

# MAXIM Programmable Negative Voltage Regulator

ICL7664

## General Description

The ICL7664 is a high efficiency negative voltage regulator with a quiescent current of less than 10 $\mu$ A. The output voltage is set by two external resistors to any voltage in the -1.3V to -16V range, with an input voltage range of -2V to -16V. The ICL7664 is well suited for battery powered supplies, with a 10 $\mu$ A quiescent current, an output current capability of 25mA, low  $V_{IN}$  to  $V_{OUT}$  differential, current limiting, and a logic input level shutdown control.

The Maxim ICL7664 is compatible with existing ICL7664 designs when used with an output filter capacitor of 10 $\mu$ F or greater.

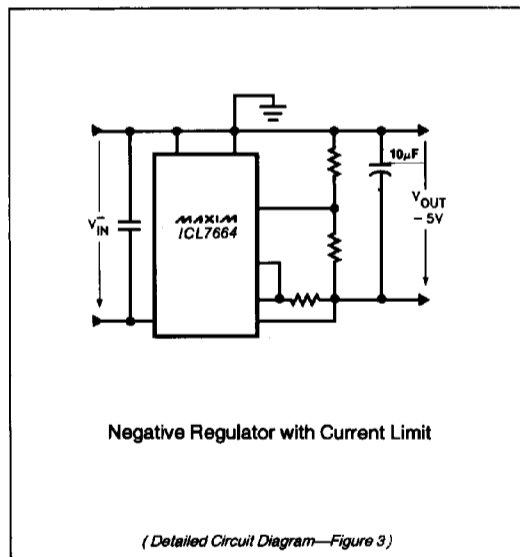
The ICL7664A is an enhanced version of the ICL7664, with a 1% accurate voltage reference, which eliminates the need for trimming the output voltage in most applications.

## Applications

Designed specifically for battery powered systems, the ICL7664 negative voltage regulator excels wherever low quiescent power, wide voltage range operation, medium output current levels, current limiting, and logic-controlled shutdown is desired.

Handheld Instruments  
LCD Display Modules and Systems  
Paggers  
Remote Data Loggers

## Typical Operating Circuit



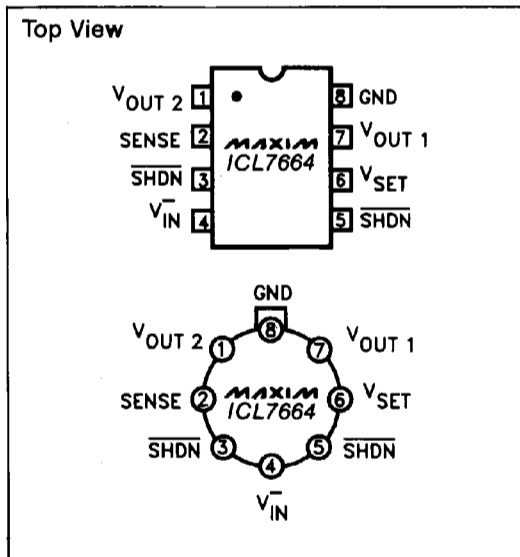
## Features

- ◆ 1% Output Voltage Accuracy (ICL7664A)
- ◆ -2V to -16V Operating Range
- ◆ 25mA Output Current, with Current Limiting
- ◆ Adjustable Output Voltage
- ◆ Low Input-to-Output Voltage Drop
- ◆ Low Power CMOS: 4 $\mu$ A Quiescent Current

## Ordering Information

PART	TEMP RANGE	PACKAGE
ICL7664C/D	0°C to +70°C	Dice
ICL7664CJA	0°C to +70°C	8 Lead Cerdip
ICL7664CPA	0°C to +70°C	8 Lead Plastic Dip
ICL7664CSA	0°C to +70°C	8 Lead Small Outline
ICL7664CTV	0°C to +70°C	8 Lead TO-99 Can
ICL7664AC/D	0°C to +70°C	Dice
ICL7664ACJA	0°C to +70°C	8 Lead Cerdip
ICL7664ACPA	0°C to +70°C	8 Lead Plastic Dip
ICL7664ACSA	0°C to +70°C	8 Lead Small Outline
ICL7664ACTV	0°C to +70°C	8 Lead TO-99 Can

