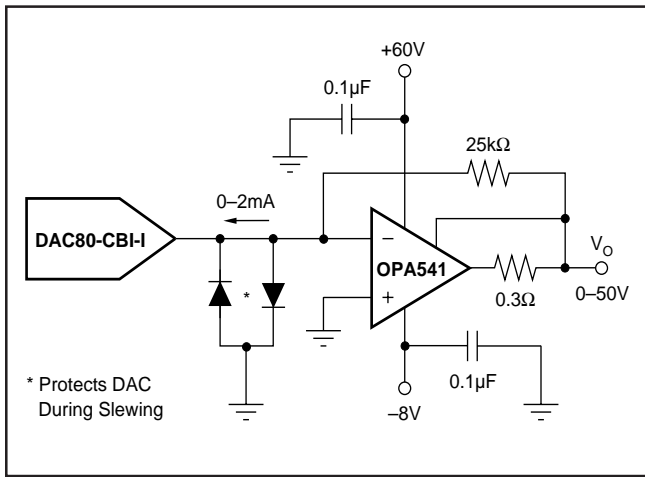


FIGURE 6. Programmable Voltage Source.

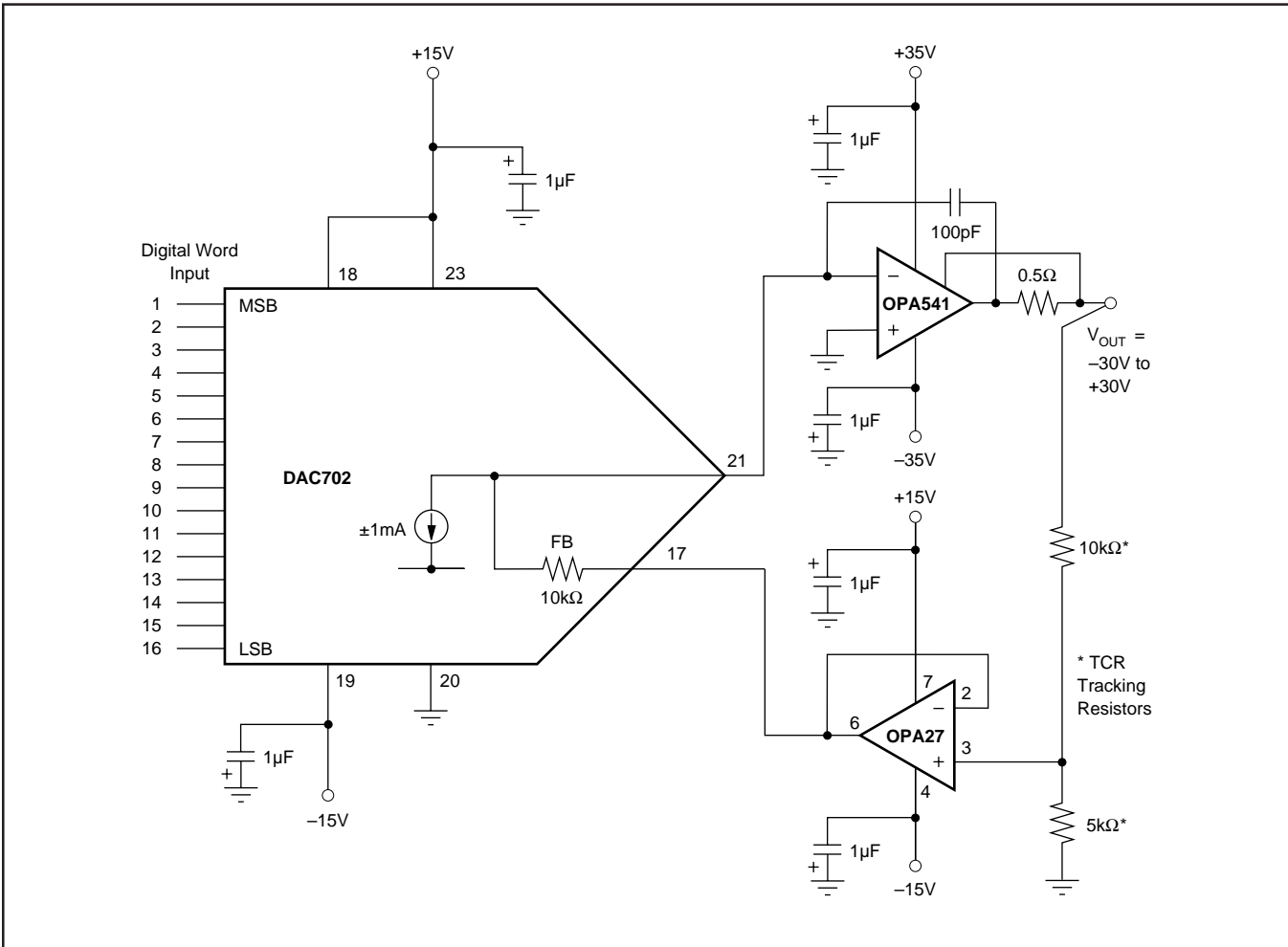


FIGURE 7. 16-Bit Programmable Voltage Source.



**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
OPA541AM	NRND	TO-3	LMF	8	18	Pb-Free (RoHS Exempt)	Call TI	N / A for Pkg Type
OPA541AM-BI	NRND	ZZ (BB)	ZZ030	8		TBD	Call TI	Call TI
OPA541AP	ACTIVE	TO-220	KV	11	25	Green (RoHS & no Sb/Br)	Call TI	N / A for Pkg Type
OPA541APG3	ACTIVE	TO-220	KV	11	25	Green (RoHS & no Sb/Br)	Call TI	N / A for Pkg Type
OPA541BM	NRND	TO-3	LMF	8	18	Pb-Free (RoHS Exempt)	Call TI	N / A for Pkg Type
OPA541SM	NRND	TO-3	LMF	8	18	Pb-Free (RoHS Exempt)	Call TI	N / A for Pkg Type
OPA541SM-BI	OBSOLETE	TO-3	LMF	8		TBD	Call TI	Call TI

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

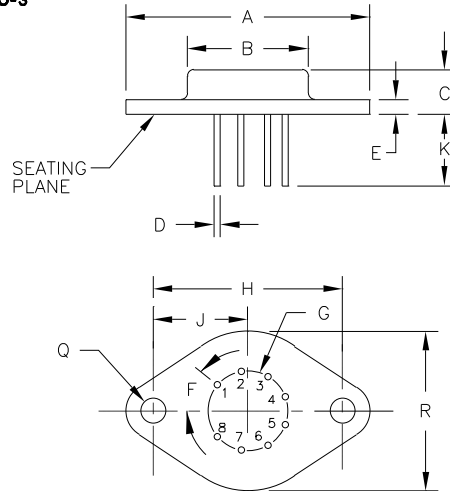
**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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Package Number 030 - 8-Pin Metal TO-3



DIM	INCHES		MILLIMETERS		NOTE	DIM	INCHES		MILLIMETERS		NOTE
	MIN.	MAX.	MIN.	MAX.			MIN.	MAX.	MIN.	MAX.	
A	1.510	1.550	38.35	39.37							
B	.745	.770	18.92	19.56							
C	.260	.300	6.60	7.62							
D	.038	.042	0.97	1.07							
E	.080	.105	2.03	2.67							
F	40°	BASIC	40°	BASIC							
G	.500	BASIC	12.70	BASIC							
H	1.182	1.192	30.02	30.28							
J	.591	.596	15.01	15.14							
K	.400	.500	10.16	12.70							
Q	.151	.161	3.84	4.09							
R	.980	1.020	24.89	25.91							

NOTES:  
 1. LEADS IN TRUE POSITION WITHIN .010" (.25mm) @ MMC AT SEATING PLANE.  
 2. PIN NUMBERS SHOWN FOR REFERENCE ONLY. NUMBERS MAY NOT BE MARKED ON PACKAGE.

PACKAGE NUMBER: ZZ030      REV.: C  
 JEDEC NUMBER: UNKNOWN



PACKAGE DRAWING





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Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>	Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>	Broadband	<a href="http://www.ti.com/broadband">www.ti.com/broadband</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>	Digital Control	<a href="http://www.ti.com/digitalcontrol">www.ti.com/digitalcontrol</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>	Military	<a href="http://www.ti.com/military">www.ti.com/military</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>	Optical Networking	<a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>	Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Low Power Wireless	<a href="http://www.ti.com/lpw">www.ti.com/lpw</a>	Telephony	<a href="http://www.ti.com/telephony">www.ti.com/telephony</a>
		Video & Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>
		Wireless	<a href="http://www.ti.com/wireless">www.ti.com/wireless</a>

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