## Pin Configuration



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### ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage	-18V	Operating Temperature Range	
Input or Output Voltage (Note 1)	(GND + 0.3V) to (VIN - 0.3V)	ICL7664C/D	0°C to +70°C
Terminals (1, 3, 5, 6, 7)	(VIN - 0.3V)	ICL7664CPA	0°C to +70°C
Sense Pin (Pin 2)	(GND + 0.3V) to (VOUT1 - 0.3V)	ICL7664IJA	-20°C to +85°C
Output Sink Current (Terminals 1, 7)	-25mA	ICL7664ITV	-20°C to +85°C
Power Dissipation (Note 2)		Storage Temperature	-65°C to +150°C
Minidip	200mW	Lead Temperature (Soldering, 10 seconds)	+300°C
TO-99 Can	300mW		
CERDIP	500mW		

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

### ELECTRICAL CHARACTERISTICS

(VIN = -9V, VOUT = -5V, TA = +25°C, test circuit unless noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	
Input Voltage	VIN					V	
Quiescent Current	IQ	RL = ∞, -1.4V ≤ VOUT ≤ -8.5V					
		V-IN = -16V, 0°C ≤ TA ≤ +70°C		4.0	12	μA	
		V-IN = -9V, 0°C ≤ TA ≤ +70°C		3.5	10		
Reference Voltage	VSET	IOUT = 100μA, VOUT = VSET	ICL7664A	-1.275	-1.29	-1.305	V
			ICL664B	-1.26	-1.29	-1.32	
			ICL7664	-1.235	-1.3	-1.365	
Temperature Coefficient	$\frac{\Delta V_{SET}}{\Delta T}$			±100		ppm/°C	
Line Regulation	$\frac{\Delta V_{SET}}{V_{SET} \Delta V_{IN}}$	-2V ≤ VIN ≤ -15V		0.03	0.35	%/V	
VSET Input Current	ISET	0°C ≤ TA ≤ +70°C		±0.01	±10	nA	
Shutdown Input Current	ISHDN	GND ≤ VSHDN ≤ VIN		±0.01	±10	nA	
Shutdown Input Voltage	VSHDN	VSHDNHI: Both VOUT Enabled		-0.7		V	
		VSHDNLO: Both VOUT Disabled			-1.7		
Sense Pin Input Current	ISENSE	VSENSE = VOUT1		±0.01	±10	nA	
Sense Pin Input Threshold	VCL	VCL = VOUT2 - VSENSE (Current-Limit Threshold)		-0.7		V	
Input-Output Saturation Resistance (Note 3)	ROUT	VOUT1 Connected to VOUT2					
		V-IN = -2V		150	500	Ω	
		V-IN = -9V		40	80		
		V-IN = 15V		30	60		
Load Regulation	$\frac{\Delta V_{OUT}}{\Delta I_{OUT}}$	ΔIOUT = 100μA		2.0	5.0	Ω	
Output Current, VOUT1 connected to VOUT2	IOUT	V-IN = -3V VOUT = VSET		-2		mA	
		V-IN = -9V VOUT = -5V		-20			
Minimum Load Current (Includes VSET Divider)	IL(MIN)	0°C ≤ TA ≤ +70°C			1.0	μA	

**Note 1:** Connecting any terminal to voltages greater than (GND + 0.3V) or less than (VIN - 0.3V) may cause destructive device latch-up. It is recommended that no inputs from sources operating on external power supplies be applied prior to ICL7664 power-up.

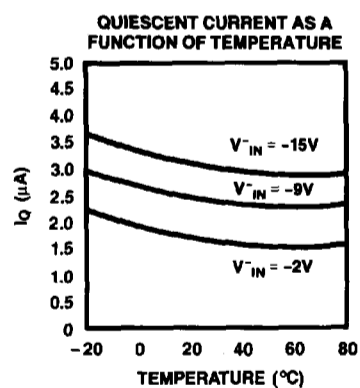
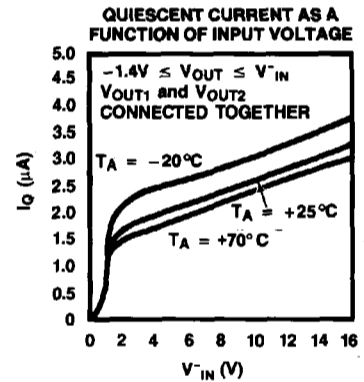
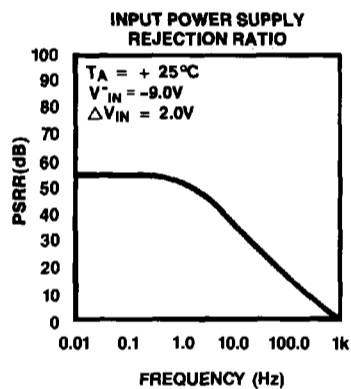
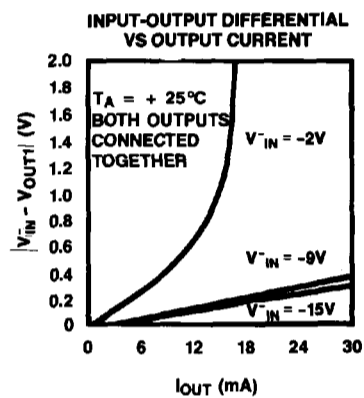
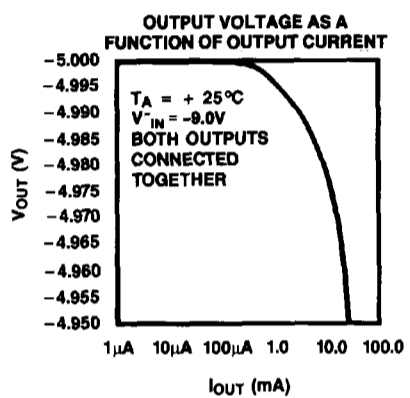
**Note 2:** Derate linearly above 50°C at 5mW/°C for minidip and 7.5mW/°C for TO-99 can.

**Note 3:** This parameter refers to the saturation resistance of the MOS pass transistor. The minimum input-output voltage differential can be determined by multiplying the load current (including set resistor current, but not quiescent current) by this resistance.

# Programmable Negative Voltage Regulator

## Typical Operating Characteristics

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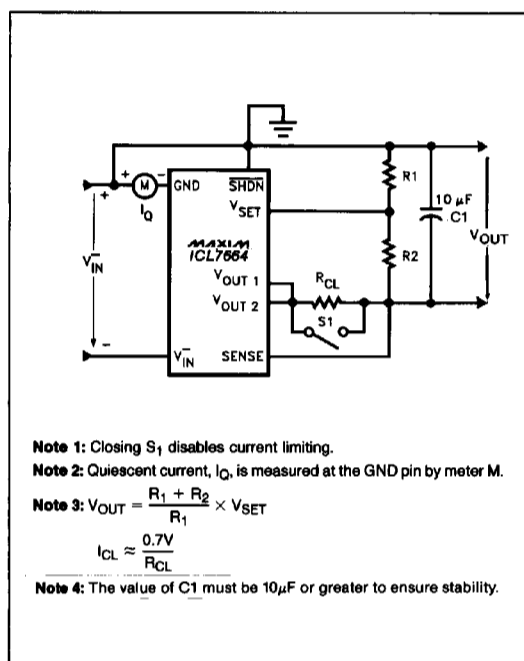


Figure 1. Test Circuit

### Detailed Description

#### Block Diagram

As shown in the block diagram of Figure 2, the main elements of the ICL7664 are a micropower bandgap reference, an error amplifier, and two n channel FET output drivers.

The bandgap reference of the ICL7664A, which uses less than 1 μA of quiescent current, is precisely trimmed to 1.29 ± 15mV. The output of the bandgap reference and the input voltage at the V<sub>SET</sub> terminal are compared in Amplifier A. This output drives the series pass FET output drivers which are connected to V<sub>OUT1</sub> and V<sub>OUT2</sub>. These outputs, suitable for output currents of up to 50mA total, can drive low current loads with an input-to-output voltage differential that approaches 0V. The minimum input-to-output voltage increases at the rate of I<sub>OUT</sub> × R<sub>SAT</sub>.

Also onboard the ICL7664 is a sense comparator that will current limit the output when the voltage across the current sense resistor, R<sub>CL</sub>, is greater than approximately 0.7V; and a logic shutdown input that turns off the output by logic level control.

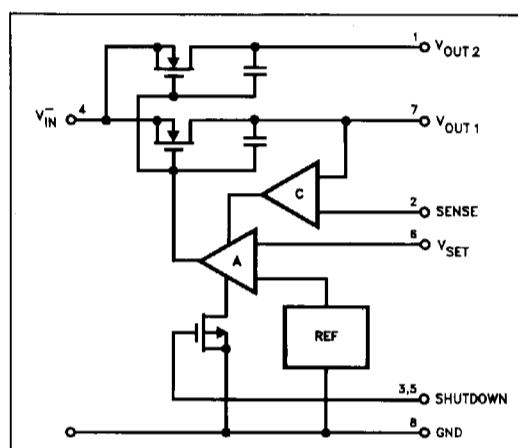


Figure 2. Block Diagram of the ICL7664.

#### Basic Circuit Operation

Figure 3 shows a typical negative voltage regulator using the ICL7664. The input voltage, V<sub>IN</sub>, can range from a maximum of -16V to a minimum of the output voltage plus the input-output differential. The output voltage is set by the resistors R<sub>2</sub> and R<sub>1</sub>, and the output current limit is set by R<sub>CL</sub>. The 0.047 μF capacitor on the input is used to limit the rate-of-rise during power-up and also removes some of the high frequency noise on the input voltage. In Figure 3, the logic shutdown is not used and is therefore grounded. V<sub>OUT1</sub> and V<sub>OUT2</sub> should be connected directly to SENSE if current limiting is not used.

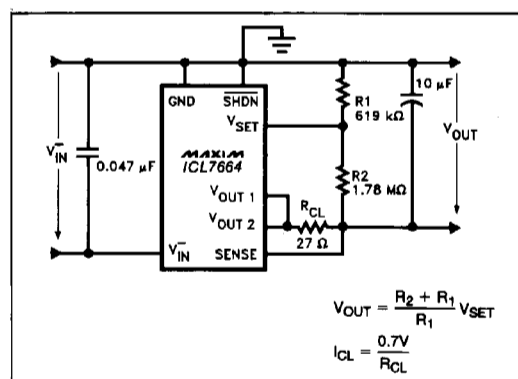


Figure 3. ICL7664 as Negative Regulator with Current Limit

## Programmable Negative Voltage Regulator

### Output Voltage Selection

The output voltage can be calculated from the formula:

$$V_{OUT} = V_{SET} \times \frac{R1 + R2}{R1}$$

The ICL7664A  $V_{SET}$  voltage is guaranteed to be  $1.29V \pm 15mV$  at  $25^{\circ}C$ , eliminating the need for trim pots in most cases. Specifically, using the ICL7664A and the resistor values shown in Figure 3, the initial voltage will be within  $\pm 2.7\%$  of 5V, assuming  $\pm 1\%$  tolerance resistors. The output voltage will still be within  $5V \pm 5\%$ , including the ICL7664A effects of the  $V_{SET}$  error, the  $\pm 1\%$  initial tolerance on both resistors, and the resistor ratio temperature coefficient of nearly 200ppm. Since the resistor ratio temperature coefficient is generally much lower than the absolute temperature coefficient, 100 or 200ppm resistors can be used, even over the full temperature range while still guaranteeing that the output will stay within 4.75V to 5.25V.

For 5V supplies that have a looser tolerance, the 5% resistor values of 1.6M $\Omega$  and 560k $\Omega$  are suitable values for R2 and R1. With resistors of  $\pm 5\%$  initial tolerance, the initial output voltage will be  $5V \pm 8.7\%$ .

### Current Limiting

The circuit in Figure 3 will limit the output current to approximately 25mA. Current limiting will start when the output current exceeds 25mA and the voltage drop across the 27 $\Omega$   $R_{CL}$  is 700mV. For other current limits the value of  $R_{CL}$  can be calculated from the formula:

$$R_{CL} = \frac{0.7V}{I_{CL}}$$

where  $I_{CL}$  is the current limit value.

The current limit resistor should be chosen so that neither the 50mA absolute maximum output current specification (25mA each from  $V_{OUT1}$  and  $V_{OUT2}$ ) nor the maximum power dissipation specification is violated.

The ICL7664 activates current limiting by internally pulling the  $V_{SET}$  terminal down towards  $V_{IN}$ . The main error amplifier then reacts as if the output voltage is greater than the desired output voltage, and shuts off the output. For this current limiting action to work, the parallel resistance of the voltage divider connected to  $V_{SET}$  must be greater than 10k $\Omega$ .

### Input-Output Differential Voltage

The minimum input-output differential voltage (also called dropout voltage) sets the lower limit for usable battery voltage in battery powered supplies. In the ICL7664, the minimum input-output differential voltage is the product of the output current and the ICL7664 output saturation resistance. See the typical characteristics graphs for a plot of input-output differential vs. output current.

### Output Current Booster

Figure 4 shows a circuit that will supply -5 volts at 2 amperes, with a 6.5V input. The base of the high power external series pass PNP transistor is driven by  $V_{OUT1}$

and  $V_{OUT2}$  in parallel. This circuit is useful in circuits where the 50mA maximum output current of the ICL7664 is inadequate, with the only limitation to output current being that the ICL7664 must not supply more than 50mA of base drive to the external PNP transistor. With a beta of 40, the output current would be a maximum of 2 amperes.

This circuit is particularly useful for battery powered systems that alternately draw high current, then shut down to extend the battery life. In the shutdown state, the circuit will draw only the 4 $\mu A$  typical quiescent current of the ICL7664, plus the leakage current of the transistor, which is normally less than 1 $\mu A$ .

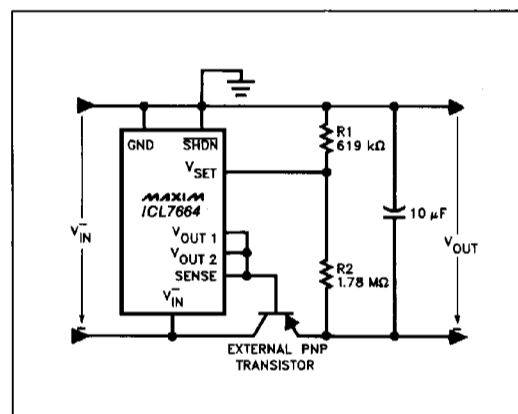


Figure 4. Output Current Boosting

### Logic Level Shutdown

The ability to turn off the output of the ICL7664 using a single logic level pin is useful in systems where the equipment is on intermittently. The Shutdown input should preferably be driven by CMOS logic since the input logic high level is only -0.3V. An alternate way of driving is with an open collector PNP transistor and a resistive pullup to ground. The pullup resistor need only draw a fraction of a microamp since the Shutdown terminal input current is less than 10nA.

Figure 4 shows a circuit that will supply up to 2 amperes of output current when active, but will shut down to 4 $\mu A$  quiescent current by merely switching the Shutdown pin to the high state.

### Cautions

While the ICL7664 is stable under most conditions, a 10 $\mu F$  output filter capacitor is required to ensure stability under all conditions. This output filter capacitor will also improve the high frequency line and load regulation.

As with all junction isolated CMOS devices, the ICL7664 can be destroyed by SCR latchup if standard precautions are not observed. First, no pins should ever

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be driven more than  $\pm 0.3V$  above ground or more than  $-0.3V$  below the  $V_{IN}$ . Secondly, the rate-of-rise on  $V_{IN}$  should not be excessive. The rate-of-rise can be several hundred volts per microsecond if the  $V_{IN}$  source has a low internal impedance (such as Nicad or lead-acid batteries). There is no current limiting resistance or inductance between the battery and the ICL7664, and there is no input filtering. Carbon-zinc and alkaline batteries normally do not have sufficient current output capability to cause a rate-of-rise SCR, but the simple addition of a  $0.1\mu F$  or greater bypass capacitor on the input will ensure that these batteries will not cause SCR latchup.

Figure 5 shows a combined application of the ICL7664, an ICL7663 positive regulator, and the ICL7660 voltage inverter in a  $\pm 5V$  regulated power supply whose power source is a single  $+9V$  battery. The ICL7660 inverts the  $+9V$  input voltage to  $-9V$  which is then regulated by the ICL7664 negative regulator to a constant  $-5V$  output. The ICL7663 positive voltage regulator uses the  $+9V$  input directly to generate a regulated  $+5V$  output. The combined quiescent current of the Maxim ICL7660 and the two regulators is less than  $100\mu A$ , while the output current capability is  $40mA$ .

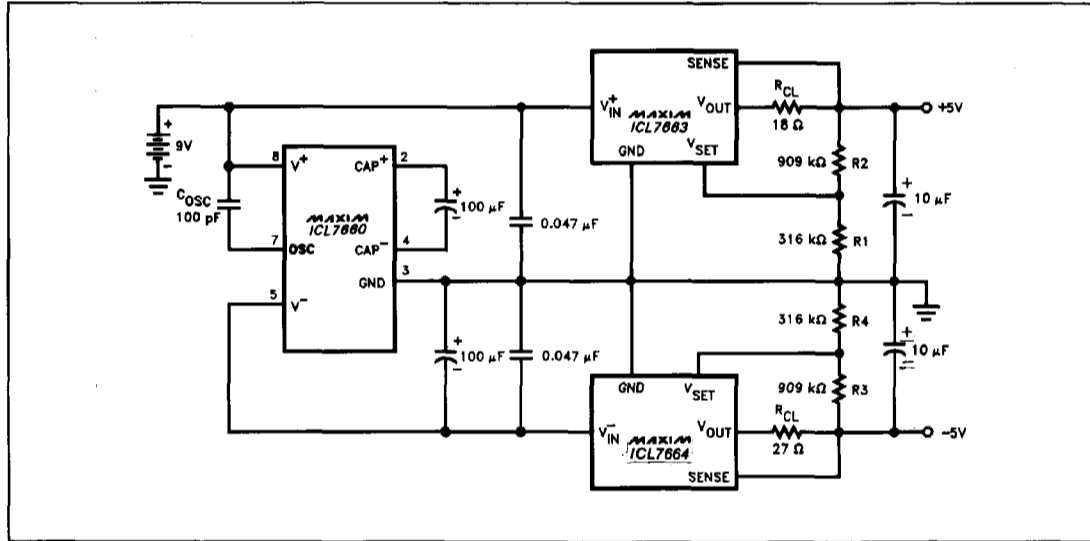
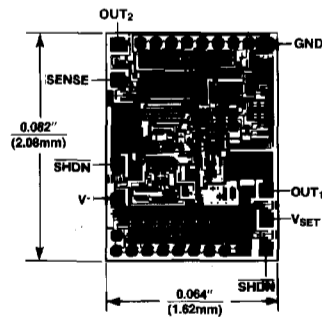


Figure 5.  $\pm 5V$  Power Supply Using One 9V Battery

### Chip Topography



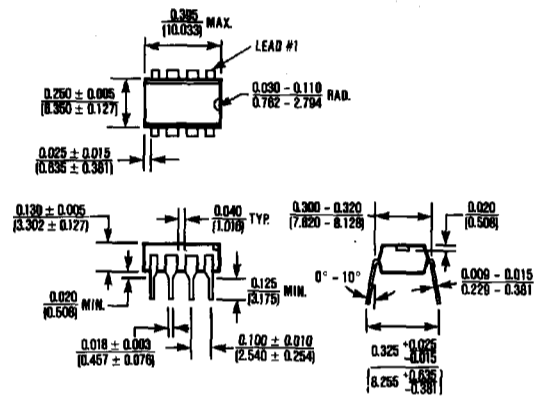
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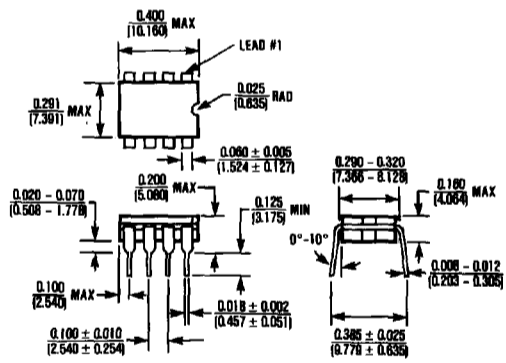
### Package Information

ICL7664



**8 Lead Plastic DIP (PA)**

$\theta_{JA} = 160^{\circ}\text{C/W}$   
 $\theta_{JC} = 75^{\circ}\text{C/W}$



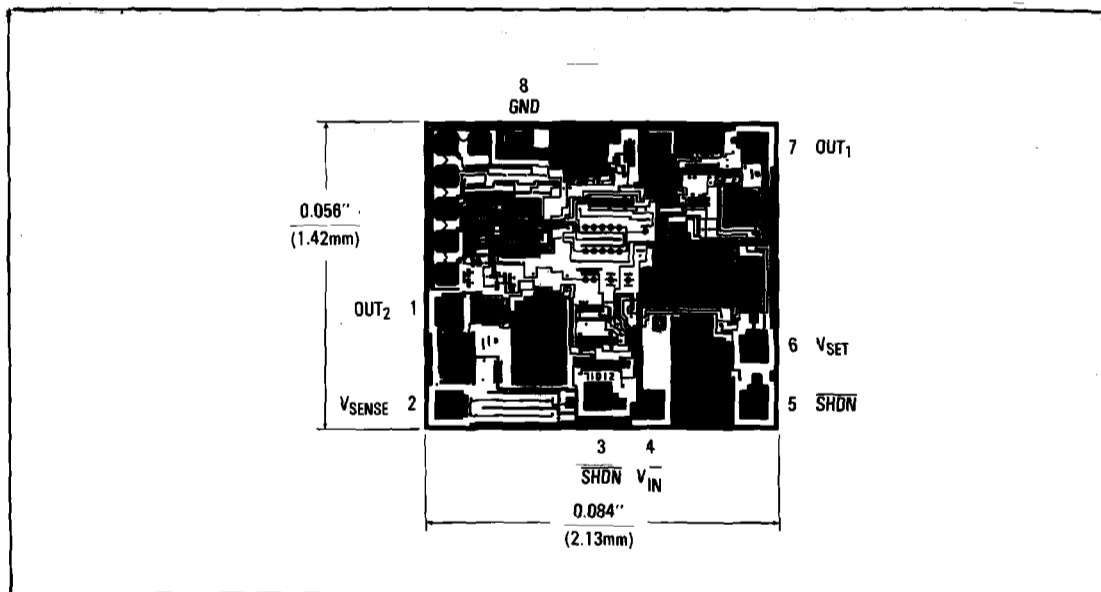
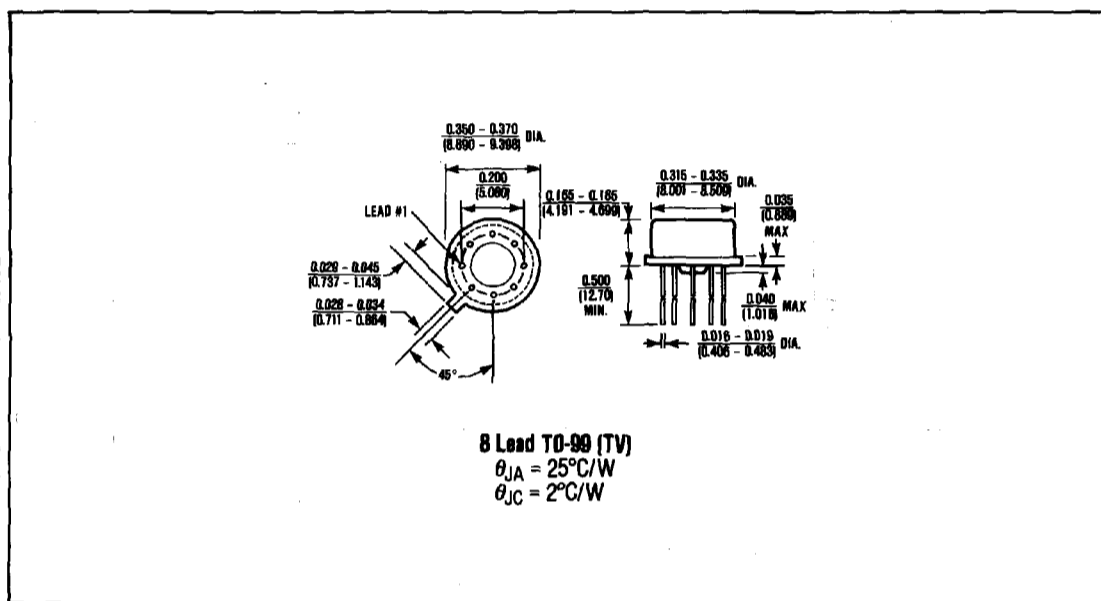
**8 Lead CERDIP (JA)**

$\theta_{JA} = 125^{\circ}\text{C/W}$   
 $\theta_{JC} = 55^{\circ}\text{C/W}$

ICL7004

# Programmable Negative Voltage Regulator

## Package Information



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